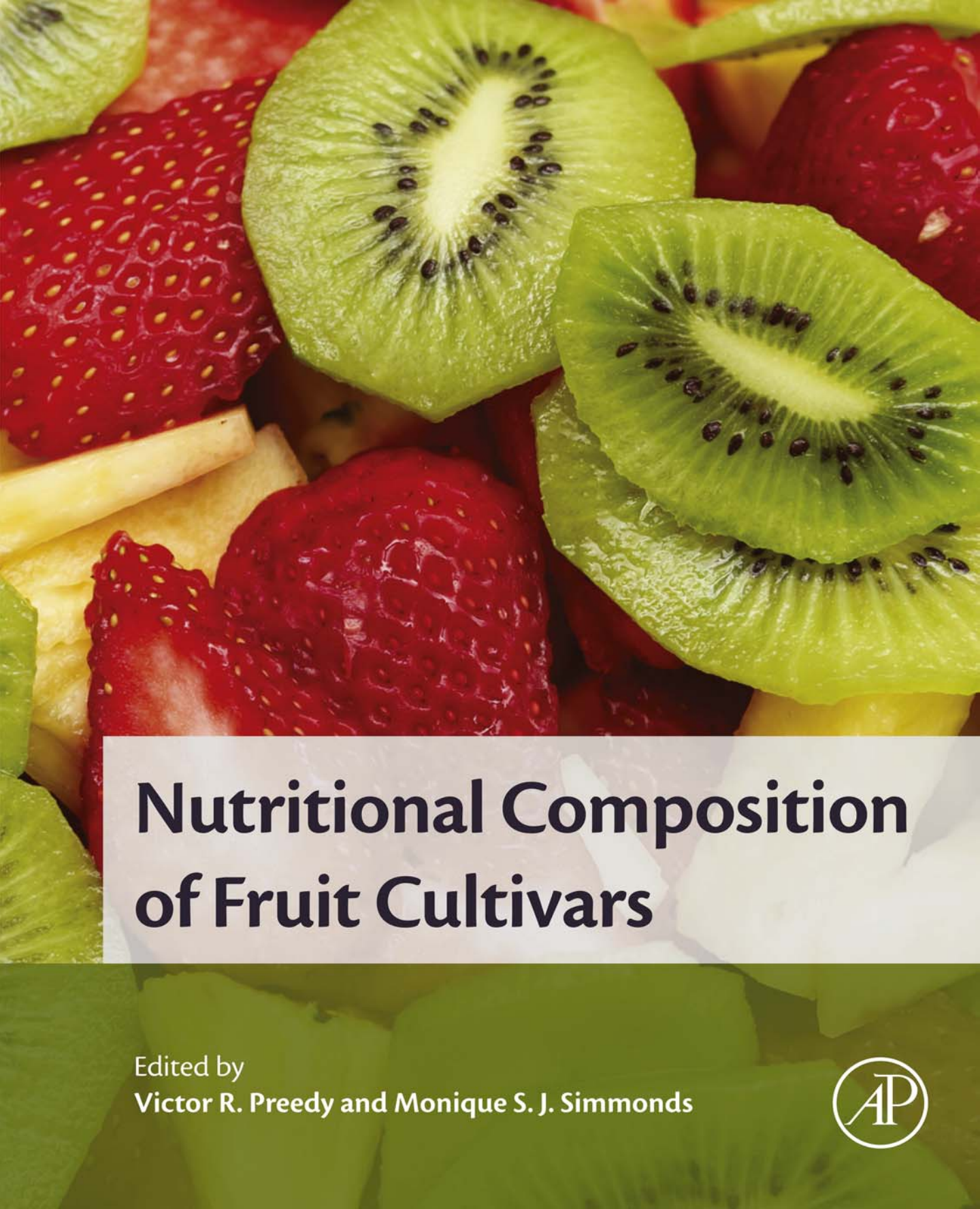




Nutritional Composition of Fruit Cultivars

Edited by
Victor R. Preedy and Monique S. J. Simmonds



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FOREWORD

This is a book about many of the fruits that we all enjoy so much from both the tropical and temperate regions of the world. Included are some of my favorites from the tropics, such as the custard apple and the mango, and all the favorite temperate fruits, such as strawberries and raspberries, or the versatile apple and plum, and even the date from the deserts of Africa. A feature I like about the chapters is that for each fruit, there are several expert authors from the different countries where the fruit is important. The gathering together of so many expert authors from many different countries was no easy task for the editors, but that brings special value to this book because of the accumulated knowledge it has brought together. These are people who know the many cultivated varieties of the fruit about which they have written and also about the chemical content and nutritional value of the fruits.

There has been a most unfortunate tendency in recent years for the market to concentrate on just a few varieties of each fruit, usually selected more for their appearance and shape, rather than for taste or nutritional value. Here we see the astonishing variation of chemical properties and differences between the many cultivars of the selected fruits. This shows how much chemical variation there is hidden in this array of genetic differences. It stresses to me the importance for conserving the germplasm of both the ancient and modern varieties of all types of fruits. To maintain quality and to be able to defend fruit crops from pathogens, it is vitally important to preserve as much of the ancient genetic variation as possible that has been selected by cultivators over thousands of years. This will also increase the potential for more flavourful and adaptable varieties. It is my hope that this book will encourage institutions and individuals to preserve as many cultivars of each fruit as possible before it is too late. I fear that the genetic variety has already been eroded for some species.

The information presented here about the detailed chemistry of these popular fruits will be invaluable for food scientists and nutritionists who need to know the array of chemicals and the nutritional value that can be found in any species of fruit. It will also be a much-needed tool for cultivators and breeders of these fruits and hopefully for those in charge of germplasm banks for fruit crops. This is a mine of information about some of our most popular fruits. I hope that it will also stimulate people to use more of these fruits in their daily diet.

Ghilleen Prance FRS, VMH

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PREFACE

Historically, the advancement of man has gone hand-in-hand with advances in both agricultural practices and health. Modern food-providing plants offer better yields and reliance to pests and disease. Such foods have better postharvest features and are less prone of bruising or rotting. They are more uniform in size and shape. The commercialization of agricultural practices has also meant that the number of varieties of plants used for foods has diminished. For example, a single staple food may have been derived from 100 varieties at the turn of the twentieth century, but presently only a handful of varieties may be grown. In terms of fruits, a good illustration is the humble apple. It is reported that there are about 7500 varieties of apples in the world, and in the USA, for example, only 100 are grown commercially. While some may be used in processed food (juices, yogurts, cider, pies, etc.) some supermarkets may only sell five varieties as packaged or loose items.

Presently there is a considerable investment—both commercial and academic—in the health-related properties of foods. It is thus important to document historical cultivars in terms of their nutritive composition before they are lost. This has its relevance when the composition of such historical or traditional cultivars is compared with modern-day cultivars. These also have considerable diversity, and a substantial body of the compositional studies are now directed toward such commercial varieties. This information is useful for a number of reasons, such as finding traits and features that may be transposed from one variety to another. Compositional and sensory features may also be used for commercialization and also to characterize adulteration. Detailed characterization of cultivars can be used to identify “super foods.” Alternatively, unmasked historical cultivars may be the focus of reinvigorated commercial practices. Hitherto, there is no single publication that documents the nutritive contents of historical and modern cultivars for the wide range of variety of fruits. This is addressed in **Nutritional Composition of Fruit Cultivars**, which embraces an international approach by recruiting authors from many countries of the world.

In this volume we cover apples, apricots, bananas, bilberries, black and red currants, clementines, cherries, cranberries, custard apples, dates, figs, grapes, guavas, jackfruits, kiwifruits, loquats, lychees, mandarins, mangos, oranges, papayas, passion fruits, peaches, pears, pineapples, plums, pomegranates, prickly pears, raspberries, and strawberries.

Each chapter has sections on:

- Botanical Aspects
- Composition of Traditional, Ancient or Modern Cultivars
- Summary points

In terms of content, each chapter documents a variety of compositional indices, such as vitamins, minerals, anthocyanins, antioxidant activity, esters, fiber, flavones, flavonoids, flavor volatiles, sugars, amino acids, juice yield, phenolic acids, acidity, and other descriptors that embrace the concept of food quality. Where possible, sensory features such as aroma, taste, color, and texture are also described.

The book **Nutritional Composition of Fruit Cultivars** describes biological diversity in its broadest sense. It is designed for food scientists, technologist, food industry workers, dietitians and nutritionists, as well as research scientists. Contributions are from leading national and international experts including those from world-renowned institutions.

Monique S.J. Simmonds, and Victor R. Preedy
The Editors

CHAPTER 1

Profile of Compounds in Different Cultivars of Apple (*Malus x domestica*)

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LIST OF ABBREVIATIONS

FW Fresh weight

DW Dry weight

GAE Gallic acid equivalent

INTRODUCTION

Early historical records show that apples have been cultivated in Asia and parts of Europe for thousands of years (Morgan and Richards, 1993). Remains of apples have been found in Anatolia that date back to 6500 BC, and by 500 BC the apple was being cultivated through the Persian Empire. The Romans cultivated the apple throughout northern and western Europe. It is estimated that by the thirteenth century, there were at least 120 cultivars in western Europe. The majority of the apple cultivars were used for cooking and for making drinks. The cultivation of apples spread in the seventeenth and eighteenth centuries with the creation of hundreds of cultivars. The Royal Horticultural Society of England records 1200 cultivars of apples in 1826. The diversity of eating apples increased in the eighteenth and nineteenth centuries, with many local cultivars being developed through Europe. The interest in apples spread and, during the nineteenth and twentieth centuries, many cultivars were developed in different parts of Russia, North America, Japan, Australia, and New Zealand. At the start of the twentieth century, the greatest volume of commercial apples entering the trade were

from North America, with Russia increasing its production during the latter part of the twentieth century. Currently China is the largest producer, especially of concentrated apple juice. Nowadays, although there are small orchards producing crops of local cultivars, the diversity of cultivars being traded is dominated by a narrow range of cultivars. If the health potential for having a regular intake of apples is to be realized, then it is important that the cultivars meet not only the esthetic and taste needs of people in different countries, but also contain beneficial compounds at levels that, if ingested regularly, have a beneficial impact on health. This review provides an overview of recent literature on the profile of phenolics in some of the old, new, and commercially grown cultivars.

BOTANICAL ASPECTS

Apples belong to the genus *Malus* which consists of 8–78 species, depending on the rank given to some of the species, as most can be readily hybridized (Phipps et al., 1990). *Malus* is a member of the Maloideae subfamily of the family Rosaceae. The Maloideae are characterized by a hypanthium and gynoecium that remain fused to form an inferior ovary that develops into a fleshy indehiscent fruit.

There have been many different suggestions as to the origin of the domesticated apple, which is usually designated *Malus x domestica* Borkh (Korban and Skirvin, 1984). *Malus x domestica* was first described by Borkhausen in 1803 as a hybrid derived from *Malus sylvestris* Mill., *Malus dasyphyllus* Borkh (synonym for *Malus pumila*), and *Malus praecox* Borkh (a synonym for *M. sylvestris* var. *praecox* (Pall)) (Korban and Skirvin, 1984). Despite the fact that the morphological characters initially used to differentiate among the species of *Malus* were continuous and overlapping, Zohary and Hopf (1993) stated that *M. sylvestris* (L.) Mill., a European species found in Spain, Italy, Greece, and parts of Russia, was “undoubtedly” the principal but not the only source of the domestic apple. In contrast, Watkins (1995) suggested that *Malus sieversii* (Ledeb.) M. Roem from Central Asia was the major species that contributed to *M. x domestica*, with minor contributions from *Malus orientalis* Uglitzk. ex Juz from Caucasia and *M. sylvestris*. A consequence of sequencing the complex heterozygous genome of *M. x domestica* variety, Golden Delicious shows that the wild ancestor of the domestic apple was *M. sieversii* (Velasco et al., 2010). In fact, this study suggests that *M. x domestica* and *M. sieversii* are the same species, and proposes that the appropriate name for the species should be *M. pumila* Mill.

Malus sieversii is widespread in temperate forest areas of central Asia. People have practiced nomadic agriculture in this area for thousands of years, and material could have easily been traded from China to the Middle East and Europe, resulting in the current diversity of apple cultivars. Now apples are grown mostly in temperate climates throughout the world, and there are thought to be more than 10,000 local cultivars (Janick et al., 1996).

The majority of species of apple are $2n = 2x = 34$, although higher somatic numbers of 51, 68, and 85 exist, and several cultivated types are triploid (Chyi and Weeden, 1984). Triploids usually have larger fruits and are thus of commercial interest.

The apple plant is a deciduous tree or large shrub that can grow up to 15 m in height. The density of the plant is determined by rootstock selection and pruning. The majority of apple cultivars have simple oval leaves that are arranged alternately along the length of the stem. The leaves are bright to dark green, with serrated margins. The undersides of most apple leaves are gray–silver and slightly downy. Apples have single, cup-shaped flowers with five petals that open flat to about 5 cm. Inflorescences consist of a cyme with four to six flowers. Flowers are usually white, although they can have pink markings. Flowering occurs in spring. A normal flower consists of five carpels, each with two ovules and five sepals, petals, and styles and can contain up to 10 seeds. The terminal or “king” flower within the cyme is the first to open and usually gives rise to the largest fruit.

Most cultivars require cross-pollination, and thus care must be taken to ensure that compatible pollinizers are selected that will flower at the same time and that, if possible, are annual rather than biennial. Some commercial growers place suitable pollen at the entrance to honey bee hives, whereas others use dusts or sprays to disperse pollen. The timing of pollination is vital for successful fertilization. After fertilization, many fruits fail after 4–6 weeks of growth, and failure is often associated with adverse weather conditions or less rigorous root stock. The time taken for the fruit to mature varies among cultivars and with the environmental conditions but is usually between 50 and 80 days.

The fruit matures in late summer to autumn, and the size varies, depending on the variety. The majority of modern varieties are 7.0–8.3 cm in diameter. The skin of ripe apples is generally red, yellow, green, pink, or russeted, although many bi- or tricolored varieties may be found. The flesh is generally pale yellowish-white, although there are varieties with pink or yellow flesh.

Although apples can be grown relatively easily from seed, the resulting trees can vary greatly in vigor and fruit characteristics; therefore there has been a long tradition of grafting fruiting scions onto rootstock. It is thought that the use of rootstocks is the key to the successful development of many of the apple cultivars.

THE CHEMISTRY OF HERITAGE AND OLDER APPLE CULTIVARS

To date, most studies on old cultivars have provided information about the basic nutritional content of cultivars, as well as information about the levels of compounds such as vitamin C, sugars, and β -catotene (USDA, 2008) (Table 1). More recent studies have re-evaluated the metabolite profile of the older commercial cultivars as well as local cultivars, especially the profile of polyphenols (Iacopini et al., 2010; Jakobek et al., 2013; De Paepe et al., 2015). These studies include hydroxycinnamic acids and their derivatives including chlorogenic acid, flavan-3-ols such as epicatechin and catechin, procyanidins,

Table 1 The composition of nutrients in apples
Concentration (100g FW)

Water (g)	85.6
Energy (kcal)	52
Energy (kJ)	218
Protein (g)	0.26
Total lipid (fat: g)	0.17
Total carbohydrates (g)	13.81
Total sugars (g)	10.39
Sucrose	2.07
Glucose (dextrose)	2.43
Fructose	5.9
Total dietary fiber (g)	2.4
Pectin (g)	0.5
Ash, total minerals (g)	0.19
Potassium, K (mg)	107
Calcium, Ca (mg)	6
Magnesium, Mg (mg)	5
Phosphorus, P (mg)	11
Iron, Fe (mg)	0.12
Vitamin C, total ascorbic acid (mg)	4.6
Vitamin A (IU)	5.4
Vitamin E (α -tocopherol) (mg)	0.18
β -Carotene (μ g)	27
Lutein + zeaxanthin (μ g)	29

Based on data in [USDA \(2008\)](#).

anthocyanins (cyanidin and its derivatives), flavonols (especially glycosylated quercetin compounds), and dihydrochalcones (phloridzin and its derivatives). The levels of these compounds are known to vary depending on the maturity of the fruit tested, environmental factors, and genetic variations. [Belviso et al. \(2013\)](#) showed that within an orchard, the chlorogenic acid and phloridzin levels differed between years, whereas the levels of catechins and procyanidins did not. The levels of phenolic compounds will also be influenced by the solvents used to make the extracts as well as the methods used to analyze the extracts. Thus care is needed when comparing data from independent studies. The literature on the phenolic composition of many apple cultivars, especially commercial cultivars, was reviewed critically by [Kalinowska et al. \(2014\)](#). Overall, these studies report that older cultivars, including the older commercial cultivars, have higher levels of polyphenols than new commercial cultivars.

Amounts of phenolics varied greatly in a study of 13 older cultivars by [Jakobek et al. \(2013\)](#). They showed that the total content in the peel varied from 5885.4 to 14,002.2 mg/kgFW and in the flesh from 2651.6 to 6860.2 mg/kgFW. Of the flavan-3-ol compounds, epicatechin (flesh contained 35.6–259.2 mg/kgFW; peel contained

58.2–541 mg/kgFW) occurred at higher levels than catechin, which was detected only in trace amounts. Reports on the levels of proanthocyanidins vary greatly among studies, due to the lack of detailed quantitative information (Jakobek et al., 2013). In the 13 cultivars studied by Jakobek et al. (2013), the proanthocyanidin content varied from 1703.5 to 5329.5 mg/kgFW in the flesh to 4473.8–11,455.6 mg/kgFW in the peel. Anthocyanins are usually reported from the peel of red apples, and many heritage cultivars have higher levels (79.4–761 mg/kgFW) than a commercial cultivar such as Red Delicious (100–500 mg/kgFW; Karaman et al., 2013), although a study on Red Delicious by Escarpa and Gonzalez (1998) reported higher levels of 585–1037 mg/kgFW. The flesh of a heritage cultivar Ljubeničarka contained 761 mg/kgFW anthocyanidins (Jakobek et al., 2013). Levels as high as this are of commercial interest, as a fruit with a red flesh could attract a premium price as well as having potential health benefits. In another study, De Paepe et al. (2015) studied the polyphenols in the peel and flesh of 47 cultivars growing in Belgium. In this study, they were able to show clear differences in the composition of the peel from the old “heritage” cultivars compared to the classic and more modern cultivars (Tables 2 and 3). Heritage cultivars were characterized by flavan-3-ols, dihydrochalcones (phloretin-2'-O-glucoside and 3-hydroxyphloretin-2'-O-glucoside), procyanidins, *p*-coumaroyl quinic acid, and chlorogenic acid. The higher levels of the flavan-3-ols and chlorogenic acid could not only contribute to the health benefits of these cultivars but could also explain why some of these cultivars are more resistant to diseases such as scab disease (Khanizadeh et al., 2006), as can the higher levels of the dihydrochalcone phloridzin (Slatnar et al., 2010). De Paepe et al. (2015) were also able to show that the composition of the red-peeled apples differed from those with a green peel. The key difference was that apples with a red peel had high levels of chlorogenic acid and caffeic acid, and low amounts of oligomeric procyanidins and flavanols. The peel of the older heritage cultivars is characterized by higher levels of quercetin-3-O-arabinoside. The flesh of old and new cultivars also differs. The heritage cultivars usually have higher levels of (–)-epicatechin, (+)-catechin, and caffeic acid. When comparing the results of different studies, care must be taken in attributing a single factor as contributing to the levels of the compounds, as the apples could be sampled at different maturity times and as the trees are exposed to different soil and environmental conditions. In their study, De Paepe et al. (2015) tried to decrease the environmental factors by selecting apple cultivars that were growing under similar conditions, so that the observed differences in chemistry could be attributed to the genetic background of the cultivars. However, it should be noted that in their study, the heritage cultivars were grown under organic agricultural methods, whereas the classic and new cultivars were under conventional agricultural methods. A few studies have suggested that organically grown apples may contain higher levels of phenolics than those grown nonorganically (Verberic et al., 2005). However, there are very few robust studies that compare like with like, that is, that compare the same cultivar grown in similar soil/environmental conditions but with a different agricultural method.

Table 2 Amounts of some of the phenolics reported in the peel of heritage and older cultivars of apple (mg/kg DW)

Cultivar	pCQA	CA	CHLA	QUE	QUEGLU	QUEGAL	QUERUT	QUEARA	QUERHA	CAT	eCAT	CYAGLU	CYAGAL	PHLGLU	PHXYGLU	HPHLGLU	HPHXYGLU	eCATB2
ALK	31.7	10.9	0.1	4.6	55.6	289.3	4.9	260.5	80.4	74.9	832.5	0.0	48.3	64.1	97.0	4.1	10.9	1138.2
ARG	118.5	11.0	521.6	1.5	28.1	159.8	7.8	172.4	142.8	45.8	822.0	0.0	140.8	141.6	102.4	3.3	11.0	805.3
RD	42.5	4.8	422.0	4.0	157.8	291.3	41.0	176.1	64.5	28.5	249.4	0.0	34.6	387.8	605.9	5.3	32.7	309.9
RDFR	209.6	13.2	724.8	18.1	69.9	310.0	18.0	207.4	56.4	72.1	874.1	0.0	219.6	323.5	101.1	11.6	11.9	784.1
JS	305.0	8.0	689.8	3.5	55.1	315.4	39.2	345.9	169.5	49.2	465.7	0.0	481.0	32.9	48.1	0.7	3.7	274.2
CDSS	641.6	8.1	1029.7	5.6	76.5	308.6	28.2	259.7	128.6	23.9	468.1	0.0	0.0	91.1	147.3	4.3	19.2	676.6
GDM	103.1	14.1	609.1	1.2	18.8	27.1	2.6	88.7	62.4	67.0	980.2	0.0	8.1	236.7	209.3	3.6	15.9	1079.8
EK	38.2	8.6	888.6	2.8	89.8	372.7	51.8	368.6	173.1	29.7	598.8	0.0	287.4	182.5	270.1	4.3	23.6	850.7
JL	42.8	7.8	404.5	1.9	44.1	44.1	2.6	117.4	64.8	55.5	490.2	0.0	1.3	155.9	130.0	4.2	14.3	639.6
LC	42.4	11.3	188.5	7.0	121.6	499.4	54.2	366.6	203.0	63.7	557.7	0.0	14.6	158.1	35.7	5.4	2.6	679.3
JM	317.6	11.9	764.7	2.8	47.2	90.8	39.3	135.3	55.4	67.5	869.0	0.0	101.0	726.2	692.0	21.4	49.1	1028.9
PVD	132.2	10.3	391.3	2.6	142.7	663.3	27.4	685.3	321.1	62.6	825.3	0.0	16.6	602.4	1281.3	28.1	103.3	1101.6
RE	505.1	12.8	979.9	2.7	90.1	406.5	39.6	312.5	310.4	57.9	723.8	15.6	615.2	168.4	76.3	1.5	21.1	393.2
RDC	428.4	9.7	1382.5	10.2	78.3	237.6	8.3	327.6	91.1	45.7	705.1	0.0	15.3	548.3	245.5	9.8	2.7	1008.4
MJDT	206.9	9.9	614.1	4.9	74.8	276.8	25.7	285.8	136.9	53.8	710.0	1.2	142.3	285.8	303.3	7.7	22.8	782.9
RBP	165.7	21.8	68.8	1.2	50.7	160.0	47.3	87.8	66.3	26.8	227.1	86.0	0.0	47.6	254.5	1.3	11.3	227.3
RDFL	278.2	47.6	75.1	2.7	66.7	146.3	11.4	112.2	45.8	25.0	308.6	0.0	0.0	398.1	383.3	4.6	12.3	354.1

Cultivars: ALK, ‘Alkmene’; ARG, ‘Argilière’; RD, ‘Reinette Descarde’; RDFR, ‘Reinette de France’; JS, ‘Jan Steen’; CDSS, ‘Calville de Saint-Sauveur’; GDM, ‘Gueule de Mouton’; EK, ‘Sabot d’Eysden’; JL, ‘Jaque Lebel’; LC, ‘Lombarts-Calville’; JM, ‘Joseph Mush’; PVD, ‘Président Henri Van Dievoet’; RE, ‘Reinette Étoilée’; RDC, ‘Reinette des Capucins’; MJDT, ‘Marie-Joseph d’Othée’; RBP, ‘Reinette Bakker Parmentier’; RDFL, ‘Reinette de Flandre’.

Compounds: pCQA, *p*-coumaroyl quinic acid; CA, caffeic acid; CHLA, chlorogenic acid; QUE, quercetin; QUEGLU, isoquercitrin; QUEGAL, hyperin; QUERUT, rutin; QUEARA, avicularin; QUERHA, quercitrin; CAT, catechin; eCAT, epicatechin; CYAGLU, kuromanin; CYAGAL, ideain; PHLGLU, phloridzin; PHXYGLU, phloretin-2'-*O*-xylosylglucoside; HPHLGLU, 3-hydroxyphloridzin; HPHXYGLU, 3-hydroxyphloretin-2'-*O*-xylosylglucoside; eCATB2, procyanidin-B2.

Based on data in [De Paepe et al. \(2015\)](#).

Table 3 Amounts of some of the phenolics reported in the flesh of heritage and older cultivars of apple (mg/kg DW)

Cultivar	pCQA	CA	CHLA	QUE	QUEGLU	QUEGAL	QUERUT	QUEARA	QUERHA	CAT	eCAT	CYAGLU	CYAGAL	PHLGLU	PHXYGLU	HPHLGLU	HPHXYGLU	eCATB2
ALK	2.5	10.7	36.9	0.5	3.7	8.4	0.3	12.4	33.5	71.0	376.9	0.0	0.5	44.1	0.0	0.0	0.0	589.2
ARG	15.3	5.2	126.4	0.4	0.2	0.1	0.0	0.6	1.1	32.6	234.7	0.0	0.2	37.9	0.0	0.0	0.0	144.0
RD	7.1	3.9	122.1	0.4	0.8	0.2	0.1	1.1	1.9	37.3	186.9	0.0	0.0	24.4	0.0	0.0	0.0	190.2
RDFR	16.8	4.3	115.3	0.5	0.6	1.8	0.1	3.0	3.2	43.1	181.0	0.0	1.1	23.0	0.0	0.0	0.0	172.9
JS	25.0	1.5	126.0	0.5	0.7	4.1	0.4	10.3	8.0	21.4	65.4	0.0	2.0	58.4	0.0	0.0	0.0	13.6
CDSS	57.1	4.1	209.7	0.5	8.3	7.2	0.6	16.0	10.6	32.3	134.3	0.0	0.2	53.2	0.0	0.0	0.0	145.4
GDM	12.0	7.3	185.2	0.0	0.8	0.2	0.1	5.6	6.4	126.1	264.0	0.0	0.2	103.7	0.0	0.0	0.0	93.3
EK	2.5	4.7	215.6	0.4	0.7	1.8	0.2	4.2	6.0	21.4	167.9	0.0	1.4	61.8	0.0	0.0	0.0	156.3
JL	9.4	4.6	126.8	0.4	1.3	0.3	0.0	2.9	2.5	36.6	259.3	0.0	0.0	47.1	0.0	0.0	0.0	365.6
LC	10.8	8.0	79.0	0.7	12.7	25.3	2.0	26.1	20.7	134.6	311.3	0.0	0.7	31.7	0.0	0.0	0.0	327.3
JM	27.7	4.9	232.1	0.5	2.9	0.3	0.1	12.1	10.6	62.7	166.6	0.0	0.4	109.8	0.0	0.0	0.0	135.1
PVD	21.8	7.7	117.8	0.4	4.5	3.7	0.4	30.2	39.4	43.8	309.7	0.0	0.0	77.6	0.0	0.0	0.0	310.3
RE	56.1	0.3	202.7	0.5	0.4	0.0	0.2	2.1	1.6	1.5	11.5	0.0	0.0	7.9	0.0	0.0	0.0	3.8
RDC	10.5	0.5	173.0	0.4	0.2	0.0	0.0	0.7	0.4	2.3	22.5	0.0	0.0	3.3	0.0	0.0	0.0	27.3
MJDT	42.6	0.8	22.1	0.0	1.0	0.5	0.0	0.8	2.6	6.0	59.7	0.0	0.1	10.2	0.0	0.0	0.0	99.4
RBP	20.2	4.4	131.8	0.4	2.7	3.5	0.3	7.7	10.7	40.4	204.7	0.0	0.4	41.0	0.0	0.0	0.0	183.2
RDFL	42.8	3.3	63.5	0.0	0.2	0.1	0.0	0.4	0.8	39.3	143.6	0.0	0.1	17.8	0.0	0.0	0.0	170.3

Cultivars and compounds as in footnotes to [Table 2](#).
Based on data in [De Paepe et al. \(2015\)](#).

It is clear from the studies on old cultivars that they are an important genetic resource for breeding programs. There is also potential in looking at the levels of phenols in related wild species of *Malus*, especially the species known as crab apples. A study by [Li et al. \(2014\)](#) of 10 different locally grown plants that represented six different species of *Malus* showed that the phenolic content of these species was greater than those of many commercial cultivars. The phenolic and flavonoid content (as expressed as milligrams of gallic acid equivalent per 100 g of fresh weight = mg GAE/100 g) in ethanol extracts of the apples varied from 302.8 to 1265 mg GAE/100 g and from 352.4 to 2351 mg GAE/100 g, respectively. In contrast, phenolic content of the cultivar Fuji (167.1 mg GAE/100 g) was lower ([Viera et al., 2009](#)).

THE CHEMISTRY OF MODERN AND COMMERCIAL CULTIVARS

The majority of the information about the metabolites in apple cultivars relates to modern cultivars, especially the cultivars that dominate the international trade, such as the following: Red Delicious, Golden Delicious, McIntosh, and Jonagold, developed in North America; Braeburn and Royal Gala from New Zealand; Granny Smith from Australia; and Fuji from Japan. In fact there is a great deal of data about the polyphenolic compounds in these cultivars grown in different countries such as Austria and Slovenia ([Verberic et al., 2005](#)), Canada ([Khanizadeh et al., 2008](#)), Italy ([Lamperi et al., 2008](#)), Greece ([Valavanidis et al., 2009](#)), New Zealand ([Volz and McGhie, 2011](#)), and Poland ([Wojdylo et al., 2008](#)). The profile of polyphenols in a wider group of commercial and new cultivars growing in Europe and New Zealand was reported by [Ceymann et al. \(2012\)](#) and [Volz and McGhie \(2011\)](#), respectively. The results of many other studies on commercial apple cultivars were collated by [Kalinowska et al. \(2014\)](#). They showed that in most cases the levels of total phenolic compounds, total procyanidins, and total flavonoids are higher in the peel than in the flesh. However, in some studies, cultivars such as Golden Delicious, Granny Smith, and Reineta had greater concentrations of chlorogenic acid in the flesh than in the peel ([Escarpa and Gonzalez, 1998](#)). In a study by [Alarcón-Flores et al. \(2015\)](#) of seven commercial cultivars, the authors found that Granny (793 mg/kg DW), Fuji (793.1 mg/kg DW), and Red (683.4 mg/kg DW) had the greatest amounts of phenolic compounds in the flesh, and the cultivar Ambrosia had the lowest amount (459.9 mg/kg DW). The only phenolic acid that they detected in the flesh was chlorogenic acid, with the greatest levels being found in Fuji (431.6 mg/kg DW), Royal (350.5 mg/kg DW), and Pink Lady (283.9 mg/kg DW) and the least in Ambrosia (118.3 mg/kg DW). Levels of epicatechin in the flesh varied from 61.5 mg/kg DW in Fuji to 307.2 mg/kg DW in Granny. Levels of phloridzin in the flesh varies from 81.5 mg/kg DW in Royal to 289 mg/kg DW in Red. Gala contained more *p*-coumaroylquinic acid and procyanidin B1 in the flesh than in the peel ([Khanizadeh et al., 2008](#)).

The study by [De Paepe et al. \(2015\)](#) of new and classical cultivars growing in Belgium showed that overall the classic and new cultivars had high levels of flavonols but lower levels of dihydrochalcones, proanthocyanidins, and chlorogenic acid compared to old heritage cultivars ([Tables 4 and 5](#)). They also showed some differences from other studies, in that red-skinned apples usually have high levels of quercetin-glycosides, whereas in their study the peel of these cultivars contained high levels of chlorogenic acid and caffeic acid. They were usually characterised by high levels of quercetin-glycosides such as quercetin-3-*O*-galactoside. The most abundant dihydrochalcones in the new cultivars were phloretin-2'-*O*-xylosylglucoside and 3-hydroxyphloretin-2'-*O*-xylosylglucoside; these were also present in the flesh of the new cultivars. Whole fruit extracts of Golden Delicious contain about 219.1 mg/kgDW dihydrochalcones, with the dominant compounds being phloretin 2'-*O*-glucoside (146.8 mg/kgDW) and phloretin 2'-*O*-xylosylglucoside (7.3 mg/kgDW) ([Wojdylo et al., 2008](#)) compared to a new cultivar, Macfree, which contains higher amounts of both phloretin 2'-*O*-glucoside (231.3 mg/kgDW) and phloretin 2'-*O*-xylosylglucoside (203 mg/kgDW). These dihydrochalcones contribute to the antioxidant potential of apple products.

Levels of flavonols vary in the peel of commercial cultivars Empire, Red Delicious, and Golden Delicious from 220 to 350 mg/kgFW ([Tsao et al., 2003](#)) and 238 to 1220 mg/kgFW ([Escarpa and González, 1998](#)). These levels are lower than in many older heritage cultivars that can be up to 2240 mg/kgFW ([Verberic et al., 2005](#)). The diversity of phenolic compounds are usually greater in the peel than in the flesh, and this can be supported by the study on commercial cultivars by [Alarcón-Flores et al. \(2015\)](#). They recorded compounds such as isorhamnetin 3-*O* glucoside, kaempferol-3-*O*-glucoside, kaempferol-3-*O*-rutinoside, quercetin 3-*O*-rutinoside, and epigallocatechin in the peel of many of the commercial cultivars. Overall, they found that the relatively new cultivar Pink Lady was the cultivar with the greatest concentration of phenolic compounds (4106.7 mg/kgDW).

The study by [De Paepe et al. \(2015\)](#) also showed that if a narrow range of parents are used in apple breeding, then the diversity as well as the abundance of phenolics can decrease. Some of the new cultivars that they tested also have very low levels of chlorogenic acid and higher levels of *p*-coumaroyl quinic acid. The ratio of these two compounds is important, as they differ in their effects on the polyphenoloxidase enzymes involved in browning that occurs after an apple is cut or pressed. The relative concentrations of these compounds influence the oxidation process and thus the browning. Cultivars with a balanced composition of flavan-3-ols and hydroxycinnamic acids, low chlorogenic acid, and a small chlorogenic/*p*-coumaroyl quinic acid ratio are usually the best for making apple juice as well as for apple slices used in salads. Currently, fresh-cut apple slices can be dipped in calcium ascorbic acid and stored under modified atmosphere conditions for up to 28 days to delay browning ([Aguayo et al., 2010](#)). Growing apples to make apple juice is an important economic driver, and thus it is understandable

Table 4 Amounts of some of the phenolics reported in the peel of new and commercial cultivars of apple (mg/kg)

Cultivar	pCQA	CA	CHLA	QUE	QUEGLU	QUEGAL	QUERUT	QUEARA	QUERHA	CAT	eCAT	CYAGLU	CYAGAL	PHLGLU	PHXYGLU	HPHLGLU	HPHXYGLU	eCATB2
BEL	55.2	21.9	27.8	2.1	177.0	227.3	27.5	144.8	63.4	24.0	211.8	55.8	50.4	314.9	192.2	6.6	20.3	184.3
NCGRN_E1	1.6	10.6	0.1	4.2	371.8	501.9	58.8	296.8	327.4	7.7	250.3	0.0	0.0	23.4	180.3	4.3	43.3	262.5
NCGRN_E2	1.0	12.3	0.1	5.4	569.9	588.5	32.4	292.2	474.7	11.1	132.0	0.0	0.0	31.2	121.4	3.4	47.9	156.4
NCTR_E1	1.9	7.4	26.8	2.4	421.2	612.7	69.0	242.0	134.0	11.0	171.3	55.4	48.0	12.1	179.6	1.3	37.0	164.7
NCTR_E2	2.6	7.9	13.8	1.2	333.6	857.8	40.1	195.0	146.7	5.9	237.6	47.3	36.3	14.0	150.4	1.8	47.4	99.7
RBSTP	9.3	22.9	47.3	2.1	276.7	410.4	25.7	184.2	197.1	29.5	335.3	91.6	81.4	35.1	236.9	2.1	21.8	245.1
RDLCF	61.6	19.6	0.1	1.4	115.2	182.7	9.1	144.7	172.5	30.1	562.7	16.3	14.5	67.1	75.6	2.7	16.4	410.8
PIN	13.6	20.6	16.9	0.7	293.5	393.2	9.0	253.1	71.6	22.6	346.4	39.4	36.0	36.6	178.8	1.3	21.2	321.0
BOSK	20.3	11.2	53.6	4.5	370.2	508.4	0.1	343.6	344.2	38.3	363.9	209.8	183.9	30.0	67.5	2.5	10.0	268.4
BREA	26.9	11.1	23.5	1.1	146.7	193.3	15.1	128.8	50.6	8.8	203.2	49.3	43.0	26.8	98.1	2.1	26.7	233.3
COX	16.6	9.5	24.5	2.3	327.6	441.7	29.5	223.8	67.7	16.0	203.8	53.1	46.1	13.4	71.5	1.4	28.0	205.2
GAL	48.0	17.3	193.0	1.2	334.3	429.6	46.0	201.3	114.7	27.0	313.7	371.2	328.5	33.5	195.3	1.2	24.9	209.2
GOLD	35.3	18.3	0.1	1.6	365.7	458.8	53.9	201.9	175.4	14.1	206.1	7.0	7.3	59.6	150.4	6.5	23.1	196.8
GRSM	6.5	10.2	1.5	1.6	471.3	588.9	202.7	316.5	320.8	25.2	280.3	0.0	3.2	13.1	111.9	1.1	20.9	286.2
JNGLD	18.4	11.6	122.4	2.5	459.5	644.1	53.3	339.4	331.7	19.5	295.1	413.7	368.2	43.6	140.7	5.2	18.8	248.8

Cultivars: BEL, 'Belgica'; NCGRN_E1, 'Nicogreen'; NCGRN_E2, 'Nicogreen'; NCTR_E1, 'Nicoter'; NCTR_E2, 'Nicoter'; RBST, 'Rubinstep'; RDLCF, 'Red Delcorf'; PIN, 'Pinova'; BOSK, 'Schone van Boskoop'; BREA, 'Breaburn'; COX, 'Cox's Orange Pippin'; GA, 'Gala'; GOLD, 'Golden Delicious'; GRSM, 'Granny Smith'; JNGLD, 'Jonagold'.

Compounds as in footnote to [Table 2](#).

Based on data in [De Paepe et al. \(2015\)](#).

Table 5 Amounts of some of the phenolics reported in the flesh of new and commercial cultivars of apple (mg/kg DW)

Cultivar	pCQA	CA	CHLA	QUE	QUEGLU	QUEGAL	QUERUT	QUEARA	QUERHA	CAT	eCAT	CYAGLU	CYAGAL	PHLGLU	PHXYGLU	HPHLGLU	HPHXYGLU	eCATB2
BEL	25.9	2.2	0.0	0.0	0.5	0.3	0.0	1.4	1.6	9.3	70.4	0.0	0.0	46.8	72.1	0.7	1.4	23.6
NCGRN_ E1	6.9	4.2	0.0	0.1	0.5	1.9	0.2	2.0	5.7	12.1	154.9	0.0	0.0	7.7	74.4	0.0	3.2	0.0
NCGRN_ E2	7.9	2.9	0.0	0.1	0.5	1.9	0.3	2.4	5.2	7.9	128.6	0.0	0.0	6.4	104.5	0.0	2.4	0.0
NCTR_ E1	18.9	2.0	27.6	0.3	0.8	1.1	0.1	6.7	22.2	3.8	62.5	0.0	1.5	35.7	17.1	0.6	0.0	66.1
NCTR_ E2	17.4	2.2	28.4	0.3	0.9	1.2	0.1	5.9	19.7	3.0	54.2	0.0	2.0	30.2	22.6	0.7	0.0	73.5
RBSTP	34.8	2.4	14.2	0.2	0.7	3.5	0.4	3.9	7.3	9.6	83.0	0.1	0.3	37.2	56.6	0.7	1.0	62.2
RDLCF	102.1	4.5	37.9	0.3	1.7	1.9	0.3	3.0	2.4	15.7	135.2	0.0	0.5	19.7	42.1	0.6	1.5	66.0
PIN	1.1	2.0	15.0	0.1	0.9	1.4	0.1	2.2	7.7	5.4	99.0	0.0	0.0	11.4	104.4	0.7	1.0	39.5
BOSK	8.5	2.8	16.7	0.1	0.9	0.0	0.0	1.8	3.6	25.5	120.8	0.0	0.1	14.5	21.9	0.7	1.2	68.3
BREA	35.4	1.8	0.0	0.0	1.4	1.1	0.1	0.9	1.0	7.7	65.5	0.0	0.1	11.9	19.0	0.7	1.0	24.1
COX	19.1	2.6	7.4	0.1	0.8	0.7	0.0	1.1	2.0	12.1	120.8	0.1	0.1	9.0	21.9	0.7	1.2	138.1
GAL	30.1	1.7	15.2	0.0	0.3	1.0	0.1	1.2	2.6	11.2	66.1	0.4	0.6	14.1	32.2	0.7	1.1	17.0
GOLD	27.0	2.2	16.7	0.1	0.9	3.2	0.3	2.9	10.0	5.1	73.1	0.0	0.0	15.9	28.6	0.7	1.4	73.4
GRSM	10.9	4.0	10.3	0.1	1.3	3.3	1.1	2.3	3.6	47.3	187.6	0.0	0.0	15.4	33.9	0.7	2.1	149.0
JINGLD	6.5	1.6	15.1	0.1	0.5	0.1	0.0	2.3	10.4	4.2	57.2	0.0	0.1	13.3	13.2	0.2	0.0	80.8

Cultivars as in footnote to [Table 4](#).Compounds as in footnote to [Table 2](#).Based on data in [De Paepe et al. \(2015\)](#).

why some of the new cultivars are low in these phenolic compounds. The compounds also contribute to the flavor of the apples, as bitter cultivars usually have higher levels of hydroxycinnamic acid than less bitter cultivars.

Apples also contain low concentrations of chloroplastic pigments that are usually at higher concentrations in the peel than in the flesh. These compounds could contribute to some of the health benefits of apples. However, levels decrease as the fruit matures. To date, most of the work on these compounds have been focused on commercial cultivars such as Golden Delicious and Cox's Orange Pippin. A study by [Delgado-Pelayo et al. \(2014\)](#) characterized the levels of 25 chlorophyll and carotenoid compounds in 13 commercial cultivars of apples. The two most abundant compounds in the flesh were diesterified xanthophylls, which varied from 3.9 $\mu\text{g/gDW}$ (Granny Smith) to 25 $\mu\text{g/gDW}$ (Golden Montaña), and chlorophyll *a*, which varied from 0.8 $\mu\text{g/gDW}$ (Fuji) to 47 $\mu\text{g/gDW}$ (Granny Smith). These two compounds were also the most abundant in the peel, with diesterified xanthophylls varying from 4.9 $\mu\text{g/gDW}$ (Fuji) to 38.4 $\mu\text{g/gDW}$ (Ariane). In the peel, chlorophyll *a* varied from 18.4 $\mu\text{g/gDW}$ in Golden Rosett to 1049.2 $\mu\text{g/gDW}$ in Granny Smith. Overall, of the 13 cultivars tested, Granny Smith had the greatest pigment content in the peel (1510.7 $\mu\text{g/gDW}$) and flesh (71.7 $\mu\text{g/gDW}$). [Delgado-Pelayo et al. \(2014\)](#) found that cultivars with a green peel had high amounts of chlorophyll content in the peel, although some of the red-skinned cultivars (Fuji from Italy, Pink Lady, and Starking Red Chief) also had high levels. Cultivars with low chlorophyll content were those with yellow skins (Golden Delicious, Golden Rosett, and Golden Montaña). Overall, levels of carotenoids were low (less than 50 $\mu\text{g/gDW}$), except for Granny Smith and Ariane, which contained 151 $\mu\text{g/gDW}$ and 61.1 $\mu\text{g/gDW}$ in the peel, respectively. In the 13 cultivars studied by [Delgado-Pelayo et al. \(2014\)](#), lutein was the main free carotenoid, followed by violaxanthin, neoxanthin, and β -carotene. The exceptions were the peels of the yellow-skinned cultivars Golden Montaña and Golden Rosett, and the red-skinned cultivars Royal Gala and Ariane, in which neoxanthin and violaxanthin were the main carotenoids. The authors were able to show that the carotenoid content correlated positively with the amount of esterified xanthophylls, and suggested that the esterification is involved in the accumulation of the carotenoids in the vegetable tissues.

Overall, the data show that many classic and modern cultivars contain lower amounts of polyphenols and other compounds that could contribute to the health benefits of eating apples than do older cultivars, and this could have a negative impact on people's health especially if apples are seen as a major source of their daily polyphenol intake ([Jakobek et al., 2013](#)).

As indicated earlier, the differences in the profile of phenolic compounds in the cultivars are influenced not only by the cultivar but also by environmental factors and fruit maturation. These factors must modulate the regulation of the biosynthetic pathways involved in the production of these phenolic compounds. Our understanding of these

pathways and the genes involved has greatly improved with a better understanding of the apple genome (Velasco et al., 2010), so there is greater potential for more targeted selection for optimizing the levels of these compounds in apples. However, the challenge will be in keeping the appropriate balance of sweet- and bitter-tasting compounds so that an apple does not become too bitter and thus not be eaten as part of a balanced diet.

APPLE POLYPHENOLS AND HEALTH

Polyphenols from dietary plants have been associated with numerous health benefits, indicated from mechanistic, clinical, and epidemiological studies. Several studies associate increased consumption of fruit and vegetables, a source of polyphenols, with favorable effects on cardiovascular disease (CVD) and on risk factors for type 2 diabetes and some cancers, whereas a low fruit and vegetable intake is a risk factor for cancer (Howes and Simmonds, 2014; Weichselbaum et al., 2010). Epidemiological studies have associated apple consumption in particular with a reduced risk of some cancers, including lung cancer (Boyer and Liu, 2004). Furthermore, apple intake has been correlated with a reduced risk of CVD, as observed from a 6.9-year follow-up study that surveyed almost 40,000 women (Boyer and Liu, 2004). Although intake of dietary polyphenols has been suggested to have a favorable impact on some diseases and disease conditions, such as CVD, diabetes, cancer, and dementia, more conclusive evidence is needed to understand the most relevant polyphenols and the optimum dietary concentrations required for health.

The flavonol quercetin is widely distributed in the plant kingdom, but is particularly abundant in apples. Metabolites of quercetin (3-O-glucuronic acid and 3-O-sulfate), a flavonoid-rich apple extract, and constituent flavonoids were able to inhibit in vitro angiotensin-converting enzyme (Balasuriya and Rupasinghe, 2012), which is a pharmacological target to modulate hypertension. Furthermore, apple peel extracts and constituent polyphenols (including phloridzin and quercetin, as well as quercetin metabolites) inhibited low-density lipoprotein oxidation in vitro at physiological concentrations (Thilakarathna et al., 2013). These studies provide some insight into the mechanisms that might explain the potential benefits of apple polyphenols in CVD. Indeed, apple polyphenols, particularly quercetin, have produced beneficial effects on blood pressure in some human studies. One study showed a dose of 150 mg/day quercetin over 6 weeks to significantly decrease systolic blood pressure in overweight and obese adults, with efficacy observed in prehypertensive or hypertensive subjects at baseline, but not in those with normal blood pressure (Weichselbaum et al., 2010). A randomized, double-blind, placebo-controlled crossover study in prehypertensive and stage 1 hypertensive adults associated a higher dose of quercetin with a reduction in blood pressure, when taken at 730 mg/day for 4 weeks (Weichselbaum et al., 2010). Although these outcomes are promising for CVD, it should also be considered that studies investigating a single polyphenol at a high dose may not directly correlate with the mixture of polyphenols that

occur in apples or with the levels at which they occur. For example, 150 mg quercetin/day would be the equivalent to the content of this flavonol in approximately 20–30 apples (Weichselbaum et al., 2010). Therefore the clinical relevance of apple polyphenols when consumed via the diet, and the effects of high doses of single polyphenols, particularly in longer-term studies, need to be investigated further.

Apple purees (230 g/day; 25 healthy subjects) containing ≥ 25 mg or 100 mg of the polyphenol epicatechin attenuated platelet reactivity and increased plasma concentrations of nitric oxide (NO) metabolites; thus apple intake may reduce CVD risk via effects on platelet aggregation. Interestingly, the higher dose of epicatechin was no more effective than the lower dose in this study (Gasper et al., 2014). Polyphenol-rich homogenized apple skin (80 g) and flesh (120 g), composed of 184 mg total quercetin glycosides and 180 mg epicatechin, also augmented NO status, but did not affect cognitive function or mood, when administered to healthy volunteers in a randomized, controlled, cross-over trial with healthy men and women (Bondonno et al., 2014). However, another study concluded that consumption of a polyphenol-rich apple (40 g apple; 0.21 g polyphenols/day) did not improve vascular function in hypercholesterolemic patients over a 4 week period (Auclair et al., 2010). It is important to consider that although there are conflicting data and outcomes with regard to polyphenol intake and health, the flavan-3-ol epicatechin, which occurs in a variety of dietary food plants, has been associated with numerous mechanistic effects relevant to CVD, cancer, diabetes, and cognitive functions (Howes and Simmonds, 2014). Furthermore, it has been concluded that noncitrus fruits including apples account for the highest intake of total flavan-3-ols in Europe (other than the United Kingdom) (Knaze et al., 2012). Apples therefore appear to be one of the most important dietary sources of polyphenols such as epicatechin, and their potential for health would be particularly relevant to investigate further.

Apple (and pear) intake has been inversely associated with asthma and has been positively correlated with general pulmonary health, as observed in a study involving 1600 adults. Total fruit and vegetable intake was not associated with asthma risk or severity. Other studies also support these conclusions (Boyer and Liu, 2004). Apples in particular may therefore be more beneficial for pulmonary parameters compared to some other fruits. Consumption of fruit and vegetables, or their juices, is also associated with a decreased prevalence of cognitive impairment and a reduced risk of Alzheimer's disease, which is considered to be due to the content of polyphenols (Howes and Simmonds, 2014). It has also been suggested that apple polyphenols may protect against gastric mucosal damage following aspirin ingestion, since this effect was observed with two different apple polyphenol extracts in vivo (Paturi et al., 2014). Mechanistic effects to explain the anti-inflammatory potential of apple polyphenols have been explored further, as described in a study that investigated a phytochemically characterized extract of dried apple peels (containing phenolic acids, flavonol glycosides, flavan-3-ols, and procyanidins) in human epithelial intestinal cells (Caco-2/15) in vitro. This study revealed that

the apple peel extract could reduce oxidative stress and downregulate inflammatory mediators, including cytokines and prostaglandin E₂ (Denis et al., 2013).

Apple consumption is also linked with a reduced risk of type 2 diabetes, as concluded from a study involving 10,000 participants (Boyer and Liu, 2004). In addition, polyphenol intake has been associated with some benefits for metabolic syndrome, while mechanistic effects relevant for diabetes have also been discovered. An extract and individual polyphenols from apples reduced sodium-coupled glucose transporter 1-mediated glucose uptake in vitro and in vivo, while administration of the apple extract to 10 healthy volunteers reduced venous blood glucose and plasma insulin levels in an oral glucose tolerance test (Schulze et al., 2014). Another study associated consumption of a polyphenol-rich cloudy apple juice (750 mL/day) for 4 weeks with a significant reduction of the percentage of total body fat and an increment in lean body mass in obese subjects, although other studies showed no effect on obesity parameters (Galleano et al., 2012). The variability in outcomes for studies that investigate the potential health benefits of polyphenols highlights the need for robust clinical studies that assess the effects of phytochemically characterized and standardized sources of polyphenols; this would enable firmer conclusions on the most “active” polyphenols and the levels required for health.

The phytochemical composition of plants, including fruits, may vary considerably due to numerous factors such as the cultivation environment, the species or subspecies, the cultivar or variety, the plant part (e.g., for apples, the flesh, peel, core), and the growth stage when harvested; other post-harvest factors such as storage time and conditions, and processing methods, might also influence the phytochemical composition and potential for health-associated effects. It is therefore not surprising that there has been considerable variation in study outcomes to associate particular fruits with mechanistic, clinical, and epidemiological evidence for health. The comparative assessment of the phytochemical and mechanistic profiles of apples and apple products would therefore be relevant to establish more firmly, to enable conclusions in relation to health to be more informative and robust. Indeed, chemical profiling of different varieties of apples has revealed that some varieties (such as ‘Granny’ and ‘Fuji’) contain higher levels of polyphenols (793–794 mg/kgDW) in the flesh compared to other varieties, while others (such as ‘Pink lady’) contain higher levels of polyphenols in the peel (4107 mg/kgDW) (Alarcón-Flores et al., 2015).

Another study revealed that apple polyphenol content (including epigallocatechin gallate) was correlated with antioxidant potential, and this was higher in a species of wild apple (*Malus x prunifolia* (Willd.) Borkh.) compared to a cultivated apple (John et al., 2014). Other species of wild crabapples (*Malus* spp.) have been described as rich sources of polyphenols (particularly epicatechin, rutin, hyperin, and phloridzin) with high antioxidant activity (Li et al., 2014), and may also be of interest to investigate further for their potential relevance to health. Furthermore, processing of apples may reduce the polyphenol content, since levels of some polyphenols such as phloridzin are reported to

decrease significantly when apples are processed to produce juice (Alarcón-Flores et al., 2015). The impact of processing methods on the polyphenol levels in apple products, and any consequences for health, also needs to be explored further.

In conclusion, plant polyphenols, including those from apples, have shown numerous biological activities that indicate relevance for maintenance of health. Observations in humans (clinical and epidemiological) that associate plant polyphenols with health and reductions in risk for some diseases are promising, although not conclusive. Furthermore, polyphenols are widely documented as “antioxidant” and are considered to reduce oxidative stress, yet how antioxidant mechanisms are translated in vivo for health and the impact of metabolism and biokinetics must also be scrutinized more extensively. Nevertheless, there appears to be emerging evidence that there may be some scientific basis for the old proverb “An apple a day keeps the doctor away.”

SUMMARY

- Overall, many old heritage cultivars of apples contain a higher amount and diversity of phenolic compounds than new cultivars.
- Apple peel contains a greater amount and diversity of phenolic compounds than the flesh.
- The flavan-3-ols and hydroxycinnamic acids contribute to both the resistance of apples to many pathogens and pests as well as to the potential health benefits of apples.
- More research is needed to fully evaluate the potential health benefits of the phenolics in apples taking into account the levels that specific compounds that occur in the apples.
- The levels of phenolics such as phloridzin that could contribute to the health benefits of apples decrease significantly during processing, thus more research is needed to look at ways to optimize the levels of these compounds in apple-derived products.

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CHAPTER 2

Apricot (*Prunus armeniaca* L.)

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LIST OF ABBREVIATIONS

AA Ascorbic acid
β-CA β-Carotene
γ-CA γ-Carotene
CA Citric acid
CAE Caffeic acid
CAT Catechin

CCG Cryptochlorogenic acid
CG Chlorogenic acid
3CQ 3-*O*-*p*-Coumaroylquinic acid
β-CR β-Cryptoxanthin
DPPH 2,2-Diphenyl-1-picrylhydrazyl
DW Dry weight
EPI Epicatechin
FA Fumaric acid
FeA Ferulic acid
FRAP Ferric reducing antioxidant power assay
FW Fresh weight
GAE Gallic acid equivalents
IsA Isocitric acid
MA Malic acid
NCG Neochlorogenic acid
***p*-CA** *p*-Coumaric acid
Prov A Provitamin A
QA Quercetin-3-acetylhexoside
QGluc Quercetin-3-glucoside
RUT Rutin (Quercetin-3-rutinoside)
SA Succinic acid
ShA Shikimic acid
TA Titratable acidity
TCA Total Carotenoids
TSS Total soluble solids
Vit A Vitamin A
Vit C Vitamin C
Vit E Vitamin E

INTRODUCTION

Apricot is a delicious fruit with a pleasant flavor and aroma. It is consumed fresh, dried, or canned and highly appreciated by many.

The name ‘apricot’ (albicocco, albericocco) is presumably derived from the combination of Arbor precox from the Latin word praecocia (precocious), due to its early maturation (Faust et al., 1998).

Apricot is believed to have originated in China, close to the Russian border, in the area of the Great Wall, and not from Armenia as it is supposed by its botanical name (*Prunus armeniaca*) (Rieger, 2006). Other possible areas of origin include the central Asian center (from Tien-Shan to Kashmir) or the Near-Eastern center (Iran, Caucasus, Turkey). The cultivation in China dates back almost 3000 years, although there is a report that apricot was cultivated during the years of Emperor Yu (2205–2198 BC) (Faust et al., 1998). From China, it was spread through Central Asia, Armenia, and Anatolia, and then to Europe, probably by the Romans. Its spread was quite slow, when considered that,

in Europe, it came around 70–60 BC by means of the Romans, through Greece, but became an important cultivation in Europe in the seventeenth century. It was probably introduced to the New World by the Spaniards and English colonists (Faust et al., 1998).

As in other stone fruit trees, apricot leaves, flowers, and especially bark and seed contain toxic compounds that produce cyanide, which at high doses can be lethal. The kernel contains the highest amounts of cyanide-generating compounds (laetrile) (Kaur and Verma, 2015) and have been, and still are, used in some regions against tumor cells (Rieger, 2006).

Turkey is the world leader in apricot production, while Iran, Italy, Spain, France, and the United States are other major producing countries (Ghorpade et al., 1995; Rieger, 2006).

BOTANICAL ASPECTS

Apricot (*Prunus armeniaca* L.) belongs to the genus *Prunus*, subgenus *Prunophora*, in the subfamily *Prunoidae* of the family *Rosaceae* (Rieger, 2006). Other known species similar to apricot are the *P. sibirica* L., *P. mandshurica* (Maxim), *P. mume* Sidb., and Zucc., among others (Ghorpade et al., 1995; Rieger, 2006). Recently, hybrids between apricot and plum have been developed, including ‘plumcots’, ‘pluots’, and ‘apriums’, each one characterized by the percentage participation of each parent species (from 50% each to 75% apricot or plum) (Rieger, 2006).

Apricots are small- to medium-sized deciduous trees with either spreading or upright growth habit (Ghorpade et al., 1995; Rieger, 2006; Webb, 1968). They generally reach a height of approximately 4 m under cultivation, but under natural conditions they can reach even 10–15 m height (Faust et al., 1998; Rieger, 2006). They are characterized by reddish to gray-brown bark, with young twigs and leaves appearing reddish.

Leaves are simple, alternate, ovate to round-ovate, sharp pointed 5–12 × 5–10 cm, glabrous with the petioles 2–4 cm, bearing glands (Faust et al., 1998; Ghorpade et al., 1995; Webb, 1968). They are characterized by serrate margins with red-purple petioles, truncate or subcordate at the base.

Flowers are solitary, 2–3 cm, pink to white with deep red sepals, appearing before leaves (Faust et al., 1998; Webb, 1968). They are formed on 1-year-old wood and more often on short spurs. Flowers bear five sepals and petals and many erect stamens, with the ovary being perigenous. Petals are white to pale pink, approximately 10–15 mm in length (Webb, 1968). Most traditional cultivars are self-fertile, although the modern ones yield better when cross pollinated. Flowering occurs early in spring (early to March to early April), although fruits need approximately 3–6 months to mature, depending on the cultivar.

Fruit is a drupe of 3.5–8 cm wide, quite flattened, with a distinct suture line, characterized by a double sigmoidal curve, as in the other stone fruits (Webb, 1968). Skin color

ranges from yellow to deep orange, with a distinct red blush in many modern cultivars, with a light pubescence in some cultivars or semi-glabrous in some others (Faust et al., 1998; Webb, 1968). The stony endocarp is flattened, smooth, with three narrow ridges along one margin. The flesh color is orange, although some white-fleshed cultivars exist. Fruit weight ranges from 40 to 50 to the extreme of 100 g. Trees are precocious, beginning to bear fruit from the second to third year.

Apricot trees grow best in deep, fertile, well-drained soils. They do not tolerate water logging while are fairly tolerant to elevated soil pH, this depending on the rootstock used. Apricot thrives in Mediterranean type climates, where the danger of late winter or early spring frosts is limited (Rieger, 2006). It requires cool weather to break bud dormancy and dry sunny spring and a warm summer for excellent fruit quality. Apricot is quite cold tolerant when dormant, withstanding temperatures as low as -34°C . The length of the growing season is not considered a limitation for apricot culture, since most cultivars ripen late in spring (early May) until late July, although some new cultivars mature in late summer. Hot weather during maturation (temperatures around 38°C or higher) damages the fruit, causing pit burn.

COMPOSITION OF TRADITIONAL APRICOT CULTIVARS

Organoleptic Characteristics and Sensory Attributes of Traditional Apricot Cultivars

‘Proimo Tyrinthos’ is the cultivar that has presented the lowest total soluble solids (TSS) concentration (8.8°Brix), although it has been reported to have up to 9.8°Brix (Caliskan et al., 2012; Drogoudi et al., 2008) (Table 1). Most of the cultivars, however, exhibit values of TSS above 10°Brix , with ‘Soğancı’, ‘Hacıhaliloğlu’, ‘Cöloğlu’, and ‘Kabaası’ presenting values up to 23.6, 23.2, 22.2, and 20.7°Brix , respectively (Akin et al., 2008). Titratable acidity (TA) has been found to range between 0.2 and $1.9\text{ g malic acid equivalents } 100\text{ g}^{-1}$ fresh weight (FW) in ‘Hacikiz’ and ‘Harcot’, respectively (Drogoudi et al., 2008; Kalyoncu et al., 2009) as well as between 13.5 meq and 33.3 meq malic acid 100 g^{-1} FW in ‘Polonais’ and ‘Goldrich’, respectively (Aubert and Chanforan, 2007; Guichard and Souty, 1988).

A taste panel on ‘Bebecou’ and ‘Diamantopoulou’ fruits was performed, using a 1–5 scoring scale (1 for low and 5 for high scoring for each specific attribute). ‘Bebecou’ received higher scoring for firmness, acidity, appearance, mouth aroma, and aftertaste than ‘Diamantopoulou’, which was characterized by better aroma (Table 2) (Roussos unpublished data).

Carbohydrates in Traditional Apricot Cultivars

The main carbohydrates found in apricot fruits are sucrose, glucose, fructose, and sorbitol (Ledbetter et al., 2006). Sucrose is the predominant carbohydrate among them, with its concentration ranging from $3.9\text{ g } 100\text{ g}^{-1}$ FW in ‘Chuan Zhi Hong’ to $8.8\text{ g } 100\text{ g}^{-1}$ FW in ‘Hargrand’ (Table 3) (Aubert and Chanforan, 2007; Schmitzer et al., 2011). The highest

Table 1 Organoleptic characteristics of traditional apricot cultivars

Cultivar	TSS (°Brix)	TA (g MA 100 g ⁻¹ FW)	Cultivar	TSS (°Brix)	TA (g MA 100 g ⁻¹ FW)	Cultivar	TSS (°Brix)	TA (g MA 100 g ⁻¹ FW)
Alyanak	10.6–11.3	0.6 ^c –1.3	Hargrand	15.9	16.8 ^a	Orangered	12.5	0.9
Bebecou	10.6–11.6	1.4	Hasanbey	13.0–17.4	0.2 ^c	Palsteyn	10.8	33.2 ^a
Bergeron	10.6–15.5	14.0 ^a –20.7 ^a	Iğdir	11.0	0.8 ^c	Polonais	13.7	13.5 ^a
Búlida	10.7	1.3 ^b	Ismailaga	11.9	0.3	Proimo	8.8–9.8	1.5–1.6
Bursa	10.2	1.0 ^c	Kabaası	20.7	0.3 ^c	Tyrinthos		
Canino	13.0	0.57 ^c	Karacabey	12.0	1.4	Robada	15.8–16.4	0.7–0.8
Tardivo						Rouge de Roussillon	14.7	22.0 ^a
Çataloğlu	15.3–19.5	0.1 ^c –0.3	Kurukabuk	11.0	1.0	Skaha	11.2	1.79 ^c
Ceglédi	15.7	1.8	Lorna	15.3–15.4	1.0–1.1	Soğanci	13.9–23.6	0.2 ^c –0.3
óriás								
Cöloğlu	22.2	0.08 ^c	Mauricio	11.2	1.9 ^b	Sekerpere	14.0	0.2
Currot	11.0	1.52 ^b	Monaco	9.8	2.09 ^c	Super Gold	13.4	1.6
Goldrich	11.7–13.2	2.9/33.3 ^a	Bello			Sylred	13.8	31.9 ^a
Hacihaliloğlu	14.1–23.2	0.2 ^c –0.4	Moniqui	13.1	20.0 ^a	Tokaloğlu	11.0–17.0	0.4 ^c –0.9
			Monte	10.2	2.07 ^c			
Hacikiz	14.0–15.9	0.1 ^c –0.2	Ruscello			Vitillo	10.3	1.37 ^c
Harcot	10.7–13.6	1.8–1.9	Nicole	17.3–19.6	0.8–0.1	Zerdali	12.2	1.2
			Ninfa	10.3–10.6	1.1–1.2			

Abbreviations: TSS, Soluble solid content; TA, Titratable acidity; MA, Malic acid.

^aTitratable acidity expressed as meq malic acid 100 g⁻¹ FW.

^bTitratable acidity expressed as g malic acid 100 mL⁻¹ juice.

^cTitratable acidity expressed as g citric acid 100 g⁻¹ FW.

Adapted from: Akin et al. (2008), Aubert and Chanforan (2007), Caliskan et al. (2012), Drogoudi et al. (2008), Guichard and Souty (1988), Hegedús et al. (2010), Kalyoncu et al. (2009), Roussos et al. (2011) and Voi et al. (1995).

Table 2 Taste panel scoring of apricot fruits from traditional and modern cultivars, according to specific quality attributes

Cultivar	Taste	Aroma	Sweetness	Firmness	Acidity	Appearance	Mouth aroma	Aftertaste	Acceptance
Traditional cultivars									
Bebecou	2	2	3	4	3	4	2	3	2
Diamantopoulou	2	3	3	3	2	3	1	2	2
Modern cultivars									
Nostos	3	3	3	5	2	4	3	4	3
Tomcot	4	3	4	5	3	3	3	3	4

Scoring scale 1–5 (1 for low and 5 for high scoring for each specific attribute).

Adapted from: Roussos (unpublished data).

Table 3 Carbohydrate composition of traditional apricot cultivars

	Sucrose	Glucose	Fructose	Sorbitol		Sucrose	Glucose	Fructose	Sorbitol
Cultivar	g 100 g ⁻¹ FW				Cultivar	g 100 g ⁻¹ FW			
Alyanak ^a	41.3	18.3	6.5	2.5	Iğdir ^a	34.8	17.1	11.9	6.4
Aurora ^a	37.3	8.3	1.2	0.8	Ivonne	4.2	1.6	0.5	—
A.Vecchioni	5.2	1.1	0.5	0.06	Liverani				
Bavinity	4.4	1.1	0.3	—	Kabaaşı ^a	39	18.6	13.1	19.1
Bebecou	5.2–5.9	1.1–3	0.7	0.3	Lorna	6.7	2.8	0.6	0.3
Bergeron	4.4–4.9	1.6–3.7	0.3–1.4	0.5	Mono	4.4	1.9	1.2	0.3
Bursa ^a	49.9	9.5	6.3	3.4	Monaco Bello	4.2	1.2	0.3	—
Çataloğlu ^a	24.9	21.4	15.1	26.8	Nicole	5	2.6	1.1	0.5
Chuan	3.9	2.8	1.4	0.6	Ninfa	5.8/36.7 ^a	1.9/5.3 ^a	0.9/0.6 ^a	0.5 ^a
Zhi Hong					Orangered	7.2/34.5 ^a	1.8/11 ^a	0.5/2.1 ^a	4.6 ^a
Cöloğlu ^a	34.9	18.9	15.7	24.4	Proimo	4.4–5.2	0.4–2.1	0.09–0.6	—
Cricot	5.3	1.1	0.8	0.2	Tyrinthos				
Farmingdale	6.5	0.9	0.3	—	Reale di	5.1–6.5	0.7–1	0.3–0.7	0.7
Goldrich	5.9/35.8 ^a	1.7/10.2 ^a	0.8/2.7 ^a	3.6 ^a	Imola				
Hacihaliloğlu ^a	23	19.2	13.6	26.8	Robada	6.2–8.3	1.8–3.1	0.4–0.9	0.4
Hacikiz ^a	30.1	23.7	11	19.9	San Castrese	4.1	1	0.3	—
Harcot	5.8/38.1 ^a	2.8/11.8 ^a	1.2/4 ^a	2.3 ^a	Septik	5.3	1.9	1.3	—
Hargrand	8.8	1.5	0.6	—	Soğancı ^a	25.7	17.2	13.9	22.7
Hasanbey	8.6/35.9 ^a	5.5/14.7 ^a	4.4/12.2 ^a	2.4/16.9 ^a	Stark Early	5.3	1.5	1.2	0.4
Hungarian	5.2	2.3	2	0.4	Orange				
Best					Super Gold	5.8	3.5	1.6	—
					Tokaloğlu ^a	56.8	11.4	7.8	5.1
					Trevatt	5.1	2.7	0.5	—

^aSugars expressed as g 100 g⁻¹ DW.

Adapted from: Akin et al. (2008), Aubert and Chanforan (2007), Bartolozzi et al. (1997), Bassi et al. (1996), Caliskan et al. (2012), Drogoudi et al. (2008), Ledbetter et al. (2006), Roussos et al. (2011), Schmitzer et al. (2011) and Wills et al. (1983).

glucose concentration was detected in ‘Hasanbey’ at $5.5 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ (Schmitzer et al., 2011) and the lowest one in ‘Proimo Tyrinthos’ at $0.4 \text{ g } 100 \text{ g}^{-1} \text{ FW}$, although in the same cultivar higher glucose concentration has also been reported ($2.1 \text{ g } 100 \text{ g}^{-1} \text{ FW}$) (Bassi et al., 1996; Caliskan et al., 2012). Fructose concentration ranges from $0.09 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Proimo Tyrinthos’ (Caliskan et al., 2012) to $2.0 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Hungarian Best’ (Schmitzer et al., 2011). Sorbitol was detected occasionally in a few cultivars, being the least abundant carbohydrate in the fruit. The sorbitol concentration ranges from $0.06 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘A. Vecchioni’ to $2.4 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Hasanbey’ (Bartolozzi et al., 1997; Schmitzer et al., 2011).

Organic Acid Composition of Traditional Apricot Cultivars

Malic acid, followed by citric acid, are the most abundant organic acids found in apricots (Table 4). Isocitric acid, succinic acid, fumaric acid, shikimic acid, as well as quinic acid have also been detected in apricot fruits (Schmitzer et al., 2011; Voi et al., 1995; Wills et al., 1983). ‘Bavinity’ was characterized by high citric acid concentration, reaching $21.3 \text{ mg g}^{-1} \text{ FW}$, as well as by the presence of quinic acid ($0.62 \text{ mg g}^{-1} \text{ FW}$) (Wills et al., 1983), and ‘Bursa’ also exhibited a high concentration of citric acid ($100 \text{ mg g}^{-1} \text{ dry weight (DW)}$) (Akin et al., 2008). The lowest concentration of citric acid has been found in ‘Hasanbey’ fruits ($0.18 \text{ mg g}^{-1} \text{ FW}$) and in ‘Cöloğlu’ ($4.3 \text{ mg g}^{-1} \text{ DW}$) (Akin et al., 2008; Schmitzer et al., 2011). Isocitric acid has been found in concentrations ranging from 0.09 to $0.17 \text{ mg g}^{-1} \text{ FW}$ in ‘Canino Tardivo’ and ‘Monte Ruscello’, respectively, while the lowest concentration of succinic acid has been detected in fruits of ‘Monaco Bello’ and the highest concentration in ‘Canino Tardivo’ (0.01 and $0.12 \text{ mg g}^{-1} \text{ FW}$, respectively) (Voi et al., 1995). Shikimic acid concentration has been found to range between 5.3 and $13.2 \text{ mg g}^{-1} \text{ FW}$ in ‘Bergeron’ and ‘Mula Sadik’ respectively, with the former cultivar exhibiting the lowest concentration of fumaric acid ($1.6 \text{ mg g}^{-1} \text{ FW}$) and ‘Hasanbey’ the highest ($9.7 \text{ mg g}^{-1} \text{ FW}$) (Schmitzer et al., 2011).

Phenolic Compound Composition and Antioxidant Capacity of Traditional Apricot Cultivars

Apricots are fruits rich in catechin, epicatechin, rutin, chlorogenic acid, and neochlorogenic acid, as can be seen in Table 5. ‘Bulida’ has been found to have the highest concentration of catechin ($491 \text{ mg Kg}^{-1} \text{ FW}$) along with ‘Henderson’ ($428 \text{ mg Kg}^{-1} \text{ DW}$) (Radi et al., 2003; Ruiz et al., 2005). Epicatechin was found at high concentration in ‘Rouge de Roussillon’ ($398 \text{ mg Kg}^{-1} \text{ DW}$) (Radi et al., 2003), while ‘Hacıhaliloğlu’ was found to have the lowest concentration ($0.4 \text{ mg Kg}^{-1} \text{ DW}$) (Kan et al., 2014). Caffeic acid, *p*-coumaric acid, and ferulic acid have been detected in ‘Bebecou’, ‘Cataloğlu’, ‘Hacıhaliloğlu’, ‘Kabaşı’, and ‘Zerdali’ (Kan et al., 2014; Roussos et al., 2011). Rutin was the most abundant phenolic compound in ‘Bebecou’ (Roussos et al., 2011), while ‘Canino Tardivo’ was also found in high concentration ($180 \text{ mg Kg}^{-1} \text{ DW}$)

Table 4 Organic acid composition of traditional and modern apricot cultivars

Traditional Cultivars (mg g ⁻¹ FW)												
Cultivars	CA	MA	IsA	SA	Cultivars	CA	MA	Cultivars	CA	MA	ShA	FA
A. Vecchioni	0.7	20.2	—	—	Alyanak ^a	35.2	38.9	Bergeron	1.3	19.5	5.3	1.6
Bebecou	8.9–16.4	5.8	0.10	0.02	Bavinity	21.3	4.4	Chuan Zhi	3.8	16.9	12.8	6.8
Canino	4.1	4.1	0.09	0.12	Bursa ^a	100	39.3	Hong	0.2	9.4	11.6	9.7
Tardivo								Hasanbey				
Cricot	6.2	7.1	—	—	Çataloğlu ^a	4.4	9.7	Hungarian best	2.9	11.8	7.5	2.6
Fronne	10.9	9.4	0.13	0.02	Cöloğlu ^a	4.3	13.1	Mula Sadik	3.6	16.2	13.2	2.7
Fresche								Modern Cultivars (mg g ⁻¹ FW)				
Monaco	11.7	10.5	0.15	0.01	Hacihaliloğlu ^a	7.8	18.1					
Bello								Olimp	0.1	6.6	7.4	4.8
Mono	6.6	7.3	—	—	Hacikiz ^a	4.4	13.5	Gvardejsky	0.4	3.8	5.3	2.2
Monte	12.2	10.6	0.17	Trace	Harcot ^b	18.1	4.8					
Ruscello								Nafsika	8.2	8.5	—	—
Reale di	2.8	1.2	—	—	Hasanbey ^a	7.4	23.4					
Imola								Niove	11	6.2	—	—
Skaha	10.8	9.1	0.12	0.02	Iğdir ^a	77	30.3	Salah-Jerevani	0.7	11.6	12	4.2
Soğanci ^a	7.3	10.9	—	—	Kabaaşı ^a	9.2	12.8	St. Early Orange	0.2	9.5	4.9	5.8
Sun Giants	16.1	11.8	0.13	Trace	Moniqui ^b	19.8	6.1	Strepet	0.7	12.3	13.4	2.3
Tokaloğlu ^a	20.5	26.6	—	—	Orangered ^b	9.4	6.7	Vesna	0.7	9.5	8.5	2.2
Trevatt	6.6	7.70	—	—	Palsteyn ^b	15.3	20.3	Vestar	1.4	17.9	10.1	21.6
Vitillo	13.7	5.7	0.12	0.02	Proimo	13.3	9.2					
					Tyrinthos ^b							

Abbreviations: CA, Citric acid; MA, Malic acid; IsA, Isocitric acid; SA, Succinic acid; ShA, Shikimic acid; FA, Fumaric acid.

^amg g⁻¹ DW.^bmeq 100 g⁻¹ FW.

Adapted from: Akin et al. (2008), Drogoudi et al. (2008), Roussos et al. (2011), Schmitzer et al. (2011), Voi et al. (1995) and Wills et al. (1983).

Table 5 Phenolic compound composition of traditional apricot cultivars

	CAT	EPI	CAE	RUT	FeA	<i>p</i> -CA	NCG	CG	3CQ	CCG	QGluc	QA
Cultivar	mg Kg ⁻¹ FW											
Bebecou	6.5	5.3	2.6	93.7	0.2	0.6	13.7	10.1	—	—	—	—
Bergeron	—	—	—	27.8	—	—	17.8	65.3	5.8	7.3	1.3	1.3
Búlida	491	—	—	—	—	—	81	147	—	—	—	—
Cafona ^a	232.1	145.1	—	167.2	—	—	267.4	505.2	—	—	22.6	—
Canino Tardivo ^a	167	337	—	180	—	—	277	246	—	—	—	—
Çataloğlu ^a	13.6	4.2	0.6	28.6	4.3	0.05	—	36.5	—	—	—	—
Chuan Zhi Hong	—	—	—	13.1	—	—	1.4	13.8	0.8	6.3	0.7	0.3
Currot	396	—	—	—	—	—	160	114	—	—	—	—
Hacihaliloğlu ^a	15.6	0.4	1.9	15.5	3.7	0.07	—	75.4	—	—	—	—
Hasanbey	—	—	—	1.6	—	—	1.3	4.4	0.3	1.1	0.1	—
Henderson ^a	428	205	—	148	—	—	52	197	—	—	—	—
Hungarian Best	—	—	—	13.3	—	—	1.51	21.4	110	4.4	0.8	0.3
Kabaşi ^a	21.4	3.1	3.6	26.6	8.9	0.2	—	5.9	—	—	—	—
Mauricio	225	—	—	—	—	—	35	33	—	—	—	—
Moniqui ^a	—	41	—	100	—	—	68	225	—	—	—	—
Rouge de Fournes ^a	200	92	—	155	—	—	120	390	—	—	—	—
Rouge de Roussillon ^a	115	398	—	119	—	—	83	103	—	—	—	—
Polonais ^a	80	132	—	119	—	—	87	123	—	—	—	—
Proimo Tyrinthos ^a	—	70	—	438	—	—	170	159	—	—	—	—
Stark Early Orange	—	—	—	5.5	—	—	1.2	4.4	0.6	1.3	0.5	0.5
Zerdali ^a	10.7	3.7	2.8	17.6	11.4	0.05	—	10.6	—	—	—	—

Abbreviations: CAT, Catechin; EPI, Epicatechin; CAE, Caffeic acid; RUT, Rutin (Quercetin-3-rutinoside); FeA, Ferulic acid; *p*-CA, *p*-Coumaric acid; NCG, Neochlorogenic acid; CG, Chlorogenic acid; 3CQ, 3-*O*-*p*-Coumaroylquinic acid; CCG, Cryptochlorogenic acid; QGluc, Quercetin-3-glucoside; QA, Quercetin-3-acetylhexoside.

^aPhenolic compounds expressed as mg Kg⁻¹ DW.

Adapted from: Kan et al. (2014), Madrau et al. (2009), Radi et al. (2003), Roussos et al. (2011), Ruiz et al. (2005) and Schmitzer et al. (2011).

(Radi et al., 2003). ‘Currot’ and ‘Canino Tardivo’ was found to have high concentration of neochlorogenic acid ($160 \text{ mg Kg}^{-1} \text{ FW}$ and $277 \text{ mg Kg}^{-1} \text{ DW}$, respectively), with ‘Stark Early Orange’ and ‘Henderson’ exhibiting the lowest concentration ($1.2 \text{ mg Kg}^{-1} \text{ FW}$ and $52 \text{ mg Kg}^{-1} \text{ DW}$, respectively) (Radi et al., 2003; Ruiz et al., 2005; Schmitzer et al., 2011). Chlorogenic acid was found at high concentration in ‘Búlida’ and ‘Cafona’ but at low one in ‘Hasanbey’, ‘Stark Early Orange’, and ‘Kabaası’ (Kan et al., 2014; Madrau et al., 2009; Ruiz et al., 2005; Schmitzer et al., 2011). Schmitzer et al. (2011) reported the presence of various other phenolic compounds, like 3-*O-p*-coumaroylquinic acid (ranging from 0.3 to $110 \text{ mg Kg}^{-1} \text{ FW}$), cryptochlorogenic acid (ranging from 1.1 to $7.3 \text{ mg Kg}^{-1} \text{ FW}$), quercetin-3-glucoside (ranging from 0.1 to $1.3 \text{ mg Kg}^{-1} \text{ FW}$), and quercetin-3-acetylhexoside (ranging from 0.3 to $1.3 \text{ mg Kg}^{-1} \text{ FW}$), in ‘Chuan Zhi Hong’, ‘Hasanbey’, ‘Bergeron’, ‘Stark Early Orange’, and ‘Hungarian Best’, while quercetin-3-glucoside has also been found in ‘Cafona’ (Madrau et al., 2009).

‘Proimo Tyrinthos’ has been found to have low concentration of phenolic compounds, expressed as mg gallic acid equivalents (GAE) $100 \text{ g}^{-1} \text{ FW}$, i.e., $21.2 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ by Caliskan et al. (2012), while Drogoudi et al. (2008) measured them at $104.9 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ (Table 6). The highest concentration of total phenolic compounds has been detected in ‘Robada’, almost $560 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ (Drogoudi et al., 2008), while ‘Kurukabuk’, ‘Hasanbey’, and ‘Wilson Delicious’ also exhibited high amount of phenolic compounds, close to $300 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ (Kalyonku et al., 2009). Antioxidant capacity of apricot fruits is relatively low, compared to other fruits, ranging from 0.11 to $1.4 \text{ mg ascorbic acid g}^{-1} \text{ FW}$ in ‘Bebecou’ and ‘Robada’, respectively (Drogoudi et al., 2008). Based on ferric reducing antioxidant power (FRAP) assay, antioxidant capacity in ‘Super Gold’ was estimated to be $12.3 \text{ mmol Fe Kg}^{-1} \text{ FW}$ (Caliskan et al., 2012), while in ‘Tonda di Costigliole’ it was found to be only $0.5 \text{ mmol Fe Kg}^{-1} \text{ FW}$ (Contessa et al., 2013).

Vitamins Concentration in Traditional Apricot Cultivars

Vitamins A, C, and E, along with provitamin A, have been found mainly in apricot fruits (Table 7). Among them, vitamin C is the most abundant. It has been detected in concentrations ranging from $7.3 \text{ mg } 100 \text{ g}^{-1} \text{ DW}$ in ‘Hacihaliloğlu’ (Kan et al., 2014) to $97 \text{ mg } 100 \text{ g}^{-1} \text{ DW}$ in ‘Bursa’ (Akin et al., 2008) and from $2.8 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ in ‘Canino Tardivo’ (Voi et al., 1995) to $16 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ in ‘Trevatt’ (Wills et al., 1983). Vitamin A and vitamin E have been found in ‘Cataloğlu’, ‘Hacihaliloğlu’, and ‘Kabaası’ in concentrations of $0.013\text{--}0.021 \text{ mg } 100 \text{ g}^{-1} \text{ DW}$ for vitamin A and $0.028\text{--}0.038 \text{ mg } 100 \text{ g}^{-1} \text{ DW}$ for vitamin E (Kan et al., 2014). Ruiz et al. (2005) determined provitamin A in ‘Búlida’, ‘Currot’, and ‘Mauricio’ in concentrations of 746, 267, and $557 \text{ IU mg}^{-1} \text{ FW}$, and vitamins K and D have been reported in ‘Kabaası’ by Ozsahin and Yilmaz (2010). Wills et al. (1983)

Table 6 Total phenolic compounds and antioxidant capacity of traditional apricot cultivars

Cultivar	Total phenols (mg GAE 100 g ⁻¹ FW)	DPPH (mg Kg ⁻¹ AA FW)	FRAP (mmol Fe Kg ⁻¹ FW)	AEAC (mg AA g ⁻¹ FW)	Cultivar	Total phenols (mg GAE 100 g ⁻¹ FW)	FRAP (mmol Fe Kg ⁻¹ FW)	AEAC (mg AA g ⁻¹ FW)
Alyanak	161.6/677.3 ^a	—	—	—	Kabaaşı	176.3/582.3 ^a	—	—
Bebecou	68.8–100.3	0.4 ^b	6.6/1.7 ^b	0.1	Kurukabuk	302.1	—	—
Bergeron	13.7 ^d	384.3 ^d /36.9 ^c	—	—	Mahmudun Erigi	208.4	—	—
Bursa	818.1 ^a	—	—	—	Ninfa	28.2–48.4	4.9	0.2
Çataloğlu	146.8/610.8 ^a	—	—	—	Orangered	356.3	—	0.6
Chuan Zhi	3.29 ^d	29.2 ^d	—	—	Proimo	21.2–104.9	4.1	1.2
Hong	—	—	—	—	Tyrinthos	—	—	—
Ceglédi óriás	—	29.1 ^c	—	—	Robada	559.6	—	1.4
Cöloğlu	567.5 ^a	—	—	—	Sekerpere	116.8	—	—
Erken Agerik	141.6	—	—	—	Septik	21.6	2.3	—
Goldrich	119–208.7	21.9 ^c	11.6	0.4	Soğanci	58.4/496.6 ^a	—	—
Hacihaliloğlu	140.5/534.2 ^a	—	—	—	Stark Early Orange	1.42 ^d /104.2 ^a	—	—
Hacikiz	72.1/659.3 ^a	—	—	—	Super Gold	88.9	12.3	—
Harcot	59.1–220.4	—	7.9	0.7	Tokaloğlu	141.1/423.4 ^a	—	—
Hasanbey	294.7/582.8 ^a	133.5 ^d	—	—	Tonda di Costigliole	97.8	0.5	—
Hungarian Best	1.5 ^d	181.5 ^d	—	—	Wilson	299.5	—	—
Iğdir	582.4 ^a	—	—	—	Delicious	—	—	—
Ismailaga	137.4	—	—	—	Yegen	144.2	—	—
					Zerdali	165.8	—	—

Abbreviations: GAE, Gallic acid equivalents; AA, Ascorbic acid.

^aTotal Phenols expressed as mg gallic acid Kg⁻¹ DW.^bFRAP and DPPH expressed as µmoles Trolox g⁻¹ FW.^cDPPH expressed as % inhibition.^dTotal Phenols and DPPH were measured in apricot pulp without the skin.

Adapted from: Akin et al. (2008), Caliskan et al. (2012), Contessa et al. (2013), Drogoudi et al. (2008), Hegedús et al. (2010), Kalyoncu et al. (2009), Roussos et al. (2011) and Schmitzer et al. (2011).

Table 7 Vitamin concentration in the fruit of traditional and modern apricot cultivars

Traditional cultivars					Modern cultivars		
Cultivar	Vit C	Vit A	Vit E	Prov A	Cultivar	Vit C	Prov A
	mg 100 g ⁻¹ FW			IU mg ⁻¹ FW		mg 100 g ⁻¹ FW	IU mg ⁻¹ FW
Alyanak ^a	38	—	—	—	Aurora	7.1	—
Bavinity	7	—	—	—	Banesa	9.6	—
Bebecou	4.1–5.4	—	—	—	Ceglédi arany	5.8	—
Bergeron	11.4	—	—	—	Ceglédi Piroska	9.8	—
Búlida ^a	—	—	—	746	Dorada	—	834
Bursa ^a	97	—	—	—	Goldrich	3	—
Canino Tardivo	2.8	—	—	—	Harmat	5.3	—
Çataloğlu ^a	20.3–28	0.018	0.038	—	Kech-Pshar	5	—
Ceglédi óriás	9.2	—	—	—	Konservnyi Pozdnii	6.6	—
Cöloğlu ^a	20	—	—	—	Korai zamatos	7.2	—
Currot ^a	—	—	—	267	Murciana	—	1049
Fronne Fresche	5.4	—	—	—	Nafsika	1.2	—
Gonci Magyarkajsi	12.9	—	—	—	Niove	1.4	—
Hacihaliloğlu ^a	7.3–37	0.021	0.038	—	Preventa	16.2	—
Hacikiz ^a	37	—	—	—	Rojo Pasi6n	—	680
Hasanbey ^a	49	—	—	—	Selene	—	1744
Iğdir ^a	68	—	—	—			
Kabaası ^a	11.5–42	0.013	0.028	—			
Mauricio ^a	—	—	—	557			
Mistikawi	9.4	—	—	—			
Monaco Bello	5.8	—	—	—			
Monte Ruscello	6.1	—	—	—			
Shalakh	13.6	—	—	—			
Skaha	4.7	—	—	—			
Soğanci ^a	38	—	—	—			
Sun Giants	6.1	—	—	—			
Tokaloğlu ^a	46	—	—	—			
Trevatt	16	—	—	—			
Vitillo	4	—	—	—			

Abbreviations: Vit A, Vitamin A; Vit C, Vitamin C; Vit E, Vitamin E; Prov A, Provitamin A.

^aVitamin concentration expressed in mg 100 g⁻¹ DW.

Adapted from: Akin et al. (2008), Hegedús et al. (2010), Kan et al. (2014), Ozsahin et al. (2010), Roussos et al. (2011), Ruiz et al. (2005) and Wills et al. (1983).

have reported the presence of lipophilic vitamins such as vitamin B1, B2, and B3 in 'Bavinity' and 'Trevatt', with B1 and B2 concentration around 0.02–0.04 mg 100 g⁻¹ FW and that of B3 around 1.1–1.4 mg 100 g⁻¹ FW.

Carotenoids Concentration in Traditional Apricot Cultivars

The major carotenoid found in apricot fruits is β -carotene, with its concentration ranging from 0.14 to 48.7 mg 100 g⁻¹ DW in 'Moniqui' and 'Alyanak', respectively (Table 8) (Akin et al., 2008; Kurz et al., 2008). γ -Carotene and β -cryptoxanthin have been found in 'Búlida', 'Currot', and 'Mauricio' in low concentrations, ranging from 0.6 to 1.9 mg 100 g⁻¹ FW (for γ -carotene) and from 0.5 to 1.6 mg 100 g⁻¹ FW (for β -cryptoxanthin). In 'Bavinity' cultivar, α -carotene was estimated to be around 7 mg 100 g⁻¹ FW (Wills et al., 1983), whereas in 'Bergeron' β -cryptoxanthin, trans-phytofluene, and *cis*-phytofluene have been measured at 4.2 μ g g⁻¹ DW, 5.5 μ g g⁻¹ DW, and 15.5 μ g g⁻¹ DW, respectively (de Rigal et al., 2000). Lutein has been found in 'Bergeron', 'Moniqui', and 'Orangered' at 0.16, 0.06, and 0.14 μ g g⁻¹ DW, respectively (Kurz et al., 2008). Zeaxanthin was not detected in 'Moniqui', while it was quantified to be 0.13 μ g g⁻¹ DW in 'Bergeron' and 0.11 μ g g⁻¹ DW in 'Orangered' (Kurz et al., 2008). Lycopene has been detected in 'Bergeron', 'Cataloglu', 'Hacihaliloglu', 'Kabaasi', and 'Polonais' at 3.2, 0.57, 0.71, 0.48, and 19 μ g g⁻¹ DW, respectively (de Rigal et al., 2000; Kan et al., 2014; Radi et al., 2003). Total carotenoid concentration has been found to be high in 'Bursa' and 'Alyanak' (91.9 and 91.8 mg equivalent β -carotene 100 g⁻¹ DW, respectively) (Radi et al., 2003) and low in 'Bebecou' (6.2 mg equivalent β -carotene 100 g⁻¹ DW).

Amino Acid Composition of Traditional Apricot Cultivars

The main amino acid found in apricot fruit is asparagine (Table 9). It has been detected in concentrations ranging from 2727 mg Kg⁻¹ FW in 'Canino Tardivo' cultivar to 6895 mg Kg⁻¹ FW in 'Bebecou' (Voi et al., 1995). Other major amino acids found are aspartic acid (ranging from 116 in 'Sun Giants' to 197 mg Kg⁻¹ FW in 'Bebecou'), serine (detected in concentrations ranging from 52 in 'Monaco Bello' to 275 mg Kg⁻¹ FW in 'Bebecou'), alanine (ranging from 52 in 'Sun Giants' to 195 mg Kg⁻¹ FW in 'Bebecou'), and glutamic acid (detected in concentrations ranging from 73 to 166 mg Kg⁻¹ FW in 'Canino Tardivo' and 'Bebecou', respectively) (Voi et al., 1995). Threonine, proline, glycine, valine, hydroxyproline, leucine, isoleucine, phenylalanine, GABA, histidine, and glutamine have been also detected in apricot fruits in lower concentrations. Cysteine, tyrosine, cystine, and methionine have been found in trace amounts. 'Bebecou' is found to have the highest concentration of total amino acids, followed by 'Monte Ruscello', 'Sun Giants', 'Monaco Bello', and 'Skaha', with 'Canino Tardivo' exhibiting the lowest concentration (Voi et al., 1995).

Table 8 Carotenoid composition of traditional and modern apricot cultivars

Cultivar	β -CA	γ -CA	β -CR	TCA	Cultivar	β -CA	γ -CA	β -CR	TCA
Traditional cultivars (mg 100 g⁻¹ DW)									
Alyanak	48.7	—	—	91.8	Iğdir	13.4	—	—	25.3
Bavinity ^a	0.28	—	—	0.6	Kabaaşı	26.2	—	—	40
Bebecou	0.4–0.5	—	—	6.2	Mauricio ^a	3.1	0.6	0.5	4.6
Bergeron	2.5	0.9	—	—	Moniqui	0.2–0.5	—	—	—
Búlida ^a	3.7	1.9	1.6	7.6	Ninfa ^a	—	—	—	1.2
Bursa	42.2	—	—	91.9	Orangered	2.8	—	—	2.9 ^a
Canino Tardivo	5	—	—	—	Polonais	5.7	3.2	—	—
Çataloğlu	17.5	—	—	32.1	Proimo Tyrinthos	7.4	1.3	—	2.3 ^a
Cöloğlu	5.7	—	—	14.8	Robada ^a	—	—	—	3.3
Currot ^a	1.3	0.7	0.7	2.8	Rouge de Roussillon	3.4	—	—	—
Hacıhaliloğlu	8.9	—	—	21.9	Soğanci	9.2	—	—	23.3
Hacikiz	13.1	—	—	22.8	Tokaloğlu	21.6	—	—	50.1
Harcot ^a	—	—	—	2.6	Trevatt ^a	0.1	—	—	0.2
Hasanbey	22.1	—	—	50.8					
Modern cultivars (mg 100 g⁻¹ FW)									
Aurora	—	—	—	1.8	Nike	—	—	—	3.1
Danae	—	—	—	2.8	Niove	—	—	—	2
Dorada	4.3	1.1	1.4	7.4	Nostos	—	—	—	1.7
Goldrich	—	—	—	2.7	Rojo Pasi6n	3.7	0.6	0.7	6.1
Murciana	5.8	0.9	1.1	9.1	Selene	9.3	1.5	2.4	14
Neraida	—	—	—	1.8	Soledane	—	—	—	2.3
Nereis	—	—	—	1.1	Tomcot	—	—	—	3.8

Abbreviations: β -CA, β -Carotene; TCA, Total Carotenoids; γ -CA, γ -Carotene; β -CR, β -Cryptoxanthin.

^aExpressed as mg 100 g⁻¹ FW.

Adapted from: Akin et al. (2008), de Rigal et al. (2000), Drogoudi et al. (2008), Kan et al. (2014), Kurz et al. (2008), Radi et al. (2003), Ruiz et al. (2005) and Wills et al. (1983).

Table 9 Amino acids of traditional apricot cultivars

Amino acids	Traditional cultivars (mg Kg ⁻¹ FW)							
	Bebecou	Canino tardivo	Fronne fresche	Monaco bello	Monte ruscello	Skaha	Sun giants	Vitillo
Alanine	195	180	139	59	61	98	52	73
Asparagine	6895	2727	3822	5257	6204	5073	6259	3444
Aspartic acid	197	194	122	176	128	132	116	159
Cysteine	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Cystine	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
GABA	Trace	147	51	40	34	67	21	37
Glutamic acid	166	73	132	137	121	105	113	139
Glutamine	88	89	31	28	26	41	17	16
Glycine	33	9	8	17	21	11	20	12
Histidine	25	16	9	18	21	20	6	5
Hydroxyproline	10	9	9	5	11	16	8	6
Isoleucine	46	Trace	15	15	25	23	10	11
Leucine	25	20	4	6	18	15	3	19
Lysine	4	2	Trace	2	2	2	Trace	Trace
Methionine	Trace	Trace	2	Trace	Trace	3	2	3
Ornithine	2	1	2	2	1	3	3	Trace
Phenylalanine	24	20	8	9	16	19	9	10
Proline	60	101	21	24	41	56	5	90
Serine	275	164	104	52	113	130	133	74
Threonine	51	52	29	47	42	39	14	34
Tyrosine	3.2	7	Trace	4	Trace	40	Trace	8
Valine	74	44	22	52	78	45	12	29
Total amino acids	8173	3855	4530	5951	6942	5936	6802	4170

Adapted from: [Voi et al. \(1995\)](#).

Mineral Composition of Traditional Apricot Cultivars

Potassium is the major element of apricot fruits and has been found in concentrations ranging from 1227 to 3455 mg 100 g⁻¹ DW in ‘Cöloğlu’ and ‘Bursa’, respectively (Akin et al., 2008). ‘Cöloğlu’ has been found to have the lowest phosphorus concentration (72 mg 100 g⁻¹ DW), while ‘Hasanbey’ has been reported to have up to 264.3 mg 100 g⁻¹ DW (Haciseferoğulları et al., 2007). The lowest concentrations of potassium and manganese have been determined in ‘Orangered’ at 212.7 and 0.08 mg 100 g⁻¹ FW, respectively (Gergely et al., 2014). A low concentration of calcium has been reported in ‘Cataloglu’ (70 mg 100 g⁻¹ DW), while a high concentration has been found in ‘Alyanak’ (241 mg 100 g⁻¹ DW) (Akin et al., 2008; Haciseferoğulları et al., 2007). Magnesium concentration ranges from 40 mg 100 g⁻¹ DW in ‘Hacihaliloğlu’ to 285 mg 100 g⁻¹ DW in ‘Bursa’ (Akin et al., 2008). Sodium has also been found in apricot fruits, with ‘Kabaası’ having the highest concentration and ‘Tokaloğlu’ the lowest one (86.4 and 8 mg 100 g⁻¹ DW, respectively) (Akin et al., 2008; Haciseferoğulları et al., 2007). Iron, zinc, and manganese concentrations are found in the ranges of 2.3–41.8, 1.4–4.3, and 2.9–4.3 mg 100 g⁻¹ DW (Akin et al., 2008; Haciseferoğulları et al., 2007). Selenium and nickel have been detected in ‘Alyanak’, ‘Bursa’, ‘Cataloglu’, ‘Cöloğlu’, ‘Hacihaliloğlu’, ‘Hacikiz’, ‘Hasanbey’, ‘İğdir’, ‘Kabaası’, ‘Soğancı’, and ‘Tokaloğlu’ below 0.4 and 0.8 mg 100 g⁻¹ DW, respectively (Akin et al., 2008; Haciseferoğulları et al., 2007). Boron has been found to be lower than 0.8 mg 100 g⁻¹ FW and lithium lower than 0.4 µg 100 g⁻¹ FW (Gergely et al., 2014).

Volatile Compounds Found in Traditional Apricot Cultivars

Some of the volatiles usually found in apricot are listed in Table 11 (Gokbulut and Karabulut, 2012; Guichard and Souty, 1988; Solis–Solis et al., 2007). The apricot aroma is composed of several volatile compounds such as aldehydes, ketones, acetates, esters, alcohols, acids, lactones, terpenes, and various others. Ethyl acetate, hexyl acetate, limonene, β -cyclocitral, γ -decalactone, 6-methyl-5-hepten-2-one, linalool, β -ionone, menthone, hexanol, hexanal, (*E*)-2-hexen-1-ol, and (*E*)-hexen-2-al are the major aroma compounds identified in apricot.

‘Proimo Tyrinthos’ cultivar contained fewer volatile compounds than other studied cultivars. The most abundant volatile compounds in ‘Proimo Tyrinthos’ are γ -decalactone, δ -decalactone, and (*E*)-2-hexenal at concentrations 2112, 1064, and 1478 µg Kg⁻¹, respectively (Guichard and Souty, 1988). The ‘Palsteyn’ cultivar possessed the highest quantities of α -terpineol (1423 µg Kg⁻¹) and *p*-Cymen-8-ol (1582 µg Kg⁻¹), while 4-terpineol was most abundant in ‘Rouge de Roussillon’ (1713 µg Kg⁻¹) (Guichard and Souty, 1988). Benzaldehyde, which possesses a very strong almond aroma, is detected at high concentrations in ‘Hargrand’ (25,100 µg Kg⁻¹), ‘Rouge de Roussillon’ (12,778–15,300 µg Kg⁻¹), and ‘Palsteyn’ (11,639 µg Kg⁻¹), while phenylacetaldehyde, with its floral aroma, was abundant only in ‘Palsteyn’ (2405 µg Kg⁻¹) (Gokbulut and Karabulut, 2012; Guichard and Souty, 1988; Guillot et al., 2006).

Table 10 Mineral element concentration of traditional and modern apricot cultivars

Cultivars	P	K	Ca	Mg	Fe	Zn	Mn	Na
Traditional cultivars (mg 100 g⁻¹ DW)								
Alyanak	157	2319	241	161	7.7	2.5	2.9	10.1
Bavinity ^a	–	350	16	9	0.3	0.1	–	1
Bebecou ^a	16	314.5	2.2	9.8	–	–	–	2.6
Bursa	178	3455	230	285	11.3	3.4	2.9	11.7
Canino Tardivo ^a	11	273.7	4.3	9.7	–	–	–	2
Çataloğlu	89–202	1377–2167	70–141	43–132	3–40	2.2	1.6	14–86
Ceglédi óriás ^a	31.7	291	9.3	9.3	0.3	0.1	0.1	0.7
Cöloğlu	72	1227	87	120.4	3.7	1.6	1.7	14
Fronne Fresche ^a	15	304.2	5.2	10.1	–	–	–	3
Goldrich ^a	27.8	221	16.4	10.5	0.3	0.2	0.1	0.5
Hacihaliloğlu	107–144	1849–2160	74–102	40–135	3–42	1.4	1.4	11–78
Hacikiz	105	1605	174	147	3.51	2.1	2.3	15.9
Hasanbey	119–264	1811	84–101	48–152	3–4.2	1.4	1.6	9–113
Iğdir	238	3219	234	222	7.9	4.2	2.7	17.8
Kabaaşı	97–192	1880–2203	80–106	48–131	2.3–43	2.6	1.7	13–86
Mistikawi	18	51.2	55.7	10.9	7.5	3.5	0.6	240
Monaco Bello ^a	10	241.3	4.2	10	–	–	–	2.5
Monte Ruscello ^a	13	271.9	3.9	9.5	–	–	–	2.3
Orangered ^a	27.8	212.7	10.8	9.8	0.3	0.1	0.08	0.5
Skaha ^a	12.2	274	4.7	10	–	–	–	2.2
Soğancı	98–189	1879–2138	92–110	45–111	4–40	1.9	1.2	9–77
Sun Giants ^a	10.2	236.2	3.8	9.8	–	–	–	2
Tokaloğlu	144.1	1926	113.6	149	5.1	2.1	2	8
Trevatt ^a	–	320	15	9	0.3	0.2	–	3
Vitillo ^a	13.9	237.4	4.4	9.8	–	–	–	2.6
Modern cultivars (mg 100 g⁻¹ FW)								
Aurora	29.7	417.5	18.7	16	0.3	0.2	0.1	1.1
Gonci Magyar kajszi	25.2	287.1	8.2	8.9	0.2	0.1	0.2	0.8
M. Kajszi C.235	26	240	11.7	10	0.3	0.1	0.1	0.5

^amg 100 g⁻¹ FW.

Adapted from: Akin et al. (2008), Gergely et al. (2014), Haciseferoğullari et al. (2007), Voi et al. (1995) and Wills et al. (1983).

Table 11 Volatile compounds of traditional and modern apricot cultivars

Acetates	2-6-Dimethyl-cyclohexanal	Menthone
Amyl acetate	Heptanal	3-Methyl-2-butanone
Butyl acetate	2,4-Heptadienal	6-Methyl-5-hepten-2-one
Ethyl acetate	(<i>E,E</i>)-2,4-Heptadienal	Nerylacetone
Hexyl acetate	(<i>E</i>)-2-Heptenal	2-Octanone
Methyl acetate	Hexanal	2-Pentanone
3-Methylbutyl acetate	2-Hexenal	Pinocamphone
Pentyl acetate	(<i>E</i>)-2-Hexenal	2-Propanone
(<i>E</i>)-2-Hexenyl acetate	(<i>E,E</i>)-2,4-Hexadienal	Verbenone
(<i>Z</i>)-3-Hexenyl acetate	3-Hydroxybutanal	
	Nonanal	Lactones
Acids	Octanal	γ -Butyrolactone
Acetic acid	(<i>E</i>)-2-Octenal	γ -Decalactone
Hexanoic acid	Pentanal	δ -Decalactone
2-Propenoic acid	4-Pentenal	(<i>Z</i>)-7-Decen-5-olide
	Phenyl acetaldehyde	Dihydroactinidiolide
Alcohols		γ -Dodecalactone
Benzyl alcohol	Esters	γ -Hexalactone
1-Butanol	Butyl butyrate	γ -Jasmolactone
2-Butanol	Butyl hexanoate	γ -Octalactone
Ethanol	Cyclohexylisotiocyanate	δ -Octalactone
2-Ethyl-1-hexanol	Diethylphthalate	γ -Nonalactone
1,3-Dimethyl-cyclohexanol	Ethyl caproate	
1-Hexanol	(<i>E</i>)-2-Hexenyl butyrate	Terpenic alcohols
(<i>E</i>)-3-Hexenol	(<i>Z</i>)-3-Hexenyl butyrate	<i>p</i> -Cymen-8-ol
(<i>Z</i>)-3-Hexenol	(<i>E</i>)-2-Hexenyl propanoate	<i>p</i> -Cymen-9-ol
(<i>E</i>)-2-Hexen-1-ol	Hexyl butanoate	Geraniol
(<i>Z</i>)-2-Hexen-1-ol	Hexyl hexanoate	Linalool
(<i>Z</i>)-3-Hexen-1-ol	Hexyl isobutyrate	Linalool hydrate
Linalool	Methyl butyrate	α -Terpineol
2-Methylbutanol	Methyl-2-ethyl propanoate	4-Terpineol
6-Methyl-5-hept-en-2-ol	Methyl hexanoate	
Octanol	Isobutyl propanoate	Terpene
2-Pentanol		<i>p</i> -Cymene
Phenyl ethanol	Ketones	Limonene
α -Terpineol	Acetophenone	β -Myrcene
Thymol	Dihydro- β -ionone	α -Ocimene
	Fenchone	(<i>E</i>)- β -ocimene
Aldehydes	2-Heptanone	α -Phellandrene
Acetaldehyde	2,5-Hexanedione	β -Phellandrene
Benzaldehyde	β -Ionone	β -Pinene
Benzeneacetaldehyde	Isopinocampnone	Pulegone
β -Cyclocitral	Geranyl acetone	Styrene

Adapted from: Aubert and Chanforan (2007), Gokbulut and Karabulut (2012), Guichard and Souty (1988), Guillot et al. (2006) and Solis-Solis et al. (2007)

Among the ketones, β -ionone, with its violet-like aroma, was detected in high concentration in ‘Hargrand’ ($8000 \mu\text{g Kg}^{-1}$), ‘Goldrich’ ($3500 \mu\text{g Kg}^{-1}$), ‘Orangered’ ($3100 \mu\text{g Kg}^{-1}$), and ‘Moniqui’ ($1151 \mu\text{g Kg}^{-1}$) (Guichard and Souty, 1988; Guillot et al., 2006). Lactones possess fruity notes, and especially γ -decalactone and δ -decalactone were present in high quantities in ‘Moniqui’ ($37,310 \mu\text{g Kg}^{-1}$ and $5807 \mu\text{g Kg}^{-1}$, respectively), ‘Rouge de Rousillon’ ($21,024 \mu\text{g Kg}^{-1}$ and $7716 \mu\text{g Kg}^{-1}$, respectively), and ‘Bergeron’ ($28,171 \mu\text{g Kg}^{-1}$ and $12,629 \mu\text{g Kg}^{-1}$, respectively) (Guichard and Souty, 1988).

‘Hargrand’ was the richest in hexyl acetate ($45,700 \mu\text{g Kg}^{-1}$), while ‘Goldrich’ and ‘Polonais’ presented high content of (*E*)-hexen-2-al ($40,100 \mu\text{g Kg}^{-1}$) (Guillot et al., 2006).

COMPOSITION OF MODERN APRICOT CULTIVARS

Organoleptic Characteristics and Sensory Attributes of Modern Apricot Cultivars

Total soluble solids (TSS) concentration, as well as titratable acidity (TA), differs significantly among cultivars (Table 12). Most of the apricot cultivars exhibit TSS values above 10°Brix , while only a few present lower values, such as ‘Stark Early Orange’, ‘Sahinbey’, ‘Mirlo Blanco’, and ‘Dr Kaska’ (9.2 , 9.6 , 9.7 , and 9.7°Brix , respectively) (Caliskan et al., 2012; Kalyoncu et al., 2009; Melgarejo et al., 2014). ‘Tomcot’ and ‘Biljana’ exhibited 17.4°Brix , followed by ‘Vera’ at 16.7°Brix (Aubert and Chanforan, 2007). Low TA has been determined in ‘Aleksandar’ by (Milošević et al., 2012) at $0.6 \text{ g malic acid } 100 \text{ g}^{-1} \text{ FW}$ and in ‘Vertige’ by Aubert and Chanforan (2007) at $14.3 \text{ meq malic acid } 100 \text{ g}^{-1}$, while the highest acidity was found in ‘Aurora’ at $4.4 \text{ g malic acid } 100 \text{ g}^{-1} \text{ FW}$ (Hegedú’s et al., 2010) and in ‘Early Blush Rutbhart’ at $38.8 \text{ meq malic acid } 100 \text{ g}^{-1}$ (Aubert and Chanforan, 2007).

‘Nostos’ and ‘Tomcot’ were evaluated by a taste panel for the attributes listed in Table 2. ‘Nostos’ scored higher in overall appearance and aftertaste duration exhibiting lower acidity, while ‘Tomcot’ was superior in taste, sweetness, and overall acceptance (Roussos, unpublished data).

Carbohydrates in Modern Apricot Cultivars

‘Vera’ exhibited the highest sucrose concentration, with $11.4 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ (Milošević et al., 2012), while the lowest was detected in ‘Dr Kaska’ (Caliskan et al., 2012), with $1.2 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ (Table 13). Glucose concentration ranges from $4.4 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Aleksandar’ (Milošević et al., 2012) to $0.6 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Mirlo Anaranjado’ (Melgarejo et al., 2014), while fructose concentration ranges from $2.8 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Cagataybey’ (Caliskan et al., 2012) and ‘Colorao’ (Melgarejo et al., 2014) to $0.1 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Early Blush Rutbhart’, ‘Earlycot 1’, and ‘Mirlo Blanco’ (Aubert and Chanforan, 2007;

Table 12 Organoleptic characteristics of modern apricot cultivars

Cultivar	TSS (°Brix)	TA (g Ma 100 g ⁻¹ FW)	Cultivar	TSS (°Brix)	TA (g Ma 100 g ⁻¹ FW)	Cultivar	TSS (°Brix)	TA (g Ma 100 g ⁻¹ FW)
Alata Yildizi	10.6	1.7	Frison	16.2	20.1 ^b	Nostos	14.3	1.9
Aleksandar	16.8	0.6	Goldstrike	14.3	29.4 ^b	Perle Cot	15.5	24.9 ^b
Antonio	11.6	1.7	Harmat	12.7	2	Pisana	15.4	1.9
Errani								
Aurora	11.5–13.6	1.6–4.4	Helor	14.4	17.7 ^b	Red Sylver	14.9	19.5 ^b
Bigred	15.3	25.9 ^b	Kioto	13.8	33.1 ^b	Rojo	11.3	1.41 ^c
						Pasión		
Biljana	17.4	0.7	Korai	15.2	2.9 ^d	Roxana	11.4	2.3
			zamatós					
Cagataybey	14.6	1.4	Latica	12.1	28.5 ^b	Sadunska	12.5	1.9
Cagribey	10.9	1.3	Lilly Cot	16	35.2 ^b	Sahinbey	9.6	1.6
Ceglédi arany	14.2	1.8	Mascot	15.1	27.2 ^b	Selene	12.8	2.4 ^c
Colorao	13	23.9 ^a	Mirlo	10.4	11.5 ^a	Soledane	9.6–12.3	2.3/31.7 ^b
			Anaranjado					
Danae	11.7	2.4	Mirlo Blanco	9.7	7.7 ^a	St. Early	9.2	0.8
						Orange		
Dorada	13.8	1.2 ^c	Mogador	11.5	16.9 ^a	Super Gold	13.4	1.6
Dr Kaska	9.7	2.4	Murciana	12.6	0.9 ^c	Sweet Cot	14.2	29.1 ^b
Early Blush	12.1	38.8 ^b	Nafsika	14.4	2	Sylred	13.8	31.9 ^b
Rutbhart								
Earlycot 1	14.6	30 ^b	Neraida	10.6	2.1	Tardif de	12.5	16.6 ^b
						Tain		
Ethem Bey	10	0.8	Nereis	12.3	2	Tomcot	14–17.4	2.8–30.1 ^b
Flavor Cot	15.5	24.6 ^b	Nike	12	2	Vera	16.7	0.5
Flodea	14.3	32.1 ^b	Niove	11–13.2	2.5	Vertige	15.7	14.3 ^b

Abbreviations: TSS, Total soluble solid; TA, Titratable acidity; Ma, Malic acid.

^aTitratable acidity expressed as g malic acid L⁻¹.

^bTitratable acidity expressed as meq malic acid 100 g⁻¹.

^cTitratable acidity expressed as g malic acid 100 mL⁻¹ juiced.

^dTitratable acidity expressed as mg citric acid 100 g⁻¹ FW.

Adapted from: Akin et al. (2008), Aubert and Chanforan (2007), Caliskan et al. (2012), Drogoud et al. (2008), Hegedús et al. (2010), Guichard and Souty (1988), Kalyoncu et al. (2009), Melgarejo et al. (2014), Milošević et al. (2012), Roussos et al. (2011) and Ruiz et al. (2005)

Table 13 Carbohydrate composition of modern apricot cultivars

	Sucrose	Glucose	Fructose	Sorbitol		Sucrose	Glucose	Fructose	Sorbitol
Cultivar	g 100 g ⁻¹ FW				Cultivar	g 100 g ⁻¹ FW			
Alata Yildizi	4.9	3.5	1.5	—	Mula Sadik	6.3	2.8	2	0.5
Aleksandar	8.7	4.4	0.2	—	Nafsika	3.7	1.2	0.5	1.1
Antonio	4.9	2.6	1.3	—	Neraida ^a	40.3	13.4	3.3	2.6
Errani									
Bigred	7.6	2.1	0.6	—	Nereis ^a	34.1	11.8	4.2	3.9
Biljana	10.6	3.9	0.3	—	Nike ^a	47.1	10.1	1.9	3
Cagataybey	7.5	3.1	2.8	—	Niove	4.6/44.9 ^a	0.7/10.5 ^a	0.4/2.2 ^a	0.8/4 ^a
Cagribey	4.6	2.9	0.9	—	Nostos ^a	35.2	8.3	2.2	8.2
Colorao	6.2	1.2	2.8	—	Olimp	3.2	1.8	1.3	0.09
Danae ^a	34.7	15.1	5.8	0.6	Perle Cot	7.7	2	0.8	—
Dr Kaska	1.2	3.8	1.9	—	Red Sylver	7.3	1.7	0.9	—
Early Blush	6	1.0	0.1	—	Royal	6.2	2.8	0.6	—
Rutbhart					Roussillon				
Earlycot 1	7.7	0.8	0.1	—	Sadunska ^a	32.7	7.4	3.1	3.9
Flavor Cot	7.1	2.4	1	—	Sahinbey	5.6	1.4	0.9	—
Flodea	6.9	1.5	0.5	—	Salah-Jerevani	5.6	3.2	1.7	3.6
Frisson	7.6	2.8	0.6	—	Soledane	6.2/32.9 ^a	1.0/11.3 ^a	0.2/3 ^a	1.8 ^a
Goldstrike	6.7	1.6	0.6	—	Spring blush	6.1	2.2	0.5	—
Gvardejsky	3.4	3.7	2.3	0.06	Strepet	5.9	3.1	2.2	0.5
Helor	5.5	3.4	0.8	—	Sylred	6.2	1.6	1	—
Kioto	6.2	2	0.5	—	Sweet Cot	7.1	1.6	0.5	—
Latica	6.3	1.3	0.3	—	Tardif de Tain	5.6	2.1	0.6	—
Lilly Cot	8.9	1.1	0.3	—	Tomcot	8.4/34.1 ^a	2.5/11.5 ^a	1.1/3.1 ^a	4.3 ^a
Mascot	6.7	1.8	0.5	—	Vera	11.4	3.3	0.5	—
Mirlo	4.9	0.6	1.1	—	Vertige	8.1	1.7	0.6	—
Anaranjado									
Mirlo Blanco	3.9	0.7	0.1	—	Vesna	4.8	3	1.7	0.3
Mogador	5.9	1.2	1.8	—	Vestar	4.2	1.9	1.5	0.2

^aSugars expressed as g 100 g⁻¹ DW.

Adapted from: Aubert and Chanforan (2007), Caliskan et al. (2012), Drogoudi et al. (2008), Melgarejo et al. (2014), Milošević et al. (2012), Roussos et al. (2011) and Schmitzer et al. (2011).

Melgarejo et al., 2014). Sorbitol has been detected occasionally in a few cultivars, ranging from $3.6 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Salah-Jerevani’ to $0.06 \text{ g } 100 \text{ g}^{-1} \text{ FW}$ in ‘Gvardejsky’ (Schmitzer et al., 2011).

Organic Acid Composition of Traditional Apricot Cultivars

‘Vestar’ has been found to be the cultivar with the highest concentration of malic and fumaric acid (17.9 and $21.6 \text{ mg g}^{-1} \text{ FW}$, respectively), with ‘Gvardejsky’ exhibiting the lowest one (3.8 and $2.2 \text{ mg g}^{-1} \text{ FW}$ respectively) (Schmitzer et al., 2011) (Table 4). The highest citric acid concentration has been detected among modern cultivars in ‘Niove’ at $11 \text{ mg g}^{-1} \text{ FW}$ (Roussos et al., 2011), with ‘Olimp’ having the lowest concentration ($0.1 \text{ mg g}^{-1} \text{ FW}$) (Schmitzer et al., 2011). Shikimic acid has been found in concentrations ranging from 4.9 to $13.4 \text{ mg g}^{-1} \text{ FW}$ in ‘Stark Early Orange’ and ‘Strepet’, respectively (Schmitzer et al., 2011).

Phenolic Compound Composition and Antioxidant Capacity of Modern Apricot Cultivars

Catechin has been found in concentrations ranging from 6.8 to as high as $592 \text{ mg Kg}^{-1} \text{ FW}$ in ‘Nafsika’ and ‘Rojo Pasión’, respectively (Roussos et al., 2011; Ruiz et al., 2005) (Table 14). Epicatechin has been detected in significantly lower concentrations, below $52.2 \text{ mg Kg}^{-1} \text{ FW}$ in ‘Velika Rana’ (Dragovic-Uzelac et al., 2005). Caffeic acid, *p*-coumaric acid, and ferulic acid have also been detected in ‘Nafsika’, ‘Niove’, ‘Keckemetska ruza’, ‘Madjarska najbolja’, ‘Velika Rana’, and ‘Ananas’ in low concentration (Dragovic-Uzelac et al., 2007, 2005; Roussos et al., 2011). Rutin concentration in apricot fruits has been found to range between 1.5 and $77.3 \text{ mg Kg}^{-1} \text{ FW}$ in ‘Olimp’ and ‘Niove’, respectively (Roussos et al., 2011; Schmitzer et al., 2011). Neochlorogenic acid as well as chlorogenic acid have been also detected in low as well as high concentrations (from 1.1 to even $106 \text{ mg Kg}^{-1} \text{ FW}$). 3-*O-p*-coumaroylquinic acid, cryptochlorogenic acid, quercetin-3-glucoside, and quercetin-3-acetylhexoside have been found in the cultivars examined by Schmitzer et al. (2011), Madrau et al. (2009) and Dragovic-Uzelac et al. (2005, 2007) have reported the presence of kaempferol-3-rutinoside in the fruits of ‘Madjarska najbolja’, ‘Velika rana’, ‘Keckemetska ruza’, and in ‘Ananas’ in concentrations ranging from 9.18 to $24.17 \text{ mg Kg}^{-1} \text{ FW}$. Gallic acid has been found in ‘Keckemetska ruza’ only, while quercetin-3-galactoside has been detected in ‘Keckemetska ruza’, ‘Madjarska najbolja’, and ‘Velika rana’ in concentrations ranging from 4.75 to $9.03 \text{ mg Kg}^{-1} \text{ FW}$.

There is a great difference in total phenolic concentration between cultivars, as can be seen in Table 15. ‘Sahinbey’ has been found to have only $14.4 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ (Caliskan et al., 2012), while ‘Nike’ has $742.2 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ (Drogoudi et al., 2008), followed by ‘Rakowsky’ exhibiting $309.5 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ total phenol concentration (Kalyonku et al., 2009). Antioxidant capacity was found to be very high in ‘Nike’, reaching $1858 \text{ mg AA Kg}^{-1} \text{ FW}$ according to diphenyl picryl hydrazyl

Table 14 Phenolic compound composition of modern apricot cultivars

	CAT	EPI	CAE	RUT	FeA	<i>p</i> -CA	NCG	CG	3CQ	CCG	QGluc	QA
Cultivar	mg Kg ⁻¹ FW											
Ananas	20.3	45.7	14.1	21.8	2.0	15.5	—	20.9	—	—	—	—
Dorada	402	—	—	—	—	—	38	30	—	—	—	—
Gvardejsky	—	—	—	7.1	—	—	1.74	3.8	0.6	2.2	0.4	—
Keckemetska ruza	9.2–18.7	27.5–33.2	2.8–3.5	12.6–20.2	1.0–1.5	5.1–6.8	11.9	14.7–16.7	—	—	6.6–7.0	—
Madjarska najbolja	12.5–23.1	20.2–47.9	7.6–8.1	15.5–40.7	0.8–1.9	3.2–11.1	14.2–17.2	20.9–26.9	—	—	8.8–12.9	—
Mula Sadik	—	—	—	26.1	—	—	14.4	30.2	0.9	8.6	1.2	0.6
Murciana	391	—	—	—	—	—	61	107	—	—	—	—
Nafsika	6.8	3.8	1.9	56.5	0.6	0.5	4.1	4.6	—	—	—	—
Niove	13.2	8.9	1.8	77.3	0.4	0.4	15.7	22	—	—	—	—
Olimp	—	—	—	1.5	—	—	3.4	8.2	1.4	2.5	0.1	0.1
Pelese	13.4	11.4	—	67.6	—	—	29.9	24.2	—	—	6.5	—
Rojo Pasión	592	—	—	22	—	—	106	110	—	—	—	—
Salah-Jerevani	—	—	—	3.2	—	—	1.1	8.7	0.3	1.9	0.3	0.2
Selene	202	—	—	—	—	—	12	31	—	—	—	—
Strepet	—	—	—	4.9	—	—	1.07	9.1	0.3	2.7	0.2	0.3
Velika rana	15.2–36.9	29.9–52.2	14.3	15.7–26.9	1.5–4.3	10.2–13	12.2–15.7	16.9–20.9	—	—	9.2–15.1	—
Vesna	—	—	—	12.1	—	—	1.5	13.7	1.1	2.3	0.5	—
Vestar	—	—	—	14.5	—	—	2.1	6.5	0.6	2.4	0.6	0.6

Abbreviations: CAT, Catechin; EPI, Epicatechin; CAE, Caffeic acid; RUT, Rutin (Quercetin-3-rutinoside); FeA, Ferulic acid; *p*-CA, *p*-Coumaric acid; NCG, Neochlorogenic acid; CG, Chlorogenic acid; 3CQ, 3-*O*-*p*-Coumaroylquinic acid; CCG, Cryptochlorogenic acid; QGluc, Quercetin-3-glucoside; QA, Quercetin-3-acetylhexoside.

Adapted from: Dragovic-Uzelac et al. (2005, 2007), Madrau et al. (2009), Roussos et al. (2011), Ruiz et al. (2005) and Schmitzer et al. (2011).

Table 15 Total phenolic compounds and antioxidant capacity of modern apricot cultivars

Cultivar	Total phenols (mg GAE 100 g ⁻¹ FW)	FRAP (mmol Fe Kg ⁻¹ FW)	DPPH (mg Kg ⁻¹ AA FW)	Cultivar	Total phenols (mg GAE 100 g ⁻¹ FW)	FRAP (mmol Fe Kg ⁻¹ FW)	DPPH (mg Kg ⁻¹ AA FW)
Alata Yildizi	177.1	10.6	—	Mula Sadik ^c	9.77	—	292.5
Antonio Errani	52.9	6	—	Nafsika ^b	241.1	1.5	0.5
Aurora	28.5–49.2	3.3	170/9.8 ^a	Nefele	96.9	—	49
Baneasa	—	—	26.6 ^a	Neraida	111.9	—	95
Cagataybey	93.9	9.8	—	Nereis	30.3	—	83
Cagribey	41.4	8.4	—	Nike	742.2	—	1858
Ceglédi arany ^a	—	—	21.3	Niove	105.7/365.1 ^b	2.1 ^b	100/0.9 ^b
Ceglédi Piroska ^a	—	—	31.2	Nostos	37.8	—	27
Cekirge	193.2	—	—	Olimp ^c	3.45	—	101.6
Colorao	14.9	—	—	Preventa ^a	—	—	74.5
Danae	117.1	—	79	Rakowsky	309.5	—	—
Dr Kaska	82.3	8.1	—	Roxana	123.9	9.9	—
Ethem Bay	197.9	—	—	Sadunska	85.7	—	226
Gvardejsky ^c	5.6	—	115.6	Sahinbey	14.4	4.7	—
Harmat ^a	—	—	6.4	Sam	65.8	—	—
Kech-Pshar ^a	—	—	26.5	Salah-Jerevani ^c	2.54	—	28.7
Konservnyi	—	—	45.4	Shalakh ^a	—	—	25.4
pozdnii ^a	—	—	—	—	—	—	—
Korai zματος ^a	—	—	9.6	Soledane	65.4	—	114
Laycot	64.3	11.1	—	Strepet ^c	3.4	—	115.9
Mirlo Anaranjado	199	—	—	Tomcot	204.6	—	372
Mirlo Blanco	162	—	—	Vesna ^c	3.3	—	161.2
Mogador	222	—	—	Vestar ^c	4.2	—	138.1

Abbreviations: DPPH, Diphenyl picryl hydrazyl; FRAP, Ferric reducing antioxidant power; GAE, Gallic acid equivalents; AA, Ascorbic acid.

^aDPPH expressed as % inhibition.

^bTotal phenols expressed as mg tannic acid g⁻¹ FW; FRAP and DPPH expressed as μ moles Trolox g⁻¹ FW.

^cTotal phenols and DPPH were measured in apricot pulp without the skin.

Adapted from: Caliskan et al. (2012), Contessa et al. (2013), Drogoudi et al. (2008), Hegedús et al. (2010), Kalyoncu et al. (2009), Melgarejo et al. (2014), Roussos et al. (2011) and Schmitzer et al. (2011).

(DPPH) assay (Drogoudi et al., 2008), closely related to the cultivar's total phenol concentration. The rest of the cultivars exhibited significantly lower antioxidant capacity, with the lowest value found in 'Nostos' (Drogoudi et al., 2008). Hegedűs et al. (2010) determined the antioxidant capacity in 11 apricot cultivars and found that 'Preventa' exhibited the highest antioxidant capacity and 'Korai zamatos' the lowest (74.5% and 9.6% inhibition of DPPH molecule oxidation). Caliskan et al. (2012) found that among eight cultivars, 'Aurora' presented the lowest and 'Laycot' the highest antioxidant capacity (3.3 and 11.1 mmol Fe Kg⁻¹ FW according to FRAP assay).

Vitamins Concentration in Modern Apricot Cultivars

Vitamin C has been found in high concentration in 'Preventa', followed by 'Ceglédi Piroška' and 'Banessa' (16.2, 9.8, and 9.6 mg 100 g⁻¹ FW, respectively) (Hegedűs et al., 2010) (Table 7). On the other hand, the lowest concentration has been determined in 'Nafsika' and 'Niove' (1.2 and 1.4 mg 100 g⁻¹ FW, respectively) (Roussos et al., 2011). Ruiz et al. (2005) have also detected provitamin A in 'Dorada', 'Murciana', 'Rojo Pasión', and 'Selene' at 834, 1049, 680, and 1744 IU mg⁻¹ FW.

Carotenoids Concentration in Modern Apricot Cultivars

'Selene' is the apricot cultivar in which the highest concentration of β -carotene, γ -carotene, β -cryptoxanthin, and total carotenoids have been found (9.3, 1.5, 2.4, and 14 mg 100 g⁻¹ FW, respectively) (Ruiz et al., 2005) (Table 8). The lowest concentration of β -carotene, γ -carotene, and β -cryptoxanthin has been determined in 'Rojo Pasión', with 3.7, 0.6, and 0.7 mg 100 g⁻¹ FW, respectively (Ruiz et al., 2005), while Drogoudi et al. (2008) found in 'Nereis' the lowest total carotenoids concentration (1.1 mg β -carotene equivalents 100 g⁻¹ FW).

Mineral Composition of Modern Apricot Cultivars

Among modern apricot cultivars, 'Aurora' was found to be the one with the highest concentration of phosphorus (29.7 mg 100 g⁻¹ FW), potassium (417.5 mg 100 g⁻¹ FW), calcium (18.7 mg 100 g⁻¹ FW), magnesium (16 mg 100 g⁻¹ FW), iron (0.3 mg 100 g⁻¹ FW), zinc (0.2 mg 100 g⁻¹ FW) and sodium (1.1 mg 100 g⁻¹ FW) (Table 10) (Gergely et al., 2014). 'Conci Magyar Kajszi', on the other hand, has been found to have the lowest phosphorus, calcium, magnesium, and iron and the highest manganese (25.2, 8.2, 8.9, and 0.2 mg 100 g⁻¹ FW, respectively) (Gergely et al., 2014). Gergely et al. (2014) have determined the concentration of boron, silica, sulfur, barium, lithium, selenium, strontium, and titanium in 'Gonci Mayar Kajszi', 'Aurora', and 'M. Kajski C.235' to be lower than 0.81, 1.84, 9.21, 0.014, 0.001, 0.0005, 0.11, and 0.017 mg 100 g⁻¹ FW, respectively.

Volatile Compounds Found in Traditional apricot Cultivars

The most abundant volatile compound in ‘Dilbay’ and ‘Stark Early Orange’ has been found to be 2-hexenal ($3186.4 \mu\text{g Kg}^{-1}$ and $362.9 \mu\text{g Kg}^{-1}$, respectively), followed by hexanal ($613.1 \mu\text{g Kg}^{-1}$ and $158.9 \mu\text{g Kg}^{-1}$, respectively), (*E*)-2-hexen-1-ol, hexyl acetate, and others (Gokbulut and Karabulut, 2012) (Table 11). The highest levels of nerylactone, which has been reported as an aroma component of fresh and dried apricots, were detected in ‘Dilbay’ ($107.7 \mu\text{g Kg}^{-1}$) and ‘Stark Early Orange’ ($96.7 \mu\text{g Kg}^{-1}$) (Gokbulut and Karabulut, 2012). Butyl acetate was detected at high concentration in ‘Early Blush Rutbhart’ ($1922 \mu\text{g Kg}^{-1}$) and ‘Flavor Cot’ ($2688 \mu\text{g Kg}^{-1}$), and accounted for 55% of the volatiles quantified in these cultivars (Aubert and Chanforan, 2007), whereas linalool made up 30% in ‘Spring Blush’ ($256 \mu\text{g Kg}^{-1}$). γ -Decalactone ranged from $454 \mu\text{g Kg}^{-1}$ in ‘Early Blush’ to $21 \mu\text{g Kg}^{-1}$ in ‘Kioto’ and accounted for 30% of the volatiles quantified in ‘Sylred’, ‘Red Sylver’, ‘Perle Cot’, and ‘Frisson’ (350, 182, 212, and $230 \mu\text{g Kg}^{-1}$) (Aubert and Chanforan, 2007).

FRUIT QUALITY CHARACTERISTICS AND PHYTOCHEMICALS IN GREEK TRADITIONAL AND MODERN APRICOT CULTIVARS

Apricot is one of the most important deciduous fruit species in Greece. Two of the most important and internationally known traditional Greek cultivar are ‘Bebecou’ or ‘Bebeco’, and ‘Proimo Tyrinthos’ or ‘Tyrinthos’, which were the main apricot cultivars for decades in Greece, before the problem of plum pox virus (PPV) or sharka becomes so intense. Another traditional Greek apricot cultivar is ‘Diamantopoulou’, which is characterized by its supreme aroma. All three cultivars, however, are sensitive to sharka infection and gradually are being displaced by other, newer ones that are resistant to PPV, such as ‘Nafsika’, ‘Niove’, ‘Neraida’, ‘Nefele’, ‘Nostos’, ‘Nereis’, ‘Nike’, and ‘Danae’ among others.

The TSS of ‘Bebecou’ have been found to range between 10.6 and 11.6°Brix with ‘Proimo Tyrinthos’ exhibiting even lower values $8.8\text{--}9.8^\circ\text{Brix}$ (Caliskan et al., 2012; Drogoudi et al., 2008; Roussos et al., 2011). On the other hand, all modern cultivars exhibit higher values of TSS than the two previously mentioned traditional ones, i.e., ‘Nafsika’ 14.4 , ‘Neraida’ 10.6 , ‘Nereis’ 12.3 , ‘Nike’ 12 , ‘Niove’ $11\text{--}13.2$, and ‘Nostos’ 14.3°Brix (Drogoudi et al., 2008; Roussos et al., 2011). Titratable acidity ranged from 1.9% w/w malic acid in ‘Nostos’ to 2.5% w/w malic acid in ‘Niove’, while in ‘Bebecou’ it has been estimated at 1.4% w/w malic acid and in ‘Proimo Tyrinthos’ at 1.5–1.6% w/w malic acid (Caliskan et al., 2012; Drogoudi et al., 2008; Roussos et al., 2011). During a taste panel conducted in our laboratory, ‘Nostos’ scored higher than ‘Bebecou’ and ‘Diamantopoulou’ in most of the quality attributes tested (taste, firmness, mouth aroma, aftertaste, and overall acceptance) with the traditional cultivars exhibiting, however, significant symptoms of sharka virus infection, affecting their quality (Roussos,

unpublished data). The carbohydrates analyzed in 'Bebecou' and 'Proimo Tyrinthos' revealed the high participation of sucrose to the total carbohydrate content of the fruit, ranging from $36.6 \text{ g } 100 \text{ g}^{-1} \text{ DW}$ in 'Bebecou' to $38.7 \text{ g } 100 \text{ g}^{-1} \text{ DW}$ in 'Proimo Tyrinthos' (Caliskan et al., 2012; Drogoudi et al., 2008; Roussos et al., 2011). Glucose, fructose, and sorbitol were found in lower concentrations. Some of the modern cultivars, however, exhibited higher sucrose concentration than those found in traditional cultivars, reaching $47.1 \text{ g } 100 \text{ g}^{-1} \text{ DW}$ in 'Nike', $44.7 \text{ g } 100 \text{ g}^{-1} \text{ DW}$ in 'Niove', $40.3 \text{ g } 100 \text{ g}^{-1} \text{ DW}$ in 'Neraida', while the rest had either comparable or lower glucose concentration (34.7 , 34.1 , and $35.2 \text{ g } 100 \text{ g}^{-1} \text{ DW}$ in 'Danae', 'Nereis', and 'Nostos', respectively) (Drogoudi et al., 2008; Roussos et al., 2011). Similar trend was found regarding the rest of the sugars too, with glucose in 'Danae', 'Neraida', and 'Nereis' to be higher than that determined in 'Bebecou' and 'Proimo Tyrinthos' (Drogoudi et al., 2008).

Citric acid and malic acid are the predominant organic acids found in 'Bebecou' and 'Proimo Tyrinthos' (Drogoudi et al., 2008; Roussos et al., 2011). 'Bebecou' exhibited citric acid concentrations ranging from 8.85 to $16.4 \text{ mg g}^{-1} \text{ FW}$ while malic acid was determined at $5.8 \text{ mg g}^{-1} \text{ FW}$ (Roussos et al., 2011). In 'Nafsika', we determined citric acid at $8.19 \text{ mg g}^{-1} \text{ FW}$ and malic acid at $8.5 \text{ mg g}^{-1} \text{ FW}$, while in 'Niove' citric acid concentration was higher, at $11 \text{ mg g}^{-1} \text{ FW}$, but malic acid was lower, at $6.2 \text{ mg g}^{-1} \text{ FW}$ (Roussos et al., 2011).

The total phenol concentration in 'Bebecou' was determined at 329 mg tannic acid equivalents $100 \text{ g}^{-1} \text{ FW}$, while 'Nafsika' had significantly lower concentration at 241.1 mg tannic acid equivalents $100 \text{ g}^{-1} \text{ FW}$ and 'Niove' comparable concentration (365.1 mg tannic acid equivalents $100 \text{ g}^{-1} \text{ FW}$) (Roussos et al., 2011). The total phenol concentration in 'Proimo Tyrinthos' has been estimated to range from 21.2 to $104.9 \text{ mg GAE } 100 \text{ g}^{-1} \text{ v}$, significantly lower than that determined in 'Nike', where $742.2 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$ were found, the highest phenol concentration of any other cultivar (Drogoudi et al., 2008). 'Neraida', 'Nefele', and 'Niove' exhibited comparable high concentrations of total phenolic compounds with 'Proimo Tyrinthos' (close to $100 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$), while 'Nereis' and 'Nostos' had low total phenol concentration (close to 30 – $40 \text{ mg GAE } 100 \text{ g}^{-1} \text{ FW}$) (Drogoudi et al., 2008). The antioxidant capacity of 'Bebecou' fruits was found to be lower than that of 'Nafsika' and 'Niove' based on the DPPH assay (0.35 compared to 0.5 and $0.94 \text{ } \mu\text{moles Trolox equivalents g}^{-1} \text{ FW}$) (Roussos et al., 2011). 'Niove' exhibited higher antioxidant capacity than 'Bebecou' based on the FRAP assay also (2.01 compared to $1.68 \text{ } \mu\text{moles Trolox equivalents g}^{-1} \text{ FW}$) (Roussos et al., 2011).

The phenolic compound profile of the traditional Greek apricot cultivars is dominated by the presence of rutin, as the most abundant phenolic compound in apricot fruits (Roussos et al., 2011). 'Bebecou' was found to have 93.7 mg rutin $\text{Kg}^{-1} \text{ FW}$, followed by neochlorogenic acid, chlorogenic acid, catechin, and epicatechin, while

small amounts of caffeic acid and ferulic acids were also determined. In fruits of 'Proimo Tyrinthos', rutin was quantified to be $438 \text{ mg Kg}^{-1} \text{ DW}$, followed by neochlorogenic acid, chlorogenic acid, and epicatechin (Radi et al., 2003). 'Nafsika' and 'Niove' exhibited lower concentration of rutin than 'Bebecou' (56.5 and $77.3 \text{ mg Kg}^{-1} \text{ FW}$ respectively). 'Niove', on the other hand, presented higher values of chlorogenic acid, neochlorogenic acid, catechin, and epicatechin (22 , 15.7 , 13.2 , $8.9 \text{ mg Kg}^{-1} \text{ FW}$) than both 'Nafsika' and 'Bebecou' (Roussos et al., 2011).

SUMMARY POINTS

- The major carbohydrate of apricot fruits is sucrose, followed by glucose and fructose, while sorbitol is found in low concentration, with the concentration of carbohydrates differing among cultivars.
- Malic and citric acids are the most abundant organic acids found in apricot fruits.
- The major phenolic compounds found in fruits are chlorogenic acid, neochlorogenic acid, rutin, catechin, and epicatechin, with great differences among cultivars with regard to concentration of these compounds.
- Potassium is the predominant nutrient found in apricot fruits.
- Vitamin C is the major vitamin in fruits, while low concentrations of vitamin A, vitamin E, and provitamin A have been detected.
- The major carotenoid present in apricot fruits is β -carotene, followed by γ -carotene and β -cryptoxanthin, in various concentrations, depending on the cultivar.
- Ethyl acetate, hexyl acetate, limonene, β -cyclocitral, γ -decalactone, 6-methyl-5-hepten-2-one, linalool, β -ionone, menthone, hexanol, hexanal, 2-hexenal, (*E*)-2-hexen-1-ol, and (*E*)-hexen-2-al are the major aroma compounds identified in apricot fruits and are responsible for the typical flowery and fruity aromatic notes, but the most abundant volatile compound differs among cultivars.

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CHAPTER 3

Nutritional and Biochemical Composition of Banana (*Musa* spp.) Cultivars

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LIST OF ABBREVIATIONS

1D-GC-qMS One-dimensional gas chromatography–mass spectrometry
dHS-SPME Dynamic headspace solid-phase microextraction
DW Dry weight
FHIA The Foundation Hondurena de Investigacion Agricola
FW Fresh weight
GAE Gallic acid equivalent
GC-MS Gas chromatography–mass spectrometry
HPLC High-performance liquid chromatography
pVAC Provitamin A carotenoids
RAE Retinol activity equivalent
TSS Total soluble solids
TA Titratable acidity
TPC Total phenolic content
USDA United States Department of Agriculture

INTRODUCTION

Bananas probably originated in Southeast Asia, and they grow best in the humid lowland tropics within 30° of the equator. They are also grown commercially within the subtropics and at altitudes of 1000 m or higher in the subtropics, but growth is much slower and cropping is lighter. [Purseglove \(1972\)](#) stated that all edible bananas, except Fe'i, are derived from *Musa acuminata* Colla (*Musa* AA) and *Musa balbisiana* Colla (*Musa* BB). *Musa acuminata* had its center of diversity in the Malaysian area, where [Simmonds \(1962\)](#) reported that four of the five subspecies *malaccensis* (Ridl.) Simmonds, *microcarpa* (Beccari) Simmonds, *burmannica* Simmonds, and *siamea* Simmonds overlap. It is believed that the banana was probably one of the first foods that humans cultivated. The records of edible bananas come from India (600 BC). It was believed that bananas were first introduced to Europe in the tenth century AD. During the approximately 1000-year history of the Byzantine Empire, bananas were the chief ingredient in desserts. They even spread into the Islands of the Pacific and to the West Coast of Africa as early as 200–300 BC. Alexander the Great and his troops are believed to have found bananas growing in the valley of the Indus River as early as 326 BCE, during their abortive march through India trying to reach the ocean. The first reference to bananas in Chinese literature comes from Yang Fu, an official at the end of the later Han Dynasty around the second century AD. He used the names *pa-chiao* and *kan-chiao*. Pliny (around AD 67) mentions that the fruit was the 'food of the sages'.

Banana and plantain (often referred as cooking-type bananas) plants are cultivated in more than 130 countries throughout the tropical and subtropical regions, over a harvested area of approximately 10 million hectares ([FAOSTAT, 2013](#)). The annual world production accounts for about 145 million tons (ca. 106 million tons for banana and 39 million tons for plantain), with India as the major producer (29 million tons), Ecuador the main exporter, and the European Union and United States the major importers of bananas ([FAOSTAT, 2013](#)). Some countries, particularly those in Latin America, are very efficient banana producers, with a good infrastructure and optimum inputs giving high yields. Many banana plantations in these countries are foreign owned. Since 1965, world production has increased almost 3.9 times, from 26.4 million tons in 1965, 31.3 million tons in 1970, 36.7 million tons in 1980, 46.8 million tons in 1990, 65.4 million tons in 2000, to 102.1 million tons in 2010 ([FAOSTAT, 2013](#)).

BOTANICAL ASPECTS

The genus *Musa* has more than 50 species, with some of these species having numerous subspecies. The diversity has led to the genus being divided into three sections from the five traditional sections: *Musa* (2n = 22, incorporating *Rhodochlamys*), *Callimusa* (2n = 20, incorporating *Australimusa*), and single species section *Ingentimusa* (2n = 28) ([Wong et al., 2002](#)). Dessert bananas belong to the genus *Musa*. The Linnaean classification of 1783

gave the name *M. sapientium* L. to bananas that are eaten fresh, and *M. paradisiaca* L. to those that are cooked, for example, plantains and cooking bananas. Many authors still use the Linnaean classification, and many names have been used. However, [Simmonds and Shepherd \(1955\)](#) and [Stover and Simmonds \(1987\)](#) confirmed this and reported that many dessert varieties are derived from *M. acuminata* Colla, some being diploid and a few being tetraploid but most being triploid. *M. balbisiana* Colla has also contributed to the origin of dessert bananas and plantains by hybridization with *M. acuminata*. They recommended that in place of the species name, an A genome or a B genome should be used showing the origin and contribution of the two species. So a triploid variety whose origin is *M. acuminata*, e.g., the ‘Giant Cavendish’ and ‘Gros Michel’ varieties, would be referred to as *Musa* AAA. Where the triploid has one-third *M. balbisiana* and two-thirds *M. acuminata*, it would be referred to as *Musa* AAB. In addition, if there is a subgroup, this should be included, followed by the common name of the variety or cultivar (for example, *Musa* AAA (‘Cavendish’ subgroup) ‘Robusta’, *Musa* AA ‘Pisang Mas’, and *Musa* ABBB ‘Kluai Teparod’).

There is a conflicting and confusing terminology for banana root systems as used by different authors. Arising from the rhizome is the root axis, which may produce primary (first-order) laterals from which may branch secondary (second-order) laterals. An axis with its laterals is considered a root. The root system arising from the rhizome is, by definition, adventitious. The banana is the largest of the herbaceous plants, its pseudostem reaching a height of 2–8 m in cultivated varieties and up to 10–15 m in some wild species. The impressive aerial shoot is borne on the subterranean stem which is about 30 cm long. Bananas also have the largest leaf area, which varies between cultivars and depends upon growing conditions. The areas of individual leaves of dessert bananas are 1.27–2.80 m² ([Stover and Simmonds, 1987](#)). The overall leaf area of ‘Cavendish’ cultivars at flowering may be 16.9–25 m² ([Stover and Simmonds, 1987](#)).

The plant has a basal corm, the true stem, which has an apical meristem in the form of a flattened crown, from which grows the spirally arranged leaves whose bases form a pseudostem. The flower is produced from the corm in the center of the leaves and emerges at the top of the pseudostem. Only one flower is produced from one pseudostem. It takes about 1 month from formation to emergence of the inflorescence. The inflorescence is borne on a stout peduncle and consists of male and female flowers borne on nodes in two rows of nodal clusters with bracts in between. The top 5–15 nodal clusters produce female flowers and below this, at the distal end, male flowers. There may be hermaphrodite flowers between the male and female. The root system is adventitious with individual roots up to about 8 mm in diameter, with primary roots producing short, thinner lateral roots. They are white and fleshy, later becoming somewhat corky, and can spread up to 5 m laterally but mostly in the top 15 cm and to a depth restricted by the water table.

Botanically the fruit is a parthenocarpic berry. Fruit maturation takes 80–120 days depending on cultivar and season. During ripening, the fruits turn from green to yellow. The exocarp is made up of the epidermis and the arenchyma layer, with the flesh being the mesocarp. The endocarp is composed of a thin lining next to the ovarian cavity. Each node of the rachis has a double row of flowers, forming a cluster of fruit that is commercially called a ‘hand’, with the individual fruit called a ‘finger’. ‘Cavendish’ bananas can have 16 hands per bunch, with up to about 30 fingers per hand, and the bunch can weigh up to 70 kg.

There are at least 200–300 banana clones in various countries (Robinson and Saucó, 2010). In south India, a large diversity of bananas exists (Figure 1). There are numerous germplasm collections around the world, including those in Indonesia, Malaysia, Thailand, the Philippines, India, Honduras, Jamaica, Brazil, Cameroon, and Nigeria. Due to the difficulty of breeding infertile plants, only a few cultivars have been introduced in the last 50 years. However, the advent of clonal propagation, combined with selection programs, has led to the singling out of ‘elite’ clones in terms of yield and fruit quality, adapted to the agroecological conditions. ‘Dwarf Cavendish’, ‘Giant Cavendish’, and ‘Gros Michel’ are among the most important banana cultivars for fresh consumption. ‘Giant Cavendish’ has been the main group of varieties in international trade since the late 1940s. Selections include ‘Grand Naine’, ‘Lacatan’, ‘Poyo’/‘Robusta’, ‘Valery’, and ‘Williams’, which are largely distinguished by the height of the pseudostem. ‘Dwarf Cavendish’ is tolerant to a wide range of climates including cool conditions, whereas ‘Grand Naine’ responds well to optimal growing conditions but does not grow or yield well in suboptimal conditions. The ‘Sucrier’/‘Pisang Mas’/‘Honey’ varieties are very sweet and have small fruit, thin skin, yellowish flesh, and small bunches (up to about 13 kg).

‘Gros Michel’ was the variety first used in international trade (Robinson and Saucó, 2010). It had long been grown in Southeast Asia and Sri Lanka. Jean François Pouyat, a French botanist and chemist who settled in Jamaica in 1820, probably introduced it there. He brought the fruit from Martinique to his coffee estate. It was originally called ‘Banana Pouyat’; later, this became the ‘Martinique Banana’ and finally ‘Gros Michel’. It is called ‘Hom Thong’ in Thailand. Leading *Musa* cultivars of the world by genomic constitution are given in Table 1.

COMPOSITION OF TRADITIONAL AND MODERN CULTIVARS OF BANANA

The banana fruit, with an average annual per capita consumption that varies from 4.5 kg in the United States to 16 kg in Sweden and up to 151 kg in São Tomé e Príncipe, has a high nutritional value, contributing to an elevated intake of carbohydrates, fiber, vitamins, and minerals, together with a very low intake of fats (Arvanitoyannis and Mavromatis, 2009). In addition, banana fruit is also a rich source of phytochemicals, including unsaturated fatty acids and sterols.



Figure 1 The diversity of banana and plantains for sale in a shop in southern India (Varkala, Kerala State) with various genome compositions. Cultivars are indicated by letters above bunches: (a) cultivar 'Red' (dark gray in print version) (AAA genome constitution), a prized sweet dessert banana cultivar. Differences between bunches are mostly from water and nitrogen conditions in the field and are not genetic. (b) 'Palayam Codan' (AAB). (c) 'Njalipoovan' AB (unripe and ripe, green (gray in print version) and yellow (white in print version)) sweet dessert banana with small fingers, thin skin, and delicate flavor but poor keeping quality, and the fruits fall off bunches. (d) 'Robusta' ('Cavendish' group, AAA); 'Cavendish' cultivars ripen without changing to yellow (white in print version) (green (gray in print version) ripe) when above 22°C. (e) 'Nendran' (AAB), used for cooking and for making chips. (f) 'Peyan' (ABB), used as a vegetable for curries and for cooked snacks. (g) 'Poovan' (AAB).

Table 1 *Musa* cultivars by genomic classification

Genome	Cultivars
AA	'Inarbinal', 'Paka', 'Matti', 'Anakomban', 'Pisang Jari Muaya', 'Pisang Lilin', 'Senorita', 'Kadali', 'Sucrier' ('Kulai Khai', 'Ladys Finger', 'Orito', 'Pisang Mas')
AAA	'Ambon', 'Cavendish' ('Dwarf Cavendish', 'Giant Cavendish', 'Grand Naine', 'Williams'), 'Gros Michel' ('Cocos', 'Highgate', 'Lowgate'), 'Ibola', 'Basrai', 'Lujugira-Mutika' ('Beer', 'Musakala', 'Nakabulu', 'Nakitembe', 'Nfunka'), 'Pisang Masak Hijau' ('Lacatan'), 'Red' ('Green Red'), 'Robusta' ('Harichal', 'Malbhog')
AAAA	'Pisang Ustrali'
BB	'Bhimkol', 'Biguihan', 'Gubao', 'Pa-a-Dalaga', 'Tani'
BBB	'Abuhon', 'Inabaniko', 'Lap Chang Kut', 'Mundo', 'Saba Sa Hapon', 'Saba', 'Sabang Poti', 'Turrangkog'
AB	'Kunnan' ('Adukkal', 'Poonkali', 'Poovilla Chundan'), 'Ney Poovan' ('Kisubi', 'Safed Velchi'), 'Sukali Ndizi' ('Kumarangasenge')
AAB	'False Horn' ('French', 'French Horn'), 'Laknau', 'Maia Maoli', 'Moongil', 'Mysore' ('Sugandhi'), 'Nendran', 'Pisang Raja', 'Plantain Horn', 'Pome' ('Pachanadan', 'Pacovan', 'Prata Ana', 'Virupakshi'), 'Popoulu', 'Ilohená', 'Rasthali', 'Silk'
ABB	'Bluggoe' ('Nalla Bontha', 'Pisang Batu', 'Punda'), 'Pisang Awak' ('Klue Namwa', 'Karpuravalli', 'Pey Kunnan', 'Yawa'), 'Monthan', 'Peyan', 'Klue Teparot', 'Pelipita', 'Kalapua', 'Cardaba'
AAAB	'Atan'
AABB	'Kalamagol', 'Laknau Der',
ABBB	'Bhat Manohar'
AS	'Aso', 'Kokor', 'Ungota', 'Vunamami'
AT	'Umbubu'
AAT	'Kabulupusa', 'Karoína', 'Mayalopa', 'Sar'
ABBT	'Giant Kalapur', 'Yawa 2'
Unknown	'Fei'

Source: Nayar (2010).

Within a cultivar, there is large plant-to-plant variation and within-plant variation in nutrient composition for fruit harvested from the same field. Forster et al. (2002) showed that there were differences in the chemical compositions in the same banana variety from Tenerife and from Ecuador. Also, there were clear differences in the chemical composition of the bananas from Tenerife according to the cultivation method (greenhouse and outdoors), farming method (conventional and organic), and region of production (north and south). These authors found that the cultivar did not influence the chemical composition, except for insoluble fiber content. Cano et al. (1997) evaluated the characteristics of banana fruits (*Musa cavendishii*) of the 'Gran Enana' and 'Enana' cultivars from the Canary Islands, and compared their quality parameters with one of the most

widespread Latin American ‘Enana’ cultivars. All determinations were carried out in banana fruits at the same stage of ripeness characterized by peel color (yellow–green 70:30). Firmness values were higher in the Spanish ‘Enana’ cultivar. The Latin American cultivar ‘Enana’ showed the highest moisture content (76.05 g/100 gFW), followed by the Spanish cultivar ‘Gran Enana’ (74.04 g/100 gFW), and then the Spanish cultivar ‘Enana’ (73.24 g/100 gFW). The total soluble sugars were significantly different in the three banana cultivars. The highest amount of total sugars was recorded for the Spanish ‘Gran Enana’ fruits (11.07 g/100 gFW). This cultivar had the lowest amount of sucrose and the highest amounts of fructose and glucose. Spanish varieties of banana exhibited the highest vitamin C values.

Wall (2006) reported the following analysis: vitamin C 12.7 mg/100 g, vitamin A 12.4 mg/100 g (retinol activity equivalent (RAE)), total soluble solids (TSS) 17.9%, and moisture 68.5% for ‘Dwarf Brazil’. For ‘Williams’, Wall reported the following: vitamin C 4.5 mg/100 g, vitamin A 8.2 mg RAE/100 g, TSS 20.5%, and moisture 73.8%. Lee (2008) reported that an average-sized banana had 450–467 mg potassium. Bananas are also high in fiber, and a medium-sized banana has about 6 g of fiber. Bananas contain vitamins C, B, and A, along with other minerals. Wall (2006) reported that bananas contained higher concentrations of lutein than of the provitamin A pigments, α -carotene and β -carotene. She also showed that different varieties of banana could contain different levels of nutrients. In Hawaii, ‘Apple’ bananas had almost three times more vitamin C (12.7 mg/100 gFW) than ‘Williams’ (4.5 mg/100 g), and ‘Apple’ bananas had an average of 96.9 μ g β -carotene and 104.9 μ g α -carotene per 100 g, whereas ‘Williams’ averaged 55.7 μ g β -carotene and 84.0 μ g α -carotene per 100 g. ‘Apple’ bananas also had higher P, Ca, Mg, Mn, and Zn concentrations than ‘Williams’. These data were confirmed by United States Department of Agriculture (USDA, 2012) for what appear to be fully ripe fruit (Table 2).

Carbohydrates

Starch accumulates during maturation, and in the preclimacteric phase there is little change in the principal carbohydrate metabolites (Wardlaw et al., 1939). Starch is converted to sucrose, glucose, and fructose during ripening. In dessert bananas, ripening involves a reduction in starch content from around 15–25% to less than 5% in the ripe pulp, coupled with a rise of similar magnitude in total sugars (Desai and Deshpande, 1975; Lizada et al., 1990). During the early part of ripening, sucrose is the predominant sugar, but in the later stages, glucose and fructose predominate (Barnell, 1943). Hubbard et al. (1990) also reported that the proportion of the different sugars was related to the stage in the respiratory climacteric of the fruit. They also showed that starch was broken down to sucrose by the action of sucrose phosphate synthetase and nonreducing sugars from sucrose by acid hydrolysis. The onset of the starch to sugar conversion has been shown to be influenced by harvest maturity, with more mature

Table 2 Composition of *Musa acuminata* Colla per 100 g FW (USDA, 2012)

Nutrient/content	Value
Water (g)	74.91
Energy (kcal)	89
Protein (g)	1.09
Total lipid (fat) (g)	0.33
Carbohydrate, by difference (g)	22.84
Total dietary fiber (g)	2.6
Total sugars (g)	12.23
Calcium (mg)	5
Iron (mg)	0.26
Magnesium (mg)	27
Phosphorus (mg)	22
Potassium (mg)	358
Sodium (mg)	1
Zinc (mg)	0.15
Vitamin C, total ascorbic acid (mg)	8.7
Thiamin (mg)	0.031
Riboflavin (mg)	0.073
Niacin (mg)	0.665
Vitamin B-6 (mg)	0.367
Folate, DFE (µg)	20
Vitamin B-12 (µg)	0.00
Vitamin A, RAE (µg)	3
Vitamin A (IU)	64
Vitamin E (α-tocopherol) (mg)	0.10
Vitamin D (D2 + D3) (µg)	0.0
Vitamin D (IU)	0
Vitamin K (phylloquinone) (µg)	0.5
Fatty acids, total saturated (g)	0.112
Fatty acids, total monounsaturated (g)	0.032
Fatty acids, total polyunsaturated (g)	0.073

fruits responding earlier. These changes have been demonstrated in both triploid (*Musa* AAA) (Madamba et al., 1977) and diploid (*Musa* AA) fruit (Montenegro, 1988). In bananas, the breakdown of starch is usually completed during ripening, but in plantains this breakdown is not complete even when the fruit is fully yellow and soft (George, 1981). Arora et al. (2008) reported that the cultivar ‘Karpooravalli’ is rich in carbohydrate content in terms of total starch (1786.0 µg/gDW in the peel and 544.85 µg/gDW in the pulp) and sugars (53.53 µg/gDW in the peel and 39.05 µg/gDW in the pulp). In ‘Morish’ peel and pulp, starch content was nearly equal to 600 µg/gDW and total sugars were almost equal in ‘Hill’ banana peel and pulp (29 µg/gDW) (Figure 2).

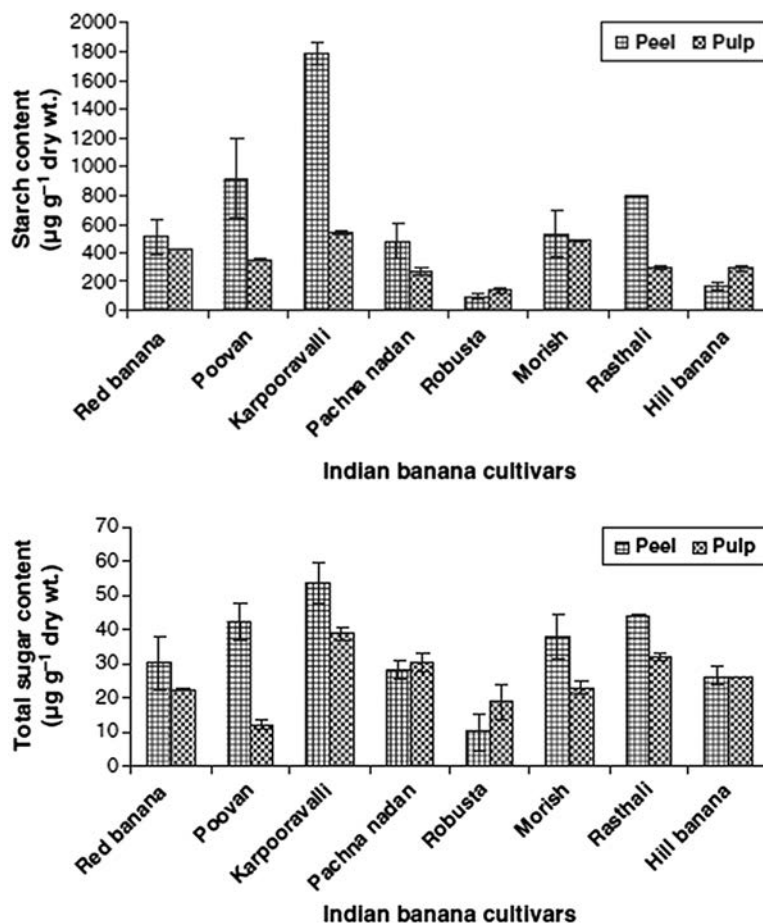


Figure 2 Carbohydrate status (starch and total sugar content) in the peels and pulp of important cultivars of Indian banana (Arora et al., 2008).

Acids

Bananas, like most other fruits, are acidic, with a pulp pH below 4.5 (Von Loesecke, 1950). Palmer (1971) showed that the main acids in bananas were ascorbic, citric, malic, and oxalic, and that the levels of these acids normally increase during ripening. Titratable acidity (TA) in the pulp was shown to increase rapidly from about 28 to 67 ml NaOH per 100 gFW from the preclimacteric minimum to the climacteric, and then to slowly decline postclimacteric to about 52 ml NaOH per 100 gFW (Wardlaw et al., 1939). These measurements were carried out on ‘Gros Michel’ at 29.4 °C and 85% RH (relative humidity) over a ripening period of 14 days.

Caulibaly et al. (2007) determined chemical composition of five banana hybrids and reported that the highest TA (3.33 meq/100 g) was observed in hybrid ‘CRBP 39’ and

Table 3 Chemical composition of banana hybrids and Orishele variety

	'CRBP 14'	'CRBP 39'	'FHIA 17'	'FHIA 21'	'Orishele'
Dry matter pulp (%)	33.16 ± 0.53	35.28 ± 0.39	23.96 ± 0.52	34.50 ± 0.69	42.63 ± 0.48
TA (meq/100 g)	2.83 ± 0.03	3.33 ± 2.88	1.66 ± 2.28	1.66 ± 2.88	1.83 ± 0.03
pH	5.89 ± 0.23	5.68 ± 0.04	6.44 ± 0.09	6.43 ± 0.01	6.28 ± 0.07
Lipids (%)	0.61 ± 0.02	0.59 ± 0.02	0.80 ± 0.01	0.48 ± 0.03	0.52 ± 0.01
Proteins (%)	2.70 ± 0.07	2.19 ± 0.05	3.17 ± 0.07	2.14 ± 0.14	2.58 ± 0.11
Total sugars (%)	3.84 ± 0.03	4.78 ± 0.44	3.32 ± 0.13	3.34 ± 0.01	4.14 ± 0.38
Reducing sugars (%)	0.59 ± 0.06	0.57 ± 0.05	0.58 ± 0.06	0.56 ± 0.04	0.58 ± 0.05
Total glucids (%)	94.54	95.25	93.04	94.84	95.47
Starch (%)	81.63	81.82	80.55	82.44	82.38
Ashes (%)	2.15	1.93	2.94	2.05	1.81
Energetic value (cal/100 g)	394.45	395.07	392.04	394.38	394.76

Source: Coulibaly et al. (2007).

the lowest (1.66 meq/100 g) in hybrid 'FHIA 17' and in the 'Orishele' variety (Table 3). The TA of three cultivars analyzed by Anyasi et al. (2015) showed that there was no significant difference in the TA of 'Luvhele' (1.61 ± 0.13) and 'Muomva-Red' (1.65 ± 0.15). Cultivar 'Mabonde' showed a markedly significant difference in its TA when compared to that of other noncommercial cultivars (Anyasi et al., 2015).

Protein and Amino Acids

John and Marchal (1995) reported that the total nitrogen in 'Cavendish' pulp was 210 mg/100 gFW and 750 mg/100 gDW, and that protein represented 60–65% of the total nitrogen. USDA (2012) gave the protein content as 1.09 g/100 gFW for *M. acuminata*. John and Marchal (1995) reported that the protein content increased from 4 to 7 g/100 gDW and from 1.3 to 1.8 g/100 gFW during ripening of 'Cavendish'. Harvest maturity and season had no particular influence on protein content. These authors also reported that in 'Dwarf Cavendish', extractable protein varied between 4 and 8 g/100 gFW, increased strongly as the pulp softened, and was stable during senescence. Toledo et al. (2012) found that the chitinase enzymes were the most abundant types of the proteins in unripe bananas, with two isoforms in the ripe fruit and isoflavone reductase also abundant at the climacteric stage. Pectate lyase, malate dehydrogenase, and starch phosphorylase accumulated during ripening. In addition to the ethylene formation enzyme amino cyclo carboxylic acid oxidase, the accumulation of S-adenosyl-L-homocysteine

hydrolase was observed to increase ethylene synthesis and DNA methylation that occurs in ripening bananas.

Dopamine is a strong, water-soluble antioxidant found in the peel (0.8–5.6 mg/g FW) and pulp (0.8–5.6 mg/g FW) of banana cv. ‘Cavendish’, and is one of the catecholamines that suppresses the oxygen uptake of linoleic acid (Kanazawa and Sakakibara, 2000). Bioactive amines such as putrescine, spermidine, and serotonin have been identified in high concentrations from banana cv. ‘Prata’.

Phenols

Banana fruits contain high levels of phenolic compounds, especially in the peel, which can contain three to five times more tannin than the pulp. Tannins are perhaps the most important phenolic from the point of view of fruit use because they can give fruit an unpleasant astringent taste. As fruits ripen, their astringency becomes lower, which seems to be associated with a change in the structure of the tannins, rather than a reduction in their levels, in that they form polymers (Von Loesecke, 1950). Mura and Tanimura (2003) also reported loss of astringency during ripening of bananas and found that it was by the polymerization of polyphenol compounds with a molecular weight of 2×10^5 . Phenolics are also responsible for the oxidative browning reaction when the pulp of fruit, especially immature fruit, is cut. The enzyme polyphenol oxidase is responsible for this reaction (Palmer, 1971). John and Marchal (1995) reported that dopamine synthesized from thyroxine represented some 80% of the tannins in the pulp at harvest. It decreased from some 60 $\mu\text{g/g}$ FW at harvest to 25 $\mu\text{g/g}$ 4 days later, forming metabolites including salsinol.

Total phenolic content (TPC) of banana peel varies greatly among cultivars. For example, cv. ‘Kulai Hom Thong’, which has 3.0 mg Gallic acid equivalent (GAE)/g FW, contains higher TPC than cv. ‘Kulai Khai’ (0.9 mg GAE/g FW) (Nguyen et al., 2003). The apparent TPC of Malaysian banana cv. ‘Pisangmas’ varies between 0.24 and 0.72 mg GAE/g FW, depending on the extraction method (Lim et al., 2007). Tsamo et al. (2015) investigated the phenolic profiles of the pulp and peel of nine plantain cultivars and compared them to those of two dessert bananas of commercial interest (‘Grand Naine’ and ‘Gros Michel’), along with hybrid ‘F568’. Hydroxycinnamic acids, particularly ferulic acid–hexoside with 4.4–85.1 $\mu\text{g/g}$ DW, dominated in the plantain pulp and showed a large diversity among cultivars. Flavonol glycosides were predominant in plantain peels, with rutin (242.2–618.7 $\mu\text{g/g}$ DW) being the most abundant. A principal component analysis on the whole data revealed that the phenolic profiles of the hybrid, the dessert bananas, and the pure plantains differed from each other. Eight Malaysian cultivars showed significant difference for antioxidant activity, TPC, and mineral contents. For the sequential extraction of dried samples, the chloroform extracts of the pulps of ‘Awak’ cultivars showed the highest TPC (23.42 ± 1.22 mg GAE/g DW) followed by the same extract of ‘Nangka’ cultivar (20.47 ± 0.49 mg GAE/g DW) (Sulaiman et al., 2011).

Table 4 Mean vitamin C (ascorbic acid), vitamin A, soluble solids, and moisture content of banana cultivars grown in Hawaii

Cultivar	Vitamin C (mg/100 g)	Vitamin A (mg RAE/100 g)	Soluble solids (°Brix)	Moisture (%)
'Dwarf Brazilian'	12.7 ± 0.7	12.4 ± 1.0	17.9 ± 0.7	68.5 ± 0.6
'Williams'	4.5 ± 0.3	8.2 ± 0.6	20.5 ± 0.4	73.8 ± 0.5
Mean	9.7 ± 0.7	10.9 ± 0.7	18.8 ± 0.6	70.4 ± 0.5

Source: Wall (2006).

Vitamin C

The vitamin C levels for 'Cavendish', based on high-performance liquid chromatography (HPLC), ranged from 2.1 to 18.7 mg/100 g (USDA, 2012; Wills et al., 1984). However, vitamin C content was shown to vary considerably among different varieties. Wall (2006) reported that the average vitamin C content for 'Dwarf Brazilian' (*Musa* AAB 'Santa Catarina Prata') was 12.7 mg/100 g and 'Williams' (*Musa* AAA Cavendish subgroup) was 4.5 mg/100 g (Table 4). These results agree with findings by Wenkam (1990), who reported vitamin C values of 5.1 mg/100 g for 'Williams' and 14.6 mg/100 g for 'Dwarf Brazilian'. Wills et al. (1984) did not detect any dehydroascorbic acid in bananas even at the 214-nm wavelength. They also reported that the variety 'Sugar' (*Musa* AAB) had higher vitamin C, starch, glucose, fructose, and dietary fiber than 'Cavendish' fruit. Ascorbic acid content of 'Dwarf Cavendish', 'Rasabale', and 'Rajabale' increased during ripening at 20 °C for 21 days and then decreased slightly up to 35 days (Desai and Deshpande, 1975).

Carotenoids and Vitamin A

Wall (2006) found that bananas were generally thought to be low in provitamin A carotenoids (pVAC), but some Fe'i bananas with yellow or orange pulp have been shown to have relatively high levels of carotenoids. In ripe bananas, the major carotenoids were lutein, α -carotene, and β -carotene. 'Dwarf Brazilian' bananas had 96.9 mg β -carotene and 104.9 mg α -carotene per 100 g, whereas 'Williams' averaged 55.7 mg β -carotene and 84.0 mg α -carotene per 100 g. Wall (2006) reported that bananas contained higher concentrations of lutein than that of the pVAC; the average lutein concentrations were 154.9 mg/100 g for 'Dwarf Brazilian' and 108.3 mg/100 g for 'Williams'. In Hawaii, 'Apple' bananas had an average of 96.9 μ g β -carotene and 104.9 μ g α -carotene per 100 g, whereas 'Williams' bananas averaged 55.7 μ g β -carotene and 84.0 μ g α -carotene per 100 g.

In bananas, most carotenoids are in the peel with generally low amounts in the pulp. Seymour (1985) found that the carotenoid content of banana peel could change during ripening depending on temperature. Those ripened at 35 °C had significantly increased carotenoids in the peel, whereas in those at 20 °C, carotenoids remained constant.

The typical yellow color of ripe bananas is developed purely because of the breakdown of chlorophyll, which masks the yellow color in unripe bananas. At high temperatures, the fruit remains greenish despite carotenoid synthesis, because chlorophyll content is only partially reduced. [Wenkam \(1990\)](#) and [Lee \(2008\)](#) also found that the level of carotenoids increased during maturation and ripening. These results confirm those of [Von Loesecke \(1950\)](#) and contradict those of [Gross and Flugel \(1982\)](#), who found a decrease in carotenoids during the initial phase of ripening of bananas.

There are differences between varieties in carotenoid content. In the early 2000s, the late Lois Englberger found that some orange-fleshed bananas, indigenous to the Pacific region, had high levels of pVAC. Moderate to high levels have since been measured in other cultivars. Studies of some orange-fleshed cultivars indigenous to the Pacific region had high levels of pVAC ([Englberger et al., 2006](#)). Measurement of the pVAC in 171 cultivars showed that levels varied from undetectable in some fruit with white-cream pulp to 3500 $\mu\text{g}/100\text{ g FW}$ for those with more orange-colored pulp ([Davey et al., 2009](#); [Pereira et al., 2011](#)). The group that had the most cultivars with yellow-orange pulp was the Fe'i bananas. At 863 nmol/gDW, 'Utin Iap' was the cultivar with the highest level of pVAC ever measured in a banana. Bananas with high pVAC levels appear to have been from *Musa acuminata* ssp. *banksii*, or an *Australimusa* (*Callimusa*) species, and all appear to have originated in the New Guinea area ([Pereira et al., 2011](#)). These included African plantains, Pacific plantains, and *Musa* AA cultivars from Papua, New Guinea. Bunch morphology also seems to be related to levels of pVAC, with bunches that are oriented in such a way that they receive more light having the highest levels ([Davey et al., 2007](#)). In a study of some Micronesian cultivars, those with the highest pVAC content consistently also had 75–100% of all-trans- β -carotene. The only other carotenoid species consistently detected in fruit pulp extracts are small amounts of lutein and a few unidentified minor compounds ([Englberger et al., 2003](#)). The pVAC content of Hawaii's 'Dwarf Brazilian' ranged from 7.7 to 17.1 mg RAE/100 g. Variability in the maturity of 'Dwarf Brazilian' bananas contributed to the wide range in pVAC values. However, this variability reflects a range that can be expected in commercially harvested fruit. [Wenkam \(1990\)](#) reported 4.1 mg RAE (49.2 mg β -carotene/100 g) for 'Dwarf Brazilian' bananas, which falls below the range of values given by [Wall \(2006\)](#). For most of the 'Dwarf Brazilian' bananas, α -carotene levels were equal to or greater than β -carotene concentrations, which illustrates the importance of separating and quantifying all of the vitamin A pigments for accurate nutritional information. β -Carotene is the most active pVAC in banana, and α -carotene is less active ([Wall, 2006](#)). In a comparison between some Indian banana varieties, [Arora et al. \(2008\)](#) reported that the cultivar 'Karpooravalli' showed the maximum carotenoid content in the peel (68 $\mu\text{g}/\text{g DW}$) while being the second highest in β -carotene content (143.12 $\mu\text{g}/100\text{ g DW}$). However, 'Red Banana' ranked highest in total carotenoid content for pulp (4 $\mu\text{g}/\text{g DW}$) and β -carotene was estimated to be the highest in the peel (241.91 $\mu\text{g}/100\text{ g}$) and in pulp (117.2 $\mu\text{g}/100\text{ g}$). The USDA National

Nutrient Database (USDA, 2012) lists 3 mg RAE/100 g for ‘Cavendish’ bananas. Wall (2006) reported the vitamin A content as 12.4 mg RAE/100 g. She also reported that ‘Williams’, harvested from four locations in Hawaii, had 8.2 mg RAE/100 g for vitamin A and ranged from 6.1 to 9.3 mg RAE/100 g. This was higher than the 4.5 mg RAE/100 g reported by Wenkam (1990) for ‘Cavendish’.

One of the local Australasian cultivars, ‘Utin Iap’, was found to contain about 8500 mg of β -carotene/100 g FW (Englberger et al., 2006), accounting for 400 times higher β -carotene than that present in commercially reputed cv. ‘Cavendish’. Data on total carotenoids, lutein, α -carotene, and β -carotene (Table 5) indicate high content of total carotenoids of nearly 21.0 mg/g FW in ‘Red Banana’, followed by ‘Nanjanagudu Rasabale’ (1.38 mg/g FW), ‘Elakkibale’ (0.91 mg/g FW), and ‘Cavendish’ (0.6 mg/g FW). When carotenoids were further separated to analyze pVAC by the HPLC method, the pulp extracts showed the presence of three distinct peaks of β -carotene, α -carotene, and lutein. Apart from β -carotene, α -carotene and lutein were also highest in ‘Red Banana’ (9.32 mg/g FW and 1 mg/g FW, respectively), which together account for the highest RAE of 114 mg/100 g FW. ‘Nanjanagudu Rasabale’ showed reasonable contents of β -carotene and lutein (0.71 mg/g FW and 0.4 mg/g FW, respectively). Interestingly, in ‘Elakkibale’, lutein was found to be the major carotenoid (0.37 mg/g FW). ‘Red Banana’ and ‘Cavendish’ showed slightly higher contents of α -carotene than β -carotene (9.32 and 0.36 mg/g FW) (Lokesh et al., 2014). Orange-fleshed banana and plantain fruits have shown to contain high levels of pVAC (Davey et al., 2011; Englberger et al., 2003). One variety of banana, namely ‘Karat’ of Micronesia, was reported to accumulate β -carotene of about 2230 mg/100 g (Englberger et al., 2006).

Seven Fe’i cultivars and three non-Fe’i cultivars were analyzed for pVAC (β - and α -carotene), total carotenoids, and riboflavin. Five Fe’i and two non-Fe’i cultivars were identified as carotenoid rich. Of 10 cultivars analyzed, the concentrations of β -carotene equivalents ranged from 45 to 7124 mg/100 g. Compared to cultivars with light-colored flesh, the yellow/orange-fleshed cultivars generally contained higher carotenoid concentrations. All Fe’i cultivars contained riboflavin, from 0.10 to 2.72 mg/100 g, some having substantial concentrations (Englberger et al., 2010). Fungo and Pillay (2011) used HPLC to determine the β -carotene content of 47 banana genotypes from the International Institute of Tropical Agriculture germplasm collection in Uganda. There was a wide variability in β -carotene levels within and among the different groups of banana studied. Banana genotypes from Papua, New Guinea, had the highest levels of β -carotene with values as high as 2594.0 μ g/100 g edible pulp (Table 5).

Minerals

Bananas have high potassium content; K is reported to be essential for keeping human blood pressure normal and also helps in proper functioning of the heart. Lee (2008) reported that an average-sized banana had 450–467 mg K. The average K content for

Table 5 Carotenoid contents ($\mu\text{g}/100\text{g}$ edible portion) of selected banana cultivars

Cultivar	<i>Trans</i> β -carotene	<i>Cis</i> β -carotene	α -Carotene	β -Carotene equivalents	Lutein	Reference
'Asupina 1'	1412	33	296	1593	74	Englberger et al. (2006)
'Asupina 2'	1403	19	185	1515	51	Englberger et al. (2006)
'Kirkirnan 2'	1092	29	1055	1649	17	Englberger et al. (2006)
'Kirkirnan 1'	315	21	384	528	7	Englberger et al. (2006)
'Pisang Raja'	650	72	508	976	74	Englberger et al. (2006)
'Horn Plantain 1'	571	85	650	981	28	Englberger et al. (2006)
'Horn Plantain 2'	567	54	580	911	73	Englberger et al. (2006)
'Kluai Khai Bonng 2'	535	32	298	716	11	Englberger et al. (2006)
'Kluai Khai Bonng 1'	288	19	175	395	10	Englberger et al. (2006)
'Wain'	486	15	61	532	146	Englberger et al. (2006)
'Pacific Plantain 2'	483	25	360	688	22	Englberger et al. (2006)
'Pacific Plantain 1'	287	30	346	490	39	Englberger et al. (2006)
'Lakatan'	272	17	129	354	25	Englberger et al. (2006)
'Red Dacca'	208	6	305	367	80	Englberger et al. (2006)
'Sucrier'	204	23	211	333	64	Englberger et al. (2006)
'Lady Finger'	95	17	132	178	76	Englberger et al. (2006)
'Williams 1'	64	8	123	134	42	Englberger et al. (2006)
'Williams 2'	50	7	93	104	33	Englberger et al. (2006)
'Red Banana'				117.20		Arora et al. (2008)
'Karpooravalli'				27.99		Arora et al. (2008)
'Rasthali'				29.61		Arora et al. (2008)
'Hill Banana'				29.46		Arora et al. (2008)
'Suria 1'	5945		2358	7124		Englberger et al. (2010)
'Suria 2'	2572		1517	3331		Englberger et al. (2010)
'Fagufagu'	3428		1524	4190		Englberger et al. (2010)
'Ropa'	1324		3682	3165		Englberger et al. (2010)
'Vudito 1'	695		79	734		Englberger et al. (2010)
'Vudito 2'	447		42	468		Englberger et al. (2010)
'Toraka Parao'	526		250	651		Englberger et al. (2010)

Continued

Table 5 Carotenoid contents ($\mu\text{g}/100\text{ g}$ edible portion) of selected banana cultivars—cont'd

Cultivar	<i>Trans</i> β -carotene	<i>Cis</i> β -carotene	α -Carotene	β -Carotene equivalents	Lutein	Reference
'Baubaunio'	332		249	457		Englberger et al. (2010)
'Huki Matawa'	296		293	443		Englberger et al. (2010)
'Warowaro'	166		<2	167		Englberger et al. (2010)
'Saena'	58		79	98		Englberger et al. (2010)
'Akeakesusu'	35		20	45		Englberger et al. (2010)
'Pisang Mas'				1138.7		Fugo and Pillay (2011)
'Williams'				620.48		Fugo and Pillay (2011)
'GCTV 215'				577.4		Fugo and Pillay (2011)
'Dwarf Cavendish'				460		Fugo and Pillay (2011)
'Grand Naine'				447.1		Fugo and Pillay (2011)
'IC2'				401.8		Fugo and Pillay (2011)
'Red Banana'			932	914	100	Lokesh et al. (2014)
'Nanjanagudu Rasabale'			20	71	40	Lokesh et al. (2014)
'Elakkibale'			6	30	37	Lokesh et al. (2014)
'Cavendish'			36	30	6	Lokesh et al. (2014)

Hawaii's bananas ('Dwarf Brazilian' and 'Williams') was 330.6 mg/100 g FW, and Mg content averaged 35.1 mg/100 g. Fe, Cu, and Mn are other minerals of nutritional importance in bananas (Wall, 2006). Hardisson et al. (2001) reported that for bananas grown in Tenerife, values of 5.09 mg/g K, 0.59 mg/g P, 0.38 mg/g Ca, and 0.38 mg/g Mg on an FW basis were observed. They further reported that the area of origin had a significant effect on macroelements. It was found that the Mg, P, and K were responsible for the differences observed between bananas grown in southern and northern Tenerife Island. It was also revealed that the concentrations of Mg, P, and K were considerably higher in the pulp of the banana from the northern part of the island than in that from the southern part, whereas the contents of Ca were higher in the banana samples collected from the south. Significant differences were also observed in the macroelements of the banana samples, with levels of Fe, Cu, Zn, and B being greater in the bananas cultivated in northern Tenerife.

Forster et al. (2002) determined the concentrations of Na, K, Ca, Mg, Fe, Cu, Zn, and Mn in banana cultivars 'Gran Enana' and 'Pequena Enana' cultivated in Tenerife and in 'Gran Enana' bananas from Ecuador. The cultivars did not affect the mineral concentrations except in the case of Fe. The mineral concentrations in the bananas from Tenerife and from Ecuador were clearly different. Bananas from Tenerife had higher mean contents of Na, K, Mg, and Fe, and the bananas from Ecuador had higher contents of Ca, Cu, Zn, and Mn. These important differences could be explained by mineral composition of the soil.

Wall (2006) reported 'Apple' bananas also had higher P, Ca, Mg, Mn, and Zn concentrations than 'Williams'. In Nigeria, Adeyemi and Oladiji (2009) gave the following for different stages of ripeness:

Unripe: 73.47% ash, 0.68% Zn, 0.146% Mn, 0.506% Co.

Ripe: 77.19% ash, 0.80% Zn, 0.271% Mn, 0.886% Co.

Overripe: 79.22% ash, 0.78% Zn, 0.118% Mn, 0.756% Co.

The peel of some Cameroon banana cultivars has a relatively high content of minerals, namely K (50.0 mg/g DW), P (22.2 mg/g DW), Mg (11 mg/g DW), and Ca (18 mg/g DW) (Emaga et al., 2007). Generally, Ca content is low in banana; however, Micronesian cv. 'Krat' contains relatively high Ca content (Englberger et al., 2003) (Table 6).

Volatiles

Amyl esters give bananas their distinctive flavor and aroma, and butyl esters give them a fruity flavor and aroma. However, other esters and aldehydes, alcohols, and ketones have been associated with flavor, and their production rates can increase during ripening (Tressl and Jennings, 1972). McCarthy et al. (1963) also claimed that amyl esters gave bananas their distinctive flavor and aroma, and that butyl esters gave them a fruity flavor and aroma.

Table 6 Minerals of different banana cultivars (mg/100 g)

Cultivar	Na	K	Ca	Mg	P	Fe	Cu	Zn	Mn	B	References
'North Tenerife'	12	534	17.9	41.2	63.4	0.36	0.13	0.18	0.07	0.21	Hardisson et al. (2001)
'South Tenerife'	11.4	483	19.9	33.6	54.7	0.28	0.12	0.16	0.07	0.18	Hardisson et al. (2001)
'Gran Enana'	0.179	501	4.08	38.9		0.309	0.079	0.157	0.063		Forster et al. (2002)
'Pequena Enana'	0.166	510	4.21	37.7		0.279	0.080	0.156	0.064		Forster et al. (2002)
'Gran Enana' (Ecuador)	0.08	372.3	6.2	32.0		0.26	0.11	0.18	0.26		Forster et al. (2002)
'Dwarf Brazilian'	16.11	342.32	7.24	39.38	26.30	0.76	0.26	0.36	0.66	0.16	Wall (2006)
'Williams'	17.33	318.94	4.91	30.77	21.73	0.83	0.25	0.23	0.21	0.14	Wall (2006)
'CRBP14'	7.4	226.8	9.5	35.8		0.4					Coulibaly et al. (2007)
'CRBP39'	0.6	223.7	7.6	39.2		0.4					Coulibaly et al. (2007)
'FHIA17'	0.8	100.2	19.4	83.8		0.7					Coulibaly et al. (2007)
'FHIA21'	0.6	222.8	6.1	23.9		0.3					Coulibaly et al. (2007)
'Orishele'	0.6	244.5	5.8	31.8		0.4					Coulibaly et al. (2007)
'Mas'	12.2	370.3	0.2	32.1	28.3	0.5		0.6	0.1		Sulaiman et al. (2011)
'Kapas'	9.5	338.7	0.1	27.9	26.4	0.4		0.4	0.2		Sulaiman et al. (2011)
'Berangan'	6.5	463.6	0.1	26.3	35.9	0.7		0.3	0.3		Sulaiman et al. (2011)
'Rasthali'	8.7	354.4	0.1	25.5	37.7	2.0		0.4	0.3		Sulaiman et al. (2011)
'Raja'	12.3	429.0	0.3	42.7	30.5	0.6		0.5	1.8		Sulaiman et al. (2011)
'Nangka'	14.5	334.9	0.1	17.1	44.8	0.4		0.3	2.4		Sulaiman et al. (2011)
'Awak'	15.3	330.3	0.2	30.9	70.9	0.2		0.4	0.2		Sulaiman et al. (2011)
'Nipah'	12.8	295.7	0.2	43.1	47.1	0.8		0.4	1.3		Sulaiman et al. (2011)

Volatile compounds of several banana cultivars have been widely studied by many authors in the world: ‘FLHORBAN 920’ and ‘Grand Naine’ (Bugaud et al., 2009); ‘Gran Enana’, a subgroup of the ‘Cavendish’ originating from Central and South America (Vermeir et al., 2009); various cultivars grown on Madeira Island (Nogueira et al., 2003); banana fruits (*Musa sapientum* L. var. ‘Cavendish’) from Honduras and their aqueous essences (Jordan et al., 2001); free and glycosidically bound volatile compounds of the ‘Valery’ and ‘Pequeña Enana’ cultivars (Pérez et al., 1997); banana fruits (*Musa cavendishii* L.) of the ‘Gran Enana’ and ‘Enana’ cultivars from the Canary Islands and the ‘Enana’ cultivar from Colombia (Cano et al., 1997); Philippine bananas (‘Del Monte’, ‘Cavendish’), and Taiwanese bananas (cv. ‘Sen-nin’) and ‘Delicious’ bananas (hybrid between ‘Philippine’ and ‘Taiwanese’) (Shiota, 1993). Generally esters such as butyl acetate, isoamyl acetate, ethyl acetate, butyl butanoate, and isoamyl isobutanoate are responsible for the characteristic aroma of fresh banana and constitute the major class of compounds present in banana’s volatile profile (Salmon et al., 1996).

Typical aroma of banana is characterized by the presence of a wide range of volatile metabolites, with different volatilities and concentrations, that can vary among the different cultivars, as the initial work of Cano et al. with Spanish and Columbian ‘Enana’ cultivars showed (Cano et al., 1997). They identified the compounds and the ratios of peak area/internal standard area corresponding to the Gas chromatography–mass spectrometry (GC–MS) of the purge and trap analysis of three banana cultivars (Spanish ‘Enana’, Spanish ‘Gran Enana’, Latin–American ‘Enana’). Quantifiable differences among the flavors of the banana cultivars were found. Spanish ‘Enana’ fruit was found to be the richest in flavor compounds. McCarthy et al. (1963) classified the various components of banana aroma. A banana-like flavor was assigned to the amyl and isoamyl esters of acetic, propionic, and butyric acid, whereas the alcohols and carbonyls gave odors described as green, woody, or musty. In their study, the Latin American banana flavor displayed the presence of ethanol, 1-butanol, and hexanal, but these compounds were not found in any of the Spanish banana varieties. Furthermore, only Spanish bananas exhibited the presence of hexyl butanoate, which is related to a banana-like flavor.

Volatiles belong to distinct chemical classes, mainly ethyl esters (Jordan et al., 2001) and, to a lesser extent, carbonyl compounds, monoterpenoids, C13-norisoprenoids, and furan compounds. According to Tressl and Albrecht (1985), although the acetates and butyrate esters are the most abundant in bananas, some 3-methylbutyrate esters, 2-methylpropionates, and caproates are also produced in minor accounts. Acetates are of particular importance due to their high concentrations and low odor thresholds.

Perez et al. (1997) studied the free volatile compounds of two banana cultivars of species *M. acuminata* (AAA), ‘Valeri’, and ‘Pequena Enana’. Flavor evaluation of bananas with a similar degree of ripeness, assessed by color and firmness measurements, showed that fruits of ‘Pequena Enana’ had slightly lower aroma intensity than ‘Valery’ bananas,

as it can be deduced from the total amount of volatiles analyzed in the headspace of each variety. Acetates account for 40% of the volatiles identified in the headspace of the two samples, ethyl acetate being the major component in ‘Valery’ bananas (20.9%), whereas methyl acetate is the most abundant volatile compound in ‘Pequena Enana’ (32.1%).

Boudhrioua et al. (2003) showed that 3-methylbutyl acetate, 3-methylbutyl butyrate, and 3-methylbutyl-3-methyl butyrate, isoamyl acetate, pentan-2-one, and isoamyl butyrate are characteristics of the geographic origin of the fruit. In addition, fatty acids, generated by the oxidative degradation of linoleic and linolenic acids, contribute to ester biosynthesis in fruit. Degradation of fatty acids results in the production of volatile aldehydes, which in turn are used by alcohol dehydrogenases, generating alcohols, aldehydes, and branched/aromatic aliphatic acids. These compounds contribute to, and in some cases determine, the primary aroma of many fruits (Perez et al., 2002). Moreover, some volatiles are particularly good indicators of the ripening stage of bananas. This is the case of hexanal and (E)-2-hexenal, characteristic of ripened bananas, and isobutyl acetate and isopentyl acetate, more abundant in ripening bananas (Mayr et al., 2003).

Free and glycoconjugated volatile composition of three bananas from cultivars of *Musa* sp. grown in the French West Indies: ‘Cavendish’, ‘Frayssinette’, and ‘Plantain’ were investigated by Aurore et al. (2011). The main volatile compounds found in ‘Cavendish’ banana were (E)-2-hexenal and acetoin, in ‘Plantain’: (E)-2-hexenal and hexanal, and in ‘Frayssinette’: 2,3-butanediol and two diastereomer solerols. The most abundant of aglycons were 3-methyl-butanol, 3-methyl-butanoic acid, solerol (two diastereoisomers), and acetovanillone. This compound, rarely identified in fruits, is detected for the first time in glycoconjugated volatile compounds of fruits. The abundance of these two isomers in the extracts of ‘Frayssinette’ seemed to be characteristic of this variety of banana (Table 7).

Pontes et al. (2012) evaluated the effect of the cultivar (‘Dwarf Cavendish’, ‘Prata’, ‘Maçã’, ‘Ouro’, and ‘Platano’) on the volatile profile of five different banana varieties determined by dynamic headspace solid-phase microextraction (dHS-SPME) combined with one-dimensional gas chromatography–mass spectrometry (1D-GC–qMS). This approach allowed the definition of a volatile metabolite profile to each banana variety and can be used as pertinent criteria of differentiation. A total of 68 volatile organic metabolites were tentatively identified and used to profile the volatile composition in different banana cultivars, thus, emphasizing the sensitivity and applicability of SPME for establishment of the volatile metabolomic pattern of plant secondary metabolites. Ethyl esters were found to comprise the largest chemical class accounting 80.9%, 86.5%, 51.2%, 90.1%, and 6.1% of total peak area for ‘Dwarf Cavendish’, ‘Prata’, ‘Ouro’, ‘Maçã’, and ‘Platano’ volatile fraction, respectively.

de Vasconcelos Facundo et al. (2012) determined the volatile differences in two cultivars of banana under cold storage conditions. Cold storage more strongly affects the 'Nanicão' than the 'Prata' cultivar. Esters such as 2-pentanol acetate, 3-methyl-1-butanol acetate, 2-methylpropyl butanoate, 3-methylbutyl butanoate, 2-methylpropyl 3-methylbutanoate, and butyl butanoate were drastically reduced in the cold group of the 'Nanicão' cultivar.

Other Phytochemicals

A phytochemical is a natural bioactive compound found in plant food that works with nutrients and dietary fiber to protect against disease. Imam and Akter (2011), in their phytochemical and pharmacological review, gave the following phytochemicals in various parts of bananas and plantains:

Catecholamines such as norepinephrine, serotonin, dopamine, tryptophan, indole compounds, pectin in the pulp

Flavonoids and related compounds (leucocyanidin, quercetin and its 3-O-galactoside, 3-O-glucoside, and 3-O-rhamnosyl glucoside) from the unripe pulp of plantain

Serotonin, norepinephrine, tryptophan, indole compounds, tannin, starch, iron, crystallizable and noncrystallizable sugars, vitamin C, B-vitamins, albuminoids, fats, mineral salts in the fruit pulp

Acyl sterol glycosides such as sitoindoside-I, sitoindoside-II, sitoindoside-III, sitoindoside-IV, and sterol glycosides such as sitosterol gentiobioside, sitosterol *myo*-inosityl- β -D-glucoside

A bicyclic diarylheptanoid, *rel*-(3*S*,4*aR*,10*bR*)-8-hydroxy-3-(4-hydroxyphenyl)-9-methoxy-4*a*,5,6,10*b*-tetrahydro-3*H*-naphtho[2,1-*b*]pyran, and 1,2-dihydro-1,2,3-trihydroxy-9-(4-methoxyphenyl)phenalene, hydroxyanigorufone, 2-(4-hydroxyphenyl)naphthalic anhydride, 1,7-bis(4-hydroxyphenyl)hepta-4(*E*),6(*E*)-dien-3-one

Several triterpenes such as cyclomusalenol, cyclomusalenone, 24-methylenecycloartanol, stigmast-7-methylenecycloartanol, stigmast-7-en-3-ol, lanosterol, and β -amyrin

An antihypertensive principle, 7, 8-dihydroxy-3-methylisochroman-4-one from the fruit peel

Cycloartane triterpenes such as 3-epicycloeucalenol, 3-epicyclomusalenol, 24-methylenepollinastanone, 28-norcyclomusalenone, 24-oxo-29-norcycloartanone have been isolated from the fruit peel

Cellulose, hemicelluloses, arginine, aspartic acid, glutamic acid, leucine, valine, phenylalanine, and threonine have been isolated from pulp and peel

Hemiterpenoid glucoside (1,1-dimethylallyl alcohol), syringin, (6*S*, 9*R*)-roseoside, benzyl alcohol glucoside, (24*R*)-4 *α* ,14 α ,24-trimethyl-Sacholesta-8,25(27)-dien-3 β -ol have been isolated from the flower.

Table 7 Volatile compounds determined in various banana cultivars

Volatiles	Cano et al. (1997) (mg/kg)			Nogueira et al. (2003) (mg/kg)			
	Spanish 'Enana'	Spanish 'Gran Enana'	Latin-American 'Enana'	'Dwarf Cavendish'	'Giant Cavendish'	'Robusta'	'Williams'
1-Butanol	0	0	0.56				
1-Hexanol	0.1	0.07	0.03				
1-Methylbutyl isobutyrate							
1-Pentanol	0.51	0.1	0.02				
2,3-Butanediol							
diacetate							
2,3-Butanediol							
2,3-Butanediol monoacetate							
2,3-Butanedione							
2-Buthoxyethanol							
2-Butyl butanoate							
2-Furyloctanoic acid							
2-Heptanol							
2-Heptanone							
2-Heptyl butanoate				0	0.4	0.5	0.7
2-Hexanone							
2-Hexenal							
2-Methyl propanol				2.8	2.7	5.1	6
2-Methyl propyl				0.6	0.7	0.8	0.8
3-methyl butanoate							
2-Methyl propylacetate				2.1	3.1	5.5	6.7
2-Methyl propylbu- tanoate				1.9	2	3.6	2.9
2-Methyl-1- propanol							
2-Methylbutyl butanoate							
2-Pentanol							
2-Pentanol acetate							
2-Pentanone							
2-Pentyl acetate							
2-Pentyl-2- methylpropanoate							
3,4,5-Trimethoxy- acetophenon							
3,4-Dimethoxyace- tophenone							

Perez et al. (1997) (ng/g)		Jordan et al. (2001) (ppm)		Aurore et al. (2011) (µg/kg equivalent of 4-nonanol)		
'Valery'	'Pequena Enana'	'Cavendish' (essence)	'Cavendish' (fresh fruit)	'Cavendish'	'Frayssinette'	Plantain
0.119 0.047	0.096 0.006	2.05	0.43	583 173	78 26	0 72
		1.63	n.d.	227	24	5
				264 36	1547 125	161 7
				161	0	0
0.75	0.21	19.05	n.d.	104	0	0
		2.59	n.d.	5676 1982	473 76	3340 0
0.014	0.013	100.53	n.d.			
0.026	0.036	319.99 159.59 474.64	14.26 4.79 2.71	1361 196	15 0	26 0
		3.82	n.d.			

Continued

Table 7 Volatile compounds determined in various banana cultivars—cont'd

Volatiles	Cano et al. (1997) (mg/kg)			Nogueira et al. (2003) (mg/kg)			
	Spanish 'Enana'	Spanish 'Gran Enana'	Latin-American 'Enana'	'Dwarf Cavendish'	'Giant Cavendish'	'Robusta'	'Williams'
3-Hepten-2-one							
3-Methyl butanal				3.2	3.4	6.3	5.6
3-Methyl butanol				5.6	5.7	7.9	6
3-Methyl butyl acetate				6	7.8	11.5	13.9
3-Methyl butyl butanoate				15.8	19.9	20.5	16.6
3-Methyl butyl pentanoate				0.3	0.5	0.3	0.3
3-Methyl-1- butanol							
3-Methylbutanal							
3-Methylbutanoic acid							
3-Methylbutyl acetate							
3-Methylbutyl butanoate							
4-Hepten-2-ol							
4-Hexenyl acetate							
9-Oxononanoic acid							
Acetal				0.3	0.8	0.1	0.3
acetaldehyde							
Acetic acid	0.06	0.04	0.02	0.9	0.6	0.9	0.2
Acetoin							
Benzaldehyde	0.03	0.01	0.01				
Benzene							
Benzoic acid							
Borneol							
Butan-1-ol				3.2	3.1	3.2	5.1
Butan-2-one							
Butane-2-dione	0.59	0.16	0.01				
Butanoic acid							
Butanol							
Butyl acetate				1.5	2.7	2.8	4.1
Butyl butanoate				8.4	10.7	17.3	16.2
Butyl butyrate							
Butyl heptanoate				0.1	0.2	0.2	0.3
Butyl pentanoate				0.5	1.1	1.4	1.2
Damascenone				0.2	0.3	0.2	0.2

Perez et al. (1997) (ng/g)		Jordan et al. (2001) (ppm)		Aurore et al. (2011) (µg/kg equivalent of 4-nonanol)		
'Valery'	'Pequena Enana'	'Cavendish' (essence)	'Cavendish' (fresh fruit)	'Cavendish'	'Frayssinette'	Plantain
2.082	0.193	66.43	20.33	2451	286	124
		877.55	7.9			
Tr	0.075	32.89	n.d.			
0.416	0.764					
Tr	0.008					
		1.94	n.d.	137	0	0
19.48	Nd					
0.428	0.376			3387	857	35
0.166	0.134					
		9	n.d.			
0.988	0.182					
0.230	0.167					
0.357	0.139			129	11	4
-	-	304.34	1.06			
1.425	0.150	106.54	1.32	90	15	0
				30	6	0
		12.6	0.83			

Continued

Table 7 Volatile compounds determined in various banana cultivars—cont'd

Volatiles	Cano et al. (1997) (mg/kg)			Nogueira et al. (2003) (mg/kg)			
	Spanish 'Enana'	Spanish 'Gran Enana'	Latin-American 'Enana'	'Dwarf Cavendish'	'Giant Cavendish'	'Robusta'	'Williams'
Decanal	0.14	0.01	0				
Decanoic acid				0.3	<0.05	<0.05	0.1
Dodecanoic acid				0.3	0.1	0.2	0.1
(<i>E</i>)-2-Hexen-1-ol							
(<i>E</i>)-2-Hexenal							
(<i>E</i>)-4-Hepten-2-ol							
(<i>E</i>)-4-Hexen-1-ol							
Elemicin				0.5	0.4	0.8	0.5
Ethanol	0	0	0.16	5.5	6.9	23.7	23.9
Ethyl 2-hydroxy- 3-methylbutyrate							
Ethyl 3- hydroxybutanoate							
Ethyl 3- hydroxyhexanoate							
Ethyl acetate	1.13	0.16	0.45	0.7	0.8	1.5	2.2
Ethyl butyrate							
Ethyl crotonate							
Eugenol				<0.05	0.1	0.1	0.2
Fenchol							
Heptan-2-ol				0.4	0	0	0
Heptan-2-one				0.6	1.1	1	1.1
Heptan-2-yl acetate				1.4	3.2	3.2	3.2
Heptanal	0.77	0.57	0.07				
Hex-2-en-1-ol				0.5	0.6	1	0.5
Hex-2-enal				5.9	8.7	8	8
Hexadecanoic acid				0.6	0.2	0.7	1
Hexan-1-ol				0.1	0.2	0.2	0.1
Hexanal	0	0	0.26	1.8	3.5	3.5	4.1
Hexanol							
Hexyl acetate	0.47	0.38	0	0.8	1.3	1.6	1.8
Hexyl butanoate	0.08	0.02	0	0.7	0.8	0.4	0.5
Hexyl butyrate							
Hexyl isovalerate							
Isoamyl 3- methylbutyrate							
Isoamyl acetate	0.31	0.16	0.08				
Isoamyl butyrate							
Isoamyl isobutyrate							
Isobutyl acetate							
Isobutyl butanoate							
Isobutyl butyrate							

Perez et al. (1997) (ng/g)		Jordan et al. (2001) (ppm)		Aurore et al. (2011) (µg/kg equivalent of 4-nonanol)		
'Valery'	'Pequena Enana'	'Cavendish' (essence)	'Cavendish' (fresh fruit)	'Cavendish'	'Frayssinette'	Plantain
3.435	0.475	4.24	n.d.			
		n.d.	32.2			
		34.41	n.d.			
		3.15	n.d.	417	446	303
		3.63	n.d.	1	98	0
				0	118	0
		2.65	n.d.			
		11.71	0.15			
		0.23	n.d.			
0.013		n.d.	2.65	191	0	0
		10.39	n.d.	87	0	0
		31.19	21.47	2382	878	1856
		38.29	1.17			
		2.41	0.57			
		n.d.	0.06			
		n.d.	0.06			
		1.14	1.48			
		229.73	4.85	1027	59	7
		n.d.	7.13			
		1.27	0.31	211	67	0
		266.51	2.45	344	11	4
				74	4	0
		14.92	1.26			

Continued

Table 7 Volatile compounds determined in various banana cultivars—cont'd

Volatiles	Cano et al. (1997) (mg/kg)			Nogueira et al. (2003) (mg/kg)			
	Spanish 'Enana'	Spanish 'Gran Enana'	Latin-American 'Enana'	'Dwarf Cavendish'	'Giant Cavendish'	'Robusta'	'Williams'
Isobutyl isobutyrate							
Limonene							
Methyl acetate							
Methyl butyrate							
Methyl decanoate							
Methyl eugenol				0.1	0.1	0.1	0.1
<i>n</i> -Propyl acetate							
Octanal	0.08	0.01	0				
Octyl acetate				2.4	3.2	3.1	1.6
Pentan-2-ol				3.1	4.3	5.7	6.1
Pentan-2-one	1.18	0.07	0.46	4.8	4.8	5.3	6
Pentan-2-yl acetate				3.6	4.3	3	4.3
Pentan-2-yl butanoate				4.8	5.5	4.7	3.2
Pentanoic acid							
Pentanol							
Pentyl acetate							
Pentylacetic acid							
Propan-1-ol				0.2	0.2	0.4	0.4
Propanoic acid							
Propionic acid				0.4	0.5	0.8	0.7
<i>R</i> -terpineol							
Terpinen-4-ol							
Tetradecanoic acid				0.1	<0.05	0.2	0.2
Veratryl alcohol							
Toluene							
(<i>Z</i>)-3-Hexenyl acetate							
(<i>Z</i>)-3-Octen-1-ol							
(<i>Z</i>)-5-Octen-1-ol							

Perez et al. (1997) (ng/g)		Jordan et al. (2001) (ppm)		Aurore et al. (2011) (µg/kg equivalent of 4-nonanol)		
'Valery'	'Pequena Enana'	'Cavendish' (essence)	'Cavendish' (fresh fruit)	'Cavendish'	'Frayssinette'	Plantain
1.270	2.615	0.68 n.d.	n.d. 0.94			
0.476		1.48	0.46			
		10.13	0.07			
1.321 2.201	0.753 1.270			1725	3	9
0.226	0.193					
tr	0.032	3.65	n.d.			
0.190	0.118					
		1.07 1.47	n.d. n.d.			
0.256	0.096			6	355	32
		0.32	n.d.			
		9.23 6.93	n.d. n.d.			

SUMMARY POINTS

- Banana and plantains are the most important tropical fruit in terms of production and consumption. These are consumed raw as well as cooked and as staple food in many African countries.
- Bananas are rich in potassium and low in sodium. They are beneficial for blood pressure and cardiac disease. Many of the cultivars contain very high amount of potassium as well as other minerals such as Fe, Cu, B, Zn, and Ca.
- Bananas are a good source of provitamin A or β -carotene. Some of the hybrids of FHIA origin have very high carotene content. These may be useful for combating vitamin A deficiency in children. Carotene-rich banana flour may be fortified with many processed products for consumption.
- There are more than 200–300 cultivars in the world. Genomic contribution also affects the nutritional and biochemical composition of fruit cultivars.
- Amyl esters give bananas their distinctive flavor and aroma, and butyl esters give them a fruity flavor and aroma; however, other esters and aldehydes, alcohols, and ketones have also been associated with flavor. Different cultivars showed different volatile compounds in dominance and therefore, contain distinctive peculiar flavor.

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CHAPTER 4

Bilberry (*Vaccinium myrtillus* L.) Ecotypes

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LIST OF ABBREVIATIONS

DW Dry weight
FW Fresh weight

INTRODUCTION

Bilberry, also known as the European blueberry (*Vaccinium myrtillus* L.), is among the most economically significant wild berries in Europe. The bilberry is recognized for its bioactive properties and as one of the best sources of anthocyanins, the reddish to bluish phenolic compounds (Prior et al., 1998). Bilberries have anthocyanins both in the skin and in the flesh, which explains the high anthocyanin yields compared with many other berries (Riihinen et al., 2008). The aroma of a bilberry is also regarded as special and delicious. No allergenic compounds have been reported, and therefore it can be considered as an excellent source of functional food (Figure 1).

Wild berries are a valuable part of the European nature and tradition. Especially in the northern and eastern parts of Europe, wild berries grow abundantly, and picking of wild berries is an important form of recreation for many people. In these areas, about half of the wild berries used are picked for personal consumption and the other half for commercial use. The average bilberry yield in Nordic countries has been



Figure 1 Bilberry (*Vaccinium myrtillus*) is one of the most important wild berries in Europe. Photograph Ilkka Jaakola.

estimated to be more than 500 million kg per year, of which only 5–8% is currently exploited (Paasilta et al., 2009). Most bilberries picked commercially in North Europe are exported frozen and unprocessed to East Asia or to the Central European food industry. China and Japan have been the major buyers, increasingly focusing on health products. The wild berry industry in Europe is typically fairly small and fragmented. It has certain challenges, such as the variation in the annual wild berry crop yields in different areas, and the inaccurate crop estimations using currently available methods. The distinctions in the forest policies, access rights, and the berry picking traditions also differ to some extent inside Europe. To secure the availability of bilberries for commercial exploitation, methods for field cultivation and semicultivation of natural stands have been considered. Semicultivation of wild stands of *Vaccinium* spp. has been a great success in North America for decades. The North American lowbush blueberry, *Vaccinium angustifolium* Aiton, is semicultivated using modern agricultural practices such as fertilization, pruning, and mechanical harvesting. Attempts to cultivate and semicultivate the bilberry have been initiated in Denmark, Norway, and Finland (Nestby et al., 2011).



Figure 2 Distribution map of bilberry, *Vaccinium myrtillus* and *Vaccinium myrtillus* ssp. *Oreophilum*. The distribution map is created according to the information from: <http://linnaeus.nrm.se/flora/di/erica/vacci/vaccmyrv.jpg>.

BOTANICAL ASPECTS

The genus *Vaccinium* contains more than 200 morphologically diverse species including many commercially important berry producing plants, such as blueberries and cranberries. Members of the genus occur in cold to temperate and tropical climates around the world, but are absent from Australia, New Zealand, Antarctica, and most of Africa (Vander Kloet and Dickinson, 1999). However, nowadays Australia and New Zealand are important producers of cultivated blueberries originating from North America.

Bilberry (*V. myrtillus* L.) is a deciduous shrub characteristic of moist boreal forests dominated by Norway spruce (*Picea abies* (L.)H.Karst.). It also grows in dryish upland forests, heaths, and mountains in Europe, and abundantly from the west coast of Northern Europe to Caucasus toward the northern Asia Pacific coast (Figure 2). A few disjunct populations have been reported in western North America and central Japan (Vander Kloet and Dickinson, 1999). Two subspecies have been delineated on the basis of morphological differences: *V. myrtillus* ssp. *myrtillus* and *V. myrtillus* ssp. *oreophilum* (Rydb.) Dorn, but without scientific consensus so far on whether the differences are significant enough to warrant formal recognition as subspecies. Bilberries are usually diploid, but *V. myrtillus* with higher ploidy levels have been found in North America (Flora of North America).

Bilberry is a non-climacteric fruit. As with other *Vaccinium* species, the fruit is an epigynous berry, that is, the fruit develops from an inferior ovary (Ballington, 2001),

sometimes also referred to as a false berry or accessory fruit. The bilberry flowers in early spring, when the leaves are unfolding from winter buds, making it sensitive to the weather fluctuations. Indeed, the spring weather plays a major role in determining annual crop yields. A cold period at flowering time can restrict the activity of pollinators, of which bumblebees, other bees, small flies, and butterflies are the most important. Frost can also damage the flowers and delay or prevent berry development. Bilberry flowers are solitary or borne in pairs in axils, unlike many other *Vaccinium* species that bear flowers (and later berries) in clusters. Fruit development usually takes 8–10 weeks from flowering, varying between years (Sjörs, 1989). The ripening phase lasts 2–3 weeks, during which accumulation of anthocyanin pigments is rapid. Tissue softening and the accumulation of flavor compounds and aromatic volatiles occur at the same time as other characteristics associated with ripening.

COMPOSITION OF ANCIENT ECOTYPES

Vaccinium species have been used as food and for medicinal purposes since the prehistoric era. In Europe, bilberry pollen was found in the digestive tract of the Tyrolean Iceman discovered in the Alps in 1991 (Dickson et al., 2000). Archaeological remains of bilberry have been found in different sites, for instance in a Neolithic site in Embo, Sutherland (Dickson and Dickson, 2000). Roman writer and naturalist Pliny the Elder (AD 23–79) is one of the first to specify bilberry in a surviving written source. Dioscorides (40–90), a Roman physician, pharmacologist, and botanist of Greek origin, recommended bilberries for treating dysentery. Bilberries were used for dyeing clothes and textiles from ancient times in many cultures, for example, among Celts and in Scandinavia.

In the Middle Ages (ca. 500–ca. 1500) bilberries were considered to have astringent, tonic, and cleansing properties; berries were used traditionally in many European countries to treat diarrhea, dysentery, hemorrhoids, gastrointestinal inflammation, scurvy, and urinary complaints (Morazzoni and Bombardelli, 1996). However, the dark color of the berries also raised doubts about their healthiness among medieval people. The German abbess and herbalist Hildegard of Bingen (1098–1179) wrote botanical and medicinal texts in which she mentioned “CLXXI. Bilberry: The plant on which bilberries (walt bere) (which are black and sometimes called whortleberries) grow has very great cold. It is the cold which cedes a bit to heat, when the cold humor of the earth and stones does more harm than good. It is not useful as medicine, and the fruit harms the person who eats it, stirring up gicht in him.” (Throop, 1998). In the early modern era, German herbalist Hieronymus Bock (1498–1554) recommended bilberries to treat bladder stones and lung and liver disorders (Trehane, 2004). Nicholas Culpeper (1616–1654), an English botanist, herbalist, and physician, wrote in his *Complete Herbal* (1653) in detail about the appearance and growth habit of bilberries and lingonberries (*Vaccinium vitis-idaea* L.). He also observed that “It is a pity they are not used more in medicine than they

are. The black bilberries are good in hot agues, and to cool the heat of the liver and stomach; they do somewhat bind the belly, and stop vomiting; the juice of the berries made into a syrup, or the pulp made into a conserve with sugar, is good for the purposes aforesaid; as also for an old cough, or an ulcer in the lungs, or other diseases therein. The red worths are more binding, and stop women's menses, spitting of blood, or any other flux of blood and humours, being used as well outwardly as inwardly." (Culpeper, 2009).

In Nordic countries, the significance of wild berries as food and in medicine as well as in folklore has traditionally been more central than in southern parts of Europe. Since premodern times, bilberries were among the most important medicinal plants. The Swedish botanist Carl von Linné (1707–1778) mentioned that bilberries taste best fresh and that dried berries are suitable as filling and purée (von Linné, 1749). A Finnish physician and philologist Elias Lönnrot (1802–1884) mentioned bilberries in his *Flora Fennica* (1860) to be helpful in stomach diseases and to offer cooling in fever (Linnilä et al., 2002).

COMPOSITION OF MODERN ECOTYPES

In recent years, numerous studies have been conducted on the health benefits of bilberries and other *Vaccinium* species. Health benefits of berries have become widely accepted after the reports of the highest antioxidant activity linked with the high content of phenolic compounds, especially in *Vaccinium* berries, compared with other fruits and vegetables (Prior et al., 1998). These compounds have been reported to possess various health-beneficial activities including antioxidant, antimutagenic, anticarcinogenic, anti-inflammatory, antiproliferative, and antimicrobial effects (Landete, 2012), and will be covered in detail in the next chapter.

Nutritional information on bilberry origins is compiled in Tables 1–5 from various research results and public databases. It is important to note, however, that the numbers represent mean values of the studies, and in many cases the compounds have been analyzed with different methods in different laboratories in different years, which makes a reliable comparison difficult. Studies with bilberries and other species have shown variation in the nutrition and metabolite levels within the same berry clone/variety due to environmental factors (Uleberg et al., 2012). Therefore, large and consistent long-term studies on this topic would be needed before obtaining a full picture of the level of variation between different ecotypes.

Berries in general contain low levels of energy in proportion to the nutrient levels, and the same is true with bilberries (Table 1). Also the composition of fatty acids is good, although studies on the composition of fatty acid in bilberries are still scarce (Table 2). Bunea et al. (2012) analyzed fatty acids in bilberries in comparison to cultivated blueberries (*Vaccinium corymbosum*) growing in Romania. The composition was quite similar among the species, although higher levels of polysaturated and monosturated fatty acids,

Table 1 Composition of general nutritional factors in bilberries of different origins. Carbohydrates, proteins, fatty acids, and fibers

Nutritional factor	Unit/100 g	Iceland	Norway	Sweden	Finland	Denmark	Belgium	Germany	Italy	Estonia	Czech Republic
Energy	kJ (kcal)	253 (60)	215 (51)	221 (53)	184 (44)	201	117 (28)	153 (36)	103 (25)	166 (39,7)	213 (51)
Water	g	84.9	83	86		87.1	84	84.6	85	86	86.1
Carbohydrates	g	14.3	7.5	9.1	6.4	8.7	6	6.05	5.1	6.4	12.3
Glucose	g				3			2.5		3	2.6
Fructose	g				2.9			3.3		2.9	3.6
Sucrose	g			0.5	0.5			0.2		0.5	0.2
Proteins	g	0.6	1	0.7	0.5	0.6	1	0.6	0.9	0.5	
Tryptophan	mg				10	11					
Fat	g	0		0.8	0.6	0.5	0	0.6	0.2	0.6	0.6
Total fibers	g	1.8	4.6	4.6	3.3		7.3	4.9	3.1	3.3	3.4
Polysaccharides, water soluble	g				0.5			1.4			
Fiber, water insoluble	g			3.1	2.6	2.8		3.5			

Data are collected from national websites of food nutrition (Iceland, www.matis.is/ISGEM/en; Norway, www.matvaretabellen.no; Sweden, <http://www.slv.se/en-gb/Group1/Food-and-Nutrition/The-Food-Database/>; Finland, www.fineli.fi; Denmark, http://www.foodcomp.dk/v7/fcdb_default.asp; Belgium, www.internubel.be; Germany, www.sfk-online.net; Italy, http://nut.entecra.it/646/tabelle_di_composizione_degli_alimenti.html; Estonia, <http://tka.nutridata.ee>; Czech Republic, <http://www.ncbi.nlm.nih.gov/pubmed/21045853>).

Table 2 Composition of fatty acids in different bilberry ecotypes

Fat	Unit/100g	Iceland	Norway	Sweden	Finland	Denmark	Belgium	Estonia	Czech Republic	Romania
Fatty acids, total	g				0.3		0	0.4		
SFA	g	0	0	0	<0.1	0	0	0	0.02	0.05
MUFA	g	0	0.1	0.1	<0.1	0	0	0.1		0.1
n-9									0.07	
n-9 (18:1)				0.1					0.07	
PUFA	g	0	0.5	0.5	0.2	0	0	0.3		0.5
n-3 18:3 (α -linolenic acid)	g				0.1		0	0.1	0.22	0.2
n-6 18:2 (linoleic acid)	g			0.2	0.12		0	0.2	0.17	0.2
Sterols	mg				26.4		0			

SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polysaturated fatty acids.

Data are collected from national websites of food nutrition (Iceland, www.matis.is/ISGEM/en; Norway, www.matvaretabellen.no; Sweden, <http://www.slv.se/en-gb/Group1/Food-and-Nutrition/The-Food-Database/>; Finland, www.fineli.fi; Denmark, http://www.foodcomp.dk/v7/fcdb_default.asp; Belgium, www.internubel.be; Estonia, <http://tka.nutridata.ee>; Czech Republic, <http://www.ncbi.nlm.nih.gov/pubmed/21045853>; Romania, Bunea et al., 2012).

Table 3 Composition of mineral elements in bilberries growing in different areas

Minerals	Unit/100 g	Iceland	Norway	Sweden	Finland	Denmark	Belgium	Germany	Italy	Estonia	Czech Republic
Calcium	mg	15	29	23	19	15	15	10	41	19	13
Copper	mg		0.11	0.11		0.11	0.1	0.8		0.11	
Iron	mg	0.7	0.4	0.6	0.6	0.8	1	0.7	0.7	0.6	0.7
Potassium	mg	102	122	86	110	103	80	78	160	110	66
Magnesium	mg		11	9	9	7		2.4		9	3
Manganese	mg					3.3		4.2		4.2	
Sodium	mg	3	0	3	0.3	3	1	1	2	0.3	4
Phosphorus	mg		29	20	20	9	15	13	31	20	14
Chloride	mg							5			
Zinc	mg		0.3	0.2	0.2	0.1		0.1		0.2	
Nickel	µg						0.1	7		7	
Selenium	µg		0	0	0.1	0	1			0	
Chromium	µg					1		0.3		0.3	
Cobalt	µg							0.1			
Vanadium	µg							0.2			
Fluoride	µg							2			
Boron	µg							50			
Iodide	µg		1	1	1	1.2				1	

Data are collected from national websites of food nutrition (Iceland, www.matis.is/ISGEM/en; Norway, www.matvaretabellen.no; Sweden, <http://www.slv.se/en-gb/Group1/Food-and-Nutrition/The-Food-Database/>; Finland, www.fineli.fi; Denmark, http://www.foodcomp.dk/v7/fcdb_default.asp; Belgium, www.internubel.be; Germany, www.sfk-online.net; Italy, http://nut.entecra.it/646/tabelle_di_composizione_degli_alimenti.html; Estonia, <http://tka.nutridata.ee>; Czech Republic, <http://www.ncbi.nlm.nih.gov/pubmed/21045853>).

Table 4 Levels of vitamins in bilberry ecotypes growing in different areas

Vitamins	Unit/100 g	Iceland	Norway	Sweden	Finland	Denmark	Belgium	Germany	Italy	Estonia	Czech Republic
Niacin	mg		0.7	0.3	0.6	0.4	0.4		0.5	0.3	
Nicotinic acid + nicotinamide	mg				0.4			0.4			
Pyridoxine (vitamin B6)	mg		0.07	0.06	0.06	0.06	0.04	0.06		0.07	
Riboflavine (vitamin B2)	mg	0.03	0.01	0.07	0.07		0.02		0.05	0.07	0.02
Thiamin (vitamin B1)	mg	0.03	0.03	0.04	0.04	0.03	0.01	0.02	0.02	0.04	0.01
Ascorbic acid (vitamin C)	mg	0	12	8	15	44	10	22	15	15	15.7
Pantotenic acid	mg					0.16		0.16		0.16	
Tochopherols (vitamin E)	mg	1.85	2	0.1	1.9		1.9	2.1		1.9	0.57
Folate	µg	6	31	10	11.5	6	11	11		12	
Retinol (vitamin A)	µg	2	0	0	3.9	0	2	5.7	13	0	0
B-carotene	µg		47	96	310	13	13	34		47	34
Vitamin K	µg			15	9			12		12	
Biotin (vitamin B7)	µg							1.1		1.1	

Data are collected from national websites of food nutrition (Iceland, www.matis.is/ISGEM/en; Norway, www.matvaretabellen.no; Sweden, <http://www.slv.se/en-gb/Group1/Food-and-Nutrition/The-Food-Database/>; Finland, www.fineli.fi; Denmark, http://www.foodcomp.dk/v7/fcdb_default.asp; Belgium, www.internubel.be; Germany, www.sfk-online.net; Italy, http://nut.entecra.it/646/tabelle_di_composizione_degli_alimenti.html; Estonia, <http://tka.nutridata.ee>; Czech Republic, <http://www.ncbi.nlm.nih.gov/pubmed/21045853>).

Table 5 Anthocyanidins and total anthocyanin contents (mg/100 g) in bilberries of different origins

Country	Year	No. of populations	FW or DW	Dp	Cy	Pt	Pn	Mv	Total anthocyanins (FW or DW)	Total phenolics	References
Finland (–)	2000	1	FW	126	125	52	18	39	360	–	Nyman and Kumpulainen (2001) ^e
Finland (north)	2005	6	DW	1150	920	440	179	377	3053	–	Lätti et al. (2008)
Finland (central)	2005	7	DW	989	1014	417	227	419	3090	–	Lätti et al. (2008)
Finland (south)	2002	1	FW	276	293	86	18	128	1201	–	Määttä-Riihinen et al. (2004) ^d
Finland (south)	2003	1	FW	218	181	79	36	97	611	–	Koponen et al. (2007) ^c
Finland (south)	2005	1	FW	179	174	63	32	69	516	–	Koponen et al. (2007) ^c
Finland (south)	2005	7	DW	822	902	345	201	333,5	2549	–	Lätti et al. (2008)
Sweden (north)	2007	1	DW	1564	1177	600	187	443	3971	–	Åkerstrom et al. (2010)
Sweden (north)	2008	1	DW	1157	763	344	76	201	2541	–	Åkerstrom et al. (2010)
Sweden (south)	2007	2	DW	940	696	368	94	232	2329	–	Åkerstrom et al. (2010)
Sweden (south)	2008	2	DW	751	559	301	780	186	2059	–	Åkerstrom et al. (2010)
Norway (south)	2004	3	FW	–	–	–	–	–	548	576	Skrede et al. (2014)
Denmark	2007	1	DW	680	837	279	129	170	2095	–	Åkerstrom et al. (2010)
Denmark	2008	1	DW	633	608	256	92	151	174	–	Åkerstrom et al. (2010)
Poland	–	11	FW	–	–	–	–	–	990	845	Roslon et al. (2011) ^f
Poland	–	1	DW	649	876	233	87	337	2180	2660	Kusznierewicz et al. (2012)
Romania	2010	1	FW	–	–	–	–	–	216	–	Oancea et al. (2013)

Romania	2011	1	FW	—	—	—	—	—	329	355	Oancea et al. (2013)
Slovakia	2011	5	DW	—	—	—	—	—	218	2713	Habanova et al. (2013)^b
Austria	2004	3	DW	841	534	349	329 (Pn + Mv)		2051	—	Rieger et al. (2008)^g
Austria	2005	3	DW	746	444	320	267 (Pn + Mv)		1777	—	Rieger et al. (2008)^g
Italy (Appenines)	2006	2	FW	435 ^a	137 ^a	17 ^a	124 ^a	230 ^a	338	596	Giovanelli and Buratti (2009)
Slovenia	2007	7	FW	486	364	176	75	183	1210	1246	Moze et al. (2011)
Montenegro	2009	11	FW	55	38	15	12	33	176	456	Jovancevic et al. (2011)
Serbia	—	1	FW	—	—	—	—	—	448	808	Stajčić et al. (2012)^h
Turkey	2008	10	DW	879	905	379	183	306	2651	—	Primetta et al. (2013)

Data are reported as mean values.

^aData are reported in $\mu\text{mol}/100\text{gFW}$.

^bHabanova, M., Haban, M., Kobidova, R., Schwarzova, M., Gazo, J., 2013. Analysis of biologically active substances in bilberry (*Vaccinium myrtillus* L.) in selected natural localities of Slovak Republic. Journal of Central European Agriculture. 14, 1210–1219.

^cKoponen, J.M., Happonen, A.M., Mattila, P., Törrönen, R., 2007. Contents of anthocyanins and ellagitannins in selected foods consumed in Finland. Journal of Agricultural and Food Chemistry 55, 1612–1619.

^dMäättä-Riihinen, K.R., Kamal-Eldin, A., Mattila, P.H., González-Paramás, A.M., Törrönen, A.R., 2004. Distribution and contents of phenolic compounds in eighteen Scandinavian berry species. Journal of Agricultural and Food Chemistry 52, 4477–4486.

^eNyman, N.A., Kumpulainen J.T., 2001. Determination of anthocyanidins in berries and red wine by high-performance liquid chromatography. Journal of Agricultural and Food Chemistry 49, 4183–4187.

^fRoslon, W., Osinska, E., Piore-Jabrucka, E., Grabowska, A., 2011. Morphological and chemical variability of wild populations of bilberry (*Vaccinium myrtillus* L.). Polish Journal of Environmental Studies 20, 237–243.

^gRieger, G., Müller, M., Guttenberger, H., Bucar, F. (2008) Influence of altitudinal variation on the content of phenolic compounds in wild populations of *Calluna vulgaris*, *Sambucus nigra*, and *Vaccinium myrtillus*. Journal of Agricultural and Food Chemistry 56, 9080–9086.

^hStajčić, S.M., Tepić, A.N., Djilas, S.M., Šumić, Z.M., et al., 2012. Chemical composition and antioxidant activity of berry fruits. APTEFF 43, 1–342.

in addition to oleic (18:1), linoleic (18:2), and linolenic acids, were detected in bilberries, whereas levels of arachdic (20:0) and *cis*-11-eicosanoic acids were higher in blueberries. Yang et al. (2011) reported that the major content of fatty acids in bilberries is present in seeds. Bilberry seed oil contains a significantly high proportion of unsaturated fatty acids such as 18:1 n-9 (21.8%), 18:1 n-7 (0.6%), 18:2 n-6 (35.9%), and 18:3 n-3 (36.1%). For this reason, bilberry seed oil is optimal as a food ingredient or food supplement, in addition to use in cosmetics. Moreover, the seed oil contains α -tocotrienols (10 mg/100 g oil) and γ -tocotrienols (30 mg/100 g oil; Yang et al., 2011). Bilberries also contain sterols. The sterol content of Romanian bilberries was 142.90 ± 7.32 mg/100 g of lipids (FW), in which the major component was β -sitosterol ($73.10\% \pm 3.15\%$) (Dulf et al., 2012). The same compounds were found in Polish (4.72 mg/100 g DW) and Finnish (4.41 mg/100 g DW) bilberry fruits, with significant differences in sterol profiles among the bilberries originating from different countries (Szakiel et al., 2012).

In general, the nutritional profile of minerals is fairly constant among different bilberry origins. However, some variation in the levels of calcium, potassium, magnesium, sodium, and phosphorus has been detected in bilberries of different origins (Table 3). The bilberries of Italian origin show the highest levels of calcium, potassium, and phosphorus, whereas the lowest levels of the same compounds are detected in bilberries growing in the area of the Czech Republic, except phosphorus in the area of Denmark. Barizza et al. (2013) compared the nutritional profiles of bilberries in open and forest habitats in the area of the eastern Italian Alps. The nutritional profile did not differ between open and forest habitats, but, compared to cultivated blueberries, higher levels of calcium, phosphorous, and magnesium were detected in bilberries. However, compared with other berries, bilberries can be considered as a moderate source of macro- and micro-nutrients.

Bilberries contain high yields of carotenoids, especially lutein, which has been shown to provide protection in eye health (Grover and Samson, 2013). Bunea et al. (2012) analyzed carotenoid composition of bilberries in comparison to cultivated blueberries. They identified lutein, β -cryptoxanthin, and β -carotene in both species. The contents of all individual as well as total carotenoids were higher in bilberries compared to different blueberry cultivars, with total carotenoid levels of 307–317 μ g/100 g FW fruit in bilberries. A study on carotenoid levels in different berry species in the Komi republic, Russia, also indicated high levels of lutein in bilberries compared to other studied berries (Lashmanova et al., 2012). Recently, Zoratti et al. analyzed 3000 μ g/100 g DW levels of total carotenoids in Finnish bilberries (unpublished data). Carotenoid levels analyzed in different studies in different bilberry origins are shown in Table 3.

Vaccinium berries are also a good to moderate source of vitamins (Table 3). Compared with other berries, bilberries can be considered as a moderate source of vitamin C, with levels of 8–44 mg/100 g analyzed in different origins. Vitamin C degrades easily during the storage of samples and the sample analysis. This can also cause potential differences

between origins when samples are analyzed in different laboratories. The levels of vitamin C have been shown to be relative stable during the fruit development and ripening of bilberries (Cocetta et al., 2012).

Bilberry extracts have recently been shown to have potential against ulcerative colitis (Biedermann et al., 2013) and Alzheimer disease (Vepsäläinen et al., 2013). Regular consumption of bilberries may also reduce the low-grade inflammation associated with the cardiometabolic risk (Kolehmainen et al., 2012) and the metabolic syndrome associated with obesity and type II diabetes (Lehtonen et al., 2011; Suzuki et al., 2011). Many of these effects have been assumed to be related to high levels of phenolic compounds, especially anthocyanins, in bilberries; but these berries contain other compounds as well that can have a role in prevention of disease. One of these compounds is plant hormone abscisic acid (ABA), which has been shown in mice to have therapeutic efficacy in regard to type II diabetes by enhancing the insulin-secreting ability of pancreatic β -cells (Bassaganya-Riera et al., 2010). Bilberries have recently been found to contain high levels of ABA, especially at the onset of ripening but also in ripe berries (Karppinen et al., 2013).

COMPOSITION OF PHENOLIC COMPOUNDS IN BILBERRIES

The focus in bilberry research has been on anthocyanins as bilberry fruits are fully packed with these compounds in both the skin and flesh representing one of the best sources of the anthocyanins. In bilberries, anthocyanins comprise about 90% of the total phenolic compounds of the fruit (Kähkönen et al., 2003; Heinonen, 2007). Anthocyanins consist of an anthocyanidin aglycon that is bound to one or more sugar moieties (Figure 3). The commonly occurring anthocyanidin aglycons are cyanidin, delphinidin, malvidin, pelargonidin, peonidin, and petudinin, of which pelargonidins have rarely been found in *Vaccinium* berries. The 15 major anthocyanidin glycosides commonly found in bilberries are 3-O-glucosides, 3-O-galactosides, or 3-O-arabinosides of five aglycons (Jaakola et al., 2002; Kähkönen et al., 2003).

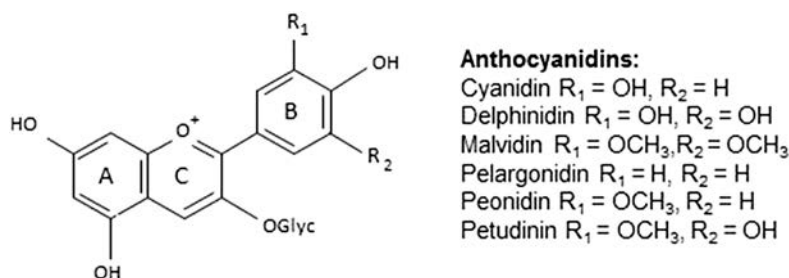


Figure 3 The basic structure of anthocyanins. OGlyc=3-O-glucoside, 3-O-arabinoside, or 3-O-galactoside. According to Strack, D., Wray, V., 1989. Anthocyanins. In: Dey, P.M., Harborne, J.B. (Eds.), *Methods in Plant Biochemistry*. Academic Press, London, UK, pp. 325–356.

Geographic variation of anthocyanin content among bilberry ecotypes has been reported in several studies (Table 5). Lätti et al. (2008) reported south–north axis variation in quantitative and qualitative anthocyanin content of bilberry clones growing in latitudes from 60°21'N to 68°34'N. The berries of the northernmost clones contained higher total yields of anthocyanins and the proportion of the more hydroxylated anthocyanidins, delphinidin glycosides, was higher in northern berries, whereas cyanidin glycosides dominated in southern populations. Delphinidin glucosides are responsible for the bluish hues in berries and flowers, and especially delphinidins have been shown to be effective in inhibiting the growth of human leukemia cells in vitro (Katsube et al., 2003). A similar trend was detected in the area of Sweden and Denmark between latitudes 56°50'N and 66°57'N (Åkerström et al., 2010). The common garden experiment in the same study revealed that the detected differences were related to the genetic origin, as even after more than 10 years at the same growth site in Oulu, Finland, the more northern clones had higher total anthocyanin yields and proportions of delphinidins in the anthocyanidin profile. Moreover, a controlled study with more northern and southern bilberry clones confirmed higher production of anthocyanins in northern clones, but it also showed that climate conditions (temperature, length of day) affect the anthocyanin yield and profile (Uleberg et al., 2012). A study on phenolic composition of bilberry leaves also showed south–north axis–related and altitude–related differences between latitudes 59°49'N and 70°04'N in Finland (Martz et al., 2010). The leaves from more northern latitudes and higher altitudes had greater soluble phenolic and flavonol levels but lower content of chlorogenic acid derivatives.

There are several reports on anthocyanin content in bilberries growing in the areas of different European countries (Giovannelli and Buratti, 2009; Moze et al., 2011; Kusznierevicz et al., 2012; Barizza et al., 2013; Skrede et al., 2014). The total anthocyanin contents vary between 246 and 1201 mg/100 g FW and 1370–5889 mg/100 g DW. However, the analysis methods used in different studies vary to some extent. The anthocyanin content also changes during the ripening process and varies from year to year, which affects the comparisons (Åkerström et al., 2010; Oancea et al., 2013). Some results have shown higher anthocyanin levels at open growth habitats compared to forest stands (Jovancevic et al., 2011), although some others have not found differences (Barizza et al., 2013).

Primetta et al. (2013) compared anthocyanin profiles among various Turkish and Finnish bilberry populations. The results showed variations between bilberry origins but not clear differences that could be used in geographical discrimination between Finnish and Turkish bilberries. However, the sugar moieties of anthocyanidin aglycons grouped according to geographical origin showing potential to be used in source identification of the raw material.

Besides anthocyanins, bilberry fruits also contain flavonols, of which higher levels quercetin and myricetin glycosides and minor levels of kaempferol, laricitrin, syringetin,

and isorhamnetin glycosides have been detected in different studies (Laaksonen et al., 2010; Lätti et al., 2011). Tannin molecules procyanidins and prodelphinidins, as well as flavan-3-ols, their monomeric units, have also been detected in bilberries (Lätti et al., 2011). Among proanthocyanidins, A-type linkages dominate in *Vaccinium* berries over B-type linkages, which are common in many other plant species (Määttä-Riihinen et al., 2005). In addition, bilberries contain high levels of hydroxycinnamic acids, especially *p*-coumaric, caffeic, and ferulic acids both in berries and in leaves (Riihinen et al., 2008; Laaksonen et al., 2010). Moreover, stilbene trans-resveratrol, commonly found in wine grapes (*Vitis vinifera*), has also been detected in bilberries, albeit to lesser degrees (Moze et al., 2011). The phenolic compounds also contribute to the taste of berries. Laaksonen et al. (2010) were able to show that especially myricetin glycosides and a caffeoyl quinic acid derivative contribute to astringency and bitterness in bilberries. The characteristic aroma compounds in bilberries have been found to be hydroxy esters, together with 2-phenylethanol and its esters and the γ - and δ -lactones (Hirvi and Honkanen, 1983).

SUMMARY POINTS

- Bilberries are, economically, among the most important wild berries in Europe
- Bilberries have been used as food and in medicine since prehistoric times
- Bilberries are one of the best sources of anthocyanin pigments
- Quantitative and qualitative variations have been detected in anthocyanin profiles among different bilberry ecotypes
- Bilberries are rich sources of various phenolic compounds and carotenoids, as well as good-to-moderate sources of vitamin C

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CHAPTER 5

Black (*Ribes nigrum* L.) and Red Currant (*Ribes rubrum* L.) Cultivars

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INTRODUCTION

Black and red currants are the two main *Ribes* species that are well known in the world production of the berry fruits (Djordjevic et al., 2014). Several thousand *Ribes* cultivars could be roughly subdivided into five groups: red currants, white currants, black currants, gooseberries, and currant–gooseberry hybrids (Weigend, 2007). Black currant cultivars are derived mainly from the species *Ribes nigrum* L., and red currants from the species *Ribes rubrum* L. Although this genus comprises more than 150 species that are mostly native throughout northern Europe, Asia, North America, and Patagonia (Hummer and Barney, 2002; Pfister and Sloan, 2008), only 10–12 species have been used as a gene pool for breeding of cultivars (Hummer, 2006). World production of currants is increasing, and since there are constant demands for better cropping potential of cultivars as well as increasing interest in the nutritional benefits of currants, numerous cultivars have recently been developed (Table 1) (FAO, 2012). Regarding black currants, which are dominantly used for processing (mostly juices, jams, syrups, jellies, and wine), the main producers are in Europe. The main producers of red currants are in Europe as well (Poland, Holland, Belgium, Germany, France) (Brennan, 1996, 2008).

Table 1 Countries with the highest production of currants in the world

#	Country	Production (tonnes)
1	Russian Federation	346,000
2	Poland	194,522
3	Ukraine	24,100
4	Austria	19,140
5	United Kingdom	15,400
6	Denmark	12,793
7	France	11,411
8	Germany	10,764
9	New Zealand	7600
10	Hungary	3326
11	Netherlands	3000
12	Czech Republic	2469
13	Uzbekistan	2300
14	Finland	1636
15	Azerbaijan	1600
16	Belgium	1600

Source: [FAOSTAT Database Results \(2012\)](#).

In recent years, there has been an increased need for *Ribes* fruits in the fresh market sector. In the United States, the production of *Ribes* species was limited, since these species are alternative hosts for *Cronartium ribicola* Fisch. (white pine blister rust) ([Brennan, 2008](#)). The quality of black and red currants is estimated according to their organoleptic and nutritional characteristics as well as their chemical composition, especially because of their positive effects in dietary management of various diseases (hypertension, osteoporosis, inflammation, cancer, cardiovascular disease) ([Knekt et al., 1996](#); [Seeram et al., 2003](#)). The main groups of primary metabolites that are present in these berries are sugars and organic acids, whereas the dominant groups of secondary metabolites are phenolic compounds. Ascorbic acid, anthocyanins, and flavonoids are the most valuable compounds present in black and red currants. Thus, the ascorbic acid content in these fruits is much higher in comparison with other berries ([Benvenuti et al., 2004](#); [Ciornea et al., 2009](#)). Content of these compounds is influenced by the type of cultivar, cultivation methods, environmental conditions, time of harvesting ([Anttonen and Karjalainen, 2006](#); [Maatta-Riihinen et al., 2004](#); [Zheng et al., 2012](#)). Cyanidin 3-rutinoside, delphinidin 3-rutinoside, delphinidin 3-glucoside, and cyanidin 3-glucoside are dominant anthocyanins in black currants, whereas the most abundant anthocyanins in red currants are cyanidin 3-glycosides ([Figure 1](#)) ([Djordjević et al., 2010, 2013](#)) ([Figure 2](#)).

Although berries represent the most important part of currant plants, the buds and leaves are becoming of interest as potential sources of biologically active compounds. In traditional European folk medicine, black currant leaves are used in treatment of rheumatism, arthritis, and respiratory problems ([Wichtl, 1994](#)). Black currant buds are used for essential oil production for application in the cosmetics and perfume industries

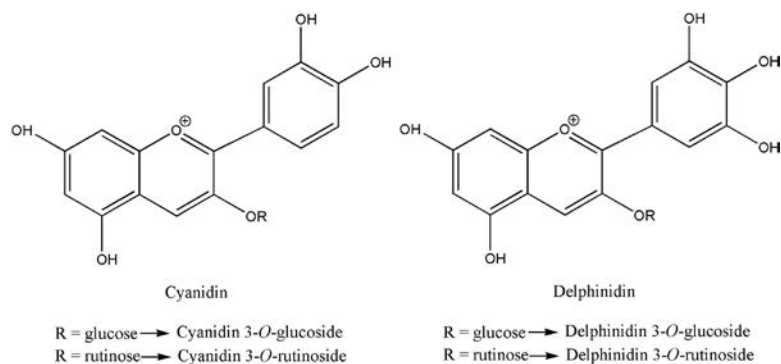


Figure 1 Main anthocyanins present in black and red currants.



Figure 2 Black currant cultivar 'Čačanska crna'.

(Dvaranauskaite et al., 2008; Piry et al., 1995) and are constituted mainly of aliphatic and oxygenated mono- and sesquiterpenes (Dvaranauskaite et al., 2008). Depending on cultivar type, different phenolic compounds have been identified in black currant buds and leaves (rutin, quercetin, myricetin, kaempferol, chlorogenic acid, proanthocyanidins, epicatechin) (Stević et al., 2010; Vagiri et al., 2012). Currant seeds, a by-product of juice production, are also recognized as a valuable source of oil rich in polyunsaturated fatty acids. Šavikin et al. (2013a) reported that the oil content in seeds of black and red currants ranged from 18.2% to 27.7% and that estimated oil yields in field production ranged from 26.4 to 212.4 kg/ha.

BOTANICAL ASPECTS

The genus *Ribes* L. was formerly included in the family Saxifragaceae, but it is now placed in Grossulariaceae on account of its floral morphology (Cronquist, 1981; Sinnott, 1985). *Ribes* is generally considered to be the only genus in the family Grossulariaceae (Senters and Soltis, 2003), which has been divided into 6–12 subgenera by different authors (Berger, 1924; Keep, 1962). There have been conflicting opinions as to whether currants and gooseberries belong to one genus (*Ribes*) or two genera (*Ribes* and *Grossularia* Mill.) (Berger, 1924; Coville and Britton, 1908; Komarov, 1971). Production of gooseberry and black currant hybrids may be considered as indirect evidence for the unity of these two genera (Pikunova et al., 2012). According to Pikunova et al. (2012), cultivated species of *Ribes* belong mainly to three subgenera: *Coreosma* (black currants), *Ribesia* (red currants), and *Grossularia* (gooseberries), although the taxonomy and phylogeny of *Ribes* have still not been determined (Brennan, 2008; Pikunova et al., 2012). Thus, Pikunova et al. (2012) analyzed interspecific, intraspecific, and intervarietal polymorphism of 47 *Ribes* samples by a molecular method (random amplified polymorphic DNA analysis), and concluded that black currants, red currants, and gooseberries are taxa of the same level in two separate subgenera (Pikunova et al., 2012). Existing black currant cultivars have been mostly derived from *R. nigrum* and its varieties *europaeum* Jancz., *scandinavicum*, and *sibiricum* W. Wolf, *Ribes dikuscha* Fisch. ex Turcz., *Ribes ussuriense* Jancz., *Ribes bracteosum* Douglas, and *Ribes petiolare* Douglas (Brennan, 1996). All red currant plants in the subgenus *Ribesia* are spineless shrubs. The main species in cultivation programs are *Ribes sativum* (Rchb.) Syme, *Ribes petraeum* Wulfen, *R. rubrum* L., and *Ribes multiflorum* Kit. ex Schult., whereas white and pink currants are color forms of *R. rubrum* (Brennan, 1996). The basic chromosome number of all *Ribes* species is $x = 8$ (Zielinski, 1953), and all species and cultivars are diploid ($2n = 2x = 16$) (Brennan, 1996).

These plants are unarmed shrubs that grow up to 2 m tall (Rehder, 1986). *Ribes* species are predominantly monoecious, with a few examples of dioecious types (Brennan, 2008). Plants usually reach their full maturity in 3–4 years, when they start yielding (Vagiri, 2012). The shoots are glabrous or have glandular hairs, and young growth bears crystalline glands (Brennan, 1996). Older stems are covered with a smooth, pale-yellow bark. The leaves are deeply cordate, with 3–5 lobes, and 6–7 cm in diameter. The flowers occur in long racemes (consisting of 2–70 flowers, depending on the species), and are greenish tinged with purple. They are usually inferior and pentamerous. Black currants have mostly between 6 and 12 flowers per raceme, whereas red currants have more. The hypanthium is almost flat and the petals are very small. The fruit is globose, 6–10 mm in diameter, and glabrous with a translucent skin (Brennan, 1996; Hummer and Barney, 2002).

Ribes species are insect-pollinated, although most of the cultivars used for breeding are almost self-pollinated (Brennan, 2008). Nevertheless, cross-pollination is of great importance for achieving optimal yields (Denisow, 2003). The start of flowering is strongly dependent on the type of cultivar and environmental conditions, and flowering lasts up to 3–4 weeks (Atkinson et al., 2005; Vagiri, 2012). Currant flowers (especially of black currants) are sensitive to late spring frost, although if supercooling is minimized

they can withstand temperatures to about -5°C (Brennan, 2008; Carter et al., 1999). Therefore, many breeding programs focus on producing new cultivars that are more resistant to low temperatures or that flower later. For successful currant breeding, it is of great importance that the winter be cold (during the dormant period, temperatures have to be less than 8°C for 800–1600 h), since bud break, time and duration of flowering, as well as fruit quality are affected by winter chilling (Barney and Hummer, 2005). Moreover, mild summer conditions are important too, because high temperatures and intense sunlight could increase the risk of foliar damage (Šavikin et al., 2013b; Vagiri, 2012).

Apart from the high content of ascorbic acid and other active compounds with potential health benefit effects (anthocyanins, proanthocyanidins, flavonoids, phenolic acids), good nutritional and sensory qualities are international requirements for currants. Yield, fruit size (mostly dependent on end use), resistance to pests and diseases, and uniform ripening are of great importance as well. Many existing commercial breeding programs aim to develop new currant cultivars to fulfill these criteria.

COMPOSITION OF TRADITIONAL AND MODERN CULTIVARS

The word “currant” is derived from the ancient Greek city Corinth, and at the beginning it was used to describe small dried grapes from that region. In early English texts, cultivated species of *Ribes* were described by variations such as corinthes, corans, currans, and bastarde corinthes (Hummer and Barney, 2002). The most commonly used early English reference is attributed to Lord Bacon (1561–1626), who called them corans. The Italian term for this fruit is uvetta, or little grape. According to the first written data, black currants were grown in Russia since the eleventh century. The Russian author Burnistrov (1985) noted that the former name of the River Moscow was the River Smorodinovka, which was named after currants. In that period, in the river’s valley, huge populations of wild species of black currants were located, which were later disseminated in other countries of Eastern and Central Europe.

Five berry species were described as small black, small red, big red, red Dutch, and white types of berries by Rea in 1665 (Barney and Hummer, 2005). In the United Kingdom, the black currant was introduced from the Netherlands at the beginning of seventeenth century. In the early eighteenth century, the first orchard and trade of berries were recorded in Russia and Eastern Europe.

Due to the accumulated knowledge on nutritional quality and medicinal properties of currant berries and other plant organs, more intense expansion of the black currant began, in the nineteenth century, especially in Northern Europe. By 1826, five black currant cultivars appeared on the Royal Horticultural Society’s recommended plant list. The cultivars Black Naples and Black Grape, both of unknown origin, were the most widely grown currants. During the 1800s, the number of black currant cultivars increased. Hatton (1920) divided the cultivars into four groups of similar genotypes: ‘French Black’, ‘Boskoop Giant’, ‘Goliath’, and ‘Baldwin’. Bunyard (1925) described more than 15 cultivars in England, while Hedrick (1925) described 61 cultivars in the United States. The most popular cultivar of that time was ‘Baldwin’.

Unlike European countries, where the production of berries increased, in North America, it regressed. The main reason for the decline of this production was the emergence of currant rust disease (white pine blister rust) caused by the fungus *Cronartium rubicola* JC Fisch. This disease came from Asia to America in the late eighteenth century and early nineteenth century. Since it caused great damage to pine trees, especially to the white pine (*Pinus strobus* L.), the decision was made to eradicate currants. In Canada, during the 1940s and 1950s, Hunter (1955) was trying to develop rust-resistant *Ribes* cultivars. Thus, he combined the *Cr* gene for rust immunity from *R. ussuriense* with the black currant cultivar ‘Kerry’ and released three cultivars: ‘Crusader’, ‘Coronet’, and ‘Consort’. Fungal uredia were not formed on these cultivars under laboratory or field conditions. Unfortunately, these cultivars are low yielding and susceptible to powdery mildew.

Red and white currant breeding probably started in Netherlands and Denmark. Red currants were first cultivated as common garden plants in the sixteenth century in Holland, Denmark, and the coastal plains around the Baltic Sea (Brennan, 1996). The French name for red currant, “grosseillier d’outre mer” (currant from over the sea), implies a Dutch origin. Red currant species grow wild in northern France, Germany, and Austria, but these fruits do not attain the size and quality of those originated from more northern species. There are numerous documents written by various biologists and herbalists about growing medicinal traits of red currant dating back to the sixteenth century.

According to Barney and Hummer (2005), fruits of red and white currants were used to make various types of desserts. Also, these berries were suitable for cooking and for relieving stomach discomfort. In the eighteenth century, the juices of red and white currants were very popular in the Paris buffet. At that time, an extremely popular summer table wine of white currant berries was made. The most popular variety was ‘Red Dutch’.

A memorandum from 1629 (Barney and Hummer, 2005) stated that the first introduced variety in countries of North America was the red currant ‘Red Dutch’. However, many believe that the introduction of red and white currants took place much earlier.

Most breeding programs are focused on the creation of new genotypes of black currant, and a much smaller number are engaged in the creation of red and white currants. According to Brennan (2008), there were about 15 active *Ribes* breeding programs worldwide. The breeding of red currants and gooseberry is now generally located in Eastern Europe and Russia, and it is dominantly produced for local markets. The aims of all breeding programs are the following: production of a genotype resistant to powdery mildew and gall mite (*Cecidophyopsis ribis*); good flavor and taste; suitability for machine harvesting; high productivity; winter hardiness; and spring frost resistance (Brennan, 2008; Pluta et al., 2008). Activities in this area include genetic and molecular studies as well as development of new cultivars. Directed crosses are the main tools used in breeding programs. Some of the significant black and red currant varieties are described below, and a comparative overview of their agronomical parameters (Table 2) and disease susceptibility (Table 3) is presented.

Table 2 Comparative overview of agronomical parameters of black and red currant varieties

Variety	Origin	Season	Bush	Fruit	Yield	Frost	Sunburn	Mechanical harvest
Black currants								
Boskoop Giant	Netherlands	Middle	High	Very large	High	Tolerant	Susceptible	Suitable
Cotswold Cross	England	Mid-late	Low	Medium large	Medium	Tolerant	Mod. susceptible	Unsuitable
Wellington XXX	England	Early	Compact	Medium large	Medium	Mod. tolerant	Tolerant	Unsuitable
Ben Lomond	Scotland	Late	Vigorous	Large	High	Tolerant	Tolerant	Mod. susceptible
Ben Sarek	Scotland	Early	Low	Very large	Medium	Tolerant	Very susceptible	Suitable
Ben Alder	Scotland	Late	Vigorous	Medium large	High	Tolerant	N/A	Suitable
Bona	Poland	Early	Low	Extremely large	Medium	Mod. tolerant	Susceptible	Suitable
Ben Gaire	Scotland	Early	Compact	Large	High	Tolerant	N/A	Very suitable
Ben Hope	Scotland	Middle	Compact	Medium large	High	Tolerant	N/A	Suitable
Tiben	Poland	Mid-early	Compact	Large	High	Tolerant	Tolerant	Very suitable
Čačanska crna	Serbia	Mid-late	Vigorous	Large	Medium	Tolerant	Tolerant	Unsuitable
Red currants								
Jonkheer van Tets	Netherlands	Very early	Vigorous	Large	Moderate	Susceptible	N/A	N/A
Rondom	Netherlands	Late	Vigorous	Large	High	Mod. susceptible	N/A	N/A
Red Dutch	Netherlands	Mid-late	Vigorous	Medium large	High	Resistant	N/A	N/A
Red Lake	USA	Late	Med. vigorous	Large	Moderate	Med. resistant	N/A	N/A
Heinemann's R.S. ^a	Germany	Very late	Vigorous	Large	High	Resistant	N/A	N/A
Rovada	Netherlands	Late	Med. vigorous	Medium large	High	Resistant	N/A	N/A
Detvan	Slovakia	Middle	Vigorous	Medium large	Very high	Med. resistant	N/A	N/A
Redpoll	England	very late	Vigorous	Medium large	High	Resistant	N/A	N/A
Rolan	Netherlands	Middle	Vigorous	Very large	Moderate	Med. resistant	N/A	N/A
Hron	Slovakia	Middle	Vigorous	Medium large	Moderate	Med. resistant	N/A	N/A

N/A, data not available; Med., medium; Mod., moderately.

^aR.S., Heinemann's Rote Spatlese.

Table 3 Comparative overview of disease susceptibility of black and red currant varieties

Variety	Mildew	Leaf spot	WPBR ^b	Anthrachnose	BRV ^c	BGM ^d
Black currants						
Boskoop Giant	Resistant	Susceptible	Susceptible	N/A	Mod. susceptible	Mod. susceptible
Cotswold Cross	Susceptible	Susceptible	Immune	N/A	Mod. susceptible	Mod. susceptible
Wellington XXX	Mod. tolerant	Susceptible	Susceptible	Tolerant	Mod. susceptible	Mod. susceptible
Ben Lomond	Mod. tolerant	Tolerant	Susceptible	Resistant	Susceptible	Susceptible
Ben Sarek	Resistant	Tolerant	Susceptible	Tolerant	Susceptible	Susceptible
Ben Alder	Resistant	Resistant	Tolerant	N/A	Susceptible	Susceptible
Bona	Mod. susceptible	Tolerant	Susceptible	Mod. susceptible	Susceptible	Susceptible
Ben Gaire	Resistant	Resistant	Tolerant	N/A	Resistant	Resistant
Ben Hope	Resistant	Resistant	Tolerant	N/A	Mod. susceptible	Mod. susceptible
Tiben	Mod. susceptible	Tolerant	Mod. susceptible	Mod. susceptible	Mod. susceptible	Mod. susceptible
Čačanska crna	Resistant	Resistant	Resistant	Resistant	Resistant	Resistant
Red currants						
Jonkheer van Tets	Mod. resistant	Mod. resistant	Mod. resistant	Resistant	N/A	N/A
Rondom	Resistant	Mod. resistant	Resistant	Resistant	N/A	N/A
Red Dutch	Tolerant	Tolerant	Tolerant	Resistant	N/A	N/A
Red Lake	Mod. resistant	Mod. resistant	Susceptible	Susceptible	N/A	N/A
Heinemann's R.S. ^a	Mod. susceptible	Tolerant	Tolerant	Mod. susceptible	N/A	N/A
Rovada	Susceptible	Mod. susceptible	Susceptible	Mod. susceptible	N/A	N/A
Detvan	Mod. susceptible	Mod. susceptible	Mod. susceptible	Mod. susceptible	N/A	N/A
Redpoll	Mod. susceptible	Mod. susceptible	Mod. susceptible	Medium resistant	N/A	N/A
Rolan	Mod. susceptible	Mod. susceptible	Susceptible	Mod. susceptible	N/A	N/A
Hron	Mod. susceptible	Mod. susceptible	Mod. susceptible	Mod. susceptible	N/A	N/A

N/A, data not available; Mod., moderately.

^aR.S., Heinemann's Rote Spatlese.^bWPBR, white pine blister rust.^cBRV, black currant reversion virus.^dBGM, black currant gall mite.

CULTIVARS

Black Currant

Boskoop Giant—Netherlands

This black currant has been grown since 1885. The fruit is very large and ripens evenly on the strig. Fruits have tender skin, juicy, rich, subacidic, and sweetish flesh, and ripen early. Berries have a high content of vitamin C. Fruit from a productive, vigorous bush is easy to pick.

Cotswold Cross—Long Ashton, England

Parentage ‘Baldvin’ × ‘Victoria’. Fruit is medium-large, with a low quality of juice, and berries drop before maturity. Berries have a moderate to high content of vitamin C. This cultivar is prone to alternate bearing.

Wellington XXX—East Malling, England

Parentage ‘Boskoop Giant’ × ‘Baldvin’. Fruit is medium-large, blooms early, and the bush is medium productive. Berries have a moderate content of vitamin C. Canes are compact, spreading, and very vigorous. This cultivar is tolerant to anthracnose.

Ben Lomond—Scottish Crop Research Institute, Scotland

Parentage (‘Brodtop’ × ‘Janslunda’) × (‘Consort’ × ‘Magnus’). Fruit is large, with tough skin, and ripens evenly on the strig. Berries have a high content of vitamin C, more than 150mg/100g FW. The bush blooms later and tolerates lower temperatures during the bloom. This is a very productive cultivar. Canes are compact, spreading, moderately vigorous, and moderately tolerant to powdery mildew. This cultivar is susceptible to white pine blister rust.

Ben Sarek—Scottish Crop Research Institute, Scotland

Parentage ‘Goliath’ × ‘Ojebyn’. This cultivar flowers early. Fruit is very large and ripens evenly on the strig. Berries have a moderate to high content of vitamin C. Canes are compact, spreading, and low vigorous. This cultivar is very susceptible to sunburn during the summer period and also to white pine blister rust and black currant reversion virus (BRV). It is suitable for mechanical harvesting.

Ben Alder—Scottish Crop Research Institute, Scotland

Parentage ‘Ben Lomond’ × ‘Ben More’. Fruit is medium-large and produces an excellent quality of juice. Berries have a moderate content of vitamin C. Canes are vigorous and can be dense. This cultivar is very susceptible to white pine blister rust, and can be mechanically harvested.

Bona—Institute of Pomology in Skierniewice, Poland

Parentage ‘Ojebyn’ × S/12 (*R. dikuscha* × ‘Climax’). Fruit is extremely large, weighs more than 1.7g, ripens evenly on the strig, is aromatic, and is suitable for fresh consumption. Berries have a low to medium content of vitamin C. Canes are compact, spreading, moderately vigorous, and moderately susceptible to powdery mildew and anthracnose.

Ben Gaire—Scottish Crop Research Institute, Scotland

Parentage 'Ben Alder' × 'Golubka'. The fruit is large and ripens evenly on the strig. Berries have a moderate to low content of vitamin C. Canes are compact, spreading, and moderately vigorous. The main advantage of this cultivar is its resistance to BRV and good resistance to foliar diseases.

Ben Hope—Scottish Crop Research Institute, Scotland

Parentage 'Westra' × (238/36 × EM21/15). Fruit is medium large and acceptable for commercial production. Yields are consistently high. Canes are compact, vigorous, and upright-growing. This cultivar has a high level of resistance to black currant gall mite based on the *Ce* gene, and good resistance to both mildew and leaf spot.

Tiben—Institute of Pomology in Skierniewice, Poland

Parentage 'Titania' × 'Ben Nevis'. The fruit is large, and yields are consistently high. Berries have moderate to high content of vitamin C. Canes are compact, very vigorous, and upright-growing. This cultivar is very suitable for harvesting mechanically. It is moderately susceptible to powdery mildew and white pine blister rust.

Čačanska crna—Fruit Research Institute, Čačak, Serbia

This cultivar was developed in 1980 by open pollination of the cultivar Malling Jet and was selected in 1984. The number of berries per long strig averages 8.5. Berries are large (0.82 g), separating easily from the stalk. 'Čačanska crna' is a heavy cropper. Under favorable growing conditions, the yields exceed 13 t/ha. The season is mid to late. The bush is vigorous. The branches are first erect growing, and later become spreading under the weight of the crop. The raceme has a long central axis with 10–15 flowers. 'Čačanska crna' is a self-fertile cultivar with excellent cropping. It is tolerant to low winter temperatures. It is highly resistant to major diseases and pests, and is resistant to currant rot (*C. ribicola*) and leaf spot (*Pseudopezizaria*). The berries are delicate and thus, recommended for fresh consumption, freezing, and processing.

Red Currant

Jonkheer van Tets—Netherlands, has been grown since 1941

Parentage 'Fay's Prolific' × 'Scotch'. Flowering is very early and susceptible to spring frost. Strig is a long cluster. Berries are variable in size, of average quality, have a tendency to split in wet weather; and have a moderate content of vitamin C. The bush has moderate yield and matures very early. Canes are erect, vigorous, susceptible to wind damage, and only moderately resistant to mildew. The cultivar is resistant to anthracnose.

Rondom—Netherlands, has been grown since 1946

Backcross of *R. multiflorum* to red currant cultivars. Flowering is late. Berries are large, and 10–18 per cluster. The fruits form in tight clusters and hang well after ripening. Berries have a moderate to high content of vitamin C, more than 60 mg/100 g FW. This is a high-yielding late cultivar. Canes are erect and vigorous. This cultivar is resistant to powdery mildew, white pine blister rust, and anthracnose. It is suitable for fresh consumption.

Red Dutch—Netherlands

Probably originated from *R. petraeum* Wulf. Berries are medium large and 10–15 per cluster. Canes are erect and vigorous. This cultivar is resistant to anthracnose and low temperature.

Red Lake—University of Minnesota, has been grown since 1933

Parentage unknown. Berries are large, uniform, juicy, flavorful, and ripen to late season. Clusters are long and easy to pick. Canes are moderately vigorous, erect, and moderately resistant to powdery mildew. This cultivar is susceptible to white pine blister rust and anthracnose.

Heinemann's Rote Spatlese—Germany, has been grown since 1942

Parentage 'Red Dutch' × 'Andenken aus Lorgus'. Flowering is very late. Berries are large and uniform, have good firmness, ripen to very late season, and have a moderate to high content of vitamin C. Clusters are long, with more than 25 berries. This is a productive cultivar, and canes are very vigorous.

Rovada—Institute for Horticultural Plant Breeding, Netherlands

Parentage 'Fay's Prolific' × 'Heinemanns Rote Spatlese'. Flowering is late. Berries are medium-large with a good taste, are uniform, and 13–21 per cluster. Clusters are long, and good for hand picking. Berries have a high content of vitamin C. This is a late-ripening, high-yielding cultivar. It is susceptible to powdery mildew and somewhat susceptible to white pine blister rust.

Detvan—Slovakia

Parentage 'Jonkheer Van Tets' × 'Heinemanns Rote Spatlese'. Flowering is early. Berries are medium-large with a good taste, and ripen mid-season. Clusters are long, suitable for hand picking, and have 14–23 berries. Berries have a low to moderate content of vitamin C. This cultivar is very high yielding. Canes are moderately vigorous. The cultivar is moderately susceptible to diseases.

Redpoll—Institute Ist Malling, England

Parentage 'Red Lake' × (*Ribes longeracemosum* × *R. multiflorum*). Flowering is very late. Berries are medium-large, with a good taste, and ripen mid-season. Clusters are very long, suitable for hand picking, and have more than 35 berries. Berries have a moderate to high content of vitamin C. Canes are moderately vigorous, and medium resistant to anthracnose.

Rolan—Wageningen, Netherlands

Parentage 'Jonkheer Van Tets' × 'Rosetta'. Flowering is late. Berries are very large, with a good taste, and ripen in early to mid-season. Clusters are long, very suitable for hand picking, and have a low to moderate content of vitamin C. This cultivar is moderately yielding. Canes are vigorous and erect.

Hron—Slovakia

Parentage 'Jonkheer Van Tets' × 'Heinemanns Rote Spatlese'. Berries are medium large and aromatic, with a good taste, ripening in mid-season. Berries have a moderate

to high content of vitamin C. This cultivar is moderately yielding. Canes are vigorous, and can be harvested mechanically. The cultivar is medium susceptible to diseases.

FOCUSED AREAS OF RESEARCH

The area of conventionally or organically grown black currants has rapidly increased in Europe during late 1990s ([Hakkinen et al., 1999](#)). Black and red currants are widely consumed throughout the world in fresh or frozen form, as juices, in various dishes, or as a constituent of functional foods. Their extracts or isolated compounds are also used as bioactives in different dietary supplements.

The biological value of currants relies on their nutritive and nonnutritive constituents. Currently, scientists are especially interested in detailed chemical composition ([Table 4](#)) and the potential health benefits of currants and their phenolics. Currants are good sources of vitamins (vitamin A, C, E, folic acid), provitamins and related compounds (carotene and lutein), minerals (calcium and selenium), and phytosterols, but the proposed health benefits are usually connected with phenolics as the main biologically active compounds of currants ([Brennan, 1996, 2008; Djordjevic et al., 2014](#)). Currant phenolics include anthocyanins, flavonols, flavanols, condensed tannins (proanthocyanidins), hydrolyzable tannins, (ellagitannins and gallotannins), and phenolic acids. The most ubiquitous anthocyanin aglycones were found to be cyanidin and delphinidin, and their amounts varied among cultivars. A number of factors may affect the flavonoid content of currants, including agricultural practices, environmental factors, ripening, processing, storage, and cooking.

No adverse effects have been associated with high dietary intakes of flavonoids, but this lack of adverse effects may be explained by the relatively low bioavailability and rapid metabolism and elimination of most flavonoids ([Vagiri, 2012](#)). The potential health benefits of these fruits may be greatly increased if berries from cultivars with high contents of antioxidant compounds are used as raw materials ([Mikkonen et al., 2001](#)). Apart from phenolics, black currant fruits have long been known to be a good source of vitamin C, which also contributes to their high antioxidant activity ([Moyer et al., 2002](#)). There is growing interest in the possibility that consuming a diet rich in antioxidants may reduce the risks of many common chronic diseases ([Soobrattee et al., 2005](#)).

In the last decade, most of the production of black currant berries is for use in processed products ([Brennan et al., 2003](#)). As the currants' shelf life is typically short, the processing and storage effects on the quality of berries have been extensively studied, especially freezing as the most common processing and preservation technology applied to berries ([Zhao, 2007](#)). Black currant berries are consumed mainly in the form of juice, which has been reported to maintain berry antioxidant activity ([Sandell et al., 2009](#)).

According to the literature, most chemical studies investigate total phenolics, total anthocyanins, and individual anthocyanins and flavonols. Numerous species and varieties of currants contain total phenols in far greater quantities than representatives of other

Table 4 Chemical composition of black and red currant varieties

Variety	Soluble solid ^b (%)	Titrateable acid (%)	Total sugars (%)	Invert sugars (%)	Ascorbic acid (mg/100g FW)
Black currants					
Boskoop Giant	11.7–13.4	1.7–3.3	7.7–9.1	7.2–8.4	144.5–198.3
Cotswold	10.6–14.2	1.9–3.4	7.2–9.8	7.4–8.2	123.2–155.8
Cross					
Wellington XXX	12.3–14.6	1.8–3.4	7.9–8.9	6.8–8.1	119.6–144.6
Ben Lomond	11.7–15.6	1.5–3.8	7.8–10.2	7.0–8.9	134.3–206.4
Ben Sarek	10.7–14.5	1.9–4.3	8.5–10.2	6.8–9.4	132.1–169.3
Ben Alder	11.2–16.4	2.1–3.6	8.8–10.3	7.2–9.1	144.5–239.2
Bona	11.1–13.2	1.6–3.2	8.7–10.1	7.6–8.8	108.3–146.9
Ben Gaire	12.7–14.3	2.2–3.8	7.6–10.5	6.9–8.5	116.2–149.5
Ben Hope	12.6–15.7	1.9–3.9	7.3–10.2	6.5–8.9	140.8–231.6
Tiben	13.5–17.9	2.3–4.1	8.4–11.2	7.6–10.1	123.2–185.3
Čačanska crna	12.6–15.5	1.7–3.2	9.2–12.0	8.4–11.2	172.3–232.5
Red currants					
Jonkheer van Tets	9.7–11.6	1.6–3.1	6.8–7.8	6.1–6.6	39.5–51.3
Rondom	10.8–12.6	1.2–2.9	8.3–8.8	7.5–8.2	45.8–64.2
Red Dutch	10.2–13.5	1.6–3.4	7.1–8.0	6.0–6.8	35.6–55.2
Red Lake	9.8–14.1	2.2–3.8	6.9–8.2	5.9–7.1	33.1–48.3
Heinemann's R.S. ^a	12.8–15.3	2.7–3.5	8.6–9.2	7.2–8.4	40.2–58.3
Rovada	11.8–14.5	1.6–3.8	8.8–10.1	8.0–8.9	36.9–59.2
Detvan	11.8–14.9	1.9–3.2	7.4–9.5	5.7–8.2	51.8–71.2
Redpoll	12.2–13.6	2.1–3.5	8.0–9.2	7.4–8.1	42.5–58.4
Rolan	11.9–14.1	1.6–3.9	8.6–10.2	7.9–9.0	29.3–45.8
Hron	10.8–14.2	2.1–3.7	7.3–9.1	5.9–8.0	39.5–55.6

^aR.S., Heinemann's Rote Spatlese.^bData in table are presented as minimum–maximum range based on measurements of three repetitions.

fruit. Analyzing the fruits of more than 110 different genotypes of raspberries, blackberries, blueberries, and currants, [Moyer et al. \(2002\)](#) found that varieties of black currant, together with some varieties of black raspberries, had the highest average content of these compounds. [Lugasia et al. \(2011\)](#) found different amounts of total phenols in the black currant varieties that they analyzed ranging between 229 and 871 mgGAE/100g FW of the fruit. Among the tested varieties, the highest content was found in variety Tsema, followed by Ben Lomond and Tenah. Tsema even exceeded total phenol content of chokeberry, known as the one of the richest sources of phenolics. [Benvenuti et al. \(2004\)](#) reported that total phenol content in black currant varieties ranged from 530 to 888 mgGAE/100g, whereas [Giongo et al. \(2008\)](#) reported that these values ranged

between 312.8 and 845.5 mg GAE/100 g of fresh fruit. In both studies, Tsema was the most abundant in phenolic compounds. In addition, varieties Ben Nevis, Ben Lomond, Titania, and Ojebin had more than 800 mg GAE/100 g FW (Moyer et al., 2002). High levels of total phenols in the black currant varieties Ben Nevis and Ben Lomond was confirmed by Bakowska-Barczak and Kolodziejczyk (2011).

Besides genetic predispositions, environmental factors such as temperature, light, humidity, and agricultural practices as well as the methods of extraction applied have significant influence on the content of phenolic compounds in currants as well as in other fruits (Heinonen, 2007). The dependence of total phenol content and the genetic basis of cultivars were reported by Anttonen and Karjalainen (2006). According to these authors, the fruit varieties grown under the same conditions significantly differ in total phenol content, and the highest content of phenolics was found in the stage of full maturity also confirmed by Bordonaba and Terry (2008). Lapornik et al. (2005) showed how the content of total phenols depends on the type of solvent used for extraction, as well as its duration. Content of phenols in black currants ranged from 242 to 972 mg GAE/100 g of fresh fruit, with minimum value determined by the extraction in distilled water.

The type of currants' primary processing (mulching, particle size) has an effect on the phenolic content, especially anthocyanins in juice (Sójka and Krol, 2009). According to these authors, the size of currant parts should be from 2 to 5 mm, to obtain juice with the highest content of phenols. In any case, currant processing to juice most commonly leads to reduced content of phenols (Sójka et al., 2009), even up to 80% (Häkkinen et al., 2000). According to Hilz (2007), the reduction of total phenols occurs as consequence of the high level of pectin in the cell wall of the epidermis, which prevents extraction of these substances from the fruit. Enzymatic treatment could contribute to an increase in the content of total phenols in juice (Buchert et al., 2005). The addition of black currant juice to apple juice (Oszmiański and Wojdyła, 2009), milk, and dairy products (Skrede et al., 2004) increased total phenol content and antioxidant activity from 40% to 100%. By analyzing the content of total phenolics in a large number of fruits of dark color, Jakobek et al. (2007) determined the superiority of black currant juice in comparison to all other juices. Konic-Ristic et al. (2011) analyzed chemical composition and biological activity of the different types of berry fruit juices, and found that black currant juice has the highest content of phenolic compounds and the most obvious radical scavenging activity. Total phenol content in these juices ranged from 133 mg GAE/100 mL juice for red currants and up to 260 mg GAE/100 mL juice for black currants. During the storage of juices, reduction in phenolic compounds together with reduction of vitamin C content and antioxidant activity were recorded (Piljac-Žegarac et al., 2009).

Very often, berries and juices are stored for shorter or longer period in a frozen state. Although, in most studies, the amount of biologically active compounds was decreased during freezing, the loss of active compounds was not significant. Keeping black currant juices for 6 months at a temperature of 4 °C resulted in 50% reduction of total phenol content (Oszmiański and Wojdyła, 2009), while keeping it frozen resulted in a reduction of total

phenol content of less than 20% (Häkkinen et al., 2000). Moreover, in rare examples, storage in the frozen state led to an increase of their content (Pascual-Teresa and Sanchez-Ballesta, 2008). The high stability exhibited by phenolic substances during storage in the frozen state allows storage of fruits of currants for a long period. The fruits of five varieties of black currants stored in a frozen state for 9 months maintained high levels of total phenolics and antioxidant activity. The highest content of total phenolics in berries after harvest was the variety Ben Nevis (741.7 mg/100 g fresh fruit). After 9 months of storage in the frozen condition, the total phenol content was not significantly changed. In three varieties, an average reduction of 3% was recorded, whereas in Ben Sarek and Ben Nevis the phenolic content slightly increased (Bakowska-Barczak and Kolodziejczyk, 2011). Analyzing individual phenolic compounds in black currants, Häkkinen et al. (2000) found that the method of processing and longer storage life in the frozen condition affected their contents. The highest content was found in fresh berries, and a minimum reduction of about 5% was registered in the berries after storage in the frozen state for 9 months.

Bakowska-Barczak et al. (2009) found that the residues after juice pressing are a valuable source of phenolic compounds with strong antioxidant activity. The content of total phenols in black currant cultivar residue ranged from 160 to 230 mg GAE/100 g, with the highest amount in variety Ben Sarek. Kapasakalidis et al. (2006) reported that the content of total phenolics, total anthocyanins, and antioxidant activity was much higher (7–10 times higher) in the residue after juice pressing than in the edible parts of the fruit from which the epidermis was removed. This finding supports the claim that the major amount of bioactive compounds is concentrated in the fruit skin.

The varieties of red currants usually have a lower content of phenol compounds in relation to the varieties of black currant (Määttä et al., 2001). In red currant cultivars, the total phenol content ranged from 382 to 502 mg GAE/100 g fresh fruit (Benvenuti et al., 2004), whereas significantly lower contents of phenolics, ranging from 67.2 to 153.4 mg GAE/100 g, were recorded by Djordjević et al. (2010). As the most promising red currant cultivar, Redpul was emphasized by Giongo et al. (2008) and Djordjević et al. (2010). Lapornik et al. (2005) pointed out that the phenolic content of red currants ranged from 40 to 117 mg GAE/100 g FW. Depending on the solvent used in the extraction as well as the extraction process itself, the amount of phenolics significantly changed, and the lowest value of total phenol content was obtained by water extraction. In juices and other processed products of red currants, significant changes in the content of total phenols were recorded (Plessi et al., 2007). In our previous study (Konić-Ristić et al., 2011), it was shown that processing significantly influenced chemical composition, and among different berries, red currant juice was characterized by the lowest total phenol content (133 mg GAE/100 mL juice). Also, we recorded that juices of different red currant cultivars undergo reduction, even as much as 50%, of total phenol content during storage (Djordjević et al., 2010). Among analyzed varieties, Redpul had the highest content of total phenolics, both in fruits and in juices (Table 5). Red currants as well as black currants have a short shelf life. Freezing is a usual way of preservation. In a great number of varieties, we noticed a decrease in the content of phenols in fruits after

Table 5 Phenolic (mg GAE/100 g) and anthocyanin (mg/100 g) contents in berries and juice of red currant varieties

Variety	Fresh berries				Fresh juice			
	TP ^a	TACy	Dp	Cy	TP	TACy	Dp	Cy
Redpoll	153.4 ± 3.5	19.3 ± 1.9	7.2 ± 0.3	17.5 ± 0.7	90.8 ± 1.8	25.6 ± 0.2	2.0 ± 0.1	11.0 ± 0.2
Junifer	79.1 ± 2.2	14.2 ± 1.3	5.1 ± 0.2	11.3 ± 0.8	42.5 ± 1.1	17.9 ± 0.1	1.4 ± 0.2	8.0 ± 0.2
Jonkheer	96.4 ± 2.8	18.8 ± 2.1	4.3 ± 0.2	16.0 ± 0.4	41.4 ± 2.3	24.0 ± 0.2	1.1 ± 0.1	11.0 ± 0.3
Rolan	72.7 ± 2.5	11.1 ± 1.1	5.0 ± 0.3	9.1 ± 0.5	43.7 ± 1.9	14.8 ± 0.1	1.3 ± 0.1	7.0 ± 0.2
Stanza	98.1 ± 3.6	13.5 ± 1.5	6.0 ± 0.2	10.0 ± 0.5	45.4 ± 2.5	13.1 ± 0.1	1.4 ± 0.1	7.0 ± 0.3
Rondom	110.6 ± 6.5	12.4 ± 1.6	5.4 ± 0.2	11.3 ± 0.4	45.5 ± 1.4	15.5 ± 0.2	1.1 ± 0.1	5.0 ± 0.2
Mirana	108.4 ± 4.9	9.6 ± 0.9	6.2 ± 0.3	11.2 ± 0.6	39.5 ± 1.9	8.0 ± 0.1	1.2 ± 0.1	5.0 ± 0.2
Rovada	80.2 ± 2.6	8.2 ± 0.7	5.3 ± 0.1	8.4 ± 0.6	38.3 ± 2.0	8.9 ± 0.1	1.3 ± 0.2	4.1 ± 0.1
London	129.3 ± 6.5	15.0 ± 1.1	5.5 ± 0.2	11.5 ± 0.4	44.5 ± 2.1	14.2 ± 0.2	1.2 ± 0.1	8.0 ± 0.1
Market								
Makosta	67.2 ± 3.0	9.3 ± 1.1	4.3 ± 0.2	8.0 ± 0.3	42.2 ± 1.3	9.4 ± 0.1	1.3 ± 0.1	4.0 ± 0.1
Slovakia	72.0 ± 3.6	7.1 ± 1.2	4.0 ± 0.2	6.3 ± 0.6	28.0 ± 1.0	5.8 ± 0.1	1.2 ± 0.1	4.0 ± 0.2

TP, total phenolics; TACy, total anthocyanins; Dp, delphinidin; Cy, cyanidin.

^aData in table are presented as mean ± SD, in which each mean value is the average of three repetitions (Djordjevic et al., 2010).

storage in the frozen state, whereas in juices, an increase in total phenols was recorded (Djordjević et al., 2010). High levels of phenolic compounds and antioxidant activity of different black and red currant varieties have been attributed to the presence of anthocyanins, mainly distributed in epidermis (Oszmiański and Wojdyła, 2009).

The content of anthocyanins in currants depends on many factors, such as genetic predisposition, variety, weather conditions during the growing, harvesting period, method of processing, and storage of fruits (Bordonaba et al., 2010). By studying the contents of total and individual anthocyanins in number of varieties of blueberries, raspberries, and currants, Scalzoa et al. (2008) found that black currants had the highest content of total anthocyanins, ranging from 280 to 379 mg/100 g FW.

According to Anttonen and Karjalainen (2006), the anthocyanin content in different currant varieties grown under the same conditions could differ by 12% to 77%. Usually, in total phenol content in black currant cultivars, anthocyanins have ranged from 60% to 85% (Lugasia et al., 2011). Moyer et al. (2002) found that the content of total anthocyanins in black currant cultivars varied from 128 to 411 mg/100 g FW, which is far more than in other types of small fruits. According to Benvenuti et al. (2004), the total anthocyanin content in a large number of varieties of black currants, ranged from 153 to 281 mg/100 g; among them, Tsema and Tenah were the most abundant. The high content of anthocyanins in black currant fruits were also found by Rubinskiene et al. (2006), and the average values of the compounds, according to the results of their analysis, were from 285 to 508.8 mg/100 g FW.

The value of total anthocyanins increases with fruit ripening. Studying the impact of three harvesting periods (early, 90%; full, 95%; and late, 100% black fruits) on the content of anthocyanins in black currants for a period of 2 weeks, Bordonaba et al. (2010) found that the moment of harvesting had a significant impact. As expected, the highest content of these compounds was found in the third harvesting period. Depending on the duration of the extraction and the type of solvent, data on the anthocyanin content significantly changed. The smaller value, as well as in the case of total phenolics, was obtained after water extraction (Lapornik et al., 2005). Also, Djordjević et al. (2010) found that processing of fruits into juices in most varieties increased the anthocyanin content.

In the chemical class of anthocyanins, the most abundant aglycones, both in black and in red currants, are delphinidin and cyanidin. Among them, cyanidin is less stable, so one of the goals of breeding is to create varieties with more delphinidin content in fruits and, later, in the juices. As in red currant varieties, derivatives of cyanidin dominate, and the fruits and juices have reduced anthocyanin content in relation to the black currant (Springett, 2001). On the other hand, glycosides are much more stable than the aglycones, so more than 250 different anthocyanins were found in plants. The richness of purple, red, and pink colors of berries and juices, depending on the presence of cyanidin and delphinidin and their glycosides, influence the quality and acceptability by consumers (McDougall et al., 2005).

Four major glycosides, 3-O-glycosides and 3-O-rutinosides of cyanidin and delphinidin, make up about 97% of the total anthocyanin content (Figure 1). These results are confirmed by number of authors (Djordjević et al., 2010, 2013; Heinonen, 2007; Scalzoa et al., 2008).

By analyzing the content of aglycones in black currant and related juice, Iversen (1999) reported that, during processing, the content of aglycone declined and an almost identical percentage of reduction was found for all leading aglycones. Also, Oszmiański and Wojdyła (2009), after preserving black currant juice at a temperature of 4 °C for 6 months, found a significant reduction (about 50%) of anthocyanins. The most stable was cyanidin-3-O-rutinoside, with a reduction of 21%. In our previous study (Djordjević et al., 2010), processing of red currants into juice significantly reduced the content of the two most dominant aglycones, while any significant change after their storage in a frozen state was not noticed.

Most of the studies focus on the research on currant fruit and juice anthocyanins, and little on juice by-products. Kapasakalidis et al. (2006) studied anthocyanin profile and contents in black currant pomace and black currant press residue extracts, extracted with formic acid in methanol or with methanol/water/acetic acid. Four main anthocyanins, delphinidin-3-glucoside, delphinidin-3-rutinoside, cyanidin-3-glucoside, and cyanidin-3-rutinoside, were detected in both pomace and extracts. All samples showed significant antioxidant activity.

The stability of polyphenols, especially anthocyanins, has been studied, and it has been shown that they are affected by different parameters such as pH, metal ions, exposure to light, temperature, oxygen, and enzymatic activities (Bakowska et al., 2003). On the other hand, the stability of polyphenol compounds could be improved using microencapsulation technologies, such as spray drying (Ersus and Yurdagel, 2007). Bakowska-Barczak and Kolodziejczyk (2011) evaluated the concentration of bioactive compounds in five black currant varieties (Ben Alder, Ben Tirran, Ben Nevis, Ben Conan, and Ben Sarek) and the retention of their polyphenol compounds as well as antioxidant activity after microencapsulation by spray-drying. These authors showed that spray-dried polyphenol powders were characterized by high storage stability at both temperatures tested (8 and 25 °C for 12 months) which was better than that in maltodextrins extracts.

Another significant focus of scientists studying currants is the biological activity and health benefit effects of these fruits. The healing properties of fruits, especially berries, are known from the earliest times. Many studies have confirmed that consumption of black currants contributes to the prevention and treatment of various diseases in humans (Moyer et al., 2002). Currants have a wide range of biological activities, from antioxidant to anticancer, anti-inflammatory, antibacterial, antimycotic, and antiviral properties. It was also shown that black currants decrease platelet aggregation and blood pressure, and have a positive effect on the metabolism of cholesterol (Karjalainen et al., 2009; Konić-Ristić et al., 2011).

Borges et al. (2010) studied total antioxidant capacity of five different berries using a ferric reducing ability of plasma assay, and black currants had the highest antioxidant capacity ($51.6 \mu\text{mol Fe}^{2+}/\text{g}$), whereas for red currants it was $24.6 \mu\text{mol Fe}^{2+}/\text{g}$, just before cranberries. Jakobek et al. (2007) evaluated the antioxidant activity of different berries using DPPH assay, showing a high value for black currant ($30.15 \mu\text{mol TE}/\text{mL}$). Black currant juice also possessed the strongest radical scavenging activity ($0.91 \pm 0.07 \text{ IC}_{50} \text{ mg}/\text{mL}$), whereas the activity of red currant juice was significantly lower ($3.14 \pm 0.23 \text{ IC}_{50} \text{ mg}/\text{mL}$) (Konić-Ristić et al., 2011).

In vitro studies have shown that currant extracts and their bioactive compounds inhibit cell proliferation, modulate cell cycle arrest, and induce apoptosis in cancer cells with marked selectivity toward normal cells. Black and red currant juices were tested for antiproliferative activities against cervix cell line (HeLa), melanoma cell line (Fem X), colon cell line (LS 174), breast cell line (MCF-7), and prostate cell line (PC-3), and both juices examined showed antiproliferative activity in a dose-dependent manner (Konić-Ristić et al., 2011). Black currant extract, investigated by Jia et al. (2012), inhibited the proliferation of gastric cancer cells SGC-7901 in a dose- and time-dependent manner, with the IC_{50} of 12.7, 10.2, and $9.0 \text{ mg}/\text{mL}$ for 12, 24, and 48 h, respectively. Moreover, morphologic study provided evidence of cell shrinkage, formation of cytoplasmic filaments, condensation of nuclear chromatin, and cell apoptosis in the presence of extract.

In an animal study, Bishayee et al. (2011) investigated the chemopreventive effects of anthocyanin-rich black currant skin extract using model of rat liver carcinogenesis. Extract, in a dose-dependent manner, decreased the incidence, total number, multiplicity, size, and volume of preneoplastic hepatic nodules. The antihepatocarcinogenic effect was also confirmed by histopathological, immunohistochemical, and mechanistic studies.

Numerous epidemiological studies have shown a positive correlation between currant consumption and cardiovascular health. Matsumoto et al. (2005) reported that anthocyanins from black currants could help heart muscle rate and blood flow. Eight weeks' consumption of different berries or berry juices (bilberries, lingonberries, black currants, strawberries, chokeberries, and raspberries) in a single-blind, randomized, placebo-controlled intervention study with patients with the presence of cardiovascular risk factors exerted beneficial effects on HDL-cholesterol levels, but statistically significant effects on low-density-lipoprotein levels and triglycerides were not observed (Erlund et al., 2008).

In addition, a capsule that consisted of 17 different naturally purified anthocyanins from bilberries and black currants was shown to have positive effects in subjects with diabetes mellitus (type 1 or type 2), dyslipidemia, or metabolic syndrome (Qin et al., 2009). Regarding eye health in elderly people, a few studies dealing with the effects of black currant anthocyanins in patients with glaucoma suggested a potential protective effect of these extracts by decreasing ocular pressure and increasing ocular blood flow (Ohguro et al., 2013).

The third direction of modern research is related to agroecological and environmental conditions and plant protection. High yield is a very important trait, which determines the profit of a currant plantation. New currant cultivars must have yields higher than 8 t/ha/year (Pedersen, 2008). Productivity is determined by genetic factors, especially by degree of self-fertility, and also by environmental factors. In addition, yield depends on weather during differentiation of flowers and flowering. Most black currant cultivars are partially self-sterile, and cross-pollination is essential for optimal yields. In Europe, about 20% of the plants on a plantation are usually pollinizer cultivars. Breeding and growing self-pollinated cultivars is of great importance for the successful production of currants. With self-fertilizing cultivars, crops could be grown in a single cultivar planting, thereby, achieving a substantially higher economic effect and simplifying production.

Growing currant cultivars in high tunnels is a relatively economical form of protected culture, and offers cultural advantages such as protection from the bad weather conditions and an extended production season. Interest in high tunnels for small fruit production has been increasing. Growers are using multibay and single-bay high tunnels for production of currants. In most cases, high tunnels increased the yields of berry crops, improved quality, and decreased the incidence of most diseases compared with field production, with powdery mildew (*Sphaerotheca macularis*) being a notable exception. In currants grown in heated high plastic tunnels or greenhouses, especially red currants, the ripening phase starts earlier.

Successful growing of black currants depends on the influence of a large number of environmental factors, especially light and temperature. A moderate change in environmental factors using different types of shading nets resulted in the improvement of conditions for cultivation (Šavikin et al., 2013b). High temperatures and intensive solar radiation in summer cause problems in fruit growing. Sunburn on fruit results in browning and necrosis as a consequence of increased surface temperatures. Plants grown under nets had less damage to leaves and berries, resulting in a lower yield lost, and providing economic advantages for the growers. Also, those cultivars still had a high content of ascorbic acid, sugars, and radical scavenging activity, thus, representing a good source of valuable nutritive and biologically active compounds.

After mild winters, the bud break is unbalanced or poor, the flower period is lengthened, and the flower and fruit development is uneven. Overall, this leads to fruit and flower fall and thus, low yields and poor fruit quality. There is a need to control the break of dormancy and the balance in flowers and flowering time. In conclusion, the changing climate and the need for more sustainable cultural management will change the present production system and clearly demand different approaches in research and development for the future. The effects of warmer winters, with an associated reduction in chilling levels, are beginning to have a serious impact on the performance of some black currant germplasm, with uneven bud break and reduced fruit quality at harvest. As a result, there is an increasing interest in the selection of germplasm with a reduced winter chilling requirement.

Currants are susceptible to many pest and disease problems that interfere with production worldwide, such as American powdery mildew (*Sphaerotheca mors-uvae*), leaf spot (*Gloeosporidiella ribis*), and white pine blister-rust (*C. ribicola*). The most serious pest in black currants is the Gall mite (*C. ribis*), causing the damaging condition known as ‘big bud’ and also transmitting BRV within and between plantations. The identification of resistant germplasm and creation of new cultivars are, at present, time-consuming and expensive processes. Resistance based on gene *Ce* introgression from gooseberry has been used in the United Kingdom breeding programs for black currants (Brennan et al., 2009). Also, many other breeding programs have, as a main aim of their research, the development of cultivars resistant to many pests and diseases.

Analyzing the trends in the development of currant production over the years, high variability of the profitability could be observed. Currant producers have continually been looking for new cultivation technologies that could make it possible to reduce production costs. Due to high labor costs, commercial currant producers use mechanical harvesting. Cultivars suitable for mechanical harvesting (Ben Sarek, Ban Alder, Ben Hope, Tiben, Hrom) are compact, moderate, have upright growth. Mechanical harvesting significantly reduces production costs, improves the effect of harvest, and increases the percentage of harvested fruits.

In addition, the breeding objectives for new cultivars of *Ribes* are increasingly aligned with the commercial requirements of the relevant industry and downstream processors, and fruit quality parameters are now of equal importance to many agronomic traits. The high yield is no longer the main driver for the selection of new black currant cultivars, and there is an increasing demand for fruit of high quality, particularly in nutritional and sensory components. This demand now extends to the small fresh market for *Ribes* fruits, partly as a result of public health awareness.

SUMMARY POINTS

- Black and red currants are the two main *Ribes* species well known in the world production of the berry fruits.
- Black and red currants are widely consumed throughout the world in fresh or frozen form, as juices, in various dishes, and as constituents of functional foods.
- The main groups of primary metabolites present in these berries are sugars and organic acids; while phenolic compounds comprise the dominant group of secondary metabolites.
- Cyanidin 3-rutinoside, delphinidin 3-rutinoside, delphinidin 3-glucoside, and cyanidin 3-glucoside are dominant anthocyanins in black currants, whereas the most abundant anthocyanins in red currants are cyanidin 3-glycosides.
- Anthocyanins are distributed mainly in the epidermis.
- Black currant buds are used for essential oil production for application in the cosmetics and perfume industries.

- Currant seeds, a by-product during juice production, are also recognized as a valuable source of oil rich in polyunsaturated fatty acids.
- Besides genetic predispositions, environmental factors such as temperature, light, humidity, and agricultural practices as well as methods of extraction have significant influence on the content of phenolic compounds in currants.
- Currants have a wide range of biological activities from antioxidant to anticancer, anti-inflammatory, antibacterial, antimycotic, and antiviral.
- Numerous epidemiological studies have shown a positive correlation between currant consumption and cardiovascular health.
- Cultivars resistant to diseases such as powdery mildew, white pine blister rust, and anthracnose, with compact canes and vigorous, upright growth so as to be suitable for mechanical harvesting, are the focus of breeding programs.

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CHAPTER 6

Composition of the Cherry (*Prunus avium* L. and *Prunus cerasus* L.; Rosaceae)

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LIST OF ABBREVIATIONS

ABTS ^{•+} 2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)
CTIFL Center Technique Interprofessionnel des Fruits et Légumes
FA Fatty acid
FW Fresh weight
GC-MS Gas chromatography-mass spectrometer
HPLC-DAD/ESI-MS High performance liquid chromatography-diode array detection/electrospray ionization-mass spectrometer
HS-SPME Headspace-solid phase microextraction
ORAC Oxygen radical absorbance capacity
RAE Retinol activity equivalent
TA Titratable acidity
TAA Total antioxidant activity

TE Trolox equivalent

TPC Total phenolic content

TSS Total soluble solids

TSS/TA Maturation index

BOTANICAL ASPECTS

Cherries belong to the genus *Prunus*, subgenus *Cerasus*, within the Rosaceae family, most of which are native to the Europe and Asia. This subgenus is divided into eight sections, with section 1 (Eurocerasus) being the most important. The predominant species of the Eurocerasus section grown for their fruit are the sweet (*Prunus avium* L.), sour (*Prunus cerasus* L.), and ground cherries (*Prunus fruticosa* Pall.). All *Prunus* species have a basic chromosome number of $x=8$. Sweet cherry has a diploid genome ($2n=2x=16$), whereas sour and ground cherries are tetraploid ($2n=4x=32$).

Tetraploid hybrids of *P. avium* $\times$ *P. cerasus* can occur naturally, resulting from sour cherry pollination with unreduced pollen ($2n$). They are known as Duke cherries (*Prunus gondouini* (Poit. & Turp.) Rhehd.), with fruit and tree features intermediate between the two species. Ground cherry and sour cherry can also hybridize, and some of those cultivars are marketed in Russia and Eastern Europe.

Sweet cherries have been classified into subgroups according to fruit color, shape, and texture. These groups are black geans, amber geans, hearts, and bigarreaux. Geans have heart-shaped fruits with tender flesh, black geans have dark-colored flesh, and amber geans have light yellow and translucent flesh and skin. Bigarreaux have light-colored skin with hard, cracking flesh. Hearts are dark, with flesh texture in between that of geans and bigarreaux (Kappel et al., 2012).

Sour cherries are divided into two groups (amarelles and morellos) according to the skin and juice color and the fruit shape. The amarelles are generally flattened fruits with pale red skin and colorless juice. Morello fruits are spherical or cordate with very dark red skin and juice. In 1953, Linnaeus named these two groups *Prunus cerasus capronia* and *Prunus cerasus austere*, respectively.

Cherry and sour cherry trees are deciduous trees that grow in areas with temperate climates and well-differentiated seasons, where they have adapted to low winter temperatures and summer drought. The climatic conditions that are most limiting to production of these species include temperature, precipitation, and wind. Other factors to be considered are sudden freezes during winter, spring frosts, incidence of summer winds, and potential for hail and lightning. These species require a latency period that begins during autumn with movement of assimilates to storage organs (roots and wood) and subsequent defoliation. Growth starts after a certain amount of winter chilling occurs, and heat is then necessary to achieve full bloom. However, different studies suggest that in *Prunus*, chilling requirements have much stronger effects on flowering time than heat (Alburquerque et al., 2008). Chilling requirement is a varietal characteristic and generally ranges between 750 and 1400 hours (Seif and Gruppe, 1985).

During bloom, higher temperatures can reduce fruit set because of accelerated pollen tube growth rates and reduced numbers of pollen tubes growing along the style; in the ovary, ovule degeneration accelerates (Hedhly et al., 2007). High summer temperatures during floral differentiation may lead to formation of double pistils, with the subsequent appearance of double fruits (Beppu et al., 2001).

Moreover, cherries are entomophilous species. In most cases, they need adequate weather conditions for cross-pollination during flowering. Conditions such as low rainfall, temperatures greater than 13–14 °C, and wind speeds lower than 4–5 m/s are usually suitable for the flight of bees.

Selection of cherry rootstock is dependent on the soil. Cherries prefer light, well-drained soils at a pH of 5.5–7.5. Silt loam is the best soil, but cherries can tolerate soil classes ranging from sandy loam to clay loam, provided there is good drainage.

Frequent irrigation inputs are required during the cherry growing season, but not during flowering or ripening. In these periods, rainfall can compromise production. With respect to flowering and ripening, the lack of fruit set and fruit cracking can occur (especially when the cherries are changing color from yellow to red), respectively.

ANCIENT CULTIVARS

Sweet cherry (*P. avium*, L.) and sour cherry (*P. cerasus*, L.) trees are two of the economically most valuable stone fruit tree species. As mentioned, the origin of these species is located in Central Europe and areas surrounding the Caspian and Black Seas, and it is widespread through mainland Europe and in western Asian areas (Wünsch and Hormaza, 2002). The first archaeological evidences were cherry pits that were found in caves in different parts of Europe, dated about 5000 to 4000 BCE (Janick, 2011). The earliest description of sweet cherry was made by Theophrastus (about 300 BCE), who described a large tree with red and round fruit and named it *Kerasos* in honor of the name of the town Kerasum. By the Roman era, cherries were commonly included as a dietary component, as evidenced by cherry seeds found during archaeological excavations carried out in Germany (Janick, 2011). Their cultivation spread through Europe during this era, although the authentic spread was not until the sixteenth century (Watkins, 1976). In addition, Pliny and Virgil described the cherry cultivars of the Roman Empire, including the cultivar ‘Junian’ whose characteristics fit with those of the French ‘Guigne’ and the ancient cultivar ‘Lusitanina’ that corresponds to the modern cultivar ‘Griotte’ of Portugal (Hedrick, 1915; Janick, 2011). Therefore, most sweet cherry cultivars currently grown are only a few generations from wild clones or landraces well adapted to each area of cultivation (Lezzoni et al., 1990; Wünsch and Hormaza, 2002). The spread of sour and sweet cherry cultivation throughout North America was likely based on seeds and budwood of a limited number of cultivars brought by the early European settlers (Janick, 2011; Wünsch and Hormaza, 2002). Among sweet cherry cultivars described were ‘Bigarreau’, ‘English Morello’, and ‘Napoleon’, also renamed as

‘Royal Ann’. In 1875, Seth Lewelling obtained two new cultivars from the seeds of the ‘Republican’ cultivar called ‘Bing’ and ‘Yan’ (Hedrick, 1915). Nowadays, the ‘Bing’ cultivar is the most important cherry cultivar of the United States. Concerning the sour cherry, the ‘Montmorency’ cultivar, originating in the Montmorency Valley of France, was introduced in North America before the seventeenth century. This sour cherry cultivar is considered to be the main cultivar grown in North America (Janick, 2011).

The regular consumption of cherries is related to a balanced diet and broad spectrum of health benefits due to the great quantity of bioactive or nutraceutical compounds present in this fruit (González-Gómez et al., 2010; Tomás-Barberán et al., 2013). By late fourteenth and early fifteenth centuries, cherries were included in an Italian medical book, because they were considered to be fruit with health benefits and were probably collected for medical purposes (Janick, 2011).

COMPOSITION OF MODERN CULTIVARS

Chemical composition of cherries is dependent on the cultivar (Gonçalves et al., 2006). In addition, maturation stage, agricultural practices, and environmental conditions can also alter chemical composition. Although overall the concentration of soluble solids increases during maturation (Crisosto et al., 2002), whereas titratable acidity (TA) declines, parameters such as sugar composition, total soluble solids (TSS), acidity and organic acid profiles, and maturation index (TSS/TA) affect quality and consumer preference. For example, Usenik et al. (2010) reported that scion–rootstock interaction impacts quality of the ‘Lapins’ cultivar. Similar results were obtained regarding the quality of the ‘Sunburst’ cultivar when the impact of different rootstocks was evaluated (Jiménez et al., 2004). In addition, Bieniek et al. (2011), Faniadis et al. (2010), and Gonçalves et al. (2004) showed that the chemical composition of cherry cultivars is influenced by environmental conditions.

Moisture

Water is the major constituent of the fruit. The moisture of the sweet and sour cherries at the optimal point of ripening is around 80–83% (ANSES/Ciqual French food composition table, 2012; RedBEDCA, 2014; Saxholt et al., 2008; USDA, 2013), although some varieties, such as ‘Sciazza’ (Esti et al., 2002), ‘Van’, and ‘Noir De Guben’ (Vursavuş et al., 2006), are harvested at lower moisture.

Carbohydrates

Carbohydrates are the main chemical compounds in cherries, with contents of 12.2–17.0% (Canadian Nutrient File database, 2012; INSA, 2014). Aside from carbohydrates, dietary fiber represents 1.3–2.1% of the total compounds. Cherries are not considered a significant source of dietary fiber, but their content is higher than other *Prunus* fruits

(McCune et al., 2011). No starch has been found in cherries, and available sugar content typically ranges from 11 to 15%. However, sugar composition is variable (even within cultivars) and depends on climatic conditions, cultivation systems (Hrotko, 2008), and rootstock (Gonçalves et al., 2006; Usenik et al., 2010). Thus, some cultivars of cherries contain between 8 and 11% of sugars (Bieniek et al., 2011; Jänes et al., 2010; Sirbu et al., 2012), and other cultivars contain up to 20% of sugars (Girard and Kopp, 1998; Gündoğdu and Bilge, 2012; Usenik et al., 2010). The main sugar in cherries is glucose. The amount of this sugar usually ranges from 6 to 10 g/100 g of fresh weight (FW) in a wide range of cultivars including, 'Ferprime', 'Burlat', 'Van', 'Bing', 'Lapins', and 'Sweetheart' (Table 1). However, the amount of glucose (and other sugars) depends on the cultivar. For instance, the Turkish cultivars 'Beyrudi', 'Kısa ap', and 'Uzun' exhibit sap contents containing 15.1–21.5 g of glucose/100 g of FW (Gündoğdu and Bilge, 2012). In contrast, some Canadian varieties, such as 13S-43-48 and 13S-20-30, have glucose contents lower than 6 g/100 g of FW (Girard and Kopp, 1998). Fructose, the second most abundant sugar, ranges from 4.6 to 6.7 g/100 g of FW (Table 1), although cultivars such as 'Badascony', 'Early Van Compact', 'Fernier', and 'Lala Star' exhibit values around 10 g/100 g of FW (Usenik et al., 2008). Even the picota type of 'Ambrunés' sweet cherry shows values of 12 g/100 g of FW, making fructose the main sugar present during the last stages of maturation (Serradilla et al., 2011). According to the Canadian Nutrient File database (2012), the contents of glucose and fructose of sour cherries are lower than those of sweet cherries (4.2 and 3.5 g/100 g of FW, respectively). However, other reports showed that the contents of glucose and fructose in sour cherry are 7–9 and 3.5–4 g/100 g of FW, respectively (Papp et al., 2010). The composition of sorbitol usually ranges from 0.44 to 4 g/100 g of FW (Table 1). Sucrose content varied from 0.05 g/100 g of FW in 'Ferrovia' and 'Sciazza' (Esti et al., 2002) to 1.18 g/100 g of FW in the French cultivar 'Fernier' (Usenik et al., 2008).

Composition of sugars is directly related to TSS, which is one of the most important factors determining consumer acceptability (Crisosto et al., 2003; Sloulin, 1990). Most sweet cherry cultivars exhibit percentages of TSS between 15 and 19% (Table 1). Despite this fact, 'Salmo' (Girard and Kopp, 1998), 'Ambrunés' (Serradilla et al., 2011), and 'Mollar' (Pérez-Sánchez et al., 2010) cultivars, among others, exhibited contents higher than 23%. On the other hand, the early cultivar 'Burlat' had a TSS content lower than 15% (Faniadis et al., 2010; Garcia-Montiel et al., 2010), which is in contrast with studies that showed around 18% (Ballistreri et al., 2013; Usenik et al., 2008). Percentage of TSS in the sour cherry is similar to that of the sweet cherry. Papp et al. (2010) reported values from 14.4 to 23.1% of soluble solids in 11 Hungarian varieties.

Organic Acids

Acidity is another crucial factor for consumer acceptability. Sweet cherries are mildly acidic fruits with pH values between 3.7 and 4.2 (Table 1), although some cultivars, such as 'Minnulara' and 'Napoleona Grappolo', have pH values up to 4.5 (Ballistreri et al., 2013).

Table 1 Physicochemical parameters of different sweet cherry cultivars

Physicochemical parameters	Cultivars according to time of maturity					
	Early		Mid		Late	
	Ferprime (primulat)	Burlat	Van	Bing	Lapins	Sweetheart
% TSS	16.7	18.4	19.4	16.7	14.7	17.9
pH	3.9	4.2	3.8	3.7	3.9	3.8
Titrateable acidity (% malic acid)	0.73	0.83	0.90	0.83	0.39	0.87
TSS/TA ratio	23.8	22.2	19.9	20.0	37.7	22.4
Malic acid (mg/100 g)	360	750	845	755	417	823
Citric acid (mg/100 g)	12.0	12.0	2.6	5.6	42.0	4.8
Fumaric acid (mg/100 g)	0.38	0.75	0.20	0.12	0.87	0.38
Glucose (g/100 g)	6.2	7.9	6.8	6.3	10.2	6.5
Fructose (g/100 g)	5.1	6.7	5.0	5.1	4.6	4.7
Sorbitol (g/100 g)	0.44	1.4	4.0	3.6	1.3	3.0
References	d, f	a, f	c, h	c	f, g	b, c, e

TSS, Total soluble solid; TSS/TA, maturation index.

^aBallistreri et al. (2013).

^bDiaz-Mula et al. (2009).

^cGirard and Kopp (1998).

^dSansavini and Lugli (2008).

^eSerradilla et al. (2012).

^fUsenik et al. (2008).

^gUsenik et al. (2010).

^hVursavuş et al. (2006).

Values of pH in sour cherries range from 3.1 to 3.6 (Milošević and Milošević, 2012; Papp et al., 2010). The TA in most of sweet cultivars varies from 0.7 to 0.9% of malic acid. However, cultivars including ‘Lapins’ (Table 1), ‘Corazón Serrano’, ‘Del Valle’, and ‘Lamper’, among others, show low TA (Pérez-Sánchez et al., 2010). In contrast, some cultivars contain higher values of TA (e.g., ‘Newstar’, ‘NY-6479’, ‘Sonata’, and ‘Sweetheart’), with values higher than 1.2% of malic acid (Díaz-Mula et al., 2009; Serrano et al., 2009). In sour cherries, the values of TA are typically 1.2% of malic acid, and some cultivars can exhibit values of 1.9% of malic acid (Ansari and Davarynejad, 2008; Milošević and Milošević, 2012; Papp et al., 2010). The main organic acid in cherries is malic acid, with values of 600–900 mg/100 g of FW. Cultivars such as ‘Ferprime’, ‘Lapins’ (Table 1), and ‘Ambrunés’ can exhibit values around 300 mg/100 g of FW. Other cultivars contain values above 1100 mg/100 g of FW, including ‘Beyrudi’, ‘Kısa ap’, and ‘Marvin’ (Gündoğdu and Bilge, 2012; Serrano et al., 2005). Citric acid is found at levels of 4–50 mg/100 g of FW (Table 1), although some cultivars, such as ‘0900 Ziraat’, ‘Beyrudi’, and ‘470’, achieve concentrations of 170–300 mg/100 g of FW (Gündoğdu and Bilge, 2012; Serrano et al., 2005). The concentration of succinic acid ranged from 4 mg/100 g in the ‘0900 Ziraat’ cultivar (Gündoğdu and Bilge, 2012) to 38 mg/100 g of FW in the ‘Bing’ cultivar (Girard and Kopp, 1998). Other minor organic acids are shikimic, fumaric, and oxalic acids, with levels lower than 5 mg/100 g of FW.

Percentage of TSS/TA is widely used as an indicator of harvesting time because of its influence on the flavor of sweet cherry (Crisosto et al., 2002, 2003). TSS/TA usually ranges from 20 to 30, but some cultivars have achieved values around 40 (Serradilla et al., 2012; Usenik et al., 2010). The values of TSS/TA in sour cherries are usually lower than 16 (Ansari and Davarynejad, 2008; Papp et al., 2010), although some cultivars had values up to 20 (Milošević and Milošević, 2012).

Nitrogen Compounds

Protein content in cherries varied between 0.8 and 1.4% (Saxholt et al., 2008; USDA, 2013). Proteins contain all essential amino acids but exist in low amounts, from 5 to 10 mg of methionine/100 g of edible portion to 32–46 mg of lysine/100 g of edible portion. Proteins in cherries are rich in aspartic acid, which comprised 57–62.3% of total amino acids (569–740 mg/100 g of edible portion). The most abundant amino acids are glutamic acid and lysine, with 0.04–0.08% and 0.03–0.04% of total amino acids, respectively (Saxholt et al., 2008; USDA, 2013).

Sweet cherries are also a good source of indolamines, such as tryptophan, melatonin (N-acetyl-5-methoxytryptamine), and serotonin (5-hydroxytryptamine). Melatonin and serotonin are biosynthesized from the essential amino acid tryptophan through the shikimic acid pathway. González-Gómez et al. (2009) reported that the relationship between melatonin and serotonin is also characteristic for each sweet cherry cultivar. For example, the highest content of melatonin was found in the ‘Burlat’ (22.4 ng/100 g), variety,

whereas the highest content of serotonin was found in ‘Ambrunés’ (37.6 ng/100 g). For sour cherries, [Burkhardt et al. \(2001\)](#) reported that the cultivar ‘Montmorency’ had almost six times more melatonin than ‘Balaton’. In humans, melatonin acts in the regulation of the sleep–wake cycle and as an antioxidant agent; serotonin acts as neurotransmitter and also controls mood behavior.

Lipids

Cherries are low-fat foods. Their fat content varies between 0.2 and 0.7 g/100 g of edible portion and is evenly distributed in saturated, monounsaturated, and polyunsaturated fatty acids (FAs) ([ANSES/Ciqual French food composition table, 2012](#); [Canadian Nutrient File database, 2012](#); [Saxholt et al., 2008](#); [USDA, 2013](#)). Palmitic (C 16:0) and stearic acids (C 18:0) are the main saturated FA, with 30–50 mg/100 g and 10–20 mg/100 g of edible portion, respectively; no short saturated FAs have been found. The majority of monounsaturated FA in cherries consists of oleic acid (C 18:1; n-9), with amounts between 10 and 80 mg/100 g of edible portion. The main polyunsaturated FAs are linoleic (C 18:2 c9, c12; n-6) and α -linolenic acids (C 18:3 c6, c12, c15; n-3), with amounts of 25 and 50 mg/100 g of edible portion, respectively. The amounts of plant sterols are around 12 mg/100 g of edible portion. Cholesterol has not been detected ([ANSES/Ciqual French food composition table, 2012](#); [Saxholt et al., 2008](#); [USDA, 2013](#)).

Minerals

Cherries contain noteworthy amounts of potassium and are considered a good source of this mineral ([McCune et al., 2011](#)). The amounts of potassium are 170–260 mg/100 g of edible portion. The other minerals in cherries exist in low concentrations, including phosphorous (15–18 mg/100 g), calcium (13–20 mg/100 g), magnesium (8–13 mg/100 g), and sodium (1–8 mg/100 g). Other minerals, such as iron, manganese, copper, zinc, iodine, and selenium, are also present at very low concentrations (<1 mg/100 g of edible portion) ([ANSES/Ciqual French food composition table, 2012](#); [Canadian Nutrient File database, 2012](#); [Saxholt et al., 2008](#); [USDA, 2013](#)).

Vitamins

Cherries are a good source of ascorbic acid (vitamin C), with mean values of 6–10 mg/100 g of FW ([ANSES/Ciqual French food composition table, 2012](#); [Saxholt et al., 2008](#); [USDA, 2013](#)). [Jänes et al. \(2010\)](#) reported that 8 out of 12 Estonian cultivars exhibited levels up to 20 mg/100 g of FW; furthermore, the cultivar ‘470’ contained 27 mg/100 g of FW ([Serrano et al., 2005](#)). In contrast, contents lower than 4 mg/100 g of FW have been found in the cultivars ‘Van’, ‘Noir De Guben’, and ‘0900 Ziraat’ ([Vursavus et al., 2006](#)). Contents of the other water-soluble vitamins in cherries are much lower. Contents of niacin and pantothenic acid vary from 0.15 to 0.40 mg/100 g of edible portion. Thiamine, riboflavin, and pyridoxine contents ranged

from 0.02 to 0.05 mg/100 g of edible portion, whereas folate and biotin exist in microgram concentrations. Vitamin E is the major soluble lipid vitamin, with amounts of 0.07–0.2 mg of tocopherol equivalent/100 g of edible portion. Levels of vitamin A in sweet cherries are around 3 mg of retinol activity equivalent (RAE)/100 g of edible portion, whereas 64 mg of RAE/100 g exist in sour cherries.

Phenolic Compounds

Sweet and sour cherries are considered excellent sources of phenolic compounds and polyphenols. These are secondary metabolites synthesized by plant tissues through the process of photosynthesis that are relevant to the quality of plant foods because of their important role in the appearance, taste, and flavor of cherries and their health-promoting properties (Tomás-Barberán and Espín, 2001). In fact, epidemiological studies have demonstrated that consumption of fruits and vegetables rich in bioactive compounds or phytochemicals can reduce the risk of degenerative diseases caused by oxidative stress, such as cancer, atherosclerosis, and cardiovascular disease (Chaovanalikit and Wrolstad, 2004). It has also been reported that consumption of sweet and sour cherries reduces the risk of cancer (Kang et al., 2003), as well as pain from arthritis and inflammation (Jacob et al., 2003; Seeram et al., 2001), and offers protection against neurodegenerative diseases (Kim et al., 2005).

The polyphenol composition of sweet and sour cherries has been reported by several studies (Ballistreri et al., 2013; González-Gómez et al., 2010; Khoo et al., 2011; Mulabagal et al., 2009; Serradilla et al., 2011; Tomás-Barberán et al., 2013; Usenik et al., 2008). Cherry phenols contain substantial amounts of flavonoids, such as anthocyanins, flavan-3-ols, and flavanols. Anthocyanins are water-soluble pigments located in the vacuole responsible for the characteristic red color of cherry skin; a positive correlation between changes of skin color with the accumulation of anthocyanins during ripening has been reported (Gonçalves et al., 2004; Mozetič et al., 2004; Valero and Serrano, 2010). Therefore, their content has a great influence on the final quality, because skin color is one of the most important indicators of quality in cherries (Crisosto et al., 2003). Anthocyanins are derived from a precursor common to all flavonoids called *flavanone 2S-naringenin* (Cheynier et al., 2012). These compounds exhibit a basic structure (flavylium (2-phenylbenzopyrilium)), that can also be called *aglycones* or *anthocyanidins*. These compounds can be glycosylated by one or more sugars, mainly D-glucose, L-rhamnose, D-galactose, D-xylose, and arabinose, to form the glycosides, or with different acylated groups to form acylglycosides. In sweet cherries, the major anthocyanins include cyanidin-3-O-rutinoside (red-purple color) and cyanidin-3-O-glucoside (orange-red color), followed by peonidin-3-O-rutinoside (orange-red color) and peonidin-3-O-rutinoside (orange-red color). Pelargonidin-3-O-rutinoside occurs in much lower amounts (Gonçalves et al., 2007). It has been reported that the total anthocyanin content ranges from 2 to 300 mg/100 g (Valero and Serrano, 2010), because the concentration of these compounds depends on genotype, ripening stage, year of study, and agronomic and storage

conditions (Gonçalves et al., 2007; Usenik et al., 2008; Valero and Serrano, 2010). Thus in light-colored cherries (score of 3 on the Center Technique Interprofessionnel des Fruits et Légumes (CTIFL) color chart), such as 'Van', 'Lapins', and 'Sweetheart', anthocyanin contents varied from 2 to 47.1 mg 100/g, whereas dark cherries (score of 5 on the CTIFL color chart), such as 'Burlat' and 'Bing', ranged from 82 to 297 mg 100/g (Gao and Mazza, 1995) (Table 2). On the other hand, among early cultivars, 'Santina' and 'Burlat' have been reported to exhibit the highest total anthocyanin contents, with 129 and 84.59 mg/100 g, respectively (Ballistreri et al., 2013; Tomás-Barberán et al., 2013). However, for mid and late cultivars, 'Bing' and 'Kordia' showed the highest levels, with 224.67 and 185 mg 100/g, respectively (Gao and Mazza, 1995; Mulabagal et al., 2009). In general, light-colored and dark-colored red sweet cherry cultivars contain cyanidin-3-O-rutinoside as the primary anthocyanin (77–96.2% of total anthocyanin content), and for this reason, these sweet cherry cultivars exhibit this characteristic color (Ballistreri et al., 2013; Gonçalves et al., 2007; González-Gómez et al., 2010; Mozetič et al., 2002; Serrano et al., 2009; Usenik et al., 2008). The highest amount of this compound has been observed in a hybrid line of sweet cherry called '13S-10-40', with 243.9 mg/100 g (Gao and Mazza, 1995), and the yellow sweet cherry cultivars 'Rainier' and 'Gold' exhibited the lowest levels (<1 mg/100 g). On the other hand, the sour cherry cultivars 'Montmorency' and 'Batalon' are characterized by exhibiting cyanidin-3-O-glucosylrutinoside and cyanidin-3-O-rutinoside at a ratio of 3:1 (Mulabagal et al., 2009).

The second-most important anthocyanin is cyanidin-3-O-glucoside. Ballistreri et al. (2013), González-Gómez et al. (2010), and Usenik et al. (2008) have reported that early cultivars ('Burlat', 'Ferprime', 'Moreau', and 'Navalinda') are characterized by exhibiting the highest proportions of cyanidin-3-O-glucoside (compared with the total anthocyanins), ranging from 16.8 to 48.72% of total anthocyanins. In contrast, the bicolored cultivar 'Ferrador' shows the lowest concentration of cyanidin-3-O-glucoside (0.03 mg/100 g) (Usenik et al., 2008). Epidemiological studies on cyanidins have reported that these compounds exhibit biologically relevant antioxidant properties (McCune et al., 2011). Other minor anthocyanins identified in sweet cherries are pelargonidin-3-O-rutinoside and peonidin-3-O-rutinoside, which range from 0.49 to 8.09% and 0.92 to 1.88% of total anthocyanins, respectively (Usenik et al., 2008). In the case of pelargonidin-3-O-rutinoside, 'Bing' and 'Sciazza' cultivars show the highest amounts (3.11 and 3.5 mg/100 g, respectively), according to Gao and Mazza (1995) and Ballistreri et al. (2013) (Table 2). With respect to peonidin-3-O-rutinoside, the highest levels were found in the 'Sciazza' (27.5 mg 100/g) and 'Sylvia' (15.8 mg/100 g) cultivars (Esti et al., 2002; Gao and Mazza, 1995), and the lowest level was found in 'Ferrador' (0.02 mg/100 g). In addition, other studies (Esti et al., 2002; Gao and Maza, 1995) reported peonidin-3-O-glucoside (Table 2). Esti et al. (2002) and Gao and Maza (1995) reported that the highest concentrations of peonidin-3-O-glucoside were found in 'Sciazza' (3 mg/100 g) and 'Bing' (0.76 mg/100 g) (Table 2).

Table 2 Color and phenolic compounds of different sweet cherry cultivars

	Cultivars according to time of maturity							
	Early			Mid			Late	
	Ferprime (primulat)	Burlat	Blaze Star	Van	Sunburst	Bing	Lapins	Sweetheart
Harvest timing days $\pm$ Burlat ^a	−3	0	+12−+14	+17−+21	+18−+21	+22−+25	+24−+30	+33−+35
Skin color (CTIFL color chart)	4	5	6	4	5	6	2	5
Cyanidin-3- O-glucoside ^b	1.78 $\pm$ 0.06	34.84 $\pm$ 0.44	2.71 $\pm$ 0.03	1.51 $\pm$ 0.01	1.46 $\pm$ 0.02	31.06 $\pm$ 0.49	0.10 $\pm$ 0.02	1.39 $\pm$ 0.02
Cyanidin-3- O-rutinoside ^b	7.44 $\pm$ 0.72	46.92 $\pm$ 0.43	51.87 $\pm$ 0.14	43.57 $\pm$ 0.29	21.84 $\pm$ 0.14	180.57 $\pm$ 0.24	3.07 $\pm$ 0.48	22.42 $\pm$ 0.07
Peonidin-3- O-glucoside ^b	—	—	—	0.63 $\pm$ 0.01	—	0.76 $\pm$ 0.08	—	—
Pelargonidin-3- O-rutinoside ^b	0.35 $\pm$ 0.03	0.50 $\pm$ 0.01	3.06 $\pm$ 0.10	0.19 $\pm$ 0.00	0.41 $\pm$ 0.18	3.11 $\pm$ 0.21	0.31 $\pm$ 0.08	0.44 $\pm$ 0.02
Peonidin-3- O-rutinoside ^b	0.10 $\pm$ 0.00	2.31 $\pm$ 0.03	4.73 $\pm$ 0.01	1.20 $\pm$ 0.03	0.94 $\pm$ 0.01	9.17 $\pm$ 0.18	0.04 $\pm$ 0.01	3.83 $\pm$ 0.06
Total anthocyanins ^b	9.67 $\pm$ 0.00	84.59 $\pm$ 1.55	62.38 $\pm$ 0.39	47.10 $\pm$ 0.00	24.66 $\pm$ 0.23	224.67 $\pm$ 0.00	3.52 $\pm$ 0.58	—
Neochlorogenic acid ^b	8.75 $\pm$ 1.57	9.18 $\pm$ 0.72	23.22 $\pm$ 3.75	17.31 $\pm$ 0.16	16.92 $\pm$ 0.30	128.16 $\pm$ 1.25	8.70 $\pm$ 0.88	9.88 $\pm$ 0.51
<i>P</i> -coumaroylquinic acid ^b	6.32 $\pm$ 2.89	11.28 $\pm$ 0.51	26.62 $\pm$ 4.39	4.15 $\pm$ 0.25	9.25 $\pm$ 0.23	42.67 $\pm$ 3.22	0.77 $\pm$ 0.06	28.10 $\pm$ 1.17
Chlorogenic acid ^b	0.60 $\pm$ 0.06	1.83 $\pm$ 0.14	2.33 $\pm$ 0.44	5.77 $\pm$ 0.06	1.62 $\pm$ 0.03	0.77 $\pm$ 0.02 ^c	1.69 $\pm$ 0.15	1.46 $\pm$ 0.10
Rutin ^b	2.81 $\pm$ 0.34	4.54 $\pm$ 0.51 ^c	—	3.55 $\pm$ 0.09	—	3.66 $\pm$ 0.22 ^c	2.06 $\pm$ 0.28	—
Epicatechin ^b	4.51 $\pm$ 0.00	3.05 $\pm$ 0.60 ^c	—	6.33 $\pm$ 0.29	—	2.89 $\pm$ 0.23 ^c	0.43 $\pm$ 0.09	—
Catechin ^b	—	—	—	4.51 $\pm$ 0.19	—	—	—	—
Total phenolics ^b	87.9 $\pm$ 9.11	122.04 $\pm$ 1.26	138.80 $\pm$ 3.01	88.72 $\pm$ 0.00	102.76 $\pm$ 1.91	76.6 $\pm$ 5.13 ^c	44.3 $\pm$ 3.42	89.56 $\pm$ 0.16
References	Usenik et al. (2008)	Ballistreri et al. (2013) ^c Usenik et al. (2008)	Ballistreri et al. (2013)		Ballistreri et al. (2013)	Gao and Mazza (1995) ^c Usenik et al. (2008)	Usenik et al. (2008)	Ballistreri et al. (2013)

CTIFL, Center Technique Interprofessionnel des Fruits et Légumes.

^aDays $\pm$ relative to 'Burlat' (May 5, Jerte Valley, Spain).^bmg/100 g.^cData obtained from Usenik et al. (2008).

As stated previously, sweet cherries are rich in phenolic acids (Mulabagal et al., 2009; Serra et al., 2011; Tomás-Barberán et al., 2013). A total of five phenolic compounds have been analyzed by several authors (Gao and Maza, 1995; Gonçalves et al., 2004; González-Gómez et al., 2010; Serradilla et al., 2011; Usenik et al., 2008). These included derivatives of the hydroxycinnamic acids, which are the main type of phenols found in sweet cherries; a flavan-3-ol; and a flavonol. Regarding hydroxycinnamic acid derivatives, the most abundant in sweet cherries are neochlorogenic and *p*-coumaroylquinic acid, followed by chlorogenic acid. In almost all cultivars, authors have reported that the content of neochlorogenic acid is higher than *p*-coumaroylquinic acid. However, there are other cultivars whose *p*-coumaroylquinic acid contents are much higher than neochlorogenic acid. Hence, the ratio of neochlorogenic acid to *p*-coumaroylquinic acid is a distinct characteristic of each sweet cherry cultivar (Mozetič et al., 2006). The content of neochlorogenic acid of sweet cherry cultivars can be classified into three groups, according to Ballistreri et al. (2013): The first group contains neochlorogenic acid levels ranging from 40 to 128 mg/100 g ('Lambert', 'Bing', 'Larian', 'Ducignola Nera', and 'Black Star'); the second group has intermediate neochlorogenic acid levels between 20 and 40 mg/100 g ('Blaze Star', 'Ferrovia', 'Grace Star', 'Noir de Guben', and '0900 Ziraat'); and, finally, the third group contains levels ranging from 4 to 20 mg/100 g ('Freprime', 'Burlat', 'Lapins', and 'Sweetheart'). *p*-Coumaroylquinic acid levels range from 0.77 ('Lapins') to 131.45 mg/100 g ('Sam'). This acid has been positively correlated with the antioxidant potency of cherry extracts on human low-density lipoproteins (Gonçalves et al., 2004). Chlorogenic acid concentrations fluctuate from 0.17 mg/100 g in the 'Genovese' cultivar to 8.73 mg/100 g in 'Larian' (Ballistreri et al., 2013).

The flavonol *nutin* (quercetin-3-*O*-rutinoside) has been described in sweet cherries in several studies (González-Gómez et al., 2010; Serra et al., 2011; Serradilla et al., 2011; Usenik et al., 2008). The highest levels have been found in 'Noir de Gube' and 'Badascony' (5.87 mg/100 g and 5.78 mg/100 g, respectively), followed by cultivars with late ripening time (Pico Negro Limón, Pico Negro, Pico Colorado and Ambrunés), whereas the lowest was observed in 'Van' (1.84 mg/100 g) (González-Gómez et al., 2010; Serra et al., 2011). Flavan-3-ols identified in the sweet cherry include epicatechin and catechin. In sweet cherries, the content of epicatechin is generally higher than catechin, although this ratio is also characteristic of each cultivar. 'Larian' and 'Navalinda' cultivars have been characterized as exhibiting the highest epicatechin contents (14.84 and 13.30 mg/100 g, respectively) (González-Gómez et al., 2010), and, according to Usenik et al. (2008), 'Lapins' contained the lowest levels of this compound (0.43 mg/100 g). However, Serra et al. (2011) found that among cultivars studied, 'Lapins' showed the highest epicatechin content. This difference reflects the influence of agronomic and environmental conditions on concentrations of these compounds. Regarding catechin, Kelebek and Selli (2011) found that the concentration ranged from 2.92 mg/100 g in '0900 Ziraat' to 9.03 mg/100 g in 'Noir de Guben', and Serra et al. (2011) reported that the catechin content varied between 2.16 mg/100 g in 'Garnet' and 6.88 mg/100 g in 'Lapins'.

Regarding total phenolic content (TPC), a wide range of concentrations of total phenolics has been reported (Ballistreri et al., 2013; Tomás-Barberán et al., 2013; Usenik et al., 2008). In addition, this range varies depending on the crop area. For example, Usenik et al. (2008) reported that the amount of total phenolics ranged from 44.3 ('Lap-ins') to 87.9 mg/100 g ('Ferprime') (Table 2) for cultivars grown in northern Europe. However, Ballistreri et al. (2013) and Tomás-Barberán et al. (2013) reported that the concentration of total phenolics ranged from 84.96 ('Napoleona Grappolo') to 192 mg/100 g ('Sonata') for cultivars grown in a southern area of Europe. On the other hand, sour cherries exhibit total higher phenolic contents than sweet cherries. According to Khoo et al. (2011), the concentration of total phenolics in sour cherries fluctuated between 74 ('Surefire') and 754 ('Birgitte × Böttermö') mg/100 g (Khoo et al., 2011). Chaovanalikit and Wrolstad (2004) also reported that the distribution of total phenolics in sweet ('Bing', 'Royal Ann', and 'Rainer') and sour ('Montmorency') cultivars was highest in skin, followed by flesh, and the lowest occurred in pits.

Another important aspect of phenolic compounds is their antioxidant activity. To date, numerous studies have reported that cherries are an excellent source of natural antioxidant substances (Chaovanalikit and Wrolstad, 2004; McCune et al., 2011; Serra et al., 2011; Tomás-Barberán et al., 2013). Ballistreri et al. (2013) determined the total antioxidant activity (TAA) through the oxygen radical absorbance capacity assay. They reported that the antioxidant activity ranged from 646 to 3166 $\mu\text{molTE}/100\text{g}$; the cultivar 'Sweet-heart' (728 $\mu\text{molTE}/100\text{g}$) had the lowest values, whereas the highest were found in 'Moreau' (3166 $\mu\text{molTE}/100\text{g}$). In sour cherries, Khoo et al. (2011) found that the cultivar 'Birgitte × Böttermö' showed the highest antioxidant activity (6300 $\mu\text{molTE}/100\text{g}$), and the cultivar 'Surefire' had lowest (200 $\mu\text{molTE}/100\text{g}$). Generally, the antioxidant capacity of sour cherries is greater than that of sweet cherries. On the other hand, Tomás-Barberán et al. (2013) reported that sweet cherries exhibited antioxidant activity in both hydrophilic and lipophilic fractions by measuring the scavenging capacity of 2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) radicals. Thus, the cultivar 'Sonata', classified as dark-colored, exhibited the highest concentrations in both fractions, reaching 135 mg/100 g and 75 mg/100 g for hydrophilic and lipophilic antioxidant activities, respectively. Conversely, the cultivar 'Brooks', classified as a light-colored cultivar, showed the lowest concentrations in both fractions. Regarding *in vivo* assays, Serra et al. (2011) reported that cultivars that showed the highest levels of anthocyanins exhibited the highest antiproliferative effects against human colon and gastric cancer cells. In fact, the cultivar 'Ulster', considered a dark-colored cultivar, exhibited the highest antiproliferative effect against human colon and gastric cancer cells. Therefore, dark-colored cultivars present greater health-promoting potential than light-colored cultivars.

Sweet cherries are also a good source of indolamines, such as melatonin and serotonin. González-Gómez et al. (2009) reported that the relationship between melatonin and serotonin is also characteristic for each sweet cherry cultivar. For example, the highest content of melatonin was found in 'Burlat' (22.4 ng/100 g), and the highest content

of serotonin was found in ‘Ambrunés’ (37.6 ng/100 g). For sour cherries, [Burkhardt et al. \(2001\)](#) reported that the cultivar ‘Montmorency’ contained almost six times more melatonin than the ‘Balaton’ cultivar.

Volatile Compounds

More than 100 volatile compounds have been identified, comprising the aroma of sweet cherries among free and glycosidically volatile compounds. The chemical classes that contribute to the aroma profile of this fruit are mainly carbonyls, alcohols, acids, esters, terpenes, and norisoprenoids.

The aldehydes hexanal, (E)-2 hexenal, and benzaldehyde are among the predominant volatile flavor constituents in both sweet and sour cherries ([Table 3](#)). The C6 aldehydes, hexanal and (E)-2-hexenal, are formed by activity of the lipoxygenase pathway of FAs and are associated with green/grassy notes. Both aldehydes can represent more than 30% of the free aromatic compounds in the sweet cherry. Other minor aliphatic aldehydes of the same origin also have been shown to greatly contribute to the aroma in some cultivars because of their odor thresholds ([Serradilla et al., 2012](#); [Zhang et al., 2007](#)). The compounds (Z)-3-hexenal, decanal, nonanal, (E,Z)-2,6-nonadienal, and (E,E)-2,4-nonadienal have been identified as important odorants in ‘Lapins’, ‘Rainier’, ‘Stella’, ‘Hongdeng’, and ‘Zhifuhong’ cultivars ([Girard and Kopp, 1998](#); [Wen et al., 2014](#)). The aromatic carbonyl benzaldehyde originates from the enzymatic hydrolysis of the amygdalin in fruit and can be more than 15% of whole volatile compounds in some cultivars of picota types of sweet cherry. In cultivars of sour cherry, this compound has been identified as the main volatile linked to the characteristic cherry aroma ([Levaj et al., 2010](#)). Branched aldehydes, such as 3-methylbutanal, are also present in low concentration in these cultivars, contributing to the picota-type sweet cherry aroma ([Serradilla et al., 2012](#)). Ketones also have a discrete role in the aroma of sweet cherries. The compounds 2-propanone, 4-methyl-2-pentanone, 1-octen-3-one, and 4,6-dimethyl-2-heptanone have been found in some of the most relevant cultivars of sweet cherry ([Girard and Kopp, 1998](#)). On the other hand, 2-heptanone has been described as a major component of the aroma of sour cherry cultivars ([Levaj et al., 2010](#)).

The most abundant alcohols found in cherry are benzyl alcohol, 1-hexanol, and (E)-2-hexen-1-ol, most of which are derived from reduction of their respective aldehydes. (E)-2-hexen-1-ol and benzyl alcohol are related to green notes and the fresh green odor characteristically associated with fruits, and are also considered to be predominant flavor volatiles in both sweet and sour cherries. Ethanol is mainly identified at the ripe stage of sweet cherries and has been linked to increasing fruit respiration; it has been associated with a negative effect on fruit flavor ([Mattheis et al., 1997](#)). Other alcohols found are 3-methyl-3-buten-1-ol, 3-methyl-2-buten-1-ol, 2-ethyl-1-hexanol, and 1-octen-3-ol. The compound 1-octen-3-ol has been described as among the most potent volatiles in ‘Hongdeng’, ‘Hongyan’, and ‘Rainier’ cultivars of sweet cherry ([Wen et al., 2014](#)).

The acids detected in the sweet cherry also include mainly linear and branched acids derived from their respective aldehydes, such as hexanoic acid, (E)-2-hexenoic acid, nonanoic acid, and 3-methylbutanoic acid (Wen et al., 2014). However, one of the pre-dominant volatile acids found is acetic acid, especially in some cultivars of sweet cherry including 'Bing' and 'Pico Negro' (Mattheis et al., 1992; Serradilla et al., 2012). The aromatic sensory threshold of this acid is high; thus, its actual contribution to the aroma of sweet cherry is limited. However, the acetic acid is a precursor to many relevant esters.

Esters increase during ripening of sweet cherry, although their final concentrations are discrete (less than 2% of total volatile compounds). Ethyl acetate, butyl acetate, hexyl acetate, (Z)-2-hexenyl acetate, and (E)-2-hexenyl acetate are among the main ester compounds found in sweet cherry cultivars (Girard and Kopp, 1998). Likewise, methyl benzoate has been described as among the most potent volatiles in some cultivars, such as 'Rainier'.

Monoterpenes (C10), sesquiterpenes (C15), and diterpenes (C20) are very common in plants and serve various physiological and ecological roles. In particular, those containing no oxygen functionalities or only hydroxyl or carbonyl functionalities are generally volatile and often emitted from plants to attract pollinators or repel herbivores. They also contribute to the aroma and flavor of foods consumed by humans, making them important to the food quality. Most studies analyzing the aromatic components in sweet cherry cultivars have shown that terpenes and norisoprenoids have little impact on the total volatile compounds, with limonene, linalool, and geranylacetone being the most common (Girard and Kopp, 1998; Goliáš et al., 2012; Serradilla et al., 2012; Sun et al., 2010). However, these works focused on free-form volatile compounds, and they did not consider the glycosidically bound compounds. Wen et al. (2014) reported the occurrence of both free and glycosidically bound aromatic compounds in three sweet cherry cultivars ('Hongdeng', 'Hongyan', and 'Rainier') and identified 20 different terpenoids in both fractions, although they were more abundant in the bound fraction, which represented the second largest class after alcohols. Therefore, as a result of their abundance in bound fraction, these compounds likely contribute markedly to the sweet cherry flavor. In fact, linalool and geraniol demonstrated to contribute significantly to cherry aroma and were associated with floral attributes (Wen et al., 2014). The odor of (E)- β -ionone has been characterized in violets and is a very low odor constituent (0.007–0.09 $\mu\text{g/L}$) in fruit.

INFLUENCE OF THE RIPENING STAGE ON COMPOSITION OF THE 'AMBRUNÉS' CULTIVAR

The cultivar 'Ambrunés' is a picota-type cultivar, which is harvested naturally without a stem. This cultivar is characterized by its excellent physicochemical, bioactive, and organoleptic properties (Bernalte et al., 2003; González-Gómez et al., 2010). 'Ambrunés'

sweet cherries are considered to be very sweet because of their higher fructose content compared with glucose. During ripening, glucose and fructose levels exhibit different behaviors. The content of glucose decreases during ripening, whereas fructose levels increase. Regarding anthocyanins, five have been identified by high-performance liquid chromatography–diode array detection/electrospray ionization–mass spectrometer in the ‘Ambrunés’ cultivar (Serradilla et al., 2011). As mentioned, in dark-colored cultivars, the primary anthocyanin is cyanidin-3-*O*-rutinoside, ranging from 17.84 (stage 1, score of 3 on the CTIFL color chart) to 51.75 mg/100 g (stage 5, score of 5 on the CTIFL color chart), followed by cyanidin-3-*O*-glucoside and peonidin-3-*O*-rutinoside. The lowest levels were observed for aglycones cyanidin chloride and malvidin chloride. In addition, the content of anthocyanins increased during ripening, showing significant differences in stages 1–5. This change was also reflected positively in physical skin color parameters, therefore, confirming that anthocyanins play an important role in skin color of sweet cherries. Regarding hydroxycinnamic acids, the cultivar ‘Ambrunés’ contains *p*-coumaroylquinic acid as the main hydroxycinnamic acid, with concentrations ranging from 64.7 (stage 1) to 45.8 (stage 5) mg/100 g. Therefore, this compound showed an overall decline during fruit maturation. On the other hand, levels of this phenolic compound in the same cultivar were higher than those obtained by other cultivars, such as ‘Bing’, ‘Sweetheart’, and ‘Blaze Star’ (Table 2). Moreover, this cultivar showed high rutin contents at the last ripening stage (stage 5), reaching 5.07 mg/100 g (Serradilla et al., 2011). This was the only phenolic compound that accumulated during the ripening of the ‘Ambrunés’ cultivar. Other phenolic compounds identified in ‘Ambrunés’ were neochlorogenic acid, chlorogenic acid, and epicatechin, each showing no clear tendency to increase or decrease during ripening. Regarding TAA, ‘Ambrunés’ showed concentrations that were higher than those reported by Tomás-Barberán et al. (2013) for other cultivars, ranging between 317.92 (stage 1) and 439.10 mg/100 g (stage 5). In ‘Ambrunés’, anthocyanins and neochlorogenic acid are mainly responsible for TAA (Serradilla et al., 2011). González-Gómez et al. (2009) reported that ‘Ambrunés’ also contained relevant serotonin contents (37.6 ng/100 g).

With respect to TPC, ‘Ambrunés’, like other dark red sweet cherries, contained a high TPC (117 mg/100 g). However, among picota-type sweet cherry cultivars studied, the highest level of TPC was found in ‘Pico Negro’ (154 mg/100 g), whereas the lowest level corresponded to ‘Pico Colorado’ (46 mg/100 g). Because of their high levels of TPC and great antioxidant activities, ‘Ambrunés’ and ‘Pico Negro’ cultivars are of great interest to sweet cherry breeding programs.

Volatile compounds of picota-type sweet cherry cultivars (‘Ambrunés’, ‘Pico Negro’, and ‘Pico Colorado’) were analyzed using headspace–solid phase microextraction and gas chromatography–mass spectrometer (Serradilla et al., 2012). The aroma of the ‘Ambrunés’ cultivar was characterized by the content of linear alcohols, such as (Z)-2-penten-1-ol, 1-nonanol, and the branched alcohol 2-methyl-3-octanol (Table 3).

Table 3 Percentage of main volatile compounds identified in different sweet cherry cultivars at different maturation stages

	Cultivars											
	Ambrunés			Pico Negro			Pico Colorado			Sweetheart		
Volatile compounds	Early	Medium	Late	Early	Medium	Late	Early	Medium	Late	Early	Medium	Late
<i>Linear aldehydes</i>												
Hexanal	23.99	29.83	31.71	11.47	17.49	17.86	33.98	34.81	41.18	43.74	26.37	31.85
(E)-2-hexenal	38.04	30.38	35.81	37.87	27.83	35.89	27.30	22.48	31.43	7.87	28.81	12.97
(E,E)-2,4-hexadienal	1.44	0.88	1.35	0.95	1.11	1.11	0.63	0.46	1.25	1.39	0.74	1.11
Nonanal	0.18	0.14	0.18	0.12	0.13	0.20	0.13	0.13	0.13	0.28	0.17	0.32
<i>Aromatic aldehydes</i>												
Benzaldehyde	8.76	3.50	2.58	20.16	16.53	13.16	12.65	9.50	9.81	3.92	3.34	4.03
<i>Branched aldehydes</i>												
3-methylbutanal	0.07	0.08	0.06	0.01	0.06	0.06	0.00	0.02	0.03	0.00	0.01	0.00
2-methylbutanal	0.03	0.03	0.03	0.03	0.04	0.01	0.00	0.00	0.01	0.00	0.01	0.02
<i>Linear alcohols</i>												
Ethanol	0.13	0.00	0.00	0.01	0.01	0.05	0.01	0.00	0.01	0.01	0.06	0.13
(Z)-2-penten-1-ol	0.05	0.01	0.11	0.00	0.01	0.00	0.00	0.00	0.01	0.05	0.00	0.00
(E)-2-hexen-1-ol	21.91	28.64	25.00	16.42	24.70	22.07	20.43	21.17	12.17	25.18	32.26	39.74
1-hexanol	1.39	3.18	0.82	0.41	0.48	1.18	1.84	1.59	1.06	5.89	0.19	0.17
1-nonanol	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.04
<i>Aromatic alcohols</i>												
Benzenemethanol	1.19	0.63	0.44	9.06	5.38	4.56	1.39	0.70	0.90	4.72	4.62	4.66
Benzeneethanol	0.02	0.02	0.02	0.07	0.03	0.03	0.03	0.01	0.01	0.09	0.06	0.11
<i>Branched alcohols</i>												
3-methyl-3-buten-1-ol	0.05	0.04	0.09	0.03	0.63	0.40	0.08	0.12	0.25	0.01	0.08	0.22
3-methyl-2-buten-1-ol	0.05	0.16	0.06	0.27	0.57	0.59	0.07	0.26	0.19	0.13	0.23	0.35
2-ethyl-1-hexanol	0.03	0.01	0.03	0.01	0.01	0.00	0.02	0.01	0.01	0.02	0.01	0.03
2-methyl-3-octanol	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Organic acids</i>												
Acetic acid	0.33	0.31	0.28	0.39	2.31	0.22	0.23	0.07	0.21	0.91	0.47	0.61
Hexanoic acid	0.00	0.08	0.07	0.06	0.02	0.01	0.07	0.03	0.05	0.02	0.02	0.02
Hexadecanoic acid	0.05	0.08	0.04	0.15	0.01	0.00	0.23	0.04	0.01	0.46	0.12	0.32
<i>Alkanes</i>												
Hexane	0.21	0.21	0.06	1.06	0.34	1.06	0.03	0.19	0.05	0.23	0.35	0.30
Unknown alkane	0.32	0.20	0.18	0.26	0.11	0.23	0.17	0.15	0.29	0.31	0.17	0.39
<i>Others</i>												
2-Furancarboxaldehyde	0.00	0.07	0.00	0.00	0.86	0.00	0.00	1.22	0.00	0.02	0.01	0.00
l-limonene	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.04
α -ionone	0.01	0.02	0.01	0.00	0.01	0.00	0.02	0.02	0.01	0.00	0.00	0.00

However, the aroma of ‘Pico Negro’ showed the maximum levels of aromatic alcohols, especially benzenemethanol. Finally, the aroma of ‘Pico Colorado’ contained the highest amounts of hexanal and hexanoic acid. In addition, branched aldehydes, such as 3-methylbutanal and N,N-dibutyl-formamide, and norisoprenoid derivatives, such as α -ionone, also could possibly influence the aromatic profile of the picota sweet cherry cultivars. On the other hand, descriptive sensorial analysis of these cultivars showed the highest values of sweetness for ‘Ambrunés’, the best values of firmness for ‘Pico Colorado’ and the lowest scores for ‘Pico Negro’ in fruit flavor, sweetness, firmness and overall evaluation. (Serradilla et al., 2012).

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CHAPTER 7

Nutritional Composition of Clementine (*Citrus x clementina*) Cultivars

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INTRODUCTION

The taxonomic origin of the clementine has to be referred to the *tangor* hybrid group, which includes all the natural and engineered interspecific hybrids between mandarin (*Citrus reticulata* Blanco) and sweet orange (*Citrus sinensis* L. Osbeck). Within this group, the most relevant cluster in terms of numerical entities and commercial significance is represented by the clementine; thus, many authors consider it as a separate individual species (*Citrus x clementina*). It is generally recognized that the 'Ordinary Clementine' was isolated for the first time around 1900 by the French missionary brother Marie-Clément Rodier in Misserghin in Algeria, as a natural hybrid presumably deriving from the cross between the 'Avana' mandarin and a selection of sour orange named 'Granito' (Continella and Russo, 2012). However, little credence is now given to this possible origin. Although various male parents have been proposed other than sour orange (Samaan, 1982), serological and molecular studies demonstrated that the clementine is likely a hybrid of mandarin and sweet orange (Nicolosi et al., 2000; Ollitrault et al., 2012). In a paper published in *Nature Biotechnology* (Wu et al., 2014), this hypothesis has been confirmed at the sequence level by definitively identifying mandarin and sweet orange alleles at each clementine locus.

The world production of the mandarin and mandarin-like fruits (tangerines, mandarins, clementines, satsumas) in 2012 is estimated to be at 27,060,756 tons, mostly comprising the clementine fruit (FAOSTAT, 2012). In the Mediterranean basin, many countries such as Spain (the leading exporter country of clementine fruit in Europe), Italy, Turkey, Portugal, Greece, Morocco, Tunisia, and Algeria are leading producers of clementine fruits with an overall estimated production of 4,795,000 tons (approximately 25% of the whole citrus production in these areas). In South America, the production is estimated at almost 2 million tons, thanks to the contribution of some leading countries such as Brazil, Argentina, Peru, and Uruguay. In Asia, a production of almost 19 million tons has been estimated, with China as the leading producing country, contributing almost 14 million tons alone.

Nowadays the clementine fruit is consumed worldwide mostly as fresh fruit, and its juice and essential oils are employed for the production of fruit beverages, soft drinks, and smart beverages.

BOTANICAL ASPECTS

The taxonomy of mandarin and mandarin-like fruits (including the clementine) is very complex, because there are many interspecific hybrids and cultivars, some of whose origins and taxonomic relationships are uncertain. Swingle's classification (1943) recognizes five groups ('King', 'Satsuma', 'Mediterranean and real mandarins', 'Tangerines', and 'Small-fruited mandarins') belonging to a single species, *C. reticulata* Blanco. However, according to Tanaka's classification (1954), all mandarin and mandarin-like fruits belong to 36 species. In this classification, the clementine is considered to be a distinct species, *C. clementina* Hort. ex Tanaka. The clementine has also been considered to be derived from a cross between mandarin (*C. reticulata* Blanco), and sweet orange (*C. x sinensis* (L.) Osbeck), and belongs to the tangor group, one of several cultivar groups recognized within the genus *Citrus*. The name of this group derives from *tang-* (tangerine), the general name used to indicate the mandarin fruit, which typically has a red-orange colored peel, and *-or* (orange). In the absence of pollinator species, self-incompatibility allows the production of seedless monoembryonic fruit, which are much appreciated in the fresh fruit market. The tree is quite vigorous, medium in size, and characterized by an erect habit (4–5 m high). The primary and secondary branchlets are fine-stemmed, willowy, and nearly thornless, and they extend at an acute angle to the main trunk. The leaves are narrow, broadly lanceolate, and variable in size. Heterophily (i.e., leaves of different shapes and sizes) is common. The tree is strongly cold-resistant. Fruits are variable in size, ranging from medium-small to medium (70–100 g). Their shape is likewise variable, ranging from slightly oblate through globose to oblong and sometimes broadly pyriform, deriving from the development of a neck or collar (Hodgson, 1967). The base of the fruit is usually rounded and sometimes collared or necked. The apex is depressed. The rind is

moderately firm and adherent, easy peeling, and medium in thickness. The surface is slightly pebbled as a result of prominent oil glands. Peel color ranges from deep orange to reddish-orange, and flesh color is deep orange. Fruits mature early, with selections and mutants ripening from mid-September through October to mid-February. The flesh is tender and melting, juicy, subacid, and pleasantly aromatic. The essential oil has a typical deep yellow color and its odor is very delicate, and resembling that of sour orange (*Citrus x aurantium*).

The clementine has some peculiar climatic preferences. It is known for its low temperature requirements ($\geq 3^{\circ}\text{C}$) for fruit maturity and the sensitivity of the seedless fruit to unfavorable conditions, such as frost, during the flowering and fruit-setting period. In the best climatic and pedological conditions (mild climate and loose soils) trees become productive in their fourth or fifth year after planting. Clementine fruit is the highest yielding early *Citrus* variety in the Mediterranean basin and is highly promising in other regions of similar climate where there are minimum daily temperature variations during the fruit-setting period (from mid-May to mid-July).

COMPOSITION OF TRADITIONAL OR ANCIENT CULTIVARS

Clementine fresh fruits have been prized for their typical flavor since the isolation, in the first decade of the twentieth century, of their first ancient genotype, 'Ordinary Clementine', in Algeria. The traditional or ancient genotypes laid the foundations on which the clementine industry developed. The main countries that invested on this crop are Italy and Spain. The oldest genotypes worldwide are considered to be 'Fina' (or 'Comune') and 'Monreal' cultivars.

Known in Spain as 'Fina' and in Italy as 'Comune' since its isolation in the early 1900s, the 'Ordinary Clementine' was first introduced into Spain in 1925, probably from Algeria. The 'Fina' clementine was the unique cultivar grown on any scale in Spain until the early 1960s, and it is still narrowly cultivated nowadays. All other Spanish clementine genotypes are derived from the 'Fina' cultivar, either directly or via one generation. The fruit of this cultivar has excellent organoleptic characteristics, such as high juice content, very tender and sweet rind with good acid level, and high sugar to acid ratio. Moreover, it has the strong and pleasant aroma that typifies the clementine fresh fruit. Unfortunately, the fruit is very small, so this cultivar cannot compete on the market with other selections that produce larger, if inferior, fruit. Because of the fruit size problems, the 'Fina' cultivar is no longer planted in Spain, but around 10,000 hectares are still in production. In the 1950s, two new bud mutations deriving from the 'Fina' cultivar were isolated in Spain, namely 'Clemenules' and 'Oroval', and they constitute more than half of the current clementine plantings in Spain. As reported in literature, the 'Fina' clementine had two main defects: scarce productivity and the small size of fruit. One of the first promising mutants, the 'Monreal' clementine, was found in Algeria in 1940. It had a fair

productivity and presented fruit with a larger size than the 'Fina' fruit. One of the first works reporting technical data on the evidence of the promising characteristics, in terms of productivity and earliness, of the 'Monreal' clementine was published in the *Annales de L'Institut Agricole et des Service de Recherches et d'Experimentation Agricole de l'Algerie* in 1949 (Simonneau and Auguste, 1949). Figures 1–3, show the results of this comparative study between the 'Fina' clementine, cited as *clementine ordinaire*, and the 'Monreal' clementine sampled in two different areas of the Habra peneplain in Algeria (Moutonniere and Moulin). The authors determined their sugar to acid ratio, the fruit weight, and the juice yield. It can be easily noticed that the 'Fina' cultivar presented fruit with a smaller size compared with the 'Monreal' fruit. Moreover, although the juice yield of the two cultivars was comparable, the sugar to acid ratio was significantly higher in the 'Monreal' cultivar than in the 'Fina' cultivar that was sampled at the same harvest date, thus showing the earliness and hence, the top commercial value of the new cultivar. The sugar to acid ratio is intended as the ratio between total soluble solids (TSS) and total acidity (TA), expressed as anhydrous citric acid. This physicochemical parameter is of relevant significance for the commercialization of the fresh fruit, for both domestic and international markets, because it is universally considered to be the maturity index (TSS/TA) of the fruit. The 'Monreal' cultivar reached a sugar to acid ratio of 7.5 (at that time that was the boundary value accepted for the export market) well before the 'Fina' cultivar. It must

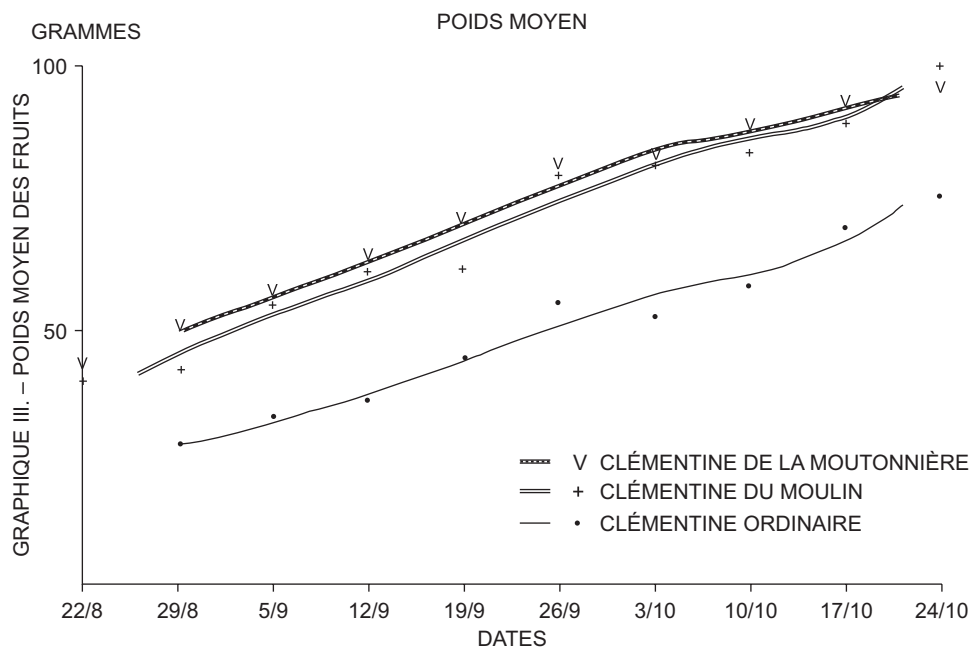


Figure 1 Average fruit weight of clementine fruit belonging to 'Comune' and 'Monreal' cultivars. Reprinted from Simonneau and Auguste (1949).

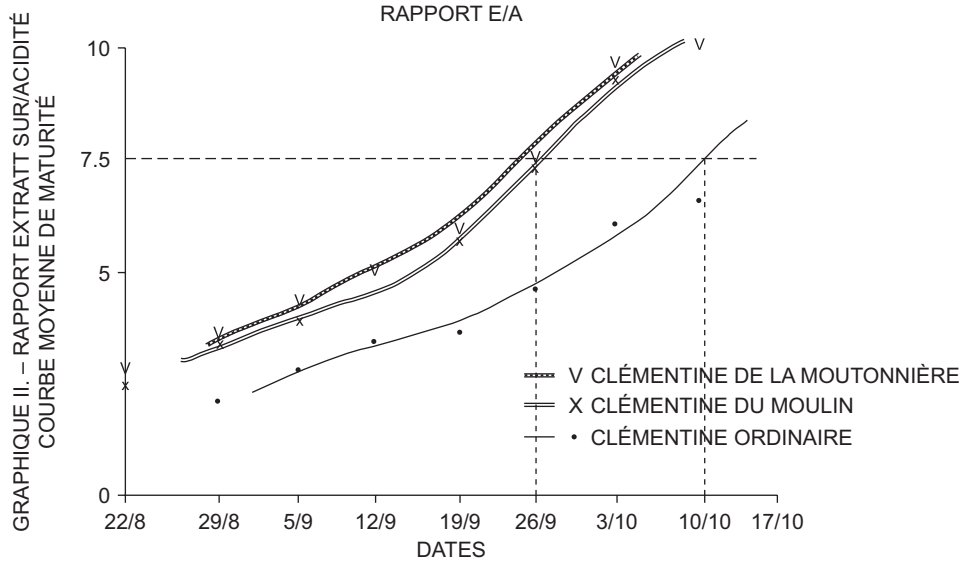


Figure 2 Sugar to acid ratio of clementine fruit belonging to 'Comune' and 'Monreal' cultivars. Reprinted from [Simonneau and Auguste \(1949\)](#).

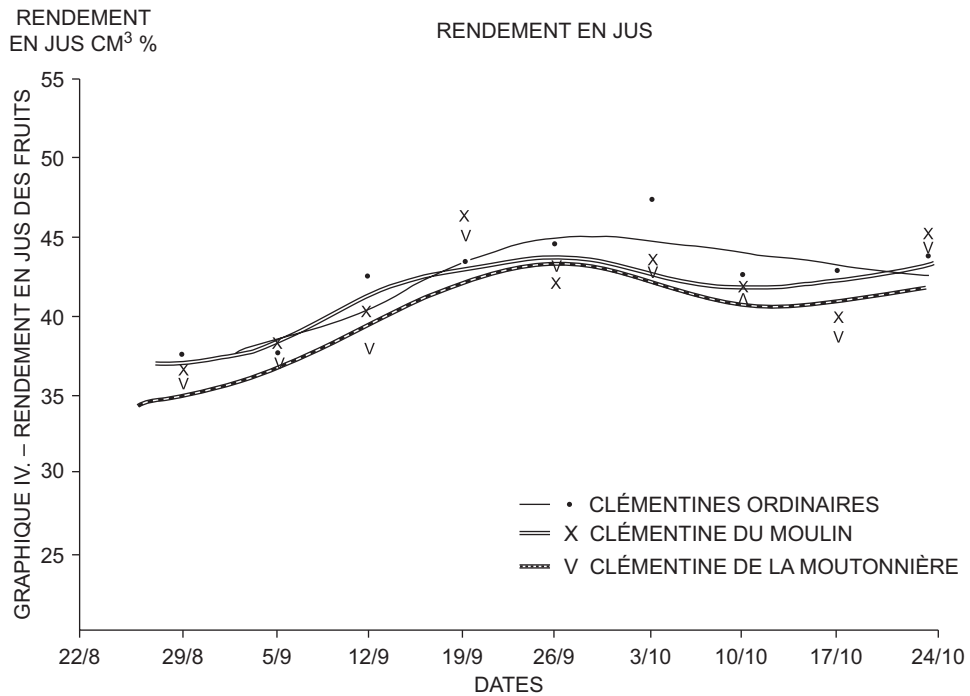


Figure 3 Juice yield of clementine fruit belonging to 'Comune' and 'Monreal' cultivars. Reprinted from [Simonneau and Auguste \(1949\)](#).

be also noticed that the authors pointed out, as a negative notation, the higher presence of seeds in the 'Monreal' cultivar in comparison with the 'Fina' one, although this drawback was considered to be offset by the absence of concurrence at its maturity time (mid-September). Nevertheless, in the following decades, it was demonstrated that the seeds in the fruit belonging to the 'Monreal' cultivar are a result of the self-compatibility of this variety, and this caused the slow decline of this mutant.

Relatively little information is available on the nutritional composition of the fruit of these varieties when compared with other citrus fruits, such as the orange, the lemon, or the grapefruit. Comprehensive studies on the physicochemical and nutritional composition of the traditional clementine cultivars are present in literature since the beginning of the 1970s. One of the first works reported the results of a wide study aimed at setting accurate average values for each of the main nutritional parameters in order to detect the possible adulterations that may be made to clementine juices (Royo Iranzo and Pauletti, 1974). In this study, 22 samples of clementine juices ('Fina', 'Clemenules', and 'Oroval' cultivars) obtained in two different collecting seasons (1971–1972 and 1973–1974) were used for the determination of vitamin C, nitrogen, sodium, potassium, calcium, magnesium, iron, phosphorus, sulfates, and nitrates. The obtained results for each component were statistically treated in order to determine the value of each one as a parameter for the detection of adulterations (Table 1). Vitamin C values range from 26.1 to 67.1 mg/100 mL, with an average content of 49.4 mg/100 mL, quite similar to that of some varieties of

Table 1 Physicochemical and nutritional composition of clementine juice ('Fina', 'Clemenules', and 'Oroval' cultivars)

Parameter	Maximum value	Minimum value	Average value (X)	Standard deviation (S)	S/X * 100
Vitamin C (mg/100 mL)	67.1	26.1	49.40	9.098	18.42
Total nitrogen (mg/100 mL)	132.8	57.6	90.47	24.135	26.68
Ashes (g/100 mL)	0.46	0.24	0.33	0.050	15.05
Na (mg/100 mL)	2.67	0.45	1.65	0.694	42.02
K (mg/100 mL)	235.0	100.3	153.7	35.319	22.97
Ca (mg/100 mL)	15.05	7.65	10.18	1.678	16.48
Mg (mg/100 mL)	13.40	9.10	11.10	1.180	10.59
Fe (mg/100 mL)	0.19	0.04	0.08	0.030	36.90
P (mg/100 mL)	14.50	7.25	11.15	2.808	25.25
Sulfates (mg SO ₄ ²⁻ /L)	244.0	120.0	177.8	39.733	22.34
Nitrates (mg N ₂ O ₅ /L)	3.00	0.45	1.05	0.687	65.41

Ca, Calcium; Fe, Iron; K, Potassium; Mg, Magnesium; Na, Sodium; P, Phosphorus.

Adapted from Royo Iranzo and Pauletti (1974).

common oranges, but surely lower to that of the ‘Tarocco’ orange, the blood orange variety that accumulates the most ascorbic acid in the juice (Rapisarda and Russo, 2000). Potassium is the major nutrient element in clementine juices, occurring at an average value of 153.7 mg/100 mL. Sulfates are also present at an average level of 177.8 mg/L. Remarkable is the presence of some ions, such as calcium, magnesium, and phosphorus, all at an average level of around 11 mg/100 mL. The same authors investigated the relationship between the Brix degrees (°Bx) and the soluble components of the clementine fruits belonging to the ‘Fina’, ‘Clemenules’, and ‘Oroval’ cultivars collected at different dates (Royo Iranzo and Peris Toran, 1977). Taking into consideration that the most abundant soluble components in citrus juices are represented by sugars and acids, the authors reported the results of the determinations of TSS (expressed as °Bx), TA (expressed as percentage of anhydrous citric acid), TSS/TA, and percentage of total sugars in clementine juice samples (Table 2). TSS ranged from 9.0 to 14.5 °Bx, this parameter being strictly related to the date of collection. Similarly, TA ranged from 1.20% to 0.51%. After the statistical processing of the acquired data, the authors found that two new relations [°Bx – (total sugars + TA) and °Bx / (total sugars + TA)] could be usefully employed for the detection of possible adulteration of clementine juices. In particular, the parameter °Bx – (total sugars + TA) ranges from 1.30 to 1.11, with an average value of 1.20, and the ratio °Bx / (total sugars + TA) has an average value of 2.01 (Table 3).

Table 2 Relationship between °Bx and the soluble components of clementine juice (‘Fina’, ‘Clemenules’, and ‘Oroval’ cultivars)

Date of collection	TSS (°Bx)	TA (% anhydrous citric acid)	TSS/TA	Total sugars (%)
75/20/10	9.00	1.30	6.92	6.30
75/24/10	9.80	1.63	6.01	7.14
76/10/2	12.50	0.52	24.03	9.50
76/8/3	14.50	0.51	28.43	11.74
76/3/11	10.60	1.20	8.83	7.63

TSS, Total soluble solids; TSS/TA, Maturity index.
Adapted from Royo Iranzo and Peris Toran (1977).

Table 3 Mathematical relations to be used for the detection of possible adulteration of clementine juices (‘Fina’, ‘Clemenules’, and ‘Oroval’ cultivars)

Parameter	Maximum value	Minimum value	Average value (X)	Standard deviation (S)	S/X * 100
°Bx / (total sugars + TA)	1.30	1.11	1.20	0.0565	4.70
°Bx – (total sugars + TA)	2.82	1.03	2.01	0.5240	26.06

Bx, Brix; TA, Total acidity.
Adapted from Royo Iranzo and Peris Toran (1977).

In another study, [Martin et al. \(1984\)](#) investigated the amino acid changes in the juice and peel of clementine fruits during ripening. N-containing substances represent 5–10% of TSS and are mostly composed of free amino acids, proteins, peptides, and lecithins. In this study, free amino acids were detected in green and mature fruit of two early season varieties ('Fina' and 'Oroval') and one late season variety of clementine ('Hernandina'). Total free amino acids in juice increased from 297–421 mg/100 mL to 414–534 mg/100 mL with maturation. In all the three varieties, proline, arginine, asparagine, aspartic acid, glutamic acid, serine, and γ -aminobutyric acid were predominant. During maturation, aspartic acid, serine, asparagine, and glutamic acid declined, whereas proline, arginine, and γ -aminobutyric acid increased ([Table 4](#)). In the peel, free amino acids increased from 1.749–2.810 mg/100 g DW to 2.428–3.036 mg/100 g, whereas protein amino acids decreased slightly from 4.907–5.992 mg/100 g to 3.903–4.419 mg/100 g. Approximately 70% of the total free amino acids in the peel were accounted for by proline and asparagine. With maturation, proline and arginine increased, whereas asparagine and serine declined; in the late season variety, this change was retarded by 1–2 months. In another study, 'Fina', 'Oroval', and 'Hernandina' varieties were even evaluated during ripening with respect to the fruit weight, rind color, acidity, maturity index, and major individual sugars in the juice ([Tadeo et al., 1981](#)). The TSS/TA of the three cultivars varied in a similar way throughout the season, although 'Hernandina' reached the final rind color around 2 months later than 'Fina' and 'Oroval'. Sugar analysis indicated that sucrose is the main component of the juice, followed by fructose and glucose. In the studied cultivars, soluble sugars had a similar evolution during maturation. In particular, fructose and glucose concentrations varied from 1 to 1.5 g/100 mL and sucrose accumulated with ripening from 2.4 to 7.8 g/100 mL.

In 1985, a comprehensive study on the chemical and nutritional composition of citrus juices was published in Italy ([Pennisi, 1985](#)). In this work, clementine juice ('Comune' and 'Monreal' cultivars) is characterized with respect to its TA, vitamin C, β -carotene, and total carotenoids contents ([Table 5](#)). Citrus juices are rich sources of antioxidants, including vitamin C, carotenoids, and other hydrophilic phenolic compounds that are beneficial to health. Among these, some authors have stressed the main role of vitamin C and the two most abundant flavanone glycosides in mandarin-like species, hesperidin and narirutin ([Cano et al., 2008](#)). [Table 6](#) shows the values of narirutin, hesperidin, and total vitamin C in both traditional and modern clementine cultivars. Vitamin C values of the three traditional varieties ('Clemenules', 'Fina', and 'Oroval') range from 37.5 to 41.7 mg/100 g FW, the 'Fina' cultivar displaying the highest concentration. Otherwise, hesperidin and narirutin showed higher values in 'Clemenules' cultivar, reaching values of 28.7 and 7.0 mg/100 g FW, respectively, in comparison with the other two traditional genotypes in which lower concentrations of these two bioactive constituents are reported. Regarding juice to pulp ratio, the results showed that the juiciest cultivar is 'Oroval'. Nevertheless, other modern clementine cultivars are pointed out in this study because of

Table 4 Evolution of free amino acids in the juice of clementine fruits belonging to the varieties 'Fina', 'Oroval', and 'Hernandina' during ripening
Composition (%)

Amino acids	September 15			December 1			February 15		
	F	O	H	F	O	H	F	O	H
Aspartic acid	14	14.2	17.7	5.7	7.0	7.2	2.5	4.0	2.7
Threonine	0.6	0.6	0.5	0.5	0.4	0.4	0.5	0.5	0.5
Serine	9.5	9.8	9.8	5.6	5.2	5.2	5.0	5.1	4.6
Asparagine	18.5	20.7	17.6	11.5	13.2	9.3	7.7	11.2	6.8
Glutamic acid	6.9	6.9	7.8	2.8	3.3	3.4	3.0	2.8	2.0
Glutamine	2.0	1.7	1.8	2.1	1.6	1.5	1.7	1.4	2.2
Cysteine	0.9	1.1	1.1	1.4	0.8	1.3	1.2	1.1	1.4
Proline	24.8	23.9	27.8	41.2	38.5	42.5	40	40.8	48
Glycine	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4
Alanine	3.2	3.1	2.6	2.1	2.0	1.9	2.6	2.6	2.3
Valine	0.4	0.4	0.4	0.4	0.3	0.3	0.5	0.4	0.4
Methionine	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Isoleucine	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Leucine	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Phenylalanine	0.4	0.4	0.4	0.2	0.2	0.2	0.4	0.4	0.3
Γ-Aminobutyric acid	4.0	3.4	4.7	4.1	4.1	4.6	7.1	6.8	6.1
Histidine	0.9	1.0	1.0	0.5	0.6	0.9	2.0	1.8	1.1
Ornithine	0.5	0.7	0.4	0.6	0.4	0.6	0.4	0.4	0.4
Lysine	0.7	0.6	0.6	0.8	0.7	0.9	0.8	1.0	1.0
Arginine	11.6	10.6	4.9	19.8	21.1	19.1	23.4	18.8	19.3
Total content (mg/100 mL)									
	297	421	308	414	488	377	599	541	534

F: Fina; O: Oroval; H: Hernandina.

Adapted from [Martin et al. \(1984\)](#).

Table 5 Physicochemical and nutritional characterization of clementine juice ('Comune' and 'Monreal' cultivars)

Parameter	Maximum value	Minimum value	Average value (X)
TA (% anhydrous citric acid)	1.10	0.60	0.85
Vitamin C (mg/100 mL)	42.25	32.80	37.52
β -Carotene (mg/L)	0.78	0.22	0.50
Total carotenoids (mg/L of β -carotene equivalents)	22.40	9.60	16.00

TA, Total acidity.

Adapted from Pennisi (1985).

Table 6 Juice to pulp ratio (%) and total vitamin C, hesperidin, and narirutin content (mg/100 g FW) in the pulp of different clementine varieties

Varieties	Juice/Pulp	Vitamin C	Hesperidin	Narirutin
Clemenules	62.0 $\pm$ 1.7	38.7 $\pm$ 2.5	28.7 $\pm$ 3.6	7.0 $\pm$ 0.1
Fina	60.7 $\pm$ 1.6	41.7 $\pm$ 2.9	19.6 $\pm$ 1.1	3.9 $\pm$ 0.3
Oroval	66.8 $\pm$ 0.5	37.5 $\pm$ 3.2	22.7 $\pm$ 2.6	4.1 $\pm$ 0.7
Arrufatina	62.0 $\pm$ 0.9	39.7 $\pm$ 1.7	60.6 $\pm$ 4.3	30.0 $\pm$ 1.4
Clemenpons	65.6 $\pm$ 0.9	43.6 $\pm$ 2.5	35.4 $\pm$ 0.2	7.6 $\pm$ 0.7
Hernandina	60.7 $\pm$ 0.9	46.0 $\pm$ 2.2	13.2 $\pm$ 0.5	2.6 $\pm$ 0.2
Loretina	67.5 $\pm$ 1.6	39.8 $\pm$ 0.8	26.8 $\pm$ 3.0	4.0 $\pm$ 0.2
Marisol	69.8 $\pm$ 2.0	37.0 $\pm$ 1.1	28.9 $\pm$ 3.6	3.2 $\pm$ 0.3
Orogrande	62.7 $\pm$ 1.7	39.2 $\pm$ 1.3	24.1 $\pm$ 2.4	5.5 $\pm$ 0.3
Oronules	77.9 $\pm$ 6.1	47.4 $\pm$ 3.1	24.7 $\pm$ 4.4	3.4 $\pm$ 0.4

Adapted from Cano et al. (2008).

their higher content in bioactive compounds. The nutritional and antioxidant composition of modern varieties of clementines will be treated in the following section.

COMPOSITION OF MODERN CULTIVARS

Clementine fruits are vegetatively propagated, and the new cultivars are obtained after careful selection of spontaneous somatic mutations. Bud mutations often arise in citrus and are generally detected by the growers in branches of trees showing altered horticultural traits, such as maturity and flowering time or fruit characteristics. In recent decades, the clementine production has gathered a constant and wide diffusion thanks to an early ripening of its fruits compared with others within the genus *Citrus*. The rapid spread of this crop in the twentieth century has produced the isolation of several natural selections that are strictly different compared with the ancient genotype in terms of ripening stage, peel color, vegetative *habitus*, fruit size, and other characteristics (Harty et al., 1996; Lovicu et al., 1996). This has led to an extension of the harvest period of the fresh fruit from September through October to mid-February. As a consequence of the multitude

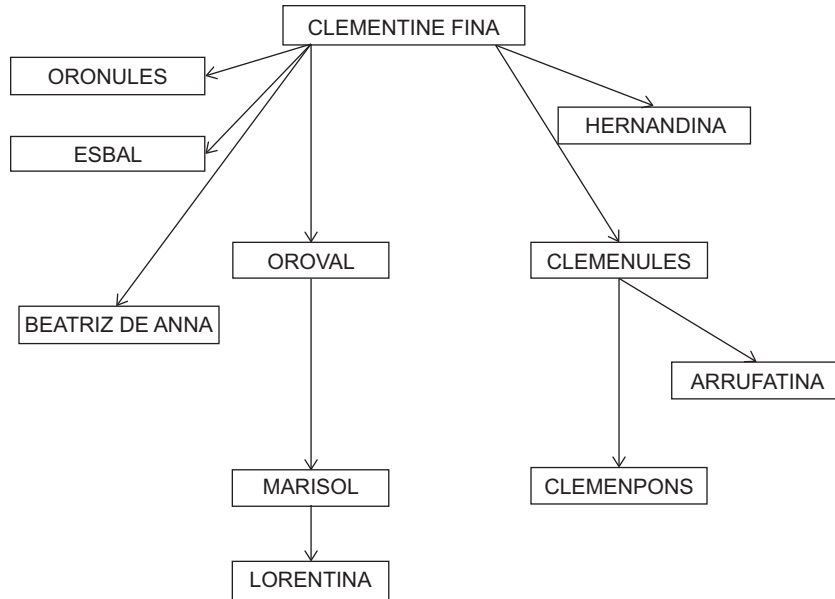


Figure 4 Clementine mutants deriving from ‘Fina’ cultivar selected in Spain in the last decades (1950-2000). Adapted from [Agusti \(2000\)](#).

of clones and selections that have been released, the outcome market of the clementine fresh fruit is represented by more varieties and genotypes than that of other citrus fruit.

As a matter of the fact, in the 1990s, European consumers started to greatly appreciate seedless early-ripening (‘Marisol’, ‘Ragheb’, ‘Caffin’, ‘Spinoso’, ‘Corsica 1’, ‘Corsica 2’, ‘SRA 89’, ‘Fedele’) and late-ripening selections (‘Hernandina’, ‘Tardivo’). Spain is the European country that has mostly improved clementine production through the selection of many early- and late-ripening mutants, as schematically reported in [Figure 4 \(Agusti, 2000\)](#). In Italy, several mutants, such as ‘Fedele’, ‘Precoce di Massafra’, ‘Spinoso’, ‘Tardivo’, ‘Rubino’, have been selected. In Corsica, a collection of mutants named SRA has been developed, which contains many cultivars with an ascending numerical progression (‘SRA 63’, ‘SRA 64’, ‘SRA 85’, ‘SRA 88’, ‘SRA 89’, ‘SRA 92’), and there are some early-ripening cultivars (‘Ristorcelli’, ‘Kuneyll’) ([Calabrese and Pensabene Bellavia, 2009](#)). Similarly, in Morocco, some interesting genotypes have been selected that have found a fair collocation even in the international markets, including ‘Bekria’, ‘Caffin’, ‘Sidi’, ‘Aissa’, ‘Cadoux’, ‘Muska’, ‘Nour’ ([Devaux, 1981](#)). The most thriving clementine fruit mutants, deriving from the ancient genotypes ‘Ordinary Clementine’ selected along the last century in the countries of the Mediterranean basin, are reported in [Table 7 \(Continella and Russo, 2012\)](#).

The nutritional and antioxidant composition of modern clementine varieties has been fully investigated in recent years, although it must be pointed out that most of the

Table 7 Main spontaneous mutations of clementines selected in the Mediterranean Basin in the twentieth century

Varieties	Country	Year of diffusion	Mutation of
Monreal	Algeria	1940	Fina
Fedele	Italy	1966	Fina
Tardivo	Italy	1969	Fina
Spinoso	Italy	1988	Fina
Rubino	Italy	1991	Fina
Oroval	Spain	1950	Fina
Clemenules	Spain	1953	Fina
Hernandina	Spain	1966	Fina
Esbal	Spain	1966	Fina
Arrufatina	Spain	1968	Nules
Clemenpons	Spain	1968	Nules
Marisol	Spain	1970	Oroval
Oronules	Spain	1970	Fina
Orogrande	Spain	1978	Nules
Loretina	Spain	1992	Marisol
Clemenrubì	Spain	1996	Oronules
SRA 92	France	1960	Fina
Corsica 2	France	1962	Fina
SRA 63	France	1963	Fina
SRA 85	France	1965	Fina
SRA 88	France	1965	Fina
SRA 89	France	1965	Fina
Caffin	Morocco	1968	Unknown
Nour	Morocco	1980	Unknown

Adapted from [Continella and Russo \(2012\)](#).

published research studies on these topics are mainly focused on other fruits belonging to the *Citrus* genus (i.e., orange, lemon, grapefruit, and mandarin genotypes).

A comprehensive study on the modern clementine selections grown in Italy, aimed at finding out the most promising mutants in terms of fruit quality and commercial attitude, was carried out by [Russo et al. \(2001\)](#). The comparative investigation targeted some medium-early ('Marisol', 'Corsica 1', 'Caffin', 'Spinoso', 'Ragheb', 'Fedele', 'Esbal', 'Corsica 2', 'Comune', 'SRA 63', 'SRA 85', 'SRA 88', 'SRA 89', 'SRA 92') and late-ripening ('Rubino', 'Hernandina') selections. The samples were collected on three different dates, according to the earliness or lateness of the investigated genotypes. [Table 8](#) shows the qualitative characterization of the varieties. Among the early selections collected in October, the 'Caffin' cultivar exhibited the most remarkable earliness characteristics in terms of sugar to acid ratio and peel color. The results of the analysis on the samples collected in November showed that all the selections presented sugar to acid ratios higher than 10.0 (except for the 'Marisol' cultivar) and well-colored fruits (except for the 'SRA 92' selection). With regard to the two late-ripening selections, 'Hernandina' and 'Rubino', although they presented a very high sugar to

Table 8 Qualitative characterization of some early- and late-ripening clementine selections grown in Italy^a

Selection	Fruit weight (g)	TSS (%)	TA (%)	TSS/TA	Peel color (a/b)
Early selections (date of collection: October, 15)^b					
Caffin	86.0 AB	10.0 A	1.0 C	1.0 A	0.23 A
Ragheb	68.1 C	9.2 C	1.0 C	9.2 AB	0.01 B
Corsica 1	64.3 C	9.6 ABC	1.0 C	9.2 AB	−0.03 B
Corsica 2	69.0 C	9.7 ABC	1.1 BC	9.2 AB	−0.06 BC
Spinoso	73.3 BC	9.6 ABC	1.3 A	7.6 C	−0.06 BC
SRA 89	69.6 C	9.8 AB	1.0 C	9.6 A	−0.08 BC
Fedele	77.5 BC	9.9 AB	1.2 AB	8.1 BC	−0.10 BC
SRA 63	70.0 C	9.4 BC	1.2 AB	8.2 BC	−0.11 BC
Marisol	97.5 A	9.6 ABC	1.3 A	7.5 C	−0.27 C
Early selections (date of collection: November, 15)^c					
Caffin	98.3 B	10.6 A	0.8 BC	13.6 A	0.57 A
Fedel	92.2 BC	10.4 AB	0.9 AB	11.3 BCD	0.47 B
Corsica 1	74.7 F	9.8 CD	0.8 BC	12.3 ABC	0.46 BC
Corsica 2	86.7 BCDE	10.0 BC	0.8 BC	12.0 ABC	0.45 BC
SRA 89	83.4 CDEF	9.9 BC	0.8 BC	12.3 ABC	0.43 BCD
Spinoso	85.2 CDEF	10.1 ABC	1.0 A	10.6 CD	0.42 BCDE
SRA 85	81.3 CDEF	10.1 ABC	0.9 AB	11.8 BC	0.42 BCDE
Ragheb	83.1 CDEF	9.6 CD	0.8 BC	12.7 AB	0.42 BCDE
SRA 63	83.1 CDEF	9.8 CD	0.8 BC	10.9 CD	0.41 CDEF
Marisol	127.5 A	9.4 D	1.0 A	9.8 D	0.39 DEF
SRA 88	79.9 DEF	10.0 BC	0.8 BC	12.7 AB	0.39 DEF
Esbal	91.5 BCD	9.6 CD	0.8 BC	11.5 BCD	0.38 DEF
Comune	78.9 EF	10.0 BC	0.8 BC	12.2 ABC	0.38 DEF
SRA 92	80.1 DEF	10.0 BC	0.8 BC	12.1 ABC	0.36 F
Late selections (date of collection: January, 15)^d					
Hernandina	90.1	10.1	0.4	22.8	0.32
Rubino	80.1	9.6	0.5	17.5	0.42

TSS, Total soluble solids; TSS/TA, Maturity index.

^aMean values followed by the same letter within a column showed no significant difference (Tukey test, $p \leq 0.01$).^bData are the mean of 4 years of collection.^cData are the mean of 5 years of collection.^dData are the mean of 1 year of collection.

Adapted from Russo et al. (2001).

acid ratio before the end of January, the fruit color allowed an extension of the collecting period until mid-February. Based on this evidence and the data reported on yields, the authors assessed that ‘Caffin’, ‘Spinoso’, ‘Fedele’, and ‘Ragheb’ selections might be successfully cultivated because they allow the grower to anticipate trading the fresh fruit of 2–3 weeks’ growth, compared with the traditional ‘Comune’ cultivar. ‘Corsica 2’ and ‘Esbal’ may be also

considered as valid substitutes for the ‘Comune’ clementine, because they are more productive and show good fruit size. Moreover, ‘Rubino’ and ‘Hernandina’ allow the trading period to be delayed until February, owing to their rind vitality.

An attempt to establish a cultivar classification according to the chemical composition of different *Citrus* species and varieties has been made using narirutin, hesperidin, and total vitamin C (Cano et al., 2008). Table 6 reports the juice to pulp ratio, the total vitamin C, and the hesperidin and narirutin content within the pulp of different clementine varieties investigated in this study. The ‘Arrufatina’ cultivar, with juice to pulp ratio and vitamin C values comparable to those of the other genotypes, has significantly higher contents of hesperidin and narirutin (60.6 mg/L and 30.0 mg/L, respectively) if compared with the other traditional genotypes. The other modern selections showed similar concentrations of these compounds when compared with the traditional ones.

A study by Dhuique-Mayer et al. (2005) reported the interspecific influence of different citrus juices on the content of the main antioxidant microconstituents (flavanones, carotenoids, and vitamin C) present in different orange varieties, one mandarin genotype, and one clementine cultivar (‘SRA 85’). The results of the characterization of the clementine fruit show that the ‘SRA 85’ clementine contains an average total vitamin C content of 53.1 mg/100 mL, which is higher than that reported in other studies for the traditional ‘Fina’, ‘Clemenules’, ‘Oroval’, and ‘Monreal’ cultivars (Table 9). Additionally, the two most represented flavanone glycosides, hesperidin and narirutin, have significantly higher concentrations compared with those reported by Cano et al. (2008) for the

Table 9 Flavanone glycoside, vitamin C, and carotenoids composition of clementine juice (‘SRA 85’)

Parameter	Clementine ‘SRA 85’ (TSS/TA 7.0)
Ascorbic acid (mg/100 mL)	52.8 ± 0.9
Total vitamin C (mg/100 mL)	53.1 ± 0.9
Hesperidin (mg/L)	754 ± 1
Narirutin (mg/L)	46.4 ± 1.6
Ratio hesperidin/narirutin	16.2
Phytoene (mg/L)	0.59 ± 0.04
Phytofluene (mg/L)	0.56 ± 0.04
Violaxanthin (mg/L)	2.79 ± 0.16
Lutein (mg/L)	0.31 ± 0.01
Zeaxanthin (mg/L)	1.03 ± 0.06
β-Cryptoxanthin (mg/L)	8.63 ± 0.35
β-Carotene (mg/L)	1.45 ± 0.08
Lycopene (mg/L)	nd
Vitamin A value (RE)	960 ± 19

RE, Retinol equivalent; TSS/TA, Maturity index.

Adapted from Dhuique-Mayer et al. (2005).

traditional 'Fina', 'Clemenules', and 'Oroval' cultivars (Table 6). The qualitative and quantitative characterization of the carotenoid compounds of the 'SRA 85' clementine is reported in this study. β -Cryptoxanthin was the most abundant nutritional carotenoid, with 8.63 mg/L. Making a comparison between β -carotene concentration in 'SRA 85' and the average concentration reported by Pennisi (1985) for 'Comune' and 'Monreal' cultivars (Table 5), the modern cultivar shows a higher content, almost threefold greater than the average content reported for the traditional cultivars.

Thirteen modern clementine cultivars ('Caffin', 'Corsica 2', 'Esbal', 'Fedele', 'Isa', 'Oronules', 'Precoce di Massafra', 'Ragheb', 'Rubino', 'Spinoso', 'SRA 63', 'SRA 89', 'SRA 92') grown in Italy were characterized with respect to their total polyphenols, carotenoids, vitamin C, hesperidin, narirutin, naringin, and rutin content (Milella et al., 2011). The mean content of β -carotene found in all the studied fruits was 13.58 mg/L, ranging from 10.96 mg/L in the 'Fedele' cultivar to 17.54 mg/L in the 'SRA89' cultivar. All the analyzed varieties showed a high content of this bioactive compound compared with that reported in other studies. Regarding the total polyphenols, all the cultivars showed a content ranging from 259 to 487 mg/L, with the 'Caffin' cultivar noted for its high content (554 mg/L). Vitamin C content in all the studied clementine cultivars was similar to that reported by Dhuique-Mayer et al. (2005), ranging from 484.11 mg/L in the 'Oroval' cultivar to 643.73 mg/L in the 'Fedele' cultivar. Only the cultivar 'Caffin' exhibited a significantly different and unusual vitamin C concentration, with the highest (755 mg/L) value. Flavonone glycosides level was in agreement with those reported by other authors, with hesperidin ranging from 88.71 mg/L in the 'Ragheb' cultivar to 165.81 mg/L in the 'Rubino' cultivar, and narirutin ranging from 5.58 mg/L in the 'Caffin' cultivar to 26.78 mg/L in the 'Spinoso' cultivar. Moreover, in this study, low levels of naringin (a compound typically found in grapefruit and sour orange) were reported in all the investigated fruits, ranging from 0.02 mg/L in the 'Caffin' cultivar and 2.70 mg/L in the 'Esbal' cultivar. Furthermore, this was the first study reporting the presence of rutin (quercetin-3-O-rutinoside) in clementine fruits, ranging from 38.75 in 'Ragheb' to 75.15 mg/L in 'Rubino' cultivars.

In order to obtain citrus fruit with high nutritional and health-promoting properties, a breeding program developed by CRA-ACM used clementine fruit as female parent in a series of crosses with blood oranges that were aimed at obtaining triploid hybrids. The new red-fleshed, mandarin-like citrus hybrids are seedless and easy to peel, have increased size, and have new original sensory characteristics and pigmentation resulting from anthocyanin components. The juice quality of two new pigmented hybrids [diploid 'Monreal' clementine (*C. x clementina*) $\times$ tetraploid 'Tarocco' orange (*Citrus sinensis* L. Osbeck)] containing anthocyanin, namely 'Tacle' and 'Clara', have been investigated (Rapisarda et al., 2008). Compared with their parents, both the hybrids present at commercial maturity the typical agreeable physicochemical characteristics of the clementine fruit, with a low acidity (approximately 1%) and a good sugar level (TSS 12%), thereby producing a well-balanced sugar to acid ratio. The main

inherited trait of the male parent has to be referred to the accumulation of bioactive compounds at higher levels compared with clementine. At full ripeness, the vitamin C values in the 'Clara' hybrid (approximately 70 mg/100 mL) were comparable to those in the 'Tarocco' orange, which is the orange variety that is the richest in vitamin C. Anthocyanin maximum concentration was reached in both hybrids in March, with values of 13.56 mg/L in the 'Tacle' and 2.66 mg/L in the 'Clara'. These are values that, even if well below those of the 'Tarocco' oranges, give to these hybrids a slight pleasant red pigmentation of the flesh. Total flavanones and total hydroxycinnamates also reached high concentrations at fruit maturity: 216.05 mg/L and 89.41 mg/L in the 'Tacle' hybrid and 333.87 mg/L and 96.77 mg/L in the 'Clara' hybrid, respectively. In order to identify the optimal stage for fruit processing and to evaluate polyphenol evolution during fruit cold storage, this study reports the juice quality attributes of fresh fruits harvested at different ripening stages and of cold-stored fruits kept for 104 days at $6 \pm 1^\circ\text{C}$ and 90–95% relative humidity. The chemical composition of 'Tacle' and 'Clara' fresh fruits at different stages of ripening showed that the optimal period for fruit processing is February, when there are a suitable TSS/TA ratio; high vitamin C values; and good anthocyanin, flavanone, and total hydroxycinnamic acid concentrations. Likewise, fruit storage further improved juice quality, even though low TA values in both hybrid juices after 72 days of storage may negatively affect their taste. Nevertheless, anthocyanin development in fruits during 104 days of cold storage may positively influence the sensory and functional quality of processed products. In addition, the increase in flavanones and hydroxycinnamic acids and the preservation of vitamin C during cold storage suggest that the consumption of these juices alone, blended with other commercial citrus juices, or mixed in the formulation of new beverages can play a significant role in human health promotion.

Other interesting pigmented and nonpigmented new citrus hybrids belonging to the OTA ['Oroval' clementine (*C. x clementina*) × 'Tarocco' orange (*C. sinensis* L. Osbeck)] and OMO ['Oroval' clementine (*C. x clementina*) × 'Moro' orange (*C. sinensis* L. Osbeck)] groups developed at the CRA-ACM have been characterized with respect to their fruit quality as well as the content of health-promoting components such as ascorbic acid, total phenolics, flavanones, anthocyanins, and phenolic acids (Rapisarda et al., 2009). Among others, two most promising hybrids were identified, namely OTA 9 and OTA 31, as new sources of phenolic complex and vitamin C, respectively. Indeed, the OTA 31 juice exhibited higher ascorbic acid content than that of the 'Tarocco' orange, which is known as the richest source of vitamin C among orange varieties, with an average content of 91.60 mg/100 mL. Total anthocyanin content reached about 500 mg/L in the OTA 9 hybrid, an almost fivefold higher value compared with its male parent, the 'Tarocco' orange. In addition, these hybrids have shown a high antioxidant activity, suggesting that their consumption could be useful in the prevention of diseases in which free radicals are involved.

Because the consumption of commercial clementine juice is fast increasing as a result of its delicious, organoleptic, volatile flavor, and its antioxidant quality, researchers have been considering the influence of two different juice extraction systems (plug inside fruit and rotating cylinders) on the juice itself (Alvarez et al., 2012). The results showed that juice extracted by the former method presented higher yields and hesperidin content, whereas no significant difference was found when compared with the physicochemical parameters related to juice quality (Bx/acid ratio, pH, and ascorbic acid). The organoleptic quality was not affected by the processing technique, whereas there were significant differences in the chemical flavor profile. When comparing the average total chromatographic areas of the samples, juice obtained by rotating cylinders exhibited a very low volatile fraction in headspace conditions with respect to juice from plug inside fruit extractor. Moreover, the juice extracted by using rotating cylinders had a higher content of essential oils than the juice obtained with the other technology. Regarding the extraction system through rotating cylinders, the principal volatile components of the juice were cyclic monoterpenes (97.41%), mainly sabinene and limonene; noncyclic monoterpenes (1.19%), mainly β -myrcene and β -linalool; nonterpenic compounds (0.61%), mainly n-octanol and n-decanal; and sesquiterpenes (0.29%), mainly α -copaene and α -sinensal. For the other extraction system the primary volatile components of the juice were cyclic monoterpenes (88.76%), mainly 1R- α -pinene, β -pinene, and limonene; noncyclic monoterpenes (6.95%), mainly β -myrcene; nonterpenic compounds (2.71%), mainly n-octanal and n-decanal; and sesquiterpenes (0.59%), mainly α -copaene, β -sinensal, and α -sinensal.

All of the studies discussed here display how the composition of nutritional and biologically active compounds and sensory profile of clementine fruit vary with different genotypes. It is also worth mentioning that other than genetic factors, climate, soil type and conditions, cultural practices, and rootstocks could also have a significant influence on the nutritional composition of the fruit, whatever the species involved; however, these topics are not to be treated in this book.

FOCUSED AREA OF RESEARCH: CAROTENOID ACCUMULATION IS DIFFERENTIALLY EXPRESSED IN THE CLEMENTINE 'COMUNE' COMPARED WITH ONE OF ITS NEW LATE-RIPENING MUTANTS, THE CLEMENTINE 'TARDIVO'

Whatever the species, fruit development and ripening are physiological phenomena that are under hormonal, nutritional, and environmental control. Citrus fruits are nonclimacteric and the color-break of their peel, resulting from massive accumulation of carotenoids and chlorophyll degradation, is one of the most evident changes of late maturation. This change in flavedo color is regulated by metabolic signals, including ripening inducers, such as ethylene and sucrose, and ripening retardants such as gibberellins. Recently, ethylene treatments were correlated to carotenoid accumulation, establishing the upregulation of

carotenoid biosynthetic genes in oranges (Rodrigo and Zacarias, 2007). It was suggested that ethylene application accelerates the biochemical and gene expression changes that naturally occur during ripening. Thus, even if citrus fruits, being nonclimacteric, produce extremely low amounts of ethylene during ripening, complex regulations of ethylene production and perception might exist through the maturation period. In a recent work, the authors have used the characterization of a late-ripening mutant of the 'Comune' clementine as a useful system to investigate on the biochemical mechanisms involved in carotenoid accumulation during maturation. The 'Tardivo' clementine is indeed a natural bud mutation of 'Comune', which differs for an extended harvest period mainly because of a delayed fruit color-break. 'Comune' usually fully ripens in December, whereas 'Tardivo' ripens about a month later. In order to find out whether total carotenoid levels and their biosynthesis at a molecular level could be influenced by the cultivar, a comprehensive study has been carried out on morphological, chemical, and molecular characteristics of fruits of both genotypes during the whole maturation process (Distefano et al., 2009). The qualitative carotenoid profile of the flavedo of the two selections was analyzed by High Performance Liquid Chromatography - Photodiode Array detector (HPLC-PDA), and total carotenoid content was determined spectrophotometrically. The quantitative gene expression analysis of the main genes involved in chlorophyll catabolism, carotenoid biosynthesis, ethylene biosynthesis, and signal transduction was carried out through quantitative Real Time-Polymerase Chain Reaction (RT-PCR). The results showed that apart from color change, which was the most marked difference between 'Comune' and 'Tardivo' clementines, the internal maturity of the fruits of the two varieties proceeds at the same rate. Although 'Comune' and 'Tardivo' reach their respective orange-peel colors in December and January, the juice acidity and TSS levels are always comparable to the maturation of the fruit (Figure 5). These results indicated that 'Tardivo' was not a mutant modifying all of the ripening process, but only showed a different rate of external fruit pigmentation. Indeed, at harvest time (January for 'Comune' and February for 'Tardivo'), 'Tardivo' fruits showed similar diameter and slightly higher weight compared with 'Comune'. Total carotenoid content both in 'Comune' and 'Tardivo' varieties quickly declined from mid-October to November. The levels of the 'Tardivo' mutant further declined in December, remaining constant in January and February and slightly increasing again only in March. Differently, total carotenoids in the 'Comune' cultivar showed an increase in December and January (Figure 6(a)). HPLC analysis of individual carotenoids during the different developmental stages revealed different accumulation trends of phytoene, a colorless carotenoid; α -carotene; β -carotene; β -cryptoxanthin; lutein; and violaxanthin in the fruit of the two varieties. In general, the trend recorded for the accumulation of these compounds in the two varieties is the same as that previously found by other authors for clementine fruit (Alos et al., 2006), with a decrease in α - and β -carotene and lutein and an increase in cryptoxanthin and violaxanthin. At full ripeness both genotypes reach similar levels of these carotenoids; however, some marked differences are evident in the two selections during the fruit development stages. Phytoene accumulation in 'Comune' was almost four times higher than that in the

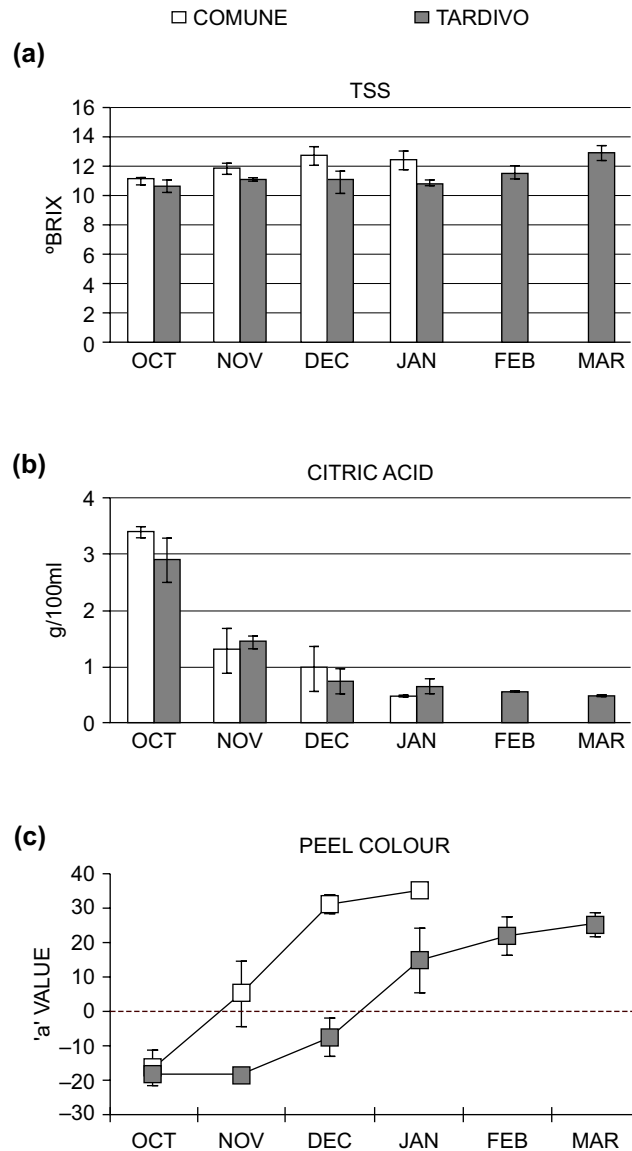


Figure 5 Physiological measurements performed on 'Comune' and 'Tardivo' clementine fruits, sampled on every first day of the month: (a) TSS in fruit juice; (b) citric acid in fruit juice, quantified indirectly by measuring TA (titration with 0.1 N NaOH); (c) peel color during development and ripening. Data are means $\pm$ SD ($n=3$). Reprinted with permission from Distefano et al. (2009). Copyright 2009 American Chemical Society.

late-ripening variety (Figure 6(b)), and, with regard to the colored carotenoids (α -carotene, lutein, β -carotene, β -cryptoxanthin, violaxanthin), 'Tardivo' generally showed delayed accumulation (Figure 6(c–g)). Because there are differences in the color-break phenotypic process and in the accumulation of total and individual carotenoids of the two investigated

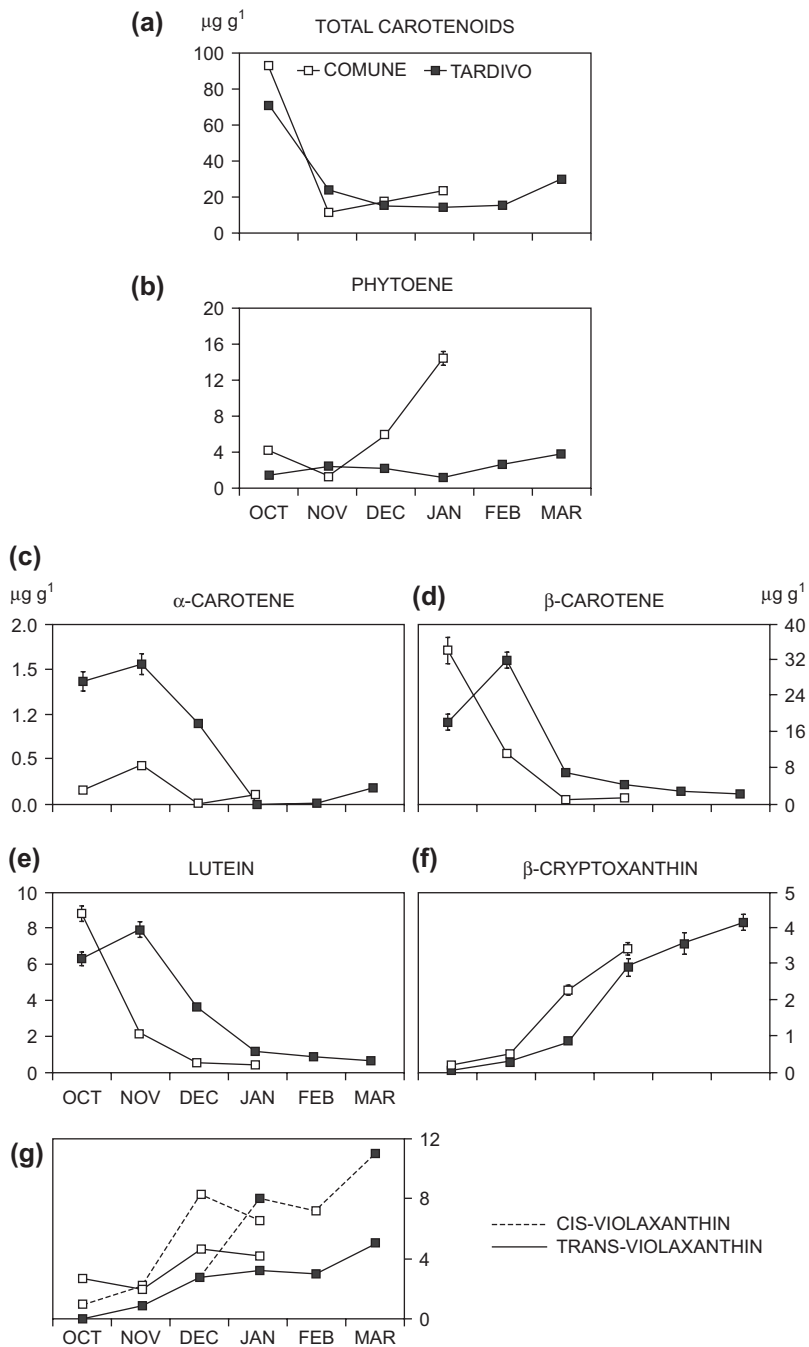


Figure 6 Carotenoids ($\mu\text{g/g}$) in the flavedo of 'Comune' and 'Tardivo' clementines during fruit development and ripening. Data are means $\pm$ SD ($n=3$). Reprinted with permission from [Distefano et al. \(2009\)](#). Copyright 2009 American Chemical Society.

genotypes, the molecular analysis of the genes involved in carotenoid biosynthesis, chlorophyllase expression, and ethylene biosynthesis and perception helped determine the variables that are responsible at a molecular level for the delayed flavedo pigmentation of the 'Tardivo' mutant compared with its traditional parent 'Comune'. Specifically, phytoene synthase transcript levels are differentially expressed in the 'Comune' and 'Tardivo' flavedos from November onward. Phytoene synthase transcript levels clearly increase as the fruit matures only in the 'Comune' genotype, whereas in 'Tardivo', this gene is downregulated and does not reach the levels present in the 'Comune' variety. This behavior is also correlated with the phytoene accumulation quantified by HPLC. A further difference is related to the chlorophyllase gene expression. During 'Comune' color break, this gene shows a transient increase, whereas in 'Tardivo', a low expression is recorded. Moreover, regarding the perturbation of ethylene biosynthesis genes, significant differences in their expression levels is observed during November, when 'Comune' is at the color-break stage and 'Tardivo' is still green, and December, with ethylene biosynthetic genes in the 'Comune' variety being downregulated and then reaching comparable values in January when the rind is full-orange colored.

Similarly, expression levels of the ethylene receptor genes, involved in ethylene signal transduction, show differential expression patterns in the two genotypes. Specifically, the messenger ribonucleic acid levels are somewhat constitutive in 'Comune', whereas in 'Tardivo' they reach a maximum level in November; that is, the period where this genotype is still fully green and 'Comune' is already at color break. The results of this study highlighted that although the internal maturity of the two selections proceeds at the same rate, differences in fruit-ripening period, and thus, in the extended harvest period of the late-ripening mutant, might have been influenced by an alteration in 'Tardivo' ethylene signaling compared with that in 'Comune'. This perturbed sensitivity surely influences carotenoid biosynthesis and accumulation. As a conclusion, the study added new valuable information to better understand the complex process of ripening in early- and late-ripening selections of clementine fruits.

SUMMARY POINTS

- The oldest clementine genotypes worldwide are considered to be 'Fina', or 'Comune', and 'Monreal' cultivars.
- The clementine fruit, present typical agreeable physicochemical characteristics at commercial maturity, such as low acidity (1%), good sugar level (TSS 12%), and a well-balanced sugar to acid ratio.
- Comprehensive studies on the physicochemical and nutritional composition of the traditional clementine cultivars are present in literature since the first years of the 1970s. Potassium is the major nutrient element in clementine juices and is present at an average value of 153.7 mg/100 mL. Sulfates are also present at an average level of

177.8 mg/L. Remarkable is the presence of some ions such as calcium, magnesium, and phosphorus, all present at an average level of around 11 mg/100 mL. Proline, arginine, asparagine, aspartic acid, glutamic acid, serine, and γ -amino butyric acid are the predominant amino acids.

- Citrus juices are considered to be rich sources of antioxidants, including vitamin C, carotenoids, and other hydrophilic phenolic compounds that contribute to the beneficial health effect. Vitamin C is present at an average content of 49.4 mg/100 mL. The two most abundant flavanone glycosides in clementines are hesperidin and narirutin. Carotenoids, predominantly α -carotene, lutein, β -carotene, β -cryptoxanthin, and violaxanthin, are also present.
- Clementine fruits are vegetatively propagated and the new cultivars are obtained after careful selection of spontaneous somatic mutations that often arise in citrus and are generally detected by the growers in branches of trees showing altered horticultural traits. The rapid spread of the clementine's popularity has produced the isolation of several natural selections that are strictly different when compared with the ancient genotype in terms of ripening stage, peel color, vegetative *habitus*, and fruit size.
- Among modern cultivars, 'Caffin', 'Spinoso', 'Fedele', and 'Ragheb' selections might be successfully cultivated, because they allow the anticipation of trading the fresh fruit after 2–3 weeks, compared with the traditional 'Comune' cultivar. 'Corsica 2' and 'Esbal' may be also considered as valid substitutes for the 'Comune' clementine, because they are more productive and show good fruit size. Moreover, 'Rubino' and 'Hernandina' allow the trading period to be delayed to February because of their rind vitality.
- Some modern cultivars (i.e., 'SRA 85' and 'Arrufatina') contain higher levels of carotenoids, hesperidin, and narirutin when compared with the average content reported for the traditional cultivars.
- Clementine fruits have been conveniently employed in breeding programs aimed at obtaining triploid seedless pigmented hybrids. Some of the new hybrids (i.e., OTA 9 and OTA 31) have shown a high antioxidant activity, suggesting that their consumption could be useful in the prevention of diseases in which free radicals are involved.
- Although the internal maturity of the traditional and modern genotypes proceeds at the same rate, differences in fruit-ripening period, and thus in the extended harvest period of the late-ripening mutants, are influenced by an alteration in ethylene signaling in the late-ripening mutants. This perturbed sensitivity surely influences carotenoid biosynthesis and accumulation.

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CHAPTER 8

Phytochemical Composition of the Large Cranberry (*Vaccinium macrocarpon*) and the Small Cranberry (*Vaccinium oxycoccos*)

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LIST OF ABBREVIATIONS

ASC	Ascorbic acid
BA	Benzoic acid
DHA	L-Dehydroascorbic acid
GAE	Gallic acid equivalent
HPLC	High-performance liquid chromatography
SS	Soluble solids
TAC	Total anthocyanins
TP	Total phenolics

INTRODUCTION

The ancient indigenous people of North America, Europe, and Siberia were aware of the healing properties of cranberries and used these berries to treat colds, digestive issues, and urinary diseases. American whalers and mariners used the valuable berries of the large cranberry (American cranberry) *Vaccinium macrocarpon* Aiton on their voyages to prevent scurvy. In North America, the initial cultivation of the large cranberry involved transplantation of the native plants to artificial “bogs” (Trehane, 2004). Captain Henry Hall began planting cranberry vines in Massachusetts in 1816. The first plantations of the

large cranberry were established near Boston in 1833. The cultivation of the large cranberry then developed extremely rapidly, and cranberry plantations consisting of approximately 1600 ha in Massachusetts were established in 1850. The number of cranberry plantations continued to increase throughout the nineteenth century (Eck, 1990; Jasperson, 1991). Later, cranberry plantations were also established in Canada, specifically in Nova Scotia, Quebec, and the Pacific coast of British Columbia.

The first cranberry cultivars were derived in the United States by selecting wild clones from natural bogs. The ancient cranberry cultivars were 'Howes' (derived in 1843), 'Early Black' (in 1852), 'McFarlin' (in 1874), and others. In the middle of twentieth century, after over 100 years of commercial cranberry cultivation, more than 90% of the cranberry crop consisted of four cultivars: 'Early Black', 'Howes', 'McFarlin', and 'Searles'. These cultivars, all selected from native bogs, were named the "big four." Scientists have continued to select new cranberry cultivars to improve the berry size, yield, and disease resistance. Various crosses between 'Early Black', 'Howes', and 'McFarlin' were successfully performed. The cultivar 'Stevens' is a relatively new hybrid released in 1950, which now covers a third of the total cranberry plantation area in Massachusetts.

The small cranberry (European cranberry), *Vaccinium oxycoccos* L., is also an excellent source of phenolic compounds (Česonienė et al., 2009). The small cranberry is an important forest berry in the markets of the Baltic States, Poland, Belarus, Ukraine, and Russia. However, there has been a significant increase in the anthropogenic influence on the sources of the European cranberry in its natural bog habitats. Therefore commercial plantations of the large cranberry have been established in various European countries. Consequently, production and consumption of the large cranberry have been continually increasing in Europe. The area of the Latvian cranberry plantations is the third largest in the world (Abolins et al., 2009). Several large, modern, commercial plantations of cranberries have been established in Germany, Belarus, Russia, and Lithuania. The most popular cultivars grown in these plantations were designated 'Stevens', 'Ben Lear', 'Bergman', 'Searles', and 'Lemunyon' (Abolins, and Ansevica, 2006; Dierking et al., 2006; Egoshina, 2006).

Both cranberry species are rich in many classes of chemical compounds. The classes of phytochemicals identified in cranberries include anthocyanins, flavonols, proanthocyanidins, organic acids, and carbohydrates. The analysis of the chemical composition clarifies the complexity of the multiple nutraceutical actions of fresh and processed cranberries.

BOTANICAL ASPECTS

The large cranberry, *V. macrocarpon* Aiton (or *Oxycoccus macrocarpus* (Aiton) Pers.; Ericaceae), is also known as the American cranberry. It is closely related to the small cranberry, *V. oxycoccos* L. (or *Oxycoccus palustris* Pers.), also called the *European cranberry*. The large cranberry is native to eastern and central North America, including the eastern territories of Canada

and the United States from Newfoundland to Long Island. The large cranberry is also found in the mountainous regions of Arkansas, Illinois, North Carolina, and Ohio (Trehane, 2004), and in bogs in the northeastern and Great Lakes regions of United States. Populations of the mid to southern Appalachians and the North Carolina coastal plain define the southern limit of distribution of *V. macrocarpon* (Stewart and Nilsen, 1995).

Cranberry roots have a symbiotic relationship with mycorrhizae. It is likely that the mycorrhiza provide a filter to prevent entry of harmful minerals and microorganisms. In turn, the cranberry plant provides the fungi with carbohydrates manufactured through photosynthesis (Trehane, 2004).

The large cranberry is a perennial evergreen shrub with creeping horizontal stems (often called *runners*) up to 2 m long. Erect (upright) shoots reach 7–15 cm in length and produce flowers and fruit. Large numbers of these shoots form a dense cover over the entire surface. American settlers noticed the flowers resemble the head and beak of the native sandhill crane; hence its former name *craneberry* (Trehane, 2004). Fruiting shoots do not branch and have very short internodes with large numbers of buds. Berry yield depends on the number of these shoots, the optimal number being from 2 to 3000 per square meter. The leaves are elliptical, up to 22 mm long and up to 9 mm wide, with entire or slightly folded (revolute) edges. The leaflike bracts are at the top of pilose peduncles. The flowers are pale pink, almost white, with petals 6–10 mm long, and borne in racemes of between 2 and 7 flowers (Brown and McNeil, 2006). Flowering occurs in the second half of June to early July. The flower buds are distributed along the fruiting shoot. Flowering begins at the lower part of the shoot and proceeds upward. Flowers lower down the shoot have a higher probability of setting fruit than those situated at the top of the stem. In a given year, large cranberry plants produce only one to three fruits per fruiting stem, even when there are up to seven flowers (Baumann and Eaton, 1986). Assuming the limitation of fruit set is the result of insufficient pollination, cranberry farmers rent honey bees or bumblebees to ensure better pollination (Kevan et al., 1983).

The large cranberry has a variety of fruit shapes, including round, terete, spindle, or egg-shaped. Commercial cultivars are distinguished by differences in their berry shape and size. Berry color can be red, dark red, or dark purple. Early-ripening cultivars usually start to ripen near the end of summer to the beginning of September. The ripening phase of late cultivars continues throughout October.

Compared with the large cranberry, the geographical distribution of the small cranberry, *V. oxycoccos*, is considerably wider. It occurs in forest areas in Europe, Asia, and North America. To the north, it reaches the Arctic Circle, and it extends as far south as the north of Italy and Spain. In the east, it occurs in Siberia and the Far East. This species is found in the sphagnum bogs of the boreal zone. It is an evergreen shrub with creeping stems, and grows on peat in poorly drained sites with a very high water table. The horizontal stems are up to 100 cm (usually 30–50 cm) long. The ovate leaves are 8–16 mm long and 3–6 mm wide. The flowers bloom in groups of two to six in umbellate

inflorescences at the tips of shoots. Flowering starts in the last week of May. The berries ripen during late August through September and can persist on plants under the snow until spring. In natural habitats, pear-, egg-, spindle-shaped, and round or cylindrical berries are found ([Česonienė et al., 2006](#)).

The small cranberry is more resistant to cold than the large cranberry. It is a very important native berry in regions where cultivation of the large cranberry is not possible. However, the small cranberry cannot compete with the large cranberry for productivity and fruit size.

COMPOSITION OF TRADITIONAL AND ANCIENT CULTIVARS OF CRANBERRY

Both cranberry species have been used for centuries in North America, as well as some parts of Asia and Europe, with the intention of preventing or curing different diseases. A review of the historical literature confirms the various manners in which fresh or processed forms of cranberries are consumed in the human diet. There are many recommendations for the use of cranberries to prevent diseases of the urinary tract and digestive system, thus avoiding the overuse of antibiotics ([Upton, 2002](#)). It is for this reason that the chemical composition of cranberries has been investigated for many years. The large intraspecies variability is characteristic of the two cranberry species. The morphological and genetic diversity of chemical differences between the large and small cranberry, as well as intraspecies variation in the constituent chemical compounds have been the subjects of scientific investigations. The early studies of cranberries were focused on comparative investigations of both cranberry species and include the first cranberry cultivars, which were selected from wild clones of the large cranberry ([Zeldin and McCown, 2004](#)). The ancient cultivars ‘Early Black’, ‘Howes’, and ‘McFarlin’ were selected in Massachusetts, whereas ‘Searles’ was selected from a wild population in Wisconsin ([Trehane, 2004](#)). Interest in the chemical compounds of the small cranberry has increased because of its long-standing use in folk medicine in Eastern Europe, Finland, Sweden, and Russia ([Kozłowski et al., 2006](#)).

There are some bibliographic data referring to the initial studies of chemical composition of the large and small cranberry ([Table 1](#)). The ripe berries of the small cranberry contain from 84.2% to 92% water. The larger amount of water was detected in the berries that were collected in the spring after the snow had melted. The pulp of large cranberry is distinguished by a drier consistency, because these berries accumulate less water (up to 88.0%). Depending on the amount of water, dry substances comprise 8–15.1%, which includes 3.8–3.87% insoluble substances and 8.5–10.8% soluble dry substances ([Cherkasov et al., 1981](#); [Liebster, 1972](#)).

The berries of the small cranberry accumulate from 2.10% to 4.85% of titratable acids. The berries of the large cranberry contain less titratable acids. Citric acid dominates this class of compounds and comprises 1.8–2.6% of the berries of the small cranberry.

Table 1 Biochemical composition of berries of combined samples of large and small cranberry

Component	Large cranberry, <i>Vaccinium macrocarpon</i>	Small cranberry, <i>Vaccinium oxycoccos</i>
Moisture, %	84.8–88.0	84.2–98.8
Dry matter, %	9.2–15.2	8.0–15.1
Mineral content, %	0.2–0.23	0.2–0.28
Titrateable acidity, %	1.9–2.4	2.1–4.9
Monosaccharides, %	3.4–7.1	2.2–6.0
Sucrose, %	3.9–5.3	0.1–1.57
Fructose, %	1.0–2.2	1.0–2.2
Pectins, %	0.4–1.3	0.2–1.4
Benzenecarboxylic acid (benzoic acid), mg/100 g	65.0–123.0	41.0–63.4
Ascorbic acid, mg/100 g	7.5–32.1	15.3–30.0

Adapted from [Eck \(1990\)](#), [Liebster \(1972\)](#) and [Schmid \(1977\)](#).

The berries of the ancient ‘Howes’ and ‘Early Black’ cultivars of the large cranberry accumulate 1.88 and 6.08 mg/g of citric acid, respectively. The concentrations of benzoic, quinic, ursolic, chlorogenic, malic, and oleanolic acids were also determined ([Wang and Wang, 2009](#)).

Monosaccharides comprise from 2.2% to 6.0% of the small cranberry and from 3.4 to 7.1 of the large cranberry and are dominated by glucose and fructose, with glucose amounting to 58.9–65.9%. The small cranberry usually contains only 0.01–0.5% sucrose, whereas the large cranberry accumulates significantly larger amounts (3.9–5.3%) of sucrose.

Some authors describe insignificant differences in the soluble solids (SS) of the oldest cultivars of the large cranberry. The content of SS ranged from 8.3 mg/g (‘Early Black’) to 8.7 mg/g (‘Howes’) ([Wang and Wang, 2009](#)). The content of sucrose and fructose increases during storage. Storage temperatures have been shown to influence the fructose and sucrose contents. The largest amounts of these sugars were found in the berries of the cultivars ‘Early Black’ and ‘Howes’ after storage at 15°C for 4 months. The sucrose content of the berries of the cultivar ‘Early Black’ increased from an initial 23.7 mg/g to 40.5 mg/g, and in the same berries, the fructose increased from 2.98 mg/g to 7.86 mg/g ([Wang and Wang, 2009](#)).

Cranberries contain ascorbic acid ([Table 1](#)). The small cranberries accumulate an average of between 15.3% and 30% ascorbic acid. A significantly larger content of ascorbic acid 47.5% was detected in the berries of the large cranberry cultivar ‘Early Black’ ([Dorofejeva et al., 2011](#)). Very different reports of the amounts of ascorbic acid in both the small and large cranberry have been published. The biologically active isomer of ascorbic acid (vitamin C) is L-ascorbic acid (ASC), but the activity of this form has been discussed in several different studies. L-dehydroascorbic acid (DHA) is easily formed

from ASC during storage. It is likely that in studies in which smaller amounts of ascorbic acid were detected, the contributions of DHA were not included in the final results (Dorofejeva et al., 2011; Povilaitytė et al., 1998; Schmid, 1977).

Mineral substances comprised 0.19–0.28% of the fresh weight (FW) and 1.08–2.45% of the dry weight (DW) of the berries of the small cranberry. The seeds accumulate an average of 10.3% of various mineral substances, and much smaller amounts (1.26%) were measured in the berry skin and even less (0.2%) in the berry pulp (Cherkasov et al., 1981). The studies on the mineral composition indicate that potassium and nitrogen are the main mineral components in both cranberry species (Table 2). The berries of the small and large cranberries accumulate an average of between 78.0 and 93.6 mg/100 g versus between 68.9 and 98.8 mg/100 g of potassium, respectively, and between 1 and 78.0 versus between 10.4 and 65.0 mg/100 g of nitrogen, respectively. The largest amounts of calcium and magnesium, averaging 13.0 versus 7.8 mg/100 g, respectively, were detected in the small cranberry. The small cranberry is distinguished by a high content of manganese (0.9–4.0 mg/100 g), whereas the largest amounts of iron, an average of 0.5 mg/100 g, were found in the berries of the large cranberry (Karlsens et al., 2009; Krzebietke et al., 2007).

Small amounts of vitamins B₁, B₂, and E were detected. The berries of the small cranberry accumulate an average of 0.32 mg/100 g of vitamins B₁ and 0.23 mg/100 g of vitamin B₂. Small amounts (0.14 and 0.37 mg/100 g, respectively) of these vitamins were also detected in the ancient ‘Early Black’ cultivar of the large cranberry. The berries of the ancient cultivars did not differ significantly in amounts of vitamin E, which ranged from 1.31 mg/100 g (in the berries of the ‘Early Black’ cultivar) to 1.56 mg/100 g (in a sample of berries collected from the small cranberry in its natural habitat) (Dorofejeva et al., 2011).

Table 2 Content of macroelements and microelements in the berries of the large and small cranberry

Elements	Large cranberry, <i>Vaccinium macrocarpon</i>	Small cranberry, <i>Vaccinium oxycoccos</i>
Macroelements, mg/100 g FW		
Potassium	68.5–99.0	78.0–93.6
Phosphorus	6.5–11.0	6.0–7.8
Nitrogen	10.4–65.0	13.0–78.0
Magnesium	5.2–10.5	2.9–9.1
Microelements, mg/100 g FW		
Iron	0.22–2.12	0.11–0.42
Manganese	0.06–0.91	0.90–4.00
Copper	0.04–0.06	0.04–0.10
Zinc	0.03–0.17	0.10–0.19

Adapted from Cherkasov et al. (1981), Krzebietke et al. (2007) and Karlsens et al. (2009).

The results of chemical investigations revealed approximately 0.00011% of volatile oils. Sixty-eight compounds, including monoterpenes dominated by α -terpineol (24% of the total volatile oils), cineol (0.7%), carvacrol (0.5%), limonene (0.4%), and linalool (0.3%) and diterpenes (kaurene 1.1%, pimaradiene 1.0%, and manoyloxide 0.3%) were detected (Upton, 2002). β -Glucosides of caffeic, sinapic, ferulic, and coumaric acids were found in the berries of the large cranberry (Marwan and Nagel, 1982).

Forty-two compounds that define the aroma are detected in the juice of the large cranberry. A variety of aromatic compounds, terpenes, aliphatic alcohols, aliphatic aldehydes, benzoic, and 2-methylbutyric acids comprise approximately 95% of the aroma complex and are the main constituents in the cranberry aroma (Croteau and Fagereson, 1968). The large and small cranberries accumulate similar aroma components. Benzaldehyde, benzyl and benzoate esters, and terpenes appear to be the major contributors. Some new compounds, including carvenone, 1-phenylethanol, 3-phenylpropan-1-ol, salicylaldehyde, *p*-cymene, thujene, 4-methoxybenzaldehyde, 3-phenylpropanal, and vanillin were detected in the berries of the small cranberry. In all, approximately 70 substances were detected in the berries of the large and small cranberries; however, the berries of the small cranberry were distinguished by four to five times greater concentrations of the individual components. Terpinhydrate (*p*-methane-1,8-diol) had not previously been detected in any fruits (Hirvi et al., 1981).

Cranberries of both species are a source of numerous phenolic compounds, such as phenolic acids, flavonoids (anthocyanins, flavonols), and tannins. The berries of the large cranberry have been considered to be an exceptionally valuable food and curative agent in folk medicine because of these substances. Flavonoids were identified as the dominant compounds among over 150 individual components detected in the large cranberry. Thirteen anthocyanins, 16 flavonols, and even 26 phenolic acids and benzoates were identified. The total amounts of anthocyanins vary from 13.6 to 171 mg/100 g (Pappas and Schaich, 2009). The ancient cultivars 'Early Black' and 'Searles' are distinguished by exceptionally large total amounts of anthocyanins: 225 mg/100 g and 198.8 mg/100 g, respectively (Povilaitytė et al., 1998). The average content of phenolic acids was determined to be 570 mg/100 g (Zuo et al., 2002). Investigations of the dynamic changes in anthocyanins in the berries of the ancient cultivars 'McFarlin' and 'Searles' indicated increases in the total amounts during ripening. Unripe light red berries of these two cultivars contained 25.3 and 25.5 mg/100 g, respectively; medium red berries contained 43.3 and 38.1 mg/100 g, respectively; and dark red ripe berries contained 79.9 and 61.3 mg/100 g of total anthocyanins (TAC), respectively (Sapers and Hargrave, 1987).

Several studies have been performed to measure the content of phenolic compounds in the large cranberry *V. macrocarpon*, which is commercially grown in the North America. Only a few reports have focused on the small cranberry *V. oxycoccos* (Česonienė et al., 2011). The polyphenols of the small cranberry include flavonoids, such as anthocyanins, catechins, and flavones (often called *bioflavonoid*; i.e., biologically active flavonoids).

The average amounts of the total phenolics (TP) vary from 288.5 to 456.3 mg/100 g; similarly, the anthocyanins vary from 43.3 to 96.8 mg/100 g (Borowska et al., 2009; Povilaitytė et al., 1998). Studies of the localization of the anthocyanins in the small cranberry showed that the amounts of these compounds in the berry skin are 6 to 10 times higher than in the pulp. The amounts of proanthocyanidins and catechins change significantly during berry ripening.

COMPOSITION OF MODERN CULTIVARS

Successful selection of cultivars of the large cranberry was achieved by purposeful crosses. Breeders sought to develop new cultivars with large berries and high yields. The cultivar 'Stevens' was derived from a 'McFarlin' and 'Potters' hybridization and gained popularity because of its excellent yield and berry quality characteristics. Moreover, the success of this cultivar was a substantial reason for the continued breeding of the large cranberry. The interest in natural pharmaceuticals and functional foods has led plant breeders to initiate the selection of cranberry cultivars with higher contents of biologically active substances. A high-yielding cultivar 'Pilgrim' was derived after crossing 'Prolific' and 'McFarlin', and the cultivar 'Franklin' is a cross between 'Early Black' and 'Howes' (Trehan, 2004). A program for genetic improvement of the cranberry has been developed at the University of Wisconsin. By using multiple methods such as conventional breeding, transgenic breeding, and polyploidy breeding, new cultivars of large cranberry were selected (Zeldin and McCown, 2004). The large cranberry hybrids 'Crimson Queen' ('Stevens' × 'Ben Lear'), 'Mullica Queen' ('Lemunyon' × 'No 35'), and 'Demoranville' ('Franklin' × 'Ben Lear') were released by Rutgers University in New Jersey in 2006 (Vorsa and Johnson-Cicalese, 2012).

Six cultivars of the small cranberry *V. oxycoccos* were bred in Estonia and included in the list of berry cultivars recommended for growing in Estonia. They were selected from a total of 760 accessions gathered from the cranberry bogs throughout Estonia between 1966 and 1972. There are two breeders: Henn Vilbaste, originator of the cultivars 'Kuresoo', 'Nigula', and 'Tartu'; and Juta Vilbaste, originator of 'Maima', 'Soontagana', and 'Virussaare'. These cultivars were registered in 1996 (Jänes, 2006). The selection of economically valuable clones of the European cranberry was carried out in the Russian Kostroma Forest Research Station. The long-term research resulted in the selection of six *V. oxycoccos* clones. These clones were registered as the first Russian cultivars: 'Alaya Zapovednaya', 'Krasa Severa', 'Sazonovskaya', 'Severyanka', 'Sominskaya', and 'Khotavetskaya' (Makeev et al., 2000). Five cultivars, 'Amalva', 'Vaiva', 'Žuvinta', 'Reda', and 'Vita', were bred in Lithuania (Česonienė et al., 2011). Generally, the content of the biologically active substances in the berries of the new small cranberry cultivars is similar to the amounts described in berries of wild cranberries collected in natural habitats. However, some of chemical components are accumulated in considerably larger amounts. Berries of the cultivar 'Sazonovskaya' are distinguished by relatively high contents of

sugar (7.45–8.66%). The Russian cultivars of the small cranberry ‘Sazonovskaya’ and ‘Sominskaya’ accumulate significantly larger amounts of ascorbic acid than other cultivars: 20.2–31.7 mg/100 g and 30.4–50.2 mg/100 g, respectively (Makeev et al., 2000).

Investigations of the phytochemical profiles of the large cranberry cultivars in New Zealand demonstrated that the modern cultivars ‘Wilcox’, ‘Stevens’, ‘Olson’s Honkers’, ‘Crowley’, ‘Black Veil’, ‘Bergman’, ‘Bekwith’, and ‘Bain #1’ do not differ significantly in sugar, starch, or total acid contents. Among these, the berries of the cultivars ‘Bekwith’, ‘Stevens’, and ‘Wilcox’ accumulate the largest amounts of dry matter: 14.91, 12.98, and 14.81%, respectively (Miller et al., 2009).

The soluble carbohydrates glucose, fructose, and sucrose contribute the sweetness to cranberries. These sugars are important as indicators of the metabolic functions during synthesis. The total sugar amounts in the berries of large cranberry cultivars vary from 4.57% to 8.04% (Table 3). It is important that cranberries accumulate significant contents of reducing sugars, which are rapidly take up by the human body.

Glucose comprises up to 80% of the carbohydrates, while the amounts of sucrose and fructose were significantly lower. As Wang and Wang (2009) reported, the amounts of sugars and organic acids change during storage, and these changes depend on temperature. Investigations of modern cultivars revealed that the amounts of fructose, glucose, and sucrose increased significantly at higher storage temperatures. The initial amounts of glucose in berries of the cultivars ‘Ben Lear’, ‘Pilgrim’, ‘Stevens’, and ‘Crowley’ were 34.7, 26.3, 29.4, and 29.6 mg/g FW, respectively. After storage for 4 months at 10°C, the contents of glucose were 39.4, 36.5, 38.7, and 37.7 mg/g FW, respectively. The results of berry storage at 15°C revealed significantly greater glucose amounts: 46.4, 40.7, 45.8, and 39 mg/g FW, respectively. The same tendencies for increasing amounts of fructose and sucrose were observed during berry storage (Wang and Wang, 2009).

Table 3 Sugar amounts in the berries of various large and small cranberry cultivars

Cultivar	Total sugars, %	Reducing sugars, %	Sucrose, %
Vaccinium macrocarpon			
Bergman	6.46	5.34	1.12
Stevens	5.23	5.00	0.23
Ben Lear	8.04	5.27	2.77
Black Veil	5.23	5.14	0.09
Pilgrim	5.47	4.94	0.53
Lemunyon	4.57	4.46	0.11
Vaccinium oxycoccos			
Soontagana	6.83	5.47	1.36
Virussare	7.92	5.27	2.65
Maima	6.75	6.52	0.23

Adapted from Povilaitytė et al. (1998).

The investigations of the complex carbohydrates revealed differences between the large cranberry cultivars. Cellulose, hemicellulose, and pectin were detected in cranberry cakes. The alcohol-insoluble fraction was dominated by protopectin (54–67%), with smaller amounts of high methoxyl pectin (10–18%) in the lyophilized berries of the large cranberry (Pappas and Schaich, 2009).

The results of investigations demonstrated that citric, malic, and quinic acids were the main acids in the berries of the large cranberry (Miller et al., 2009). The total amounts of organic acids in the berries of the modern cultivars increased from 3.81 to 11.94 mg/g FW ('Wilcox') and from 6.64 to 12.60 mg/g FW ('Stevens') during berry storage at 15°C (Wang and Wang, 2009).

The variations in the pH, the SS level, and the titratable acidity level in juices prepared from the large cranberry were small, with the coefficients of variation not exceeding 10% (Česonienė et al., 2011). The fresh juice of *V. macrocarpon* berries contained averages of 8.77% of SS, 2.29% of titratable acidity, 43.11 mg/L of benzoic acid (BA), and 92.45 mg/L of TAC content. The differences in terms of titratable acidity, SS, and BA occur as a result of genetic variations. The SS amount in the large cranberry cultivars range from 8.10% to 9.35% (Table 4). The juices of the cultivars 'Franklin' and 'Early Richard' have the highest amounts of TAC, 155.46 mg/L and 109.00, respectively, whereas the highest TAC contents among *V. oxycoccos* cultivars are found in 'Sazonovskaja' and 'Nigula', with values of 93.00 and 84.78 mg/L, respectively. The juice of the *V. macrocarpon* cultivars contain from 27.93 ('Black Veil') to 59.92 mg/L ('Franklin') of BA. The juices of the *V. oxycoccos* cultivars 'Maima' and 'Virussaare' are characterized by very low total amounts of anthocyanins: 19.44 and 12.29 mg/L, respectively (Table 5).

As several authors (Tikuma et al., 2014; Povilaitytė et al., 1998) have reported, the fresh berries of the cultivars 'Stevens' and 'Septembra' (Latvian selection) are characterized by larger ascorbic acid contents, 28.5 and 28.6 mg/100 g, respectively. Significantly less ascorbic acid accumulates in the berries of the cultivars 'Bergman', 'Pilgrim', 'Lemunyon', and 'Prolific': 15.5, 18.7, 16.0, and 16.5 mg/100 g, respectively. Analyses of the variation in ascorbic acid content in the berries of the cultivars 'Pilgrim', 'Ben Lear', 'Black Veil', and 'Stevens' during the ripening process showed that the content depends on the berry ripening stage and cultivar characteristics. Larger amounts of ascorbic acid accumulate in ripe berries (an average of 14.20 mg/100 g). However, the ascorbic acid content decreases in overripe berries (average: 10.30 mg/100 g). Greater quantities of ascorbic were found in ripe berries of the cultivar 'Ben Lear': 15.8 mg/100 g (Viškelis et al., 2009). Because of their high acidity and tart flavor, cranberries are not usually consumed as fresh berries, but are usually processed into cranberry juice (approximately 65%) and cranberry sauce (approximately 30%). Consequently, ascorbic acid can be lost as a result of the exposure of the cranberry juice to oxygen, high temperature, enzymes, and metal ions during processing. Investigations of cranberry processing have confirmed that thermal processing of the berries causes substantial degradation of ascorbic acid, up to 25% (Pappas and Schaich, 2009).

Table 4 Biochemical components of large cranberry cultivars

Cultivar	pH	TA, %	SS, %	BA, mg/L	TAC, mg/L
Franklin	2.49 ^c	2.21 ^a	8.75 ^b	59.92 ^e	155.46 ^f
Early Richard	2.48 ^c	2.25 ^b	9.10 ^c	57.25 ^e	109.00 ^e
Washington	2.44 ^b	2.20 ^a	8.10 ^a	44.34 ^d	101.01 ^e
Le Munyon	2.50 ^d	2.21 ^a	8.93 ^c	39.81 ^c	73.63 ^c
Pilgrim	2.43 ^a	2.30 ^c	8.52 ^b	41.04 ^c	74.80 ^d
Stevens	2.43 ^a	2.41 ^d	9.00 ^c	25.95 ^b	63.93 ^a
Black Veil	2.42 ^a	2.41 ^d	9.35 ^d	27.93 ^a	72.03 ^b

BA, Benzoic acid; SS, soluble solids; TA, titratable acidity; TAC, total anthocyanins.

Means with columns that are followed by the same letter showed no significant difference (Duncan's multiple range test).

^{a-f}Significant at $p \leq 0.01$.

Adapted from Česonienė et al. (2011).

Table 5 Biochemical components of small cranberry cultivars

Cultivar	pH	TA, %	SS, %	BA, mg/L	TAC, mg/L
Vaiva	2.42 ^f	2.85 ^{a,b}	10.55 ^{g,h}	19.85 ^{c,d}	48.08 ^j
Reda	2.31 ^a	3.3 ^{c,d,e}	8.99 ^a	5.19 ^a	32.68 ^e
Žuvinta	2.32 ^a	3.45 ^e	9.56 ^{b,c}	4.63 ^a	33.00 ^f
Vita	2.33 ^{a,b}	3.45 ^{d,e}	9.49 ^b	11.35 ^b	28.19 ^d
Amalva	2.35 ^{b,c}	3.25 ^{c,d,e}	9.57 ^{b,c}	4.30 ^a	59.05 ^k
Krasa Severa	2.35 ^{b,c}	3.05 ^{b,c}	9.54 ^{b,c}	22.54 ^{e,f}	20.40 ^c
Dar Kostromy	2.42 ^f	2.65 ^a	9.82 ^{c,d}	29.73 ^g	47.41 ⁱ
Sazonovskaja	2.46 ^g	2.75 ^a	10.81 ^h	17.76 ^c	93.00 ^m
Soontagana	2.37 ^{c,d}	3.05 ^{b,c}	11.15 ⁱ	13.12 ^b	34.17 ^g
Kuressoo	2.39 ^{d,e}	3.05 ^{b,c}	10.21 ^{e,f}	22.04 ^{d,e,f}	40.58 ^h
Nigula	2.33 ^{a,b}	3.25 ^{c,d,e}	10.04 ^{d,e}	20.98 ^{d,e}	84.78 ^l
Virussaare	2.41 ^{e,f}	3.05 ^{b,c}	10.26 ^{e,f,g}	24.20 ^f	12.29 ^a
Maima	2.42 ^f	2.75 ^a	10.46 ^{f,g}	32.12 ^h	19.44 ^b

BA, Benzoic acid; SS, soluble solids; TA, titratable acidity; TAC, total anthocyanins.

Means with columns that are followed by the same letter showed no significant difference (Duncan's multiple range test).

^{a-m}Significant at $p \leq 0.01$.

Adapted from Česonienė et al. (2011).

Various studies of cranberries have focused on the content of phenolics. As several authors (Borowska et al., 2009; Povilaitytė et al., 1998) have shown, significant differences in the total amounts of phenolics among the modern large cranberry cultivars were detected. The cultivar 'Ben Lear' is distinguished by its large content of TP (374.7 mg/100 g). The berries of the cultivar 'Pilgrim' accumulate a significantly lower content of TP. The average amount of phenolics in samples of the berries of the small cranberry collected in the natural habitat was 288 mg/100 g (Borowska et al., 2009). The berries of the modern cultivars of the small cranberry accumulate from 100.4 mg/100 g ('Virussaare') to 154.8 mg/100 g ('Soontagana') of TP (Povilaitytė et al., 1998). Investigations of acidified ethanol extracts of berries and berry cakes of

Table 6 Total phenolics and anthocyanins content in berries and berry cakes of large cranberry cultivars

Sample	TAC content, g/L	TP content, g/L
Stevens berries	0.25 ± 0.06	0.62 ± 0.01
Stevens berry cakes	0.51 ± 0.06	0.90 ± 0.02
Pilgrim berries	0.24 ± 0.03	0.59 ± 0.01
Pilgrim berry cakes	0.41 ± 0.03	0.79 ± 0.01
Ben Lear berries	0.54 ± 0.06	0.70 ± 0.01
Ben Lear berry cakes	0.55 ± 0.07	0.79 ± 0.02
Black Veil berries	0.30 ± 0.02	0.66 ± 0.02
Black Veil berry cakes	0.47 ± 0.04	0.87 ± 0.02

TAC, Total anthocyanins; TP, total phenolics.

Adapted from Viškelis et al. (2009).

the cultivars ‘Stevens’, ‘Pilgrim’, ‘Ben Lear’, and ‘Black Veil’ reveal higher amounts of anthocyanins and TP. Presumably, the presence of the berry skins in the berry cakes contribute to the higher amounts of these pigments (Table 6).

Various amounts of BA and its analogs are identified in the berries of the large cranberry cultivars. BA is the most abundant; however, *o*-hydroxybenzoic, *m*-hydroxybenzoic, *p*-hydroxybenzoic, 2,3-dihydroxybenzoic, and 2,4-dihydroxybenzoic acids are also detected. These BAs occur primarily in the bound forms, although 10% of them are in a free form (Zuo et al., 2002).

Some authors (Lyutikova and Turov, 2011; Pappas and Schaich, 2009) noted that aldehydes and ketones influence the taste and aroma of the small cranberry. Benzaldehyde has an aroma of bitter almond, whereas acetophenone and benzophenone present fruity aromas. The berries of the small and large cranberry cultivars accumulate low concentrations of monoterpenes, diterpenes, and sesquiterpenes. However, camphor, edulan, and campesterol were identified in the berries of the small cranberry. The aroma of the small cranberry depends on many esters. Campesterol, edulan, and β -sitosterol, as well as many esters, were identified in the small cranberry. Anethole was identified in all cranberry samples (Lyutikova and Turov, 2011).

PHENOLIC COMPOUNDS AND THEIR DIVERSITY IN THE BERRIES OF THE LARGE AND SMALL CRANBERRY

The medicinal potential of the berries from the large cranberry, *V. macrocarpon*, and the small cranberry, *V. oxycoccos*, comes from their antioxidant potential, a property determined by numerous phytochemicals. The cultivars of both species are characterized by a high content and wide diversity of phenolic compounds. The phenolics differ with regard to molecular weight, structure, and biological activity. Phenolics are appreciated in food science, because these substances influence the astringency and storability of berries and the stability of berry products (Kähkönen et al., 1999). In cranberries, this class of compounds is represented by phenolic acids (benzoic and cinnamic acid derivatives), tannins, stilbenes, and flavonoids.

As several authors have reported (Borowska et al., 2009; Côté et al., 2010; Pappas and Schaich, 2009), the structures of the phenolic compounds vary from simple to highly polymerized substances in different fruits. These substances are found in complexes with carbohydrates, different organic acids, and proteins, and form insoluble complexes. Therefore extraction of phenolics from cranberries results in mixtures of various classes of phenolics. The contents of such mixtures depend on the solvents used. The methods used for further characterization and quantification of these compounds include High-performance liquid chromatography (HPLC) combined with ultraviolet visible (UV/Vis) and mass spectrometry detection, gas chromatography, and capillary zone electrophoresis (Côté et al., 2010). In cranberries, flavonoids and phenolic acids are found in combined forms, such as glycosides and esters. An HPLC method for easy and simultaneous determinations of different phenolic compounds in cranberry juice has been reported. The flavonoids and other phenolic compounds were fractionated into neutral and acidic groups by means of a solid-phase extraction method followed by HPLC separations. This method results in high resolution of individual flavonoids and phenolic acids (Chen et al., 2001). The ultra performance liquid chromatography-photodiode array-fluorescence (UPLC-PDA-FLR) chromatogram of *V. oxycoccos* demonstrates that proanthocyanidins are the leading component (63%) of the phenolic compounds. Smaller amounts of anthocyanins (16%), flavonols (14%), hydroxycinnamic acids (7%), and hydroxybenzoic acids (0.05%) were also detected (Kylli et al., 2011).

Several investigations have confirmed that both cranberry species and modern cultivars are among of the richest sources of TP (Namiesnik et al., 2013; Pappas and Schaich, 2009; Viškelis et al., 2009). It was found that water, ethyl acetate, and diethyl ether extracts of the large cranberry contain 22.13, 3.14, and 2.11 mg gallic acid equivalent (GAE)/g DW, respectively. The same extracts of gooseberry contain 5.37, 0.29, and 0.14 GAE, respectively, and extracts of blueberry contain 46.56, 3.87, and 4.13 mg GAE/g DW, respectively (Namiesnik et al., 2013).

Comparisons of the modern large cranberry cultivars demonstrate differences in the content of TP. The amounts of the phenolics ranged from 192.1 mg/100 g of fresh mass ('Pilgrim') to 374.7 mg/100 g of fresh mass ('Ben Lear'). The TP in the berries of the small cranberry reached an average of 288.5 mg/100 g of fresh mass (Borowska et al., 2009). The berries of the small cranberry cultivars are also excellent sources of phenolic compounds compared with other berry plants. The quantitation of TP in the ethanol extracts confirmed variations in their amounts depending on the cultivar features. The berries of the small cranberry accumulate from 255 mg/L ('Sazonovskaya') to 416 mg/L of TP. The Estonian cultivar 'Kuresoo' and the Lithuanian cultivar 'Vaiva' are distinguished by the largest content of phenolics: 401.3 and 416.9 mg/L, respectively (Česonienė et al., 2009). Studies have shown that berries grown in colder climates without fertilizers or pesticides are distinguished by higher contents of phenolics than the cultivars grown in a milder climate. The accumulation of phenolic compounds in cranberries is determined by environmental factors such as cultivation, region, weather conditions, ripeness, harvesting time, and others (Häkkinen and Törrönen, 2000; Viškelis et al., 2009).

An investigation of large cranberry cultivars during the ripening process showed that the total amount of phenolic compounds depends on the degree of berry ripening and cultivar peculiarities (Table 7). Significantly larger amounts of TP were measured at the beginning of berry ripening ('Stevens', 'Pilgrim', and 'Ben Lear') or at the reddish berries stage ('Black Veil'). Significant decreases in the TP content occurs in ripe or overripe berries of large cranberry cultivars. In summary, the largest amounts of phenolics were found in white or 50% reddish berries of these cultivars, averaging 392.37 and 398.52 mg/100 g FW (Viškelis et al., 2009).

Flavonoids (proanthocyanidins and flavonols) play an important role in the plant defense mechanisms and are strong antioxidants because of their polyphenolic structure. They also demonstrate antibacterial, antiviral, anticarcinogenic, antiinflammatory, and vasodilatory activities, and are consequently valuable components in human nutrition. Fresh cranberry juice is a rich source of flavonoid compounds. An average of 400 mg of total flavonoids (56%) and other phenolic compounds (44%) was found per liter of fresh cranberry juice. The major flavonoids in the freshly squeezed cranberry juice were quercetin and myricetin (Chen et al., 2001).

An investigation of the flavonoids of the large cranberry showed that isolated proanthocyanidins have similar oligomer profiles for the ancient and modern cultivars of cranberry 'Howes', 'Mullica Queen', and 'Early Black'. Proanthocyanidins are responsible for organoleptic properties of cranberries. The total proanthocyanidin content, quantified as procyanidin A2 by the dimethylaminocinnamaldehyde method, ranged from 18 to 92 g/kg of dried berries. The main constituents were A-type (epi)catechin oligomers. The 'Howes' cultivar was distinguished by the highest total amount of proanthocyanidins (76–92 g/kg), whereas the dried berries of the cultivars 'Mullica Queen' and 'Early Black' contain from 48 to 82 g/kg. The dried berries of the cultivar 'Ben Lear' were characterized by significantly lower amounts of proanthocyanidins. This is one of the reasons to investigate the susceptibility of this cultivar to disease (Carpenter et al., 2014).

Investigations of cranberry flavonoids during berry development and ripening demonstrated significant changes in their amounts. As Vvedenskaya and Vorsa (2004) reported, the amounts of proanthocyanidins and total flavonols were higher at early ripening stages for the cultivars 'Ben Lear' and 'Stevens'. Later, the proanthocyanidin concentrations decreased quickly, whereas the decline in the amounts of flavonols was gradual. Galactosides and arabinofuranosides were demonstrated to be the main glycosides that accumulate in cranberries during berry growth. Quercetin glycosides contributed an average of 80% of the total flavonols over the different stages of cranberry ripening. The changes in the flavonol glycosides quercetin-3-galactoside and quercetin-3-arabinofuranoside were similar for the cultivars investigated during the ripening period. The cultivars 'Ben Lear' and 'Stevens' were characterized by particular changes in levels of quercetin-3-arabinopyranoside, quercetin-3-rhamnoside, quercetin-3-(6"-benzoyl)- β -galactoside, methoxyquercetin pentoside, and quercetin-3-(6"-coumaroyl)- β -galactoside during the berry development (Vvedenskaya and Vorsa, 2004).

Table 7 Changes of large cranberry biochemical composition during ripening
Berry maturity

Cultivar	Beginning of ripening		50% Reddish berries		Ripe berries		Overripe berries	
	TP, mg/100 g	TAC, mg/100 g	TP, mg/100 g	TAC, mg/100 g	TP, mg/100 g	TAC, mg/100 g	TP, mg/100 g	TAC, mg/100 g
Stevens	395.8	2.2	381.5	12.1	184.4	58.8	199.1	105.5
Pilgrim	388.8	4.8	346.9	16.7	167.7	43.3	234.8	137.0
Ben Lear	386.7	3.5	361.6	19.2	196.0	113.0	257.8	163.9
Black Veil	398.2	3.9	504.1	23.3	221.1	118.1	259.9	202.9
Average	392.37	3.60	398.52	17.82	192.30	83.30	237.90	152.2

TAC, Total anthocyanins; TP, total phenolics.
Adapted from [Viškelis et al. \(2009\)](#).

The anthocyanins are a large group of water-soluble pigments responsible for the berry color of cranberries. They are located in the external layers of the berry skin. Anthocyanins are found in vacuoles as various sizes of granules. Some authors have reported that berries of different cultivars of the large cranberry differ regarding the anthocyanin mass fraction (Viškelis et al., 2009; Vvedenskaya and Vorsa, 2004; Borowska et al., 2009). Ripe berries of the cultivars ‘Ben Lear’, ‘Bergman’, ‘Early Richard’, ‘Pilgrim’, and ‘Stevens’ accumulate 51.9, 73.0, 77.2, 59.9, and 54.6 mg/100 g of fresh mass, respectively (Borowska et al., 2009). The results reported by the different authors indicated that the anthocyanin amounts are affected not only by genetic factors but also depend on the cranberry cultivation technologies.

The highest amounts of anthocyanins among the *V. oxycoccos* cultivars were found in ‘Sazonovskaja’, ‘Nigula’, and ‘Amalva’ with values of 93.00, 84.78, and 59.05 mg/L, respectively (Table 5). The juices of the *V. oxycoccos* cultivars ‘Maima’ and ‘Virussaare’ were characterized by very low anthocyanin concentrations: 19.44 and 12.29 mg/L, respectively (Česonienė et al., 2011). Separation of the cranberry anthocyanins by HPLC-UV/VIS revealed six anthocyanins. The mass spectra showed the compounds to be cyanidin-3-glucoside, cyanidin-3-galactoside, cyanidin-3-arabinoside, peonidin-3-arabinoside, peonidin-3-galactoside, and peonidin-3-glucoside. The dominant anthocyanin in the berry juice of the analyzed *V. macrocarpon* and *V. oxycoccos* cultivars was peonidin-3-galactoside. This anthocyanin comprised from 30.30% to 37.63% of the TAC in the juice of *V. macrocarpon* cultivars and from 20.33% to 40.39% of the TAC in the juice of *V. oxycoccos* cultivars (Table 8). A conspicuous variation in the amount of cyanidin-3-glucoside among the cultivars was detected. This anthocyanin was not detected in the juice of the *V. oxycoccos* cultivar ‘Soontagana’ and the *V. macrocarpon* cultivar ‘Pilgrim’. The mean percent of cyanidin-3-glucoside varied in other *V. oxycoccos* cultivars from 1.12% (‘Dar Kostromy’) to 5.81% (‘Maima’), and in *V. macrocarpon* cultivars from 1.28% (‘Searles’) to 2.04% (‘Stevens’) (Česonienė et al., 2011).

The quantitative analysis of the anthocyanins revealed that the investigated *V. oxycoccos* cultivars could be tetraploid (Table 8). Other studies confirmed that the tetraploid *V. oxycoccos* accessions are more comparable to *V. macrocarpon*, whereas the diploid *V. oxycoccos* profiles differ by having considerably higher levels of glucosides. It was determined that the anthocyanin profiles differed for the diploid and tetraploid *V. oxycoccos* accessions. The first generation hybrids of *V. macrocarpon* × *V. oxycoccos* (2x) were characterized by reduced galactosides and arabinosides while having increased levels of glucosides. The interspecific hybrids of backcrossed populations maintained the higher amounts of glucosides. The mean percentage of cyanidin-3-glucosides and peonidin-3-glucosides increased from 1.3% and 3.7%, respectively (*V. macrocarpon*), to 13.2% and 29.0%, respectively, in the hybrids (*V. macrocarpon* × *V. oxycoccos* (2x) and reciprocal (Vorsa and Polashock, 2005).

Table 8 Qualitative and quantitative anthocyanin composition in the juice of large and small cranberry

Species	Cyanidin-3-galactoside, %	Cyanidin-3-glucoside, %	Cyanidin-3-arabinoside, %	Peonidin-3-galactoside, %	Peonidin-3-glucoside, %	Peonidin-3-arabinoside, %
<i>Vaccinium macrocarpon</i>	24.11	1.46	18.73	33.29	6.41	16.00
<i>Vaccinium oxycoccos</i>	20.44	3.23	21.33	29.15	6.21	19.64

Adapted from Česonienė et al. (2011).

The results of the analysis of anthocyanin accumulation during the ripening process indicate that these compounds are found at low concentrations in berries of the cultivars 'Ben Lear' and 'Stevens' collected at the first harvest date. The anthocyanins cyanidin-3-galactoside, cyanidin-3-arabinoside, and peonidin-3-galactoside were found in the berries of the cultivars 'Ben Lear' and 'Stevens' from the beginning of berry development. However, anthocyanin synthesis in the 'Ben Lear' berries started earlier than in the 'Stevens' berries (Vvedenskaya and Vorsa, 2004). The results of other studies confirm the dependence of TAC amounts on the degree of berry ripening and genotype. The analyses of the variation of the anthocyanins in the berries of different cultivars during ripening demonstrated significant increases of their amounts. The largest amounts of anthocyanins accumulate in the overripe berries of the cultivars 'Ben Lear' and 'Black Veil' (Table 7) (Viškelis et al., 2009).

It was also determined that the flavonol levels increase slightly during fruit ripening. The berries of the cultivars 'Ben Lear' and 'Stevens' demonstrated a similar flavonol composition. Flavonols constitute an average of 19% of total flavonoids at berry set and 15% in ripe berries. Consequently, galactosides and arabinofuranosides accumulate in similar concentrations during the growth and ripening of cranberries. Investigations of the cranberry ripening process demonstrate that quercetin glycosides contribute up to 80% of the total flavonol amounts during all stages of berry development (Vvedenskaya and Vorsa, 2004).

During the ripening process, the berries of the different cranberry cultivars acquire the proper shape, weight, texture, color, aroma, and flavor. The chemical composition of the cranberries varies through the ripening and is determined by environmental conditions as well. An estimation of the temperature changes demonstrated an impact of the air temperatures on the total amounts of anthocyanins, flavonols, and phenolics. Higher temperatures at the bloom and fruit-set stages caused increases in the total amounts of anthocyanins and flavonols. Warmer temperatures during the preharvest stage were associated with increased accumulation of TP (Vanden Heuvel and Autio, 2008).

Stilbenes, and in particular *trans*-resveratrol (3,5,4'-trihydroxy-*trans*-stilbene), have been detected in some plant species, including cranberries. This phenolic compound is a phytoalexin distinguished by antimicrobial and antioxidant properties and is synthesized by plants at sites subject to infections. Resveratrol is classified as a multifunctional compound with regard to its effects on human health. Investigations of resveratrol accumulation in cranberries showed that all of the investigated cultivars 'Ben Lear', 'Bergman', 'Early Richard', and 'Pilgrim' contained less resveratrol than berry samples of the small cranberry collected in their natural habitat. The content of resveratrol was estimated at 712.3 ng/g of fresh mass in the berries of the small cranberry. The berries of investigated cultivars accumulated from 533.4 ng/g of fresh mass ('Stevens') to 598.2 ng/g of fresh mass ('Ben Lear') (Borowska et al., 2009).

SUMMARY POINTS

- Both cranberry species, *V. macrocarpon* and *V. oxycoccos*, have been broadly used in the food and pharmaceutical industries. Cranberries are applied to treat a wide range of maladies. To increase the use of cranberries in foods and pharmaceuticals, analyses of their biochemical compounds and their health-promoting activities are needed.
- The major phenolic substances in cranberries are anthocyanins, phenolic acids, flavonols, and anthocyanidins, which have been considered to be the major compounds that influence the dietary and therapeutic properties of these berries.
- Quercetin glycosides contribute the largest part of total flavonols, whereas galactosides and arabinofuranosides are the main glycosides during berry growth. Six major anthocyanins, cyanidin-3-galactoside, cyanidin-3-glucoside, cyanidin-3-arabinoside, peonidin-3-galactoside, peonidin-3-glucoside, and peonidin-3-arabinoside, were detected in both cranberry species. The dominant anthocyanin in the juice of the large cranberry and tetraploid small cranberry cultivars is peonidin-3-galactoside.
- The modern cultivars of large cranberry are distinguished by larger amounts of TAC and BAs in the berry juice; meanwhile, the juices of the small cranberry cultivars accumulate more SS and titratable acidity.
- The content of phenolic compounds in the berries of both species is determined by many factors, including cultivar peculiarities, cultivation technologies, region, weather conditions, ripeness, harvesting time, and storage time and conditions. Cranberries accumulate the largest amounts of TP at the beginning of berry ripening. The cultivars grown in colder climate conditions are distinguished by larger contents of phenolics than the same cultivars grown in a mild climate.
- Significant differences in the mineral composition demonstrate that the berries of the large cranberry are distinguished by higher levels of phosphorus and iron, whereas small cranberries accumulate higher levels of calcium, magnesium, manganese, zinc, and copper.
- The soluble carbohydrates glucose, fructose, and sucrose contribute sweetness to cranberries. The amounts of fructose, glucose, and sucrose increase during storage and are significantly affected by higher temperatures.
- Cultivars of the small cranberry accumulate significantly larger amounts of ascorbic acid than those of the large cranberry. The newest Russian cultivars of small cranberry have been identified as the best source of this vitamin.
- Terpenes, aliphatic alcohols, and aldehydes are the main compounds that determine the aroma of cranberries. Approximately 70 substances have been identified in the berries of the large and small cranberry, but the small cranberry is characterized by four to five times larger amounts of the individual aroma components.

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CHAPTER 9

Nutritional Value of the Pulp of Different Sugar Apple Cultivars (*Annona squamosa* L.)

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INTRODUCTION

Annonaceae is an essentially tropical and subtropical family that comprises approximately 135 genera and 2500 species. In Brazil, 29 genera that subdivide into 260 species have been reported (Lobão et al., 2005). The family has considerable economic importance, mainly as a source of edible fruit. Among the most important is the prickly sour-sop (*Annona muricata* L.), which is widely used in the production of pulp and juice, as well as the sugar apple (*Annona squamosa* L.), cherimoya (*Annona cherimola* Mill), and custard apple (*Annona reticulata* L.), which are consumed *in natura*.

Some species of Annonaceae family have different applications in popular medicine. For instance, the infusion of *Annona dioica* A. (“St. Hil”) seeds is used to treat diarrhea, and plasters prepared with the fruit are considered to have emollient properties. The infusion of leaves is said to help treat rheumatism (Rodrigues and Carvalho, 2001). Some species of this family are known for their composition of secondary metabolites with a role in defense mechanisms, including alkaloids, flavonoids, and terpenoids (Leboeuf, 1982). Acetogenins are also typically detected, and have recently been investigated for their potential as

bioactive agents. In a previous study, six acetogenins with highly cytotoxic action against Hep G₂, Hep2,2,15, KB, and CCM₂ cancer cells were detected in ethanolic extracts of seeds of the hybrid 'Atemoya' (Chang et al., 1999). Additionally, the acetogenins extracted from the leaves and roots of *A. squamosa* have proved action against insects, affecting their respiratory systems and producing toxic effects when absorbed by the gastrointestinal tract, thereby affecting growth and acting as repellent (Cordeiro et al., 2000).

Annona squamosa is native to Antillean isle of Trinidad (Cordeiro et al., 2000). According to Pinto and Jackson (2006), initially the species spread to Mexico and all of South America, and subsequently reached Asia and Africa. *Annona squamosa* was introduced in Brazil in 1626, in the state of Bahia, by Governor Dom Diogo Luiz de Oliveira, the Earl of Miranda. This is why the Portuguese name of the species is *fruta do conde* (*conde* means *earl* in Portuguese) (Cordeiro et al., 2000). This fruit is highly appreciated, and commercial plantations are widespread in northeastern and southeastern Brazil (Andrade et al., 2001). In these regions, the states of Bahia, Alagoas, Pernambuco, Sergipe, São Paulo, and Rio Grande do Norte stand out as the main producers, with plantations covering areas in excess of 1500 ha (Araújo Filho et al., 1998). However, *A. squamosa* is also grown and marketed in other tropical or subtropical regions, including northern South America, Central America, North America, Asia, and Africa. The species is widely cultivated in India and Pakistan. According to Chouksey et al. (2013), in India it is grown in high rainfall regions, and plantations cover 42 ha. This species is very popular in the Deccan plateau, being grown and marketed in the states of Pradesh, Bihar, Madhya Pradesh, Maharashtra, Uttar Pradesh, Tamil Nadu, Assam, Karnataka, and Orissa.

The several synonyms and popular names of *A. squamosa* used in different parts of the world are shown in Table 1.

The fruit of *A. squamosa* are consumed mainly *in natura*, though it is also a popular ingredient of juices, desserts, ice creams, and liqueurs. Apart from the nutritional value, studies have pointed to the medicinal properties of different plant parts.

BOTANICAL ASPECTS

Annonaceae is a family consisting mainly of trees with alternate distichous leaves, as well as a few shrubs and lianas. The family has cymose inflorescences, although sometimes single flowers are observed. The flowers are normally large, attractive, hermaphrodite, and dichlamydeous, with a trimerous or tetramerous calyx and a corolla formed of one to two whorls with three to four petals. Stamens are numerous, usually spirally arranged, and have dehiscent anthers. The gynoecium is commonly apocarpous and pluricarpellar, with spiral carpels and erect or marginal placentation with one or several ovules. The fruit may be apocarpous or syncarpous, and is commonly baccate and protogynous; that is, the stigma is receptive before the anthers shed their pollen. However, some aspects of the pollination of Annonaceae are still poorly known. The main pollination syndrome is cantharophily, which is associated with pedunculate flowers with floral chambers that limit access by forager beetles, followed by scented fruit (Kishore et al., 2012).

Table 1 Scientific names, synonyms, and some popular names of *Annona squamosa* and of its hybrid in different regions of the world

Scientific name	Synonyms	Common names	References
<i>Annona squamosa</i> L.	<i>Annona asiatica</i> Dun. <i>Annona biflora</i> Moç. & Sesse <i>Annona cinerea</i> Dun. <i>Annona forskahlli</i> DC <i>Guanabanus squamosus</i> M. Gómez <i>Xylopia frutescens</i> Sieb	Sweetsop, sugar apple, custard apple (United States); ata, pinha, pinheira fruta do conde (Brazil); attire (France); anon, saramuya, and Aztec (Mexico); anon (Bolivia, Costa Rica, Cuba, Panama); anon de azucar, anon domestico, hanon, mocuyo (Colombia); rinon (Venezuela); anona blanca (Honduras, Guatemala, Dominican Republic); anona de castilla (El Salvador); anona de Guatemala (Nicaragua); cachiman (Argentina); cachiman cannelle (Haiti); applebush (Grenadines); sitaphal (Tamil), seethapalam, athichakku (Malaya); nona sri kaya (Malaysia); seethapandu (Telugu); amritphala, seethaphala (Kannada); aatoa, shariffa, sitaphal (Hindi); ata luna (Bengali); noina, manonah, noinah, pomme cannelle du Cap (Thailand); Gwanda masar (Hausa); ates or atis (Philippines); atte (Gabon); kaneelappel (Suri nam); pomme cannelle (Guadeloupe, French Guiana, French West Africa), qu a na (Vietnam); mang cau ta (Cambodia); mak khbieb (Laos); fan-li-chi (China).	Pinto et al. (2005) Paul and Duarte (2011) Morton (1981)
<i>A. squamosa</i> L. × <i>Annona cherimola</i>	<i>Annona</i> × <i>atemoya</i> Mabb.	Atemoya, custard apple, annon (United States); atemoya (many Spanish-speaking countries); pine-apple sugar apple (Taiwan); anón (Cuba); chirimorion (Venezuela); achta (Palestine and Lebanon)	Index Kewensis, Crane et al., 2013

Annona squamosa L. is a tropical, cold-intolerant species. Its habit varies from a shrub to a small-sized tree (between 5 and 6 m tall). Young branches are sparsely pubescent, from which flowers emerge singly or in groups of two to four. The three sepals are triangular and between 2 and 3 cm long. The three outer petals are lanceolate, thick, and 1.5 cm long, yellow to greenish on the outside, and yellowish with a purple spot at the base on the inside. When present, the three inner petals are very small, oval, and between 6 and 8 mm long. There are many stamens with short filaments. Carpels uniovulate. The compound fruits are round, 6–10 cm in diameter, with a thick epicarp and fleshy mesocarp. The seeds are hard with a dark brown to black testa (EOL, Encyclopedia of Life, <http://eol.org/pages/1054831/details>). A study carried out in India showed that flowers of *A. squamosa*, as typically observed in the family, are hermaphrodite but exhibit protogynous dichogamy, the stigma being receptive 1 day before anthesis (Araújo Filho et al., 1998; Kishore et al., 2012).

Annona squamosa grows in a wide range of conditions. It does not require specific soils, but prefers deep, medium-fertile, well-drained soils. The species is well adapted to the climate of Brazil's coastline, as well as to the country's northeastern semiarid region. Low temperatures and excess rainfall during flowering and fruiting affect the size and quality of fruit. Propagation is usually by seeds, or sometimes by grafting (Araújo Filho et al., 1998).

'Atemoya' is the hybrid between the sugar apple (*A. squamosa*) and the cherimoya (*A. cherimola* Mill.). This subtropical, semideciduous tree gradually sheds its leaves in spring, although a few persistent leaves may be retained into the following season (Olesen and Muldoon, 2009). The name is a compound noun formed by joining parts of the popular parental names, *ata* (one of the common names of *A. squamosa*) and *moya* (from cherimoya-*A. cherimola*). A study carried out in southern Florida revealed that the pollination pattern of atemoya is similar to that of the sugar apple. The stigma becomes less receptive throughout the day as a result of water loss. Because pollen is released at the end of the day, self-pollination is thereby difficult (Nagel et al., 1989).

The optimal yield of atemoya depends on several number of factors. Highest yields are obtained when temperatures are between 22–32 °C and relative humidity is greater than or equal to 70% during flowering and fruit set. George and Nissen (2002) found that moderate drought causes leaf fall and reduced shoot growth, and an increase in the number of flowers per lateral shoot, although overall fruit set is not affected by drought. A detailed discussion of the tolerance of atemoya to climatic and environmental stress factors and methods of propagation is given in Crane et al. (2013).

In Brazil, the cultivars 'Thompson' and 'Gefner' are the most widely grown. The former is more tolerant to frost, whereas the latter produces more fruit in higher temperature zones. These cultivars have different fruit characteristics. The fruits of 'Gefner' have pointed carpels and a more delicate epidermis, and the pulp is more consistent and translucent. The fruits of 'Thompson' have rounded, rough carpels with white, creamy pulp. Both cultivars have good productivity and qualities, and are relatively tolerant to several fungal diseases (CATI, <http://www.cati.sp.gov.br>).

NUTRITIONAL COMPOSITION OF THE PULP OF DIFFERENT CULTIVARS OR VARIETIES, GENOTYPES, SELECTIONS, AND ECOTYPES OF SUGAR APPLE (*ANNONA SQUAMOSA*)

The existence of different cultivars of *A. squamosa* has been acknowledged in several countries (Figure 1 and Table 2). Research has attempted to select genotypes with desired characteristics, selection, or ecotypes, especially concerning fruit quality and productivity (Cavalcante et al., 2011).

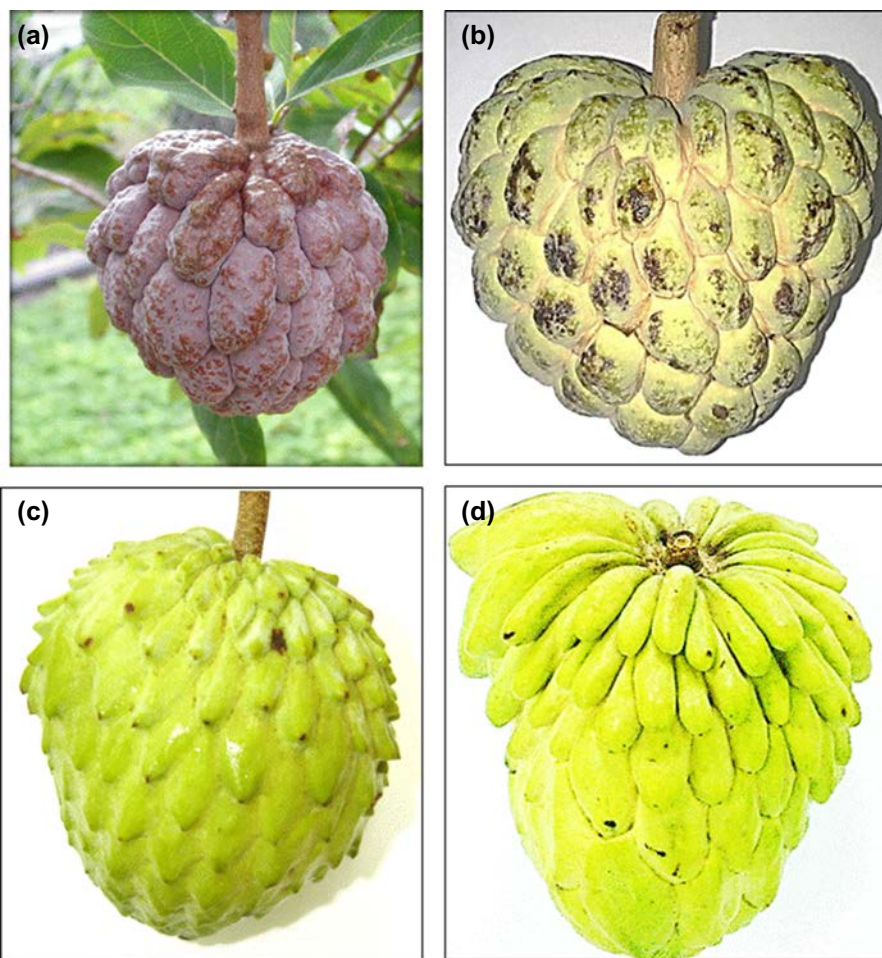


Figure 1 Some *Annona squamosa* fruit and its hybrid (*Annona squamosa* × *Annona cherimola*). (a) *A. squamosa* cultivar 'Kampong Mauve'; Photo: [@toptropicals.com](https://www.toptropicals.com); (b) *A. squamosa*; (c) *A. squamosa* × *A. cherimola* cultivar 'Gefner' (atemoya 'Gefner'); (d) *A. squamosa* × *A. cherimola* cultivar 'Pink Mammoth' (atemoya 'Pink'). Photos: Egydio, A.P.M.

Table 2 Names of cultivars or varieties of *Annona squamosa* in several countries of the world

Name	Local	Reference
Barbados Seedling, Balanagar, Sahebganj, Mammoth, Sitaphal (red/lad), Borhodes, Britshbaroa, Arka Sahan, Washington 97, Purandhar, Arka, Sangareddyiz, Red-Speckled, Crimson, Yellow, White-Stemmed, Kakarlapahad	India	Morton (1987), Pinto et al. (2005)
Lessard, Kampong Mauve, Purple Sugar, Red Sugar, Barbados, British Guiana, Thai Seedless	United States	Crane et al. (2013)
Pinha FAO, Pinha AP, Seleções IPA, Seedless Brazilian	Brazil	
Seedless Cuban	Cuba	Morton (1987)
Molate, Lobo, Acess 6333	Philippines	Pinto and Jackson (2006)
Fai Kaew, Fai Krung, Nang Kaew, Nang Sir Krung, Nang Thong, Noi Ruan-zhi, Cu-lin, Da-mu, Tainung No. 1, Xi-lin	Thailand	Pinto et al. (2005)
Beni Mazar, Abd El Razik	Taiwan	Paul and Duarte (2011)
KJ Pinks, Maroochy Gold, Palethorpe, Maroochy Yellow, Nielsen, Island Gem	Egypt	Morton (1987)
Fenglishijia	Australia	Pinto et al. (2005)
	China	Zhichang et al. (2013)

For Pinto and Jackson (2006), the most important commercial cultivars are ‘Red’ in the United states, ‘IPA’ in Brazil, ‘Noi’ in Thailand, ‘Molate’ and ‘Lobo’ in the Philippines, ‘Cuban Seedless’ in Cuba, and ‘Balanagar’ and ‘Red Sitaphal’ in India.

According to Nietsche et al. (2004), some of the main physicochemical characteristics of the sugar apple, both for the *in natura* consumption and for the production of fruit pulp are color (dark green, yellow-green, purple), weight (0.09–0.39 kg), number of seeds (between 24 and 68 in one fruit), pulp color (white to cream), and percentage of pulp (28–54%). Nevertheless, few reports have comparatively characterized the composition of *A. squamosa* cultivars.

Table 3 shows the general chemical composition of the pulp sugar apple, including data of several varieties, genotypes, selections, and ecotypes with no distinction. Some varieties have had their chemical composition established, such as ‘Sitaphal’, ‘Balanagar’, ‘Barbados Seedling’, ‘Washington 97’, ‘Tsulin’, and the ‘IPA’ selections. Research has also been conducted to assess genotypes, selections, and ecotypes from different countries (although these papers do not mention which varieties were analyzed), including the United States (Florida and the Hawaiian island of Oahu), Cuba, Brazil (states of Piauí, Alagoas, Ceará, Pernambuco, Rio Grande do Norte,

Table 3 Approximate chemical composition of the pulp of different cultivar, genotypes, and ecotypes of *Annona squamosa*

Components	Values
Energy (calories) (kcal)	80–105
Water (g)	65–81.6
Proteins (g)	0.7–3.84
Lipids (g)	0.3–1.25
Carbohydrates (g)	14–25.2
Fiber (g)	0.9–6.6
Ash (g)	0.55–2.8
Calcium (mg)	17–53.7
Iron (mg)	0.28–1.38
Magnesium (mg)	21–34
Potassium (mg)	142–391
Nickel (mg)	0.28–1.38
Copper (mg)	0.09–0.3
Manganese (mg)	0.16
Zinc (mg)	0.11–0.55
Selenium (mg)	0.26–80
Cobalt (mg)	10–20.7
Sodium (mg)	2–9
Ascorbic Acid (mg)	6–138.5
Thiamine (mg)	0.1–0.13
Riboflavin (mg)	0.086–0.175
Niacin (mg)	0.53–1.2
Pyridoxine	0.09
Total soluble solids (°Brix)	15.3–30.8
Total titratable acidity (mg of citric acid)	0.01–0.44
pH	3.81–5.72

Adapted from Almeida et al. (2009), Andrade et al. (2001), Cavalcante et al. (2011), Chan and Heu (1975), Chouksey et al. (2013), Dantas et al. (1991), Folorunso and Modupe (2007), Guzman et al. (1985), Hassan et al. (2008), Herrmann (1987), Kolegar and Tagad (2012), Leterme et al. (2006), Marcellini et al. (2009), Morton (1987), Orsi et al. (2012), Pal and Kumar (1995), Poul et al. (2009), Purohit (1995), Silva et al. (2002), Singh (2007), Sousa et al. (2006), USDA (2004), and Wenkam (1990).

Bahia, and São Paulo), Venezuela, Colombia, Nigeria, Taiwan, the Philippines, Papua New Guinea, and Thailand (Almeida et al., 2009; Alves et al., 2001; Andrade et al., 2001; Cavalcante et al., 2011; Chouksey et al., 2013; Folorunso and Modupe, 2007; Guadarrama and Andrade, 2012; Hassan et al., 2008; Kolegar and Tagad, 2012; Leterme et al., 2006; Marcellini et al., 2009; Morton, 1987; Orsi et al., 2012; Poul et al., 2009; Purohit, 1995; Silva et al., 2002; Singh, 2007; Sousa et al., 2006; USDA, 2004; Wenkam, 1990).

In general, the pulp of *A. squamosa* is rich in calorie content and is considered an excellent source of total soluble sugars, vitamin C and vitamin B complex, and some minerals (Chouksey et al., 2013).

Previous studies have shown that the genotype 'PAG25', from the municipality of Presidente Dutra in the state of Bahia, Brazil, has highest content of water (81.6 g), whereas the one with the lowest water content was shown to be the genotype analyzed in Pará, Brazil, (65 g) (Andrade et al., 2001; Souza et al., 2006). According to Folorunso and Modupe (2007), the fruits of other *Annona* species, such as *A. muricata* and *Annona senegalensis*, were shown to have high water contents ($91.76 \pm 0.03\%$ and $82.09 \pm 0.13\%$, respectively).

High contents of total sugars, varying between 14 g and 25.2 g, have been detected in all types of *A. squamosa*. 'Sitaphal' (Chouksey et al., 2013; Purohit, 1995; Singh, 2007) and the genotypes from the Philippines and from Cuba contain the highest levels of total sugars (Hassan et al., 2008; Morton, 1987), and the cultivar 'Balanagar' (Poul et al., 2009) has the lowest. Also, it is known that the content of reducing sugars is between 12.13% and 19.06% (Sousa et al., 2006). Studies showed that genotypes from Cuba, the Philippines, and Brazil (state of Pará) contain approximately 7 g of saccharose, glucose, and fructose, whereas the genotypes analyzed in Malaysia have 3.11, 5.15, and 3.49 g of these sugars, in that order (Andrade et al., 2001; Morton, 1987).

Starch levels were shown to vary in samples from the state of Pernambuco, Brazil (0.87%) (Alves et al., 2001) and from Bogotá, Colombia (2.5–3.7%) (Andrade et al., 2001). According to Carvalho et al. (2006), part of the starch may reach the human colon, where it is fermented by the microflora and converted into short-chain fatty acids. The other part of this substance is not metabolized and helps increase the absorption of calcium, magnesium, iron, zinc, and copper, reducing cholesterol and triglycerides in plasma, and also helps prevent colon cancer.

The concentration of proteins and lipids is low in fruits of this and other species of the genus. 'Balanagar' has the highest content of proteins (3.84 g) (Poul et al., 2009), and the genotype from Nigeria has the lowest (0.7 g) (Folorunso and Modupe, 2007).

The highest lipid levels (1.25 g) were detected in a genotype from Nigeria (Folorunso and Modupe, 2007), and the cultivar 'Sitaphal' and a genotype from India were found to have the lowest levels of lipids (0.3 g) (Chouksey et al., 2013; Purohit, 1995; Singh, 2007). Andrade et al. (2001) detected linoleic (19.9%), palmitic (22.4%), and oleic (18.8%) acids as the main fatty acids in fruit from the Brazilian Amazon. The authors also detected lauric, myristic, stearic, and linolenic acids. Diets rich in unsaturated fatty acids have been pointed out as having central importance in human nutrition. The human body does not synthesize a few important unsaturated fatty acids, and these compounds are highly valued in the international market. Olive oil is a traditional source of oleic acid, and it has been suggested that it helps reduce the risk of several kinds of cancer. Omega unsaturated fatty acids are also very important. Linoleic acid (omega-6 fatty acid) is an essential fatty acid for humans. Several researchers suggest that oleic and linoleic acids induce a reduction in plasma cholesterol and help minimize the risk of cardiovascular diseases (Egydio and Santos, 2011).

Evaluations of the content of vitamins in Annonaceae have been conducted, showing that the genotypes from the municipality of Bom Jesus in the state of Piauí, Brazil, are notable for their high vitamin C contents (67.5–138.5 mg) (Cavalcante et al., 2011) when compared with those from other parts of the world (6–44.4 mg) (Table 4). It has been hypothesized that storage conditions influence the content of ascorbic acid. Alves et al. (2001) observed that the vitamin C level in the variety ‘Tsulín’ is rather low, with a maximum content of 6 mg/100 g when the fruit is stored at different temperatures (16 °C, 20 °C, and 28 °C). Nevertheless, most types of sugar apple have more than 25 mg of vitamin C. For this reason, these fruits have been considered a good source of this vitamin.

Vitamin C content indicates that the fruits of this species may have high antioxidant capacity. As a rule, fruit in general is a rich source of antioxidants, such as phenolic substances, vitamins, carotenoids, and minerals with potentially useful chemopreventive properties. Vitamin C is a major natural antioxidant in the human diet. A high correlation

Table 4 Names of cultivars or varieties of atemoya (*Annona squamosa* × *Annona cherimola*) and locations of origin

Name	Local	References
African Pride	South Africa or Israel	Paull and Duarte (2011), Morton (1987)
Bernitski	Israel	Morton (1987)
Bradley	United States (Florida)	Paull and Duarte (2011)
Caves		Morton (1987)
Cherimata	Egypt	Morton (1987)
Chirimorinon A, B, C		Morton (1987)
Finny	Egypt	Morton (1987)
Gefner	Israel	Paull and Duarte (2011), Morton (1987),
Island Gem	Australia	Paull and Duarte (2011)
Island Beauty	Australia	Morton (1987)
Kabri	Israel	Paull and Duarte (2011), Morton (1987)
Keller		Morton (1987)
Lindstrom		Morton (1987)
Malalai	Israel	Paull and Duarte (2011), Morton (1987)
Malamud	Israel	Morton (1987)
Nielsen	Australia	Paull and Duarte (2011)
Page	United States (Florida)	Paull and Duarte (2011)
Pink’s Mammoth	Australia	Paull and Duarte (2011), Morton (1987)
Priestly		Morton (1987)
Stermer		Morton (1987)

between antioxidant activity and vitamin C has been observed in fruit that contains a high level of this vitamin, such as citric fruits and guava (Almeida et al., 2009).

Phenolic substances are another class of antioxidants in the pulp of the sugar apple. Contents of these compounds have been estimated at between 0.15% and 0.18%. Phenolic substances help prevent diseases associated with oxidative stress, such as cancer, atherosclerosis, and neurovegetative conditions. One of the mechanisms behind the antioxidant activity of natural compounds is the inhibition and suppression of the formation of reactive oxygen species through inhibition or chelation of oligoelements that participate in the formation of free radicals. Antioxidants also act as scavengers of free radicals by regulation or protection of the endogenous antioxidant defense system (Almeida et al., 2009).

Complex B vitamins also vary across different genotypes of *A. squamosa*. For example, niacin and thiamin were shown to vary from 0.654–0.931 mg to 0.13 mg, in Cuban and Philippine genotypes, respectively. Riboflavin oscillates between 0.086 mg and 0.175 mg in the ‘Sitaphal’ cultivar. According to Manzetti et al. (2014), thiamin is an essential nutrient involved in several cell functions, including energy metabolism and the degradation of sugars and carbon skeletons. Other roles attributed to this vitamin include neuronal communication, activation of the immune system, maintenance and signaling in cells and tissues, and the maintenance of the cell-membrane dynamic. These important roles underline the importance of thiamin absorption and transportation in the body. According to Kirkland (2012), niacin deficiency has been linked with genomic instability, largely as a result of harm to the poly (adenosine diphosphate–ribose) polymerase family of polyenzymes. In several models, niacin deficiency may be detrimental to the cell cycle and apoptosis, leading to the progression of cancer. Adelekan and Thurnham (1990) affirmed that riboflavin plays a role in the structural maintenance and integrity of red blood cells mediated by the reductase glutathione of flavin-dependent erythrocytes. Therefore, riboflavin deficiency may result in prematurely lysed red blood cells and, like malaria, might be implicated in cases of anemia.

Previous studies showed that ‘Sitaphal’ can also contain the highest as well as the lowest percentage of fiber contents, between 0.9 g and 6.6 g (Chouksey et al., 2013; Purohit, 1995; Singh, 2007). It is widely known that fibers contribute to good health. The differences in fiber content between cultivars are an important parameter as far as improvement of fruit quality and the reduction of cholesterol levels are concerned. High fiber intake has various positive effects on health, because it helps retain water during the passage of foods to the large intestine, producing larger volumes of softer feces. A fiber-rich diet has been associated with reduced prevalence of colon cancer, cardiovascular diseases, and diabetes mellitus. The recommended daily intake of fiber in human diet is 12–38 g (Hassan et al., 2008).

The level of soluble solids in *A. squamosa* varies between 15.3 °Brix and 30.8 °Brix. A genotype from the municipality of Aracati in the state of Ceará, Brazil (Silva et al., 2002),

has the highest content of soluble solids, whereas the lowest content was detected in a genotype from the municipality of Bom Jesus in Piauí, Brazil. Soluble solids include sugars, acids, vitamins, and some water-soluble pectins. These constituents represent an important quality parameter, because they characterize sweet flavor, especially in Annonaceae (Cavalcante et al., 2011). Soluble solids are crucial in defining the agreeable flavor of *in natura* fruit, as well as in the possibility of reducing the amount of added sugars in juices. High soluble solids are also important in the industrial processing of juices. They reduce evaporation time of water, which helps lower energy consumption and increases yields in processing (Silva et al., 2002).

Previously published data show that pH and total titratable acidity vary between 3.81 g and 5.72 g and between 0.01 g and 0.44 g, expressed as content of citric acid. The variety ‘Balanagar’ has the highest pH (Poul et al., 2009), and a genotype from the municipality of Recife, in the state of Pernambuco, Brazil, has the highest titratable acidity (Alves et al., 2001). It has been hypothesized that types with lower acidity levels ripen more promptly when exposed to the air. These values are lower than those of other fruit of the genus, such as the prickly soursop (0.58%). High titratable acidity is an important characteristic in fruit processing, because it enables the use of fewer artificial acid supplements. However, for fruit destined for *in natura* consumption, lower acidity is preferred (Cavalcante et al., 2011). The pulp of this species is highly appreciated because of its low acidity.

The ratio of total soluble solids to total titratable acidity is one of the most useful parameters to assess flavor, because it is more representative than the separate measurement of sugars and acidity. High ratios are desirable in the market of fresh fruit (Sousa et al., 2006). The ratio of sugars to inorganic acids is used to describe the balance between sweet and acid flavor, and is a good indicator of fruit quality. The ratio of soluble solids to total titratable acidity has been shown to vary significantly among the genotypes of *A. squamosa* that have been investigated and ranges from 43.33 to 2100 (Cavalcante et al., 2011; Sousa et al., 2006).

Chouksey et al. (2013) observed that the decrease in total soluble solids during ripening may be caused by the uninterrupted utilization of sugars during respiration. This is also attributed to a metabolic disturbance and to fruit senescence, as a result of water loss during storage. The authors also state that the decrease in titratable acidity is the result of the conversion of acids into sugars and to the use of organic acids during respiration, a respiratory substrate required for the catabolic processes in fruit. Orsi et al. (2012) also observed low total acids and high levels of soluble solids and total sugars (fructose and glucose) in the prickly soursop, atemoya, and sugar apple. These characteristics are consistent with the decomposition of complex carbohydrates and organic acids typically associated with Annonaceae fruit during the ripening process, when the fruit is quite sweet.

Different studies have revealed that total ash levels in *A. squamosa* vary from 0.55–2.8 g. The lowest value was reported for a genotype from Nigeria (Folorunso and Modupe,

2007), and the highest was detected in a genotype from Cuba (Morton, 1987). This concentration is higher than the value normally detected in *Annona* fruits, which is between 0.5% and 1.4%. Folorunso and Modupe (2007) underline the fact that high ash content indicates high concentrations of metals, and that the pulp may contain important elements for human health (Hassan et al., 2008).

Annona squamosa and other species of the genus contain high levels of some important elements for human health, such as potassium, calcium, magnesium, and phosphorus. One genotype from the municipality of Fortaleza, in the state of Ceará, Brazil, has the highest concentration (391 mg), whereas a genotype from Oahu, Hawaii, exhibits the lowest (142 mg). Calcium is the second most common mineral. A genotype from the municipality of Fortaleza in the state of Ceará, Brazil, has 53.7 mg of the element, and the genotypes from Oahu, Hawaii, and Cuba have the lowest calcium content (17 mg). The highest and lowest contents of magnesium (34 mg and 21 mg) were found in one genotype from Colombia and one from Florida, respectively. The level of phosphorus is the highest in a genotype from Cuba (55.3 mg), and the lowest is in a genotype from Fortaleza, in the state of Ceará, Brazil. These elements play important roles in several biological functions, helping protect bones and teeth, providing strong muscles, and improving general health (Pinto and Jackson, 2006).

Some *A. squamosa* types contain high levels of other minerals, such as nickel and selenium. The genotype richest in these two elements was from Colombia (70 mg and 80 mg, respectively). A genotype from the municipality of Fortaleza in Ceará, Brazil, has the lowest recorded levels of nickel and selenium: 19.4 mg and 0.26 mg (Alves et al., 2001). Selenium is an essential trace element; that is, the amounts required by the human body are minimal, and large doses can be toxic. According to Burk (2002), selenium is an essential constituent of a number of enzymes, some of which have antioxidant functions. Deficiency of the element in animals makes them susceptible to injury by certain types of oxidative stress. At least one human disease occurs only in individuals with a deficiency of selenium; therefore, it seems prudent to avoid selenium deficiency.

Other elements have been found either at low concentrations or as trace elements. For instance, iron varies from 0.28 mg in a genotype from the Philippines (Morton, 1987), to 1.38 mg in a genotype from Colombia (Alves et al., 2001; Leterme et al., 2006). Sodium levels are between 2 mg in a genotype from Oahu, Hawaii (Wenkam, 1990), and 9 mg in a genotype from Florida. In turn, copper contents are between 0.09 mg in a genotype from Florida, and 0.3 mg in a genotype from Colombia (Alves et al., 2001; Leterme et al., 2006). The manganese level is 0.16 mg (in a genotype from Fortaleza, state of Ceará, Brazil, and in a genotype from Colombia) (Almeida et al., 2009; Alves et al., 2001; Leterme et al., 2006). Zinc varies from 0.11 mg in a genotype from Florida to 0.55 mg in a genotype from Colombia (Alves et al., 2001; Leterme et al., 2006). Additionally, cobalt contents range from 10 mg (a genotype from Colombia) (Alves et al.,

2001; Leterme et al., 2006) to 20.7 mg (genotype 1 from the municipality of Fortaleza, in the state of Ceará, Brazil) (Almeida et al., 2009).

According to Enweani et al. (2004), the levels of electrolytes and nutrients in the juices of *A. squamosa* were found to be higher than the recommended World Health Organization (WHO)/United Nations Children's Fund (UNICEF) standard values prescribed in oral rehydration therapy (ORT), an important treatment strategy in cases of severe diarrhea. The disease is considered a serious health problem, and is responsible for substantial morbidity and mortality figures among children and adults, both in developing and in developed countries. Diarrhea has also been reported to be more common among those who are under 5 years of age, a demographic that accounts for a reasonable percentage of death caused by dehydration, hypovolemia, acidosis, hemoconcentration, and loss of electrolytes.

The mineral composition of the sugar apple juices compares favorably with the WHO/UNICEF composition standards for oral rehydration solution (ORS). Citrate concentration in sweetsop juice is also higher (3.53 g/L) than that in the WHO/UNICEF ORS recommendation: 2.9 g/L, expressed as trisodium citrate dihydrate. The chloride concentration in sugar apple juice is 3.4 g/L, whereas the WHO/UNICEF ORS preparation standard is 3.5 g/L of sodium chloride or 1.5 g/L of potassium chloride. The bicarbonate content of sweetsop juice is higher than that in soursop juice and the ORS composition standard. Carbonate was found to be present only in the fruit juices. Micronutrients in the juices help provide adequate quantities of electrolytes to correct the deficits associated with acute diarrhea. Replenishment of specific deficiencies in vitamins and minerals (e.g., zinc) is also advisable. In addition, the same is valid for some important nutrients that may be used as a source of energy, such as glucose. Potassium in juice is important in view of the significant potassium depletion associated with acute diarrhea, especially in infants. The function of citrate or bicarbonate is to correct the base deficit acidosis. The absorption of sodium and water in the small intestine is directly related to the absorption of glucose (Enweani et al., 2004).

Smell is one of the most important commercial attributes of many fruits. Esters, terpenes, and alcohols are the most important compounds that influence the smell profiles of *Annona* species. The yield of volatile oils in the sugar apple of Malaysia is estimated at 6 mg/kg. One study identified 32 volatile components, among which terpenoids account for 88.5%. Of the 13 monoterpenoids detected, the most abundant were terpineol (5.1%), acetate (1.8%), 1,8-cineole (1.4%), and β -pinene (1.3%). The levels of the sesquiterpenoid alcohols epi- α -cadinol, muurolol, spathulenol, and globulol were 37%, 12.4%, 6.8%, and 4.0%, respectively (Andrade et al., 2001). These authors also identified 27 monoterpenoids and sesquiterpenoids in the pulp of *A. squamosa* from the Brazilian Amazon, which in total accounted for 99.1% of volatile oil content. Monoterpenoids represent 75.5% of the oils in *A. squamosa*, the most common of which are α -pinene (25.3%), sabinene (22.7%), and limonene (10.1%). In turn, sesquiterpenoids account for

21.6% of total oils. The most abundant are spathulenol (6.3%), germacrene-D (6.0%), and bicyclogermacrene (3.5%). A comparison between aromatic components in fruit from Brazil and from Malaysia indicates that the predominance of terpenoids is shared by these fruits, although the actual proportion of each constituent varies.

The cultivars, varieties, selections, genotypes, and ecotypes of *A. squamosa* vary considerably between countries. This indicates that the concentration of chemical constituents in *A. squamosa* may be influenced by geographic factors, such as edaphoclimatic conditions, genotypic differences, nutritional status of plants, and postharvest conditions.

NUTRITIONAL COMPOSITION OF THE PULP OF DIFFERENT CULTIVARS OF THE INTERSPECIFIC HYBRID OF *ANNONA SQUAMOSA* × *ANNONA CHERIMOLA* (ATEMOYA)

According to estimates, Annonaceae plantations cover 10,000 ha in Brazil. The state of São Paulo is the largest producer, accounting for 43.8% of the country's total production, followed by Minas Gerais, Paraná, and Bahia. These species may be consumed *in natura* or as juice (Silva and Muniz, 2011).

Atemoya (*A. squamosa* × *A. cherimola*) is the result of the crossing of the sugar apple (*A. squamosa*) and the cherimoya (*A. cherimola*). The hybrid was developed in the beginning of the twentieth century in Florida. Subsequently, a number of varieties have been developed (Figure 1 and Table 4). However, few have been analyzed in detail.

According to Coordenadoria de Assistência Técnica Integral (CATI) (<http://cati.sp.gov.br/>), two cultivars stand out in Brazil: 'Thompson' and 'Gefner' (native to Israel). They produce medium-sized to large fruits weighing 450–500 g with levels of sugars up to 250°Brix when the fruit is ripe. Other cultivars that are potentially interesting when grown under specific conditions include 'African Pride' (from Australia), 'Pink Mammoth', 'QAS', and some local selections, such as 'PR-3' and 'PR-1'. Data collected in Companhia de Entrepósitos e Armazéns Gerais de São Paulo (CEAGESP) in 2003 showed that 'Gefner' and 'Thompson' each represent 32% of the atemoya cultivars marketed, followed by 'PR' (13.7%), 'African Pride' (10.3%), 'Pink Mammoth' (8.6%), and 'QSA' (1.7%).

In Florida, the cultivar 'Gefner', which does not require manual pollination, has the highest production numbers. The yield of cultivar 'Page' is good, but the fruit tends to break when ripe. When unassisted by manual pollination, the production of 'African Pride' ('Kaller') and of 'Bradley' is low. Other varieties, like 'Bernistski', 'Caves', 'Chirimoriño A', 'Chirimoriño B', 'Chirimoriño C', 'Hette', 'Island Gem', 'Lindstrom', 'Kabri', 'Malali', 'Malamud', 'Mammoth' ('Pink Mammoth'), 'Priestly', and 'Stermer' have not yet reached the status of commercially viable fruit (Crane et al., 2013).

Compared with sugar apple, atemoya fruits are larger, taste sweeter, and have appropriate levels of potassium, which is important in the general nutritional balance and neuromuscular function. Additionally, atemoya is richer in fiber, an interesting property

that improves intestinal function and helps control cholesterol. These fruits also have higher contents of vitamin C, which strengthens the immune system and improves iron absorption. Atemoya is rich in carbohydrate. In an analysis of several common fruit in Taiwan, [HsuehYun et al. \(2009\)](#) detected high levels of folate ($95 \pm 25 \mu\text{g}/100 \text{g}$). However, because it is also rich in calorie content, care should be taken when atemoya is to be consumed as a source of folate.

The pulp of atemoya can be consumed *in natura*, although it is also widely used in elaborate desserts and mixed with custards and meringues. Moreover, it may be used in the preparation of ice cream or yogurt. As a rule, the fruit is rich in carbohydrates ([Paull and Duarte, 2011](#)) (Table 5).

As with all climacteric fruits, atemoya decays rather quickly and is susceptible to mechanical damage during harvest, transportation, and handling. These aspects are considered obstacles to its wide commercialization and to the maintenance of quality standards ([Silva and Muniz, 2011](#)). [Batten \(1990\)](#) investigated the effect of temperature on fruits of the cultivar ‘African Pride’ and observed that fruit stored at 28°C ripen slightly faster than those stored at 32°C . However, the smell produced by atemoya is significantly affected when fruits are exposed to higher temperatures. The author also showed that storing atemoya fruits at lower temperatures affects quality and appearance, posing

Table 5 Approximate composition of the pulp of atemoya (*Annona squamosa* × *Annona cherimola*) in 100 g of an edible portion

Components	Values
Energy (calories) (kcal)	94–97
Water (g)	71.5–78.7
Proteins (g)	1–1.4
Lipids (g)	0.3–0.6
Carbohydrates (g)	15.8–25.3
Fiber (g)	0.05–2.5
Ash (g)	0.4–0.75
Calcium (mg)	17–23
Iron (mg)	0.2–0.3
Magnesium (mg)	25–32
Potassium (mg)	250–300
Sodium (mg)	1–5
Ascorbic acid (mg)	10–50
Thiamine (mg)	0.05–0.09
Riboflavin (mg)	0.07–0.08
Niacin (mg)	0.8–1.5
α -carotene (μg)	10
β -carotene (μg)	10
Cryptoxanthin (μg)	10

Adapted from [Morton \(1987\)](#), [Paull and Duarte \(2011\)](#), and [TACO \(2011\)](#).

marketability problems. Additionally, the amount of soluble solids in the pulp of ripe atemoya, which varied between 22 °Brix and 24.8 °Brix, did not correlate with storage conditions. ‘African Pride’ fruits reach respiration peaks approximately 3 days after picking, and the best time for consumption is after another 2 days. Therefore, the best is to consume the fruit in 5 days after harvest (Paull and Duarte, 2011).

The main components responsible for the smell produced by atemoya ‘African Pride’ were monoterpenes or sesquiterpenes, among which are α - and β -pinene (25.6% and 21.0%), bicyclogermacrene (14.6%), and germacrene D (10.9%) (Wyllie et al., 1987). However, this chemical composition may vary significantly for other cultivars (Pino, 2010).

The analysis of parameters associated with quality of fruits of the cultivar ‘Gefner’ picked at two different ripening stages (green and ripe) and stored for up to 9 days showed that except for firmness, no statistically significant differences were detectable. Nevertheless, storage time affected all parameters considerably. Soluble solids levels varied from 10 °Brix to 32.15 °Brix throughout storage. Although total acid content also increased, vitamin C levels fell drastically, from about 88 mg/100 g fresh matter to 25–30 mg/100 g MF (Silva and Muniz, 2011).

Free amino acids comprise an important kind of biologically active compound that works as building blocks of proteins and polypeptides, or acts as essential compounds in metabolism maintenance. A clear quantitative and qualitative distinction was reported for free amino acids in the pulp of fruits of the cultivars ‘Gefner’ and ‘Pink Mammoth’. The amount of free amino acids in the cultivar ‘Gefner’ was approximately four times as high as that in the cultivar ‘Pink Mammoth’ (23.1 mg/g dry matter [DM] and 5.6 mg/g DM, respectively). Glutamine was the main amino acid in ‘Gefner’ (20.1 mg/g DM), whereas serine was the major amino acid in ‘Pink Mammoth’ (2.3 mg/g DM) (Egydio et al., 2013).

Cruz et al. (2013) assessed the physicochemical properties of the atemoya fruit cultivar ‘Gefner’. The results showed that the samples contained 6.8 mg/100 g DM protein, 4.7 mg/100 g DM ash, and 23 mg/100 g DM fibers, of which 20.5 mg/100 g DM were soluble and 2.5 mg/100 g DM were insoluble. Other components included 60.9 mg/100 g DM ascorbic acid, 58 mg/100 g DM total sugars, 95.16 μ mol/min g trypsin inhibitors activity, 10.38 mg/100 g⁻¹ DM phenolic compounds, and 722.35 hemagglutination units protein⁻¹ lectin DM.

Sugar apple, atemoya, and prickly soursop are tropical fruits. Like many others of this class, these fruits have large economic potential for the exportation of *in natura* or even derivate products. Jam production is an alternative in strategy to consider for the use of overripe fruits that may add value to the exploration of a given species. In Brazil, jams are not produced using these *Annona* species. Orsi et al. (2012) analyzed the chemical composition of fresh fruit and respective jams. Atemoya fruits presented approximately 72% water, 22% carbohydrates, 21.9% total sugars, and 25.1 °Brix of soluble solids. In turn, results of the analyses of jams revealed 27.9% water, 71.4% carbohydrates, a pH level of 3.34, and

65 °Brix of total solids. Apart from these values, the researchers also obtained good acceptance results based on the sensorial assessment of jams by volunteers, who preferred atemoya jam.

LINE OF RESEARCH OF THE AUTHORS

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SUMMARY

- The fruit of *A. squamosa* and its hybrid atemoya are consumed mainly *in natura*, although they are also a popular ingredient of juices, desserts, ice creams, and liqueurs. Apart from the nutritional value, studies have pointed to the medicinal properties of different plant parts.
- Sugar apple and its hybrid, atemoya, have been widely cultivated and marketed in several countries in tropical or subtropical regions in South America, Central America, North America, Asia, and Africa.
- The pulps of both sugar apple and atemoya are rich in total sugars, ascorbic acid, niacin, thiamin, riboflavin, and some minerals, such as calcium, magnesium, and phosphorus.
- The fruits of this species may have high antioxidant capacity. As a rule, fruits in general are good sources of antioxidants, such as phenolic substances, vitamins, carotenoids, and minerals with potentially useful chemopreventive properties.
- The levels of electrolytes and nutrients in the juices of *A. squamosa* were found to be higher than the recommended WHO/UNICEF standard values prescribed for ORT, a treatment strategy that is very important in cases of severe diarrhea.
- Like many other tropical fruits, sugar apple, atemoya, and prickly soursop have large economic potential for the exportation of *in natura* fruits or derivate products. The production of jams represents a good alternative for use of overripe fruits that may add value to the exploration of a given species.

- The existence of different cultivars of sugar apple and atemoya has been acknowledged in several countries. Research has attempted to select genotypes with desired characteristics, selection, or ecotypes, especially concerning fruit quality and productivity.
- The chemical composition of different cultivars, varieties, selections, genotypes, or ecotypes of sugar apple and of atemoya varies considerably among countries. This indicates that the concentrations of the chemical compounds in *A. squamosa* may be influenced by factors that vary from region to region, such as edaphoclimatic conditions, genotypic differences, nutritional status of plants, postharvest treatments, and others.

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CHAPTER 10

Date Fruits: Nutritional Composition of Dates (*Balanites aegyptiaca* Delile and *Phoenix dactylifera* L.)

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LIST OF ABBREVIATIONS

BC before Christ
GAE galic acid equivalent
HS-SPME headspace solid phase microextraction
QE quercetin equivalent

INTRODUCTION

There are many neglected and underused plants species, even though they are known for their nutritional values and have been adapted to low-input agriculture. Whether wild, managed, or cultivated, these species have a potential impact on the food security and well-being of the low-income population (Barnes et al., 2013; Chirinos et al., 2013). *Balanites aegyptiaca* Del. is a spiny evergreen wild plant with fruit called the *desert date* in English (Hall, 1992). Although the exact origin of the date palm (*Phoenix dactylifera* L.) is not known with certainty, according to ancient writings (3000 BC), the geographical origin of the date palm tree is probably Mesopotamia and the valley of the Nile in Egypt

(Al-Bakr, 1972). These two trees are commonly grown in arid regions of Africa, the Middle East, and southern Asia, and their fruits are widely consumed; their nutritional significances are highly admired (Yadav and Panghal, 2010). Almost all the parts of *B. aegyptiaca* and *P. dactylifera* L. plants are traditionally used as food or in folk medicines. In the Sahara region of Africa, the *B. aegyptiaca* fruits (desert date) are used as oral hypoglycemic drugs (Hall, 1992; Yadav and Panghal, 2010); the stem, root, and leaf extracts of *B. aegyptiaca* are used as traditional folk medicines, especially in Africa and southern Asia. The date palm tree, *P. dactylifera* L., is a known tree of major interest because of its high nutritional value and desirable fruits (Odeh et al., 2014). Apart from nutritional benefits, date fruits have been related to several biological effects, including antioxidant, antimutagenic, antiinflammatory, anticancer, antimicrobial, and immunostimulant (Saafi et al., 2009; Odeh et al., 2014). The date palm has always played an essential role in the diet of local inhabitants of date-producing countries.

Wild and semi-wild food resources are commonly consumed as the dominant source of fruits, especially in rural communities (Umaru et al., 2007). Desert date wild fruits have helped provide a steady supply of fruits during the dry season when cultivated fruits are scarce and expensive for low-income earners who traditionally have large families. These fruits are used in treating whooping cough, leukoderma, and other skin diseases (Chothani and Vaghasiya, 2011; Koko et al., 2005). In Egyptian folk medicine, desert dates are used for oral hypoglycemic (Koko et al., 2005) and antidiabetic therapy, and the mesocarp aqueous extract is used in Sudanese folk medicine for the treatment of jaundice (Sarker et al., 2000). Traditionally, date palm fruits are used in medicine as syrups recommended for the treatment of liver diseases and for pregnant women before and after delivery; moreover, date palm fruits or date syrups are a component of beverages, confections, bakery products, and ice cream (Al-Mamary et al., 2014). The nutritional significance of date fruits, as well as beneficial health effects of these natural wonders, proves that the fruits contain varieties of components of polyphenols, including phenolic acids, hydroxycinnamates, flavonoid glycosides, coumarins, alkaloids and proanthocyanidin oligomers, and more (Kamel, 1998; Mohamed et al., 2014). Analytical findings from the chemical analysis explain the complex multiple nutraceutical actions of both desert date (*B. aegyptiaca* Del.) and date palm fruits (*P. dactylifera* L.). This chapter is aimed to compare the nutritional composition of their fruits.

BOTANICAL ASPECTS

Balanites aegyptiaca is a multibranched, spiny, evergreen wild shrub or tree that grows up to 10m in height (Figure 1) belonging to the Zygophyllaceae family (Chothani and Vaghasiya, 2011; Hall, 1992). It is endemic to dry land areas. The crown is spherical and grows in one or several distinct masses. Its trunk is short and often branches from near the base. The bark is dark brown to gray and deeply fissured. Branches are armed with stout yellow

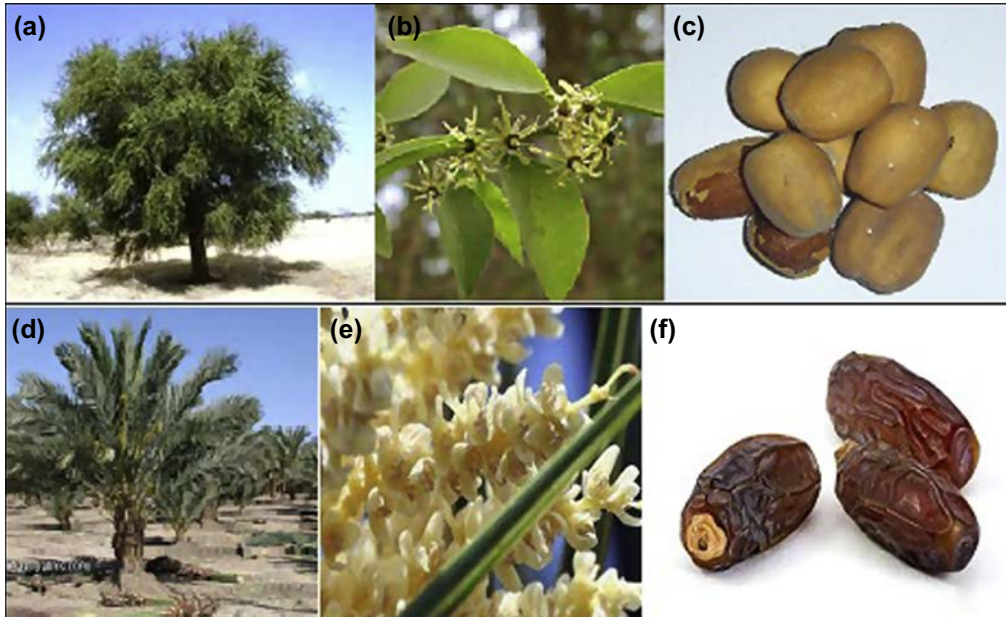


Figure 1 *Balanites aegyptiaca* Del. (a) Tree (fruitipedia.com), (b) flowers (wildflowers.co.il), and (c) fruits (desert date); *Phoenix dactylifera* L. (d) Tree (Medjool-date-palms.com), (e) flowers (pbase.com), and (f) fruits (vibrandorange.com).

or green thorns up to 8 cm long. Leaves have two separate leaflets that are obovate, asymmetric, 2.5–6 cm long, bright green, and leathery, and have fine hairs when young. Flowers grow in fascicles in the leaf axils and are fragrant and yellowish-green (Yadav and Panghal, 2010). Date palm trees were probably first found around 5000–6000 BC in Iran, Egypt, and Pakistan, although the earliest cultivations occurred around 4000 BC in Eridu and Lower Mesopotamia (Al-Bakr, 1972). *P. dactylifera* is now found in tropical and subtropical regions all over the world as well as in temperate and arid regions in USA, Australia, southern Spain, and the Mediterranean coast of Africa and West Asia. *Phoenix dactylifera* belongs to Arecaceae (Palmaceae) family; the name *Phoenix* was derived from the legendary bird of old Greece, and *dactylos* means *finger*, taking into account the shape of the fruit. Natural distribution of *B. aegyptiaca* is a result of cultivation and naturalization. However, the date palm is a dioecious species in which the male and female organs are carried by separate trees. It is the tallest tree among all the *Phoenix* species, and in some conditions, the non-branching trunk can grow higher than 30 m (Al-Bakr, 1972; Torres, 2014).

It is believed that *B. aegyptiaca* is endemic to all dry lands south of the Sahara desert, extending southward to Malawi in the Rift Valley and to the Arabian Peninsula; however, it has been introduced to Latin America and India. The tree has wide ecological distribution, although it is mainly found on level alluvial sites with deep sandy loam and free access to water. After the seedling stage, it is intolerant to shade and prefers open woodland or savannah

for natural regeneration. It is a lowland species, growing up to 1000 m altitude in areas with mean annual temperature of 20–35 °C and mean annual rainfall of 250–400 mm (Hall, 1992; National Plant Data Center). On the other hand, the *P. dactylifera* plant has one terminal shoot apex that ensures its growth lengthwise with a highly developed root system. The leaves are large (4–5 m wide), long (4–8 m), and pinnate; they grow in an alternate pattern from the ground upward in a spiral pattern on the trunk, with sheathing in dense terminal rosettes or crowns of 100–120 leaves. The date palm plant is generally propagated by offshoots and seeds. The offshoot method of plant propagation is slow but healthier than using the seeds. Normally date palm from offshoots begin to bear fruit within an average of 5–8 years after planting; they reach their maturity at around 30 years. On the other hand, seed germination is the easiest, but seedlings may take up to 10 years before flowering and fruiting occur.

Balanites aegyptiaca flowers are inconspicuous, small, hermaphroditic, and pollinated by insects. Seeds are dispersed by birds and animals. Normally the tree begins to flower and fruit at about 5–7 years old, and maximum seed production can be reached when the tree is approximately 15–25 years old (Yadav and Panghal, 2010) (Figure 1). The fruit of the desert date tree is rather a long, narrow drupe, 2.5–7 cm long, and 1.5–4 cm in diameter. While young, the fruits are green and tomentose, but they turn yellow and glabrous when they mature (Figure 1). It has a bitter-sweet edible pulp. The seeds (stone) contain pyrene and are 1.5–3 cm long, light brown, fibrous, and extremely hard, comprising about 50–60% of the fruit. There are 500–1500 dry, clean seeds per kilogram (Aviara et al., 2005; Hall, 1992).

The lack of roots in the top soil of the date palm tree allows other cultures, such as wheat, lucerne, and vegetables, to be intercropped. The high concentration and deep primary roots allow the date palm to benefit from underground moisture, and consequently, most fruit palms are water resistant and can stand drought conditions. A fully productive date palm tree can support up to 10 clusters, which can carry more than 100 kg of fruit (Figure 1). The fruit is medium sized, and its shape is broadly ovate to somewhat rounded (egg-shaped), commonly with a wedge shaped taper from middle to bluntly pointed apex. Fruit length is small (± 32.5 mm) with a big diameter (± 25.4 mm). Fruit of thinned bunches may be about 31 mm long and 27 mm wide (length to width ratio is about 1:15). The average weight ± 15 –20 g. Date palm fruits can be eaten before the final stage of ripening (50% soft brown color and 50% hard yellow or red colors) or consumed after complete ripening (100% soft brown color) (Aviara et al., 2005; Babiker et al., 2013; Sedra, 2011).

COMPOSITION OF TRADITIONAL AND MODERN CULTIVARS

‘Medjool’ Date

There are many varieties of dates that have been developed over thousands of years through selection of seedlings, although only those possessing desirable characteristics have been retained and propagated. The date palm accounts for more than 3000 varieties found around the globe. There are about 244 in Morocco, 250 in Tunisia, 370 in Iraq,

400 in Iran, and many additional varieties in the other major date growing countries (Devanand and Chao, 2003; Sedra, 2011). The ‘Medjool’ variety (meaning unknown) is originally from Morocco but largely spread around the world and can be found in the United States, Israel, and Saudi Arabia. It was principally exported in the seventeenth century to Europe and sold in a fancy box as a Christmas gift (Al-Bakr, 1972). The ‘Medjool’ date palm is characterized by its medium-sized trunk and short to medium leaves, which are organized with little curvature. The ‘Medjool’ date is of high commercial value and is considered to be one of the best exported dates with regard to its fruit quality and size in comparison with other varieties. The Fruits are recognized by their yellow–orange color with clear dark red strips at the color stage (also called *Khalal stage*). The ‘Medjool’ date is considerably large and elongated, weighing about 20–40 g. It is somewhat ovate in shape, about 5 cm long by 3.2 cm in diameter. Moreover, irregularities in shape are common and are associated with ridges on the seed. At maturity, ‘Medjool’ fruit color is related to the climate and growing conditions. ‘Medjool’ dates get very little damage from rain, although the fruit quality remains very sensitive to temperature and humidity. Both low and high extremes are not suitable for achieving high-quality fruits (Sedra, 2011).

Palm date fruits can be eaten before the final stage of ripening or consumed after complete ripening. In general, these dates provide a wide range of essential nutrients, and they are well known as a very good source of dietary potassium. It was noted that date palm fruits accumulate most of their sugar, both the sucrose type and the reducing sugar type, during the color stage, at which the color of the seed changes at the end from white to brown. The moisture content of date palm fruits decreases drastically as they ripen, and it is about 24.2% at the full ripe stage (also called the *Tamar stage*) and reaches 4–10% in dry dates (Babiker et al., 2013). Farag et al. (2014) stated that differences in date varieties mainly emanate from the content of flavonol glycosidic conjugates and sugars, which are relevant classes of date chemical composition for having an impact on its product quality and/or efficacy, as well as sensory variability and market appeal. Date palm fruits contain a high concentration of sugar, which is considered the main component. The sugar content of ripe dates is about 80%; the remaining 20% consists of protein, fiber, and trace elements including boron, cobalt, copper, fluorine, magnesium, manganese, selenium, and zinc (Hong et al., 2006; USDA, 2015). Substances responsible for enzymic browning found in date palm fruits are often the caffeic acid glycoside 3-O-caffeoylshikimic acid (popularly known as *dactylifric acid*) and its isomers. During the ripening process of these dates the nonsoluble solid substances are gradually broken down by enzymes to more soluble compounds, rendering the fruit more tender and soft. Crude fiber amounts to 2–8% in the date flesh; however, it is about 6.7% in the ‘Medjool’ date and as low as 2.7% in ‘Lulu’ date cultivar from the United Arab Emirates region and 2.92% for the ‘Aseel Sindh’ date grown in Pakistan (Table 1). The polyphenols, including the tannins, in fresh date palm fruit may account up to 3% the fruit’s dry weight. Many authors report that dates palm fruit at the stage of maturation—in which they are

Table 1 Chemical composition of 100 g of desert date and date palm fruit

Dates varieties	Moisture (g)	Fat (g)	Proteins (g)	Fiber (g)	Sugars, total (g)	Ash (g)
Desert date ^a	16.31	0.41	4.10	42.57	212.25	9.06
Deglet Noor ^b	20.53	0.39	2.45	8.00	63.35	3.10
Medjool ^{b,c}	21.32	0.15	1.81	6.70	66.47	1.67
Khodari ^f	19.50	0.18	3.42	—	79.40	3.42
Safawy ^f	23.60	0.12	2.48	—	75.30	1.68
Dhokki ^e	24.40	0.51	2.42	3.31	66.10	1.43
Aseel Sindh ^e	24.14	0.41	1.57	2.92	67.11	1.77
Hillavi ^e	23.12	0.43	2.73	3.38	67.16	1.37
Horra ^d	17.81	0.25	5.10	—	55.44	2.30
Lulu ^g	—	0.10	2.50	2.70	78.50	1.60
Ajwa ^f	22.80	0.47	2.91	—	74.30	3.43
Burni ^f	24.40	0.67	2.50	—	81.40	2.02

^aAmadou et al. (2012) and Sagna et al. (2014).^bUSDA (2015): <http://ndb.nal.usda.gov/ndb/foods/show/>.^cDevshony et al. (1992).^dat *tamr* stage El Arem et al. (2011).^eNadeem et al. (2011).^fAssirey (2015).^gAl-hooti et al. (1997).

normally and mostly consumed—contain two groups of substances of importance for nutritional purposes (vitamins A, B1, B2, and niacin); however, other vitamins, notably vitamin C, are of insignificant amounts (Aslam et al., 2013). ‘Medjool’ dates have no vitamin C (Table 2), remarkable magnesium content (54%), and a potassium content of 696 mg, much higher than that of other date palm cultivars (Table 3). The most abundant oils in date palm were oleic (C18:1 n-9) and lauric (C12:0) acids, followed by palmitic (C16:0), linoleic (C18:2 n-6), and myristic (C14:0) acids, which account for about 90% of the total fatty acids (El Arem et al., 2012; USDA, 2015).

Table 2 Amount of vitamins in the desert date and date palm fruit (value per 100 g)

Vitamins	Dates		
	Desert ^b	‘Deglet Noor’ ^a	‘Medjool’ ^a
Vitamin A (IU)	—	10	149
Thiamine (mg)	0.6638	0.052	0.050
Riboflavin (mg)	0.0036	0.066	0.060
Niacin (mg)	—	1.274	1.610
Vitamin B6 (mg/mL)	0.0021	0.165	0.249
Vitamin C (mg)	0.0966	0.4	0
Folate (μg)	0.6	19	15

^aUSDA (2015): <http://ndb.nal.usda.gov/ndb/foods/show/>.^bAdapted from unpublished results: Amadou I. State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, China.

Table 3 Total phenol, flavonoid, and minerals content in the date fruits varieties (value per 100 g)

Minerals	Dates							
	Desert ^a	'Deglet Noor' ^{b,c}	'Medjool' ^{b,d}	'Ajwa' ^e	'Khodari' ^e	'Safawy' ^e	'Burni' ^e	'Lulu' ^f
Sodium (mg)	48	2	1	7.5	4.9	8.6	8.9	2.2
Potassium (mg)	2220	656	696	476.3	289.6	512	422.5	402.8
Magnesium (mg)	73	43	54	150	60	56	100	43.6
Phosphorus (mg)	48	62	62 ^b	27	16	12	18	64.7
Iron (mg)	4.94	1.02	0.90	—	—	—	—	1.38
Calcium (mg)	141	39	64	187	133	123	168	43.2
Zinc (mg)	0.65	0.29	0.44	—	—	—	—	0.29
Phenol content	3.85%	80.19 (mg GAE/100 g)	0.46%	—	—	—	—	—
Flavonoid content	3.17%	2.34 (mg QE/100 g)	0.945%	—	—	—	—	—

GAE, gallic acid equivalent; QE, quercetin equivalent.

^aAmadou et al. (2012) and Sagna et al. (2014).

^bUSDA (2015): <http://ndb.nal.usda.gov/ndb/foods/show/>.

^cAdel et al. (2013).

^dOdeh et al. (2014).

^eAssirey (2015).

^fAl-hooti et al. (1997).

'Deglet Noor' Date

The organoleptic taste of date fruit is closely related to the maturity and ripeness stage of the date. Generally, most date palm fruit is harvested during the stage of ripeness, when the fruits are brown with low moisture and tannin contents and high concentrations of sugars. Dates are traditionally good food for boosting energy quickly; they are an energy-dense food packed with carbohydrates, including sucrose, fructose, and glucose. 'Deglet Noor' dates (*dates of light* in Arabic) are the most widely grown dates in North Africa and the United States. The seed of a 'Deglet Noor' date can be seen right through the flesh when held up to the sun or light; in addition, it is amber-colored with a delicate flavor, although not as sweet or moist as the 'Medjool' date (Adel et al., 2013; Hong et al., 2006). In addition, 'Deglet Noor' dates are relatively smaller than 'Medjool' dates.

The date palm protein content ranges from 1% to 3%, with 23 different amino acid patterns favorable for human requirements, in contrast to the many amino acid patterns present in the most popular fruits, such as bananas, apples, and oranges. Al-Showiman (1998) noticed that aspartic acid, proline, serine, glutamic acid, threonine, alanine, and glycine are found in dates; in addition, isoleucine is present in dates at over 800 times the quantity it occurs in apples. The lysine content of dates accounts for nearly 2000 times that in the apples, nearly 5000 times that in oranges, and over 2000 times that in bananas. In addition, the 'Khodari' date (a Saudi Arabian cultivar) was reported to have the highest leucine (100 mg) and smallest histidine (9 mg) values compared with other dates (Table 4) (Assirey, 2015). The flesh of date palm fruit contains 0.2–0.5% oil and the seed contains 7.7–9.7% oil (Table 5). The fatty acids occur in both flesh and seed as a range of saturated (capric, lauric, myristic, palmitic, stearic, margaric, arachidic, heneicosanoic, behenic, and tricosanoic acids) and unsaturated (palmitoleic, oleic, linoleic, and linolenic) acids. Oleic acid is known to dominate nearly up to half of the fatty acid in most of the seeds; however, the average mean of oil content in the date palm varieties is about 6.7%, with the highest percentages of unsaturated and saturated fatty acids among the cultivars that were related to the oleic and lauric acids (Devshony et al., 1992; Walid and Marshall, 2003). Date palm seeds of the 'Deglet Noor' and 'Medjool' cultivars contain 42.3% and 21.8% oleic and lauric acids, respectively; however, an Iraqi 'Zahdi' date cultivar has a higher oleic acid content (Table 5). Hong et al. (2006) concluded in their investigations on flavonoid glycosides and procyanidin composition of 'Deglet Noor' dates that there are 13 flavonoid glycosides of luteolin, quercetin, and apigenin, with 19 others more identified when considering isomeric forms. In contrast Liquid Chromatography-Electrospray Ionization/Mass Spectrometry/Mass Spectrometry (LC-ESI/MS/MS) spectra indicated that quercetin and luteolin were the primarily O-glycosidic linkages formed, whereas apigenin was present as the C-glycoside.

Table 4 Amino acid content of date fruits (mg/100 g dry weight)

Amino Acids (mg/100 g)	Desert date ^a	'Ajwa' ^b	'Khodari' ^b	'Safawy' ^b	'Burni' ^b
Aspartic acid	171	186	147	127	225
Glutamic acid	196	205	232	158	265
Serine	45	59	57	64	62
Histidine	16	26	9	21	27
Glycine	101	83	102	98	90
Threonine	41	53	50	51	42
Arginine	83	93	58	37	60
Alanine	114	82	104	105	78
Tyrosine	14	—	40	15	16
Cysteine-s	25	—	36	32	46
Valine	46	65	78	—	86
Methionine	16	27	21	18	17
Phenylalanine	37	45	56	54	48
Isoleucine	63	44	55	43	45
Leucine	44	57	100	84	82
Lysine	25	73	60	52	51
Proline	1209	86	97	110	113
Tryptophan	20	44	—	46	13

^aAdapted from unpublished results: Amadou I. State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, China.

^bAssirey (2015).

Table 5 Content of fatty acids in 100 g of date fruit varieties

Dates

Fatty acids (% w/w)	Desert ^a	'Deglet Noor' ^b	'Medjool' ^b	'Zahdi' ^b	'Alig' ^c	'Halawy' ^b
Capric	—	—	0.30	—	—	0.30
Lauric	—	24.0	22.70	19.60	—	21.10
Myristic	0.14	9.60	10.70	12.10	2.62	11.20
Palmitic	22.02	9.60	8.70	10.20	21.93	9.70
Stearic	—	1.30	1.40	1.90	10.71	1.60
Oleic	37.17	41.10	41.40	44.10	29.83	42.80
Linoleic	27.73	14.50	14.90	12.00	4.59	13.50

^aAdapted from unpublished results: Amadou I. State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, China.

^bDevshony et al. (1992).

^cAt *tamr* stage El Arem et al. (2011).

Aduwa Fruit or Desert DATE

Natural distribution of the desert date (*Aduwa* means *desert date* in Hausa) is obscured by cultivation and naturalization. It is believed to be indigenous to all dry lands south of the Sahara desert, extending southward to Malawi in the Rift Valley and to the Arabian Peninsula, and has been introduced into cultivation in Latin America and India. The tree has wide ecological distribution, although it is mainly found on level alluvial sites with deep sandy loam and free access to water. After the seedling stage, it is intolerant to shade and prefers open woodland or savannah for natural regeneration. It is a lowland species, growing up to 1000 m altitude in areas with mean annual temperature of 20–35 °C and mean annual rainfall of 250–400 mm (Hall, 1992; National Plant Data Center).

The mesocarp of the desert date contains 4–9% protein, 35–43% sugars, 15% organic acids, and other constituents such as 3-rutinoside, 3-rhamnogalactoside, and diosgenin (Amadou et al., 2012; Chothani and Vaghasiya, 2011; Gnoula et al., 2008; Sagna et al., 2014). It also contains a mixture of 22*R* and 22*S* epimers of 26-(*O*-β-d-glucopyranosyl)-3-β-[4-*O*-(β-d-glucopyranosyl)-2-*O*-(α-l-rhamnopyranosyl)-β-d-glucopyranosyloxy]-22,26-dihydroxyfurost-5-ene. However, the mesocarp kernel contains xylopyranosyl, a derivative of saponin (Chothani and Vaghasiya, 2011). Balanitoside (furostanol glycoside), 6-methyldiosgenin (Hosny et al., 1992), and balanitin-3 (spirostanol glycoside) have been reported in *B. aegyptiaca* fruits (mesocarp) (Yadav and Panghal, 2010). Balanitin-6 and -7, or diosgenyl saponins (Gnoula et al., 2008), are two pregnane glycosides, namely pregn-5-ene-3β,16β,20(*R*)-triol 3-*O*-(2,6-di-*O*-α-l-rhamnopyranosyl)-β-d-glucopyranoside (balagypitin) and pregn-5-ene-3β,16β,20(*R*)-triol 3-*O*-β-d-glucopyranoside (Kamel and Koskinen, 1995), a long chain hydrocarbon. The kernels contain 32.4% protein and 45.0–46.1% oil comprised of palmitic, stearic, oleic, and linoleic acids, which are main fatty acids (Al Ashaal et al., 2010; Hussain et al., 1949). The desert date kernel contains about 0.41% oil and a series of hydrocarbons ranging from C11 to C28, of which the main hydrocarbons are C20 and C21 (Al Ashaal et al., 2010; Sagna et al., 2014). However, the major unsaturated fatty acid found in the desert date is oleic acid, and the major saturated fatty acid is palmitic acid (Table 5). No branched chain fatty acids or hydrocarbons have been reported in the desert date (Al Ashaal et al., 2010). Studies demonstrate that desert date kernel cake contains nine saponins, six of which have molecular masses of 1196, 1064, 1210, 1224, 1078, and 1046 Da, with a compound mass of 1210 Da being the main saponin (about 36%) (Chothani and Vaghasiya, 2011; Hosny et al., 1992; Kamel, 1998). Desert date contains the highest level of saponin (16.01%) compared with the other wild fruits found in the Sahel region (Umaru et al., 2007).

In general, consumption of fruits is reported to have a profound protective effect against cancer. Flavonoids are structurally related compounds that are abundant among plants and plant foods (Barnes et al., 2013; Chirinos et al., 2013). Phenolic compounds

are reported to produce antioxidant activity, which allows them to scavenge both active oxygen species and electrophiles, to inhibit nitrosation, and to chelate metal ions, modulating cellular enzyme activities (Amadou et al., 2011; Amessis-Ouchemoukh et al., 2014). The bioflavonoids (flavonoids) represent the major group of nonnutrients that accumulate in epidermic cells of plants and provide a barrier against ultraviolet radiation damage. Carotenoids are a class of isoprenoids widespread in fruits as pigments, mostly in yellow-orange fruits and vegetables. Vitamins catalyze important body reactions and because the human body cannot produce its own vitamin C, it is therefore important for a diet to contain high amounts of vitamin C. Assessment of nutritional composition in desert date fruit shows presence of several secondary metabolites classes, such as cumarins, flavonoids, and steroidal saponins, that have biological activity (Balz and Jane, 2003; Chirinos et al., 2013; Sarker et al., 2000); however, two furostanol glycosides and 6-methyl-diosgenin have been identified in desert date fruit (Kamel, 1998). Composition studies of desert date pulp extract (Table 1) revealed a higher protein content (4.1%) (Amadou et al., 2012). Amino acids are biologically important organic compounds that consist of a basic amino group ($-\text{NH}_2$), an acidic carboxyl group ($-\text{COOH}$), and a specific organic side chain that is specific to each amino acid. Comprising more than 50% of the total amino acids, proline is the amino acid most present in the desert date, as shown in Table 4 and reported by Sagna et al. (2014). However, analysis indicated that desert date pulp extract contains a trace amount of the sulfur-containing amino acids methionine and cysteine-s, with 0.72% and 1.10% of the total amino acids, respectively. The polyphenol and flavonoid contents of desert date pulp extract appear in low values (3.85% and 3.17%, respectively). The content of vitamin C is 0.0966 mg/100 g of the desert date pulp extract (Table 2); and minerals content are very high, with a sodium value of 48% (Table 3).

FLAVOR VOLATILE COMPOUNDS

Dates are good source of flavoring compounds; when used as a component in food preparations like sweets, snacks, baking products, institutional feeding, and health foods, they provide superb taste to the final product (Jaddou et al., 1984; Paravisini et al., 2014). The date fruit pulp is a good source of phytochemicals, such as sterols, phenolics, carotenoids, procyanidins, anthocyanins, and flavonoids; although their concentrations and ratios depend on the stage of fruit picking, type of fruit, location, and soil conditions (Chothani and Vaghasiya, 2011; Farag et al., 2014; Odeh et al., 2014).

Date Palm

These phytochemicals also add to the nutritional and organoleptic properties of the fruits (Barnes et al., 2013; Saafi et al., 2009; Nehdi et al., 2010). The volatile

compounds of date palm fruits are a result of the organoleptic properties of the fruits. In fleshy palm date pulp, 14 esters representing an area of about 23%, 10 alcohols (average area, 17%), 4 lactones (average area, 8%), 8 aldehydes (15%), and 3 ketones (average area 3.5%) (Farag et al., 2014) have been identified, indicating that the principal volatile compounds present include ethyl acetate, acetaldehyde, isopropyl acetate, δ -valerolactone, octanal, furfuryl alcohol, 5-methyl furfural, linalool, δ -valerolactone, and γ -undecalactone. Dates are a good source of flavoring compounds that are responsible for the fruit's specific aroma. El Arem et al. (2012) stated that number of aromatic compounds differ according to the date fruit variety and found that 'Deglet Noor' dates produce the highest number of aromatic compounds (28 in number), however only eight of the total identified compounds (2-propanol, isopentyl alcohol, dihydrocarveol, ethyl acetate, benzaldehyde, decanal, (Z)-2-tridecene, and (E)-2-tridecene) are common to all other date samples. Moreover, the authors have determined that 45 identifiable aromatics belong to seven chemical groups, namely 11 alcohols, 3 esters, 10 aldehydes, 8 terpenoids, 2 ketones, 7 saturated hydrocarbons, and 4 unsaturated hydrocarbons. Different date palm seed varieties' specific aromas depend on the quantity of compounds of alcohols, aldehydes, and unsaturated hydrocarbons (El Arem et al., 2012; Norman and Fouse, 1977). Alcohols, aldehydes, ketones, and derivatives are responsible for the date palm fruit's characteristic citrus, floral, and fruity aroma (El Arem et al., 2011). On the other hand, Jaddou et al. (1984) used gas-liquid chromatography to analyze flavor volatile compounds in 'Zahdi' dates and showed that these dates contain 6 saturated normal hydrocarbon compounds, 2 unsaturated hydrocarbons, 5 aldehydes, 6 ketones, 5 alcohols, 3 phenols, and 11 free fatty acids. In addition, these authors showed that the aliphatic hydrocarbons in the volatile compounds of date are of secondary importance to date flavor (Table 6).

Desert Date

Desert date pulp extract is comprised of diverse flavor volatile compounds predominant with hexanoic acid and ethyl ester (Table 6). The overall amount of esters in wild desert date fruit pulp extract is the compounds that mainly responsible for fruity aroma (El Arem et al., 2011; Paravisini et al., 2014). On the other hand, a low aldehyde content was observed (Table 6) in desert dates. This shows that desert dates have been used and accepted in the mixture of folk medicines (Kamel, 1998; Kamel and Koskinen, 1995; Koko et al., 2005). Ideally aldehydes are compounds responsible for the odor quality of the fruit, and their concentrations vary with the nature of the fruit. The probable flavor volatile compounds common in desert date and date palm fruits are hexanal, nonanal, ethyl acetate, 1-pentanol, and 1-hexanol. In addition, compounds such as cyclotetrasiloxane, octamethyl-, and 2,3-pentanedione are also

Table 6 Flavor components^a of date fruits varieties

Constituents	Desert date ^b	'Allig' ^c	'Degla' ^c	'Deglet Noor' ^c	'Gosbi' ^c	'Horra' ^c	'Zahdi' ^d
Alcohols							
2-propanol	—	2.7	18.3	10.7	34.0	11.7	—
Isoamyl alcohol	—	2.9	4.9	4.6	14.1	3.1	—
1-Pentanol	0.73	—	—	—	—	—	10.10
2,3-Butandiol	—	3.2	2	1.9	0.3	—	—
3-Pentanol	—	—	—	—	—	—	5.70
4-Methyl-2-Hexanol	0.60	—	—	—	—	—	—
1-Hexanol	4.57	—	—	—	—	0.3	—
3-Hexen-1-ol, (E)-	2.06	—	—	—	—	—	—
1-Octanol	—	—	—	—	—	—	19.40
1-Nonen-3-Ol	—	1.5	1.2	1.8	0.2	1.9	—
3-Octanol	0.75	—	—	—	—	—	—
3,5-Octadien-2-ol	0.45	—	—	—	—	—	—
1-Octen-3-Ol	2.28	—	—	—	—	—	—
2-Octen-1-Ol, (Z)-	1.12	—	—	—	—	—	—
(E)-2-Caren-4-ol	0.47	—	—	—	—	—	—
Cyclohexanol, 1-methyl-4-(1-methylethyl)-	2.00	—	—	—	—	—	—
1-Nonanol	1.21	—	—	—	—	—	—
2-Nonanol	—	1.8	1.2	2.4	—	2.5	—
1-Undecanol	0.88	—	—	—	—	—	26.20
1-Dodecanol	—	—	—	—	—	0.8	28.20
Phenylethyl alcohol	—	3.8	—	0.7	2.5	—	—
Dihydrocarveol	—	1.1	2.3	1.9	—	1.7	—
Esters							
Acetic acid ethenyl ester	1.05	—	—	—	—	—	—
Benzoic acid, 2-[(trimethylsilyl)oxy]-, trimethylsilyl ester	0.37	—	—	—	—	—	—
Ethyl acetate	0.78	17.8	15.0	7.5	24.1	15.5	—
Ethyl hexanoate	—	—	0.4	—	0.7	0.6	—
Ethyl octanoate	—	2.6	4.7	3.7	5.4	2.0	—

Continued

Table 6 Flavor components^a of date fruits varieties—cont'd

Constituents	Desert date ^b	'Allig' ^c	'Degla' ^c	'Deglet Noor' ^c	'Gosbi' ^c	'Horra' ^c	'Zahdi' ^d
Ethyl nonanoate	—	—	0.4	0.5	0.6	—	—
Ethyl decanoate	—	—	2.1	1.0	5.7	0.6	—
Ethyl dodecanoate	—	6.7	1.1	—	2.0	—	—
Ethyl tetradecanoate	—	3.9	0.7	0.6	0.9	—	—
Ethyl pentadecanoate	—	3.4	—	0.3	0.4	—	—
Hexanoic acid, ethyl ester	40.87	—	—	—	—	—	—
3-Hexenoic acid, methyl ester	0.85	—	—	—	—	—	—
3-Hexenoic acid, ethyl ester	0.47	—	—	—	—	—	—
Heptanoic acid, ethyl ester	2.03	—	—	—	—	—	—
Hexanoic acid, butyl ester	0.91	—	—	—	—	—	—
Octanoic acid, ethyl ester	1.39	—	—	—	—	—	—
Formic acid, heptyl ester	1.97	—	—	—	—	—	—
4-Hydroxymandelic acid, ethyl ester, Di-tms CID622432	0.49	—	—	—	—	—	—
Formic acid, octyl ester	7.93	—	—	—	—	—	—
Hexanoic acid, hexyl ester	0.50	—	—	—	—	—	—
Diethyl phthalate	0.52	—	—	—	—	—	—
Aldehydes							
Butanal, 3-methyl-	0.46	—	—	—	—	—	—
Hexanal	3.47	—	—	0.2	—	—	4.30
2-Hexenal	0.85	—	—	—	—	—	—
Heptanal	—	—	—	—	—	—	7.40
Octanal	1.10	—	—	—	—	—	11.00
Nonanal	0.95	4.6	5.3	7.2	—	—	14.10
Decanal	—	2.3	2.9	3.8	—	1.6	—
Tridecanal	—	—	—	1.1	—	0.8	—
3-Furaldehyde	0.45	—	—	—	—	—	—
2-Furancarboxaldehyde, 5-methyl-	0.43	—	—	—	—	—	—
Ketones							
3-Penten-2-one	0.68	—	—	—	—	—	—
2-Heptanone	0.93	—	—	—	—	—	—
2-Octanone	1.45	—	—	—	—	—	—

5-Hepten-2-one, 6-methyl-	0.38	—	—	—	—	—	—
2-Nonanone	0.90	—	—	—	—	—	—
2-Methyl-2-nonen-4-one	—	—	1.6	2.5	—	2.7	—
Ethanone, 1-(2-furanyl)-	0.61	—	—	—	—	—	—
3,5-Heptadien-2-one, 6-methyl-, (E)-	0.34	—	—	—	—	—	—
(E)- β -Ionone	—	0.9	1.2	0.9	—	1.2	—
Bicyclo[2.2.1]heptan-2-one, 1,7,7-trimethyl-, (1R)-	0.63	—	—	—	—	—	—

Saturated hydrocarbons

Cyclotrisiloxane, hexamethyl-	0.70	—	—	—	—	—	—
Cyclotetrasiloxane, octamethyl-	0.49	—	—	—	—	—	—
7-Methoxy-2,2,4, 8-tetramethyltricyclo [5.3.1.0(4,11)]undecane	0.40	—	—	—	—	—	—
n-Undecane	—	1.2	0.8	1.1	0.2	—	—
Oxime-, methoxy-phenyl- n-Hexane	0.84	—	—	—	—	—	0.50
n-Heptane	—	—	—	—	—	—	0.75
n-Decane	—	—	—	—	—	—	—
n-Tridecane	—	0.6	0.4	0.7	—	—	12.10
n-Pentadecane	—	1.5	0.4	—	0.1	1.1	—
n-Hexadecane	—	—	—	—	—	—	22.30
n-Heptadecane	—	—	—	—	—	—	27.50

Unsaturated hydrocarbons

Dodecene-1	—	—	—	—	—	—	10.30
Tridecene-1	—	—	—	—	—	—	13.10
(Z)-2-Tridecene	—	—	6.7	8.3	0.6	8.6	—
(E)-2-Tridecene	—	8.1	7.8	10.2	0.7	9.8	—
1-Pentadecene	—	0.8	0.7	1.6	—	0.6	—

^aPercentages obtained by FID peak area normalization.

^bAdapted from unpublished results: Amadou I. State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, China.

^cAt *tamr* stage El Arem et al. (2011).

^dJaddou et al. (1984).

among the most predominant found in the desert date. Alcohols are known to influence in the juice flavor; over 10 alcoholic compounds have been identified in the desert date, although fewer are present in date palm fruit (Table 6). Alcohol was identified in previous studies as an active aroma compound in unpasteurized fruit juice and heated juice by headspace–solid phase microextraction–Osme (El Arem et al., 2011; Sagna et al., 2014; Sarker et al., 2000; Wen et al., 2014). 1-Octen-3-ol was the most abundant alcohol found in the desert date (Table 6).

SUMMARY POINTS

- Literature shows that date fruits have a long history of traditional uses as food or medicine for treatment of a wide range of diseases. However, dates as wild or new cultivar provide nutritious compounds rich in vitamins, phenolic compounds, and flavor elements.
- Date palm fruit is a traditional good food for boosting energy quickly, it is an energy-dense food packed with sugar content up to 80%; and low concentrations of protein and lipids. The predominant mineral is potassium and the predominant sugars are glucose and fructose.
- Chemical composition studies of the desert date revealed several classes of secondary metabolites, such as cumarins, flavonoids, and steroidal saponins, some of which have demonstrated biological activity; however, two furostanol glycosides and 6-methyldiosgenin have also been identified in the desert date.
- The date palm fruit's protein content is 1–3%, with 23 different favorable amino acid patterns, in contrast to the many amino acids present in popular fruits, such as bananas, apples, and oranges. Proline content is the most prevalent amino acid found in desert date pulp, making up more than 50% of the total amino acids.
- The fatty acid content of the desert date is about 46% oil, such as palmitic, stearic, oleic, and linoleic acids, whereas date palm mean oil content account is about 6.7%, with the highest percentages of unsaturated and saturated fatty acids among the cultivars that were related to the oleic and lauric acids.
- The flavor volatile compounds are dominated by hexanoic acid and ethyl ester in desert date pulp, whereas in date palm pulp alcohols, aldehydes, and ketones are responsible for the date palm fruit's characteristic citrus, floral, and fruity aroma.
- There are several differentiating characteristics of date fruit varieties; for example, 'Medjool' dates have an exceptionally large size with a large amount of "fruit meat" and are extremely sweet. On the other hand, 'Deglet Noor' dates are smaller in size, translucent blond in color, and have a soft caramel-like taste. The desert date is irregular in size, has a pungent bitter taste, and is yellowish in color.

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CHAPTER 11

Phytochemical Composition of Common Fig (*Ficus carica* L.) Cultivars

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INTRODUCTION

Common figs, or simply, figs (*Ficus carica* L.), are believed to be one of the oldest cultivated plants. For centuries, their fruits have been used fresh or dried as food for humans and their animals. Figs have been popular not only because of their pleasant taste but possibly also because of their medicinal properties (Ercisli et al., 2012).

The East Mediterranean region is considered to be the area of the common fig domestication (Ercisli et al., 2012), and from there the cultivation spread to the West Mediterranean area, where fig populations were already present in natural habitats before domestication. The process of domestication resulted in sweeter and bigger fruits (Falistocco, 2009).

Fig trees are commonly cultivated in warm and dry climates. The ideal conditions for intensive fig cultivation are a semiarid climate and orchards equipped with an irrigation system (Veberic et al., 2008a). According to the Food and Agriculture Organization of the United Nations the world production of fig fruit is stable, with a decade average of approximately 1.1 million tons per year. Turkey is the biggest world producer with 298,914 tons in 2013 accounting for 26.8% of total world production. The top five

producers (in addition to Turkey) include Egypt, Algeria, Morocco, and Iran combined, supplying almost 70% of the world's fig market in 2013. This underlines that the majority of fig production is still centered in the Mediterranean basin and the Near East. However, other countries such as the United States, Brazil, India, Japan, and China are important players in the market with a stable or increasing fig production since 2000 (<http://faostat3.fao.org>).

Figs constitute an important part of the Mediterranean diet, either fresh or dried; figs are especially rich in fiber, trace minerals, polyphenols, proteins, and sugars. The levels of these compounds are strongly dependent on the fig cultivars and genotypes (Ercisli et al., 2012). Peeled or unpeeled, the fruits may be prepared in several ways, such as fig pies, puddings, cakes, or other bakery products. Figs can also be added to ice cream mixtures. Home growers preserve whole fruits in sugar syrup or prepare them as jam, marmalade, or paste. Fig paste (with added wheat and corn flour, whey, syrup, oils, and other ingredients) is used as a delicious filling in various bakery products (Chawla et al., 2012).

Aroma is a significant constituent of fruit quality. The aroma profile of fig fruit is a mix of different volatiles that enrich to a pleasant note and taste of the mature fruit. According to Trad et al. (2012), different esters, ketones, and alcohols participate in fig fruit aroma. Among esters, especially butyl acetate and isoamyl acetate, and among ketones, particularly 3-hydroxy-2-butanone could be regarded as the volatile fingerprint of ripe figs. When comparing pollinated and nonpollinated fruits, no significant differences could be detected in the aroma profile. Nevertheless, some compounds important for the pleasant aroma and flavor degrade when nonpollinated figs reach maturity (Trad et al., 2012).

Plant parts and extracts of the fig tree have traditionally been used for internal, as well as external, application. For example, poultices from fresh or dried figs, fig leaves, or fig wines; lye from fig tree bark; or latex from stems and leaves have been used to aid in many conditions. Latex has been used as expectorant, diuretic, and anthelmintic, or to ameliorate anemia. Leaves are known for their antidiabetic and vermifugal effect. However, they also cause contact dermatitis in humans and phototoxicity in animals. Seeds are processed to edible oil or lubricants (Chawla et al., 2012). Sporadic cases of fig allergy after ingestion of fig fruit have been reported, especially in patients who are allergic to *Ficus benjamina* (Hemmer et al., 2010). Also, phytophotodermatitis caused by contact with different parts of *F. carica* has been reported and linked to furanocoumarins in latex (Polat et al., 2008).

BOTANICAL ASPECTS

The genus *Ficus* includes more than 800 species belonging to the mulberry family Moraceae (Chawla et al., 2012), mostly found in tropical and subtropical regions. Apart from *F. carica* (fig, or common fig), *Ficus sycomorus* L. (sycamore, or sycamore fig) is cultivated

in the Near East, although on a much smaller scale (Galil, 1968). Hybrids with some other *Ficus* species are also edible but not cultivated. Several *Ficus* species are important in horticulture as ornamental landscape or potted plants. Fig cultivars are mostly diploid ($2n=26$), although triploids ($2n=39$) of cultivated and wild types exist (Falistocco, 2009).

Ficus carica is a deciduous shrub or small tree with several spreading branches from a short, grayish, slightly roughened trunk. The latex of the plant is milky white and contains ficin, a protein-digesting enzyme. Figs exhibit highly pronounced heterophily of the leaf lamina that differs in size and shape. Leaves are alternate and borne on long petioles. The lamina is obovate to nearly orbicular, either undivided or with very marked lobation. Commonly up to seven lobes are formed, and the leaves have a villous surface (Chawla et al., 2012; Mawa et al., 2013).

Edible figs are multiple or compound fruits that do not differ in appearance from the flowers, a specially adapted type of inflorescence called a *syconium*. The syconium is an enlarged, fleshy, involuted, hollow, and almost closed receptacle with multiple ovaries on the inner surface (Figure 1). The syconium commonly has a bulbous shape with a small opening, called the *ostiole*, at the distal end that allows access to pollinators. The flowers are pollinated by a mutualistic wasp *Blastophaga psenes* L. in the search of an appropriate place to lay eggs. Without this pollinator, figs are unable to reproduce by seed. In turn, the syconium provides a safe and nutritious environment for the wasp offspring. Not all figs need to be pollinated to produce edible fruit. Nonpollinated fruit are parthenocarpic and do not contain viable seeds (Chawla et al., 2012; Gaaliche et al., 2011).

The cultivated fig is gynodioecious, but is functionally dioecious. The pollination is performed by the mutualistic wasps between two different fig types, namely the caprifig and edible fig. The male fig (caprifig) bears spongy, nonpalatable syconia containing both male flowers and short-styled female flowers, whereas the syconium of the female fig contains only long-styled pistillate flowers (Aradhya et al., 2010). The syconia of caprifig with



Figure 1 Cross section of fig syconium with multiple ovaries on the inside surface.

their short-styled female flowers serve primarily as the oviposition place for the pollinating wasp, whereas the long-styled flowers produce seeds and edible syconia (Falistocco, 2009).

There are three different types of cropping figs: (1) *common type* cultivars that bear parthenocarpic fruit and do not require pollination; (2) *Smyrna* figs that require pollination by the fig wasp; and (3) *San Pedro* figs that set fruit by either mechanism. A fourth type includes wild fig forms, called *caprifigs*, or *goat figs*, and provides a source of pollen for the cultivated forms that need caprification (pollination by the symbiotic wasp) (Aradhya et al., 2010; Stover et al., 2007).

Figs can have two crops per year, depending on the cultivar and growing conditions. The first crop is called the *breba crop* and is produced from flower buds on the previous year's wood, which was initiated in the previous summer. In colder climates the breba crop may be destroyed by spring frosts. The second or main crop is produced from syconia initiated in the axils of the current season's shoot growth. The crop ripens in late summer and normally produces fruit of better quality than the fruit from the breba crop (Stover et al., 2007).

Cultivars of the *Smyrna type* do not usually produce a breba crop. Syconia of the main (second) crop develop and ripen only if pollinated. *Common type* fig trees may or may not have a breba crop, but if they do, it develops to maturity without pollination. Most common fig cultivars produce a considerable main (second) crop that develops and matures without pollination. Fig trees of the *San Pedro type* also have moderate to large breba crops. These develop to maturity without pollination and ripen into edible fruits. A satisfactory second crop of syconia is initiated, but generally only pollinated flowers develop to maturity (Gaaliche et al., 2011; Trad et al., 2012).

Fig shape is usually pyriform-obovoid to globose, and the fruit develops green-yellow to red-violet hues when fully ripe (Figure 2). Fruit flesh is whitish, yellow, amber, pink,



Figure 2 Mature fruit of breba crop.

or red to purple; it is juicy and sweet when ripe and gummy with latex when unripe. Caprifiged figs are usually larger and greener than uncaperfiged figs, more susceptible to splitting, and have a darker pulp color (Gaaliche et al., 2011).

The main cultivars grown in Turkey are ‘Sarilop’ for drying and ‘Bursa Siyahi’ for fresh consumption. ‘Bursa Siyahi’ is found especially in European markets; meanwhile, ‘Sarilop’ as dry figs is found also in other world markets. Other important cultivars in Turkey are ‘Goklop’, ‘Yediveren’, ‘Yesilguz’, ‘Morguz’, ‘Sari Zeybek’, and ‘Ufak Yesil’ (Caliskan and Polat, 2008). For figs, it is common that cultivars with diverse geographic origin exhibit high genetic similarity. Papadopoulou et al. (2002) report in their study that analyzed fig cultivars of a worldwide origin have a rather narrow genetic base. This is probably a result of commonly used vegetative propagation practices of cultivars with excellent pomological characteristics; this procedure has contributed to synonymy and homonymy (Ciarmiello et al., 2015). Techniques with different molecular markers for studying plant genetic diversity revealed considerable differentiation among fig cultivars within different countries, which will help in conservation of fig genetic resources and aid different breeding programs in developing new cultivars with desired agronomic traits (Chatti et al., 2010; Ciarmiello et al., 2015).

COMPOSITION OF FIG CULTIVARS

Sugars

Glucose and fructose are the main sugars in fig fruits (Aljane et al., 2007; Caliskan and Polat, 2011; Melgarejo et al., 2003; Slatnar et al., 2011; Veberic et al., 2008b; Vemmos et al., 2013). The content of glucose is reported to range from 2503 mg/100 g in cultivar ‘Bela Petrovka’ (Slatnar et al., 2011) to 15,890 mg/100 g fresh fruit in ‘Tio Antonio’ (Melgarejo et al., 2003), and fructose from 1916 mg/100 g in cultivar ‘Tayouri Ahmar’ (Aljane et al., 2007) to 11,900 mg/100 g fresh fruit in ‘Kirmizi 2’ (Caliskan and Polat, 2011) (Table 1). Only traces of sucrose have been measured in analyzed fig fruit (Veberic et al., 2008b; Vemmos et al., 2013), and juice extracted from figs (Melgarejo et al., 2003). Caliskan and Polat (2011) showed sucrose content in 76 local Mediterranean fig accessions. In some accessions, sucrose was not determined; the highest value was measured in ‘Mor 3’ (320 mg/kg). Other authors also report that this sugar is not present in fig juice (Sugiyama et al., 1991) or not clearly distinguishable from other sugars. In contrast, sucrose is the prevalent sugar in fig leaves (Vemmos et al., 2013). Sucrose is the main translocation carbohydrate from leaves to other plant parts, including fruit. The low sucrose concentration in fig fruit could be the result of anabolic processes and respiration during fruit development. The low content of sucrose might also be caused by high invertase activity during fruit ripening. In contrast, several fruit species are characterized by the accumulation of both sucrose and fructose in ripe fruit. The latter is formed from sorbitol, which is translocated from leaves to fruit as sucrose (Vemmos et al., 2013).

The sugar composition can influence fruit sweetness. For example, fructose has a higher relative sweetness than glucose. Therefore the perception of sweetness of different fig accessions can be linked to their fructose content (Caliskan and Polat, 2011). The values in fig are comparable to those reported in some other fruits, such as apples and strawberries (Mikulic-Petkovsek et al., 2013a; Veberic et al., 2010). Total sugar content also varies among different fig cultivars (Veberic et al., 2008b). Total sugars ranged from 140.5 g/kg (‘Črna Petrovka’) to 209.4 g/kg (‘Miljska Figa’) (Veberic et al., 2008b).

Organic Acid

Organic acid content is important for fruit development. Characteristic of the Moraceae family, high malic and citric acid content can be detected in fig fruit. Different studies report (Table 1) malic acid from 66 mg/100 g in cultivar ‘Bela Petrovka’ (Slatnar et al., 2011) to 431 mg/100 g fresh fruit in cultivar ‘Brown Turkey’ (Pande and Akoh, 2010), and citric acid from 20.2 mg/100 g fresh fruit in ‘Brown Turkey’ (Pande and Akoh, 2010) to 461 mg/100 g in ‘Miljska Figa’ (Veberic et al., 2008b). It has been demonstrated in peaches that citric acid content, even in small amounts, adds more to the sourness of fruit than malic acid (Colaric et al., 2005). Fruit sweetness is correlated not only with the levels of different sugars but particularly with certain acids, such as citric and shikimic acids. The presence of specific organic acids, even in small amounts, can influence the taste of fruit and make it less sweet, despite high sugar levels (Colaric et al., 2005). Similar to fruit organic acid composition, Sugiyama et al. (1991) reported higher citric acid

Table 1 Content levels of individual sugars and organic acids in different parts of figs

	Whole fruit (mg/100 g FW)	Pulp + seed (mg/100 g FW)	Peel (mg/100 g FW)	Leaf (mg/100 g FW)	References
Sucrose	98–320				Veberic et al. (2008b), Slatnar et al. (2011), Caliskan and Polat (2011), and Aljane et al. (2007)
Glucose	1216–11,050				
Fructose	1916–11,900				
Malic acid	66–431	405	450	178	Pande and Akoh
Citric acid	20.2–461	24.7	18.8	9.7	Veberic et al. (2008b), and Slatnar et al. (2011)
Ascorbic acid	14.2	11.7	10.6	8.8	
Succinic acid	10.2	8.7	6.4	6.1	
Oxalic acid	17.5	17.2	15.4	13.4	
Fumaric acid	1.75–10.67				
Shikimic acid	4.04–5.47				

FW, fresh weight.

content compared with malic acid of juice prepared from fig fruits. Malic and citric acid have been identified as the major organic acids in figs, whereas succinic, fumaric, shikimic, and oxalic acids have been detected in amounts (Pande and Akoh, 2010; Veberic et al., 2008b) not exceeding 20 mg/100 g fresh weight (FW) in different plant parts. Therefore these organic acids do not have a significant influence on fig fruit taste characteristics (Veberic et al., 2008b). A comparison of malic and citric acid content of figs with that of other fruits shows that the levels are much lower than those of most temperate zone fruit species. However, the content is comparable to some soft fruits, such as strawberries (Mikulic-Petkovsek et al., 2013a). On the other hand, citric acid content is quite high when compared with other fruits.

Carotenoids

The natural yellow, orange-red colors of many fruits result from the carotenoids, a group of fat soluble pigments (Yemis et al., 2012). Su et al. (2002) identified and quantified major carotenoids in foods commonly consumed in the Mediterranean diet. The carotenoids in figs (Table 2) have been positively identified as lutein, cryptoxanthin, lycopene, β -carotene, zeaxanthin, and α -carotene (Su et al., 2002; Yemis et al., 2012). Lycopene was the most abundant carotenoid (0.32 mg/100 g FW), followed by lutein (0.08 mg/100 g FW), β -carotene (0.04 mg/100 g FW), α -carotene (0.02 mg/100 g FW), and cryptoxanthin (0.01 mg/100 g FW) (Su et al., 2002). The research of Yemis et al. (2012) concerning two cultivars, ‘Sarizeybek’ and ‘Sarilop’, confirmed lutein as the main carotenoid identified in fresh figs (6.14–7.15 μ g/g dry weight (DW)), followed by zeaxanthin (2.20–3.32 μ g/g DW), β -cryptoxanthin (1.85–2.04 μ g/g DW), and β -carotene (1.40–1.48 μ g/g DW). In comparison with other fruit species the levels of total carotenoids in fig is low; figs only contain 23.7–110 μ g/g DW total carotenoids (Ouchemoukh et al., 2012; Yemis et al., 2012). However, in dry figs, total carotenoid levels are much higher compared with dried prunes, apricots, and raisins (Ouchemoukh et al., 2012). The main source of carotenoids is the fruit peel (1.9 mg/100 g FW), whereas pulp contains only a small amount of carotenoids (1.1 mg/100 g FW). Carotenoids in foods can differ in composition and

Table 2 Content levels of individual carotenoids in fig fruits

	mg/kg FW	mg/kg DW	References
Total carotenoids		23.71–110.0	Su et al. (2002), Ouchemoukh et al. (2012), and Yemis et al. (2012)
Lutein	0.8	6.14–7.15	
β -Carotene	0.4		
α -Carotene	0.2	1.4–1.48	
Cryptoxanthin	0.1	1.85–2.04	
Lycopene	3.2		
Zeaxanthin		2.2–3.32	

DW, dry weight; FW, fresh weight.

quantity for many reasons, including differing cultivars; processing, storage, and climate conditions; ripening stage; and production location (Yemis et al., 2012).

Phenolic Compounds

Phenolic compounds (phenolics) are a group of secondary metabolites commonly synthesized in fruits. Two of the most important groups of phenolics are flavonoids and phenolic acids. In addition to sugars and organic acids, phenolics also contribute to sweet, bitter, or astringent flavors of fruit. However, they mostly contribute to fruit aroma (Tomas-Barberan and Espin, 2001).

Among common fruits and vegetables, fig fruits are rich in anthocyanins, flavonol glycosides, and other polyphenolics that could contribute to the high antioxidant capacity of its fruits. Fig fruits have a high commercial value not only because their excellent taste and nutritional value but also for their known health-supporting compounds.

Polyphenolic content is usually higher in the peel compared with fruit flesh or pulp. The accumulation of phenolic metabolites in plants is greatly influenced by environmental conditions, and is also genetically controlled (Mikulic-Petkovsek et al., 2013b). Most metabolites with antioxidant capacity, for example, polyphenols, are located in the fig skin (Piga et al., 2008). Thus fig cultivars with dark-colored skin ('Mission', 'Chechik', 'Brown Turkey', 'Bussa') contain higher levels of antioxidants compared to fig cultivars with light-colored skin ('Brunswick', 'Kadota') (Solomon et al., 2006).

Different groups of phenolic compounds have been detected in fig fruit: hydroxycinnamic acids, hydroxybenzoic acids, ellagic acid, flavan-3-ols, anthocyanins, and different flavonol glycosides. Flavonoids and phenolic acids constitute between 30% and 60% of total polyphenols. Fig leaves contain high levels of ellagic acid (33.8 mg/100 g FW) (Pande and Akoh, 2010). From the group of phenolic acids, chlorogenic acid (5-caffeoylquinic acid) is the prevailing form in fig fruits (Veberic et al., 2008a). In comparison with apples, apple peel and pulp, figs contain lower levels of chlorogenic acid. However, the content of phenolic acids is higher in the leaves, in which the following phenolic acids have been analyzed: *p*-coumaric acid, ferulic, and 3-caffeoylquinic acid (Oliveira et al., 2012; Pande and Akoh, 2010). High content levels of quercetin-3-rutinoside (1071 mg/kg FW) and cyanidin-3-rutinoside (901 mg/kg FW) have been measured in peel of black fig cultivar 'Mattalona' (Del Caro and Piga, 2008). Dark-skin cultivars generally contain higher levels of polyphenols, anthocyanins, and flavonoids compared with fig varieties with lighter skin (Del Caro and Piga, 2008; Solomon et al., 2006). Fig fruits are often consumed without the skin; however, fig fruit skins contain healthy nutrients that should not be discarded (Caliskan and Polat, 2011).

From the group of flavanols, catechin and epicatechin have been quantified in fig fruit. According to data in Table 3, figs do not contain ample quantities of these two compounds in comparison with various kinds of berries, apples, or plums. Fig fruits only contain 5.8 mg/kg ('Črna Petrovka') to 321 mg/kg FW of epicatechin ('Brown Turkey'), and 12.7 mg/kg ('Škofjotka') to 167 mg/kg FW of catechin ('Brown Turkey') (Pande

Table 3 Content levels of individual phenolic compounds in different parts of figs

	Whole fruit (mg/kg FW)	Peel (mg/kg FW)	Pulp + seed (mg/kg FW)	Leaf (mg/ kg FW)	References
Gallic acid	3–28	28	26	38	Pande and Akoh (2010), Veberic et al. (2008a), Oliveira et al. (2012), Slatnar et al. (2011), Del Caro and Piga (2008), and Vallejo et al. (2012)
Ellagic acid	2	4	5	338	
Caffeic acid				78	
<i>p</i> -Coumaric acid				59	
Ferulic acid				14.9–206	
Chlorogenic acid	10.5–15.7	39.63–69.33	1–13	6.3–28.9	
Syringic acid	0.33–0.79				
3- <i>O</i> -Caf- feoylquinic acid				1–16.0	
Catechin	12.7–167	171	212	208	
Epicatechin	5.8–321	318	286	178	
Psoralen				586–4616	
Bergapten				272–3633	
Kaempferol- 3-glucoside	1.3				
Quercetin				84	
Rutin	8.9–287	29–1071.41	5–18	9.7–687.3	
Kaempferol- 3-rutinoside		2–7			
Quercetin- 3-acetylgluco- side		17			
Quercetin- 3-glucoside	4.1–1402	2–32			
Luteolin- 6C-hexoside- 8C-pentoside		1–19			
Apigenin-rutin- oside		8–25			
Luteolin- 8C-glucoside					

FW, fresh weight.

and Akoh, 2010; Veberic et al., 2008a). Vallejo et al. (2012) reported that fig fruits also contain procyanidins.

Many flavonol glycosides have been identified in different parts of the fig plant. In fig fruits, kaempferol-3-glucoside, quercetin-3-glucoside, and rutin have been confirmed. The latter is present in highest levels, and its content is especially high in fruit peel. It contents range from 29 mg/kg in cultivar ‘Tio Antonio’ (Vallejo et al., 2012) to 1071 mg/kg of fruit peel in cultivar ‘Mattalona’ (Del Caro and Piga, 2008). The skin also accumulates kaempferol-3-rutinoside (the highest content is in cultivar ‘Tiberio’; 7 mg/kg),

quercetin acetylglucoside (the highest value is in cultivar ‘Nazaret’; 17 mg/kg), and quercetin-3-glucoside (‘Cuello Dama’ has the highest content; 32 mg/kg) (Vallejo et al., 2012). The level of rutin in fig fruits is comparable or even exceeds the amount measured in peel of some temperate fruit species, such as apples. Fig leaves similarly contain very high levels of rutin. Its contents range from 9.7 mg/kg in ‘Pingo de Mel’ leaves to 687 mg/kg in ‘Preta Tradicional’ leaves (Oliveira et al., 2012).

Several coumarins have been determined in figs: angelicin, marmesin, psoralen, umbelliferone, and bergapten (Innocenti et al., 1982). Two photoactive furanocoumarins (psoralen and bergapten) have additionally been detected in the leaves (Teixeira et al., 2006). Metanolic extract of fig leaves contains high amounts of psoralen and bergapten, which correspond to approximately 40.3–64.0% and 29.6–44.3% of total phenolic compounds analyzed, respectively (Oliveira et al., 2012). Significantly higher levels of psoralen have been measured in fig pulp compared with its peel. Especially psoralen has been associated with ultraviolet radiation in the treatment of skin conditions, such as skin depigmentation (psoriasis and vitiligo), mycosis fungoides, polymorphous dermatitis, and eczema (Diawara and Kulkosky, 2003).

Anthocyanins are only accumulated in fig cultivars with violet-, blue-, or pink-colored skin or pulp, and are more abundant in the peel (Table 4). The main anthocyanins responsible for the pigmentation in figs are cyanidin 3-rutinoside, cyanidin 3-glucoside,

Table 4 Content levels of individual anthocyanins in different parts of figs

	Whole fruit (mg/kg FW)	Peel (mg/kg FW)	Pulp + seed (mg/kg FW)	References
Cyanidin-3-rutinoside dimer	6.2	0.44–0.93	0.08	Duenas et al. (2008), Vallejo et al. (2012), Del Caro and Piga (2008), and Slatnar et al. (2011)
Cyanidin-3,5-diglucoside		1.99–3.80	0.09–0.57	
Cyanidin-3-malonylglucosyl- 5-glucoside		0.53–1.39	0.02–0.09	
Cyanidin-3-glucoside		1.51–28.24	0.19–95.0	
Cyanidin-3-rutinoside		15.42–901.03	1.04–17.6	
Pelargonidin-3-glucoside		0.29–0.68	0.09	
Pelargonidin-3-rutinoside		0.47–3.52	0.02–0.08	
Peonidin-3-rutinoside			0.02–0.06	
Cyanidin-3-malonylglucoside		0.67–3.51	0.02–0.09	
(Epi)catechin-4,8-cyanidin- 3-glucoside		0.48	0.03–0.13	
(Epi)catechin-4,8-cyanidin- 3-rutinoside		0.59–1.23	0.02–0.59	
(Epi)catechin-4,8-pelargoni- din-3-rutinoside		0.24	Tr	
Carboxypyranocyanidin- 3-rutinoside		1.26	0.04–0.94	

FW, fresh weight; Tr, traces.

cyanidin 3,5-diglucoside, and pelargonidin 3-rutinoside (Del Caro and Piga, 2008; Duenas et al., 2008; Solomon et al., 2006; Vallejo et al., 2012; Yemis et al., 2012). In several fig cultivars, cyanidin-3-rutinoside has been reported as the most abundant anthocyanin, ranging between 21.2 mg/100 g DW (cultivar 'Morgüz') and 91.2 mg/100 g DW (cultivar 'Bursa Siyahi') (Yemis et al., 2012). Duenas et al. (2008) reported that cyanidin 3-rutinoside accounts for 48% in 'Colar' fruit skin to 81% in 'Bursa Siyahi' skin, and 68% in 'Cuello de Dama' pulp to 79% in 'Bursa Siyahi' pulp, followed by cyanidin 3-glucoside (5% in 'Colar' skin to 18% in 'Granilla' skin, and 10% in 'Bursa Siyahi' pulp to 15% in 'Colar' pulp). However, cyanidin 3,5-diglucoside and pelargonidin 3-rutinoside are more abundant (11–12%) in the skin of the 'Colar' cultivar. In other cultivars ('Granilla', 'Cuello de Dama', and 'Bursa Siyahi'), pelargonidin derivatives represent only between 0.8% and 2.2% of the total anthocyanins analyzed. Peonidin-3-rutinoside has also been confirmed in pulp extracts of all studied cultivars ('Granilla', 'Cuello de Dama', 'Colar', and 'Bursa Siyahi'). Interestingly, this anthocyanin has not been detected in the skin (Duenas et al., 2008). Anthocyanin profile of the whole fruit (pulp and peel) of the 'Mission' cultivar consists of 75% cyanidin 3-rutinoside, 11% cyanidin 3,5-diglucoside, 11% cyanidin 3-glucoside, and 3% pelargonidin 3-rutinoside (Puech et al., 1975). It seems that cyanidin derivatives are the prevailing form of anthocyanins in both fig skin and pulp, accounting for 85–99% total analyzed anthocyanins. Typically, rutinose is bound to the aglycone, but glucose has also been confirmed. Malonyl derivatives have been detected, and usually these compounds are more abundant in skin (1.2–6.5%) than in pulp (1.0–2.6%). They are particularly abundant in the skin of the 'Granilla' variety (Duenas et al., 2008). No acylated anthocyanins have been detected in fig varieties 'Bursa Siyahi', 'Morgüz', 'Yesilgüz', 'Sarilop', and Sarizeybek' varieties (Yemis et al., 2012). The content of anthocyanins in the skin ranges from 7 µg/g in cultivar 'Brunswick' (Solomon et al., 2006) to 97 µg/gFW in 'Bursa Siyahi' (Duenas et al., 2008), and from 1.0 µg/g ('Brown Turkey', 'Chechick', 'Bursa') (Solomon et al., 2006) to 14 µg/g in the pulp of 'Colar' variety (Duenas et al., 2008).

Total Phenolic Content

Total phenolics (TP) is in a good correlation with total analyzed phenolics, and thus higher contents of individual phenolics result in a higher TP in fruits. Ercisli et al. (2012) stated that TP in 24 fig genotypes and cultivars is between 240 (genotype 'C12') and 2370 mg/kg (genotype 'C13') (Table 5). Vallejo et al. (2012) reported TP ranging from 191 ('Nazarret') to 1402 mg/kg ('VB1'), and Slatnar et al. (2011) measured TP in cultivar 'Bela Petrovka' at 74.9 mg/kg fresh fruits. The average TP value of varieties 'Mission' and 'Calimyrna' was 4860 mg/kg (Vinson et al., 2005). Higher TP has been measured in black, dark purple, and purple skin-colored genotypes rather than yellowish green, light green, and light purple skin-colored genotypes (Ercisli et al., 2012; Solomon et al., 2006; Veberic et al., 2008b). Piga et al. (2008) indicated that phenolics accumulate exclusively in the peel of fig

Table 5 Total phenolic content and antioxidant capacity in different parts of figs, values expressed in fresh weight

	Whole fruit	Peel	Pulp + seed	Leaf	References
Total phenolic content (mg GAE/kg)	74.9–4860	71–2119	5–610	454–8214	Veberic et al. (2008b), Slatnar et al. (2011), Vallejo et al. (2012), Oliveira et al. (2012), Vinson et al. (2005), Ercisli et al. (2012), Pande and Akoh (2010), and Caliskan and Polat (2011)
Antioxidant capacity					
FRAP ($\mu\text{M/g}$)	1.0–6.2 4.6–18.7	1.3–7.7	1.8–3.5	2.2–11.6	Ercisli et al. (2012) Pande and Akoh (2010)
TEAC ($\mu\text{M/g}$)	0.4–3.14 36–623 mM/kg	0.5–3.8	0.8	1.3–3.2	Ercisli et al. (2012) Pande and Akoh (2010)
AEAC	29.3–140 mg/kg	nd	nd	nd	Veberic et al. (2008b) and Slatnar et al. (2011)

AEAC, ascorbic acid equivalent antioxidant capacity; FRAP, ferric reducing ability of plasma; FW, fresh weight; GAE, gallic acid equivalents; TEAC, trolox equivalent antioxidant capacity.

fruits, with black cultivars having the highest contents of TP. Caliskan and Polat (2011) analyzed TP of 76 local fig genotypes from the Mediterranean region and reported values between 286 mg/kg ('Bakras 4') and 2119 mg/kg gallic acid equivalent (GAE) FW ('Siyah 5'). Genetic and environmental factors, as well as postharvest technology, can highly influence the phenolic content and composition of fruits (Ercisli et al., 2012).

Antioxidant Activity

Interest in natural plant-based antioxidants has increased, especially in light of the growing concern for food safety and potential negative effects of synthetic chemicals used for

food conservation. In vitro and in vivo studies have proven that fig phytochemicals can affect processes that alter the development of tumor cells and amend neurochemical and behavioral changes related with aging. Dried figs are an excellent source of nutrients and in vivo antioxidants, because the antioxidant capacity of plasma increases significantly for hours after fig ingestion (Vinson et al., 2005).

Total antioxidant capacity (Table 5) of fig fruits varies among varieties. Pande and Akoh (2010) reported ferric reducing ability of plasma (FRAP) antioxidant capacity ranging from 1.0 to 6.2 μM Trolox equivalent (TE)/g FW (cultivar 'Brown Turkey'). Ercisli et al. (2012) analyzed antioxidant capacity in 24 local fig genotypes from Turkey and in 2 standard cultivars. The genotype 'C13' showed the highest total antioxidant capacity (averaging 623 μmol of TE in 100 g FW for Trolox equivalent antioxidant capacity (TEAC) and 18.7 mmol/kg FW for FRAP assays, respectively), whereas the lowest total antioxidant capacity values were found in genotype 'C12' (36 μmol of TE/100 g FW for TEAC and 4.6 mmol/kg for FRAP, respectively). Veberic et al. (2008b) expressed antioxidant capacity as *ascorbic acid equivalent antioxidant capacity*. The highest value was measured in 'Miljska Figa' fruits (53.3 mg ascorbic acid/kg), and the lowest was found in 'Bela Petrovka' fruits (29.3 mg ascorbic acid/kg).

In general, genotypes with black and purple skin possess higher total antioxidant capacity than light-colored cultivars (Caliskan and Polat, 2011; Solomon et al., 2006). The reason is the high concentration of phenolics in the peel of black cultivars (Piga et al., 2008). Fig leaves possess the strongest antioxidant potential, and pulp has the weakest (Table 5). These facts may be partially explained by high amounts of phenolic compounds accumulating in leaves (Oliveira et al., 2009). A high positive correlation between TP and antioxidant capacity in fig fruits has been confirmed (Caliskan and Polat, 2011; Pande and Akoh, 2010).

Differences in fruit-growing region and technological measures, ripening stage, pre-harvest and postharvest conditions, and annual divergences are the most influential factors contributing to the variation of fig antioxidant activity. In addition, the antioxidant activity depends on the extraction solvent properties and the extraction techniques, as well as the process and the temperature of fig drying (Ouchemoukh et al., 2012).

Drying of Fig Fruit

The widely used sun-drying method is one of the oldest known techniques of food preservation and has been used for many fruits and vegetables because of its simplicity and low working costs. In this process, figs are hand-picked in a semidried form and subsequently dried in the sun for approximately 1 week (Yemis et al., 2012). Sun drying can ensure proper preservation of figs; however, careful selection of fruits with respect to maturity, fruit size, and health condition is often hard to ensure. Moreover, the quality of the final product is often low, because fruits are exposed to direct solar irradiation and the drying parameters are difficult to control. Sun drying is therefore seldom

homogeneous, and the final product is caramelized and crusted. Exposure to the sun also destroys the fruit color, reduces vitamin content, and the preferential oven-dried flavor of the figs (Chimi et al., 2008).

Mechanical air dehydration has important advantages over sun drying, not only because changeable weather conditions are excluded. The drying process is performed with significantly lower contamination by dust and other foreign matter. The drying parameters can be controlled and adjusted during the entire processing time, ensuring a uniform product with less quality degradation. When a constant rate of dehydration is reached, increasing the air flow can result in shorter drying time and lower labor costs (Barbosa-Canovas and Vega-Mercado, 1996).

Dried fig is one of the most produced fruit products in the world. It is used in many forms: as whole fruit for consumers; or in industrial forms, such as paste, concentrate, powder, and chopped fruit. Dried fig consumption manifests a positive effect on human health. This beneficial effect has been ascribed to many micronutrients reserved in dry fruit. Dried figs are rich in fiber, trace minerals, polyphenols, proteins, sugars, and volatile compounds that provide a pleasant characteristic aroma and are thus a good choice for a healthy snack (Bekatorou et al., 2002).

In addition to energy provided by the high sugar content, dried figs have a high nutrient content compared with other dried fruits. It is considered an important source of minerals (potassium and calcium) and vitamins (B₃ and nicotinic acid). This fruit provides more fiber than all other common fruits, which explains its laxative action (Solomon et al., 2006). Vinson et al. (2005) reported that figs are also rich in phenolic compounds that contribute to its quality.

Dried fig fruits have statistically higher content of individual and total sugars compared with fresh fruit (Table 6). The glucose to fructose ratio remains constant (1.1–1.2 in cultivar ‘Bela Petrovka’), regardless of the type of drying. This is important, because the sugar composition of fig fruit influences the perceived fruit sweetness. Therefore the perception of sweetness in figs is likely caused by the predominance of fructose, and results indicate that the figs dried in the sun do not taste sweeter than figs dried in a drying room (Slatnar et al., 2011).

In the study by Slatnar et al. (2011), dried figs of variety ‘Bela Petrovka’ were characterized by a 2.4- to 5.6-fold higher content of citric acid and 2.8- to 17.4-fold higher content of malic acid compared with fresh fruits. Significantly higher content levels of individual and total organic acids have been determined in samples dried in a drying oven compared with other treatments. According to the authors, these results were expected, because dried fruit samples contain less water and thus organic acids are more concentrated.

In the same study by Slatnar et al. (2011), the highest sugar to organic acid ratio was calculated for figs dried in the sun and fresh figs at the second sampling date. The fruit contained high sugar and low organic acid levels. On the other hand, figs dried in the

Table 6 Content levels of individual sugars and organic acids in dried figs

	Whole dried fruit (mg/100 g DW)	Peel (mg/100 g DW)	Pulp (mg/100 g DW)	Leaf (mg/100 g DW)	References
Sucrose	249–740				Slatnar et al. (2011)
Fructose	8253–19,557				
Glucose	9690–21,588				
Total sugars	18,518–41,885				
Malic acid	184–907	364.84–870.41	544.29–685.12	768.44–2417.11	Slatnar et al. (2011) and Oliveira et al. (2009)
Citric acid	333–1054	200.25	228.03–266.32		
Oxalic acid		15.55	7.94	98.34–240.61	
Quinic acid				518.33–1050.25	
Shikimic acid		14.22–15.81	8.07–13.6	9.91	
Fumaric acid		2.30–31.4	2.42–5.83	8.11	
Total organic acid	516–1925	584.04–902.49	830.03–931.58	1385.11–3716.0	

DW, dry weight.

drying room contained low sugar and rather high organic acid levels, and thus the lowest sugar to organic acid ratio.

The predominant phenolic compound in dried fig fruits is reportedly epicatechin, at a level to 25.4 mg/100 g DW in cultivar 'Bela Petrovka'. Its content is up to threefold higher than in fresh figs (Slatnar et al., 2011). In contrast, a study of sun-dried pear determined a 91% and 96% decrease of monomeric catechin and epicatechin as a result of the drying process (Ferreira et al., 2002). In dried figs, chlorogenic acid levels are also higher compared with fresh fruits. Oven-dried fruits contain statistically higher amounts of chlorogenic acid in comparison with sun-dried fruits. The results are again expected, because constant conditions can be maintained in the drying oven as opposed to the sun-drying process (Slatnar et al., 2011). Devic et al. (2010) stated that procyanidins are better preserved by the drying process than hydroxycinnamic acids or some monomeric flavanols. The latter two phenolic groups are good substrates involved in enzymatic browning.

The fig-drying process had a similar influence on the content of flavonols than on the other groups of phenolic compounds. Higher contents of kaempferol-3-glucoside, rutin, and quercetin-3-glucoside have been determined in dried 'Bela Petrovka' fig samples in comparison with fresh figs (Slatnar et al., 2011).

The response of anthocyanins to drying differs greatly. Some authors report that the content of specific and total anthocyanins reduces after drying (Table 7). Slatnar et al. (2011) measured a lower content of cyanidin-3-rutinoside in dried figs. The negative influence on the content of anthocyanins has also been confirmed by Sablani et al. (2011) and Wojdylo et al. (2009).

Dried fruits are characterized by a significantly higher TP than fresh fruits. Vallejo et al. (2012) reported that fresh figs contain from 0.5 mg/100 g (cultivar 'Siciliana') to 11.3 mg/100 g FW (cultivar 'CDN 9') of total analyzed phenolics, and dried fruit from 17.8 mg/100 g (unknown Spanish genotype) to 19.2 mg/100 g (unknown Turkish genotype). Nevertheless, approximately 15% of TP are lost in the drying process (Vallejo et al., 2012). It is assumed that polyphenols are degraded or converted to nonantioxidant forms (Ferreira et al., 2002). The comparison between fresh and dried fig fruit on a FW basis exposes a 90% increase in free polyphenols as a result of water loss. Vinson et al. (2005) similarly report an 11% increase in total polyphenols as a result of drying. This is in accordance with the reports on other fruit species (strawberry, apple, and peach) in which the levels of TP increased after drying of pureed and fresh products (Rababah et al., 2005).

Pigment losses can occur during drying in many foods. Some reactions during the drying process, such as enzymatic and nonenzymatic browning and caramelization, cause color changes of the food material, and the color of the food becomes darker and dull (Jayaraman and Das Gupta, 2006). During the first, third, fifth, and seventh day of drying, the total carotenoid content of 'Sarilop' decreased to 92.9%, 40.8%, 23.4%, and 21.5% of the initial content. A similar decrease was also observed in samples of the 'Sarizeybek' cultivar (Table 8).

Table 7 Content levels of individual phenolic compounds in dried figs

	Whole dried fruit (mg/100 g DW)	Pulp (mg/100 g DW)	Peel (mg/100 g DW)	Leaf (mg/100 g DW)	References
3-Caffeolyquinic acid			0.32		Vallejo et al. (2012), Slatnar et al. (2011), Oliveira et al. (2009), Vinson et al. (2005), and Bey et al. (2013)
5-Caffeolyquinic acid	1.4–32.42	0.28–3.29	0.83–4.3	47.3–115.8	
Ferulic acid			0.92–2.05	1198.38	
Kaempferol-3-rutinoside	1.0–2.0				
Quercetin-3-acetylglucoside	2.1–2.8				
Quercetin-3-rutinoside	1.38–14.62	6.46	49.9–62.9	1458.5–1744.0	
Quercetin-3-glucoside	0.56–3.35		3.08–3.14	61.1–163.39	
Catechin	5.88–19.75				
Epicatechin	10.44–36.65				
Kaempferol-3-glucoside	0.31–0.43				
Lutolin-8-C-glucoside	0.13–0.45				
Cyanidin-3-rutinoside	0.12–0.31				
Bergapten		4.58	2.68	133.67–462.7	
Psoralen		0.37–1.7	0.26–1.84	377.4–925.97	
Total phenolic content	17.8–815	3.66–13.0	60.06–72.3	3241.2–3447.36	

DW, dry weight.

Table 8 Content levels of individual carotenoids in dried fig fruits

	$\mu\text{g/g DW}$	References
Total carotenoids	4.06–21.27	Yemis et al. (2012)
Lutein	1.44–4.51	
β -Carotene	0.45–1.03	
α -Carotene		
Cryptoxanthin	0.98–1.78	
Lycopene		
Zeaxanthin	0.68–2.00	

DW, dry weight.

An intense decrease in total carotenoid levels has been observed on the third and fifth day of drying. Total carotenoid losses were approximately 80% at the seventh day of drying (Yemis et al., 2012). Carotenoids are susceptible to oxidation during drying because of their high degree of unsaturation in chemical structure (Jayaraman and Das Gupta, 2006).

Vinson et al. (2005) reported that dried figs are an excellent source of nutrients and potent in vivo antioxidants; the antioxidant capacity of human plasma increased significantly for hours after dried fig consumption. Results indicate that after dry fig (cultivars ‘Misson’ and ‘Calimyrna’) consumption, the antioxidant capacity increases up to 9% (Vinson et al., 2005). Dried figs have twofold higher values of in vitro antioxidant activity in comparison with fresh figs of cultivar ‘Bela Petrovka’ (Slatnar et al., 2011). Dried fruits have a high nutrient density, high fiber content, prolonged shelf life, and significantly higher phenolic content compared with fresh fruits. The quality of the antioxidants in the processed dried fruit is the same as in the corresponding fresh fruit. Phenolics in dried fruit may be important antioxidants, as revealed by the in vivo antioxidant effect after consuming a recommended serving of fig (Vinson et al., 2005).

SUMMARY POINTS

- The common fig is among of the oldest cultivated fruit species in the Mediterranean basin. It is widespread in warm and dry climates around the world with Turkey as the main producer.
- Besides wild caprifig, three types of cultivated fig exist: *common*, *Smyrna*, and *San Pedro*. They can bear one or two crops per year and produce parthenocarpic fruit or fruit resulting in pollination by *B. psenes*, a symbiotic wasp.
- Figs can be eaten fresh, dried, or processed into different products. They are a sweet-tasting fruit because of high amounts of sugars and a low organic acid content. Glucose and fructose are the main sugars, and malic and citric acid are the main organic acids in fig fruits.

- The TP is intermediate. Dark-skin cultivars generally contain higher levels of polyphenols, especially anthocyanins, compared with fig varieties with lighter skin. Fig fruit skins contain healthy nutrients that should not be discarded.
- In comparison with other fruits, the level of total carotenoids in fig is low and mostly concentrated in fruit peel. However, in dry figs, total carotenoid levels are much higher compared with some other dried fruits.
- Fruit drying is the easiest way of fig fruit preservation. The traditional sun-drying method yields produce with diverse quality. Meanwhile, automated air dehydration has several advantages and generates fruit with high sugar content and high TP. Some pigments are lost during the process of drying, especially anthocyanins and carotenoids.
- Because of the high content of beneficial compounds in fresh or dried fig fruits, their consumption should be encouraged as a potential healthy alternative for sweets.

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CHAPTER 12

Grape (*Vitis* species)

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The family Vitaceae, to which the grapevine belongs, dates to the Paleocene period, with scientific evidence of fossil vines dating 60 million years. Northern hemisphere areas (Eurasia and North America) are cited as regions of origin where *Vitis* (sect. *Euvi-tis*) *vinifera* probably evolved. The current distribution of *V. vinifera* includes North, Cen-tral, and South America; Asia; Australia; and Europe.

Domestication of wild species *V. vinifera* ssp. *sylvestris* to *V. vinifera* ssp. *vinifera* may date to 8500–4000 BCE in Eurasia. Chloroplast deoxyribonucleic acid (DNA) variation at polymorphic microsatellite loci of *V. vinifera* genotypes belonging to both *vinifera* and *sylvestris* subspecies suggest two origins for grapevine cultivars: one in the Near East, and another in the Western Mediterranean region, giving rise to most of the Western Euro-pean cultivars (Arroyo-García et al., 2006). Archaeobotany and genetics studies consider domestication as a complex, long-term, and ongoing evolutionary process that involves multiple loci (Bouby et al., 2013). Sexual hybridization has generated thousands of het-erozygous cultivated varieties, mostly for wine production. Grapes' biology changed dramatically to ensure higher sugar content, greater yield, regular production, and

adaptation to different environments (This et al., 2006). Changes in berry and bunch size and from dioecious wild to hermaphroditic cultivated plants were crucial. Parentage studies (Aradhya et al., 2003) demonstrated the importance of sexual crosses for generating new phenotypes, spread, and adoption of specific genotypes with desirable traits. *Vitis* germplasm is very variable, and the wild grape germplasm is a potential source of unique alleles for improving both wine and table grapes (This et al., 2006). Grape cultivation and wine drinking may have started around 6000 BCE. Wine, the drink of gods, was well known by doctors, Hippocrates being among those prescribing it. Texts from tombs in ancient Egypt prove that wine was used there around 2700 BCE. Egyptians recognized differences in wine quality and developed the first arbors and pruning methods. Archeological excavations uncovered jars for storing wine. Wine was spread to Europe around 1600 BCE as a commercial product, strengthening of viniculture in Western Europe as a result of Roman influence. At the first century, wine was exported from Roman Empire to Western Europe; the Languedoc region probably constituted a domestication center (Terral et al., 2010). Surrounding regions soon started planting vineyards. Roman contribution was of most importance in classifying grape colors and varieties, observing ripening characteristics, identifying diseases, and recognizing soil-type preferences. Romans were skilled in pruning and increasing yields through irrigation and fertilization. Because wine is appreciated as a drink, wine production is based on millions of varieties adapted to local conditions and improved in different traits for good wine. Grapevines retain high levels of genetic diversity (Myles et al., 2010). Developers of environmentally sustainable grapes and the wine industry rely on this tremendous diversity by genetically characterizing the world's germplasm collections and using marker-assisted breeding to improve cultivars (Myles et al., 2010). Grapevine molecular biology, including *V. vinifera* genome sequencing and use of genetic diversity, provide information for deciphering mechanisms for improving tolerance to biotic/abiotic stresses in cultivars used in wine production.

BOTANICAL ASPECTS

The genus *Vitis* L. (grape), one of the 16 genera in the family Vitaceae, includes 68 species (The Plant List, 2013). *Vitis* is distinguished from other genera in Vitaceae by its petals that remain coalescent at the top and separated at the base (calyptra), falling as a cap. According to the United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) Identifier, grape species are *Vitis acerifolia* Raf. (maple leaf grape), *Vitis aestivalis* Michx. (summer grape), *Vitis amurensis* Rupr. (Amur grape), *Vitis arizonica* Engelm. (canyon grape), *Vitis californica* Benth. (California wild grape), *Vitis cinerea* Engelm. ex Millardet (graybark grape), *Vitis girdiana* Munson (desert wild grape), *Vitis labrusca* L. (fox grape), *Vitis monticola* Buckley (sweet mountain grape), *Vitis mustangensis* Buckley (mustang grape), *Vitis x novae-angliae* Fernald (pilgrim grape),

Vitis palmata Vahl (catbird grape), *Vitis riparia* Michx. (riverbank grape), *Vitis rotundifolia* Michx. (muscadine), *Vitis rupestris* Scheele (sand grape), *Vitis shuttleworthii* House (calo-osa grape), *Vitis tiliifolia* Humb. and Bonpl. ex Schult. (West Indian grape), *Vitis vinifera* L. (European or wine grape), *V. vinifera* L. ssp. *sylvestris* Hegi (wild grape), and *V. vulpina* L. (frost grape).

The taxonomy of the genus *Vitis* has been the subject of discussion. Galet (1979) considered it to comprise two distinct sections—Muscadinia and Euvitis, differing in basic morphological, anatomical, and cytological characters: forked (Euvitis) versus unforked (Muscadinia) tendrils; pyriform (Euvitis) versus navicular (Muscadinia) seeds; presence (Euvitis) versus absence (Muscadinia) of a diaphragm interrupting the pith at the node; leaves palmate, nearly entire without lobes (Muscadinia) versus leaves generally palmate with five principal veins (Euvitis); fruit clusters with few berries that ripen and drop at maturity (Muscadinia) versus fruit clusters with numerous berries that adhere to the stem until maturation (Euvitis); and chromosome number $2n = 40$ (Muscadinia) versus $2n = 38$ (Vitis), among other features.

The Muscadinia section comprises three species. The best known, *V. rotundifolia*, originated in the southeastern United States and was domesticated by European settlers. It serves as a rootstock to cope with the high sensitivity of European grapevines to *Phylloxera* disease. This section also includes *V. munsoniana* J.H.Simpson ex Planch. (native to Florida and Bahamas), and *V. popenoei* J.L.Fennell (from Mexico, Belize, and Guatemala).

The Euvitis section includes most of the wine producing species. *Vitis vinifera*, the primary cultivated *Vitis* species, produces the most famous quality wines. Native to Asia near the Caspian Sea, it has been imported to Europe since before recorded history. It has large, jagged leaves, and the stem bark tends to peel. The grapes are green, red, or purple. *V. vinifera* has to be grafted on to *V. rotundifolia* or other resistant rootstocks to survive in regions with *Phylloxera*.

Vitis labrusca, native to North America, has strong vines with large, thick leaves. The upper leaf surface is usually dull green, and the lower surface is densely covered with white to brownish or reddish hairs. *V. labrusca* differs from other species in that it has tendrils at all nodes beyond the base of the shoot.

Vitis aestivalis, native to the southeastern United States, is a strongly growing species with leaves resembling those of *V. labrusca*, except the rusty or red-brown hairs are mostly in tufts on the lower surface. The fruits are black and without the intense flavor of *V. labrusca*.

Vitis riparia, the species most widely distributed in the northern United States, is a vigorously-growing vine occurring along streams. Its grapes are sharply acid and borne in compact clusters.

Vitis berlandieri Planch., a stocky, moderately climbing vine, is found in southwestern Texas and Mexico. It has medium to large, slightly 3-lobed leaves that are glossy above and become hairless below as they expand to full size. The fruit clusters are branched,

carrying numerous small berries. The fruit is high in sugar and acid, and ripens very late. It is difficult to root from cuttings, and is mostly used for rootstocks.

Vitis rupestris, native to Arkansas, southern Missouri, and Tennessee, is a small, multi-branched shrub that climbs slightly under favorable conditions. Its roots tend to penetrate vertically instead of spreading laterally. The leaves are small, kidney-shaped, wider than long, and light silver-green. The fruit clusters are small with small black berries that have good flavor. *V. rupestris* is used for making hybrid wine grapes and as a pest-resistant rootstock.

Vitis cinerea is similar to *V. berlandieri* and grows in wet conditions. The fruit clusters are large and lax, bearing numerous small black berries. The fruit ripens late, becoming sweet after frost. *V. cinerea* is used mostly for rootstocks.

Efforts have been made to find new landraces, and to breed or genetically engineer grapes to produce new wine or table grape varieties with increased quality and productivity or tolerance to biotic and abiotic stresses.

According to the list of Organisation Internationale de la Vigne et du Vin (OIV), 4020 cultivars (varieties) used for wine production, table consumption, or rootstocks were registered up to 2013. This list will surely be enriched with new varieties in the coming years.

COMPOSITION OF TRADITIONAL OR ANCIENT CULTIVARS

Native grapevine cultivars are important for viticulture production in countries such as Portugal, Spain, and Croatia, which stick to their own cultivars that provide wines with particular characteristics. However, autochthonous cultivars are less and less cultivated in some countries because of the present economic pressures and introduction of well-known global French cultivars, such as ‘Cabernet Sauvignon’, ‘Pinot Noir’, ‘Syrah’ and ‘Merlot’. These varieties are widely cultivated in New World countries such as Chile, the United States, and Australia.

Sugars, organic acids, and phenolic, nitrogenous, and aroma compounds are important for the nutritional value of grape fruits that ultimately influence wine quality. Sugars play a minor role in discriminating most table and wine grapes, although some differences can be found (Agudelo-Romero et al., 2013).

The content in organic acids was compared among native cultivars of Croatia because of the impact of these compounds in the color, flavor, and stability of wine (Preiner et al., 2013). The highest levels of titratable acidity and tartaric and malic acid in all years of study (2009–2011) were obtained from the ‘Grk’ cultivar (Table 1), which also had the highest sugar content. On the other hand, the ‘Debit’ cultivar had the lowest sugar content, titratable acidity, and tartaric, malic, and citric acid content. Among the cultivars ‘Debit’, ‘Grk’, ‘Plavac mali’, ‘Plavina’, ‘Pošip’, ‘Vugava’, ‘Maraština’, the latter was the cultivar with the highest citric acid content. In all 3 years of study, the white cultivars ‘Grk’, ‘Maraština’, and ‘Pošip’, but not ‘Debit’, had a higher content

Table 1 Traditional and modern varieties of *Vitis* species discussed in the text and used as table and/or wine grapes. A wide diversity of grape varieties originating from Europe, America, and Asia is presented.

Traditional <i>Vitis vinifera</i> wine grape	Affenthaler, Alvarinho, Antão Vaz, Arinto, Barbera, Borraçal, Cabernet Franc, Cabernet Sauvignon, Castelão, Chardonnay, Corbeau, Debit, Gamay, Gewürztraminer, Grenache, Grignolino, Grk, Gruener Veltliner, Jampal, Loureiro, Malbec, Maraština, Marmajuelo, Marzemino, Melon, Merlot, Moreto, Mulent Black, Muscat Rouge de Madere (also table grape), Nebbiolo di Dronero, Negro Amaro, Perrum, Petit Verdot, Pinot Noir, Plavac mali, Plavina, Pošip, Rabode-Ovelha, Riesling, Robola, Roupeiro, Saint Macaire, Salvador, Sangiovese, Sauvignon Blanc, Schioppettino, Sousão, Syrah/Shiraz, Tannat, Tempranillo/Aragonês/Tinta Roriz, Tinta Barroca, Tinta Caiada, Tinto Cão, Touriga Fêmea, Touriga Nacional, Trincadeira/Tinta Amarela, Verdello, Vertzami (also table grape), Vespolina, Vugava
Traditional <i>Vitis vinifera</i> table grape	Alphonse Lavallée, Bastardo Ruzo, Dominga, Moscatel Negro, Muscat of Alexandria (also wine grape), Ribier, Thompson Seedless/Sultanina, Tinta Pais, Verdello Tinto
Modern <i>Vitis vinifera</i> wine grape	Albarossa, Alicante Bouschet/Garnacha Tintorera, Arinarnoa, Cerason, Marselan, Pinotage, Regent, Ruby Cabernet (also table grape), Yan 73
Modern <i>Vitis vinifera</i> table grape	Autumn Royal, BRS Morena, Cardinal, Crimson Seedless, Flame Seedless, Guibao, Italia (also wine grape), Michele Palieri, Moscatel Italica, Muscadoule (also wine grape), Muscat Hamburg, Napoleon, Otilia, Perlou (also wine grape), Red Globe, Superior Seedless
Traditional and modern interspecific crossing or other species of <i>Vitis</i> .	Alachua (table grape), Baco Noir (wine grape), Beichum (wine grape), Beihong (wine grape), Beizi (juice grape), BRS Clara (table grape), Campbell Early (table grape), Canadice (table grape), Chancellor (wine grape), Concord (table and wine grape), Delaware (table grape), Eudora (table grape), Flouxa (table grape), Honey Seedless (table grape), Janet (table grape), Kyoho (table grape), Muscat Bailey A (wine and table grape), Nativa, Niagara (table grape), Ruby Seedless (table grape), Southland (table grape), Super Hamburg (wine grape), Tamnara (table grape), Tano Red (table grape)

of citric acid than the red cultivars ‘Plavac mali’ and ‘Plavina’. In fact, the organic acid content varies considerably with the genotype. The same holds true for the native Portuguese red varieties ‘Touriga Nacional’, ‘Aragonês’, and ‘Trincadeira’ (Ali et al., 2011; Agudelo-Romero et al., 2013). Differences can also be found among several cultivars of *V. vinifera*, as well as hybrids of *V. labrusca* and *V. vinifera* (Liu et al., 2006). Wine grapes are more acidic than table grapes. The ratio of malic acid to tartaric acid also varies extremely with the cultivar. For instance, the traditional cultivar ‘Mulent Black’, grown in China, is characterized by a high ratio of tartaric to malic acid (Liu et al., 2006).

Tartaric and malic acids are the dominant organic acids in grapes, but other organic acids are also identified, namely fumaric, gallic, glycolic, glyceric, lactic, pyruvic, phosphoric, shikimic, vanillic, and threonic acids (Agudelo-Romero et al., 2013).

Most wine-producing varieties are nonaromatic. Therefore the varietal character of wine resulting from nonaromatic grapes originates mainly from the transformation of odorless precursors, such as glycosidically bound volatile compounds, into odor-active compounds during wine making. The nonaromatic varieties produce mainly C6 alcohols and aldehydes such as hexanal, (E)-2-hexenal, 1-hexanol, decanal, and (E)-2-hexen-1-ol. In the work of Agudelo-Romero and co-workers (2013), several volatiles in grapes of the traditional wine grape varieties 'Touriga Nacional', 'Aragonês', and 'Trincadeira' were identified (discussed in another section of this chapter). Monoterpenes, C13-norisoprenoids, and some benzenoid compounds in both free and glycosidic forms are important grape aroma compounds in the pulp and skin of berries. Their specific profiles depend mainly on the variety, although environment may also play a role. Terpenes, for instance, are important to the pleasant aroma of many varieties, such as 'Riesling' and 'Muscat'.

In an attempt to evaluate the potential aroma of some Portuguese grapes, several glycosidic bound aroma compounds (C6 compounds, terpenes, benzenoids, phenols, and norisoprenoids) were analyzed in 10 grape varieties cultivated in Alentejo, including the white varieties 'Arinto', 'Perrum', 'Rabo-de-Ovelha', 'Roupeiro', and 'Antão Vaz', and the red varieties 'Trincadeira', 'Aragonês', 'Tinta Caiada', 'Moreto', and 'Castelão' (Cabrita et al., 2006). It was concluded that the compounds originated by enzymatic hydrolysis of glycoside precursors extracted from pulps and skins of these grapes were similar to those produced and enriched in the skin of the so-called aromatic varieties. However, the amounts quantified were significantly lower. Geraniol was the most abundant monooxygenated terpenic alcohol. In 'Trincadeira' grapes no linalool was detected. *p*-Ment-1-ene-7,8-diol, a very important aroma compound that derives from α -terpineol, was found in significant amounts in pulps from 'Tinta Caiada'. The 'Moreto' variety tends to be the richer in terpenic compounds, whereas the 'Tinta Caiada' variety has higher levels of norisoprenoid compounds. The red grapes 'Aragonês' and 'Castelão' are richer in vitispiranes, whereas 'Moreto', 'Trincadeira', and 'Tinta Caiada' are richer in actinidols. 'Moreto' is also the variety containing more β -damascenone.

Concerning white varieties, 'Arinto' has the highest values of terpenes. The *cis*-8-hydroxy-linalool, a terpene of the linalool class, was the most important, although this variety also contains a high level of compounds from the geraniol class. In addition, 'Arinto' is richer in norisoprenoid compounds, whereas 'Roupeiro' has a low content. Only 'Roupeiro' and 'Perrum' show detectable amounts of vitispiranes.

The composition of 'Loureiro' and 'Alvarinho' wines from the Vinhos Verdes region in Portugal was analyzed (Oliveira et al., 2008). Wines made with the cultivar 'Loureiro' are richer in C6-compounds and monoterpene compounds than 'Alvarinho' wines,

whereas the opposite was observed for volatile phenols. However, (Z)-3-hexen-1-ol was more abundant in 'Alvarinho' wines. The compounds that particularly influence the aroma of these wines include linalool, α -terpineol, and α -damascenone, which confers tropical fruit notes to 'Alvarinho'.

As far as monoterpenic oxides and diols are concerned, 'Loureiro' is richer than 'Alvarinho' in the majority of compounds, particularly pyran linalool oxides and 3,7-dimethylocta-1,7-dien-3,6-diol. On the other hand, (Z)-8-hydroxylinalool is more abundant in 'Alvarinho' wines. The compounds *exo*-2-hydroxy-1,8-cineole and *p*-1-menthen-7,8-diol were only identified in 'Loureiro' wines, although at trace levels.

'Alvarinho' is also rich in fatty acids, ethyl esters, and acetates of fusel alcohols, which can contribute to a fruity character. In addition, 'Alvarinho' has higher levels of volatile phenols of fermentative origin, particularly 4-vinylphenol and 4-vinylguaicol. These compounds give spicy, clovelike, and medicinal odors to some 'Gewürztraminer' wines. 'Loureiro' contains higher levels of esters of organic acids and 2-phenylethanol, conferring fruity and floral notes. Wines from the 'Alvarinho' variety are characterized by more intense tropical, dried, and tree fruit characters, whereas 'Loureiro' wines have a more pronounced citrus fruit aroma.

Varietal thiols, such as 4-mercapto-4-methylpentan-2-one, 3-mercaptohexyl acetate, and 3-mercaptohexan-1-ol, contribute to the typing of young white wines, such as 'Sauvignon Blanc'. These compounds belong to the class of varietal aromas because of the fact that they result from the cleavage by yeast of odorless precursors occurring in grapes or musts during alcoholic fermentation. Although they occur at trace levels, their contents are always above their perception thresholds, bringing appreciated fruity notes in wines. The compound 4-mercapto-4-methylpentan-2-one, reminiscent of box tree and black currant bud, often exhibits low concentrations. On the other hand, the more abundant 3-mercaptohexyl acetate and 3-mercaptohexan-1-ol yield fruity notes, such as passion fruit and grapefruit, to white or rosé wines. In addition, 3-mercaptohexyl acetate was shown to be an active odorant in 'Marmajuelo' and 'Verdello' wines (Roland et al., 2011).

Sixteen Brazilian red varietal wines were evaluated for their sensory descriptors (Miele and Rizzon, 2011). Wines from cultivars 'Tempranillo' (from Spain) and 'Aragónés/Tinta Roriz' (an iberic cultivar produced in Portugal) are distinguished by their equilibrium, quality, harmony, persistence, and body, as well as by fruity, spicy, and oak characters. They were recently introduced in the state of Rio Grande do Sul in Brazil; therefore, the young vineyards also had an impact on the wines' characteristics. Their sensory characteristics in this region prompted grape growers and winemakers to continue producing these varietal wines. 'Pinot Noir' and 'Sangiovese' (Italian variety) wines were characterized by floral aroma and floral flavor, whereas 'Cabernet Sauvignon' was notable for its sweet taste. 'Cabernet Sauvignon' is a variety cultivated worldwide, and

produces high quality wines in many viticultural regions. ‘Malbec’, an emblematic Argentinean wine, was characterized by weak floral and fruity characteristics in Brazil.

A very interesting sesquiterpene ketone, called *rotundone*, is related to aroma characteristics and considered responsible for the peppery aroma in grapes. It has a very distinctive aroma and low sensory threshold. ‘Schioppettino’ and ‘Vespolina’ are two of the red *V. vinifera* cultivars that yield very peppery wines in comparison with other cultivars, such as ‘Syrah’ (Caputi et al., 2011). ‘Gruener Veltliner’ is another white grape variety known to give peppery wines. Interestingly, these authors concluded that different clones accumulated different amounts of rotundone. More studies are needed to address the intravarietal differential accumulation of aroma compounds and other metabolites important for nutritional quality of grapes.

In an interesting study, 52 young, monovarietal red wines produced with ‘Grenache’, ‘Tempranillo’, ‘Cabernet Sauvignon’, and ‘Merlot’ grapes were analyzed for quantification of odorants (Ferreira et al., 2000). The compound 3-isobutyl-2-methoxypyrazine, associated with bell pepper scent, was only identified in two ‘Cabernet Sauvignon’ wines. Methoxypyrazines are also considered part of the specificity of white wines made from ‘Sauvignon Blanc’.

‘Tempranillo’ was clearly distinguished from the others by its high levels of eugenol, guaiacol, isoamyl acetate, and β -phenylethyl acetate, and its low levels of 2,3-butanodione, linalool, isovaleric acid, isobutanol, isoamyl alcohol, β -phenylethanol, and methionol. The composition of wines made with ‘Merlot’ was at some degree opposite to the wine obtained from ‘Tempranillo’. Wines made with ‘Grenache’ and ‘Cabernet Sauvignon’ have an intermediate composition, although linalool is found in maximum concentrations in Grenache. Some of these wines contain high levels of α -terpineol, γ -nonalactone, α -ionone, ethyl isobutyrate, ethyl 2-methylbutyrate, ethyl isovalerate, and isobutyric acid.

Norisoprenoids can originate from degradation of carotenoids in grape cells or from hydrolysis of glycoside molecules (Oliveira et al., 2006). In a study characterizing grape varieties cultivated in the Douro Region of Portugal, it was shown that grape varieties with higher concentrations of carotenoids (‘Touriga Fêmea’, ‘Tinta Amarela’ [or ‘Trincadeira’], and ‘Tinta Barroca’) tend to have lower values of free norisoprenoids (Oliveira et al., 2006). ‘Trincadeira’ has higher percentage of xanthophylls, such as neoxanthin, violaxanthin, luteoxanthin, and lutein. In addition, grape varieties that are lower in carotenoid content (‘Touriga Nacional’, ‘Sousão’, and ‘Tinto Cão’) tend to have higher concentrations of free norisoprenoids. Such is the case for β -ionone in ‘Touriga Nacional’, which gives a violet aroma, and vitispirane and 1,1,6-trimethyl-1,2-dihydronaphthalene in ‘Sousão’ and ‘Tinto Cão’. These compounds are found to be responsible for eucalyptus/camphor and kerosene flavors, respectively. ‘Touriga Nacional’ and ‘Sousão’ also have the highest levels of C13-norisoprenoid glycosides. Furthermore, ‘Touriga Nacional’ was identified as the wine variety with the highest level of total free terpenols (linalol, α -terpineol, nerol, and geraniol) that yield the floral aroma.

‘Touriga Nacional’, ‘Tinto Cão’, and the French variety ‘Merlot’ have also been found to contain more total phenolics than ‘Trincadeira’ and ‘Aragonês’ (Teixeira et al., 2013). In another study, 14 grape varieties grown in New York state were compared (Yang et al., 2009). ‘Cabernet Franc’ and ‘Pinot Noir’ contained the highest total phenolic content comparing with modern varieties, such as ‘Baco Noir’ and ‘Chancellor’. ‘Cabernet Franc’ and ‘Pinot Noir’ also exhibited the highest antioxidant activity, providing evidence of the correlation between total phenolics and total antioxidant activity. ‘Pinot Noir’ had higher flavonoid content than Baco Noir, although this modern variety had the highest resveratrol content. The authors inferred that although a single compound may show higher antioxidant activity, such as the widely mentioned activity of resveratrol, the correlation may be more dependent on the total phenolic composition because certain compounds may act additively or synergistically with other compounds.

Polyphenolic compounds, including anthocyanins, flavonols, hydroxycinnamic acids, and hydroxybenzoic acids, were identified among berries of 344 European grape cultivars (*V. vinifera*) at the USDA–Agricultural Research Service (ARS) Vitis Clonal Repository in Davis, California (Liang et al., 2011). On average, wine grapes possess higher contents of these compounds than table grapes, except for hydroxycinnamic acids. The average total content of anthocyanins in colored table grapes was significantly lower than that in colored wine grapes. The skin color determines the market value of table grapes, and also the quality of red wine and juice. Skin color is mainly dependent on the anthocyanin content. The table grape ‘Ribier’ was among those in the study with highest level of anthocyanins. French cultivars ‘Corbeau’ and ‘Saint Macaire’ were among those with the highest percentage of malvidin-derivatives. On the other hand, the cultivars with the highest levels of delphinidin-derivative included ‘Salvador’ from Spain and ‘Petit Verdot’ from France. The cultivars ‘Tannat’ and ‘Corbeau’ exhibited high levels of petunidin-derivatives. The amount of delphinidin and petunidin derivatives is higher than the amount of peonidin-derivatives in wine grapes, but the opposite was observed in table grapes (Liang et al., 2011).

Regarding flavonols, cultivars such as ‘Jampal’ from Portugal showed the highest levels of total flavanols, in particular procyanidin B1. The cultivar ‘Affenthaler’ from Germany was among those with the highest percentage of catechin, whereas ‘Barbera’ from Italy had the highest epicatechin and epicatechin gallate content. ‘Syrah’ of France and ‘Robola’ of Greece had the highest levels of kaempferol 3-O-rutinoside and isorhamnetin 3-O-glucoside, respectively.

Concerning phenolic acids, the wine grapes ‘Plavac Mali’ of Russia and ‘Negro Amaro’ of Italy were among those with a high amount of hydroxybenzoic acids. On the other hand, ‘Melon’ of France was the one with the most abundant levels of hydroxycinnamic acids. The wine and table grape ‘Muscat’ of Alexandria exhibited a high level of vanillic acid.

The cultivars ‘Melon’ and ‘Vertzami’ of Greece were found to have the highest contents of caffeic acid, whereas ‘Salvador’ had a high coumaric acid value. In wine grapes,

resveratrol contents of the cultivars ‘Corbeau’, ‘Syrah’, ‘Tannat’ and ‘Tinta Cao’ from Portugal were the highest among the 344 cultivars in the registry. In contrast, resveratrol levels for well-known table and wine grapes, such as ‘Thompson Seedless’, ‘Pinot Noir’ and ‘Chardonnay’, were much lower (Liang et al., 2011). The level of resveratrol in ‘Corbeau’ was almost 26 times the level in ‘Pinot Noir’. All together, this extended survey demonstrates the richness of polyphenolic compounds in *V. vinifera*, and the results can be used in breeding programs to improve phenolic traits and antioxidant activity in grapes.

The anthocyanin profiles of 50 accessions from a germplasm collection (red table grape cultivars) in Spain were evaluated, and high genetic heterogeneity was found (Pomar et al., 2005). Despite this, malvidin derivatives, and malvidin-3-monoglucoside in particular, were the major anthocyanins in all the varieties, whereas the cyanidin derivatives were less abundant. The major anthocyanin group in all these cultivars was 3-monoglucosides derivatives, reaching values above 90% in ‘Moscatel Negro’, ‘Tinta Pais’, and ‘Verdello Tinto’. The exception was ‘Bastardo Ruzo’, in which the major component was the *p*-coumarate group, representing 60.7% of the total anthocyanin content.

The berry skins of 91 grape varieties (*V. vinifera* L.) were classified according to the flavonol profile (Mattivi et al., 2006). In red grapes, the main flavonol was quercetin, followed by myricetin, kaempferol, laricitrin, isorhamnetin, and syringetin. On the other hand, white grapes contained mainly quercetin, followed by kaempferol and isorhamnetin. In addition, the delphinidin-like flavonols myricetin, laricitrin, and syringetin were not present in white varieties, suggesting that the enzyme flavonoid hydroxylase is not active in white grape varieties. These authors found laricitrin and syringetin glycosides in four varieties with high flavonols content: ‘Cabernet Franc’, ‘Marzemino’, ‘Merlot’, and ‘Syrah’. They also report the presence of laricitrin 3-O-galactoside and syringetin 3-O-galactoside for the first time in grapes.

Quercetin, myricetin, and isorhamnetin were always found in all red-skinned varieties. Myricetin was identified only in traces in two pink varieties, ‘Gewürztraminer’ and ‘Muscat Rouge de Madere’. Laricitrin and syringetin were undetectable in the samples of ‘Gewürztraminer’, ‘Muscat Rouge de Madere’, and ‘Grignolino’, and kaempferol was not found in the sample of ‘Tannat’.

In another study, profiles of phenolics were investigated in nine red *V. vinifera* cultivars grown in the northwest region of China (Jin et al., 2009). Wine grape cultivars such as ‘Syrah’, ‘Cabernet Sauvignon’, and ‘Merlot’ contained more types of anthocyanins, flavonols, flavan-3-ols, stilbenes, and phenolic acids than ‘Gamay’ and ‘Pinot Noir’.

Monoglucosides, acetyl monoglucosides, and coumaryl monoglucosides of delphinidin, cyanidin, petunidin, peonidin, and malvidin could be observed in ‘Cabernet Sauvignon’ and ‘Merlot’, whereas hardly any acylated anthocyanins were present in ‘Gamay’.

‘Pinot Noir’ exhibited abundant anthocyanins, but only few nonanthocyanin phenolic compounds. ‘Gamay’ produced only few anthocyanins. Cyanidin-glucoside in the skins of ‘Pinot Noir’ was at much higher values than in the other grape cultivars tested. In addition, the proportion of acetyl-anthocyanins was twice as much as that of coumaryl-anthocyanins in ‘Merlot’ and ‘Pinot Noir’. It was also noticed that the content of total flavonols in ‘Syrah’, ‘Cabernet Sauvignon’, and ‘Merlot’ were noticeably higher than those in ‘Gamay’ and ‘Pinot Noir’.

High contents of total flavonols, mainly isorhamnetin-glucoside, myricetinglucoside, and syringetin-glucoside, were identified in the skins of ‘Syrah’ and ‘Cabernet Sauvignon’, and the ‘Merlot’ cultivar was richer in isorhamnetin-glucoside and myricetinglucoside.

Among these grapes, dihydroquercetin-caffeoylglucoside was only detected in ‘Gamay’, larcitrin-hexoside only in ‘Merlot’, and dihydroquercetin-hexoside only in ‘Syrah’.

The total flavanol content in ‘Syrah’, ‘Cabernet Sauvignon’, and ‘Merlot’ were significantly higher than in ‘Gamay’ and ‘Pinot Noir’. In addition, only one flavan-3-ol, catechin, and one nonflavonoid, *trans*-piceid, were found in the skin of ‘Gamay’.

COMPOSITION OF MODERN CULTIVARS

Table grapes have been subjected to more intensive breeding than wine grapes; thus more modern cultivars are found. For this reason, table grapes are more intensively considered than wine grapes in this section, in contrast to the previous section. The putative parentage of modern grape cultivars is known through historical breeders’ data accessed at the Vitis International Variety Catalog, even though these records can contain some inaccuracies.

Flavor composition is mostly given by sugars, acids, and volatiles. Besides the flavors sweet, sour, salty, and bitter, aroma plays an important role in fruit quality, but little information is available on the key flavor compounds of table grapes.

Table grapes may have a neutral green aroma, such as ‘Thompson seedless’ (traditional cultivar), or be flowery and citrusy from terpenes (Muscat variety) or musky with anthranilate and other esters (‘Concord’ and other American varieties). Methyl anthranilate is the volatile compound responsible for the distinctive ‘foxy’ aroma and flavor of the modern ‘Concord’ grapes (Wang and De Luca, 2005).

Whether red or white, whether used in winemaking or as table grapes, and whether belonging to *V. vinifera* or a hybrid group, all Muscat varieties are characterized by their Muscat aroma. A Muscat aroma is characteristic of all grapes, musts, and wines made from Muscat varieties. The terpene compounds linalool and the linalool oxides, geraniol, nerol, and terpeneol are considered to be the most important in defining the Muscat aroma. ‘Muscat Hamburg’ is a modern red variety mostly used as a table grape. Another modern red variety used both as table and wine grape, ‘Muscadoule’, is derived from ‘Muscat Hamburg’, with a musky flavor that is more or less perceptible.

Sugar, organic acid, and amino acid compositions are important for the taste of fruits such as table grapes. [Muñoz-Robredo et al. \(2011\)](#) studied the differential composition in some of these metabolites in three commercial varieties of table grapes, namely the traditional 'Thompson Seedless', and the modern 'Red Globe', and 'Crimson Seedless'. 'Sultanina' originates from Turkey and was renamed 'Thompson Seedless' in the United States in honor of William Thompson, one of the first growers in California. Both 'Thompson Seedless' and 'Crimson Seedless' respond to the marked preference of world consumers for fresh, seedless, table grapes. These authors showed that the differences in sweetness for each table grape variety is more dependent on the amount of total sugars present in the variety than the proportion of sugars present in the berry, although fructose was the sugar that most contributed to sweetness. Regarding organic acids, 'Thompson Seedless' was the variety with the lowest tartaric to malic acid ratio, and 'Red Globe' was the variety with more citric acid.

In another study, the composition in organic acids and sugars was analyzed in the juice of 98 grape cultivars ([Liu et al., 2006](#)). These authors showed that glucose and fructose were the most prevalent sugars, although two cultivars of hybrids between *V. labrusca* and *V. vinifera* revealed high sucrose content. Cultivars of these hybrids also tend to have lower total acid and malic acid levels than *V. vinifera* cultivars.

Among the cultivars of *V. vinifera*, wine grapes were found in general to have more sugars and acids than table grapes. One of the cultivars with highest sugar content is 'Beihong', used for wine making and selected from hybrids of *V. vinifera* × *V. amurensis*, whereas the cultivar 'Beizi', a juice grape and *V. thunbergii* × *V. vinifera* hybrid, had the highest total acid content. The cultivar 'Beizi' accumulated high levels of malic acid, whereas 'Tano Red' and 'Beichum' had high tartaric acid content. 'Tano Red' and 'Niagara' also showed a high ratio of tartaric to malic acid.

The modern table grape cultivar 'Canadice' was one of hybrids between *V. labrusca* and *V. vinifera* that showed high total sugars, and another was the *V. vinifera* table grape 'Guibao'. The authors concluded that berries of *V. labrusca* and *V. vinifera* cultivars are more suitable for the Asiatic consumers who appreciate sweet fruits, because they contain more sugars, especially higher levels of fructose than those of *V. vinifera* cultivars.

Interestingly, [Shiraishi and co-workers \(2010\)](#) reported that American hybrid cultivars contain higher levels of sweet amino acids (Threonine, Serine, Alanine) than *V. vinifera* cultivars, and that this can influence berry quality. The highest total amino acid content was obtained for 'Muscat Bailey A', a modern variety bred in Japan.

Phenolic compounds also play an important role in determining grapes' quality and taste. [Nile and co-workers \(2013\)](#) showed that the total phenolic contents were found to be the highest in the grape skin of 'Floux', followed by 'Campbell Early' and 'Tannara', and then by 'Red Globe' and 'Ruby Seedless'. The total phenolic content was the lowest in 'Italia' and 'Delaware'. The quality of grape berries greatly depends on skin

color and thus on phenolics such as anthocyanins. Peonidin-derivatives were the main anthocyanins present in table grapes of *V. vinifera*, whereas malvidin 3-O-glucoside were primarily found in wine grapes (Liang et al., 2008). In this study, *V. vinifera* and hybrids of *V. labrusca* and *V. vinifera* showed low total anthocyanin content, and in general, wild species and rootstock showed higher content than interspecific hybrids. Moreover, wine grapes had significantly higher total anthocyanins than table grapes for the *V. vinifera* cultivars. The modern cultivars of the wine grape ‘Super Hamburg’ (interspecific cross between *V. labrusca* and *V. vinifera*) and of the table grape ‘Otilia’ nevertheless showed high total anthocyanins content (Liang et al., 2008). Modern table grapes, such as ‘Red Globe’ and ‘Ruby Seedless’ had lower anthocyanin content. In addition, blue grapes, such as ‘Autumn Royal’, were reported to contain higher total phenolic and anthocyanin levels than red grapes, such as ‘Red Globe’ and ‘Crimson Seedless’ (Lutz et al., 2011). ‘Autumn Royal’ also had a higher concentration of gallic acid. The most abundant phenolic compound reported in these varieties was nevertheless catechin (Lutz et al., 2011). ‘Red Globe’ was also shown to contain in general the lowest amount of each class of phenolic compound when compared with other modern table grapes, such as ‘Crimson Seedless’ and ‘Michele Palieri’ (Baiano and Terracone, 2011). In fact, concerning the absolute concentrations of phenolics in skins, ‘Crimson Seedless’ showed the highest total phenolics, total flavonoids (together with ‘Michele Palieri’), flavans (together with ‘Michele Palieri’), and proanthocyanidins, whereas ‘Michele Palieri’ had the highest total anthocyanin content (Baiano and Terracone, 2011). These authors detected in skins mainly anthocyanins but also small amounts of protocatechualdehyde, resveratrol, and 2,5-dihydroxybenzoic acid in ‘Red Globe’, whereas chlorogenic acid was detected in ‘Michele Palieri’ and *trans*-cinnamic acid was found in ‘Red Globe’ and ‘Michele Palieri’.

Regarding stilbenes, concentrations of *trans*-resveratrol were determined in 36 Korean-grown grape cultivars, including the modern cultivars ‘Kyoho’ (which has deep black skin), ‘Campbell Early’, ‘Honey Seedless’, and ‘Flame Seedless’ (Park et al., 2009). These cultivars had less *trans*-resveratrol than the traditional ‘High Bailey’.

The phenolic composition of two new Brazilian varieties of seedless grapes that are adapted to the tropical regions was also reported (Lago-Vanzela et al., 2011). These varieties, ‘BRS Clara’ and ‘BRS Morena’, contained high amounts of phenolic compounds. Proanthocyanidins and hydroxycinnamoyl-tartaric acids were the major phenolic compounds found in ‘BRS Clara’, whereas anthocyanins were the main phenolics found in ‘BRS Morena’. This last variety (a teinturier variety) showed qualitatively different phenolic composition in its skin and flesh, especially concerning the content of anthocyanin and flavonols. The anthocyanin profile of the ‘BRS Morena’ grape was dominated by malvidin-type derivatives. This differs from what has been found in other table grapes, such as ‘Red Globe’, ‘Crimson Seedless’, and ‘Napoleon’, which all showed peonidin 3-glucoside as the predominant anthocyanin (Cantos et al., 2002).

It is also different from the modern ‘Flame Seedless’ (Cantos et al., 2002) variety, which was shown to have more balanced proportions of acylated anthocyanidin 3-glucosides. In white varieties of table grapes, flavan-3-ols were shown to be the most abundant phenolics, with ‘Moscatel Italica’ having the highest content and the traditional ‘Dominga’ the lowest level compared with the modern ‘Superior Seedless’ (Cantos et al., 2002). The modern table grape ‘Italia’ was also shown to contain a higher amount of total phenolics, total flavonoids, and flavans in the skin than the traditional ‘Thompson Seedless’ (Baiano and Terracone, 2011). In pulp juices, ‘Italia’ had the highest concentration of hydroxycinnamoyl tartaric acids.

In a different report, the modern cultivar ‘Cardinal’ was shown to contain significantly fewer polyphenols, anthocyanins, and hydroxycinnamic acids than its traditional parent, ‘Alphonse Lavallée’ (Rolle et al., 2013). On the other hand, the modern table grape ‘Perlon’ was notable for having the smallest proportions of acetyl derivatives and cinnamoyl derivatives. In general, the most abundant anthocyanin compounds in grape skin of these varieties were malvidin monoglucoside derivative forms, except for in ‘Cardinal’, where peonidin monoglucoside derivative forms were predominant. Texture characteristics are also important to satisfying consumer preferences. In this context, higher values of chewiness were found in berries of the ‘Cardinal’ variety.

Muscadine grapes (*V. Rotundifolia* Michx.) are the most important *Vitis* species cultivated in the southeastern United States. (Marshall et al., 2012). In muscadine skin, free and total ellagic acid, myricetin, quercetin, and kaempferol were observed in several cultivars analyzed, including the modern ‘Eudora’ and ‘Janet’, and *trans*-resveratrol was observed in all cultivars except ‘Alachua’. Ellagic acid was the most abundant phenolic compound in muscadine grape skins, particularly in the modern ‘Southland’. This compound is commonly present in other fruits, such as raspberry, strawberry, and blackberry, but is absent in all other *Vitis* species (Marshall et al., 2012). In fact, muscadine grapes seem to be very rich in flavonols, flavan-3-ols, and ellagic acids (Zhu et al., 2012).

Regarding wine grapes, fewer modern cultivars are found, as previously mentioned. Examples of modern wine grapes are ‘Alicante Bouschet’, ‘Yan 73’, ‘Pinotage’, and ‘Regent’, which were bred for different purposes. For instance, ‘Regent’ was bred to obtain more resistance against pathogenic fungi while maintaining high quality wine.

‘Alicante Bouschet’ and ‘Yan 73’ are one of the few *V. vinifera* grape cultivars with red-colored berry flesh (teinturier grapes). Teinturier cultivars generally have a much higher anthocyanin concentration per unit juice volume or fresh mass than nonteinturier cultivars. However, the traditional Borraçal grapes were reported to have a higher phenolic content than ‘Alicante Bouschet’ (Teixeira et al., 2013).

In ‘Alicante Bouschet’, also known as ‘Garnacha Tintorera’, anthocyanins were found to be asymmetrically distributed within grape flesh and skins. Malvidin derivatives dominated in the skin, followed by peonidin-type anthocyanins, but the flesh almost exclusively contained peonidin 3-glucoside (Castillo-Muñoz et al., 2009). This was the

first report to point out the presence of pelargonidin 3-glucoside and its acetyl and *p*-coumaroyl derivatives in *V. vinifera* grapes. Flavonols also occurred in the flesh of ‘Garnacha Tintorera’ grapes, although the flavonol profile indicated lower contribution of trisubstituted flavonoid structures (myricetin, laricitrin, and syringetin) when compared with that of skin. The skin of ‘Garnacha Tintorera’ grapes also contained hydroxycinnamic acids, namely caftaric acid and coutaric acid, in higher amounts than the flesh.

‘Yan73’ is a teinturier red wine variety cultivated in China and used in wine making to strengthen red wine color. It was obtained from the hybridization of ‘Muscat Hamburg’ (*V. vinifera* L.) × ‘Alicante Bouschet’ (*V. vinifera* L.). He et al. (2010) identified 18 anthocyanins both in the skin and the pulp, as well as pelargonidin-3-O-glucoside, an anthocyanin compound hardly detected in most other *V. vinifera* berries, as previously stated. This anthocyanin in ‘Yan 73’ was also mentioned by Jin et al. (2009). However, the pulp exhibited a much lower ratio of 3',5'-substituted to 3'-substituted anthocyanins and a much higher ratio of methoxylation of anthocyanin B-ring to nonmethoxylation. In the skin of ripe ‘Yan73’ berries, the total concentration of 3',5'-substituted anthocyanins was over fourfold higher than that of 3'-substituted ones. In addition, aromatic acylated and aliphatic acylated anthocyanins were more present in the skin.

Some studies have addressed the composition ‘Pinotage’, a South African cross between ‘Pinot Noir’ and ‘Cinsaut’. In the report of Mattivi et al. (2006), ‘Pinotage’ was among the varieties that displayed higher levels of flavonoid 3'5'-hydroxylase activity in anthocyanins than in flavonols. The concentrations of malvidin-3-glucoside, procyanidin B1, caffeic acid, and caftaric acid were significantly higher in ‘Pinotage’ wines than in ‘Cabernet Sauvignon’ and ‘Shiraz’ wines (Rossouw and Marais, 2004). The ‘Pinotage’ wines differed significantly from other red wines, such as those made with ‘Merlot’ and ‘Shiraz’ as far as the content of 2-phenylethanol, butyric acid, ethyl acetate, isoamyl acetate, isoamyl alcohol, and isobutyric acid were concerned, presenting either increase or decrease in these compounds. Regarding these compounds, Pinotage red wines were in fact more similar to white wines (Louw et al., 2009).

However, little is known about the nature of aroma components of this cultivar, which typically exhibits berry and plumlike aromas. Van Wyk et al. (1979) identified isoamyl acetate as an impact aroma component of ‘Pinotage’. When present in moderate concentrations, it yields a positive banana-like aroma, but at too high concentrations, it can lead to a negative “duco”-like character. In addition, β -damascenone seems to influence the typical sweet, berry or plumlike aroma of ‘Pinotage’.

Regarding the ‘German Regent’ ([‘Sylvaner’ × ‘Mueller Thurgau’] × ‘Chambourcin’), it was shown that these grapes have a lower ratio of acetylated to coumaroylated malvidin and peonidin derivatives than the grapes from another modern cultivar, ‘Cerason’ (‘Merlan’ × [Blaufrankisch × Saint Laurent]) from the Czech Republic (Balík et al., 2013). ‘Regent’ also contains diglucosylated anthocyanins, in contrast with other interspecific hybrids, such as the modern ‘Nativa’.

Another modern wine cultivar from France named '*Marselan*' was shown to produce wines with vegetal, oaky, and salty characteristics, together with the modern 'Ruby Cabernet' from the United States (Miele and Rizzon, 2011). 'Arinarnoa' (a modern French variety) wine was characterized by spicy aroma and astringency, bitterness, and vegetal and intense flavor.

In another study comparing wines from the red varieties 'Pinotage', 'Cabernet Sauvignon', 'Merlot', 'Shiraz', and 'Ruby Cabernet', it was concluded that the total phenol content of 'Ruby Cabernet' is significantly lower than that of 'Shiraz' and 'Merlot'. On the other hand, its flavanol content was the lowest of all red cultivar wines (De Beer et al., 2003). 'Ruby Cabernet' exhibited the highest concentration of monomeric anthocyanins; however, this fact did not make up for its lower flavanol and total phenol contents in terms of total antioxidant activity, compared with the other red cultivar wines. The tartaric acid ester content of 'Shiraz' was higher than that of 'Ruby Cabernet' and 'Cabernet Sauvignon'.

The modern 'Albarossa' from Italy was compared with the parents of the cross, 'Barbera' and 'Nebbiolo di Dronero' grape varieties (Papini et al., 2010). 'Albarossa' was shown to contain less malvidin 3-glucoside and more cyanidin 3-glucoside than the other varieties. The 'Albarossa' anthocyanin percentage pattern is closer to that of 'Barbera' than that of 'Nebbiolo di Dronero' because of the high percentage (>80%), of trisubstituted nonacylated anthocyanins (malvidin, petunidin, and delphinidin) with respect to the disubstituted nonacylated anthocyanins (peonidin and cyanidin), as was evaluated for 'Barbera'. The total amount of terpenes in 'Albarossa' was in between the levels in the two parent varieties, except for geraniol, which was much higher than in the parents. 'Albarossa' and 'Nebbiolo di Dronero' had higher concentrations of *exo*-2-hydroxy-1,8-cineole and lower concentrations of *trans*-furan linalool oxide, *cis*-furan linalool oxide, *trans*-pyran linalool oxide, and *cis*-pyran linalool oxide than 'Barbera'.

METABOLIC PROFILING OF THREE PORTUGUESE WINE GRAPE CULTIVARS DURING RIPENING

The Varietal Character of Cultivars 'Touriga Nacional', 'Aragonês', and 'Trincadeira', and Platforms Used in Metabolomics

Portuguese wines are usually made with native Portuguese varieties. Among these, 'Touriga Nacional'; 'Aragonês', also called '*Tinta Roriz*' in Northern Portugal or '*Tempranillo*' in Spain; and 'Trincadeira' are exceptional red grape varieties that are often used to make both blend and monovarietal wines.

'Touriga Nacional' produces dark, full-bodied, powerful wines with complex aromas and floral notes similar to the scent of purple violet blossoms. It often presents blackberry, blueberry, rock rose, and rosemary notes. 'Aragonês' yields full-bodied, inky' and highly aromatic wines. The grape has fine and delicate aromas of red berries.

‘Trincadeira’ is known to have excellent acidity, soft tannins’ and abundant, intense aromas of plum, blackberry, and pepper.

Specific combinations of aromas, flavors, tannins, sugars, and acids create the unique varietal character of a ripe wine grape. Therefore the characterization of the metabolome of grapes, the complex mixture of compounds present in the grape, is of extreme importance in viticulture. An improved knowledge of how accumulation of sugars and flavor compounds in the berry occurs enables growers to adjust practices to market needs. A better understanding of grape ripening will help establish optimal grape maturity for harvest, a point that is difficult to determine because of the tremendous variability in ripening between berries within a grape cluster. Moreover, it will contribute to the maintenance of the sustainable production of high quality grapes in a changing environment (Fortes et al., 2011).

In order to characterize the metabolome of a sample, two complementary platforms are commonly used, namely nuclear magnetic resonance (NMR) spectroscopy and gas chromatography–mass spectrometry (GC–MS). NMR has lower sensitivity than GC–MS. However, it is nondestructive, requires simple sample preparation in relatively short time, and enables structural elucidation of unknown compounds. GC–MS, on the other hand, considerably increases the coverage of compounds as a result of its higher sensitivity (Fortes et al., 2011; Agudelo-Romero et al., 2013).

Phenotypic and Metabolic Characterization of Grape Berries During Ripening

Grape berry development consists of two successive sigmoidal growth periods separated by a lag phase; from anthesis to ripening, the growth can further be divided into three major phases with more detailed descriptive designations, referred as the Modified Eichhorn Lorenz system (E–L) and used for definition of more precise growth stages over the entire grapevine lifecycle (Coombe, 1995). During the first growth period there is formation of the seed embryos and the pericarp. This stage is characterized by exponential growth of the berry, biosynthesis of tannins and hydroxycinnamic acids, and accumulation of mainly two organic acids, tartrate and malate (EL31–EL34).

Tannins are present in skin and seed tissues and nearly absent in the flesh, and are responsible for the bitter and astringent properties of red wine. The onset of ripening, *véraison* (EL35), is a transition phase during which there is a decrease in growth, initiation of color development (anthocyanin accumulation in red grapes), and berry softening. Ripening (the last phase, EL36–EL38) involves additional berry growth mainly as a result of cell expansion, increase in pH, and accumulation of soluble sugars, cations such as potassium and calcium, anthocyanins, and flavor-enhancing compounds.

Figure 1 depicts the evolution of berry weight and anthocyanin content in three varieties, ‘Touriga Nacional’, ‘Aragonês’, and ‘Trincadeira’, at four developmental stages during one season. ‘Touriga Nacional’ is the variety accumulating more anthocyanins at

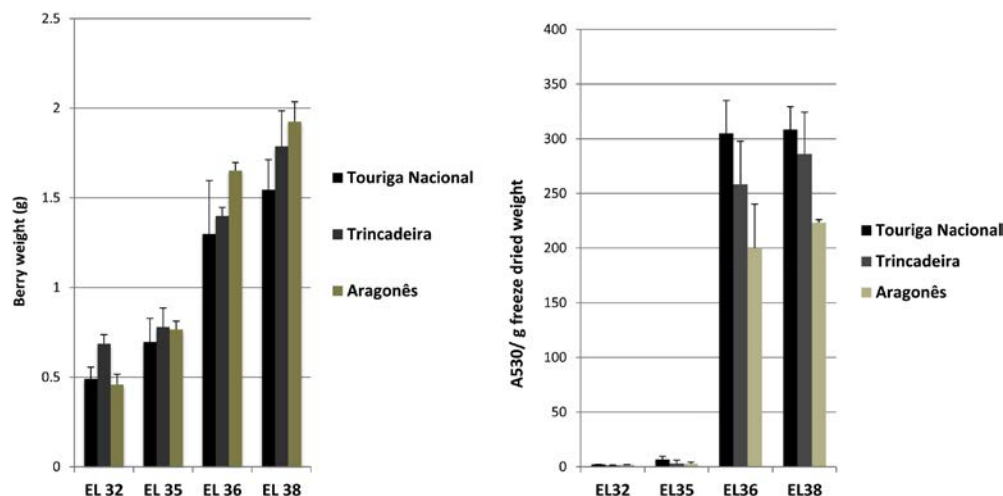


Figure 1 Fresh berry weight (g) and total anthocyanin content of berries at developmental stages of EL-32 (green), EL-35 (*véraison*), EL-36 (ripe), and EL-38 (harvest). Anthocyanin content is the value of absorbance at 530 nm/g of freeze dried material. Bars represent standard deviation. Image reproduced with permission from [Agudelo-Romero et al. \(2013, PloS One\)](#).

harvest stage (EL 38), probably because of the smaller size of the berries and because except for *teinturier* varieties, anthocyanins accumulate in the skin.

Metabolic Profiling of Grape Berries Assessed by Nuclear Magnetic Resonance

Generally, the metabolome associated with grape ripening assessed by nuclear magnetic resonance spectroscopy (NMR) is characterized by a decrease in content in phenolics and organic acids, especially malate and tartarate, and by an accumulation of amino acids and sugars ([Ali et al., 2011](#)). Increased coverage of metabolites present in berries can be achieved using ^1H NMR together with two-dimensional techniques, such as j-resolved 2D spectroscopy (J-resolved), ^1H homonuclear (^1H – ^1H), Correlation spectroscopy (COSY), Heteronuclear multiple-bond correlation spectroscopy (HMBC) and Heteronuclear Single Quantum Coherence (HSQC). The metabolites identified ([Table 2](#)) are diverse, ranging from amino acids, organic acids, carbohydrates, hydroxycinnamates, and hydroxybenzoates to stilbenes and flavonoids ([Ali et al., 2011](#); [Fortes et al., 2011](#)).

[Figure 2](#) shows the ^1H NMR spectra corresponding to four developmental stages of ‘Trincadeira’ berries. It can be observed that the decrease in phenolics (high chemical shifts) and organic acids, especially malic and tartaric acids (medium chemical shifts), occur at ripe and harvest stages. On the other hand, amino acids (low chemical shifts) such as γ -amino butyric acid (GABA), proline, methionine, and arginine increase toward harvest together with sugars, namely α -glucose ([Ali et al., 2011](#); [Fortes et al., 2011](#)).

However, ‘Touriga Nacional’, ‘Aragonès’, and ‘Trincadeira’ cultivars have differences in their metabolic profiles. [Figure 3](#) shows a comparison of the metabolic contents of the

Table 2 ^1H NMR chemical shifts (d) and coupling constants (Hz) of grape metabolites
Metabolite^a **Chemical shift and multiplicity/coupling constant**

<i>cis-p</i> -Coutaric acid	5.41 (s), 5.94 (d, J = 13.0), 6.73 (d, J = 9.2), 6.86 (d, J = 13.0), 6.93 (d, J = 9.2), 7.61 (d, J = 9.2)
<i>cis</i> -Caftaric acid	5.34 (s), 5.92 (d, J = 13.0), 6.71 (d, J = 8.4), 6.81 (d, J = 13.0), 7.03 (dd, J = 8.4, 2.0), 7.44 (d, J = 2.0)
<i>trans-p</i> -Coutaric acid	5.42 (s), 6.45 (d, J = 16.0), 6.87 (d, J = 8.8), 7.51 (d, J = 8.8), 7.65 (d, J = 16.0)
<i>trans</i> -Fertaric acid	3.89 (s), 5.38 (s), 6.32 (d, J = 16.0), 6.89 (d, J = 8.4), 7.01 (dd, J = 8.4, 2.0), 7.19 (d, J = 2.0), 7.56 (d, J = 16.0)
<i>trans</i> -Caftaric acid	5.34 (s), 6.41 (d, J = 16.0), 6.88 (d, J = 8.4), 7.02 (dd, J = 8.4, 2.0), 7.12 (d, J = 2.0), 7.62 (d, J = 16.0)
Myricetin	6.28 (d, J = 2.0), 6.51 (d, J = 2.0), 7.30 (s)
Quercetin-3-O-glucoside	5.30 (d, J = 7.6), 6.27 (d, J = 2.0), 6.49 (d, J = 2.0), 6.95 (d, J = 8.6), 7.56 (dd, J = 8.5, 2.0), 7.81 (d, J = 2.0)
(-) – Epicatechin	2.72 (dd, J = 16.8, 2.8), 2.85 (dd, J = 16.7, 4.6), 5.91 (dd, J = 10.0, 2.3), 6.96 (d, J = 2.2)
(+) – Catechin	2.49 (dd, J = 16.1, 8.2), 2.83 (dd, J = 16.0, 5.4), 4.04 (m), 4.55 (d, J = 7.5), 5.91 (d, J = 2.2), 6.75 (d, J = 8.0)
Vanillic acid	3.90 (s), 6.77 (d, J = 8.2), 7.22 (m)
Syringic acid	3.89 (s), 7.31 (s)
Gallic acid	7.03 (s)
Fumaric acid	6.52 (s)
Formic acid	8.45 (s)
Malic acid	2.68 (dd, J = 16.6, 6.6), 2.78 (dd, J = 16.6, 4.7), 4.34 (dd, J = 6.6, 4.7)
Ascorbic acid	4.52 (d, J = 2.0)
α -Linolenic acid	0.95 (t, J = 7.5)
Tartaric acid (free)	4.30 (s)
Citric acid	2.56 (d, J = 17.6), 2.74 (d, J = 17.6)
Succinic acid	2.53 (s)
Choline	3.20 (s)
Acetic acid	1.94 (s)
2,3-Butanediol	1.14 (d, J = 6.47)
Sucrose	5.39 (d, J = 3.94)
Fructose	4.08 (d, J = 7.80)
β -Glucose	4.58 (d, J = 7.89)
α -Glucose	5.17 (d, J = 3.78)
Glutamic acid	2.13 (m), 2.42 (m), 3.71 (dd, J = 7.0, 1.9)
Threonine	1.32 (d, J = 6.5), 3.51 (d, J = 5.0), 4.27 (m)
Methionine	2.15 (m), 2.65 (t, J = 8.0)
Proline	2.35 (m), 3.37 (m)
GABA	1.90 (m), 2.31 (t, J = 7.5), 3.01 (t, J = 7.5)
Alanine	1.48 (d, J = 7.4), 3.73 (q, J = 7.4)
Leucine	0.96 (d, J = 7.5), 0.98 (d, J = 7.5)
Valine	1.01 (d, J = 7.0), 1.06 (d, J = 7.0), 2.28 (m)

GABA, γ -Aminobutyric acid.^aMetabolites were identified by references and using one dimension and two dimension NMR spectra ($\text{CD}_3\text{ODeKH}_2\text{PO}_4$ in D_2O , pH 6.0).

The table was reproduced with permission from Ali et al. (2011, Food chemistry).

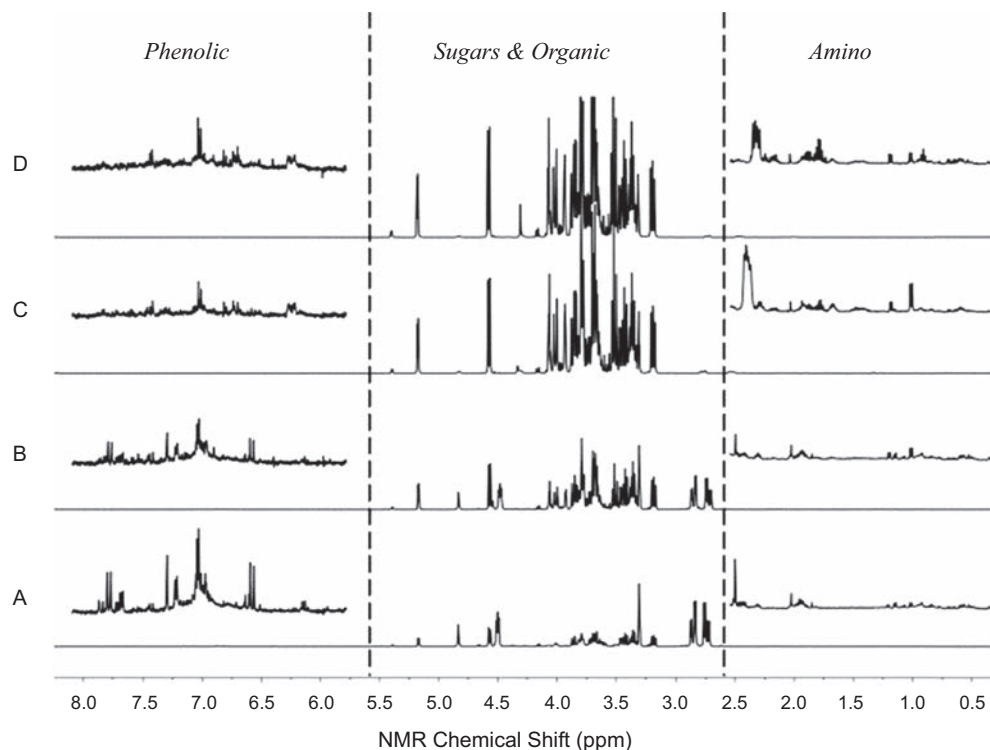


Figure 2 Comparison of grape berry metabolome at different developmental stages. ^1H NMR spectra of green (A), *véraison* (B), ripe (C), and harvest (D) stages of 'Trincadeira'. The phenolics and amino acids signal intensities are amplified. The decline in concentrations of phenolics and organic acids are noticed as the berry grows, whereas sugars and amino acids increase with the ripening of berries. NMR, Nuclear magnetic resonance. Image reproduced with permission from Ali et al. (2011, Food Chemistry).

three cultivars at green stage. Generally, 'Trincadeira' can be characterized by low phenolics but higher sugars and organic acids, whereas 'Touriga Nacional' and 'Aragonês' have higher phenolics' contents and some amino acids (Ali et al., 2011). The green and *véraison* stages of 'Trincadeira' are characterized by high levels of malic acid, choline, and succinic acid, whereas 'Aragonês' and 'Touriga Nacional' higher levels of citric acid and quercetin glucoside, along with elevated signals of hydroxycinnamic acid derivatives such as caftaric acid and coutaric acid, and sucrose at the same stages. For all the varieties, ripe and harvest stages show increased content in acetic acid, GABA, glucose, and the amino acids such as valine and proline (Ali et al., 2011; Fortes et al., 2011). However, the harvest stage of 'Trincadeira' has high levels of valine, methionine, glucose, and acetic acid, and the ripe stage shows more amino acids, such as threonine and proline. The ripe and harvest stages of 'Aragonês' and 'Touriga Nacional' had similar metabolic profiles, exhibiting higher amounts of the amino acids leucine, alanine, and GABA.

Taking into account the ^1H NMR data, the 'Aragonês' and 'Touriga Nacional' cultivars were found to have a very similar metabolic profile (Ali et al., 2011). However,

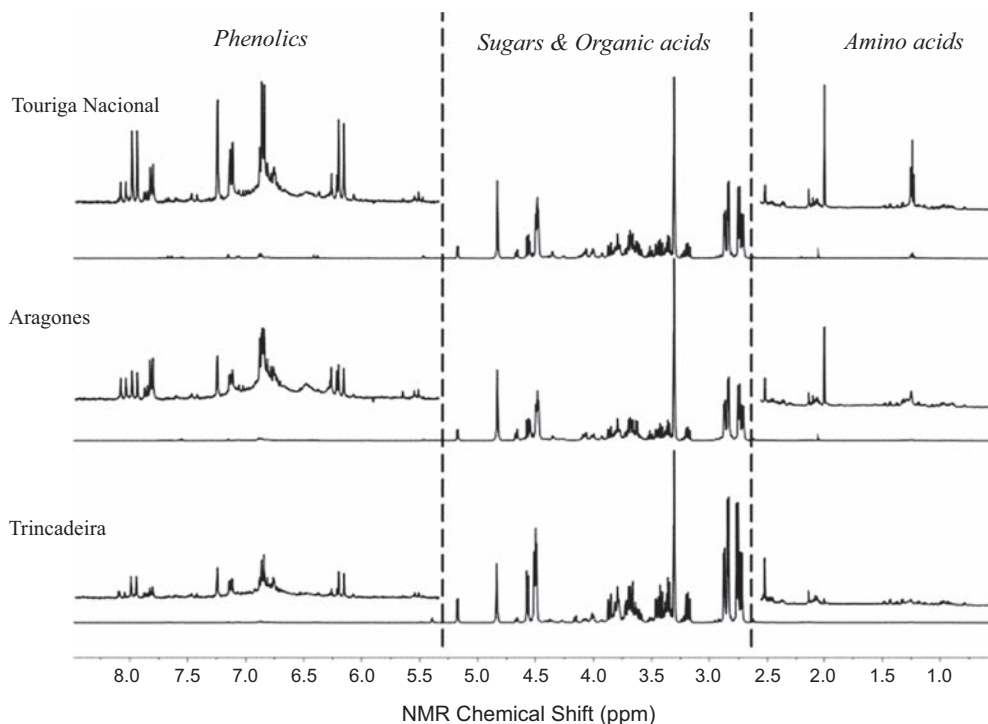


Figure 3 Comparison of ^1H NMR spectra of three grape cultivars. The phenolics and amino acids signal intensities are amplified. ‘Touriga Nacional’ was found to be more concentrated with phenolics, whereas lower phenolics intensities can be observed in ‘Trincadeira’ with high sugar and organic acid contents. Image reproduced with permission from Kashif et al. (2011, Food Chemistry).

higher resonances for proline, choline, and fertaric acid were observed in ‘Aragonés’, whereas the levels of caftaric acid and quercetin glucoside were higher in the green and *véraison* stage of ‘Touriga Nacional’, providing evidence of higher accumulation of phenylpropanoids in this variety. The ripe and harvest stages for both the cultivars were distinguished by high levels of glucose, leucine, alanine, and valine.

The characterization of the metabolites present in each stage of the grape berry development of all the three cultivars is summarized in Figure 4. Essentially, the phenolics and organic acids are more present in green and *véraison* stages, whereas the ripe and harvest stages contain increased quantities of valine, catechin, GABA, glucose, and fructose.

Metabolic Profiling of Grape Berries Assessed by Gas Chromatography-Electron Ionization-Time Of Flight-Mass Spectrometry (GC-EI-TOF/MS)

The GC-MS-based metabolome analysis of the same cultivars complemented the NMR data, and, importantly, increased the coverage to a total of 121 volatile and soluble taste and aroma components (Agudelo-Romero et al., 2013). Metabolic

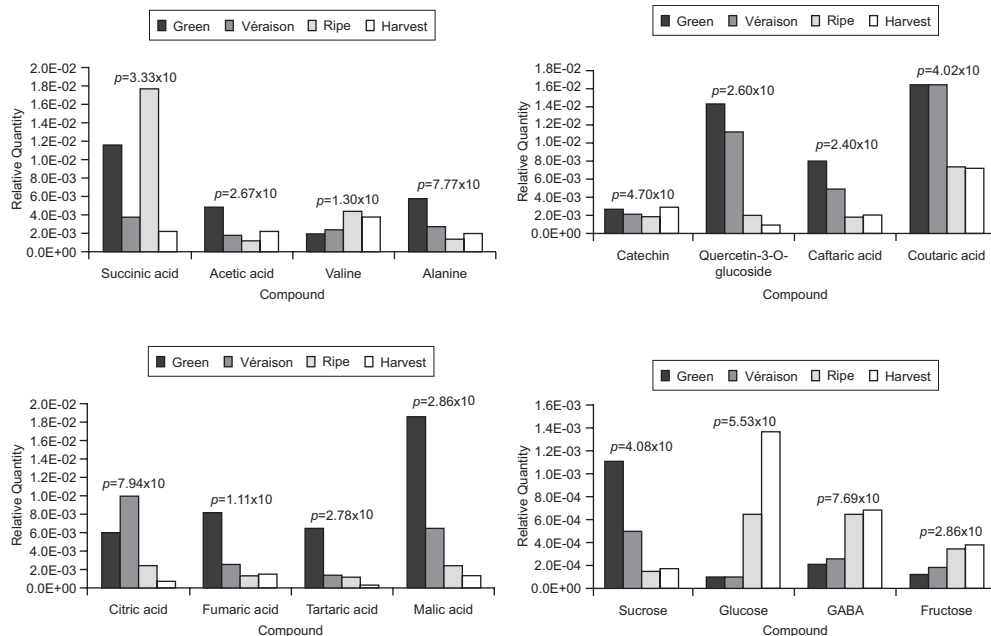


Figure 4 Relative quantification of compounds based on the mean peak area of the associated signals. The graph shows the p value after Analysis of Variance (ANOVA) between green, *véraison*, ripe, and harvest groups. Image reproduced with permission from Kashif et al. (2011, Food Chemistry).

profiling of grapes carried out using a GC-EI-TOF/MS platform enabled the relative quantification of several classes of compounds, such as fatty acids, phenylpropanoids, and sugars, among the polar compounds. These authors reported on a substantial metabolic reprogramming during berry development and ripening, as can be observed with a heat map (Figure 5, normalized responses). Some alcohols and aldehydes such as ethanol, (E)-2-hexenal, and heptanal reached the highest levels in ripe and harvest stage of fruits, and contributed to the formation of aroma. The same holds true for sugars and many fatty acids. Organic acids tend to decrease during ripening in all varieties, although they exhibit a high degree of variance among them. Phosphoric acid is an exception, because it increases at harvest stage in all varieties. Phenylpropanoids and flavonoids may also decrease or increase during ripening (Agudelo-Romero et al., 2013).

Organic acids, which are well known for their contribution to differences in wine flavor, were encountered among the three varieties, in particular at green and *véraison* stages. ‘Touriga Nacional’ tends to contain more citric acid than ‘Aragonês’ and ‘Trincadeira’. ‘Aragonês’ has elevated concentration of succinate, whereas ‘Trincadeira’ has a higher concentration of fumarate. In fact, although malic and tartaric acids showed the

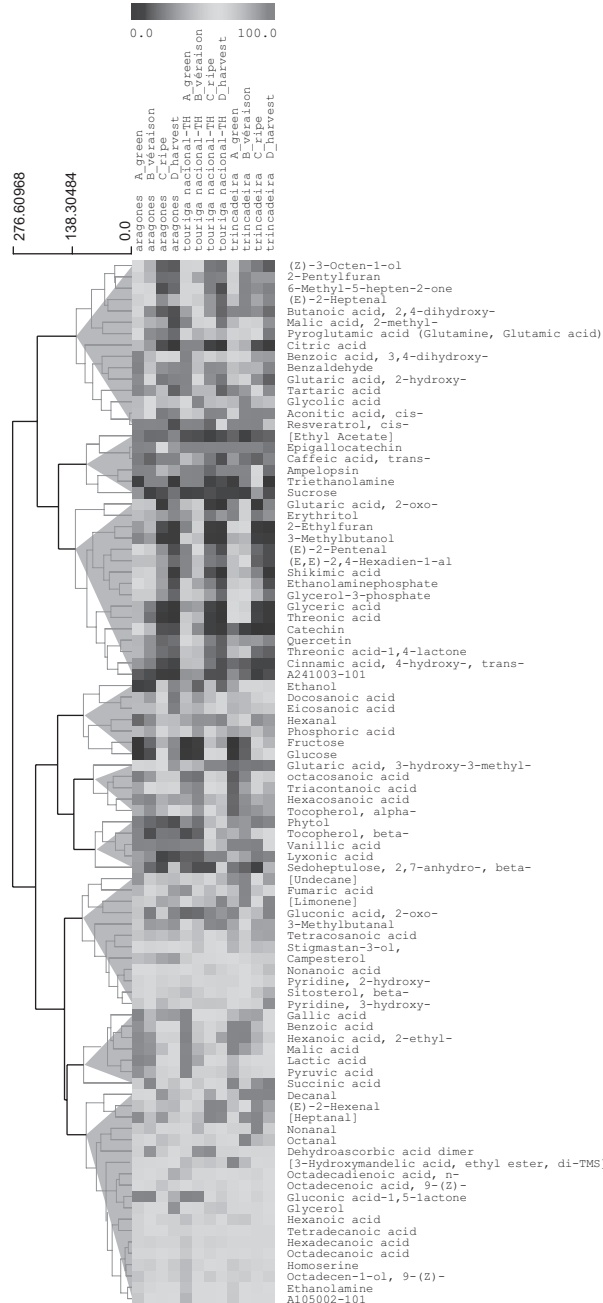


Figure 5 Heat map showing metabolite levels analyzed during berry ripening for three varieties. Each square represents the average of the biological replicates. *Image reproduced with permission from Agudelo-Romero et al. (2013, PloS One).*

highest content in green berries in all varieties, citrate, succinate, and fumarate showed the highest content in different developmental stages (green or *véraison*), depending on the variety.

Still related to carbohydrate metabolism, the sugar alcohol erythritol is more present in the 'Aragonês' cultivar at harvest stage (Figure 6), and may contribute to the final wine taste.

In this metabolic survey during grape ripening, fatty acid biosynthesis appeared to be enhanced for wax biosynthesis, as well as for aroma production, which is also the result of a specific fatty acid and correspondent esters combination.

In general, several saturated fatty acids increased at ripe and harvest stages in all the varieties, namely octacosanoic, hexacosanoic, and triacontanoic acids. This increase was much more noticed in 'Touriga Nacional' berries, whereas docosanoic and eicosanoic acids showed increased levels at harvest stage in the 'Aragonês' cultivar. Fatty acids, such as *n*-hexadecanoic acid and 9,12-(*Z*, *Z*)-octadecadienoic acid (linoleic acid), have an important influence on the flavor of strawberry fruit (Zhang et al., 2011).

It was observed that an increase in α -tocopherol occurred in all varieties during ripening, but in particular in 'Touriga Nacional'. Glycerol, which is also important to the flavor of wine, had the highest concentration at harvest in 'Aragonês'.

Regarding phenolics, ampelopsin, or dihydromyricetin, was detected at higher concentration in ripe berries and mainly in 'Aragonês' (Figure 5). Gallic acid, caffeic acid, and the tannin catechin decrease during ripening in all varieties. A reduction in tannin concentration from pre-*véraison* to harvest has been well documented. On the other hand, epigallocatechin was much higher in 'Aragonês' than in the other cultivars at harvest stage and may contribute to higher astringency of the wine (Figure 6). 'Touriga Nacional' was the variety accumulating more caffeic acid and *trans*-4-hydroxycinnamic acid or *p*-coumaric acid at green stage. As mentioned previously, through an NMR platform it was established that the green and *véraison* stages of 'Touriga Nacional' have hydroxycinnamic acid derivatives, such as caftaric acid, than 'Aragonês' and 'Trincadeira' (Ali et al., 2011).

The accumulation of stilbenes during ripening of grape berries is well known, but different varieties may have different contents. Resveratrol or *trans*-3, 4, 5-trihydroxystilbene is present at higher concentrations in 'Touriga Nacional' berries at ripe and harvest stages.

Aroma Development Evaluated by Headspace GC-EI-MS Platform

Monoterpenes, C13-norisoprenoids, and some benzenoid compounds are important grape aroma substances, as previously mentioned. Benzaldehyde and benzoic acid, which may constitute a precursor of volatile benzenoids, showed a tendency to decrease in all varieties during ripening. Among important volatiles is the alcohol 3-methylbutanol, which is considered a key odorant in 'Grenache', 'Cabernet Sauvignon', and 'Merlot'

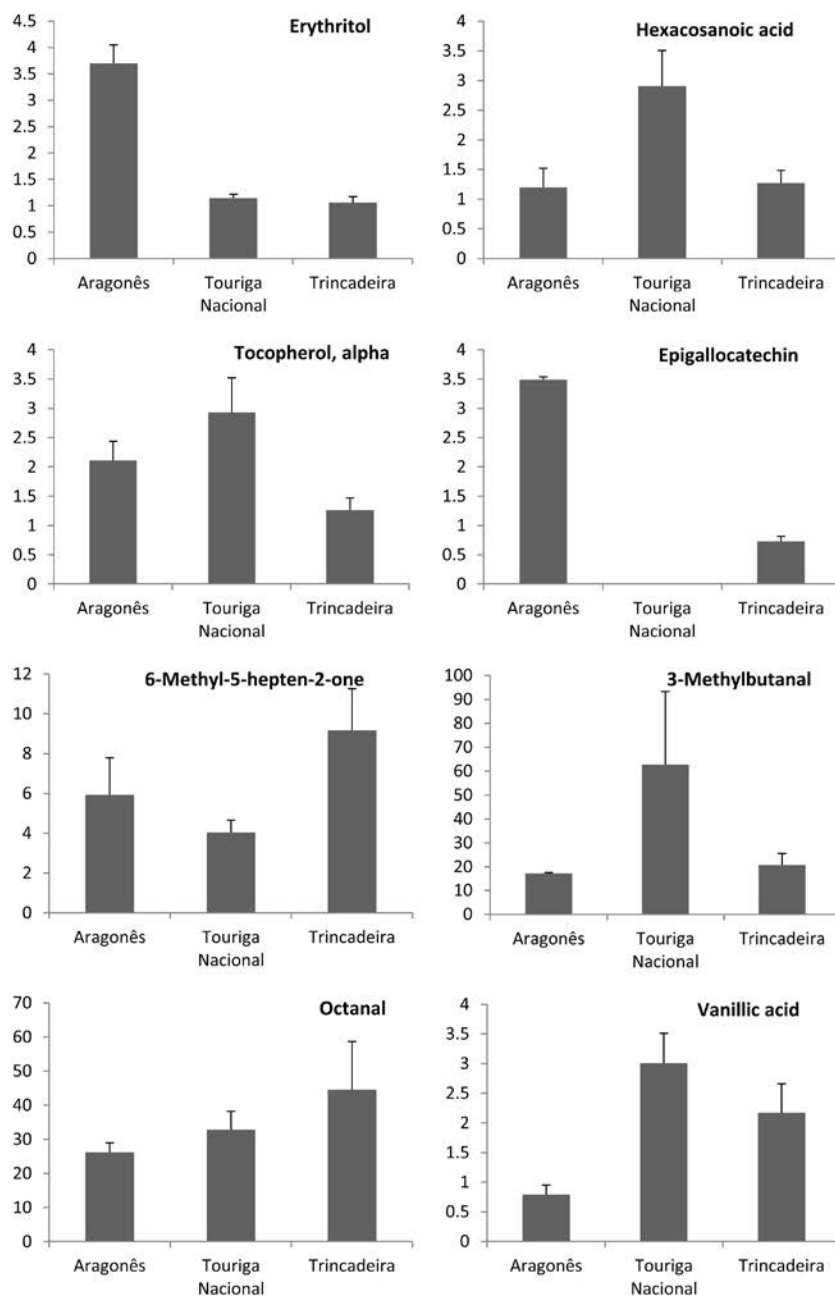


Figure 6 Relative quantification of selected metabolites based on normalized responses present in the three varieties at harvest stage. Metabolites were identified by GC-EI-TOF/MS and by headspace GC-EI-MS.

wines (Kotseridis and Baumes, 2000). This compound was present in higher concentration in ‘Touriga Nacional’ and ‘Aragonês’ berries at green stage but decreased during ripening in both varieties, showing no significant differences when compared with ‘Trincadeira’ at harvest stage.

Some flavor volatiles peak at pre-*véraison* or *véraison* stage, and others at ripe or harvest stage, and this may be also dependent on the variety (Agudelo-Romero et al., 2013). The volatiles (E)-2-pentenal, 2-ethylfuran, 2-pentylfuran, (E, E)-2,4-hexadien-1-al, 3-methylbutanol, 3-methylbutanal, benzaldehyde, 6-methyl-5-hepten-2-one, and (Z)-3-octen-1-ol were higher at green stage. On the other hand, the volatiles ethanol, hexanal, decanal, and nonanal increased their content at ripe and harvest stages, whereas (E)-2-hexenal peaked at ripe stage. The content in the putatively identified undecane peaked at *véraison* or ripe stage, depending on the variety, whereas heptanal peaked at ripe stage and limonene at harvest stage.

The compound 6-methyl-5-hepten-2-one is an important flavor volatile in tomato (Gao et al., 2008) and is significantly higher in ‘Trincadeira’ at harvest stage comparing with the other varieties (Figure 6). Furthermore, the putatively identified cyclic terpene limonene that provides a lemonlike fresh aroma reaches the highest concentrations at harvest stage in ‘Trincadeira’ and in ‘Touriga Nacional’. In fact, ‘Touriga Nacional’ wines are characterized by a fruity-citric aroma described as *sweet* and *fresh citrus*.

Dicarbonyl compounds, like methylglyoxal, are often associated with amino acids in the formation of odorous products present in wine. Leucine and methylglyoxal give rise to 3-methylbutanal, which is responsible for a moderate amylic aroma. This compound also reached the highest values in ‘Touriga Nacional’ at harvest stage (Figure 6).

In ‘Cabernet Sauvignon’ grapes, both (E)-2-hexenal and hexanal showed a significant increase after *véraison*, followed by a decrease in the harvest stage (Kalua and Boss, 2009). According to Agudelo-Romero et al. (2013), these compounds were more present in ‘Touriga Nacional’ and ‘Trincadeira’ at ripe stage.

Other aliphatic aldehydes, such as octanal and (E)-2-heptenal, provide an herbaceous odor. Octanal seems to be present in higher amounts in ‘Trincadeira’ at harvest stage, whereas (E)-2-heptenal is present at *véraison*. (E)-2-heptenal, or *trans*-2-heptenal, and (E)-2-hexenal, or *trans*-2-hexenal, are known to provide fruity, green, leafy notes. Decanal is associated with citrus peel and sawdust or plant odor and accumulates in ‘Trincadeira’ at ripe and harvest stages. Nonanal with a fatty-green aroma also accumulates at these stages, in particular in this variety.

Vanillic acid, a precursor of vanillin, was only identified in grapes at ripe and harvest stages and shown to be present in higher amounts in ‘Touriga Nacional’ (Figure 6), highlighting the known aromatic potential of these grapes.

Agudelo-Romero et al. (2013) concluded that although important differences were noticed among the three varieties, the common pattern seems to be that grapes in pre-*véraison* and *véraison* stages are enriched in carotenoids, benzaldehyde, and caffeic acid,

and post-*véraison* grapes are enriched in volatile terpenes and sulfur compounds, C6 alcohols and aldehydes, and vanillic acid.

SUMMARY POINTS

- Grape vine is one of the most important and ancient horticultural plants in the world. The family Vitaceae, which includes grape vines dating from 60 million years ago. Eurasia and North America are the regions of origin of *Vitis* (sect. *Euvitis*) *vinifera*.
- Domestication of wild species *V. vinifera* ssp. *sylvestris* to *V. vinifera* ssp. *vinifera* may date of 8500–4000 BCE in Eurasia. Changes from dioecious wild to hermaphrodite cultivated plants were crucial.
- The wild grape germplasm is a potential source of unique alleles for improving both wine and table grapes, aiming at a more efficient and environmentally sustainable grape production.
- The genus *Vitis* L. (grape) includes 68 species. This genus is distinguished from the other Vitaceae genera by having petals that remain coalescent at the top and separated at the base (calyptra), falling as a cap.
- Native grape vine cultivars are important for viticulture production in many countries, such as Portugal and Spain, that stick to their own cultivars, which provide wines with particular characteristics.
- Sugars; organic acids; phenolic, nitrogenous, and aromatic compounds are important for the nutritional quality of grape fruits that ultimately influence wine quality.
- Differences in the content in sugars and organic acids are found among traditional cultivars of *V. vinifera*, as well as in hybrids, with wine grapes being more acidic and containing more sugars than table grapes. Polyphenolic compounds, with few exceptions, are on average at higher concentrations in wine grapes than in table grapes.
- Most wine-producing varieties are nonaromatic. The varietal character of wine deriving from nonaromatic grapes originates mainly from the transformation of odorless precursors (glycosidically bound volatile compounds, such as C6 compounds, terpenes, benzenoids, phenols, and norisoprenoids) into odor-active compounds during winemaking.
- The final aroma of wine depends mainly on the cultivars and clones used, although environment may also have an impact.
- Table grapes have been subjected to more intensive breeding than wine grapes; therefore more modern cultivars are found with substantial differences in phenolic compounds and organic acids.
- Table grapes may have a neutral green aroma, be flowery and citrusy from terpenes, or be musky with anthranilate and other esters.
- Teinturier varieties may have a different profile in anthocyanins from most *V. vinifera* cultivars. Composition in anthocyanins is also different in wine and table grapes.

- Muscadine grapes are enriched in flavonols, flavan-3-ols, and ellagic acids.
- Modern wine grapes were bred for different objectives. For instance, Regent was bred in order to obtain more resistance against pathogenic fungi combined with high quality wine.
- The metabolome of three Portuguese wine grapes ('Touriga Nacional', 'Aragonês', and 'Trincadeira') were extensively analyzed during ripening, taking advantage of two complementary platforms, namely NMR spectroscopy and GC-MS. The metabolites identified are diverse, ranging from amino acids, organic acids, fatty acids, carbohydrates, hydroxycinnamates, and hydroxybenzoates to stilbenes and flavonoids, as well as aroma compounds.

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CHAPTER 13

Guava (*Psidium guajava* L.) Cultivars: An Important Source of Nutrients for Human Health

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LIST OF ABBREVIATIONS

ABTS 2,2-azinobis (3-ethyl-benzthiazoline-6-sulfonic acid)
AEAC Ascorbic acid equivalent antioxidant capacity
AFLP Amplified fragment length polymorphism
DNA Deoxyribonucleic acid
DPPH 2,2-diphenyl-1 picrylhydrazyl
FAO Food and Agriculture Organization of the United Nations
FIC Iron-ferrozine complex
FRAP Ferric reducing antioxidant power
GC Gas chromatography
GC-FID Gas chromatography with flame ionization detection
GC-MS Gas chromatography-mass spectrometry
HDL High-density lipoproteins
HS-SPME headspace solid-phase microextraction

IC₅₀ Defined as the concentration of antioxidant necessary to scavenge 50% of DPPH radicals

IIFT Institute for the Research of Tropical Fruits

IU International units

LEAC Lycopene equivalent antioxidant capacity

ORAC Oxygen radical absorption capacity

QTL Quantitative trait loci

ROS Reactive oxygen species

SSR Simple sequence repeats

TDF Total dietary fiber

TE Trolox equivalent

UV Ultraviolet

INTRODUCTION

Guava (*Psidium guajava* L.), also called the apple of the tropics, is native to tropical Central America, from Mexico to northern South America, while it has been introduced to other tropical and sub-tropical areas around the world (Padilla and Gonzalez, 2010). This fruit tree belongs to the Myrtaceae family, which comprises a large number of fruit-yielding species. It is a popular crop due to its year-round availability, affordable price, durability during transportation and handling, and overall consumer preference (Thaipong and Boonprakob, 2005).

Minor tropical fruits such as guava have undergone a significant increase in both production and value in recent years (Quijano and Pino, 2007). On a worldwide scale, however, guava is produced in much smaller quantities as compared the major tropical fruits. Nevertheless, it is economically important with different production levels in Australia, Brazil, Colombia, Bangladesh, Cuba, Egypt, India, Indonesia, Israel, Jamaica, Kenya, Malaysia, Mexico, Pakistan, South Africa, Sudan, Taiwan, Thailand, United State (Florida and Hawaii), Venezuela, and Viet Nam (Singh and Jain, 2007; Pommer and Murakami, 2009).

Guava fruit is important both for fresh consumption and for industrial processing. International trade currently focuses on processed products that are imported mainly by the United States, Japan, and Europe (Singh and Jain, 2007).

Many genotypes are obtained through natural selection and breeding programs, with the principal aim to improve fruit commercial characteristics. This process resulted in a great variability of fruit internal and external attributes of cultivars in almost every country where guava constitutes a commercial crop. These variations include agronomical characters as well as the composition of antioxidant compounds, vitamins, and minerals, all of which are important for diet and human health. Also, essential oils and some of their constituents can present a remarkable variation and are responsible for its characteristic flavor and aroma (Pomer et al., 2013). These properties permit to consider guava fruit as one of the most nutritive from the tropics.

Given the current trend of identifying natural products that contribute to nutrition and human health, new cultivars should preferably combine desired commercial characters and some other important active components to guarantee human supplements as they are required for well nutrition according to the recommended daily intakes. This chapter, therefore, comprises information regarding composition and distribution of some guava nutritional constituents in both traditional and modern cultivars.

BOTANICAL ASPECTS

Guava (*Psidium guajava* L.) belongs to the genus *Psidium* of the Myrtaceae family. *Psidium* includes shrubs or trees with opposite or sub-alternate leaves with pellucid (translucent) gland dots. The lateral nerves are mostly ascending, arcuate-anastomosing without forming a distinctive marginal nerve. Inflorescence cymose, from one to seven flowered. Calyx various, usually splitting irregularly down to the ovary in anthesis. Calyx-limb with four to five distinct teeth or lobes or completely closed in bud or with an apical pore. Petals orbiculate or obovate and white color. Stamens numerous, the filaments incurved in bud, anthers dorsifixed, dehiscing longitudinally. Ovary two to seven locular, many ovulate, the placenta appearing two lamellate; ovules in single or triple row; stigma capitate or peltate. Berries are often fleshy, mostly globose in shape, and with many seeds, which are hippocrepiform or reniform, embedded in the pulp, the testa dull, hard. Embryo is uncinatate or curved, radical elongated and cotyledons very short (Liogier, 1994; Pommer and Murakami, 2009). Several species of *Psidium* produce edible fruit, of which the most important are *Psidium cattleianum* Afzel. ex Sabine, *P. friedrichsthalianum* (O. Berg.) Nied., and especially *P. guajava* L.

Guava (*Psidium guajava* L.) is a small branched tree or shrub up to 7–10 m tall. The root system is superficial. The trunk is woody, hard, with a characteristic smooth, pale mottled bark that peels off in thin flakes, after the trunk has grown to about 20 cm in diameter. Branches can be ascending, spreading, or drooping, resulting in different canopy forms (Liogier, 1994; Pommer and Murakami, 2009; Rodríguez et al., 2010b).

Young twigs are green, yellow, reddish, or red, quadrangular and downy with green or brownish-reddish young leaves due to variation in anthocyanic pigmentation. Mature leaves are aromatic, evergreen, sub-chartaceous, and opposite, with prominent lateral veins on the underside. Leaf shape varies from elliptic to oblong-lanceolate, rarely rounded, 4–10 cm long and 2.5–6 cm wide, apex attenuate, apiculate, rounded but mainly obtuse or acute, broadly cuneate at the base, and with short petioles 2–7 mm long (Liogier, 1994; Morton, 2000; Rodríguez et al., 2010b).

Flowers faintly fragrant, hermaphrodite, white colored, large, solitary or in clusters of two to three. Flowers with 4–5 petals, but also often with 10 petals placed in two series of five. Petals obovate, white, pubescent, 1–2 cm long. Pedicels pubescent, 1.5–2.5 cm long. Stamens numerous, about 1 cm long, with much pollen and tipped with

pale-yellow anthers. Petaloid stamens can also develop (Morton, 2000; Rodríguez et al., 2010b). Flowering can be continuous, with flowers borne on newly emerging lateral shoots, irrespective of the time of year. As a result, blossom bud formation and subsequent fruit set can be very erratic during the year and between years, depending on diverse abiotic factors (Morton, 2000; Pommer and Murakami, 2009).

Guava fruits are variable in shape. They can be pyriform, oblate, rounded, ellipsoidal, oval, or cylindrical. Mature fruit has a sweet strong smell sometimes combined with different degrees of musky odor. It can weigh 25–500 g or more, is 5–12 cm long, 3–6 cm wide, with four or five protruding floral remnants (sepals) at the apex. The diameter of the calyx cavity is variable. Fruit peel can be smooth, rough, or bumpy and develop pale yellow, pale yellow-greenish, dark yellow, orange-green, dark green, or red colors at maturity (Morton, 2000; Rodríguez et al., 2010b).

Next to the skin is a layer of somewhat granular flesh of variable color. The pulp can be white, cream, pale pink, pink, or dark pink, orange-pink or orange in mature fruit, with varying degrees of juiciness, acidity, and sweetness. The thickness of this outer flesh is about 3–20.3 mm. The central pulp is juicy and normally filled with very hard yellowish seeds, variable in size, on average 3 mm long and 2 mm wide. Some rare types have soft, chewable seeds. The number of seeds per fruit ranges from 16 to 632. Seed weight ranges from 0.8 to 12.6 g (Morton, 2000; Rodríguez et al., 2010b).

COMPOSITION OF TRADITIONAL CULTIVARS

The propagation by seeds during large period of domestication has derived in high guava plant diversity in natural conditions. This, together with breeding programs that started nearly a century ago, allowed to select improved plants with desirable characteristics, which constituted the first cultivars destined for commercial uses. Some of them, due to distinctive characteristics, are either exploited nowadays or have constituted the source for generating new modern cultivars. That is why they are named “traditional” or “ancestral” cultivars. They have formed the base for breeding programs in different countries with both local and foreign cultivars. Some of them are the following: ‘Allahabad Safeda’, ‘Apple’, ‘Sardar’, and ‘Lucknow-49’ in India; ‘Paluma’ and ‘Rica’ in Brazil; ‘Patillo’, ‘Pink acid’, ‘Redland’, and ‘Supreme’ in the United States; ‘Beamount’ in Hawaii; ‘Ben-dov’ in Israel; ‘Hong Kong pink’ and ‘Hong Kong white’ in Hong Kong; ‘Mukundapuri’ and ‘Swarupkathi’ in Bangladesh; ‘Fan Retief’ in South Africa, ‘Cotorrera’ and ‘Belic L-207’ in Cuba; and ‘Media china’ in Mexico (Pommer and Murakami, 2009).

All parts of the plant, but especially the fruits of traditional cultivars exhibit considerable diversity, not only in terms of agronomic traits but also with respect to the composition of nutritional constituents (Table 1). In the following, variations of nutritional components as well as constituents responsible for aroma and flavor in guava fruits will be discussed.

Table 1 Fruit characters of some traditional guava (*Psidium guajava* L.) cultivar from different origins

Cultivar	Origin	Flesh color	Fruit mass (g)	Fruit width (cm)	Cavity width (cm)	Seeds (%)	TSS (°Brix)	Acidity (%)	Comments
Allahabad Safeda ^{a,d}	India	W	173	7.5	5.0	3.2	12.5	0.6	Sweet
Applle ^a	India	W	136	6.5	4.6	6.3	8.8	0.4	Sweet
Beaumont ^a	Hawaii	P	235	7.3	5.2	3.0	12.0	1.3	Mild acid
Belic L-207 ^{b,c}	Cuba	W	139	6.0	3.5	1.6	10.0	0.2	Sweet
Cotorrera ^b	Cuba	P	55	4.6	3.2	7.9	10.8	0.4	Sweet
Indonesian white ^a	Indonesia	W	105	6.3	4.1	1.4	10.5	0.3	Sweet
Indonesian seedless ^a	Indonesia	W	176	7.3	4.3	0.7	12.5	0.4	Sweet
Lucknow 49 ^a	India	W	227	7.3	4.4	3.3	11.0	0.4	Sweet
Hong Kong pink ^a	Hong Kong	P	288	7.6	4.9	4.5	10.7	—	Sweet
Hong Kong white ^a	Hong Kong	W	181	6.7	4.0	1.8	10.0	0.2	Sweet
Media China ^c	Mexico	Y	48	4.2	—	3.1	11.6	0.8	Sweet, excellent aroma
Paluma ^f	Brazil	R	140–250	9.0		4.9	10.0	0.5	Pleasant flavor
Patillo ^a	Florida	P	113	5.8	4.0	3.3	11.9	1.7	High acid
Peruana ^b	Mexico	W	70	4.8	—	4.7	13.7	0.9	—
Pink acid ^a	Florida	DP	167	6.9	4.7	2.7	11.7	1.7	High acid
Rica ^f	Brazil	R	100–160				11.0	0.5	Pleasant flavor
Sardar ^g	India	W	99–122	5.5–5.7			12–13	0.5–0.7	Very sweet

^aNakasone and Paull (1998).^bRodríguez et al. (2004).^cRitter et al. (2010).^dPatel et al. (2011).^eMondragón-Jacobo et al. (2010).^fPommer et al. (2013).^gSingh, (2008).

During ripening, the transformation of unripe fruit into an edible ripe product is accompanied by a metabolic process of simple degradative reactions as well as of complex biosynthetic reactions. In guava, changes in the epicarp and the endocarp colors are visualized in phase with the appearance of carotenoids and anthocyanins, with β -carotene, lycopene, and poly-phenols being the most abundant metabolites (Espinal et al., 2012). Another compound such as vitamin C is increased during the maturity process. This follows the breakdown of starch to glucose, which is then used in the biosynthesis of ascorbic acid (Lim et al., 2006). Also a broad variation of volatile constituents occurs to yield a flavor to mature fruit often described as “quince-banana”-like (Quijano and Pino, 2007).

Mature guava fruits possess an outstanding nutritional value and are recommended as part of the daily diet. They are rich in tannins, phenols, triterpenes, flavonoids, essential oils, saponins, carotenoids, lectins, fatty acids, fiber, and vitamins. The fruit is higher, for example, in vitamin C than lemons, and contains appreciable amounts of vitamin A, B₁, B₂, niacin (B₃), and pantothenic acid (B₅). It also contains a fair amount of phosphorous, calcium, iron, potassium, and sodium (Perales et al., 2005; Lim et al., 2006).

Guava fruits are characterized by a high water content, but low concentrations of hydrocarbons, fats, and proteins (Perales et al., 2005). Water is, thus, the principal component of guava fruit. According to the extreme values detected by several authors (Table 2), the averages range from 74% to 87% moisture and 13% to 26% dry matter. This variation in water content provokes different degrees of juiciness in ripe fruits.

Furthermore, guava is a low calorie fruit, with the total energy contribution ranging from 36 to 67.9 kcal per 100 g of mature fruit (Perales et al., 2005; SkipThePie.org, 2014), probably due variations of energy-providing compounds in different cultivars. Out of a total of 67.9 kcal, 53.2 kcal (78.4%) are derived from hydrocarbons

Table 2 Nutritional composition of guava (*Psidium guajava* L.) fruit
Elements Expressed in percentages (g/100 g fresh mass)

Moisture	87.17 ^a	77–86 ^b	—	74–87 ^c	—	80.8 ^e
Dry matter	—	—	—	13–26	—	—
Ash	0.53	0.43–0.70	—	0.5–10	—	1.39
Proteins	0.90	0.90–1.00	—	0.8–1.5	0.35–0.88 ^d	2.55
Fats	0.54	0.10–0.50	—	0.70	—	0.95
Hydrocarbons	10.85	9.50–10.00	5–10 ^b	—	—	14.32
Fibers	4.59	2.80–5.50	2.80	—	—	5.40
Sugars	—	—	—	—	6.24–13.10	8.92

^aCañizares (1981) (column 1).

^bPerales et al. (2005) (columns 2–3).

^cChin and Yong (1980), cited by Lim et al. (2006) (column 4).

^dPommer et al. (2013) (column 5).

^eSkipThePie.org (2014) (column 6).

(SkipThePie.org, 2014), the principal energetic compounds of the non-aqueous constituents that total about 5–14% of the fruit (Table 2). Among them, sugars represent the highest concentrations, varying from 6% to 13% (Table 2). Also fiber, which belongs to this type of compounds, is represented in 2.8–5.5% abundance (Table 2); however, lower values of 2.4% are also found (Patel et al., 2011). From soluble dietary fibers, pectin isolated from different fruits including guava has beneficial effects on human health. Significant differences in the sugar and fiber content have been detected according to the variations in guava cultivars (Patel et al., 2011).

During the maturation process, changes in total soluble solids and acidity are observed with the cultivars (Table 1). These variations determine the maturation index, an important parameter commonly used to define the maturity stage of fruits. In guava, high variability is reported with a variation coefficient of 34%, calculated on the base of 395 Cuban accessions. This is due to the broad changes of total soluble solids (7.40–18.10°Brix) and also in the titratable acidity (0.10–1.46%) (Rodríguez et al., 2010b). This progressive increase in soluble monosaccharides results from the hydrolytic degradation of hydrocarbon polymers, while the titratable acidity reduction is caused by the metabolism of organic acids (Espinal et al., 2012). The tartness in guavas is ascribed to the pH around 3–4, which is caused largely by maleic and citric acids. Diversity in these chemical parameters has also been reported in other cultivars and localities (Patel et al., 2011; Pommer et al., 2013).

Fats total from 0.1% to 0.95% in mature guava fruit (Table 2). They are also energetic compounds, but with a lower energy contribution (12%) as compared to the hydrocarbons. Mono- and polyunsaturated fats constitute more than 50% of the total fats, while saturated fats are less represented (29%) (SkipThePie.org, 2014). Also, fatty acids essential for human health (Neitzel, 2010) like omega-3 and omega-6 have been detected (SkipThePie.org, 2014).

Protein, like most other essential nutrients, is absolutely crucial for overall good health. They are very important molecules involved in virtually all cell functions. They are also energetic compounds with relative similar caloric contribution as the fats and make up some 13% of the total energy (SkipThePie.org, 2014). Together with proteins, free amino acids from vegetal origin constitute an important source of non-essential and essential amino acids. Besides other factors, cultivars seem to be an important contribution to the variation of protein content in guava. These compounds range from 0.4% to 2.6% in ripe fruits (Table 2). Along with oil, guava seeds are also a source of proteins with higher digestibility as compared, for example, to soybean. Of 100 g protein, 2.63 g are albumins, 9.47 g are globulins, and 50–87 g are glutelins. The essential amino acid profile of these proteins, except for the lysine content, is above that proposed by the FAO for adults. Besides, seeds are an important source of tryptophan (Bernardino et al., 2001).

Guava fruit is a moderate source of the B-complex vitamins as well as of vitamin E and K. More important are the high contents of vitamins A and C, both with high

Table 3 Variations of different functional compounds determined in some traditional guava (*Psidium guajava* L.) cultivar

Cultivar	Origin	Vitamin C (mg/100 g)	Phenolic (mg GAE/100 g)	Carotenoids (mg/100 g)	Dietary fiber (%)	Pectin (%)
Allahabad Safeda ^b	India	181.00	342.30		3.11	0.98
Beaumont ^{c,d}	Hawaii	162.75		5–7 ^a		
Fan Retief ^d	South Africa	396.77	300.87	1.59		
Lucknow-49 ^b	India	199.35	278.60		2.86	1.00
Media China ^e	Mexico	231.5		0.53 ^a		
Paluma ^{f,g}	Brazil	57.70		0.18–0.82		
Sangam ^b	India	190.37	352.40		2.41	0.97

^aLycopene.^bPatel et al. (2011).^cMuhammad et al. (2010).^dLancashire (2006).^eMondragón-Jacobo et al. (2010).^fSiqueira et al. (2011).^gBruna et al. (2012).

antioxidant capacity. This capacity is further increased by the presence of polyphenols such as tannins, phenolics, and flavonoids (Lin and Yin, 2012). Variation of these functional compounds in some traditional cultivars is summarized in Table 3.

With the edible fruit-producing species of the Myrtaceae, there exists a broad variation in vitamin A content with values ranging from 84 IU in *Syzygium cumini* (L.) Skees to 1600 IU in *Eugenia uniflora* L. (Mitra, 2010). Guava cultivars are in the range of 180–717.6 IU (Perales et al., 2005; SkipThePie.org, 2014). β -carotene is a common precursor of vitamin A (Alquezar et al., 2008). In Brazilian cultivars, β -carotene ranges between 0.13 and 2.54 mg/per 100 g of guava fruit. This β -carotene variability is reflected by coloration of the pulp. Guavas with pink and orange pulp have higher values than guavas with white or creamy pulp (Pommer et al., 2013). In addition to β -carotene, red-fleshed guava fruits contain other carotenoids such as γ -carotene, β -cryptoxanthin, rubixanthin, lutein, cryptoflavin, phytofluene neochrome, and lycopene, the predominant carotenoid in guava (Thaipong et al., 2006; Koguish de Brito et al., 2009). Lycopene is in a range of 0.04–4.04 mg/100 g fruit in the referred guava germplasm, and these values decrease according to pulp coloration from dark pink to white (Pommer et al., 2013).

Compared with other members of the Myrtaceae family, guava has a higher content of vitamin C (Mitra, 2010; Pommer et al., 2013) with its major concentration in the fruit peel (Lim et al., 2006). The vitamin C content shows a particularly large diversity, with a coefficient variation as high as 63.5% (Rodríguez et al., 2010b) and 72.5%

(Rodríguez et al., 2004), based on the evaluation of 395 and 49 Cuban accessions, respectively. Depending on the cultivar composition, the amount of vitamin C in 100 g of puree reaches averages of 175.9 mg (Rodríguez et al., 2004), 300 mg (Mitra, 2010), 147.8 mg (Rodríguez et al., 2010b), and 228.03 mg (SkipThePie.org, 2014). In addition, ranges of 44.6–409.7 mg of vitamin C within a Brazilian collection (Pommer et al., 2013) and 28.5–687.4 mg within a Cuban collection (Rodríguez et al., 2010b) underline the broad variation of this constituent. An interesting fact is that in both germplasm collections, some wild guavas exhibited the highest values for this vitamin. Examples are the ‘Cotorrera’ (Table 3) and ‘Microguayaba’ cultivars, which belong to the Cuban guava collection. They reach values of 444.0 and 508.7 mg, respectively (Rodríguez et al., 2004).

Polyphenols include different constituents such as tannins, phenolics, and flavonoids (Lin and Yin, 2012). The polyphenols are present mainly in the form of esters and glycosides (Lim et al., 2006). Caffeic, cinnamic, coumaric, ellagic, feluric, and rosmarinic acids and flavonoids like epicatechin, myricetin, naringenin, quercetin, apigenin, and rutin are detected in guava fruit (Thaipong et al., 2006; Lin and Yin, 2012). High contents are present in different traditional cultivars (Table 3).

A chemical characterization of 60 accessions of a Brazilian guava collection recorded high variation in total flavonoid content. Into 100 g of fruit vary from 10.67 to 46.82 mg rutin. Also, phenolic compounds vary in concentrations. Total contents expressed in gallic acid equivalents/100 g puree ranged from 158 to 447 mg (Pommer et al., 2013). In India, respective minimal and maximal values of 250.5 and 337.45 mg have been recorded for the 11 studied cultivars (Patel et al., 2011). Lower values of 138.3 mg are also reported for the cultivar ‘Vietnam GU8’ from Kampuchea (Lim et al., 2006). In a non-identified cultivar collected in a Malaysian market values ranged from 113.1 to 143.6 mg depending on the solvent used during the extraction process (Siow and Hui, 2013). Changes in concentration of these constituents vary according to different species of Myrtaceae family (Pommer et al., 2013). In guava not only variations by cultivars are observed, but also by ripeness, distribution inside the fruit, and seasons. Similar to ascorbic acid, these substances are present in high concentration in the fruit peel (Lim et al., 2006; Lin and Yin, 2012).

Fruits additionally are an important source of minerals. These elements are present in organic and inorganic combinations in food. They are most important factors in maintaining all physiological processes to sustain life and insure optimal health. In guava ash ranges from 0.5% to 1.39% (Table 2). This reflects differences in the mineral content according to cultivars. Fresh fruit is a very rich source of potassium varying from 150 to 619 mg per 100 g fruit. Guava contains more potassium than other fruits like banana on a weight basis. Also calcium (9–25 mg), phosphor (13–30 mg), magnesium (8–18 mg), sodium (3–5.5 mg), and low quantities of copper (0.2 mg) and iron (0.2–0.97 mg) have been reported (Perales et al., 2005; SkipThePie.org, 2014).

There are several reports on the volatile constituents of guava fruits, some of them including studies on the sensorial significance of these compounds (Joseph and Priya, 2011). Similar to other nutritional components, each cultivar shows a typical composition, characterized by a specific ratio between the main components and classes of substances (Quijano and Pino, 2007). This results in guava fruits of distinct aroma and tastes.

An earlier analysis of volatile constituents reported that among the 40 volatile compounds identified in guavas from Venezuela, the mixture of 2-methylpropyl acetate, hexyl acetate, benzaldehyde, ethyl decanoate, β -caryophyllene, and α -selinene contributes to the specific aroma (Joseph and Priya, 2011). Also, Pino et al. (1990) analyzed the volatile compounds by the use guava natural flavor concentrate (60 °Brix) from waste residue of hand-peeled fruits. Some important specific constituents are identified in the essence on the basis of odor qualities like methyl benzoate, ethyl benzoate, β -ionone, methyl (Z)-cinnamate, and methyl (E)-cinnamate, which together probably contribute to the overall pleasant fruity aroma. Although none of them can be considered to be particularly characteristic of guava, these constituents could be retained in any processed guava product since they seem to be the most important compounds implicated in the guava flavor.

In Cuba, the examination of cultivar 'N-6' permitted the identification of 45 compounds, 12 of them reported for the first time in this fruit. These constituents comprised 40 alcohols (31.2% of the total identified), 10 hydrocarbons (22.2%), 9 esters (20.0%), 6 carbonyls compounds (13.3%), 4 of distinct chemical nature (8.9%), and 2 acids (4.4%). In contrast to previous articles, alcohols, hydrocarbons, and esters were the major constituents. Esters like ethyl acetate, butyl acetate, and 3-phenylpropyl acetate provided a fruity-winey tone, alcohols ((Z)-3-hexenol and (E,E)-farnesol) gave a greenish-fruity tone, and hydrocarbons contributed to the freshly ethereal and woody tones giving naturalness to the aroma (Ortega et al., 1996). Furthermore, volatile fruit constituents were determined for four Cuban guava cultivars by the use of simultaneous steam distillation-solvent extraction followed by GC-MS analysis. More than 40 compounds were found in each extract, and 17 of them were identified for the first time as volatile constituents of guava (Pino and Ortega, 1999). The major volatiles were β -caryophyllene, limonene, 3-phenylpropyl acetate, (Z)-3-hexenyl acetate, and (E)-cinnamoyl acetate. Most probably, the typical guava flavor is the combination of several components, particularly of C8 aldehydes, alcohols and esters, aromatic compounds, and terpene hydrocarbons.

In Taiwan, Chen et al. (2008) analyzed the variation of volatile guava compounds by the use of headspace solid-phase microextraction (HS-SPME) coupled with gas chromatography (GC) and mass spectrometry analysis (GC-MS). They reported that the major volatile compounds are α -pinene, 1,8-cineole, β -caryophyllene, nerolidol, globulol, C6 aldehydes, C6 alcohols, ethyl hexanoate and (Z)-3-hexenyl acetate, terpenes, and 1,8-cineole and deduced that these contribute to the unique flavor of the guava fruit.

Moreover, Quijano and Pino (2007) examined the volatile constituents from fruit of three Colombian guava cultivars. These compounds were isolated by HS-SPME and

analyzed by GC–MS. A total of 97 compounds were identified with 41 esters, 18 terpenes, 17 carbonyls, 12 acids, 4 alcohols, 2 phenols, 2 furans, and 1 component with miscellaneous structure. Nineteen of these were described for the first time as volatile guava constituents. Although some major constituents were identified by previous studies, a group of other compounds represented by the cinnamyl derivatives, including cinnamyl aldehyde, cinnamyl alcohol, ethyl (E)-cinnamate, and esters of cinnamyl alcohol may play an important role in the characteristic sweet flavor of ripe guavas. The typical composition of each cultivar, characterized by a specific ratio between the main components (Table 4) and classes of substances, is clearly reflected. Also volatile constituents of the pink-fleshed Colombian guava ‘Regional rojo’ were examined (Joseph and Priya, 2011). These were carefully isolated by solvent extraction followed by solvent-assisted flavor evaporation. The aroma-active areas from the gas chromatogram were then screened by the aroma extract dilution analysis. The following compounds were identified as important aroma contributors: 4-methoxy-2,5-dimethyl-3(2H)-furanone, 4-hydroxy-2,5-dimethyl-3(2H)-furanone, 3-sulfanylhhexyl acetate and 3-sulfanyl-1-hexanol followed by 3-hydroxy-4,5-dimethyl-2(5H)-furanone, (Z)-3-hexanal, *trans*-4,5-epoxy-(E)-2-decenal, cinnamyl alcohol, ethyl butanoate, hexanal, methional, and cinnamyl

Table 4 Some major volatile compounds determined in three Colombian guava cultivars

Compound	IK ^a	Cultivars		
		Coronilla ^d	Glum Sali ^d	Palmira ICA-1 ^d
Esters				
3Z-Hexenyl acetate	1005	15.9 a	6.3 b	23.4 c
3-Phenylpropyl acetate	1378	11.9 a	2.4 c	5.2 b
(E)-Cinnamyl acetate	1446	12.4 a	4.2 b	26.6 c
Ethyl butanoate	804	4.3 a	t b ^b	t b ^b
Ethyl hexanoate	998	3.1 a	0.2 b	1.2 c
Hexyl acetate	1009	2.0 a	nd b ^c	1.2 a
Carbonyls				
Hexanal	802	14.7 a	40.4 b	14.7 a
2E-Hexenal	855	0.4 a	5.2 b	0.6 a
Cinnamyl derivatives				
(E)-Cinnamyl alcohol	1304	0.9 a	1.2 b	0.9 a
Terpenes				
Limonene	1028	3.5 a	2.0 b	4.7 c
(E)-β-Caryophyllene	1419	0.8 a	0.5 a	0.7 a

Values followed by the same letter in the same row are not significantly different at $p \leq 0.05$.

^aCovats index.

^btraces (<0.1 ppm).

^cnot determined.

^dQuijano and Pino (2007).

acetate. Enantio-selective GC revealed an enantiomeric distribution close to the racemate in 3-sulfanylhexyl acetate as well as in 3-sulfanyl-1-hexanol. Also, two fruity smelling diastereomeric methyl 2-hydroxy-3-methylpentanoates were identified as the (*R,S*)- and the (*S,S*)-isomers. In addition, seven new odorants were detected, among them 3-sulfanylhexyl acetate, 3-sulfanyl-1-hexanol, 3-hydroxyl-4,5-dimethyl-2(5*H*)-furanone, *trans*-4-5-epoxy-(*E*)-2-decenal, and methional as the most odor-active ones. Furthermore, 17 aroma-active volatiles previously identified with high flavor dilution factors in fresh pink Colombian guavas were quantified by stable isotope dilution assays. The aroma of fresh guava fruit cubes, which showed a very balanced aroma profile, was successfully mimicked in a reconstitution experiment using 13 odorants in their natural concentrations. An omission test, which ignored single odorants from the entire aroma reconstitute, revealed (*Z*)-3-hexenal (green, grassy), 3-sulfanyl-1-hexanol (grapefruit-like), 4-hydroxy-2,5-dimethyl-3(2*H*)-furanone (caramel, sweet), 3-sulfanylhexyl acetate (black currant-like), hexanal (green, grassy), ethyl butanoate (fruity), cinnamyl acetate (floral), and methional (cooked potato-like) as the key aroma compounds of pink guavas (Steinhaus et al., 2009).

Recently, volatile and odor-active compounds from guava fruit of the 'Red Supreme' cultivar were analyzed by the use of solid phase micro-extraction and simultaneous distillation-extraction combined with GC-FID (Gas chromatography with flame ionization detection), GC-MS, and aroma extract dilution analysis. A total of 141 compounds were detected including 43 esters, 37 terpenes, 18 aldehydes, 16 alcohols, 10 acids, 6 ketones, 4 furans, and 7 miscellaneous compounds. Out of these, 17 odorants were considered as the odor-active compounds, with (*E*)- β -ionone (fruity, berry-like), ethyl hexanoate (fruity), ethyl butanoate (fruity), hexanal (grassy-fruity), (*Z*)-3-hexenal (grassy), hexyl acetate (fruity-winy), (*E*)-2-hexenal (grassy-fruity), and limonene (citrus) contributing mainly to the typical guava aroma of this cultivar (Pino and Bent, 2013).

In general, both nutritional composition and volatile constituents of traditional cultivars vary among cultivars and localities, but also as a consequence of the sample processing. Modern techniques used recently have allowed to detect a large amount of these compounds. These variations observed in traditional cultivars have constituted a substantial source for modern cultivar improvement.

COMPOSITION OF MODERN CULTIVARS

As consequence of the 35–40% cross-pollination in guava specie, together with seed propagation and its heterozygotic nature, a great variability of genotypes has been produced in natural conditions. Some of these wild types have been prospected and preserved, which attached to the traditional cultivars composition in different countries,

have constituted the base to release modern cultivars with a desirable mixture of traits through accurate breeding programs (Rodríguez et al., 2004).

With a historical perspective, this subchapter is going to discuss briefly the initial breeding programs to release new cultivars, focusing in countries where guava is an important crop and others where is starting to acquire significant attention due to its nutritional value and commercial profitability.

India started its genetic breeding attempts in 1907, when seedlings derived by diverse sources were planted in different places to isolate superior genotypes. In this way, a seedling proceeding from open pollinated 'Allahabad Safeda' cultivar was selected and released as 'Lucknow 49' due to its distinctive characteristics. Since then, 'Allahabad Safeda', 'Lucknow 49', and 'Sardar', also named 'L-49', have constituted the main commercial cultivars and formed the mainstay of Indian guava industry owing to their high yield, fruit quality, and wide market acceptability (Singh, 2008). The two first are considered among the best cultivars for fresh consumption worldwide. Also, other cultivars like 'Shweta' and 'Lalit' are selected. The later, suitable by both processing and table purposes, is also gaining popularity. The improved guava cultivars, 'Apple Color', 'Chittidar', 'Red Fleshed', and others obtained by hybridization, such as 'Arka Amulya', 'Safeda Jam', 'Kohir Safeda', and 'Hisar Surkha', have been released in various states at different times for commercial cultivation (Singh and Jain, 2007; Patel et al., 2011).

Guava is also an important crop in Brazil. Most commercial areas are planted through seedlings offering great heterogeneity in fruit characteristics (Pommer et al., 2013). In this sense, breeding programs during more than 50 years have permitted to obtain cultivars with desirable internal and external attributes, such as 'Paluma', the principal commercial cultivar nowadays, as well as 'Rica', 'Século XXI', 'Pedro Sato', 'Kumagai', 'Sassaoka', 'Ogawa', 'Yamamoto', and 'Cortibel'. All of these cultivars are characterized by diverse composition of fruit constituents. From them, 'Paluma' and 'Rica' have high productivity and fruits with recognized nutritional value (Pommer et al., 2013).

In the United States, Florida is the principal region of guava production. The first cultivar named 'Redland' was described in 1941 (Morton, 2000). At the beginnings it was considered a promissory cultivar. However, due to its excessively mild flavor and low vitamin C content it was abandoned in favor of better selections. Among them, 'Supreme' and other recognized cultivars such as 'Red Indian', 'Ruby', 'Ruby x Supreme hybrid', 'Blitch', and 'Patillo' increased the list of new cultivars. Some of them are commercialized for fresh consumption and for industrial processing (Morton, 2000).

Mexico cultivates guava since more than 100 years. Currently, guava cultivars for commercial use are not available, and most areas are planted by seeds extracted from guavas known as 'Media China' and 'China' (Padilla y González, 2010; Pommer et al., 2013). They were selected by farmers using the Mexican germplasm from the central

semiarid region of Mexico. Today, there are foreign cultivars and new local selections with interesting fruit characteristics available to improve new cultivars (Padilla and González, 2010).

In Cuba, guava breeding programs have not been conducted until the 1950s. However, a consolidate industry for processing guava was well established by the use of the wild cultivar ‘Cotorrera’, which is distributed throughout the island and characterized by high variability in all plant parts, but mainly in external and internal fruit attributes. Also, these fruits were used for fresh consumption. This cultivar, together with other introduced foreign cultivars like ‘N6’, ‘Red Supreme’, ‘Indian Pink’, and ‘Indonesian white’ constituted the base to establish the first breeding program in this crop after 1960 (Rodríguez et al., 2010a).

Between 1970 and 1972, a preliminary characterization and evaluation of 82 accessions assembled in the guava germplasm collection permitted the selection of nine promising cultivars. They are ‘EEA 1-23’, ‘EEA 18-40’, ‘EEA-27’, ‘EEA 21-3’, ‘EEA 28-26’, ‘EEA 28-44’, ‘Belic L-97’, ‘Belic L-215’, and ‘Belic L-207’. Both, ‘EEA 18-40’, also named ‘Enana Roja Cubana’, and ‘EEA 1-23’ were the cultivars recommended for commercial uses due to their low tree size, reduced canopy diameter, and high yields. Later in the 80s, ‘EEA 18-40’ began to displace the other cultivars (Rodríguez et al., 2010a). Recently, this cultivar was selected as the female parent in three controlled crosses using ‘Red Supreme’, ‘N6’, and ‘Belic L-207’ as the male parents. From them, a total of 354 individuals were obtained and 25 promising genotypes were primarily selected due to its low size as well as diverse internal and external fruit qualities (Rodríguez et al., 2010a). Also, 15 new other plants having fruits with additional important agronomic and nutritional characters, totalling 40 advanced selections, were planted to evaluate their agronomical behavior in commercial orchards. Some of them exhibited better desirable attributes than the commercial ‘EEA 18-40’ and ‘EEA 1-23’ cultivars (Table 5).

At the beginnings of the guava breeding program in Hawaii, between 1948 and 1969, a total of 21 cultivars coming from seven countries were introduced and evaluated. From them ‘Beaumont’, a local cultivar was selected, constituting the first one for industrial processing in 1960. It was maintained as the only guava recommended for this purpose until the introduction in 1978 of the ‘Kahua Kula’ cultivar, derived from a seedling population of ‘Beaumont’. ‘Kahua Kula’ presents similar characteristics as does ‘Beaumont’, but contains fewer seeds and lower titratable acidity (Morton, 2000; Pommer et al., 2013).

In Egypt, guava is a popular widely planted fruit crop. ‘Bassateen El Sabahia’ has been the commercial cultivar recommended for long time. The efforts to improve its quality and yield permitted the introduction, in 1975, the promissory cultivar ‘Bassateen Edfina’. Also, recent breeding program has release new cultivars, which differs in fruit composition and possible uses (Wafa and Saky, 2013).

Table 5 Fruit characters of some modern Cuban guava (*Psidium guajava* L.) cultivars

Cultivar ^a	Flesh color	Fruit mass (g)	Fruit width (cm)	Cavity width (cm)	Seeds (%)	TSS (°Brix)	Acidity (%)	Vitamin C (mg/100 g)	Comments
EEA 18-40 or Enana roja Cubana	P	226.4	7.21	4.26	3.0	11.85	0.15	78.5	Sweet
EEA 1-23	DP	174.1	6.86	4.03	1.3	12.85	0.16	82.5	Sweet
H-5 ^b	W	180.9	6.84	3.68	1.6	13.20	0.32	200.6	Sweet
H-118 ^c	W	162.8	6.65	3.63	1.8	14.07	0.28	335.8	Very sweet
H-138 ^c	W	167.7	6.34	3.55	1.3	12.73	0.27	376.4	Sweet
H-139 ^c	P	235.1	7.03	3.72	1.2	11.27	0.26	170.8	Sweet
H-153 ^c	P	134.4	6.46	3.76	1.8	15.70	0.46	396.0	Very sweet
H-339 ^d	W	182.5	5.82	3.03	1.1	12.30	0.30	277.7	Sweet
H-345 ^d	P	171.9			1.6	11.25	0.40	300.6	Sweet

^aCharacterization data from IIFT (Institute for the Research of Tropical Fruits) guava collection.

^bseedling from EEA 18-40 X N6.

^cseedlings from EEA 18-40 X Red Supreme.

^dseedling from EEA 18-40 X Belic L-207.

In the Punjab region of Pakistan many local and foreign guava cultivars are available in the market, but information regarding their nutritive value and quality is scarce. In this sense, the characterization of local guava cultivars ‘Sufaida’, ‘Surahi’, ‘Surkha’, ‘Waikae’, and ‘Gola’ showed variation in fruit characters as a result of the breeding program (Adrees *et al.*, 2010).

In Thailand, a guava breeding program was initiated in 1998 and focused on cultivar development with superior fruit qualities. By the characterization of guava accessions from the germplasm collection, eight cultivars were selected: six white flesh dessert types (‘Klom Salee’, ‘Yensong’, ‘Pan Seethong’, ‘Khao Um-porn’, ‘Pan Yuk’, and ‘Nasuan’), one red flesh dessert type (‘Philippines’), and one pink flesh processing type (‘Pijit 12-102’). All white fleshed constitute commercial cultivars, and three of them, ‘Klom Salee’, ‘Yensong’, and ‘Pan Seethong’, are currently produced on a large scale (Thaipong and Boonprakob, 2005).

Successively, some of the modern cultivar mentioned above will be described attending to fruit attributes available.

India (Singh and Jain, 2007; Patel *et al.*, 2011)

‘Lalit’: Cultivar with a saffron yellow skin color and firm pink flesh with good blend of sugar and acid suitable for both table and processing purposes. Some other characteristics are the following: weight 116.50 g, length 5.70 cm, diameter 5.26 cm seeds number 174.60, total soluble solids 9.35 °Brix, acidity 0.61%, vitamin C content 179.00 mg/100 g of flesh, total sugar 6.92%, pectin content 1.12%, phenol content 352.40 mg GAE/100 g, and dietary fiber 2.97%.

‘Red Fleshed’: Cultivar with roundish oval fruit, yellowish peel, and pink color flesh. Some internal characteristics are the following: total soluble solids 10.62 °Brix, reducing sugar 4.25%, non-reducing sugars 5.00%, and total sugars 9.25%.

‘Hisar Safeda’: Cultivar obtained from the ‘Allahabad Safeda’ x ‘Seedless’ crosses. Fruit is small in size from about 92 g, round shape, creamy-white flesh color containing few soft seeds. Other characteristics are the following: total soluble solids 13.4 °Brix and vitamin C content 185 mg/100 g of flesh.

Brazil (Pommer *et al.*, 2013)

‘Século XXI’: Obtained from a cross between ‘Supreme 2’ x ‘Paluma’. Fruit is large in size from about 200–300 g weight, with yellow peel, rough surface, and pink reddish flesh color. Other characteristic like acidity 0.47% and vitamin C content 84.9 mg ascorbic acid/100 g of flesh are also referred.

‘Cortibel 1’: A seedling cultivar. Fruits pyriform shaped, pink-reddish fleshed with slightly rough surface from about 263 g weight, 1.12 cm flesh thickness, 265 seeds, 7.21 °Brix of total soluble solids, and 0.59% acidity; total carotenoids from 1.34 to 8.74 mg/100 g fruit mass.

‘Cortibel 2’: A seedling cultivar. Fruits oval or pyriform shaped, pink-reddish to red-dish fleshed, with smooth to slightly rough surface from about 197 weight, 1.10 cm flesh thickness, 169 seeds, 6.91 °Brix of total soluble solids, and 0.54% acidity.

‘Cortibel 3’: A seedling cultivar. Fruits obovoid shaped, red fleshed with rough surface from about 221 g weight, 1.09 cm flesh thickness, 220 seeds, 7.20 °Brix of total soluble solids, and 0.49% acidity.

‘Cortibel 4’: A seedling cultivar. Fruits ovoid shaped, white fleshed with slightly rough surface from about 221 g weight, 1.20 cm flesh thickness, 191 seeds, 7.78 °Brix of total soluble solids, 0.51% acidity, and total carotenoids from 0.28 to 0.75/100 g fruit mass.

United States (Lynch and Wolfe, 1941; Thaipong et al., 2006)

‘Supreme’: Cultivar obtained from plants propagated by seed. Fruit is medium to large in size from about 141.75 to 453.6 g weight and 1.27 cm of exterior thickness flesh, oval or pyriform, greenish-yellow to light yellow peel color, smooth surface, and white flesh color. Fruit cavity represents 16–21% of the fruit weight, which containing relatively few and small seeds.

‘Ruby’: Derived from a cultivar originally cultivated in Peru. Fruit is variable in size (113.4–283.5 g), ovate shape, greenish-yellow peel color, slightly rough surface and rose to ruby flesh color, external flesh thickness 1.27 cm. Fruit cavity represents up to 20–25% of the fruit weight containing few seeds.

‘Ruby x Supreme’: Obtained from a cross between ‘Ruby’ and ‘Supreme’ cultivars. Fruit is small in size, roundish shape, greenish-yellow peel color, and dark pink-orange flesh color. Some internal characteristics are the following: total soluble solids 13.0 °Brix, acidity 1.40%, dry matter 14.93%, protein 1.09%, mineral matter 0.88%, vitamin C content 174.27 mg/100 g of pulp, total sugars 4.50%, total phenolics content 170.07 mg gallic acid equivalents/100 g fresh mass, and total carotenoid content 2.937 mg β-carotene equivalents/100 g fresh mass.

México (Padilla and Gonzalez, 2010)

‘Selection 78’: This cultivar has fruits with rounded shape and pink flesh color; 3.3 cm length, 3.6 cm width, 0.37 cm of exterior thickness flesh with rounded shape, pink flesh color, cavity with near 112 seeds, and 19.8 °Brix total soluble solids.

‘Selection 106’: This cultivar has fruits with ovoid shape and cream flesh color; 6.6 cm length, 5.9 cm width, 0.99 cm of exterior thickness flesh, and cavity with near 314 seeds. Some chemical variables are the following: 10.4 °Brix total soluble solids, 0.67% acidity, and 291.7 mg/100 g of flesh vitamin C.

‘Selection 126’: This cultivar has fruits with ovoid shape and cream flesh color; 5.6 cm length, 5.1 cm width, 0.71 cm of exterior thickness flesh, and cavity with near 177 seeds. Some chemical variables are the following: 14 °Brix total soluble solids, 0.57% acidity, and 395 mg/100 g of flesh vitamin C.

Cuba (Rodríguez et al., 2004)

‘EEA 18-40’ or ‘Enana Roja Cubana’: Derived from ‘Indian pink’ cultivar. Fruit is large in size from about 226.4 g weight, 8.45 cm length, 7.21 cm diameter, 1.49 cm external fruit thickness, 4.26 cm diameter cavity and 286 few seeds, truncate or necked at stalk end with smooth surface, greenish-yellow peel color, and pink flesh. Some internal qualities of the fruit are the following: total soluble solids 11.85 °Brix, acidity 0.15%, and 78.5 mg/100 g of flesh vitamin C.

‘EEA 1-23’: It is a seedling derived from ‘Indian pink’ cultivar. Fruit is large in size from about 174.1 g weight, 7.02 cm length, 6.86 cm diameter, 1.5 cm external fruit thickness, 4.03 cm diameter cavity and 254.2 seeds, rounded at stalk end with smooth surface, greenish-yellow peel color, and dark pink flesh color. Some chemical qualities are the following: total soluble solids 12.4 °Brix, acidity 0.10%, and vitamin C content 66.7–82.5 mg/100 g of flesh.

Egypt (Wafa and Saky, 2013)

‘Selected genotype No.1’: Fruit is large in size from about 263.93 g weight, 7.80 cm length, and 7.33 cm diameter. Some chemical qualities are the following: 6.80 °Brix total soluble solids, 0.23% acidity, 24.06% total sugars, 8.82% reducing sugars, 15.24% non reducing sugars, 1.44% pectin, and 79.01 mg/100 g of flesh vitamin C.

‘Selected genotype No.2’: Fruit is large in size from about 170.80 g weight, 6.47 cm length, and 6.70 cm diameter. Some other qualities are the following: 8.40 °Brix total soluble solids, 0.32% acidity, 22.28% total sugars, 9.65% reducing sugars, 12.63% non reducing sugars, 1.64% pectin and 110.49 mg/100 g of flesh vitamin C.

‘Selected genotype No.5’: Fruit is large in size from about 282.30 g weight, 8.33 cm length, and 7.97 cm diameter. Some other qualities are the following: 9.40 °Brix total soluble solids, 0.23% acidity, 23.57% total sugars, 9.39% reducing sugars, 14.18% non reducing sugars, 1.14% pectin, and 80.25 mg/100 g of flesh vitamin C.

Pakistan (Adrees et al., 2010)

‘Sufaida’: Cultivar with total soluble solids 12.20 °Brix, acidity 0.70%, dry matter 14.51%, protein 1.37%, mineral matter 0.74%, total sugars 6.63%, and vitamin C content 183.46 mg/100 g of flesh.

‘Surkha’: Cultivar with total soluble solids 8.15 °Brix, acidity 0.99%, dry matter 10.11%, protein 1.00%, mineral matter 0.39%, total sugars 6.70%, and vitamin C content 208.41 mg/100 g of flesh.

‘Waikea’: Cultivar with total soluble solids 8.50 °Brix, acidity 1.41%, dry matter 13.06%, protein 0.86%, mineral matter 0.80%, total sugars 6.25%, and vitamin C content 203.61 mg/100 g of flesh.

Thailand (Thaipong and Boonprakob, 2005)

‘Klom Salee’: Fruit is very large in size from about 655.5 g, 546.6 g flesh, 108.9 g seed cavity, firmness 30.4 N. Some chemical qualities are the following: 6.5 °Brix total soluble solids, 0.33% acidity, and 104.4 mg/100 g of flesh vitamin C.

‘Philippines’: Derived by seeds introduced from Philippines. Fruit is large in size from about 306.7 g, 243.7 g flesh, 62.6 g seed cavity, firmness 25.50 N. Some other qualities are the following: 7.8 °Brix total soluble solids, 0.34% acidity, and 78.9 mg/100 g of flesh vitamin C.

‘Pijit 12-102’: Derived from ‘Beaumont’ cultivar. Fruit is medium in size from about 114.4 g, 92.38 g flesh, 22.0 g seed cavity, firmness 24.58 N. Some other qualities are the following: 9.3 °Brix total soluble solids, 0.64% acidity, and 201.9 mg/100 g of flesh vitamin C.

All this modern cultivars are selected attending to a group of attributes considered important since the firsts guava breeding programs started. Nowadays, new trends are focused to obtain cultivars that combine, not only commercial characteristics but also nutritional and medicinal components. These new aspects have contributed to the recent interest of many other countries in guava cultivation and consumption, due to the referred contribution to human health.

In this sense, the characterization of Brazilian new accessions are registered outstanding values for guava fruit active constituents. Some of them are the following: G73RO, G20MA, and G32PE for lycopene content; G21MA, G24MA, and G55SE for total flavonoids content; G03MA, G10MA, and G01MA for total phenolic content; and G01MA, G02MA, G03MA, G10MA, G16MA, G17MA, and G22MA for antioxidant activity.

Particularly on the topic related to the human health benefits, from the 60 Brazilian genotypes analyzed, the most appropriate prospects for future breeding programs are G01MA, G02MA, G03MA, G10MA, and G16MA, which associate a high concentration of various antioxidant compounds and the highest antioxidant activity (Correa et al., 2011).

Moreover, other *Psidium* species included also in this Brazilian germplasm bank shows remarkable values for the fruit components mentioned above. They are A100AM for lycopene content; A08MA for β -carotene content; A100AM, A43PE, and A80RO for total phenolic compounds; A43PE, A29PI, and A08MA for total flavonoids content; and A100AM, A43PE, and A80RO for antioxidant activity. The three last ones are considered outstanding, due to their high phenolic compound concentration, and antioxidant activity (Correa et al., 2011).

The significant values reported in different members of this genus in several countries, and specifically in guava, reinforce the hypothesis that superior genotypes can be selected, not only due to its commercial possibilities but also for its antioxidant

activity and nutritive value, as an important part of human diet intake (Thaipong et al., 2006).

NUTRITIONAL ATTRIBUTES OF GUAVA IMPORTANT FOR HUMAN HEALTH

Fruits and other plant parts can play an important role for human health, having complementary and overlapping mechanisms of action, which include modulation of detoxification enzymes, stimulation of the immune system, reduction of platelet aggregation, modulation of cholesterol synthesis and hormone metabolism, control of blood pressure, as well as antiviral, antibacterial, and antioxidant effects (Lampe, 1999).

In traditional medicine, guava is an important medicinal plant. The first report on its medicinal properties comes from the sixteenth century, but even today guava is commonly used to treat diverse diseases in several countries, making use of every part of the plant, from roots, bark, branches, leaves, to flowers and fruits (Taylor, 2005; Biblioteca Digital de la Medicina Tradicional Mexicana, 2013). Infusion or decoction of bark are administered orally and serve to treat diarrhea and dysentery, but also applied topically to treat wounds, ulcers, and skin sores. Moreover, tender leaves are chewed against bleeding gums and bad breath, and it is said that it might be used to prevent hangovers. Also washes, rinsing, and cataplasms applied to the skin are assumed to be successful to treat alopecia, pustules, rash, scarlatina, itch, and ulcer. Oral infusion and decoction of leaves are recommended for vertigo, to treat diarrheas, dysentery, stomach upsets, vomits, colic, chill, fevers, head ache, caries, cough, whooping cough, mouth and throats sores, and bleeding gums. On the other hand, decoction of leaves and branches are used as a douche for vaginal discharge and to tighten and tone vaginal walls after childbirth. Also, mashed fresh guava flowers are applied to painful eye conditions such as sun strain, conjunctivitis, or eye injuries; as an infusion, the flowers are used topically for wounds, ulcers, and skin sores. The fruit is eaten before breakfast against intestinal worms and amebas. In addition, medicasters have also used this plant in treatments against shock provoked by diverse origins, and usually medication is accompanied by orations and rituals (Taylor, 2005; Biblioteca Digital de la Medicina Tradicional Mexicana, 2013).

Along with other fruits and vegetables, the guava fruit is a good source of antioxidants (see above) that may be more effective and economical than supplements in protecting the body against oxidative damage under different conditions. These compounds help to retard aging processes and to reduce the incidence of degenerative diseases such as arthritis, arteriosclerosis, cancer, inflammation, heart disease, and brain dysfunction (Lim et al., 2006). In this sense, epidemiologic data support the association between a high intake of fruits and a low risk of chronic diseases (Lampe, 1999; Thaipong et al., 2006).

In human tissues, reactive oxygen species (ROS) are inevitably generated throughout diverse metabolic pathways. These generate reactive free radicals like superoxide, hydroxyl, peroxy, alkoxy, and non radicals such as hydrogen peroxide and hypochlorous acid (Lim et al., 2006). In general, antioxidative defense systems of the cell scavenge ROS and provide protection against their undesirable and deleterious effects. Both enzymatic and non-enzymatic components of the antioxidant defense system prevent radical formation or remove radicals before damage can occur, repair oxidative damage, eliminate damaged molecules, and prevent mutations. In human cells, oxidative damage can result when the critical balance between free radical generation and the antioxidant defense is disturbed. ROS over-accumulation provokes oxidative damage and potentially alters the structure and function of different cellular components, including hydrocarbons, proteins, lipoproteins, lipid-containing cell membranes, and nucleic acids. It has been suggested that the ROS increase plays an important role in the onset and development of chronic diseases, and increases the mortality risk in humans. The non-enzymatic antioxidant activity from vegetal origin mainly consists of water-soluble antioxidant compounds like ascorbate and polyphenols, most of which are flavonoids, and lipid soluble antioxidants such as carotenoids and tocopherols (Lim et al., 2006).

Some of the same factors that contribute to the production of ROS and oxidative damage can also lead to the production of reactive nitrogen species. The interaction of both reactive oxygen and nitrogen species with DNA bases can result in the formation of DNA adducts that contributes to the development of neoplastic cells. Also ascorbic acid, α -tocopherol, polyphenols, and fruit and vegetable extracts inhibit *N*-nitroso compound formation (Lampe, 1999).

The antioxidant activities can be primary or secondary. Antioxidant properties are generally measured to estimate antioxidant capacities in fresh fruits and their products, where most common assays include 2,2-azinobis (3-ethyl-benzthiazoline-6-sulfonic acid) (ABTS), 2,2-diphenyl-1 picrylhydrazyl (DPPH: expressed as AEAC: ascorbic acid equivalent antioxidant capacity and IC_{50} : defined as the concentration of antioxidant necessary to scavenge 50% of DPPH radicals), the oxygen radical absorption capacity (ORAC), and ferric reducing antioxidant power (FRAP). Also antioxidant activity is determined by the FIC (iron-ferrozine complex) activity, which measures the chelating ability of the extract (Lim et al., 2006; Thaipong et al., 2006; Kogushi de Brito et al., 2009).

In addition to possible variations due to the assay used to measure the antioxidant activity, other abiotic and biotic factors contribute to these variations. It can be affected by natural and processing products from different organs of the guava plant. Extracts from leaves of various guava cultivars have shown a higher scavenging effect on free radicals than commercial guava tea extracts and dried fruit extracts (Chen and Yen, 2007). This behavior is in turn observed in the same organ. Guava fruits have displayed

distinctive values of antioxidant content not only depending on the cultivars (Espinal et al., 2012) but also depending on ripeness, storage, and skin peeling (Lim et al., 2006).

Inside the Myrtaceae family the antioxidant capacity of fruits is largely diverse among *Psidium* species (Fetter et al., 2010; Pommer et al., 2013). In a Brazilian collection, the antioxidant activity (expressed in equivalents of ascorbic acid/100 g of fruit) is in the range of 280–812 mg among guava accessions and 398–575 mg in other *Psidium* species. This activity expressed in terms of reduced DPPH/g sample varies from 23.87 to 70.42 μmol and 33.21 to 47.38 μmol , respectively (Pommer et al., 2013).

A comparison of two cultivars of *Psidium cattleianum* Sab. shows that the cultivar with fruits of red peel contains more carotenoids, anthocyanins, and total phenolic compounds than cultivars with yellow peel. Similarly, the antioxidant capacity is higher in red fruits than in yellow ones (Fetter et al., 2010). Besides, the changes in the peel and pulp coloration of guava fruit during maturation is associated with the lipophilic antioxidant activity due to an increase of carotenoids, where the highest activity displayed by ripe fruits. Similarly, differences in the lipophilic antioxidant activity, determined by the β -carotene bleaching method, is associated with the pulp coloration of different cultivars, where white pulp shows the lowest value. However, the lipophilic antioxidant activity in fruits with red color is not always associated with the high concentration of β -carotene in the pulp. Examples are the red pulp Colombian cultivars 'Regional roja' and 'Palmira ICA 1'. While the former exhibits positive correlation between β -carotene concentration and the lipophilic activity during the maturation process, no correlation is detected in the 'Palmira ICA 1' cultivar. This reflects that lipophilic antioxidant activity is probably related to other carotenoid compound like lycopene (Espinal et al., 2012). In contrast, the highest lipophilic antioxidant activity has been detected in white flesh guavas as compared to other pink-fleshed guavas, although the contribution of carotenoids to the total antioxidant activity is considered negligible (Thaipong et al., 2005). However, commercial products derived from pink guava obtained during puree production are high in lycopene, and positively correlated to high lycopene equivalent antioxidant capacity (LEAC). This indicates that an industrial by-product of pink guava puree can be a potential source of lycopene and antioxidant activity (Kong and Ismail, 2011).

The guava fruit is an excellent source of carotenes including β -carotene with pro-vitamin A activity. Some benefits are associated with vitamin A intervention in the formation of bone and soft tissue and mucous membranes, pigment generation necessary for the functioning of the retina such as retinoic acid, and participation in the processes of reproduction and lactation (Burri, 1997). Diets supplemented with β -carotene and lycopene may effectively counteract the risk of many chronic diseases, such as cancer and heart diseases, and together with other carotenoids can act as a free radical scavenger (Yan et al., 2006; Corrêa et al., 2011). Also, the lipophilic antioxidant activity of β -carotene is associated with the ability to induce protection against ionizing radiation, a-singlet

oxygen neutralizing capacity and a peroxyl radicals neutralization capacity (Miller et al., 1996). Lycopene is also considered to have high resistance potential to diseases such as prostate cancer, arteriosclerosis, and skin damage from UV rays (Yan et al., 2006).

The most abundant antioxidants in fruits are ascorbic acid and polyphenols, the latter one considered as a more potent antioxidant than vitamins C and E (Lim et al., 2006). In ripening guava fruit the total phenolic compounds decrease causing the loss of astringency; however, vitamin C content is increased. This suggests that the DPPH scavenging activity of the unripe guava as measured by the AEAC value is primarily due to its higher total phenolic compounds as compared to the ascorbic acid content; while in mature fruits, the contribution of ascorbic acid to the antioxidant activity raises to some 66% (Lim et al., 2006).

Among 17 fruit crops cultivated in Ecuador, guava is in the third position in both the content of total phenolic compounds and the antioxidant activity as measured in fruit by FRAP and ABTS assays (Vasco et al., 2008). Also, the FRAP value of the guava was found to be 2.39 mg ascorbic acid equivalent/g sample and was the highest with respect to mango (*Mangifera indica* L.) cultivars (1.66–1.95 mg). The reduction power of fruits with reference to ascorbic acid was 97% in guava and between 71.4% and 82.4% in mango cultivars (Ahmed et al., 2013).

Cultivar composition shows different hydrophilic antioxidant activity in guava fruit. The examination of methanol extracts from white-fleshed ‘Allahabad Safeda’ cultivar and three pink-fleshed cultivars: ‘Fan Retief’, ‘Ruby Supreme’, and an advanced selection by ABTS, DPPH, ORAC, and FRAP, resulted in different antioxidant activities, where white-fleshed cultivar showed the highest value of 32.25 mmol Trolox equivalents/g fresh mass due to its higher ascorbic acid and total phenolic contents. The pink pulp cultivars exhibited 28.5, 18, and 25.1 mmol Trolox equivalents/g fresh mass for ‘Fan Retief’, ‘Ruby Supreme’, and the advanced selection, respectively. Also, Pearson’s correlations between antioxidant activity obtained from all assays and both total phenolic compounds and ascorbic acid content were positively correlated with coefficient ranging from 0.61 to 0.97 (Thaipong et al., 2006). This is probably due to the abundance of ascorbic acid and phenolic compounds. Both white- and red-fleshed guavas can have large hydrophilic antioxidant activity highly correlated to the total phenolic and vitamin C contents (Thaipong et al., 2005).

Also, the total phenolic compounds extracted from fresh guava fruit and processed by drying in convection ovens showed a high positive correlation to the antioxidant capacity as measured by AEAC ($R^2=0.92$) and FRAP ($R^2=0.87$). This indicates that these substances contribute to antioxidant activities such as radical scavenging and reducing ability of fresh and processed guavas (Siow and Hui, 2013). Similarly, the DPPH assay gave comparable results for antioxidant activity measured in methanol extracts of guava juices and nectars. The DPPH values showed high correlation to the ascorbic acid content and total phenolics compounds, both constituting the major contributors to

antioxidant activity (Koguish de Brito et al., 2009). In the same way, guava juice consumed in the Israel market is known for its high content of antioxidant components as well as antioxidant activity as compared to other fruit juices. This fact is consistent with the greater concentration of phenolic compounds, carotenoids, and vitamin C detected in the juice (Radam, 2008).

Not only guava pulp and peel but also seeds are an antioxidant source. The extraction of antioxidant compounds from mango, guava, and papaya (*Carica papaya* L.) seeds with 70% ethanol showed an intermediate position of guava with respect to total phenolic compounds and antioxidant activity as measured by DPPH expressed in IC_{50} . However, the highest percentage of metal ion chelating activity based on FIC assays was for guava seed extracts (Norshazila et al., 2010). In contrast, it has been reported that guava fruit shows a potent primary antioxidant property (measured by IC_{50} and FRAP), but that its function as a secondary or preventive antioxidant (measured by FIC) is low (Lim et al., 2006). While primary antioxidants scavenge radicals to inhibit chain initiation and break chain propagation, secondary antioxidants suppress the formation of radicals and protect against oxidative damage.

Vitamin C and polyphenols are important substances contributing to human health. Among other benefits, the vitamin is required for collagen synthesis, the main structural protein in the human body needed for maintaining the integrity of blood vessels, skin, organs, and bones. The intake of vitamin C prevents scurvy and contributes to resistance against infectious agents (Lim et al., 2006). Vitamin C also helps to prevent DNA damage caused by free radicals, and reduces their harmful effects on plasma lipoproteins. Epidemiological studies on antioxidant effects suggested that a daily dose of 150 mg of vitamin C, preferably in association with other vitamins, might help to reduce the incidence of cardiovascular diseases and cancer (Corrêa et al., 2011).

Besides, polyphenols as supplement to daily diet may improve some features associated with overweight and obesity such as metabolic syndrome, cardiovascular risk factors, lipid peroxidation, and inflammation (Hervert-Hernández and Goñi, 2011). Recent studies demonstrated that the pro-oxidant activity of essential oil or some of their constituents and also some polyphenols are very efficient in reducing local tumor volume or tumor cell proliferation by apoptotic, necrotic, or both effects (Joseph and Priya, 2011). Last but not least, not only contain fruit peels high amounts of phenolics and flavonoids and strong antioxidant activity, but also contain a prominent antibacterial activity. Guava peel extracts have shown significant inhibition of Gram-positive bacteria (Noriham et al., 2012).

In addition, guava peel and pulp can be used to obtain antioxidant dietary fiber, a new item which combines in a single natural product the properties of dietary fiber and antioxidant compounds (Thaipong et al., 2006). Variations in dietary fiber content and antioxidant capacity of some fruits are illustrated in Figure 1. The function of natural antioxidants and dietary fiber in foods and biological systems has received increasing attention. Evidence suggests that adequate intake of dietary fiber avoids constipation,

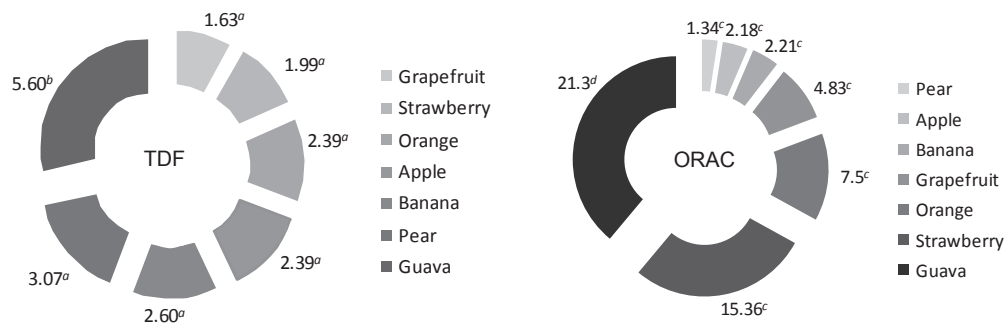


Figure 1 Variation of total dietary fiber (TDF) and antioxidant activity (ORAC: Oxygen radical absorption capacity) in different fruits: grapefruit (*Citrus paradisi* Macf.), strawberry (*Fragaria Xananassa* (Duch.) Guédès), orange (*Citrus sinensis* (L.) Osbeck), apple (*Malus domestica* Borkh), banana (*Musa sp.*), pear (*Pyrus communis* L.), and guava (*Psidium guajava* L.). ^aUSDA Nutritional Data Base. www.nutritiondata.com (2013); ^bGorinstein et al. (1999); ^cWang et al. (1996); ^dThaipong et al. (2006); ^eTotal dietary fiber (in g/100 g puree); ^foxygen radical absorption capacity (in μM TE/g puree).

coronary heart disease, fluctuation of blood glucose and insulin levels, and cancer (Weisburger et al., 1993). One major component of soluble fibers among other soluble polysaccharides is pectin, which is metabolized in the small intestine through bacterial enzymes into products that contribute to maintaining the colonic microflora and thus aids digestion (Weisburger et al., 1993). A high content of soluble fiber together with potassium, the major mineral constituent of this fruit, have the capacity to reduce blood pressure, to decrease total cholesterol levels and triglycerides, and to increase “good” HDL cholesterol (Taylor, 2005). The fluid balance in the body, vital for all life processes, is maintained largely by sodium, potassium, and chloride. This balance is regulated by charged sodium and chloride ions in the extracellular fluid and potassium in the intracellular fluid, and by some other electrolytes across cell membranes. Tight control is critical for normal muscle contraction, nerve impulse transmission, heart function, and blood pressure control. Potassium also acts as cofactors for certain enzymes.

Besides the fruits also other parts of the guava plant are commonly used against dissimilar diseases, with leaves as the primary source for decoctions and infusions. The oil from guava leaves have proven antimicrobial activity against *Bacillus cereus*, *Echerichia coli*, *Enterobacter aerogenes*, *Pseudomonas fluorescens*, *Salmonella* spp., *Staphylococcus aureus*, and *Yarrowia lipolytica*. Furthermore, leaf extracts have antispasmodic activity and a sedative effect, which result in its anti-diarrheic activity. Quercetin has been considered the active principle with the antispasmodic and probably also the anti-diarrheic effects (Biblioteca digital de la Medicina tradicional Mexicana, 2013). Additionally, anticancer activity, including a potential cytotoxic effect on human cervical cancer cell lines, along with anti-inflammatory effects was reported for leaf extracts. Other properties including insecticidal and repellent activities have also been described (Joseph and Priya, 2011).

SUMMARY POINTS

- Genetics programs have released several guava cultivars in countries where guava constitutes an important fruit crop.
- Traditional guava breeding programs usually promote the search for new cultivars based on traits such as large fruit, thick pulp with white or pink color (depending of destiny and market preferences) and low content of stone cells, few seeds, pleasant aroma and flavor avoiding muskiness, sweet pulp with more than 10°Brix, variable acidity, good postharvest behavior, and tolerance or resistance to pest (Pommer and Murakami, 2009; Pommer et al., 2013).
- Phenotypic and biochemical characterization of the accessions assembled in germ-plasm banks is a potent tool to identify guava genotypes with desirable traditional traits and as an important source of functional compounds for nutrition and health (Corrêa et al., 2011).
- Guava is becoming increasingly popular due to the attractive characteristics of the fruit and the substantial concentrations of functional compounds, which must constitute additional aims to improve new cultivars (Corrêa et al., 2011).
- Guava is an important complement of the daily diet with considerable amounts of antioxidants such as vitamin C, carotenoids, and polyphenols. These compounds are known as scavengers of free radicals and beneficial to human health. Together with dietary fiber these guava constituents decrease the risk of chronic diseases caused by ROS.
- Seeds, which represent about 6–12% of the total fruit weight, are a source of oil and proteins that can be profitable as additive in meals and also contain phenolic compounds with recognized antioxidant properties (Bernardino et al., 2001; Norshazila et al., 2010).
- Based on pro-oxidant activity, essential oils, and some of their constituents, respectively, are excellent antiseptic, insecticidal, and antimicrobial agents. Furthermore, they display antiaggregatory as well as anti-inflammatory and anticancer activities, which can contribute substantially to the modern medical domain (Joseph and Priya, 2011).
- Biotechnological tools in breeding methods such as the generation of genetic linkage maps will increase the breeding efficiency in guava and have different useful applications for genetic analysis (Rodríguez et al., 2010a).
- Important QTLs for total soluble solids, acidity, and vitamin C content have been already mapped. Mapping of QTLs for other functional compounds (carotenoids, polyphenols, and essential oils with medicinal properties) will furthermore contribute to the practical usefulness enrichment of the developed genetic linkage maps in future breeding programs.
- The identification of molecular markers associated to a particular QTL for desirable commercial, nutritional, and medicinal traits may help in marker assisted selection for guava improvement.

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CHAPTER 14

Jackfruit (*Artocarpus heterophyllus*)

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INTRODUCTION

Jackfruit (*Artocarpus heterophyllus* Lam.) is the largest edible fruit in the world (Naik, 1949; Sturrock, 1959). It originated in the forests of the Western Ghats (India), where it still grows in the wild, as well as in the evergreen forests of Assam and Myanmar. It is cultivated throughout Bangladesh, Burma, India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and to some extent in Brazil and Queensland, Australia. There are different hypothesis about how the fruit came to be named *jackfruit*. Some people propose that it is named after William Jack (1795–1822), who was a Scottish botanist. Others

(Dampier's 1699 book, *A New Voyage Round the World*) reject this proposal, because the fruit was called *jack* in English before William Jack was born. It is called *Katahal* in Hindi, *Pala-pazham* in Tamil, *Panasa* in Telugu, *Phanas* in Marathi and Gujarati, *Halasu* in Karnataka, *Nangka* in Indonesian, *Fenesi* in Kiswahili, and *Ka-noon* in Thailand. Jackfruit is locally called *kathal* and have gained the position of national fruit of Bangladesh because of its popularity and various other features. The poor people in jackfruit growing area used to eat this fruit instead of rice for one of their daily meals. It is commonly referred to as "the poor man's food" (Rahman et al., 1995). Jackfruit is a multiple fruit, consisting of edible (pulp and seed) and nonedible (rind and rachis) portions. Tender green fruit is used as a vegetable. The juicy pulp of the ripe fruit is eaten fresh as dessert. The seeds are eaten cooked, roasted, or fried. Jams, beverages, candies, preserves, and dehydrated forms are other industrial uses for the jackfruit (Naik, 1949). Jackfruit is also known to be beneficial to fight against asthma, ulcers, indigestion, tension, nervousness, and constipation. It can slow down aging and cell degeneration. This fruit can also provide protein and carbohydrates for the body, which will result in more strength for the individual. The proximate composition of two varieties of jackfruit seeds were studied, and considerable biochemical difference between the two varieties was reported by Kumar et al. (1988). Jackfruit provides approximately 2 MJ of energy per kilogram of wet weight of ripe perianth (Ahmed et al., 1986). Seeds are normally discarded or steamed and eaten as a snack, or used in some local dishes. The wood of the jackfruit tree, which ages to an orange or red-brown color, is highly durable, resisting termites and decay (Elevitch and Manner, 2006). A yellow dye is sometimes extracted from the wood and used for dyeing clothes, especially in India and the Far East (Seddon and Lennox, 1980). The uses discussed in this paragraph make it clear that all parts of the jackfruit plant are valuable to human beings for their livelihood.

BOTANICAL ASPECTS

Jackfruit (*Artocarpus heterophyllus* Lam.) is a large fruit of a tree with milky latex belonging to the Moraceae family. The fruit, botanically a sorosis, is a modification of an entire pistillate (female only) catkin and contains 100–500 large, oily seeds. The edible, pulpy part of the fruit is derived from the perianth of individual flowers. Humid tropical and subtropical climates are suitable for jackfruit. The fruits are produced along the main trunk of the tree and on mature branches, and can even be found at the bases of trees. Typically jackfruit trees reach a height of 8–25 m with a canopy diameter of 3.5–7 m at 5 years of age. All parts of the plant contain sticky, white latex. The leaves are oblong, oval, or elliptic, 4–25 cm long and 2–12 cm wide, leathery, glossy, and deep green in color. Young leaves are lobed at the premature stage. Male and female flowers are found on the same plant. Male flower heads are swollen, oblong, 1–4 cm long, and 1 cm wide. When mature, the head is covered with yellow pollen that is shed rapidly. Both male and female flower heads appear on short, stout twigs that are produced along the trunk and older

branches, or even at the base of old trees. Female flower heads look like the male heads but are without pollen, and soon begin to swell. The stalks of both male and female flower heads are encircled by a small green ring. The fruit the largest of all cultivated treeborne fruits is oblong to cylindrical and typically 30–40 cm in length, although it sometimes reaches 90 cm, making it one of the largest of all cultivated fruits. Jackfruits usually weigh 4.5–30 kg (commonly 9–18 kg), with a maximum reported weight of 50 kg. The exterior of the compound fruit is green, turning to yellow when ripe. The interior consists of large edible bulbs of yellow, banana-flavored flesh that encloses a smooth, oval, light-brown seed (Figures 1 and 2). The seeds are recalcitrant. Jackfruit occurs in two textural forms; ghila with soft and pulpy perianth when ripe and khaja (or Karcha) with firm perianth (Rahman et al., 1999). In addition, there is another type named dorosha with the characteristics of both khaja and ghila. Well-drained, frost-free, sunny, and warm locations are important for jackfruit trees. Optimum fruit production is achieved on medium or open textured deep soil with a low pH. Water should be provided as necessary. Fertilizer requirements are not well known, but frequent, weak solutions of all-purpose fertilizer increase plant growth without causing burning. Propagation is usually by seeds, which should be planted within 1 month of maturity. Germination

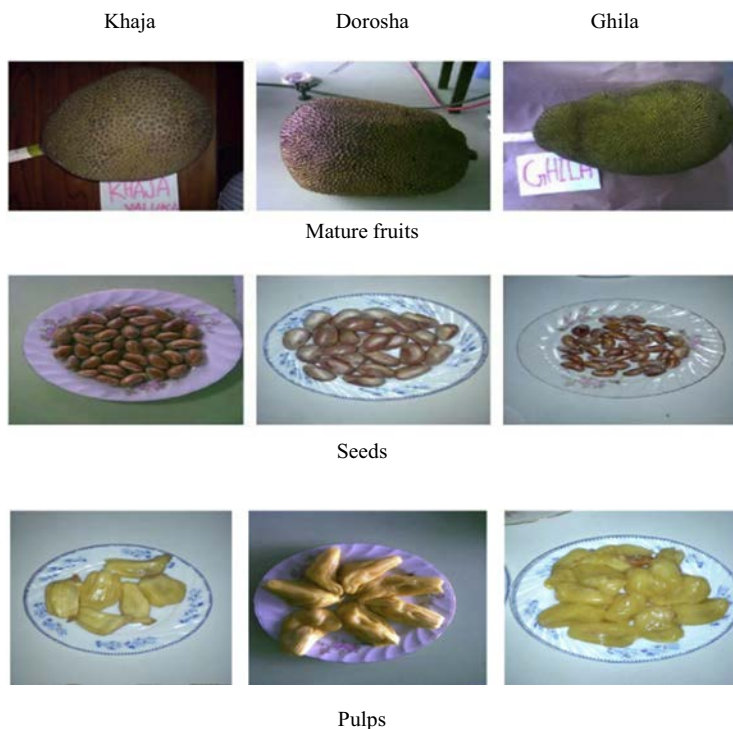


Figure 1 Khaja, dorosha, and ghila jackfruits with seeds and pulps.



Figure 2 Half-cut mature jackfruit.

takes 3–8 weeks. Before four leaves appear, the seedlings should be moved to the permanent location. Seedlings have a long and delicate tap root, making successful transplanting very difficult. Other methods of propagation include cuttings, grafting, or air layering. A little pruning may be required to ensure sufficient light for the developing fruit. Pest and disease management is required to get the best quality fruit. After 3–8 months of flowering, the fruits become mature. Usually a change of fruit color from light green to yellow-brown indicates maturity. Furthermore, there is a dull, hollow sound when the fruit is tapped. Cold storage trials indicate that ripe fruits can be kept for 3–6 weeks at 11–13°C and relative humidity of 85–95%. Cultivars include ‘Safeda’, ‘khaja’, ‘Ceylon’, ‘Bhusila’, ‘Bhadaiyan’, and ‘Handi’. In Australia, some of the cultivars are ‘Galaxy’, ‘Fitzroy’, ‘Nahen’, ‘Cheena’, ‘Kapa’, ‘Mutton’, and ‘Varikkha’.

COMPOSITION OF TRADITIONAL OR ANCIENT CULTIVARS

Although jackfruit is the largest edible fruit, very few studies have been conducted on its biochemical composition. Reviews of the available information related to the present study are given under separate headings.

Chemical Composition of Jackfruit Pulp and Roots

Jackfruit contains vitamin A, vitamin C, thiamin, riboflavin, calcium, potassium, iron, sodium, zinc, and niacin, among many other nutrients. Jackfruit has a low caloric content; 100 g of jackfruit only contains 94 calories (Mukprasirt and Sajjaanantakul, 2004). Jackfruit is a rich source of potassium, with 303 mg found in 100 g of jackfruit. Studies show that food rich in potassium helps lower blood pressure. Another benefit of eating jackfruit is that it is a good source of vitamin C (Table 1). The human body does not make vitamin C, so one must eat food that contains vitamin C to reap its health benefits. Vitamin C is an antioxidant that protects the body against free radicals, strengthens the

Table 1 Composition of jackfruit (100 g edible portion), fresh weight basis

Nutrients	Young fruit	Ripe fruit
Water (g)	76.2–85.2	72.0–94.0
Protein (g)	2.0–2.6	1.2–1.9
Fat (g)	0.1–0.6	0.1–0.4
Carbohydrate (g)	9.4–11.5	16.0–25.4
Fiber (g)	2.6–3.6	1.0–1.5
Total sugars (g)	NA*	20.6
Total minerals (g)	0.8	0.8–0.9
Calcium (mg)	30.0–73.2	20.0–37.0
Magnesium (mg)	NA*	27.0
Phosphorus (mg)	20.0–57.2	38.0–41.0
Potassium (mg)	287.0–323.0	191.0–407.0
Sodium (mg)	3.0–35.0	2.0–41.0
Iron (mg)	0.4–1.9	0.5–1.1
Vitamin A (IU)	30.0	175.0–540.0
Thiamine (mg)	0.05–0.15	0.03–0.09
Riboflavin (mg)	0.05–0.2	0.05–0.4
Vitamin C (mg)	12.0–14.0	7.0–10.0
Energy (kJ)	50–210	88–410

NA*, Information not available.

Sources: Soepadmo (1992); Gunasena et al. (1996); Azad (2000).

immune system, and keeps gums healthy (Umesh et al., 2010). Jackfruit contains phytonutrients, including lignans, isoflavones, and saponins that have wide ranging health benefits. These phytonutrients have anticancer, antihypertensive, antiulcer, and antiaging properties. The phytonutrients found in jackfruit, therefore, can prevent the formation of cancer cells in the body, can lower blood pressure, can fight against stomach ulcers, and can slow down the degeneration of cells that make the skin look young and vital. Jackfruit also contains niacin, known as vitamin B₃ and necessary for energy metabolism, nerve function, and the synthesis of certain hormones. A portion of 100 g of jackfruit pulp provides 4 mg niacin (Soobrattee and others, 2005). Boiling the root of the jackfruit and extracting and consuming it with its high nutritional content have been found to control asthma. Jackfruit root has also been used to treat skin problems. The extract of jackfruit root is believed to be able to help cure diarrhea and fever.

Seed Characteristics

Haque (2001) conducted an experiment on seed characteristics of jackfruit using the existing 45 germplasm established at Bangladesh Agricultural University, Mymensingh, Bangladesh. He observed that most of the seeds were semispheroid in shape, although ellipsoid and egg-shaped seeds were also found. Seeds were mostly light brown, but brown and deep brown were also found.

Islam (1995) investigated on different types of jackfruit seed, and stated that most of the seeds were oblong in shape. The length, breadth, and thickness of khaja and ghila types were 2.84, 1.85, and 1.27 cm; and 2.34, 1.52, and 1.18 cm, respectively. Dutta (1956) carried out an experiment on the jackfruit of Assam, India, and indicated that most of the seeds were egg-shaped or ovate, and small, medium, or large in size. He also stated that roasted seeds taste like chestnut, and boiled seeds can be made into delicious sweets.

Chemical Composition of Jackfruit Seeds

Moisture and Dry Matter

Dev (2009) reported that the moisture content of jackfruit seed varies from 51.6% to 57.77%. Hasan (2002) carried out a study on the biochemical content of seeds of jackfruits from two harvesting seasons (“off” and “on”) of two selected germplasms (‘Ah-15’ and ‘Ah-24’). He stated the moisture content of “off” and “on” season ‘Ah-15’ jackfruit seeds was 63.38% and 51.86%, respectively. The moisture content of “off” and “on” season ‘Ah-24’ jackfruit seeds was 63.52% and 64.03%, respectively. Hasan (2002) also studied the dry matter content of jackfruit seeds of from two harvesting seasons (“off” and “on”) for the ‘Ah-15’ and ‘Ah-24’ germplasms and found that “off” and “on” season ‘Ah-15’ jackfruit seeds contain 36.62% and 48.14% dry matter, respectively. The dry matter content of “off” and “on” season ‘Ah-24’ jackfruit seeds was 36.48% and 35.97%, respectively. Awal and Gheyasuddin (1991) studied on the biochemical parameters of jackfruit seeds and recorded 46.2% moisture, whereas Sammaddar (1990) reported moisture content of jackfruit seeds to be 64.5%. On the other hand, Sammaddar (1990) noted lower dry matter content of seeds at 35.5%. Begum et al. (1989) and Popenoe (1974) reported the dry matter content of seeds to be 47% and 46.52%, which are more or less similar.

Dutta (1956) described a higher dry matter content of 61.60%. Purseglove (1968) and Popenoe (1974) stated that the moisture content of jackfruit seeds was 51.6% and 53%, respectively, and Dutta (1956) reported the moisture to be 28.4%.

Brown (1951) found the moisture content of seeds to be 57.55%. Collectively, moisture content of the seeds was found to vary from 46.76% to 64.5%. However, most authors (Khuda et al., 1960; Anonymous, 1972) reported the moisture content to be in the vicinity of 64%. Kamaluddin (1966) and Popenoe (1974), however, reported the moisture content to be 46.76% and 49.18%, respectively.

Ash

Dev (2009) reported that the ash content of fresh jackfruit seed varies from 1.25% to 1.50%, and in dried seed it is 2.96%. Hasan (2002) stated that the ash content of “off” and “on” season ‘Ah-15’ jackfruit seeds was 1.51% and 1.71%, respectively. However, “off” and “on” season ‘Ah-24’ jackfruit seeds contained 2.13% and 3.02% ash, respectively. Haque (1994) carried out a study on jackfruit seeds and reported that there was a difference in ash content among the types. The highest ash content was found in the khaja type seed,

medium levels of ash were in the ghila type, and the lowest level was in the dorosha type. [Brown \(1951\)](#) reported the ash content of seed was 1.25%, and in the oven-dried seed it was 2.96%. [Hoque \(1993\)](#) studied the processing and preservation of jackfruit and use of jackfruit by-products, and found that ash content of jackfruit seed was 4.22%. On the other hand, [Popenoe \(1974\)](#) reported that the ash content was 3.49%, and [Begum et al. \(1989\)](#) reported it to be 3.3%. [Purseglove \(1968\)](#) stated that the ash content was 1.5%, and [Awal and Gheyasuddin \(1991\)](#) found 1.8% total ash, which was more or less similar.

Protein

[Dev \(2009\)](#) reported that the protein content of jackfruit seed is 6.6%. [Hasan \(2002\)](#) reported that the protein content of “off” and “on” season ‘Ah-15’ jackfruit seeds was 9.86% and 10.55%, whereas that of “off” and “on” season ‘Ah-24’ jackfruit seeds was 11.55% and 12.40%, respectively. On the other hand, [Hoque \(1993\)](#) found that the seeds of jackfruit contain 1.5% protein, which is very low compared with other reported values. [Awal and Gheyasuddin \(1991\)](#) conducted an experiment on the biochemical parameters of jackfruit seeds and found 5.69% protein. [Samaddar \(1990\)](#) reported 6.6% protein in jackfruit seeds. [Popenoe \(1974\)](#) and [Purseglove \(1968\)](#) stated that the protein contents of the seeds was 6.6% and 5.44%, respectively. This variation is presumably the result of varietal difference or the state of maturity of the seeds. [Bobbio et al. \(1978\)](#), [Kamaluddin \(1966\)](#), and [Khuda et al. \(1960\)](#) observed the protein content of jackfruit seeds to be 12.4%, 13.14%, and 12.3%, respectively.

Fiber

[Dev \(2009\)](#) reported that the fiber content of jackfruit seeds was 1.5%. [Hasan \(2002\)](#) stated the fiber content of “off” and “on” season ‘Ah-15’ jackfruit seeds was 1.45% and 1.38%, respectively, and the fiber of “off” and “on” season ‘Ah-24’ jackfruit seeds was 1.58% and 1.50%, respectively. [Coronel \(1983\)](#) reported the fiber content to be 1.4%. [Purseglove \(1968\)](#), [Aykroyd et al. \(1966\)](#), and [Bhatia et al. \(1955\)](#) studied the chemical composition of jackfruit seeds from different regions and reported that the fiber content was 1%, 1.5%, and 1.5%, respectively. They also stated that the average fiber content of seed was 1.33%.

Fat

[Dev \(2009\)](#) reported that the fat content of jackfruit seeds was 0.4%. [Hasan \(2002\)](#) stated that the fat content of “off” and “on” season ‘Ah-15’ jackfruit seeds to be 0.93% and 0.43%, but that of “off” and “on” season ‘Ah-24’ jackfruit seeds to be 0.35% and 0.88%, respectively. In an investigation of biochemical parameters of jackfruit seed made by [Awal and Gheyasuddin \(1991\)](#), fat content of jackfruit seed was found to be 0.86%. [Popenoe \(1974\)](#) hypothesized that fat content would be lower than previous results, and it was assessed to be 0.24%. [Purseglove \(1968\)](#) and [Bhatia et al. \(1955\)](#) reported a similar fat content in jackfruit seeds at 0.4%.

Starch

Hasan (2002) stated that the starch of “off” and “on” season ‘Ah-15’ jackfruit seeds was 38.79% and 44.65%, whereas that of “off” and “on” season ‘Ah-24’ jackfruit seeds was 41.93% and 49.18%, respectively. Khuda et al. (1960) noted that the seeds contained 75.61% starch, but Bhatia et al. (1955) reported 57.09% starch on moisture-free basis. Bhatia et al. (1955), in their study on the composition and nutritive value of jackfruit seed, reported that the seeds of jackfruit contained 25.8% starch.

Minerals

Dev (2009) reported that calcium, phosphorus, and iron content in fresh seeds was 0.05–0.55%, 0.13–0.23%, and 0.002–1.2%, respectively. In the case of roasted seeds, calcium, phosphorus, and iron contents were 0.13%, 0.54%, and 0.05%, respectively. Brown (1951) conducted an experiment and observed the calcium, phosphorus, and iron contents in fresh and oven-dried seeds were 0.55%, 0.23%, and 0.002%; and 0.13%, 0.54%, and 0.005%, respectively.

COMPOSITION OF MODERN CULTIVARS

Reviews of the available information (including our research) related to jackfruit are described here. However, in Bangladesh, distinct varieties of jackfruit are not available. Generally, Bangladesh jackfruits are of three types: khaja with hard pulp; ghila, in which the pulp is very juicy and soft; and dorosha, an intermediate fruit with pulp that is fairly firm and juicy (Goswami et al., 2010). In our laboratory, we collected three types of jackfruits (khaja, dorosha, and ghila) from two localities—Valuka and Modhupur (without dorosha) of Bangladesh—and conducted experiments to evaluate the differences in physiochemical characteristics of pulps and seeds of jackfruit (Figure 1).

Pulp Characteristics

Physical Properties of Pulps

There were differences in color and texture among the pulps of jackfruits from different locations (Figure 1). The pulps of the khaja jackfruit (from both Modhupur and Valuka) were firm, and those of the ghila type were very soft to soft. Intermediate textures of pulps were observed in dorosha (Table 2). The color of pulps in khaja fruits were whitish-yellow, whereas that of ghila pulps was deep yellow. The color of dorosha pulps was light yellow. Khaja, dorosha, and ghila pulps were found to be less, intermediately, and very juicy, respectively (Goswami et al., 2011).

Chemical Composition of Pulps

Moisture

There was a difference in moisture content of pulp of jackfruits of five types: Valuka khaja, Valuka ghila, Valuka dorosha, Modhupur khaja, and Modhupur ghila. The highest

Table 2 Physical parameters of pulps

Pulp	Texture	Color	Juiciness	Sweetness
Valuka khaja	Firm	Whitish yellow	Juicy	Less sweet
Valuka ghila	Very soft	Deep yellow	Very juicy	Sweet
Valuka dorosha	Intermediate	Light yellow	Medium juicy	Medium sweet
Modhupur khaja	Firm	Whitish yellow	Juicy	Less sweet
Modhupur ghila	Very soft	Deep yellow	Very juicy	Sweet

Valuka and Modhupur are two regions of Bangladesh famous for jackfruit cultivation. Khaja, ghila, and dorosha are three major types of jackfruit in Valuka and Modhupur.

moisture content was found in Valuka ghila (84.44%) and the lowest was in Modhupur ghila (79.62%). The Valuka khaja, Valuka dorosha, and Modhupur khaja contained 82.88%, 80.04%, and 80.95% moisture, respectively (Table 3). These variations may be attributed to differences in type and location. Interestingly, dorosha types of jackfruit had intermediate moisture content (80.04%). It may be because the texture of pulp was between those of the soft (ghila) and firm (khaja) pulps.

Dry matter

It was observed that the pulps of Modhupur jackfruits (both khaja and ghila) had greater dry matter content than that of the Valuka jackfruits. This might be the result of locality and various environmental factors. The highest and lowest dry matter contents were observed in Modhupur ghila (20.38%) and Valuka ghila (15.56%), respectively. Valuka dorosha contained 19.96% dry matter, which indicates the intermediate texture of its pulp (Table 3).

Ash

Ash content was highest in Valuka dorosha (1.11%). The ash content of Valuka khaja and Valuka ghila, Modhupur khaja, and Modhupur ghila were 0.98%, 1.04%, 0.88%, and 0.70%, respectively (Table 3). Khaja and ghila jackfruits collected from Valuka had greater ash content than khaja and ghila fruit from Modhupur, and there was some variation among the different types. These were may be because of differences in texture of pulps and fiber content.

Vitamin C

The vitamin C content was found to be highest in Valuka dorosha, which contained 8.18 mg% vitamin C (Table 3). Besides this, Valuka khaja and Modhupur khaja contained 5.20 and 4.57 mg% vitamin C, whereas Valuka ghila and Modhupur ghila contained 7.26 and 7.13 mg% vitamin C, respectively. In this context, vitamin C content in the khaja type of jackfruit was lower than that in the ghila type of jackfruit.

Carotene

Variation in carotene content was also observed. Valuka khaja, ghila, and dorosha; and Modhupur khaja and ghila contained 334.06, 470.91, 380.45, 346.03, and 520.46 μg

Table 3 Biochemical parameters of jackfruit pulp collected from different growing areas

Pulp	Moisture (%)	Dry matter (%)	Ash (%)	Vitamin C (mg%)	Carotene (µg/100 g)	Starch (%)	pH	Protein (%)	Titrateable acidity (%)	Total sugar (%)	Reducing sugar (%)	Nonreducing sugar (%)	TSS (%)	Fiber (%)
Valuka khaja	82.88	17.12	0.98	5.20	334.06	7.37	6.29	0.57	0.79	13.80	4.92	8.88	20.1	0.55
Valuka ghila	84.44	15.56	1.04	7.26	470.91	6.11	5.93	0.67	0.91	15.27	7.10	8.17	19.3	0.60
Valuka dorosha	80.04	19.96	1.11	8.18	380.45	7.07	5.82	0.91	0.64	11.29	4.90	6.39	27.0	0.61
Modhupur khaja	80.95	19.05	0.88	4.57	346.03	8.34	6.45	0.83	0.46	16.50	7.04	9.46	23.8	0.90
Modhupur ghila	79.62	20.38	0.70	7.13	520.46	7.27	5.61	0.97	0.61	17.89	8.19	9.70	26.4	0.51

TSS, Total soluble solids.
Valuka and Modhupur are two regions of Bangladesh famous for jackfruit cultivation. Khaja, ghila, and dorosha are three major types of jackfruit in Valuka and Modhupur.

carotene/100 g sample, respectively (Table 3). It could be observed from these values that khaja types had lower carotene content than ghila types, whereas pulps of jackfruit from Modhupur had higher carotene content than that of Valuka types. Highest carotene content was observed in Modhupur ghila (520.46 $\mu\text{g}/100\text{ g}$), and the lowest was in Valuka khaja (334.06 $\mu\text{g}/100\text{ g}$).

Starch

Variation in starch content was observed between both places and types. Valuka khaja, ghila, and dorosha; and Modhupur khaja and ghila contained 7.37%, 6.11%, 7.07%, 8.34%, and 7.27% starch, respectively (Table 3). It was also found that khaja types had higher starch content than ghila types, and pulp of jackfruit from Modhupur had higher starch content than that of Valuka types. The highest starch content was observed in Modhupur khaja (8.34%), and the lowest was in Valuka ghila (6.11%). The starch content in the pulps was low, because the carbohydrates were present in the form of free sugars.

pH

The pH values of Valuka khaja, ghila, and dorosha; and Modhupur khaja and ghila were 6.29, 5.93, and 5.82; and 6.45 and 5.61, respectively (Table 3). Khaja types contained higher pH values than ghila types. The highest pH value was found in Modhupur khaja (6.45), and the lowest was in Modhupur ghila (5.61). The dorosha type contained an intermediate pH value (5.82). The varied pH of khaja and ghila types might be because of the difference in their chemical content. Results showed that the pH of pulp ranged from 5.61 to 6.29.

Protein

Valuka khaja, ghila, and dorosha; and Modhupur khaja and ghila contained 0.57%, 0.67%, and 0.91%; and 0.83% and 0.97% protein, respectively (Table 3). It was also found that khaja types had higher protein content than ghila types, and pulp of jackfruit from Modhupur had higher protein content than that of Valuka types. The highest protein content was observed in Modhupur ghila (0.97%) and lowest was in Valuka khaja (0.57%).

Titrateable Acidity

The greatest titrateable acidity of pulp was observed in Valuka ghila (0.91%), whereas the lowest was in Modhupur khaja (0.46%). It was found that khaja types contained lower titrateable acidity than ghila types (Table 3). This may be because of the differences in texture and chemical contents. It was also found that jackfruit pulps from Modhupur had lower titrateable acidity than those of Valuka. It was also may be the result of change in location and influence of environmental factors. The intermediate value was found in dorosha, at 0.64%.

Total Sugar

Location and type of plant influenced the total sugar content of the pulps. Valuka khaja and ghila contained 13.8% and 15.27% total sugar, respectively, whereas Modhupur khaja and ghila contained 16.50% and 17.89%, respectively (Table 3). Higher total sugar content was observed in jackfruit pulps from Modhupur than those of Valuka types. Higher total sugar content was found in ghila types than khaja types. Lowest total sugar content was found in Valuka dorosha (17.89%), which might be attributed to variation in types.

Reducing Sugar

Higher reducing sugar content was found in ghila types than khaja types. The same difference was observed in case of the fruits from Modhupur than those from Valuka (Table 3). However, the lowest reducing sugar content was found in the dorosha type of jackfruit (4.90%). The reducing sugar content of Valuka khaja and ghila, Modhupur khaja, and ghila were 4.92% and 7.10, 7.04%, and 8.19%, respectively.

Nonreducing Sugar

The highest nonreducing sugar content was found in the Modhupur ghila (9.7%), and the lowest was in Valuka dorosha (6.39%). The nonreducing sugar content of Valuka khaja, Valuka ghila, and Modhupur khaja were 8.88%, 8.17%, and 9.46%, respectively (Table 3). The pulp of jackfruit from Modhupur had higher nonreducing sugar content than that of Valuka types.

Total Soluble Solids

There were variations in total soluble solids (TSS) of pulp according to different types and locations (Table 3). The highest TSS was found in Valuka dorosha (27.0%), whereas the lowest was in Valuka ghila (19.3%). Jackfruit pulp from Modhupur contains greater TSS than that of fruit from Valuka. It might be attributed to place difference. Haque (1991) studied on 32 selected jackfruits and reported TSS in pulps in the range of 14–21.5%, which agreed with our findings for most of the values. The values beyond the range might result from either harvesting time or place.

Fiber

There were slight variations in fiber content among the jackfruit pulps. The fiber content was more or less in the range of 0.50–0.65%, but one exception was observed in Modhupur khaja, which contained 0.90% fiber (Table 3). The fiber content of Valuka khaja, ghila, dorosha, and Modhupur ghila pulps were 0.55%, 0.60%, 0.61%, and 0.51%, respectively.

Seed Characteristics

Physical Properties of Seeds

The size, shape, weight, and color of the seeds varied from type to type, but an effect related to location was not so prominent. The seeds of khaja were ovate shaped and large,

Table 4 Physical characteristics of jackfruit seeds

Seeds	Length (cm)	Width (cm)	Thickness (cm)	Weight of 50 seeds (g)
Valuka khaja	3.34	1.84	1.41	257.33
Valuka ghila	2.92	1.58	1.26	179.67
Valuka dorosha	2.99	1.71	1.45	257.0
Modhupur khaja	2.94	1.94	1.52	201.0
Modhupur ghila	3.11	2.09	1.66	278.0

Valuka and Modhupur are two regions of Bangladesh famous for jackfruit cultivation. Khaja, ghila, and dorosha are three major types of jackfruit in Valuka and Modhupur.

whereas the seeds of ghila were semispheroid (Figure 1). The seeds of dorosha types of fruit were egg-shaped. The highest length, width, and thickness of seeds were found in Valuka khaja (3.34 cm), Modhupur khaja (2.09 cm), and Modhupur khaja (1.66 cm), respectively. Khaja seeds were observed to have higher length, breadth, and thickness compared with ghila seeds, whereas the seeds of dorosha had medium length, breadth, and thickness. The length, breadth, and thickness of khaja and ghila types were 2.84, 1.85, and 1.27 cm, and 2.34, 1.52, and 1.18 cm, respectively (Table 4). These observations are more or less close to the these authors' findings. The weight of 50 seeds was found to be highest in Modhupur khaja (257.33 g), whereas the lowest in was in Valuka ghila (179.67 g). The 50 seeds' weights of Valuka khaja, Valuka dorosha, and Modhupur ghila were 257.33, 257.0, and 201.0 g, respectively. Valuka dorosha seeds had medium value (257.0 g) in comparison with khaja and ghila types (from both locations) of jackfruits. The color of the jackfruit seeds of khaja and ghila were deep brown and brown, respectively (Figure 1). In contrast, dorosha seeds had light brown color with an additional white covering on it.

Chemical Composition of Seeds

Moisture

There was a difference in moisture content of seeds of jackfruits of five types: Valuka khaja, Valuka ghila, Valuka dorosha, Modhupur khaja, and Modhupur ghila. The highest moisture content was found in the Valuka khaja (58.38%) type of jackfruit seeds, and the lowest was in Valuka ghila seeds (45.31%). The seeds of Valuka dorosha, Modhupur khaja, and Modhupur ghila contained 50.64%, 45.96%, and 55.20% moisture, respectively (Table 5). These variations might be the result of differences in type and location. The dorosha type of jackfruit had intermediate moisture content (50.64%). It might be because of the texture of seed, which was between soft (ghila) and firm (khaja) seeds.

Dry matter

The data on dry matter content of three types of jackfruit pulps from two different locations were derived from the percentage of moisture content. The differences in dry matter

Table 5 Biochemical composition of jackfruit seed flour (raw and roasted)

Sample	Moisture (%)	Dry matter (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Starch (%)
V K raw	58.38	44.61	4.27	6.51	0.68	1.6	39.76
V K roasted	—	—	4.09	6.41	0.54	1.65	59.34
V G raw	45.31	54.69	4.38	6.29	0.80	1.4	71.85
V G roasted	—	—	3.91	6.83	0.56	1.26	65.81
V D raw	50.64	49.36	3.63	6.43	0.80	1.6	58.02
V D roasted	—	—	4.19	7.32	0.41	1.6	61.22
M K raw	45.96	54.04	3.93	6.07	0.71	1.46	48.65
M K roasted	—	—	4.45	6.67	0.71	1.35	55.55
M G raw	55.20	44.79	3.91	6.73	0.75	1.32	73.34
M G roasted	—	—	3.76	6.92	0.39	1.71	54.04

M G, Modhupur ghila; M K, Modhupur khaja; V D, Valuka dorosha; V G, Valuka ghila; V K, Valuka khaja. Valuka and Modhupur are two regions of Bangladesh famous for jackfruit cultivation. Khaja, ghila, and dorosha are three major types of jackfruit in Valuka and Modhupur.

content corresponded to the differences in moisture content. The highest dry matter content was observed in the Valuka ghila type of jackfruit seeds (54.69%), and the lowest was in Valuka khaja seeds (44.61%). The seeds of Valuka dorosha, Modhupur khaja, and Modhupur ghila contained 49.36%, 54.04%, and 44.79% dry matter, respectively (Table 5).

Ash

There were no significant differences in ash among the seeds' flour. The ash contents of the raw seeds of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila were 4.27%, 4.38%, and 3.63%, and 3.93% and 3.91%, respectively, whereas the ash contents of roasted seeds were 4.09%, 3.91%, and 4.19%, and 4.45% and 3.76%, respectively (Table 5). These values were more or less close to research by Hoque (1993), who studied the processing and preservation of jackfruit and the use of jackfruit by-products and found that ash content of jackfruit seed was 4.22%.

Protein

There were differences in protein content of raw and roasted jackfruit seeds. Roasted seeds contained a higher protein percentage than raw seeds. The protein contents of the raw seeds of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila were 6.51%, 6.29%, and 6.43%, and 6.07% and 6.73%, respectively, whereas those of roasted seeds were 6.41%, 6.83%, and 7.32%, and 6.67%, and 6.92%, respectively (Table 5). The highest protein content was found in the dorosha type (both raw and roasted seeds). The lowest was observed in Modhupur khaja raw seeds (6.07%).

Starch

With exceptions in ghila types, there was a trend of increased starch content in roasted seeds over raw seeds. In ghila types, however, there was a reverse trend of starch content

in roasted seeds. The starch content of the raw seeds of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila were 39.76%, 71.85%, and 58.02%, and 48.65% and 73.34%, respectively, whereas that of roasted seeds were 59.34%, 65.81%, and 61.22%, and 55.55% and 54.04%, respectively (Table 5). The highest starch content was found in Modhupur ghila raw seeds (73.34%), whereas lowest was in Valuka khaja raw seeds (39.76%).

Fat

There were differences in fat content of raw and roasted jackfruit seeds. Raw seeds contained a higher fat percentage than roasted seeds. The fat contents of the raw seeds from Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila types were 0.68%, 0.80%, 0.80%, and 0.71% and 0.75%, respectively, whereas those of roasted seeds were 0.54%, 0.56%, 0.41%, and 0.71% and 0.39%, respectively (Table 5). The highest fat content was found in dorosha and ghila types (0.80%). The lowest was observed in Modhupur ghila roasted seeds (0.39%).

Fiber

There were few differences in fiber content of raw and roasted seed flours of jackfruits. The fiber contents of the raw seeds of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila were 1.6%, 1.4%, 1.6%, and 1.46% and 1.32%, respectively, whereas those of roasted seeds were 1.65%, 1.26%, 1.6%, and 1.35% and 1.71%, respectively (Table 5). The highest fiber content was found in Modhupur ghila roasted seed flour (1.71%). The lowest was observed in Valuka roasted seed flour (1.26%).

Minerals

There were few differences in mineral content of raw and roasted seed flour of jackfruits. The raw seed flour of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila contained 0.32%, 0.24%, and 0.24%, and 0.32% and 0.32% calcium, respectively, whereas the calcium contents roasted seed flours were 0.16%, 0.24%, and 0.16%, and 0.32% and 0.16%, respectively (Table 6). The magnesium contents were observed at 0.88%, 0.78%, and 0.58%, and 0.68% and 0.78% in raw seed flour of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila types, respectively. In contrast, the magnesium contents of roasted seed flour of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila were 0.78%, 0.97%, and 0.97%, and 1.07% and 0.68%, respectively. The raw seed flours of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila contained 0.169%, 0.166%, and 0.196%, and 0.175% and 0.155% sulfur, respectively, whereas those of roasted seed flours were 0.136%, 0.162%, and 0.205%, and 0.179% and 0.199%, respectively (Table 6). The phosphorus contents were observed at 0.112%, 0.136%, and 0.132%, and 0.1% and 0.120% in raw seed flour of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila, respectively. On the other hand, the phosphorus contents of roasted seed flours of Valuka khaja, ghila, and dorosha, and Modhupur khaja and ghila were

Table 6 Mineral contents of jackfruit seed flour (raw and roasted)

Sample	Minerals			
	Ca (%)	Mg (%)	S (%)	P (%)
V K raw	0.32	0.88	0.169	0.112
V K roasted	0.16	0.78	0.136	0.112
V G raw	0.24	0.78	0.166	0.136
V G roasted	0.24	0.97	0.162	0.124
V D raw	0.24	0.58	0.196	0.132
V D roasted	0.16	0.97	0.205	0.136
M K raw	0.32	0.68	0.175	0.100
M K roasted	0.32	1.07	0.179	0.124
M G raw	0.32	0.78	0.155	0.120
M G roasted	0.16	0.68	0.199	0.136

M G, Modhupur ghila; M K, Modhupur khaja; V D, Valuka dorosha; V G, Valuka ghila; V K, Valuka khaja. Valuka and Modhupur are two regions of Bangladesh famous for jackfruit cultivation. Khaja, ghila, and dorosha are three major types of jackfruit in Valuka and Modhupur.

0.112%, 0.124%, and 0.136%, and 0.124% and 0.136%, respectively (Table 6). These above results were more or less similar to the findings of Brown (1951).

There have been a few improved varieties of jackfruit developed in India and Bangladesh. These are as follows:

‘Palur 1 Jack’, or ‘PLR-1’: This fruit is high yielding with medium height, less spreading, and suitable for high-density planting. The fruit quality is good, with attractive golden yellow firm flakes. The flakes are very sweet, with high consumer appeal, and good keeping quality. The seeds are also edible with high palatability. The TSS value is 19 °Br.

‘PPI 1 Jack’: The fruit bearing occurs twice annually (April through June and November through December) and produces high-quality crisp carpels with high TSS and ascorbic acid content. The flakes are sweet and tasty with pleasant aroma. The maximum bearing takes place on tree trunks. This variety is suitable for commercial planting and home gardens.

‘PLR (J) 2’: This jackfruit possesses good quality and bigger fruits with highly palatable and edible flakes.

‘Swarna’: The fruitlets are golden brown in color and juicy with a TSS of 25–26 °Br, with thick flakes and a very thin rind (<1 cm).

‘Gumless’ type: The flakes are light yellow; fruit is sweet in taste with TSS of 26–30 °Br and has been found promising.

‘Konkan Prolific’: This is a seedling selection with a potential yield of 450–550 kg/tree and an average yield of 420.56 kg/tree, producing 73 fruits/tree/year with individual fruit weight of 5.7 kg, fruit length of 34.4 cm, fruit breadth of 15.2 cm, medium-sized fruit, oblong shape, firm flesh even in monsoon season, golden yellow color of

flesh, fruit bearing in bunches, spiny surface, flowering in January – February, bearing after 6–7 years of planting. Fruits have TSS of 25 °Br and seed weight of 132 g.

‘BARI Kanthal 1’: This is a high yielding variety with regular bearing, early maturity, medium size fruit, and uniform fruit shape, weighing 9.5 kg. The pulp is medium soft, has a very sweet (TSS 22 °Br) taste and less fiber content, and is very juicy. The edible portion accounts for 55%. The variety yields 11,800 medium size fruits/ha. The fruit color is light green.

FOCUSED AREAS OF RESEARCH

In view of the increased population growth coupled with limitations on resources, the steady supply of food and adequate nutrition in many developing countries assumes greater significance. Thus the quality and quantity of food have become an important issue at the global level in view of widespread malnutrition. Carbohydrates, proteins, and fat are in general supplied from cereals, pulses, and oil seeds, respectively, but there are notable vitamin and mineral deficiencies in many regions. In this context, high levels of vitamins and minerals have been recorded in a number of underutilized fruits. The comparison focused on the jackfruit as a nutritionally rich fruit and a good candidate to be of nutritional significance. Recent commercial interest in several underutilized tropical fruits has resulted in an increased cultivated area in Asia and other regions of the developing world.

Distinct varieties of jackfruits are not available in Bangladesh. Bangladesh Agricultural University has established an orchard of 84 jackfruit germplasm, of which 45 were studied in detail and 21 germplasm were identified as superior ones. Jackfruit occurs naturally in two textural forms: ghila, with a soft and pulpy perianth when ripe; and khaja, with a firm perianth (Rahman et al., 1999). In addition, there is another type named *dorosha* with characteristics of both khaja and ghila. Jackfruit has been reported to contain high levels of protein, starch, calcium, and thiamine (Brukill, 1997). The juicy pulp of the ripe fruit is eaten fresh as a dessert. The bulbs (excluding the seeds) are rich in sugar, fairly high in carotene, and also contain vitamin C (Bhatia et al., 1955). Jackfruit is also rich in nutrients such as sodium, potassium, iron, vitamin B₆, calcium, zinc, and many others. Jackfruit can lower blood pressure, cure fever, and relieve diarrhea. This fruit is also known to be beneficial to fighting asthma, ulcers, indigestion, tension, nervousness, and constipation. It can slow down aging and cell degeneration. Jams, beverages, candies, preserves, and dehydrated forms are other industrial uses for jackfruit (Naik, 1949). From the data findings in this experiment, it is indicated that in addition to starch, jackfruit seeds contain substantial amount of minerals, protein, fiber, and sugars, whereas pulps contain reasonable amounts of carotene and sugar. This information will be helpful for selecting the best quality jackfruit for food preparation and preservation. Seeds can be used to prepare bread or dry food in supplementation with other flours,

such as wheat. In this regard, detailed biochemical studies should be carried out to get more information to make the maximum utilization of seeds.

SUMMARY POINTS

- Jackfruit is grown mainly on homestead farms and produces multiple products for food, feed, and industry, as well as contributes toward soil management for sustainable environments.
- From the data findings in different experiments, it was found that in addition to starch, jackfruit seeds contain substantial amount of minerals, protein, fiber, and sugars, whereas pulps contain reasonable amounts of carotene and sugar.
- Seeds can be used to prepare bread or dry food in supplementation with other flours.
- It was concluded after the studies that the proximate composition of jackfruit pulps is influenced by both type and place.
- This information will be helpful for selecting the best quality of jackfruit for food preparation and preservation.
- Detailed biochemical studies should be carried out to get more information to make the maximum use of pulps and seeds.

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CHAPTER 15

The Nutritional Composition of Kiwifruit (*Actinidia* spp.)

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LIST OF ABBREVIATIONS

AG	arabinogalactan
AP	apiogalacturonan
Ara	arabinose
CDTA	cyclohexane-trans-1,2-diamine tetraacetate
Fuc	fucose
FW	fresh weight
Gal	galactose
GalA	galacturonic acid
GAX	glucuronoarabinoxylans
GTC	guanidinium thiocyanate
HG	homogalacturonan
KOH	potassium hydroxide
Na₂CO₃	sodium carbonate
RG	rhamnogalacturonan
TLP	thaumatin-like protein
XGA	xylogalacturonan
XyG	xyloglucan

INTRODUCTION

Kiwifruit is the name commonly used for plants and fruit from the genus *Actinidia* Lindley (Lindl.) The name *Actinidia* originates from the Greek word *aktinos*, meaning ray, and was conferred on the genus by Lindley (1836) because of the radiating arrangement of the styles in the flowers (Ferguson, 1984). *Actinidia* are native to China, with a small number of species also found in a few surrounding countries where they were, until recently, only harvested from the wild (Ferguson and Huang, 2007). The earliest recordings of *Actinidia* are found in classic Chinese texts dating back to 1000–500 BCE, although the first specimens were collected from Nepal and catalogued by a Western botanist, Wallich, in 1821 (Ferguson, 1984). In China the fruit of *Actinidia* are commonly known by the name *mihoutao*, or *monkey peach*, because wild monkeys were known to consume the fruit (Ferguson and Huang, 2007). In the west, *Actinidia* were originally grown as ornamental plants, but in China, kiwifruit were used as a fresh fruit and for the relief of various disorders, including digestive problems, rheumatism, dyspepsia, vomiting, and hemorrhoids, as well as preventive therapy for various cancers (Ferguson, 1990a).

The domestication and subsequent cultivation of *Actinidia* as a commercial crop began in the late 1800s, when plants and seeds collected from the wild in China were taken to the United States, Europe, and New Zealand. In New Zealand, *Actinidia deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson (*A. deliciosa*) was first introduced as seeds by Isabel Fraser in 1904 and successfully grown to produce fruit in 1910. These fruits, known as *Chinese gooseberries* because of their gooseberry flavor, are thought to be the first *Actinidia* fruits to be grown outside of China (Nishiyama, 2007). From these humble beginnings, commercial orchards were established, and the most widely grown cultivar now in



Figure 1 *Actinidia deliciosa* 'Hayward'. With permission from shutterstock.com/Roman Samokhin.

international trade, *A. deliciosa* 'Hayward' (sold as Zespri® Green kiwifruit, [Figure 1](#)), was selected by Hayward Wright in the 1920s ([Ferguson, 1984](#)).

The first exports of Chinese gooseberries from New Zealand were in 1952 to London. As part of a marketing campaign in the United States, the fruits were renamed in the late 1950s to *kiwifruit* in recognition of their similarity to the endemic New Zealand bird, the Kiwi (*Apteryx* spp.). In the following years, the kiwifruit industry rapidly expanded, and kiwifruit are grown commercially in Chile, China, France, Greece, Iran, Italy, Japan, Turkey, and the United States, as well as New Zealand, and are a valuable commodity with an annual production exceeding 1.4 million tons of fresh fruit ([FAOStat, 2012](#)).

For many years the name *kiwifruit* referred specifically to the fruit of the 'Hayward' cultivar. As kiwifruit continued to increase in consumer popularity and more species and cultivars have been commercialized, the name *kiwifruit* has been generally accepted to describe all *Actinidia* species in scientific and commercial literature, and in this chapter the name kiwifruit will include any *Actinidia* taxon.

BOTANICAL ASPECTS

The genus *Actinidia* Lindl. belongs to the family Actinidiaceae within the order Ericales. The latest revision of the genus in the *Flora of China* recognizes 52 species in China and 55 species worldwide ([Table 1](#)), although variations on this number are recorded in the literature. For example, the latest version of [The Plant List \(2013\)](#) recognizes 75 species. The majority of kiwifruit species have not been studied in any detail, and only a few taxa are cultivated either from direct selections from the wild or from a few generations removed from the wild ([Table 2](#)). *Actinidia deliciosa* and *Actinidia chinensis* Planch. are the two species that account for the majority of all kiwifruit cultivated and traded internationally. The two most widely planted cultivars of *A. deliciosa* are 'Hayward' and 'Qinmei'. The most widely planted cultivar of *A. chinensis* is 'Hort16A' (sold as Zespri Gold

Table 1 The genus *Actinidia* Lindl. Taxa

Species	Fruit shape	Fruit weight (g)	Skin color	Skin hairs	Flesh color
<i>Actinidia arguta</i> (Siebold & Zucc.) Planch. ex Miq.	Ovate-globose, flat	4–20	Light red,	Glabrous and smooth	Green
<i>Actinidia callosa</i> Lindl.	globose, oblong		purple, green		
	Globose, short	8–9	Green	Glabrous	Green, yellow
<i>Actinidia chengkouensis</i> C.Y. Chang	cylindric				
	Near globose,	10–35	Brown	Brown tomentose	Unknown
<i>Actinidia chinensis</i> Planch.	cylindric				
	Ellipsoid	20–120	Brown	Brown, short tomentose	Green, yellow
<i>Actinidia chrysantha</i> C.F. Liang	Short, cylindric,	10–30	Brown,	Dense yellow-brown	Green
	ovoid long globose		brown-green	coarse hairs	
<i>Actinidia cylindrica</i> C.F. Liang	Long cylindric	0.5–1	Dark green	Glabrous	Light green
<i>Actinidia deliciosa</i> (A. Chev.) C.F. Liang & A.R. Ferguson	Long cylindric	30–200	Brown	Dense, yellow-brown, coarse hairs	Green
<i>Actinidia eriantha</i> Benth.	Long cylindric	10–40	Green	Dense with white hairs	Jade green
<i>Actinidia farinosa</i> C.F. Liang	Ovoid-cylindric	1–2	Light green	Short tomentose	Green
<i>Actinidia fasciculoides</i> C.F. Liang	Long cylindric		Dark green	Glabrous	Dark green
<i>Actinidia fortunatii</i> Finet & Gagnep.	Long cylindric	1–2	Dark green	Yellow short tomentose	Green
<i>Actinidia fulvicoma</i> Hance	Near cylindric	3–4	Dark green	Yellow long tomentose	
<i>Actinidia glaucocallosa</i> C.Y. Wu	Flat globose	10–15	Green, red-brown	Glabrous	
<i>Actinidia grandiflora</i> C.F. Liang	Cylindric, ellipsoid	20–60	Brown	Greyish white or yellow-brown downy hairs	Green
<i>Actinidia hemsleyana</i> Dunn	Cylindric	16–30	Brown	Dense, greyish, yellowish-brown setose	Yellow green or green
<i>Actinidia henryi</i> Dunn	Near cylindric, long cone	2–8	Green	Glabrous but spotted distinctly	Green
<i>Actinidia holotricha</i> Finet & Gagnep.	Unknown		Unknown	Unknown	Unknown
<i>Actinidia hubeiensis</i> H.M. Sun & R.H. Huang	Ovate-cone	5–9	Dark green	Glabrous but spotted distinctly	Dark green

<i>Actinidia indochinensis</i> Merr.	Short ellipsoid	6–8	Brown	Glabrous but spotted distinctly	Green, dark green
<i>Actinidia kolomikta</i> (Maxim. & Rupr.) Maxim.	Long cylindric or long globose	2–10	Green and yellow-green	Glabrous smooth	Dark green
<i>Actinidia laevis</i> C.F. Liang	Cylindric		Dark green	Glabrous	
<i>Actinidia lanceolata</i> Dunn	Long cylindric, globose-ovoid	1	Light brown	Glabrous	Dark brown
<i>Actinidia latifolia</i> (Gardner & Champ.) Merr.	Cylindric	2–4	Brown-green	Glabrous but spotted distinctly	Jade green
<i>Actinidia liangguangensis</i> C.F. Liang	Long cylindric	1–4	Green	Coarse, short, tomentose	Dark green
<i>Actinidia lijiangensis</i> C.F. Liang & Y.X. Lu	Cylindric	20–35	Green	Densely brown spotted	Jade green
<i>Actinidia linguensis</i> R.G. Li & X.G. Wang	Oblong-ovoid			Tomentose	
<i>Actinidia longicarpa</i> R.G. Li & M.Y. Liang	Oblong			Densely tomentose	
<i>Actinidia macrosperma</i> C.F. Liang	Ovoid, ovoid-globose	15–25	Orange	Glabrous and smooth	Orange
<i>Actinidia melanandra</i> Franch.	Near cylindric	10–20	Brown	Glabrous	Green
<i>Actinidia melliana</i> Hand. Mazz.	Cylindric	1–4	Light green	Short and sparsely coarse	Green
<i>Actinidia obovata</i> Chun ex C.F. Liang	Cylindric	8–23		Glabrous	Light green
<i>Actinidia persicina</i> R.G. Li & L. Mo	Short cylindric	13–18	Brown-green	Dense with brown tomentose	Green
<i>Actinidia pilosula</i> (Finet & Gagnepain) Stapf ex Hand. Mazz.	Globose		Green	Glabrous	
<i>Actinidia polygama</i> (Siebold & Zucc.) Maxim.	Near long, flat cylindric or flat cone	5–9	Green and yellow-green	Glabrous and smooth	Apricot yellow

Continued

Table 1 The genus *Actinidia* Lindl. Taxa—cont'd

Species	Fruit shape	Fruit weight (g)	Skin color	Skin hairs	Flesh color
<i>Actinidia rongshuiensis</i> R.G. Li & X.G. Wang	Cylindric			Tomentose	
<i>Actinidia rubricaulis</i> Dunn	Long cylindric	0.8–1	Dark green	Glabrous	Jade green Green
<i>Actinidia rubus</i> H Lev.	Near globose	4–9	Green	Glabrous	
<i>Actinidia rudis</i> Dunn	Long cylindric	1	Green	Glabrous	
<i>Actinidia rufa</i> (Siebold & Zucc.) Planch.	Oblong-ovoid			Glabrous	
<i>Actinidia rufotricha</i> C.Y. Wu	Ovoid, cylindric	10–19	Green		Unknown
<i>Actinidia sabiifolia</i> Dunn	Ovoid	12–25	Dark green	Glabrous	
<i>Actinidia setosa</i> (H.L. Li) C.F. Liang & A.R. Ferguson	Near globose, ovoid	20–35	Brown	Dense with brown long strigose	
<i>Actinidia sorbifolia</i> C.F. Liang	Long cylindric	9–15	Green	Dense with brown, tomentose, fruit spots	
<i>Actinidia stellatopilosa</i> C.Y. Chang	Unknown	Unknown	Unknown	Unknown	Unknown
<i>Actinidia styracifolia</i> C.F. Liang	Cylindric	2–4	Green	With green fruit spots	Yellow green
<i>Actinidia suberifolia</i> C.Y. Wu	Near globose	10–20	Brown	Tea-brown, tomentose	
<i>Actinidia tetramera</i> Maxim.	Ovoid, ellipsoid	0.8–3	Brown	Glabrous	
<i>Actinidia trichogyne</i> Franch.	Near globose, ovoid, long cylindric	12–20	Dark green	Glabrous but spotted distinctly	
<i>Actinidia ulmifolia</i> C.F. Liang	Unknown	Unknown	Unknown	Unknown	Unknown
<i>Actinidia umbelloides</i> C.F. Liang	Ovoid, short ellipsoid	10–20	Green	Sparse, white tomentose	
<i>Actinidia valvata</i> Dunn	Ovoid	7–12	Orange	Glabrous and smooth	
<i>Actinidia venosa</i> Rehder	Ovoid or short cylindric	2–8	Green	Sparse, light brown tomentose	
<i>Actinidia vitifolia</i> C.Y. Wu	Short cylindric	21–35	Brown	Brown tomentose	Light green
<i>Actinidia zhejiangensis</i> C.F. Liang	Near globose	115–25	Green-yellow	Silver, white, long tomentose	Green

The information in this table describes the physical characteristics of the fruits of the genus *Actinidia* Lindl.

Source: Li, J.-Q., Li, X.-W., Soejarto, D.D., 2007. Actinadaeaceae. In: Wu, Z.-Y., Raven, P.H., Hong, D.-Y. (Eds.), Flora of China. Hippocastanaceae through Theaceae, vol. 12. Science Press, Beijing and Missouri Botanic Garden Press, St Louis, pp. 334–360. With permission from Missouri Botanic Garden Press.

Table 2 Kiwifruit cultivars developed for commercial production

Species, country of origin, cultivar	Fruit shape and average weight (g)	Fruit skin	Fruit flesh
<i>Actinidia deliciosa</i>, China			
Cuixiang (Ximi No. 9)	Ovoid	Yellowish brown with sparse hairs	Green
Emihoutao No. 1 (Jinkui, Jinshui II-16-11)	Cylindric; 100 g	Brown with stiff hairs	Green
Guichang (Qianzi 82-3)	Long cylindric; 85 g	Brown with long hairs	Light green
Jinxiang	Ellipsoid; 90 g	Yellow-brown with yellow, stiff hairs	Green
Miliang No. 1	Long cylindric; 90 g	Dark brown with long, stiff hairs	Yellow green
Qinmei	Ovoid; 100 g	Greenish-brown, stiff yellow-brown hairs	Light green
Xuxiang	Oblong cylindric; 75 g	Yellowish-green with stiff hairs	Green
Yate (Zhouzhi No. 1)	Large cylindric; 120 g	Brown with stiff hairs	Green
Yumihoutao No. 2 (Huamei No. 2)	Large; 110 g	Yellowish brown with long hairs	Light green
<i>A. deliciosa</i>, Greece			
Tsechelidis (Megakiwi™)	Large cylindric; 170–180 g	Brown and hairy	Green
<i>A. deliciosa</i>, Italy			
Convi (Green Light®, Convi97001, Green Star)	Cylindric	Brown and hairy	Green
Earligreen® (Boverlig 02)	Cylindric	Brown with stiff hairs	Green
Summerkiwi 3373 (Summerkiwi®)	Cylindric; 108 g	Brown and hairy	Green
<i>Actinidia chinensis</i>, China			
Chuhong (Panda™ Forest Red Kiwi)	Long ellipsoid; 80 g	Dark green and hairless	Green with red flesh around white core
Cuiyu (Liangmei No. 1)	Ovoid; 90 g	Greenish brown with short hairs	Green
Ganmi No. 1 (Zaoxian No. 1, FT-79-5)	Cylindric; 85 g	Green-brown to pale brown with soft hairs	Greenish-yellow to yellow

Continued

Table 2 Kiwifruit cultivars developed for commercial production—cont'd

Species, country of origin, cultivar	Fruit shape and average weight (g)	Fruit skin	Fruit flesh
Ganmi No. 2 (Kuimi, FY 79-1, Apple Sensation, Kamitsu, Turandot)	Apple shaped; 100 g	Green-brown to dark brown with fine hairs	Yellow-green to yellow
Ganmi No. 3 (Jinfeng, FT 79-3)	Ellipsoid; 80–90 g	Yellow-brown or dark brown with short, fine hairs	Yellow
Guihai No. 4	Long cylindric; 80 g	Yellow brown with fine hair	Green-yellow
Hongyang (Red Sun, RS1)	Obovoid; 60–70 g	Dark green or greenish brown with fine hairs	Green-yellow to yellow, circle of red around white core
Huayou (Panda™ Golden Kiwi)	Ellipsoid; 90 g	Brown or yellow with sparse hairs	Light green to yellow
Jintao (C6, WIB-C6, Jingold™)	Long cylindric; 90 g	Yellow with brown hairs	Green-yellow to orange-yellow
Lushanxiang (79-2, Elizabeth, First Emperor, Yellow Joy)	Cylindric; 90 g	Brownish yellow with soft hairs	Yellow
Wuzhi No. 3 (Wuzhi 81-36)	Ellipsoid; 85 g	Dark green with soft hairs	Bright green
<i>A. chinensis</i>, Italy			
Soreli (Ac 171.76)	Oblong; >100 g	Brown with sparse hairs	Yellow
<i>A. chinensis</i>, Japan			
Sanuki Gold	Squat; 160–180 g	Brown with soft hairs	Bright yellow
<i>A. chinensis</i>, New Zealand			
Charm (Zespri® Charm)	Ovoid	Brown with soft hairs	Yellow
Hort16A (Zespri® Gold, Earligold)	Ovoid; 95–100 g	Green-brown to brown with soft hairs	Yellow-green to bright yellow
Sungold (Zespri® Sungold)		Brown with smooth skin	Yellow
<i>A. chinensis</i> × <i>A. deliciosa</i>, New Zealand			
Sweet Green (Zespri® Sweet Green)	112 g	Brown with short hairs	Green

Table 2 Kiwifruit cultivars developed for commercial production—cont'd

Species, country of origin, cultivar	Fruit shape and average weight (g)	Fruit skin	Fruit flesh
<i>Actinidia eriantha</i>, China			
White (97-4)	Long cylindric; 90 g	Green-brown with long dense hairs	Dark green
Shanong No. 18	Cylindric; 60 g	Brown with long hairs	Green
Tulong Maohua No. 1	Cylindric; 43 g	Dark green with long hairs	Light green
Anzhang Maohua No. 2	Long cylindric; 49 g	Green-brown with long hairs	Green
Heping Maohua No. 1	Cylindric; 45 g	Green-grey with long hairs	Bright green
<i>A. eriantha</i> × <i>A. chinensis</i>, China			
Jinyan	Cylindric; 100 g	Yellow-brown with small red spots, fine hairs	Brilliant yellow
<i>Actinidia arguta</i>, China			
Kuilu	Flat, oval; 18 g	Green, hairless	Green
Kuan-8348	Round; 23 g	Green, hairless	Green-yellow
Liaodan-134	Round; 23 g	Green, hairless	Green
Liaoheng-8301	Ellipsoidal; 20 g	Yellow-green, hairless	Green
<i>A. arguta</i>, New Zealand			
Hortgem Tahi	Spheroid or apple shaped; 11 g	Green, hairless	Green
Hortgem Rua	Oblong; 14 g	Green hairless	Red-centered flesh
Hortgem Toru	Cylindric; 12 g	Green hairless	Green
Hortgem Wha	Oblong; 7 g	Green hairless	Green

The information in the table describes the physical characteristics of the fruits of the commercially grown species of the genus *Actinidia* Lindl.

Sources: Ferguson, A.R., Huang, H.-W., Testolin, R., 2012. Register of new fruit and nut cultivars, List 46. HortScience 47, 536–562. With permission from the American Society for Horticultural Science; Williams, M.H., Boyd, L.M., McNeillage, M.A., MacRae, E.A., Ferguson, A.R., Beatson, R.A., Martin, P.J., 2003. Development and commercialization of 'Baby Kiwi' (*Actinidia arguta* Planch.). Acta Horticulturae 610, 81–86. With permission from the International Society for Horticultural Science; Xiao, X.-G., 1999. Progress of *Actinidia* selection and breeding in China. Acta Horticulturae 498, 25–35. With permission from the International Society for Horticultural Science. The Nutritional Value of Zespri® Kiwifruit, Health Toolkit. Zespri Group Limited, Mount Maunganui. With permission from Zespri Group Limited.

kiwifruit, [Figure 2](#)). *Actinidia chinensis* and *A. deliciosa* have been formally treated as separate species and as varieties of the same species ([Ferguson, 2013](#)). However, they are now recognized as separate species and are treated as such in this chapter. Other kiwifruit species of minor commercial importance include *Actinidia arguta* (Siebold & Zucc.)



Figure 2 *Actinidia chinensis* 'Hort16A'. With permission from shutterstock.com/Laitr Keiows.



Figure 3 *Actinidia arguta* 'arguta'. With permission from shutterstock.com/Antonio Ribeiro.

Planch. ex Miq. (marketed as *baby kiwi*, [Figure 3](#)), *Actinidia eriantha* Benth., *Actinidia kolomikta* (Rupr. & Maxim.) Maxim., and *Actinidia polygama* (Siebold & Zucc.) Maxim.

Morphology

All kiwifruit species are perennial climbing or scrambling vines with various degrees of vigor, and most are deciduous ([Ferguson and Huang, 2007](#)). Vines grown for commercial fruit production tend to be vigorous and require strong structural support when the plants are in full fruit production. The wood of kiwifruit has dimorphic vessel elements; that is, a small number of large, long vessel elements with simple perforations and a large number of smaller vessels with oblique scalariform perforation plates ([Ferguson, 1984](#)). The leaves are simple and dorsiventral, usually with a long petiole that in some species is covered with hairs ([Ferguson, 1990b](#)). The leaves undergo a biphasic growth pattern, increasing rapidly in size for the first 30 days of growth and then more slowly until they reach mature size ([Ferguson, 1990b](#)).

Generally, kiwifruit vines do not flower until they are 3–4 years old. Growth occurs in spring with bud break varying among taxa. Flowering occurs approximately 2 months after bud break with species such as *A. chinensis*, *A. deliciosa*, and *A. kolomikta* flowering before *Actinidia fulvicoma* Hance and *Actinidia latifolia* (Gardner & Champ.) Merr. in both New Zealand and China (Ferguson, 1984). The flowers are generally pentamerous; some are tetramerous, with imbricated petals colored white, pink, red, yellow, or green, depending on the species, and flowers occur adaxially to the leaf in small dichasia (Ferguson, 1984).

Reproductive Biology

Kiwifruit species are dioecious, although this is not absolute, with pistillate and staminate flowers occurring on separate plants (Ferguson, 2013). The pistillate plants have flowers with styles, stamens, and functional ovaries that develop into fruit after pollination but do not produce viable pollen (Ferguson, 2013). The staminate plants have flowers that contain viable pollen-producing stamens, but the ovary has fewer carpels and lacks ovules (Hopping, 1990). Flowering of both vines must coincide, and generally, the flowers of the pistillate plants of *A. deliciosa* ‘Hayward’ bloom for 10–18 days, whereas those of the staminate flower last 3–5 days longer (Hopping, 1990).

Cytotaxonomic studies indicate that kiwifruit are polyploids with diploid, tetraploid, hexaploid, and octoploid taxa identified (Ferguson and Huang, 2007). Studies on the cultivated kiwifruit species show that *A. deliciosa* cultivars are hexaploid, *A. chinensis* cultivars are diploid (e.g., ‘Hort16A’ and ‘Hongyang’) or tetraploid (e.g., ‘Jintao’ and ‘Kuimi’), and *A. arguta* cultivars are tetraploid (McNeilage and Considine, 1989). The basic chromosome number is $x=29$ (Ferguson, 1984).

Fruit Morphology

Kiwifruit are berries that contain numerous small seeds embedded in a juicy flesh and can occur singly or in groups of 3–5 (Ferguson, 1984). The structural regions of the fruit consist of the epicarp or surface skin, the outer pericarp, the inner pericarp with multiple locules that contain the seeds, and the columella or central core. The characteristics of the berries are diverse, and variations in size, shape, skin texture and hairiness, skin and flesh colors, flesh composition, flesh flavor, time of maturity and harvest, and storability are common (Figure 4). The size of the fruit varies from berries that are less than 10 g such as *A. arguta*, *A. kolomikta*, and *A. latifolia* to the large commercial varieties of *A. deliciosa* and *A. chinensis* (100–120 g). The shape also varies from ovoid (e.g., *A. kolomikta*), subglobose (e.g., *A. chinensis*), globose to oblong (e.g., *A. arguta*), subglobose to cylindrical (e.g., *A. deliciosa*), or cylindrical (*A. eriantha*). The skin of kiwifruit varies from smooth (e.g., *A. arguta*) to having soft, fine hair (e.g., *A. chinensis*) or dense, long hair (e.g., *A. deliciosa*), and varies in color from brown (e.g., *A. deliciosa* or *A. chinensis*) to green (*A. chinensis*) and purple and red (*A. arguta*). Internally, kiwifruit flesh color varies from

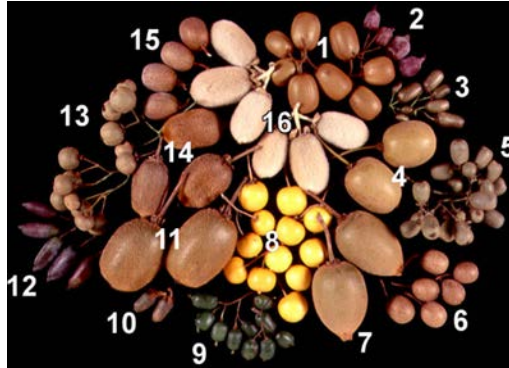


Figure 4 Fruits of the genus *Actinidia* Lindl. 1. *Actinidia rufa*, 2. *Actinidia melanandra*, 3. *Actinidia glaucophylla*, 4. *Actinidia chinensis*, 5. *Actinidia latifolia*, 6. *Actinidia indochinensis*, 7. *Actinidia chinensis* 'Hort16A', 8. *Actinidia macrosperma*, 9. *Actinidia arguta*, 10. *Actinidia fulvicoma*, 11. *Actinidia deliciosa* 'Hayward', 12. *Actinidia arguta* 'purpurea', 13. *Actinidia guilinensis*, 14. *Actinidia setosa*, 15. *Actinidia chrysantha*, 16. *Actinidia eriantha*. Reprinted from Ferguson, A.R., 1999. *New temperate fruits: Acta chinensis and Acta deliciosa*. In: Janick, J., (Ed.), *Perspectives on new crops and new uses*. ASHS Press, Alexandria, pp. 342–347. With permission from the American Society for Horticultural Science.

shades of green (e.g., *A. deliciosa*, *A. eriantha*, *A. chinensis*) and yellow (e.g., *A. chinensis* 'Hort16A' and 'Jintao') to fruit with green flesh that has a circle of red flesh around the central core (e.g., *A. chinensis* 'Hongyang'). Harvesting also varies, with *A. arguta* typically harvested 100–110 days after pollination, whereas *A. chinensis* and *A. deliciosa* are harvested 180–210 days after pollination, depending on cultivar and climate.

Geographic Distribution

Most kiwifruit species flourish in warm and humid environments but require a period of winter chill for bud break and flowering (Ferguson, 1990b). In the wild, kiwifruit are naturally distributed in Eastern Asia, with the majority of taxa occurring in south central and southwestern China between the Yangzi and Pearl rivers (Ferguson and Huang, 2007).

COMPOSITION OF KIWIFRUIT CULTIVARS

There is little detailed chemical compositional information available for kiwifruit (Drummond, 2013). The primary focus of this section will therefore be on the two main commercial varieties, *A. deliciosa* 'Hayward' (referred to as *green kiwifruit*) and *A. chinensis* 'Hort16A' (referred to as *gold kiwifruit*), with other species and cultivars of kiwifruit included where information from the literature allows. The nutrient compositions of green and gold kiwifruit are shown in Table 3 and have been determined using the flesh of ripe, ready-to-eat fruits, because these species are eaten with their skins removed.

Table 3 Nutritional composition of commercially grown *Actinidia deliciosa* cultivar 'Hayward' and *Actinidia chinensis* cultivar 'Hort16A' kiwifruit

Nutrient	Unit/100 g fresh weight	<i>A. deliciosa</i> 'Hayward' ^a	<i>A. chinensis</i> 'Hort16A' ^b
Proximate			
Moisture	g	83.07	83.22
Protein ^c	g	1.14	1.23
Lipids, total	g	0.52	0.56
Ash	g	0.61	0.76
Carbohydrate, by difference	g	14.66	14.23
Fiber, total dietary	g	3.0	2.0
Sugars, total	g	8.99	10.98
Sucrose	g	0.15	0.05
Glucose	g	4.11	5.20
Fructose	g	4.35	5.68
Maltose	g	0.19	0.05
Galactose	g	0.17	ND
Starch	g	0	0.18
Energy	kcal	61	60
Refuse	%	14 (skin)	26 (skin)
Minerals			
Calcium	mg	34	20
Iron	mg	0.31	0.29
Magnesium	mg	17	14
Phosphorus	mg	34	29
Potassium	mg	312	316
Sodium	mg	3	3
Zinc	mg	0.14	0.1
Copper	mg	0.13	0.147
Manganese	mg	0.098	0.058
Selenium	µg	0.2	3.1
Vitamins			
Vitamin C, total ascorbic acid	mg	92.7	105.4
Thiamin	mg	0.027	0.024
Riboflavin	mg	0.025	0.046
Niacin	mg	0.341	0.28
Pantothenic acid	mg	0.183	0.5
Pyridoxine	mg	0.063	0.057
Folate, total	µg	25	34
Choline, total	mg	7.8	5.0
Betaine	mg	0.5	ND
Vitamin B ₁₂	µg	0	0
Vitamin A, RAE ^d	µg RAE	4	4

Continued

Table 3 Nutritional composition of commercially grown *Actinidia deliciosa* cultivar 'Hayward' and *Actinidia chinensis* cultivar 'Hort16A' kiwifruit—cont'd

Nutrient	Unit/100 g fresh weight	<i>A. deliciosa</i> 'Hayward' ^a	<i>A. chinensis</i> 'Hort16A' ^b
Vitamin A	IU	87	72
Vitamin E (α -tocopherol)	mg	1.46	1.49
Vitamin E (γ -tocopherol)	mg	0.03	0.01
Vitamin E (δ -tocopherol)	mg	0.00	0.01
Vitamin K	μ g	40.3	5.5
Carotene, β	μ g	52	43
Carotene, α	μ g	0	0
Cryptoxanthin, β	μ g	0	0
Lycopene	μ g	0	0
Lutein + Zeaxanthin	μ g	122	114

Lipids

Fatty acids, total saturated	g	0.029	0.149
Caprylic C8:0	g	0.000	0.005
Capric C10:0	g	0.000	0.014
Lauric C12:0	g	0.000	0.014
Tridecylic C13:0	g	0.000	0.005
Myristic C14:0	g	0.000	0.009
Palmitic C16:0	g	0.017	0.090
Stearic C18:0	g	0.012	0.014
Fatty acids, total monounsaturated	g	0.047	0.036
Palmitoleic C16:1 (undifferentiated)	g	0.000	0.009
Oleic C18:1 (undifferentiated)	g	0.047	0.027
Fatty acids, total polyunsaturated	g	0.287	0.207
Linoleic C18:2 (undifferentiated)	g	0.246	0.113
Linolenic C18:3 (undifferentiated)	g	0.042	0.077
Docosapentaenoic acid 22:5 (n-3)	g	0	0.018
Cholesterol	mg	0	0

Amino acids

Alanine	g	0.053	0.040
Arginine	g	0.081	0.109
Aspartic acid	g	0.126	0.119
Cystine	g	0.031	0.025
Glutamic acid	g	0.184	0.129
Glycine	g	0.060	0.046

Table 3 Nutritional composition of commercially grown *Actinidia deliciosa* cultivar 'Hayward' and *Actinidia chinensis* cultivar 'Hort16A' kiwifruit—cont'd

Nutrient	Unit/100 g fresh weight	<i>A. deliciosa</i> 'Hayward' ^a	<i>A. chinensis</i> 'Hort16A' ^b
Histidine	g	0.027	0.020
Isoleucine	g	0.051	0.037
Leucine	g	0.066	0.056
Lysine	g	0.061	0.060
Methionine	g	0.024	0.016
Phenylalanine	g	0.044	0.030
Proline	g	0.044	0.028
Serine	g	0.053	0.040
Threonine	g	0.047	0.042
Tryptophan	g	0.015	0.044
Tyrosine	g	0.034	0.023
Valine	g	0.057	0.046

The table shows the mean nutrient composition of the two main commercially grown kiwifruit cultivars, *A. deliciosa* 'Hayward' and *A. chinensis* 'Hort16A'. The composition was determined on the flesh of the fruit. ND, Not detectable.

^aSource: USDA National Nutrient Database Release 27 (2014). Statistics report 09,148 Kiwifruit, green, raw. Fruit source not stated.

^bSource: USDA National Nutrient Database Release 27 (2014). Statistics report 09,445 Kiwifruit, gold, raw. Fruit was grown in New Zealand.

^cTotal nitrogen multiplied by 6.25 for assumed nitrogen content of protein.

^dRAE, retinol activity equivalents.

Proximate analyses reveal that the two cultivars are similar in composition, with the most notable differences being the higher dietary fiber content in green kiwifruit and the higher total sugar content in gold kiwifruit. As with all fruit, the chemical composition of kiwifruit varies not only between species and cultivars but also as a function of environmental factors, storage, and ripening conditions, as well as the methods used to analyze the nutrients (Drummond, 2013).

Macronutrient Components

Protein

The protein content of kiwifruit flesh is relatively low and ranges between 0.81 and 1.52 g/100 g fresh weight (FW), depending on the species and cultivar (Table 4). Likewise, the amino acid content of the fruit is also low (Table 3), and the protein content of the seeds only accounts for 150–200 g/kg of the weight of the seeds (Deng et al., 2014). The three major proteins identified in kiwifruit species using SDS-PAGE and Western analyses are actinidin, kiwellin, and thaumatin-like protein (TLP).

Actinidin is a cysteine protease enzyme that catalyzes the hydrolysis of peptide bonds and is considered to be the main allergen in kiwifruit. Actinidin activity is observed primarily in the outer and inner pericarp regions, with very little activity detected in the

Table 4 Protein content (g/100 g FW) of selected kiwifruit species and cultivars

Species/cultivar	Protein content ^a	References
<i>Actinidia deliciosa</i>		
Hayward	1.14	USDA (2014) ^b
Bruno	0.81	NZIPFRL (2013) ^c
<i>Actinidia chinensis</i>		
Hort16A	1.23	USDA (2014) ^d
Charm	1.52	Zespri Group Ltd (2013) ^e
Sungold	1.02	NZIPFRL (2013) ^f
<i>A. deliciosa</i> × <i>A. chinensis</i>		
Sweet Green	1.27	NZIPFRL (2013) ^g
<i>Actinidia eriantha</i>		
Bidan	1.10	Jo et al. (2007) ^h

The table shows the mean protein content determined in the flesh of selected kiwifruit species and cultivars.

^aTotal nitrogen multiplied by 6.25 for assumed nitrogen content of protein.

^bSource: United States Department of Agriculture (2014). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,148 Kiwifruit, green, raw. Fruit source not stated.

^cSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L88 Kiwifruit, Bruno, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^dSource: United States Department of Agriculture (2014). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,445 Kiwifruit, gold, raw. Fruit was grown in New Zealand.

^eSource: Zespri Group Limited (2013). The Nutritional Value of Zespri® Kiwifruit, Health Toolkit. Zespri Group Limited, Mount Maunganui: With permission from Zespri Group Limited. Fruit was grown in New Zealand.

^fSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1077 Kiwifruit, Sungold, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^gSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1078 Kiwifruit, Sweet Green, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^hSource: Jo, Y.S., Cho, H.S., Park, M.Y., Bang, G.P., 2007. Selection of a sweet *Actinidia eriantha*, 'Bidan'. Acta Horticulturae 753, 253–257: With permission from the International Society for Horticultural Science. Fruit was grown in Korea.

skin and core. It is the most abundant soluble protein found in the 'Hayward', 'Bruno', and 'Qinmei' cultivars of *A. deliciosa* (Maddumage et al., 2014; Nishiyama, 2007). In *A. chinensis* cultivars, the actinidin content is variable, ranging from trace amounts in gold kiwifruit to levels similar to green kiwifruit in 'Jin Feng' (Maddumage et al., 2014). Actinidin has not been detected in the fruits of *A. eriantha* or *Actinidia rufa* (Siebold & Zucc.) Planch. ex Miq. (Maddumage et al., 2014; Nishiyama, 2007).

Kiwellin is a cysteine-rich protein found in the fruits of both *A. deliciosa* and *A. chinensis* and can be cleaved by actinidin to form a 20 kDa protein called *KiTH* and a 39-amino acid peptide called *kissper* (Ciardiello et al., 2009). The levels of kiwellin are higher in gold kiwifruit when compared with those of the *A. deliciosa* cultivars of 'Hayward', 'Bruno', and 'Qinmei' (Maddumage et al., 2014). TLP, a pathogenesis-related protein with a molecular

mass of 24kDa that has antifungal activities and a 17kDa protein known as *kirola* has also been identified and extracted from green and gold kiwifruit (Ciardiello et al., 2009).

Lipids

Kiwifruit contain very little lipid (Table 3), most of which is found in the seed oils, with smaller amounts of membrane-associated lipids located within the flesh (Duman and Özcan, 2011). The oil content in the seeds of green kiwifruit is approximately 27–29% of the seed weight. Approximately 76% of the fatty acids in kiwifruit seed oils are polyunsaturated fatty acids, 15% are monounsaturated fatty acids, and 9% are saturated fatty acids. The oil extracted from the seeds is particularly rich in linolenic acid, which accounts for 57% (w/w) of the total seed oil content along with oleic acid (16%), linoleic acid (15.5%), palmitic acid (6.9%), and steric acid (3.5%) (Cravotto et al., 2011). The oil extracted from the seeds also contains γ -tocopherol (10.3 ± 0.8 mg/kg), γ -tocotrienol (21.6 ± 0.5 mg/kg), and δ -tocotrienol (2.6 ± 0.1 mg/kg), and whereas these levels are similar to those found in blackberry seed oil, they are significantly lower than the levels seen in the oils of other berries, such as blueberries, cranberries, red raspberries, and strawberries (Van Hoed et al., 2009).

Carbohydrates

Sugars

The key indicator of ripening and maturation in kiwifruit is the conversion of starch to soluble sugars (Drummond, 2013). The reported total soluble sugar concentrations in kiwifruit are highly variable and range between 6.5 and 10.3 g/100 g FW for *A. deliciosa* cultivars, 8.7–11.3 g/100 g FW for *A. chinensis* cultivars, 6.2–9.6 g/100 g FW for *A. arguta* cultivars, and 6.6–6.9 g/100 g FW for *A. rufa* cultivars (Table 5). The predominant sugars present in kiwifruit are glucose, fructose, and sucrose. Cultivars of *A. deliciosa*, *A. chinensis*, and *A. rufa* species contain similar amounts of glucose and fructose, with lower levels of sucrose, whereas *A. arguta* species are predominantly high in sucrose with lower glucose and fructose contents. Kiwifruit also contain the hexahydric sugar alcohol, myo-inositol. The myo-inositol content is highest in kiwifruit during the early phase of fruit growth, reaching up to 36% of the soluble carbohydrate content before declining to 1–2% as the fruit matures (Bieleski et al., 1997). *Actinidia arguta* cultivars contain the highest levels of myo-inositol (Table 5).

Dietary Fiber

The fiber content of green kiwifruit has been extensively described; however, studies conducted on gold kiwifruit have only recently been published. The fiber content of kiwifruit is similar to apples (2.3 mg/100 g FW), oranges (2.5 mg/100 g FW), and bananas (2.6 mg/100 g FW) (USDA, 2014). A detailed description of the fiber content in kiwifruit is covered in Section Dietary Fibre Composition of Green Kiwifruit and Gold Kiwifruit of this chapter.

Table 5 Total sugars, glucose, fructose, sucrose, and myo-inositol contents (g/100 g FW) of selected kiwifruit species and cultivars

Species/cultivar	Total sugars	Glucose	Fructose	Sucrose	Myo-inositol	References
<i>Actinidia deliciosa</i>						
Hayward	8.99	4.11	4.25	0.15		USDA (2014) ^a
Abbott	10.33 ± 2.26	4.06 ± 0.98	3.94 ± 0.83	2.33 ± 0.46	0.100 ± 0.023	Nishiyama et al. (2008) ^b
Bruno	7.90	3.20	3.30	1.40	0.177	NZIPFRL (2013) ^c
Elmwood	6.49 ± 0.83	2.46 ± 0.12	2.59 ± 0.11	1.43 ± 0.69	0.032 ± 0.008	Nishiyama et al. (2008)
Koryoku	9.82 ± 0.71	3.94 ± 0.25	3.79 ± 0.25	2.10 ± 0.70	0.029 ± 0.006	Nishiyama et al. (2008)
<i>Actinidia chinensis</i>						
Hort16A	10.98	5.20	5.68	0.05		USDA (2014) ^d
Golden King	9.08 ± 0.93	2.87 ± 0.32	2.47 ± 0.22	3.74 ± 0.40	0.060 ± 0.022	Nishiyama et al. (2008)
Hongyang	11.28 ± 1.17	3.70 ± 0.18	3.63 ± 0.27	3.95 ± 0.78	0.110 ± 0.020	Nishiyama et al. (2008)
Kobayashi 39	8.72 ± 0.59	3.56 ± 0.27	3.51 ± 0.29	1.66 ± 0.15	0.101 ± 0.031	Nishiyama et al. (2008)
Sanuki gold	10.42 ± 1.23	4.38 ± 0.67	3.85 ± 0.46	2.20 ± 0.14	0.050 ± 0.013	Nishiyama et al. (2008)
Sungold	12.3	5.28	5.80	1.22		NZIPFRL (2013) ^e
<i>Actinidia arguta</i>						
Ananasnaya ^f	8.94 ± 0.58	1.57 ± 0.15	1.78 ± 0.18	5.59 ± 0.81	0.575 ± 0.068	Nishiyama et al. (2008)
Hirano	6.27 ± 1.72	1.01 ± 0.06	1.15 ± 0.04	4.11 ± 1.67	0.888 ± 0.084	Nishiyama et al. (2008)
Issai	9.62 ± 0.39	0.85 ± 0.30	0.97 ± 0.30	7.80 ± 0.82	0.777 ± 0.123	Nishiyama et al. (2008)

Mitsuko	7.60 ± 1.39	0.72 ± 0.07	0.85 ± 0.05	6.02 ± 1.33	0.703 ± 0.041	Nishiyama et al. (2008)
Shimane	6.23 ± 0.52	0.83 ± 0.10	1.11 ± 0.13	4.29 ± 0.67	0.982 ± 0.068	Nishiyama et al. (2008)
<i>Actinidia rufa</i>						
Awaji	6.56 ± 0.31	2.56 ± 0.14	2.61 ± 0.13	1.39 ± 0.14	0.058 ± 0.023	Nishiyama et al. (2008)
Fuchu	6.92 ± 0.57	3.00 ± 0.20	2.89 ± 0.24	1.03 ± 0.16	trace	Nishiyama et al. (2008)
<i>A. chinensis</i> × <i>A. deliciosa</i>						
Sanryoku	10.04 ± 0.30	3.11 ± 0.08	3.17 ± 0.10	3.76 ± 0.32	0.177 ± 0.039	Nishiyama et al. (2008)
Sweet Green	12.1	4.8	5.3	1.9		NZIPFRL (2013) ^g

The table shows the total and individual sugar contents and myo-inositol content determined in the flesh of selected kiwifruit species and cultivars. Values are means ± SD where data was available.

^aSource: United States Department of Agriculture (2014). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,148 Kiwifruit, green, raw. Fruit source not stated.

^bSource: Nishiyama et al. (2008): With permission from the Japanese Society for Food Science and Technology. Fruit was grown in Japan with the exception of 'Ananasnaya' (see footnote below). Values are the mean of six measurements.

^cSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L88 Kiwifruit, Bruno, raw: With permission from the New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^dSource: United States Department of Agriculture (2014). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,445 Kiwifruit, gold, raw. Fruit was grown in New Zealand.

^eSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1077 Kiwifruit, Sungold, raw: With permission from the New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^fFruit grown in the United States and imported to Japan.

^gSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1078 Kiwifruit, Sweet Green, raw: With permission from the New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

Micronutrient Compounds

Vitamins

Vitamin C

Vitamin C (ascorbic acid) is the most important and most publicized nutrient in kiwifruit. The vitamin C content is highly variable between and within species, and ranges from as low as 4–5 mg/100 g FW in *Actinidia henryi* Dunn and *Actinidia rudis* Dunn to more than 2000 mg/100 g FW in *A. latifolia* (Huang et al., 2004). Fruit of *A. eriantha*, *Actinidia guilinensis* C.F. Liang, and *A. kolomikta* also have levels of vitamin C that exceed 500 mg/100 g FW (Huang et al., 2004; Latocha et al., 2010). Among the commercially grown crops, the vitamin C contents of *A. deliciosa*, *A. chinensis*, and *A. arguta* fruits are reported to be within the ranges of 50–250, 50–420, and 80–430 mg, respectively (Huang et al., 2004; Latocha et al., 2010; USDA, 2014). Thus a single daily kiwifruit provides sufficient vitamin C for adequate human nutrition in accordance with the European Union's recommended daily allowance for vitamin C.

Vitamin E

There are eight natural forms of vitamin E, and values for six of these have been reported in the flesh, skins, and oil extracted from the seeds of kiwifruit (Table 6). The levels of α -tocopherol in green kiwifruit are similar in the skin and flesh, whereas those of δ -tocopherol and δ -tocomonoenol are significantly higher in the skins. The levels of α -tocopherol in gold kiwifruit are significantly higher than the other forms of vitamin E present in the flesh.

Folate (Vitamin B₉)

The folate content of kiwifruit is reported to be 25 and 34 μ g/100 g FW for green and gold kiwifruit, respectively, and is not exceptional when compared with other common fruits, such as oranges (39 μ g/100 g FW), bananas (20 μ g/100 g FW), or blackberries (25 μ g/100 g FW) (USDA, 2014). The content of gold kiwifruit does, however, meet the requirements of the European Union for health claims under the European Food Safety Authority to make a source claim, because it exceeds 15% of the recommended daily allowance of 200 μ g of folate per day.

Vitamin K

In kiwifruit, vitamin K is present as the fat-soluble compound known as *phyloquinone*. Using a liquid chromatography tandem mass spectrometry method, Gentili and Caretti (2011) reported values of 86 and 53 μ g phyloquinone/100 g FW for green and gold kiwifruit, respectively.

Table 6 Vitamin E content (mg/100 g FW) in the flesh, skin, and seed oils of green and gold kiwifruit

	α	γ	δ	γ	δ		
	-tocopherol			-tocotrienol		δ -tocomonoenol	References
Green kiwifruit							
Flesh	1.46	0.03	0.64	0.10		0.85	USDA (2014) ^a Fiorentino et al. (2009) ^b Gentili and Caretti (2011) ^c
	1.02						
	1.59	0.02					
Skin	1.05		2.49			1.45	Fiorentino et al. (2009)
Seed	1.03			2.16	0.26		Van Hoed et al. (2009) ^d
Gold kiwifruit							
Flesh	1.49	0.01	0.01				USDA (2014) ^e Gentili and Caretti (2011)
	4.84	0.01					

The table shows the various forms of vitamin E determined in the flesh, skin, and seed oils of green and gold kiwifruit.

^aSource: [United States Department of Agriculture \(2014\)](#). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,148 Kiwifruit, green, raw. Fruit source not stated.

^bSource: Fiorentino, A., D'Abrosca, B., Pacifico, S., Mastellone, C., Scognamiglio, M., Monaco, P., 2009. Identification and assessment of antioxidant capacity of phytochemicals from Kiwi Fruits. *Journal of Agricultural and Food Chemistry* 57, 4148–4155: With permission from the American Chemical Society. Fruit was grown in Italy.

^cSource: [Gentili and Caretti \(2011\)](#): With permission from Elsevier. Fruit source not stated.

^dSource: [Van Hoed et al. \(2009\)](#): With permission from Wiley Periodicals Incorporated. Fruit was grown in the USA.

^eSource: [United States Department of Agriculture \(2014\)](#). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,445 Kiwifruit, gold, raw. Fruit was grown in New Zealand.

Minerals

Although the overall mineral content of kiwifruit is not outstanding, the potassium content of several species meet or exceed the 15% recommended daily allowance requirement (≥ 300 mg) of the European Union for health claims permitted under the European Food Safety Authority ([Table 7](#)).

Organic Acids

Citric Acid, Quinic Acid, and Malic Acid

Along with ascorbic acid (vitamin C), kiwifruit contain a range of organic acids, including citric, quinic, and malic acids with trace amounts of glucuronic, galacturonic, and shikimic acids ([McGhie, 2013](#)). The concentrations and ratios of the acids vary as the fruit matures, which is important for the organoleptic qualities (sugar-acid balance) of the fruit ([Table 8](#)). A study on organic acid contents of 25 kiwifruit cultivars reported that the total organic acid contents of citric, quinic, and malic acids were

Table 7 Potassium content (mg/100 g FW) of selected kiwifruit species and cultivars

Species/cultivar	Potassium content	Reference
<i>Actinidia deliciosa</i>		
Hayward	312	USDA (2014) ^a
<i>Actinidia chinensis</i>		
Hort16A	316	USDA (2014) ^b
Charm	354	Zespri Group Ltd (2013) ^c
Sungold	315	NZIPFRL (2013) ^d
<i>Actinidia eriantha</i>		
Bidan	381	Jo et al. (2007) ^e
<i>A. chinensis</i> × <i>A. deliciosa</i>		
Sweet Green	328	NZIPFRL (2013) ^f

The table shows the potassium content determined in the flesh of selected kiwifruit species and cultivars.

^aSource: United States Department of Agriculture (2014). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,148 Kiwifruit, green, raw. Fruit source not stated.

^bSource: United States Department of Agriculture (2014). National Nutrient Database Release 27. Nutrient Data Laboratory Statistics report 09,445 Kiwifruit, gold, raw. Fruit was grown in New Zealand.

^cSource: Zespri Group Limited (2013). The Nutritional Value of Zespri® Kiwifruit, Health Toolkit. Zespri Group Limited, Mount Maunganui: With permission from Zespri Group Limited. Fruit was grown in New Zealand.

^dSource: New Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1077 Kiwifruit, Sungold, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^eSource: Jo, Y.S., Cho, H.S., Park, M.Y., Bang, G.P., 2007. Selection of a sweet *Actinidia eriantha*, 'Bidan'. Acta Horticulturae 753, 253–257: With permission from the International Society for Horticultural Science. Fruit was grown in Korea.

^fSource: New Zealand Institute of Plant and Food Research., 2013. The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1078 Kiwifruit, Sweet Green, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

similar in *A. deliciosa* and *A. chinensis* cultivars, whereas *A. arguta* cultivars had lower concentrations because of lower levels of quinic acid (Nishiyama et al., 2008). In green kiwifruit, organic acids are distributed throughout the flesh, with the highest levels of citric acid located in the inner cortex and the highest levels of quinic acid located in the outer cortex of the fruit (MacRae et al., 1989). The core of the fruit contains the lowest total acid content.

Oxalate

The oxalate present in kiwifruit occurs as either soluble or insoluble salts. The insoluble oxalate is primarily found as calcium oxalate in the form of double-pointed, needlelike raphide crystals. The raphides form bundles called *druses* that range in length from 80 to 130 µm, and have been observed across the whole pericarp and beneath the surface of the skin in the fruits of *A. deliciosa*, *A. chinensis*, *A. rufa*, and *A. arguta* (Cantre et al., 2014; Nishiyama, 2007). In intact fruit, the druses are generally embedded in idioblast cells. When the fruit is eaten and the tissue is degraded in the mouth, the raphides are released

Table 8 Organic acid contents (g/100 g FW) of selected kiwifruit species and cultivars

Species/cultivar	Citric acid	Malic acid	Quinic acid	References
<i>Actinidia deliciosa</i>				
Hayward	1.10 ± 0.13	0.98 ± 0.07	0.22 ± 0.03	Nishiyama et al. (2008) ^a
Abbott	0.85 ± 0.10	1.00 ± 0.22	0.23 ± 0.08	Nishiyama et al. (2008)
Bruno	1.20 ± 0.04	1.11 ± 0.05	0.21 ± 0.07	Nishiyama et al. (2008)
Koryoku	0.84 ± 0.02	1.05 ± 0.17	0.26 ± 0.09	Nishiyama et al. (2008)
<i>Actinidia chinensis</i>				
Hort16A ^b	0.92 ± 0.08	1.12 ± 0.06	0.39 ± 0.07	Nishiyama et al. (2008)
Hongyang	0.95 ± 0.09	0.96 ± 0.05	0.26 ± 0.04	Nishiyama et al. (2008)
Sanuki Gold	1.29 ± 0.13	0.88 ± 0.09	0.23 ± 0.06	Nishiyama et al. (2008)
Sungold	0.90	0.71	0.62	NZIPFRL (2013) ^c
<i>Actinidia arguta</i>				
Ananasnaya ^d	0.54 ± 0.09	0.51 ± 0.10	0.18 ± 0.07	Nishiyama et al. (2008)
Issai	1.37 ± 0.30	0.73 ± 0.12	0.14 ± 0.07	Nishiyama et al. (2008)
Mitsuko	0.95 ± 0.16	0.62 ± 0.06	0.25 ± 0.04	Nishiyama et al. (2008)
<i>Actinidia rufa</i>				
Awaji	0.78 ± 0.14	1.62 ± 0.15	0.23 ± 0.07	Nishiyama et al. (2008)
Fuchu	0.62 ± 0.08	0.90 ± 0.22	0.13 ± 0.08	Nishiyama et al. (2008)
<i>A. chinensis</i> × <i>A. deliciosa</i>				
Sweet Green	0.87	0.89	0.61	NZIPFRL (2013) ^e

The table shows the organic acid contents determined in the flesh of selected kiwifruit species and cultivars. Values are means ± SD where data was available.

^aSource: Nishiyama et al. (2008). With permission from the Japanese Society for Food Science and Technology. Fruit was grown in Japan with the exception of 'Hort16A' and 'Ananasnaya' (see footnotes below). Values are the mean of six measurements.

^bFruit was grown in New Zealand and imported to Japan.

^cNew Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1077 Kiwifruit, Sungold, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

^dFruit was grown in the United States and imported to Japan.

^eNew Zealand Institute of Plant and Food Research (2013). The Concise New Zealand Food Composition Tables. Ministry of Health, Palmerston North, Food ID L1078 Kiwifruit, Sweet Green, raw: With permission from New Zealand Institute of Plant and Food Research Limited. Fruit was grown in New Zealand.

and often irritate the mucous membranes in the mouth resulting in a burning or “catching” sensation (Cantre et al., 2014).

Total oxalate concentrations for green kiwifruit have been reported as 23 mg/100 g FW with soluble oxalate concentrations ranging from 0.8 to 3.4 mg/100 g FW (McGhie, 2013), although more recent observations report much higher concentrations in the skin and seeds (Table 9). Soluble oxalate concentrations in gold kiwifruit are similar to those of green kiwifruit in the skin, pulp, and seeds; however, the concentrations of insoluble oxalate are higher in the pulp and seeds of green kiwifruit (Nguyen and Savage, 2013).

Table 9 Oxalate content (mg/100 g FW) of green and gold kiwifruit

	Total oxalate		Soluble oxalate		Insoluble oxalate	
	Green	Gold	Green	Gold	Green	Gold
Skin	47.7 ± 0.2	55.4 ± 1.1	10.8 ± 0.2	11.9 ± 0.3	36.9 ± 0.2	43.6 ± 1.1
Flesh	19.3 ± 0.3	15.7 ± 0.1	7.6 ± 0.2	8.5 ± 0.1	11.7 ± 0.3	7.2 ± 0.1
Seeds	116.9 ± 2.8	97.3 ± 1.4	10.2 ± 0.2	12.6 ± 0.3	106.7 ± 2.7	84.7 ± 1.4

The table shows the oxalate content determined in the skin, flesh and seeds of green and gold kiwifruit. Values are means ± SD.

Source: [Nguyen and Savage \(2013\)](#); With permission from Elsevier. Fruit was grown in New Zealand. There were three samples for each cultivar.

Carotenoids and Chlorophylls

Carotenoids

A range of carotenoid compounds have been identified in kiwifruit and include lutein, α -carotene, β -carotene, violaxanthin, zeaxanthin, and 9'-*cis*-neoxanthin ([Latocha et al., 2010](#); [McGhie and Ainge, 2002](#); [Nishiyama et al., 2005](#)). Among the different cultivars, lutein and β -carotene are the compounds with the highest concentrations ([Table 10](#)). The highest lutein contents observed in the commercially grown species are found in *A. arguta* cultivars (range 0.75–0.93 mg/100 g FW) followed by *A. deliciosa* (range 0.40–0.90 mg/100 g FW) and *A. chinensis* cultivars (range 0.09–0.40 mg/100 g FW) ([Nishiyama et al., 2005](#)). High lutein concentrations have also been reported for two cultivars of *A. rufa*, averaging 0.90 mg/100 g FW ([Nishiyama et al., 2005](#)), whereas lower levels have been observed in *Actinidia macrosperma* C.F. Liang (0.57 mg/100 g FW) and *A. polygama* (0.19 mg/100 g FW) ([McGhie and Ainge, 2002](#)). *Actinidia arguta* cultivars also contain the highest β -carotene concentrations among the commercially grown species (range 0.22–0.29 mg/100 g FW), and similar levels are found in *A. deliciosa* (range 0.09–0.17 mg/100 g FW) and *A. chinensis* (range 0.07–0.17 mg/100 g FW) cultivars ([McGhie and Ainge, 2002](#); [Nishiyama et al., 2005](#)). The highest β -carotene concentrations in kiwifruit, however, are reported for *A. macrosperma* and *A. polygama* species, which contain 25.2 and 21.6 mg/100 g FW, respectively ([McGhie and Ainge, 2002](#)).

Chlorophylls

Kiwifruit contain both chlorophylls a and b in concentrations and ratios that vary among species and cultivars ([Table 10](#)). As kiwifruit mature and ripen, chlorophyll-containing chloroplasts are retained in the flesh of green-colored kiwifruit but are transformed into chromoplasts with a loss of chlorophyll in the flesh of gold-colored kiwifruit ([Montefiori et al., 2009](#)). Hence the difference in color between green and gold fruit is because of the absence of chlorophyll and not the concentration of

Table 10 Lutein, β -carotene, and chlorophyll contents (mg/100 g FW) of selected kiwifruit species and cultivars

Species/cultivar	Lutein	β -carotene	Chlorophyll a	Chlorophyll b
<i>Actinidia deliciosa</i>				
Hayward	0.418 $\pm$ 0.082	0.088 $\pm$ 0.013	1.12 $\pm$ 0.20	0.53 $\pm$ 0.11
Abbott	0.398 $\pm$ 0.101	0.085 $\pm$ 0.009	0.92 $\pm$ 0.15	0.41 $\pm$ 0.10
Bruno	0.434 $\pm$ 0.063	0.094 $\pm$ 0.014	1.02 $\pm$ 0.18	0.44 $\pm$ 0.07
Elmwood	0.569 $\pm$ 0.104	0.093 $\pm$ 0.017	1.28 $\pm$ 0.15	0.59 $\pm$ 0.08
Koryoku	0.897 $\pm$ 0.138	0.150 $\pm$ 0.036	1.84 $\pm$ 0.57	0.90 $\pm$ 0.23
<i>Actinidia chinensis</i>				
Hort16A	0.155 $\pm$ 0.030	0.066 $\pm$ 0.008	0.07 $\pm$ 0.05	trace
Golden King	0.087 $\pm$ 0.015	0.121 $\pm$ 0.017	0.10 $\pm$ 0.03	trace
Hongyang	0.404 $\pm$ 0.072	0.123 $\pm$ 0.016	0.53 $\pm$ 0.17	0.20 $\pm$ 0.07
Jiangxi 79-1	0.107 $\pm$ 0.026	0.115 $\pm$ 0.015	trace	trace
Kobayashi39	0.144 $\pm$ 0.025	0.081 $\pm$ 0.007	0.26 $\pm$ 0.09	0.08 $\pm$ 0.05
Kuimi	0.152 $\pm$ 0.032	0.097 $\pm$ 0.019	0.20 $\pm$ 0.10	0.07 $\pm$ 0.04
Sanuki Gold	0.117 $\pm$ 0.012	0.150 $\pm$ 0.037	0.07 $\pm$ 0.02	trace
<i>Actinidia arguta</i>				
Ananasnaya	0.762 $\pm$ 0.132	0.285 $\pm$ 0.041	2.68 $\pm$ 0.67	1.20 $\pm$ 0.16
Gassan	0.746 $\pm$ 0.140	0.227 $\pm$ 0.048	2.41 $\pm$ 0.65	0.98 $\pm$ 0.19
Hirano	0.786 $\pm$ 0.209	0.224 $\pm$ 0.049	2.55 $\pm$ 0.89	1.07 $\pm$ 0.28
Issai	0.799 $\pm$ 0.178	0.247 $\pm$ 0.019	2.32 $\pm$ 0.78	0.99 $\pm$ 0.29
Mitsuko	0.933 $\pm$ 0.214	0.245 $\pm$ 0.033	3.00 $\pm$ 0.90	1.21 $\pm$ 0.29
<i>Actinidia rufa</i>				
Awaji	0.926 $\pm$ 0.050	0.177 $\pm$ 0.012	2.83 $\pm$ 0.20	1.37 $\pm$ 0.08
Nagano	0.876 $\pm$ 0.061	0.145 $\pm$ 0.017	2.41 $\pm$ 0.18	1.18 $\pm$ 0.09
<i>A. chinensis</i> $\times$ <i>A. deliciosa</i>				
Sanryoku	0.691 $\pm$ 0.056	0.110 $\pm$ 0.015	1.59 $\pm$ 0.19	0.74 $\pm$ 0.06

The table shows lutein, β -carotene, chlorophyll a and chlorophyll b contents determined in the flesh of selected kiwifruit species and cultivars. Values are the mean of eight experiments $\pm$ SD.

Source: Nishiyama et al. (2005); With permission from the American Chemical Society. Fruit was grown in Japan with the exception of 'Hort16A' and 'Ananasnaya' which were grown in New Zealand and Chile respectively and were imported to Japan.

carotenoids in the flesh (McGhie and Ainge, 2002). The total chlorophyll content in kiwifruit is reported to range from trace amounts to 4.4 mg/100 g FW (Nishiyama et al., 2005). The chlorophyll content of *A. deliciosa* cultivars ranges from 1.33 to 2.74 mg/100 g FW, whereas those of *A. chinensis* cultivars range from less than 0.05–0.73 mg/100 g FW. Chlorophyll concentrations in *A. rufa*, *A. arguta*, and their interspecific hybrid fruits are significantly higher than those in *A. deliciosa* cultivars with contents ranging from 2.91 to 4.39 g/100 g FW.

Phenolics

Phenolic Acids

The total phenolic concentration for kiwifruit has been reported to be 87mg gallic acid equivalent/100g FW using the Folin-Ciocalteu method; however, this value decreases to 28mg/100g FW after correction for the ascorbic acid contribution has been made (McGhie, 2013). Low levels (<10mg/100g) of several phenolic acids have been measured in kiwifruit flesh and include caffeic acid, ferulic acid, protocatechuic acid, vanillic acid, and *p*-coumaric acid (Mattila et al., 2006), and phenolic acid derivatives, coumarins, and hydroxycinnamic acid derivatives have been identified in kiwifruit skin (Pinelli et al., 2013).

Flavonoids

There are limited data on flavonoids in kiwifruit. The flavonoids that have been identified include flavonols (quercetin and kampferol glycosides), flavan-3-ols (catechin and epicatechin), and various anthocyanins (McGhie, 2013; Pinelli et al., 2013). Derivatives of two aglycone anthocyanidin bases, cyanidin and delphinidin, are responsible for the kiwifruit species that have red and purple flesh and skins. Cyanidin and delphinidin have been identified in kiwifruit in several glycosylated forms, including delphinidin 3-[2-(xylosyl)-galactoside], delphinidin 3-galactoside, cyanidin 3-[2-(xylosyl)-galactoside], cyanidin 3-galactoside, and cyanidin 3-glucoside (Montefiori et al., 2009). Cyanidin derivatives have been identified in all kiwifruit species that contain anthocyanins, but delphinidin derivatives are only in *Actinidia melanandra* Franch. and *A. arguta* 'Purpurea' (Montefiori et al., 2009).

In a study of 30 red- and purple-fleshed kiwifruit cultivars, the total anthocyanin content ranged from 0.35 µg/g FW to 206.1 µg/g FW, reflecting the wide range of depth, intensity, and extent of the red/purple flesh within the various species (Montefiori et al., 2009). Total anthocyanin contents were highest in *A. melanandra* cultivars (50.4–98.5 µg/g FW) and *A. arguta* 'purpurea' (161.2–206.1 µg/g FW), where anthocyanins were present in the skin, pericarp, and core of the fruits. Lower levels of total anthocyanin were observed in *A. chinensis* (4.5–98.6 µg/g FW), *A. deliciosa* (range 0.4–18.4 µg/g FW), *A. arguta* (range 2.6–6.8 µg/g FW), and *A. eriantha* (3.6 µg/g FW) cultivars. In most of these fruits, the anthocyanin content was restricted to the flesh.

Sensory Attributes

Flavor is generally accepted to be a combination of taste and aroma sensations. The main compounds detected by taste in kiwifruit are sugars and organic acids that produce sweet and sour sensations in the mouth. Fruit aroma is a mixture of volatile compounds with compositions that are specific to species and often to cultivars. Kiwifruit contain a diverse collection of free and glycosidically bound volatiles that contribute to the varied flavor characteristics of the different species and cultivars. Studies of the sensory characteristics of kiwifruit have focused on green and gold kiwifruit, with more recent research

investigating *A. arguta* and *A. eriantha* cultivars. These studies have shown that the sensory properties of kiwifruit are affected by the chemical composition of the fruit, which in turn is markedly affected by ripeness, maturity, and storage treatment.

The volatile compositions of green and gold kiwifruit are similar and contain mainly esters, alcohols, and aldehydes, although concentrations for these compounds differ between the species. The different concentrations of these volatile compounds impart the characteristic flavors of the two species along with the presence of compounds exclusive to each of the species (Wang et al., 2011). The flavor of green kiwifruit is described as “grassy” and “sulfurous” with a melon and sweet candy flavor, and the flavor of gold kiwifruit is described as “tropical,” with elements of black currant, pineapple, melon, and sweet candy flavor (Wang et al., 2011).

More than 80 compounds have been identified in the analyses of kiwifruit aroma, with the major components being methyl and ethyl butanoate, (*Z*)- and (*E*)-2-hexenal, hexanal, (*Z*)- and (*E*)-3-hexenol, and methyl benzoate. In a recent study, 95 compounds were detected in the bound volatile extracts of ripe green kiwifruit (Garcia et al., 2013). The most abundant compounds present were alcohols, norisoprenoids, and benzenoids, with (*Z*)-3-hexen-1-ol, 2-phenylethanol, 3-oxo- α -ionol, benzyl alcohol, geraniol, and 3-hydroxy- β -damascone identified as the compounds with the highest concentrations. The (*E*)-3-hexenol and (*E*)-3-hexenal compounds identified in green and not in gold, and the higher concentrations of (*E*)-2-hexenal and hexanal in green, are thought to provide green kiwifruit with the grassy, green aroma (Wang et al., 2011).

The most important odorants in gold kiwifruit are ethyl butanoate, acetaldehyde, hexanal, (*E*)-2-hexenal, and dimethyl sulfide. Garcia et al. (2013) identified 95 compounds in the bound volatiles extracted from gold kiwifruit, of which carboxylic acids, benzenoids, and terpenoids were the most abundant. The major compounds present were 2-phenylethanol, benzyl alcohol, benzoic acid, (*Z*)-3-hexen-1-ol, 3-oxo- α -ionol, and linoleic and linolenic acids. The sulfur compounds present in gold kiwifruit are thought to be important contributors to the flavor of this cultivar (Wang et al., 2011).

The aroma of *A. arguta* ‘Hortgem Tahi’ has been described as banana, floral, fruit candy, grassy, melon, and tropical (Garcia et al., 2011). Of the 89 compounds detected in the bound volatile extract of *A. arguta* fruit, the most abundant compound classes were alcohols, terpenoids, and benzenoids, and the aromatic compounds and norisoprenoids were present in the highest concentrations (Garcia et al., 2011). The major compounds in the bound volatile extract of *A. arguta* known to contribute to the caramel, grassy aroma were 2,5-dimethyl-4-hydroxy-3(2*H*)-furanone, benzyl alcohol, 3-hydroxy- β -damascone, and hexanal. The free volatile compounds identified in *A. arguta* mainly consist of the fruit esters, ethyl butanoate and ethyl hexanoate, and the green-smelling compounds (*E*)-2-hexenal, hexanal, and (*Z*)-3-hexenal. The volatile content of *A. eriantha* is lower than in other kiwifruit cultivars and, as such, this species has been described as bland and not very tasty (Garcia et al., 2012).

DIETARY FIBER COMPOSITION OF GREEN KIWIFRUIT AND GOLD KIWIFRUIT

Dietary Fiber in Fruit

Dietary fiber comprises of carbohydrate polymers with 10 or more monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine and occur naturally in the food as consumed, and of carbohydrate polymers derived from food raw materials or synthetic carbohydrate polymers, which have a physiological effect of benefit to health ([Codex Alimentarius, 2009](#)). In the human diet, dietary fiber is a diverse mixture of plant cell-wall polysaccharides, lignin, resistant starch, oligosaccharides, gums, and other noncarbohydrate components. The non-starch polysaccharides in plant cell walls are often examined after a series of treatments that separate the wall components based on solubility. The treatments are sequential and involve the use of a chelating agent to extract ionically bound pectins, sodium carbonate (Na_2CO_3) to extract pectins held by ester bonds, a dilute alkali solution to extract loosely attached cross-linking glycans, and a concentrated alkali solution to extract tightly attached hemicelluloses and cellulose. The fractions are not pure, however, and along with the target molecules based on solubility, each fraction contains mixtures of polymers that are coextracted or linked by covalent bonds.

Fleshy fruits, such as kiwifruit, are comprised primarily of un lignified primary cell walls and parenchyma cells. The primary cell walls of fleshy fruits typically contain cellulose embedded in a matrix of hemicelluloses and pectins in addition to small amounts of structural glycoproteins ([Carpita and Gibeaut, 1993](#)). The relative volumes of the constituent nonstarch polysaccharides vary between plant taxa, but all function to provide the fruit with both structural support and elasticity needed for cell expansion. Cell walls can generally be distinguished into two types. Type 1 walls representative of most dicotyledonous and nongramineous monocotyledonous plants are rich in pectins and xyloglucans (XyGs), and type 2 walls representative of commelinoid monocots, including grasses and cereals, are pectin-poor and contain glucuronoarabinoxylans (GAX) as the principal hemicellulose component ([Carpita and Gibeaut, 1993](#)).

Cellulose

Cellulose is the major load-bearing cell-wall polymer and is a linear homopolymer of 1,4- β -linked glucose units that exists as an array of parallel oriented chains held together by intermolecular and intramolecular hydrogen bonds and van der Waals forces to form aggregates called *microfibrils*. The internal region of the microfibrils is crystalline and excludes water, whereas the outer regions are more amorphous, allowing the hemicellulosic and pectic molecules to be interwoven with the surface glucan chains of the cellulose.

Hemicellulose

Hemicelluloses are a class of structurally heterogeneous polysaccharides and include XyG, mixed linkage glucans ($-(1\rightarrow3,1\rightarrow4)$ -glucans), xylans, mannans, glucomannans, galactoglucomannan, glucuronoxylan, arabinoxylan, and GAX. The most abundant hemicellulose in dicot primary cell walls is XyG, which consists of a 1,4- β -D-glucopyranose backbone with side chains of α -D-xylose residues linked to the C-6 of backbone glucose units. Some of the side-branch xylosyl units also have galactose (Gal), fucose (Fuc), and arabinose (Ara) substituents. The cellulose-XyG network is thought to be partly stabilized by XyG tethers between adjacent cellulose fibrils (Schroder et al., 1998).

Pectins

The pectins in most fruit flesh comprise a class of complex, covalently linked galacturonic acid (GalA)-rich polysaccharides and include homogalacturonan (HG), rhamnogalacturonan I (RG-I), and the substituted galacturonans, which include RG-II, xylogalacturonan (XGA), and apiogalacturonan (AP). HG is a linear homopolymer of $(1\rightarrow4)$ -linked- α -D-GalpA residues. The residues can be partially methyl-esterified at C-6 and acetyl-esterified at positions O-2 and/or O-3 (O'Neill et al., 1990). RG-I is a polymer of the repeating disaccharide, $\rightarrow2$)- α -L-rhamnosyl- $(1\rightarrow4)$ - α -D-galactosyl- $(1\rightarrow$, which possesses neutral side-chains of highly branched $(1\rightarrow5)$ - α -L-arabinans, $(1\rightarrow4)$ - β -D-galactans, and type I arabino- $(1\rightarrow4)$ - β -D-galactans. RG-I pectin side chains may be covalently attached to XyG and are strongly associated with cellulose, potentially cross-linking cellulose microfibrils or interlocking the XyG-cellulose and pectin networks together (Redgwell et al., 1997). RG-II has an HG backbone substituted with four complex side chains consisting of at least 12 different sugars and 20 different glycosyl linkages (O'Neill et al., 1990). RG-II is usually present in the cell wall as a dimer that is formed by a boratediol ester linkage between the apiose residues of two RG-II monomers (O'Neill et al., 2004). XGA and AP also have HG backbones substituted with xylose or apiose residues, respectively, but are less abundant than RG-II.

Composition of Kiwifruit Fiber

Information on the nonstarch polysaccharides in kiwifruit comes mostly from research focused on green kiwifruit, although more recent analyses have focused on the polysaccharides found in gold kiwifruit (Sauvageau et al., 2010; Yularti et al., 2008). Detailed analysis of the nonstarch polysaccharides in kiwifruit has been conducted on the cell walls after stepwise extraction with water, cyclohexane-trans-1,2-diamine tetraacetate (CDTA), Na_2CO_3 , guanidinium thiocyanate (GTC), and potassium hydroxide (KOH) (Redgwell et al., 1988; Sauvageau et al., 2010). The dietary fiber content of ripe, ready-to-eat kiwifruit is similar to that of other fruits, such as apples, oranges, and bananas, and is derived from the cell walls primarily in the form of nonstarch polysaccharides. In green and gold kiwifruit,

the dietary fiber content ranges between 1.6% and 3% FW (USDA, 2014). Analyses of the fiber content from the flesh of both of these fruits show the fruits are approximately one-third soluble fiber and two-thirds insoluble fiber (Carnachan et al., 2012). The soluble fiber fraction is primarily comprised of pectic polysaccharides, and in green and gold kiwifruit was determined to be 708 and 472 mg/100 g FW, respectively, when total uronic acid content and neutral sugar composition were analyzed (Carnachan et al., 2012). The insoluble fiber fraction is primarily cellulose and hemicellulose (Carnachan et al., 2012; Sauvageau et al., 2010; Yuliarti et al., 2008). The cellulose content for green and gold kiwifruit was 1029 and 574 mg/100 g FW, and the hemicellulose content was 339 and 182 mg/100 g FW, respectively (Carnachan et al., 2012).

Cellulose

Cellulose represents approximately half of the cell wall polysaccharides in kiwifruit (Redgwell et al., 1988; Sauvageau et al., 2010). Using nuclear magnetic resonance spectroscopy, both the $I\alpha$ and $I\beta$ crystalline forms of cellulose have been identified in kiwifruit, although the proportions of each form have not been determined (Newman and Redgwell, 2002).

Hemicellulose

The hemicellulosic polysaccharides extracted in the GTC- and KOH-soluble fractions of ripe green and gold kiwifruit included large amounts of XyG, with minor amounts of galactoglucomannan and glucuronoxylan (Redgwell et al., 1988; Sauvageau et al., 2010; Schröder et al., 2001). Analysis of the XyG isolated from the cells walls of green kiwifruit revealed that it has a molar ratio of glucose:xylose:Gal:Fuc of 10:6.9:2.1:0.3 and has an average molecular weight of 161 kDa (Li et al., 2009). Redgwell et al. (1988) determined that XyG is a typical fucogalacto-XyG based on the presence of glycosidic linkages, 4- and 4,6-linked glucose, and terminal and 2-linked xylose, together with terminal and 2-linked Gal and terminal Fuc. Analysis of the galactoglucomannan revealed it has molar ratio of Gal:glucose:mannose of 1:2:2 and a molecular weight of 16.9–41.8 kDa (Schröder et al., 2001). The backbone of the galactoglucomannan is comprised of alternating β -1,4-linked D-glucopyranosyl and D-mannopyranosyl residues with approximately one-third of the mannose residues carrying side chains at O-6 of single α -D-Galp residues or β -D-Galp-(1 $\rightarrow$ 2)- α -Galp(1 $\rightarrow$ disaccharides (Schröder et al., 2001).

The presence of xylan in the cell walls of green and gold kiwifruit was deduced by glycosyl linkage analyses, which identified 4- and 2,4-linked Xylp residues, together with terminal GlcAp and Ara_f (Redgwell et al., 1988; Sauvageau et al., 2010). Mass spectrometric analysis of green kiwifruit revealed that the glucuronic acid in the hemicellulose was 4-O-methylated (Redgwell et al., 1988). The presence of terminal Ara in hemicellulosic extracts of green kiwifruit suggests that arabinoxylan may also be a component of these cell walls (Li et al., 2009; Sauvageau et al., 2010).

Pectins

Pectic polysaccharides in kiwifruit are either water soluble or found in all the extracted fractions, and include high proportions of highly methyl-esterified GalA, together with small amounts of Gal, Ara, rhamnose, xylose, mannose, and Fuc (Carnachan et al., 2012; Redgwell et al., 1988; Sauvageau et al., 2010; Yuliarti et al., 2008). The fractions extracted from the cell walls with CDTA and Na₂CO₃ include HGs and RG-Is substituted with galactosyl residues or arabinogalactan (AG) side chains with varying degrees of branching (Redgwell et al., 1992). Detailed analysis of these pectic polysaccharides identified three categories of side chain, including: 1) 4-linked- β -D-galactosyl residues in regions of galacturonic backbone with 2,4-linked rhamnose; 2) chains containing less Gal and more Ara, xylose, and Fuc; and 3) 1,4-linked- β -D-galactans attached to the RG-I backbone (Redgwell et al., 1992). RGs were also identified in the GTC and KOH fractions but had a higher degree of branching compared with those in the CDTA and Na₂CO₃ soluble fractions (Redgwell et al., 1992).

The presence of Type II AGs in the cell walls of gold kiwifruit was suggested by glycosyl linkage analyses, which identified 3-, 6-, and 3,6-linked galactosyl residues together with terminal Ara (Sauvageau et al., 2010). Type II AGs can be present as side chains on RG-I or associated with AG-proteins, and thus far have not been identified in green kiwifruit (Redgwell et al., 1988). The Type II AG linkages in gold kiwifruit were detected together with 4-linked GalA and 2- and 2,4-linked rhamnoses, indicating that they may represent pectic side chains (Sauvageau et al., 2010). Research also shows that RG-II is a component of kiwifruit cell walls, as indicated by small proportions of 2,4 Galp in the water, CDTA, and Na₂CO₃ fractions (Redgwell et al., 1988; Sauvageau et al., 2010).

SUMMARY

- The fruit of the genus *Actinidia* is diverse in both physical characteristics and chemical composition.
- Of the 55 recognized species, only a few are commercially cultivated.
- Although there are limited data providing detailed compositional information available for the majority of kiwifruit species, it is evident from the available data that kiwifruit are rich in vitamin C and a good source of vitamin E, folate, potassium, and dietary fiber.
- It is likely that knowledge about kiwifruit nutrients, particularly phytochemicals and bioactives, is incomplete, and more nutrients are likely to be identified.
- The soluble fiber content of green and gold kiwifruit is comprised primarily of pectic polysaccharides, and the insoluble fiber content is primarily hemicelluloses and cellulose. These fiber constituents are known to play a role in gastrointestinal tract health and aid digestion.
- The benefits of consuming kiwifruit for health will continue to increase as new cultivars are developed and information on chemical composition continues to be made available.

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CHAPTER 16

Nutritional and Composition of Fruit Cultivars: Loquat (*Eriobotrya japonica* Lindl.)

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LIST OF ABBREVIATIONS

ABTS 2,2'-Azino-bis-(3-ethylthiazoline-6-sulfonate)

'BS' 'Baisha'

DAF Days after flower

DMAPP Dimethylallyl diphosphate
DMBA 7,12-Dimethylbenz[α]anthracene
DPPH 1,1-Diphenyl-2-picrylhydrazyl
DW Dry weight
EGCG Epigallocatechin gallate
FRAP Ferric reducing antioxidant power
FW Fresh weight
GC-MS Gas chromatography-mass spectrometry
HS SPME Headspace solid phase microextraction
IPP Isopentenyl pyrophosphate
'LYQ' 'Luoyangqing'
MEP 2-C-methyl-D-erythritol 4-phosphate
NAD-MDH NAD-malate dehydrogenase
NCED 9-*cis*-Epoxy-carotenoid dioxygenase
NO Nitric oxide
OA Oleanolic acid
PDA Photodiode array
PEPC Phosphoenolpyruvate carboxylase
PSY Phytoene synthase
RE Retinol equivalent
TA Titratable acidity
TPA 12-O-tetradecanoylphorbol-13-acetate
TSS Total soluble solids
UA Ursolic acid

INTRODUCTION

Loquat (*Eriobotrya japonica* Lindl.) is an economically important subtropical evergreen fruit tree originating in southeastern China. It has been cultivated for more than 2000 years in China and began to spread to Japan during the Tang Dynasty (618–907). So far, loquat has been commercially cultivated in more than 30 countries worldwide, including Japan, India, Pakistan, Israel, Turkey, Italy, France, Spain, Australia, Brazil, Armenia, and Mexico.

China is now the largest producer of loquat fruit with a cultivation area of about 170,000 ha and an annual output of about one million tons. Spain ranks second, with an annual output of about 40,000 tons; followed by Pakistan (about 30,000 tons annually) and Turkey (about 10,000–20,000 tons annually).

Loquat fruit is delicious, is a good resource for dietary carotenoids, and has high economic value. Loquat fruit can be consumed fresh or processed into jam, juice, wine, syrup, or candied fruits, and it is popular in the international market. These processed products increase the economic benefits of the crop up to threefold, compared with fresh fruit consumption alone.

Loquat is also a plant with high medicinal value, and different organs of the plant have been used historically as folk medicines for thousands of years. Loquat extracts have

been used for the treatment of cough, chronic bronchitis, inflammation, diabetes, and cancer in Chinese folk medicine. Ancient literature, such as *Compendium of Materia Medica* (Li, 1578), described the origin, classification, breeding methods, and medicinal value of the loquat tree, and laid the foundation for the development and cultivation of loquat.

The efficacy of loquat, as used in traditional Chinese medicine, is supported by current scientific evidence regarding the pharmacologically active compounds in plant extracts and their structure–activity associations. The phytonutritional composition of extracts of different organs vary considerably; for example, loquat leaf is rich in phenolics and triterpenes; the fruit is rich in sugars, organic acids, flavonoids, phenolic acids, and vitamins; and the kernel is a good source of proteins, starch, tannins, and minerals. To provide a comprehensive understanding of the current research on the health–promoting effects of loquat extracts, the reported nutritional composition of loquat extracts are summarized in this chapter.

BOTANICAL ASPECTS

Loquat belongs to the Maloideae subfamily of the Rosaceae family. Loquat is mainly distributed within 20–35 degrees north or south of the equator, but it can grow in the 45-degree latitude region in areas that have a maritime climate (e.g., Chiba in Japan and southern France). Loquat can also be found in regions of high altitude near the equatorial region, such as the highlands of Ecuador (Lin et al., 1999; Morton, 1987); it is also grown as an ornamental plant in temperate climates.

Loquat is well adapted to grow in a wide variety of climatic conditions. As long as there is no long cold winter and no waterlogging, it can be planted successfully in montane areas, on hillsides and plains, and near beaches or rivers. It grows rapidly, and under proper management can fruit early and give high yields. Three years after planting, the crown height can reach more than 1 m, and the tree starts fruiting. Ten years later, the tree enters its full fruiting period, producing 25–50 kg of fruit per tree annually. Higher yielding varieties can produce 100–200 kg or more per tree. It is commonly reported that a loquat tree of 100 years old can produce more than 500 kg of fruit per year.

Loquat is evergreen; leaves are simple, alternate, have margin serrate or subentire margins, are leathery (coriaceous), and are often pubescent underneath. They have pinnate reticulate veins, usually petiolate, and a stipule caducous. Flowers are bisexual with a terminal panicle that is often hairy, and they have a cup-shaped calyx tube or turbination; five persistent sepals; five petals that are obovate or orbicular, glabrous or hairy; a helicoidal or imbricate bud; 10–40 stamens; two to five styles that are basally connate and often glabrous; an inferior ovary, that is connate and has two to five rooms with two ovules per locule; a membranous endocarp; and one or several large seed(s) (Lin et al., 1999).

Loquat has fragrant, white flowers in winter, with the individual flower 1.2–2 cm in diameter. The fruit matures in late spring and early summer. In the main production areas

in China (such as Fujian, Zhejiang, and Jiangsu provinces), fruit ripens from April through early June, which is earlier than the majority of other domestically grown fruits. Loquat is very popular because of its delicious taste and attractive color. Loquat thus provides an extended dietary source of fresh fruit for consumers and a high economic return to producers as a result of the lack of competition within this market niche. So far, the world annual loquat output cannot meet the increasing needs of international markets. Therefore it is a very promising fruit. Taking the high economic benefits into consideration, loquat has become one of the main sources of income for local rural economies in many regions.

TRADITIONAL STUDIES ON NUTRITIONAL COMPOSITION OF LOQUATS

According to the Nutrition Department of the Chinese Central Health Research Institute (now China Disease Prevention and Control Center for Nutrition and Food Safety), the nutritional components of 100 g of loquat pulp contain 0.4 g protein, 1 g fat, 7 g carbohydrates, 0.8 g dietary fiber, 0.5 g ash, 22 mg calcium, 32 mg phosphorus, 1.33 mg carotenoids, and 3 mg vitamin C. Therefore loquat is an excellent nutritional fruit.

Fruit can be divided into two types: white-fleshed and red-fleshed cultivars (Zhou et al., 2007b). The red-fleshed loquats contain higher carotenoids, whereas the white-fleshed loquats contain an especially high content of glutamic acid. Loquat juice is rich in potassium and low in sodium, which is suitable for patients with low sodium and high potassium requirements.

Loquat flowers, fruit, leaves, roots, and bark can all be used as traditional drugs. Flowers can cure headaches and runny nose; fruit can moisturize viscera; and the root can cure consumptive cough and joint pain. The most important medicinal part is the loquat leaf, the main medicinal ingredients of which include nerolidol and farnesol volatile oils, organic acids, amygdalin, and vitamin B. Loquat leaf extract has been used for the treatment of cough originating in the lung for thousands of years (Li, 1578).

1. Loquat leaves: Amygdalin in loquat leaves can be metabolized into hydrocyanic acid and benzaldehyde, which can relieve cough and has anticancer and analgesic effects. The essential oils of loquat leaves have expectorant and antiasthmatic effects. The common loquat pastes or syrups on the market are mainly made from loquat leaf, and they are very convenient and effective in treating cough, sore throat, hoarseness, and other symptoms. Ursolic acid (UA) and hawthorn acid of loquat leaf have antiinflammatory effects, and the ethyl acetate loquat leaf extract has a significant inhibitory effect on the growth of *Staphylococcus aureus* and *Streptococcus pneumoniae*. In addition, loquat leaf also has potential in the treatment of arthritis and systemic urticaria. According to a Japanese study, loquat leaf cannot only make the skin smooth and delicate, it also can eliminate prickly heat rash and other skin inflammations, which makes it a good ingredient for skin care recipes.

2. Loquat flower: Loquat blooms in winter and has a long flowering period. It is a good winter nectariferous plant, and its honey can moisten lungs and arrest coughs. The volatile oil and oligosaccharides in loquat flower are good for the treatment of cold, cough, and headache. Loquat flowers can also gladden the heart and refresh the mind.
3. Loquat fruit: Loquat is a nutrient rich fruit. It is juicy with unique flavor, and its consumption is recommended for health and longevity. Besides fresh consumption, the fruit can also be processed into canned and preserved products. Loquat fruit, like flowers, can also moisten lungs and relieve coughs. Fresh loquat wrapped in a cold wet cloth can be used to treat burns.
4. Loquat kernel: The loquat kernel is high in starch, amygdalin, amino acid, and fatty acid content. It has a bitter taste and can be used for the treatment of cough, hemia, and edema. It can significantly improve the immune function in animal studies. The content of amygdalin in the kernel is much higher than in the leaves. This compound is useful for the treatment of inflammation and restoration of natural healing ability, and is a good natural anticancer agent.

RECENT STUDIES ON NUTRITIONAL AND COMPOSITION OF LOQUATS

In China, a germplasm collection of more than 759 loquat varieties, strains, or related species has been assembled in the city of Fuzhou by the Academy of Agricultural Sciences of Fujian Province since 1981. A superior loquat resource conservation garden was constructed in Zhejiang province, and introduction of good varieties from this loquat garden has been carried out in Jiangsu, Hubei, Anhui, Sichuan, and Jiangxi provinces.

There is a range of excellent loquat varieties taken from the selection available in each province. For example, 'Jiefangzhong', 'Zaozhong 6', 'Taicheng 4', and 'Changhong 3' are key varieties selected in Fujian province, and they are widely used for extension. Since 2005, more than ten thousand hectares of these varieties have been grown each year. The 'Luoyangqing' ('LYQ') cultivar selected from Zhejiang Huangyan accounted for more than 80% of the total loquat production in the district. Other varieties include 'Dahongpao', 'Tangxizaosheng', 'Huangyan 5', 'Tangxichihong', 'Ninghaibai', and 'Baijing 1' from Zhejiang Province; 'Baiyu', 'Bahong', 'Shicheng', 'Guanyu', and 'Fengyu' from Jiangsu Province; and 'Huabao 2', 'Huabao 3', and 'Huabao 7' from Hubei Province. The annual production of 'Dawuxing' and 'Longquan 1', which are selected from Sichuan Province, account for more than half of the national total production. Loquat breeding has been carried out in Fujian, Zhejiang, Jiangsu, and Hubei provinces, and has produced thousands of progenies, from which a number of promising excellent individual plants have been selected.

In Spain, the Valencia Agricultural Research Institute has collected 74 loquat germplasm varieties since 1981, among which 49 were from Spain and the rest from other European Union countries, the Mediterranean countries, Japan, and the Americas. No more than 40 of these varieties were used as cultivated varieties.

Although Japan only has about 40 loquat cultivars, it is so far the most advanced country in loquat breeding. Japan has nearly 100 years of history in loquat breeding, which is carried out mainly in the Nagasaki field test center and the Japanese National Fruit Test Field (formerly in Shizuoka, now Tsukuba). The commercially popular new varieties include ‘Da Fang’, ‘Nagasaki early hybrid’, ‘Yangyu’, and ‘Liangfeng’. In addition, ‘Bai Maomu’ was bred through mutation breeding. The Japanese cultivar ‘Tanaka’ has been introduced to more than a dozen countries.

Loquat fruit can be consumed fresh or processed into jam, juice, wine, syrup, or candied fruits. The nutritional compositions include carbohydrate, phenolics, terpenoids, amygdalin, vitamins, mineral content, fiber, volatiles, and other bioactive compounds.

Sugars and Acids

Sugars and acids are basic nutritional components contributing to the quality of fruit. In addition, the balance between sugars and acids is important for the sensory quality of the fruit.

Fructose, glucose, and sucrose are the principal sugars of loquat fruit, and their relative proportions vary by cultivar (Shaw and Wilson, 1981). Sucrose is the predominant sugar in loquat fruit. In a study investigating the sugar composition in white-fleshed loquat cultivars ‘Tianzhong’, ‘Biqizhong’, and ‘Bingtangzhong’, as well as in red-fleshed loquat cultivars ‘Baozhu’, ‘Dayeyangdun’, and ‘Dameiguihongpao’, sucrose was the major sugar in white-fleshed loquats (60–70%), followed by fructose (20–30%) and glucose (9–11%), and the contents of these sugars were similar in red-fleshed fruits (Chen et al., 2010). The sucrose contents were similar (4 g/100 g fresh weight (FW)) in the Brazilian cultivars ‘Néctar de Cristal’, ‘Mizauto’, and ‘Mizuho’. The lowest content was found in the ‘Centenária’ cultivar (2.0 g/100 g FW), and the highest was in ‘Mizumo’ (4.96 g/100 g FW) (Hasegawa et al., 2010). The bland flavor of cultivar ‘Christmas’ was explained by its lower sucrose content (Shaw and Wilson, 1981).

Interestingly, the total soluble solids (TSS) content of white-fleshed loquats was higher than that of red-fleshed ones, with the highest found in ‘Tianzhong’ and ‘Bingtangzhong’ (Chen et al., 2010). In addition, the percentage of sucrose among TSS was significantly higher in white-fleshed fruits than in red-fleshed ones, although the percentage of glucose and fructose was similar (Chen et al., 2010).

Organic acid content of a fruit is an important factor for the development of its flavor. Previous studies have reported organic acid composition in several loquat cultivars in different countries (Shaw and Wilson, 1981), and malic acid was the main organic acid in the fruit, which is a characteristic of the Rosaceae family (Lin et al., 1999). A more recent and comprehensive evaluation of organic acid was carried out by using 18 loquat cultivars in China (Chen et al., 2008b), where eight organic acids (malic, quinic, citric, iso-citric, α -ketoglutaric, fumaric, oxaloacetic, and tartaric acids), were identified by high-performance ion exchange chromatography. The predominant organic acids in the ripe pulp of most cultivars were

malic acid and quinic acid, with average contents of 4399 mg/kg FW and 2042 mg/kg FW, respectively, accounting for 62.7% and 29.1% of the total acids, respectively (Chen et al., 2008b). Based on titratable acidity (TA), 18 cultivars could be clustered into five groups: very high acidity ('Xiaomaopipa'), high acidity ('Jiajiao', 'Zhuonan 1', 'Jiefangzhong', and 'Fuyang'), medium acidity ('Moriowase', 'Huabao 2', 'Xiangzhong 10', 'Baihua', 'Toi', and 'Duobao 2'), low acidity ('Wugongbai', 'Luoyangchin', 'Mogi', and 'Zaozhong 6'), and very low acidity ('Baili', 'Tantou 4', and 'Changhong 3') (Chen et al., 2008b). Organic acid composition of the fruit parts, whole fruits, and the leaves were analyzed in loquat from Georgia of the United States (Pande and Akoh, 2010). High malic acid content was found in loquat (462–1918 mg/100 g FW), with the highest content being found in the peel.

Changes in organic acid content in loquat pulp were studied using low-acid 'Changhong 3' and high-acid 'Jiefangzhong' cultivars (Chen et al., 2009). The difference in TA between the two cultivars could be explained by the difference in malic acid concentration, which may result from a difference in nicotinamide adenine dinucleotide-malate dehydrogenase (NAD-MDH) and nicotinamide adenine dinucleotide phosphate-malic enzyme (NADP-ME) activities (Chen et al., 2009). Both TA and malic acid content increased during the early stages of fruit development and decreased at the later stages. NAD-MDH, NADP-ME, and phosphoenolpyruvate carboxylase activities were found to play significant roles in malic acid biosynthesis and degradation (Chen et al., 2009).

Carotenoids

Carotenoids are important nutritional components of fruits. They play multiple roles in maintaining human health, serving as powerful antioxidants, valuable chemopreventive agents, and important immune modulators. The carotenoids with at least one unsubstituted β -ionone ring and a polyene side chain, such as β -carotene, β -cryptoxanthin, and α -carotene, are especially significant and are called provitamin A, the precursors for vitamin A production in animal and humans. Vitamin A is required for growth and health of the human body, and therefore identifying plant stuffs rich in provitamin A carotenoids or even generating new plants for enhanced accumulation of carotenoids, like golden rice, is a promising goal for plant secondary metabolism studies. In addition, lutein and zeaxanthin, present in eye lens and retina, can absorb harmful blue light and therefore prevent eyes from damage by overexposure to sunlight. Deficiency in lutein and zeaxanthin in eye tissues is a major reason for occurrence of some eye diseases, such as cataracts and age-related macular degeneration.

Carotenoids are tetraterpenoids derived from successive condensation of eight C₅ isoprene units. Whereas some carotenoids, like phytoene and phytofluene, are colorless, most carotenoids are colored and range from yellowish to deep red. These colorful compounds are principal pigments for some ripe fruits, including loquats.

The loquat carotenoids were first analyzed by using traditional chromatography techniques, sometimes coupled with mass spectrometry (MS) characterization in last century,

and it was reported that β -carotene, β -cryptoxanthin, lutein, and violaxanthin are the main carotenoids in loquat fruit.

Significant progress in identification and quantification of carotenoids in loquats was achieved through high-performance liquid chromatography (HPLC) analysis coupled with a C30 reversed-phase HPLC column and a photodiode array (PDA) detector (Zhou et al., 2007b). The C30 column is more suitable than a C18 column for separating more polar compounds and is widely applied in carotenoid analysis. With this column coupled with a PDA detector, accurate identification and quantification of carotenoids, including isomers, was achieved (Table 1). However, some less common, possibly novel, plant carotenoids have not yet been characterized.

Using HPLC-PDA, the carotenoids in loquat peel, flesh, flowers, and leaves were characterized and quantified (Zhou et al., 2007b). Huge differences, averaging 12.7-fold with a maximum of 99.5-fold, in the total amount of colored carotenoids were observed in flesh tissues of different cultivars. Loquat is usually classified into two groups according to the flesh color, white-fleshed and red-fleshed (Table 2). Among characterized carotenoids, provitamin A carotenoids β -carotene and β -cryptoxanthin, are the two principal components, and in combination they account for over half of total colored carotenoids in both red-fleshed and white-fleshed cultivars. As a result, the vitamin A values, as retinol equivalents, of red-fleshed cultivars averaged 7.23 $\mu\text{g/g}$ dry weight (DW) (Table 2), or 112.46 $\mu\text{g}/100\text{ g FW}$, which is higher than some common fruits, such as mango, red watermelon, papaya, and orange, suggesting that the red-fleshed loquat is an excellent source of provitamin A (Zhou et al., 2007).

As with flesh tissue, β -carotene is the most abundant carotenoid in loquat peel, accounting for over 40% of total colored carotenoids for both red-fleshed and white-fleshed cultivars. On average, lutein and β -cryptoxanthin rank as the second and third major carotenoids in the peel (Table 3). However, color and carotenoid profile differences between the two loquat groups were observed in peel as well. The mean amount of colored carotenoids was 1.8-fold higher in red-fleshed cultivars (Table 3). In both peel and flesh, red-fleshed cultivars were characterized by a higher percentage of β -carotene among colored carotenoids and a lower percentage of lutein (Tables 2 and 3), which together with the quantitative differences, indicates that the accumulation of carotenoids in loquat is clearly genetically regulated.

In loquat flowers, the total carotenoid content for whole flower is around 25 $\mu\text{g/g}$ DW, and the two most abundant carotenoids are lutein and violaxanthin, accounting for about one-third and one-fourth of total carotenoids, respectively (unpublished data). In leaves, the carotenoid content gradually increases during development and reaches around 150 $\mu\text{g/g FW}$ for mature leaves, whereas the composition does not change much, with lutein, β -carotene, and violaxanthins comprising around 40%, 25%, and 10% of total carotenoids, respectively (unpublished data), which is quite close to values reported in other plants. No consistent differences in carotenoid accumulation in flower and leaf tissues between red- and white-fleshed loquats were observed.

Table 1 Characterization of carotenoids in loquat fruit tissues by HPLC–PDA detection

No.	Carotenoids	Retention time (min)	$\lambda_{\max}$ (nm)	Abundance (%)							
				White-fleshed cultivars				Red-fleshed cultivars			
				Ruantiaobaisha		Baisha		Dahongpao		Luoyangqing	
				Peel	Flesh	Peel	Flesh	Peel	Flesh	Peel	Flesh
1	Neoxanthin	11.1	416, 440, 469	1.59	4.67	0.48	1.94	0.34	2.71	0.22	0.27
2	Violaxanthin	11.8	(415), 439, 468	5.79	17.62	3.42	10.07	3.77	10.91	3.92	3.78
3	Luteoxanthin	13.0	401, 420, 449	4.86	9.46	2.82	6.89	1.30	2.64	0.78	2.61
4	9- <i>cis</i> -Violaxanthin	15.1	413, 436, 465	6.37	12.37	1.64	9.69	2.03	6.32	1.00	7.10
5	Lutein	17.4	(420), 445, 473	9.85	30.05	16.17	16.17	3.18	0.21	6.12	0.73
6	Phytoene	22.2	276, 286, 297	0.51	—	0.19	—	2.95	4.28	4.56	5.64
7	Phytofluene	23.7	331, 348, 365	0.12	—	—	—	0.80	0.87	—	1.29
8	β -Cryptoxanthin	24.4	(426), 451, 479	0.52	12.84	1.05	17.58	0.27	18.82	3.42	17.62
9	β -Carotene	29.0	(427), 452, 479	49.54	2.60	57.4	9.79	62.45	14.59	62.57	20.10
10	ξ -Carotene	29.4	380, 400, 425	—	—	—	—	0.10	0.18	0.93	2.20
	Unidentified in total			20.85	10.39	16.83	27.87	22.81	38.47	15.56	38.65

HPLC–PDA, high-performance liquid chromatography–photodiode array.

Source: Zhou et al. (2007b) and Fu et al. (2012) with modification.

Table 2 Carotenoid content ($\mu\text{g/g}$ DW) in flesh of loquat fruit

Group	Cultivar	Lutein	β -Cryptoxanthin	β -Carotene	Total colored carotenoid	β -Carotene equivalent	Retinol equivalent
White-fleshed	90-1	0.97	3.56	1.56	11.19	3.34	0.56
	Baisha	0.21	0.60	0.44	2.74	0.74	0.12
	Baiyu	0.22	0.45	0.20	2.24	0.43	0.08
	Bingtang-zhong	0.45	2.33	0.55	6.75	1.72	0.29
	Biqi	0.20	1.58	0.55	5.31	1.34	0.22
	Dazhong	0.85	3.21	1.05	8.96	2.66	0.44
	Guanyu	0.27	1.96	0.70	5.51	1.68	0.29
	Jidanbai	0.43	2.06	0.27	4.59	1.30	0.22
	Ninghaibai	0.22	0.29	0.15	1.23	0.30	0.05
	Qingzhong	1.46	15.94	2.34	27.39	10.31	1.72
	Ruantiao-baisha	0.80	0.79	0.71	3.71	1.11	0.18
	Tianzhong	0.65	2.63	0.73	7.89	2.05	0.34
	Tongpi	0.74	5.21	1.04	10.33	3.65	0.61
	Average	0.57 (7.63%)	3.12 (41.51%)	0.79 (10.52%)	7.53	2.36	0.39
Red-fleshed	90-2	0.68	38.28	28.48	109.05	47.62	7.94
	Algeie	0.43	28.61	12.70	50.88	27.01	4.50
	Bahong	0.42	33.58	31.40	104.52	48.19	8.03
	Baozhu	0.39	29.85	28.37	97.28	43.30	7.22
	Dahongpao	0.51	36.50	27.67	122.33	45.92	7.66
	Dameigui-hongpao	0.36	16.37	28.30	110.85	36.49	6.08
	Dawuxing	0.15	6.55	11.58	41.38	14.86	2.48
	Dayeyangdun	0.81	20.24	49.66	112.15	59.78	9.96
	Jiajiao	0.38	8.95	30.81	58.14	35.29	5.88
	Jidanhong	0.35	61.92	20.92	115.30	51.88	8.65
	Luoyangqing	0.72	30.43	29.79	116.31	45.01	7.50
	Marc	2.19	52.21	29.07	110.00	55.18	9.20
	Pelusheis	0.22	40.86	29.57	86.11	50.00	8.33
	Zaozhong	0.58	30.44	31.50	102.81	46.72	7.79
	Average	0.59 (0.61%)	31.06 (32.52%)	27.84 (29.15%)	95.51	43.38	7.23

Source: Zhou et al. (2007b) and Fu et al. (2014) with modification, e.g., for cultivars involved in both sources, the data were averaged.

Table 3 Carotenoid content ($\mu\text{g/g}$ DW) in peel of loquat fruit

Group	Cultivar	Lutein	β -Cryptoxanthin	β -Carotene	Total colored carotenoid	β -Carotene equivalent	Retinol equivalent
White-fleshed	90-1	44.50	4.69	83.38	176.91	85.73	14.29
	Baisha	23.66	1.90	54.64	110.53	55.59	9.27
	Baiyu	27.46	3.95	41.85	102.83	43.83	7.30
	Bingtangzhong	18.02	5.08	43.38	98.69	45.92	7.65
	Biqi	13.58	4.50	39.54	85.95	41.79	6.96
	Dazhong	38.79	3.39	56.04	133.41	57.74	9.62
	Guanyu	21.63	4.57	53.96	111.40	56.24	9.38
	Jidanbai	28.06	5.82	49.49	114.94	52.40	8.73
	Ninghaibai	10.18	0.71	44.38	75.25	44.74	7.46
	Qingzhong	35.56	11.90	75.08	180.05	81.03	13.51
	Ruantiaobaisha	25.12	3.63	49.58	106.06	51.40	8.57
	Tianzhong	19.20	4.63	36.65	90.54	38.96	6.50
	Tongpi	37.08	8.49	91.71	202.28	96.00	16.00
	Average	26.37 (21.58%)	4.87 (3.98%)	55.36 (45.30%)	122.22	57.80	9.63
Red-fleshed	90-2	29.23	17.45	193.34	356.5	202.07	33.68
	Algeie	37.28	18.47	115.59	241.71	124.83	20.80
	Bahong	52.37	26.75	207.27	390.11	220.65	36.77
	Baozhu	30.51	16.37	263.59	418.11	271.77	45.30
	Dahongpao	26.59	18.55	266.20	444.57	275.47	45.91
	Dameiguihongpao	16.88	9.44	255.41	397.50	260.13	43.36
	Dawuxing	19.02	7.70	269.90	393.75	273.75	45.62
	Dayeyangdun	24.15	9.37	137.15	233.65	141.84	23.64
	Jiajiao	21.98	6.32	144.37	244.78	147.53	24.59
	Jidanhong	37.99	50.78	246.94	475.22	272.33	45.39
	Luoyangqing	30.52	18.13	214.85	366.05	223.92	37.32
	Marc	17.08	32.30	135.40	279.59	151.55	25.26
	Pelusheis	25.81	22.35	130.17	239.39	141.35	23.56
	Zaozhong	33.37	27.62	196.35	347.24	210.16	35.03
	Average	28.77 (8.34%)	20.11 (5.83%)	198.32 (57.51%)	344.87	208.38	34.73

Source: Zhou et al. (2007b) and Fu et al. (2014) with modification, e.g., for cultivars involved in both sources, the data were averaged.

Phenolic Compounds

Natural phenolic compounds can be classified into several classes: phenolic acids (C₆—C₁), hydroxycinnamic acids and coumarins (C₆—C₃), xanthenes (C₆—C₁—C₆), stilbenes (C₆—C₂—C₆), flavonoids (C₆—C₃—C₆), lignins [(C₆—C₃)_n], and proanthocyanidins [(C₆—C₃—C₆)_n] (Crozier et al., 2009). For dietary polyphenols, flavonoids and phenolic acids account for approximate 60% and 30%, respectively (Nichenametla et al., 2006). The most commonly reported phenolic compounds in loquat fruit are summarized in Tables 4 and 5, and the structures of the main flavonoids and phenolic acids are illustrated in Figure 1. Among the isolated loquat flavonoids, flavonol-*O*-glycoside is widespread, and it can be used as an indicator in plant chemical classification. Chlorogenic acid and neochlorogenic acid are the main phenols in loquat. High phenolic content was proposed as an important contributory factor to the antioxidant activity of various loquat extracts.

Table 4 Molecular structures of flavonols and flavan-3-ols in loquat

Flavonols	R ₁	R ₂
Quercetin	OH	H
Quercetin-3- <i>O</i> -rhamnoside (Quercitrin)	OH	Rhamnoside
Quercetin-3- <i>O</i> -glucoside (Isoquercitrin)	OH	Glucoside
Quercetin-3- <i>O</i> -rutinoside (Rutin)	OH	Rutinoside
Quercetin-3- <i>O</i> -galactoside (Hyperoside)	OH	Galactoside
Quercetin-3- <i>O</i> -neohesperidoside	OH	Neohesperidoside
Quercetin-3- <i>O</i> -sophoroside	OH	Sophoroside
Quercetin-3- <i>O</i> -sambubioside	OH	Sambubioside
Quercetin-3- <i>O</i> -galactosyl-(1→6)-glucoside	OH	Galactosyl-(1→6)-glucoside
Kaempferol-3- <i>O</i> -glucoside	H	Glucoside
Kaempferol-3- <i>O</i> -rutinoside	H	Rutinoside
Kaempferol-3- <i>O</i> -neohesperidoside	H	Neohesperidoside
Kaempferol-3- <i>O</i> -sambubioside	H	Sambubioside
Kaempferol-3- <i>O</i> -rhamnoside	H	Rhamnoside
Kaempferol-3- <i>O</i> -sophoroside	H	Sophoroside
Kaempferol-3- <i>O</i> -α-rhamnopyranosyl-(1→2)-β-D-glucopyranoside	H	α-Rhamnopyranosyl-(1→2)-β-D-glucopyranoside
Kaempferol-3- <i>O</i> -α-L-(2",4"-di- <i>E</i> -feruloyl)-rhamnoside	H	α-L-(2",4"-di- <i>E</i> -Feruloyl)-rhamnoside
Kaempferol-3- <i>O</i> -α-L-(2",4"-di- <i>E</i> - <i>p</i> -coumaroyl)-rhamnoside	H	α-L-(2",4"-di- <i>E</i> - <i>p</i> -Coumaroyl)-rhamnoside
Kaempferol-3- <i>O</i> -α-L-(2",4"-di- <i>Z</i> - <i>p</i> -coumaroyl)-rhamnoside	H	α-L-(2",4"-di- <i>Z</i> - <i>p</i> -Coumaroyl)-rhamnoside
Flavan-3-ol	R ₁	R ₂
Epicatechin	H	H
Epigallocatechin gallate	OH	O-Gallic acid

H, hydrogen; OH, hydroxide.

Table 5 Molecular structures of phenolic acids in loquat

Phenolic acids	R ₁	R ₂	R ₃	R ₄
Hydroxybenzoic acids				
2-Hydroxybenzoic acid	OH	H	H	H
<i>p</i> -Hydroxybenzoic acid	H	H	OH	H
Protocatechuic acid	H	OH	OH	H
Gallic acid	H	OH	OH	OH
Hydroxycinnamic acids				
Caffeic acid	OH	OH	H	H
Chlorogenic acid	OH	OH	H	3-Quinic acid
Cryptochlorogenic acid	OH	OH	H	4-Quinic acid
Neochlorogenic acid	OH	OH	H	5-Quinic acid
<i>o</i> -Coumaric acid	H	H	OH	H
<i>p</i> -Coumaric acid	H	OH	H	H
3- <i>p</i> -Coumaroyl quinic acid	H	OH	H	3-Quinic acid
4- <i>p</i> -Coumaroyl quinic acid	H	OH	H	4-Quinic acid
5- <i>p</i> -Coumaroyl quinic acid	H	OH	H	5-Quinic acid
Ferulic acid	OCH ₃	OH	H	H
4-Feruloylquinic acid	OCH ₃	OH	H	4-Quinic acid
5-Feruloylquinic acid	OCH ₃	OH	H	5-Quinic acid
Hydroxycinnamic acid derivatives				
(6 <i>R</i> ,9 <i>R</i>)-3-oxo- α -Ionyl-9- <i>O</i> - β -D-glucopyranosyl	H	β -D-Glucopyranosyl		
Eriojaposide A	H	β -D-Xylopyranosyl-(1" $\rightarrow$ 6')- β -D-glucopyranosyl		
Eriojaposide B	H	α -Rhamnopyranosyl-(1" $\rightarrow$ 6')- β -glucopyranoside		
(6 <i>S</i> ,9 <i>R</i>)-Roseoside	OH	β -D-Glucopyranosyl		
(6 <i>S</i> ,9 <i>R</i>)-Vomifoliol-9- <i>O</i> - β -D-apiofuranosyl-(1" $\rightarrow$ 6')- β -D-glucopyranosyl	OH	β -D-Apiofuranosyl-(1" $\rightarrow$ 6')- β -D-glucopyranosyl		
(6 <i>S</i> ,9 <i>R</i>)-Vomifoliol-9- <i>O</i> - β -D-xylopyranosyl-(1" $\rightarrow$ 6')- β -D-glucopyranosyl	OH	β -D-Xylopyranosyl-(1" $\rightarrow$ 6')- β -D-glucopyranosyl		

H, hydrogen; OCH₃, methoxy; OH, hydrogen.

By using HPLC-DAD-ESI-MS/MS, 8 hydroxycinnamic acid derivatives and 10 flavonoid glycosides were identified in loquat leaves and fruits (peel and flesh) of six improved cultivars in Brazil ('Mizuho', 'Néctar de Cristal', 'Mizauto', 'Mizumo', 'Centenária', and 'NE-3' (Ferrerres et al., 2009)). Quantification of these compounds revealed distinct differences among loquat cultivars and tissues, and 3- and 5-caffeoylquinic and 5-feruloylquinic acids were found to be the major compounds in Brazilian loquat fruit (Ferrerres et al., 2009). The 'Mizauto' cultivar had the highest phenolic content, and the flavonoid content

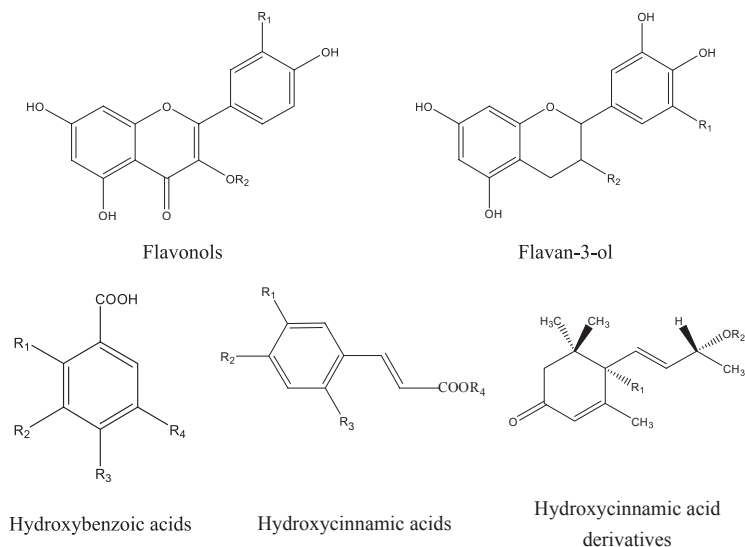


Figure 1 Most commonly reported phenolic classes in loquat.

in loquat may contribute to the DPPH scavenging capacity. In a study evaluating the effect of different loquat extracts on low-density lipoprotein oxidation, the highest content of total polyphenolic compounds was found in the seed, followed by the peel and flesh. Using HPLC-MS analysis, significant levels of polyphenolic compounds such as chlorogenic acid, cyanidin glucoside, epicatechin, epigallocatechin gallate (EGCG), and procyanidin B2 in different loquat fruit tissues were identified and quantified. Chlorogenic acid was higher in the flesh (46.4mg/100g wet weight) and peel than in seeds, whereas cyanidin glucoside was higher in the peel compared with the flesh (21.8mg/100g wet weight) and seeds (Koba et al., 2007). Loquat seeds contain high levels of phenolic acids and flavonoids, especially gallic acid (6.4 mg/100 g FW) and catechin (37.8 mg/100 g FW) (Pande and Akoh, 2010). Flavonoids, such as epicatechin, EGCG, and procyanidin B2 were found only in the ethanol extract of loquat seeds. Epicatechin, EGCG, chlorogenic acid, and epichlorogenic acid are the main phenolics in the loquat fruit (Koba et al., 2007; Pande and Akoh, 2010; Ferreres et al., 2009), and quantification of common phenolics in different parts the fruit are summarized in Table 6.

Loquat flowers are also rich in phenolic compounds, such as flavonoids. The average content of flavonoids and phenolics of loquat flowers of five cultivars were 1.59 ± 0.24 and 7.86 ± 0.87 mg/g DW, respectively, when using ethanol as an extraction solvent (Zhou et al., 2011). The contents of both bioactive components in flowers at different developmental stages and in the various flower tissues clearly differed, with the highest flavonoids and phenolics content in fully open flowers (stage 3) and petals, respectively. 2,2'-Azino-bis-(3-ethylthiazoline-6-sulfonate) (ABTS) assay showed the highest correlation coefficients between flavonoids and phenolics and antioxidant activity.

Table 6 Content of phenolic compounds in fruit tissues
Phenolic compounds

	Peel	Pulp	Seed
Chlorogenic acid (mg/100 g FW) ^a	36.8	46.4	28.2
Epicatechin (mg/100 g FW) ^a	ND	ND	58
EGCG (mg/100 g FW) ^a	ND	ND	59.4
Procyanidin B2 (mg/100 g FW) ^a	ND	ND	10.8
Epicatechin (mg/100 g FW) ^b	8.1	16.2	12.2
Gallic acid (mg/100 g FW) ^b	2.4	2.6	6.4
Ellagic acid (mg/100 g FW) ^b	0.8	0.2	0.5
<i>p</i> -Coumaric acid (mg/100 g FW) ^b	0.6	ND	ND
Ferulic acid (mg/100 g FW) ^b	1.5	0.8	0.5
Catechin (mg/100 g FW) ^b	14.5	12.2	37.8
Quercetin (mg/100 g FW) ^b	ND	ND	5.6
3- <i>p</i> -Coumaroylquinic acid (mg/kg dry basis) ^c	2.5–171.8	4.3–40.9	ND
5- <i>p</i> -Coumaroylquinic acid (mg/kg dry basis) ^c	ND	6.9–161.9	ND
3-Caffeoyl quinic acid (mg/kg dry basis) ^c	13.1–1349.8	3.3–644.4	ND
5-Caffeoyl quinic acid (mg/kg dry basis) ^c	13.0–640.2	22.1–1130.3	ND
5-Feruloylquinic acid (mg/kg dry basis) ^c	22.1–330.1	273.1–1295.5	ND
Quercetin-3- <i>O</i> -neohesperidoside + quercetin-3- <i>O</i> -sambubioside (mg/kg dry basis) ^c	1.1–26.6	ND	ND
Quercetin-3- <i>O</i> -galactoside (mg/kg dry basis) ^c	0.2–4.3	ND	ND
Kaempferol-3- <i>O</i> -neohesperidoside + quercetin-3- <i>O</i> -glucoside (mg/kg dry basis) ^c	3.2–82.1	ND	ND
Kaempferol-3- <i>O</i> -sambubioside (mg/kg dry basis) ^c	1.4–8.4	ND	ND
Quercetin-3- <i>O</i> -rhamnoside (mg/kg dry basis) ^c	3.9–46.2	ND	ND
Kaempferol-3- <i>O</i> -rhamnoside (mg/kg dry basis) ^c	1.8–18.2	ND	ND

DW, dry weight; EGCG, epigallocatechin gallate; FW, fresh weight.

^aKoba et al. (2007).

^bPande and Akoh, 2010.

^cFerreres et al. (2009).

Pentacyclic Triterpenoids

Studies of extraction, identification, and pharmacology of triterpene acids, such as oleanolic acid (OA) and UA (Figure 2) in loquat have reported on leaf (Banno et al., 2005; Li et al., 2009; Taniguchi et al., 2002), flower (Zhou et al., 2007a), and fruit (Zhou et al., 2011). OA and UA are isomeric pentacyclic triterpenoids widespread in the plant kingdom and have been reported to have various pharmaceutical properties, including antioxidative (Yin and Chan, 2007), antibacterial (Fontanay et al., 2008), antiinflammatory (Tsai and Yin, 2008), antiglycative (Wang et al., 2010), antitumor (Young et al., 1994), anti-human immunodeficiency virus (Kashiwada et al., 1998, 2000), and hepatoprotective activities (Ma et al., 1982).

Analysis of OA and UA in different loquat fruit tissues of ‘Ruantiaobaisha’ and ‘Dayeyangdun’ showed that peel contained higher OA and UA contents, whereas the flesh and kernel contained much lower amounts of OA and UA (Zhou et al., 2011).

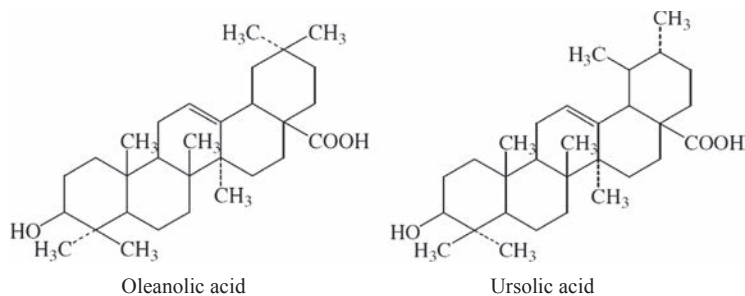


Figure 2 Chemical structure of OA and UA.

On the basis of these results, the OA and UA contents in the peel from different developmental stages and different cultivars of loquat fruits were analyzed and compared. Results showed that OA and UA contents in the peel varied with developmental stage and cultivar. The OA and UA content in the peel of ripe fruit of 24 cultivars were in the range of 0.59–1.68 and 2.82–8.20 mg/g DW, and the average OA and UA contents of 24 cultivars were 1.01 ± 0.29 and 4.98 ± 1.48 mg/g DW, respectively (Zhou et al., 2011).

Loquat flowers contain average amounts, ranging from 0.38 to 0.51 mg OA/g DW and 2.15 to 2.68 mg UA/g DW, and cultivar difference had only a minor effect on the contents of these two pentacyclic triterpenoids (Zhou et al., 2007a). However, developmental stage and flower tissue type showed a significant effect on the contents of these two bioactive components.

Vitamins

In comparison with fruits rich in ascorbic acid (vitamin C), such as oranges, which contain about 40 mg/100 g FW, loquats are not a rich source of vitamin C, and the levels are close to the values reported for other ripe fruits in the Rosaceae family. In a study of the chemical composition of five Brazilian loquat cultivars, the vitamin C content ranged from 5.28 mg/100 g FW in the ‘Centenária’ to 8.20 mg/100 g FW in the ‘Mizumo’ fruit (Hasegawa et al., 2010). By using 44 loquat varieties as material, significant differences in vitamin C content in loquat fruit, varying from 3.4 to 25.0 mg/100 g, with an average of 7 mg/100 g were also reported by Wei et al. (2009). In this study, ‘Longcaibai’ contained the highest level of vitamin C (25 mg/100 g), and ‘Xiazheng 2’ had the lowest amount of vitamin C (3.35 mg/100 g). There are 37 varieties with vitamin C content between 4 and 10 mg/100 g, which accounts for 84.1% of the germplasm studied. Only three varieties have vitamin C content lower than 4 mg/100 g, and only four varieties have vitamin C content higher than 10 mg/100 g. Interestingly, the white-fleshed loquat has a relatively higher average vitamin C content (8.2 mg/100 g) than red-fleshed loquat (6.75 mg/100 g). The edible portion of loquat has a relatively higher ascorbic acid content (5.3 mg/100 g) than the seed (3.2 mg/100 g) (Pande and Akoh, 2010). In addition, the contents of different

tocopherols in loquat fruit have also been evaluated, and γ -tocopherol was the most abundant (3.2 mg/100 g), followed by α -tocopherol (0.9 mg/100 g), δ -tocopherol (0.4 mg/100 g), and β -tocopherol (0.3 mg/100 g) (Pande and Akoh, 2010).

Mineral Content

Seasonal variations of mineral contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), and boron (B) in the leaves and fruits of loquat were evaluated from 1991 to 1993 (Ding et al., 1995). Results showed that the levels of N, P, and K declined with increasing leaf age, whereas the contents of Ca, Mg, and Mn increased gradually. The contents of Fe, Zn, and B were relatively low and varied significantly during the change in seasons. The optimal sampling period for leaf analysis is considered to be October, because the contents of most of the elements in the leaf are relatively stable in this season. In the fruit, the contents of N, P, K, Ca, Mg, Mn, Fe, Zn, and B were higher during the retardation phase of young fruits, but they quickly decreased with development of the fruits.

Lu et al. (2000) reported the seasonal changes of the major nutrient elements in 'Zaozhong 6' loquat from Fujian province of China. The order of the mineral contents was $\text{Ca} > \text{N} > \text{K} > \text{Mg} > \text{P}$ in leaves, $\text{K} > \text{N} > \text{Ca} > \text{Mg} > \text{P}$ in flower clusters, and $\text{K} > \text{N} > \text{Ca} > \text{P} > \text{Mg}$ in fruits.

Fiber

The total dietary fiber was evaluated in loquat fruit of five Brazilian cultivars (Hasegawa et al., 2010). The cultivars that showed the highest values of total dietary fiber were 'Mizumo' and 'Mizuho' (1.4 g/100 g FW), and the lowest values were found in the 'Mizauto' and 'Centenária loquats' (1.2 g/100 g FW). The content of the insoluble fiber was slightly higher than the soluble fraction, with an average of 0.73 g/100 g FW. However, more variation was found in the soluble fraction among cultivars, from 0.45 ('Néctar de Cristal') to 0.66 g/100 g FW ('Mizuho'), and it influenced the amount of total fiber content in all fruits.

Volatile Compounds

So far, about 18 volatile compounds have been reported for loquat fruit, and benzene ethanol-3-hydroxy-2-n-butanol is the main aroma component (Zhang et al., 2008). More research about volatile compounds has been carried out in the loquat flower. By using headspace–solid phase microextraction and gas chromatography–MS, about 64 volatile compounds have been isolated and 49 were identified, which account for 93.94% of the total volatile compounds. The characteristic aroma compounds of the loquat flower consisted of five acids (20.69%), six aldehydes (16.86%), six alcohols (13.2%), and six esters (8.18%), and they account for 63% of the volatile compounds. In addition, loquat flowers have small amounts of naphthalene (3.35%) and phenol (0.95%). Among the 49 identified compounds, phenylethyl alcohol (about 8.84%) has the highest content,

followed by benzaldehyde (7%), propionic acid (6.90%), anisic aldehyde (6.84%), acetic acid (5.41%), 16 alkyl (4.71%), 4-alkyl, methoxy (methyl benzoate; 4.36%), caprylic acid (4.21%) (Zhang et al., 2008). Further study showed that the volatile components in loquat flower buds and flowers are different, with hydrocarbons at a relatively higher mass fraction of flower (flower: 3.1%; bud: 0.56%) and esters at a relatively higher mass fraction (flower: 3.66%; bud: 8.57%). There are six volatile compounds that can be found in both loquat buds and flowers. Benzaldehyde accounts for more than 60% of the volatile compounds, and it produces the almond fragrance in both buds and flowers. The rose fragrance of benzene ethanol is also a major aroma component, and it plays an important role in loquat fruit development by attracting butterflies or bees for pollination. Dried loquat flowers show a dramatic loss of the volatile compounds compared with fresh ones.

FOCUSED AREA OF RESEARCH

Carotenoid Metabolism and Its Regulation

As mentioned, carotenoids are characteristic pigments in ripe fruit peel and flesh of red-fleshed cultivars, and they play various important roles in maintaining human health. Therefore carotenoid metabolism and its regulation is one of the hottest topics for plant secondary metabolism research, especially in fleshy fruits.

The carotenoid content and composition varies greatly by species. However, the backbone pathway for carotenoid metabolism is the same. Plant carotenoids are synthesized in plastids through the 2-C-methyl-D-erythritol 4-phosphate pathway, with two C5 isoprenes, isopentenyl pyrophosphate and dimethylallyl diphosphate, serving as two important intermediates. The biosynthesis steps and the corresponding genes for plant carotenoids have been almost completely elucidated (Fu et al., 2012; Neuman et al., 2014).

Fifteen genes for carotenoid biosynthesis were isolated from loquat, and the expression patterns between a red-fleshed cultivar, 'LYQ,' and a white-fleshed cultivar, 'Baisha' ('BS') were compared. However, although the changes in transcript abundance of these genes in peel of both cultivars or flesh of 'LYQ' were well correlated with carotenoid accumulation during development, the difference between two cultivars was not huge, up to around onefold, as compared with the differences, up to fiftyfold, in carotenoid accumulation (Fu et al., 2012).

Phytoene synthase (PSY) is the enzyme that catalyzes the production of phytoene, the first carotenoid molecule in the pathway, and therefore is the focus for studies on regulation of carotenoid production. In numerous plants, PSY has been proved to be one of the most critical enzymes for the pathway. In loquat, four PSY genes, *EjPSY1*, *EjPSY2A*, *EjPSY2B*, and *EjPSY3*, were studied. These members have different expression patterns, with *EjPSY1* most expressed in leaves and peel, *EjPSY2A* in peel and flesh, and *EjPSY2B* in leaves, whereas *EjPSY3* showed very low expression in any tissues (Fu et al., 2014). The expression patterns were similar between 'LYQ', red-fleshed and 'BS', white-fleshed.

However, sequence differences were found for *EjPSY2A* (Fu et al., 2014). In 'BS', a mutant *EjPSY2A^d*, lacking the C-terminal region, proved to be nonfunctional according to a functional complementation assay in *Escherichia coli*, harboring pAC-85b plasmid, which contains all genes required for β -carotene production except those for PSY. Therefore the loss-of-function mutation of *EjPSY2A* well explained the lack of carotenoids in the 'BS' flesh. This mutation appears in all six white-fleshed cultivars tested (Fu et al., 2014).

Carotenoids are synthesized in plastids, such as chloroplasts in leaves and young fruits, and chromoplasts in mature fruits. Plastid morphogenesis during loquat fruit development and ripening was studied, with 'LYQ' and 'BS' as contrasting cultivars (Fu et al., 2012). In peel, the early development of chromoplasts from chloroplasts was similar between two cultivars. However, in peel of mature fruit, the shape, size, and structure of chromoplasts are quite different between 'LYQ' and 'BS' (Fu et al., 2012) (Figure 3). In flesh, the differences are even bigger, with around 20–30 orange-colored chromoplasts per cell in 'LYQ', and no chromoplasts that could be seen in the flesh cells of 'BS' (Fu et al., 2012) (Figure 3). This indicates the failure to develop normal chromoplasts in 'BS' flesh, in addition to the mutation of the *EjPSY2A^d* gene, another functional explanation for the lack of carotenoid.

Taken together, two mechanisms, PSY mutation and chromoplast development disability, were proposed for the reduction in or absence of accumulation of carotenoids in fruits of white-fleshed loquats. It is probable that these two mechanisms are intrinsically linked, because in other plants evidence is emerging that enhanced plastid proliferation stimulates the accumulation of carotenoids and, furthermore, that manipulation of PSY expression or sequence can affect the differentiation of plastids.

Bioactivity Assay

Various biological activities have been reported for different loquat extracts. They are the result of the different composition of various bioactive compounds in different varieties and cultivars. The most commonly reported pharmacological and biological effects include antioxidant, antiinflammatory and cough-relieving, antidiabetic, antitumor, antiviral, and immune system-improving activities.

Antioxidants

Different loquat extracts (i.e., from leaves, fruits, flowers, and seeds) have been reported to have antioxidant activity (Hamada et al., 2004; Koba et al., 2007; Zhou et al., 2011, 2012). Methyl chlorogenic acid is one of the most effective antioxidant components in loquat leaf, and its activity is stronger than chlorogenic acid. The antioxidant can inhibit the activation of nuclear factor (NF)- κ B, which is sensitive to red oxidation reactions, and the isolated methyl chlorogenic acid from loquat leaf is a potential inhibitor of NF- κ B activation. Using the ferric reducing antioxidant power method, 1,1-diphenyl-2-picrylhydrazyl, and ABTS, the antioxidant activity was analyzed for flowers of different cultivars, tissues, and developmental stages (Zhou et al., 2011). Results showed that

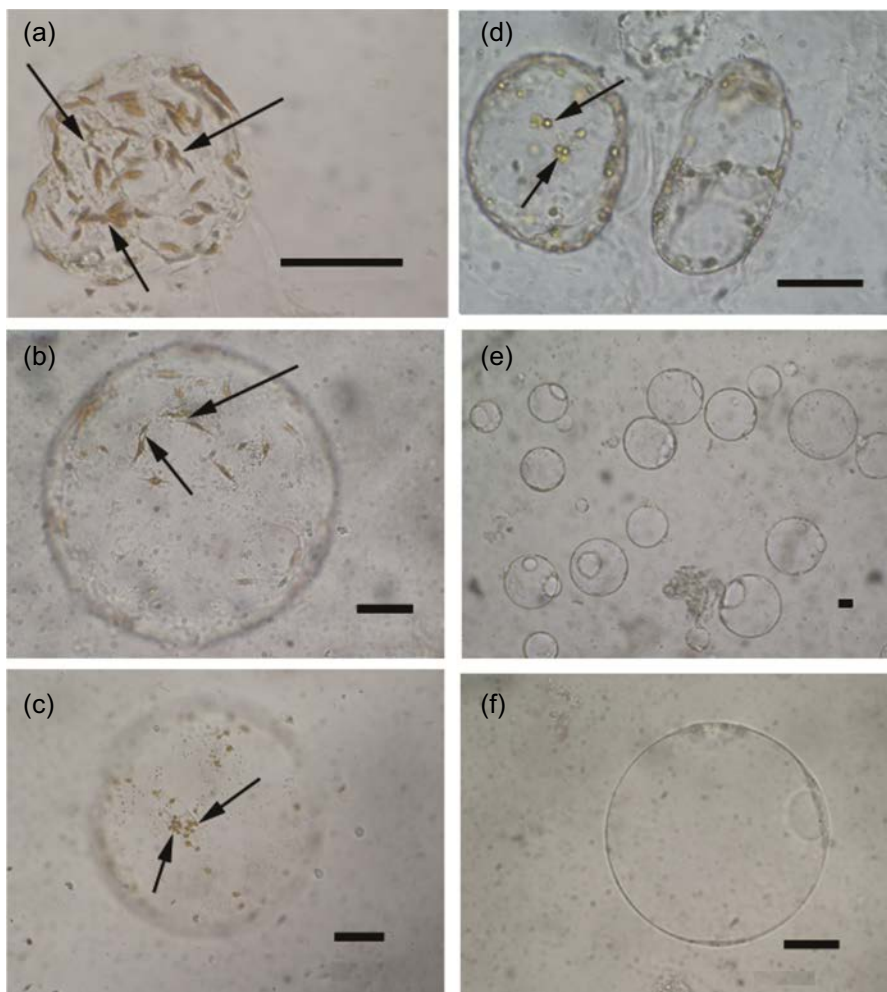


Figure 3 Light microscopy comparison of chromoplasts between 'LYQ' and 'BS' loquats. Protoplasts were prepared and not stained to show the natural color of chromoplasts (arrows). (a) Protoplasts of peel of 'LYQ'; (b and c) Protoplasts of flesh of 'LYQ'; (d) Protoplasts of 'BS' peel; (e and f) No chromoplasts were found in the protoplasts of 'BS' flesh. Bar, 20 μ m. Reproduced from: [Fu et al. \(2012\)](#) by permission of Oxford University Press.

flavonoids and phenolics are abundant in loquat flowers and are a potential source of dietary phenolics. The hydrophilic and lipophilic antioxidant activities were evaluated for 24 cultivars of loquat fruit ([Zhou et al., 2012](#)). The total antioxidant activity was mainly contributed by hydrophilic antioxidant activity, which is positively correlated with the phenolics content (ranging from 59.55 to 132.13 mg/100 g FW). The lipophilic antioxidant activity was positively correlated with lipophilic phenolics or carotenoids (ranging from 46.89 to 2699.06 mg/100 g FW).

Antiinflammatory and Cough-Relieving Components

Loquat extracts have been used for a long time as a traditional medicine to treat pulmonary inflammatory disease. Recently, the mechanisms of antiinflammatory activity of loquat extracts were studied. Twelve triterpene acids isolated from loquat leaves showed a marked antiinflammatory effect on 12-O-tetradecanoylphorbol-13-acetate (TPA)-induced inflammation in mice (Banno et al., 2005). Leaf extracts can significantly inhibit the expression levels of inflammatory mediators such as nitric oxide, iNOS, tumor necrosis factor- α , interleukin (IL-1), NF- κ B, prostaglandin E₂, and leukotriene B₄ (Huang et al., 2007; Cha et al., 2011; Choi et al., 2011). Some studies have revealed that UA may also have proinflammatory effects on normal cells and tissues (Ikeda et al., 2008). Therefore further investigations on the biological effects of loquat extracts are necessary.

Antidiabetic Components

Loquat leaves have been used traditionally for the treatment of diabetes mellitus by immersing the dried leaves in a hot water drink. More studies have shown the hypoglycemic effect of loquat using alcoholic extracts or isolated compounds. Nerolidol-3-O- α -L-rhamnopyranosyl(1-4)- α -L-rhamnopyranosyl(1-2)-[α -L-rhamnopyranosyl(1-6)]- β -D-glucopyranoside from leaves exerted a significant hypoglycemic effect in alloxan-induced diabetic mice (Chen et al., 2008a). Both the total triterpene acid fraction and flavonoid fraction from leaves showed high antidiabetic potential in streptozotocin-induced diabetic mice (Chen et al., 2009; Lü et al., 2009). Cinchonain Ib isolated from leaves showed a significant insulinotropic effect in INS-1 cells and enhanced plasma insulin levels in rats with type 2 diabetes (Qa'dan et al., 2009). However, almost all these studies focused on the effects of loquat leaf extract. So far, no anti-diabetes studies have been reported for fruit extract.

Anticancer Components

Antitumor agents from natural sources are receiving increasing attention because of their low side-effects profiles. Megastigmane glycosides and polyphenolic constituents isolated from loquat leaves were found to inhibit the TPA-induced activation of tumor in Raji cells, and roseoside and procyanidin B2 were among the most active compounds (Ito et al., 2002). The euscaphic acid from leaves exhibited marked antitumor activity in a two-stage carcinogenesis test of mouse tumor (Banno et al., 2005). The loquat hydrophilic extract can enhance the survival time of meth-A-fibrosarcoma-bearing mice through inducing interferon γ , transforming growth factor β 1, and IL-17 production within the tumor microenvironment of fibrosarcoma (Alshaker et al., 2011). Therefore loquat has great therapeutic value as a source of anticancer agents. Such research can lead to the development of improved strategies for cancer prevention or treatment.

Other Activities

As a medicinal plant, loquat extracts also have been reported to have biological activities such as improvement of liver function (Nishioka et al., 2002), gastroprotective activity (Yokota et al., 2008), antiaging effects (Muramoto et al., 2011), and antiallergic activity (Kim et al., 2009).

SUMMARY POINTS

- As a traditional medicinal plant, loquat has been used for thousands of years for its nutritional and pharmaceutical value.
- Various nutritional and bioactive compounds have been identified from loquat extracts.
- However, such studies used mainly loquat leaves or other nonedible tissues of the plant, rather than loquat fruit.
- More recently, studies investigating the in vivo metabolism and bioavailability, synergies, and competitive effects, as well as potential toxicity, of loquat extracts in animal models are receiving more attention.
- Additional extensive studies on structure–activity relationships for different potential bioactivities should be carried out.
- Because the loquat fruit has been shown to contain important compounds, such as OA, UA, and their derivatives, the positive bioactivities of which have been well studied irrespective of the source, eating the raw loquat fruit or its processed foods may have similar effects beneficial to health.
- New applications as a functional food or source of ingredients for therapeutics are anticipated.
- Breeding and genetic studies of loquat to increase the accumulation of nutritionally and therapeutically active compounds for human health may provide a new focus for loquat research and industry.

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CHAPTER 17

Nutritional and Biochemical Composition of Lychee (*Litchi chinensis* Sonn.) Cultivars

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LIST OF ABBREVIATIONS

BBCH	<i>Biologische Bundesantalt, Bundessortenamt, and Chemische Industrie</i>
BHT	Butylated hydroxytoluene
CAE	Catechin equivalents
CGE	Cyanidin-3-glucoside equivalents
DPPH	1,1-Diphenyl-2-picrylhydrazyl
DW	Dry weight
FM	Fresh mass
FRAP	Ferric reducing antioxidant power
FW	Fresh weight
GAE	Gallic acid equivalents
GC-MS	Gas chromatography-mass spectrometry
HPLC	High-pressure liquid chromatography
LFP	Lychee fruit pericarp
NMR	Nuclear magnetic resonance
RH	Relative humidity

SPME Solid phase microextraction

TLC Thin-layer chromatography

TPC Total phenolic content

VPD Vapor pressure deficit

INTRODUCTION

Lychee (*Litchi chinensis* Sonn.) of the Sapindaceae family includes *L. chinensis* ssp. *chinensis*, *L. chinensis* ssp. *philippinensis* (Radlk) Leenh, and *L. chinensis* ssp. *javensis* Leenh (Tindall, 1994; Liu et al., 2007). Among these subspecies, only *L. chinensis* ssp. *chinensis* is used for cultivation and business. This species originated in south China, north Vietnam, and the Malay Peninsula where several wild populations remain, particularly in the damp woodlands of Hainan province, the western hills of Guangdong province, the eastern region of Guangxi province, and the southern portion of Yunnan province (Hai and Dung, 2002). This species has been cultivated from ancient times; its domestication in China dates back to more than 2300 years ago (de Villiers, 2010).

Lychee is currently cultivated in over 20 countries in the tropical and subtropical regions of the world. China is the biggest producer of lychee, followed by India, Vietnam, and Thailand. Sizable cultivation of lychee can also be found in Pakistan, Madagascar, South Africa, Australia, the United States, Israel, Brazil, Mauritius, the Philippines, Thailand, Taiwan, and Indonesia (Menzel, 2001). World production of lychee was estimated to be 2.11 million tons in 2002 (Wang et al., 2011). China is the leading lychee-producing country in the world, with 950,000 tons of production of 40 export cultivars in 2002 (Lemmer, 2002). China and Taiwan export approximately 12,000–15,000 tons of lychee to the major international markets, Hong Kong, and Singapore (Mitra, 2006). The European markets import approximately 20,000 tons of lychee, of which France imports around 50%; and the rest is mainly imported by Germany and the United Kingdom. The main suppliers for Europe over Christmas and New Year's Eve are Madagascar and South Africa (Mitra, 2006). Lychees are usually eaten fresh as a dessert fruit. It is also consumed as frozen, canned, dried or fruit, or processed into juice, wine, and pickles and eaten with ice cream and yoghurt.

Different cultivars are grown around the world. Table 1 shows the commercially produced cultivars in lychee-growing countries. The protuberance type, texture, and arrangement are recommended as reliable morphological characters to identify the different cultivars rather than fruit shape, size, or taste. The shapes of some cultivars are very distinctive; for example, the round fruit of 'Kwai May Pink' can be differentiated from the egg-shaped 'Tai So' or the heart-shaped 'Haak Yip'. The fruit shoulders can be smooth or flat ('Wai Chee' and 'Kwai May Pink') or uneven ('Souey Tung' and 'Bengal'). The apex or tip of the fruit can be round ('Kwai May Pink' and 'Wai Chee'), blunt ('Souey Tung' and 'Brewster'), or pointed ('Bengal').

Table 1 Major lychee-producing countries and important cultivars

Country	Major cultivars
Australia	'Fay Zee Siu', 'Kwai May Pink', 'Salathiel', 'Souey Tung', 'Tai So', 'Wai Chee', 'Haak Yip', 'Seong Sue Wai', 'Kwai May Red', 'No Mai Chee Standard', 'Brewster', 'Groff'
China	'Bah Lup', 'Baitang-ying', 'Fay Zee Siu', 'Haak Yip', 'Kwai May Red', 'Kwai May Pink', 'Lanzhu', 'No Mai Chee', 'Wai Chee', 'Sum Yee Hong', 'Souey Tung', 'Tong Bok', 'HongPay', 'Bo Dy', 'Choo Mah Zee', 'Heong Lai', 'Ah Neong Hai', 'Soot Wai Zee', 'Tai So', 'Seong Sue Wai', 'Kom Hom Lam Chiak', 'Luk Lai', 'Sampao Kaow', 'Kwa Lok', 'Aili', 'Ziniangxi', 'Mianbaoli', 'Fengli', 'Dahong Muomizi', 'Liquili', 'Feizixiao', 'Songmei-2', 'Songmei-5', 'Songmei-9', 'Songmei-12'
India	'Bedana', 'China', 'Culcuttia', 'Late Bedana', 'Longia', 'Shahi', 'Dehra Dun', 'Dehra Rose', 'Early Large Red', 'Early Seedless', 'Hong Kong', 'Muzzafarpur', 'Rose Scented', 'Saharanpur', 'Purbi', 'Bombai', 'Longia', 'McLean'
Indonesia	'Local Selection'
Israel	'Mauritius', 'Floridian', 'Bengali'
Madagascar	'Madras', 'Mauritius'
South Africa	'Mauritius', 'McLean's Red'
Thailand	'Chacapat', 'Haak Yip', 'Kom', 'Tai So', 'Wai Chee', 'Amboina', 'Peerless', 'Cheng', 'Erewhon', 'Hong Thai', 'Jim Lee', 'Kalohe Bai Yaow', 'Kom Hom Lan Chiak', 'Luk Lai Sampao Kaow'
United States	'Brewster', 'Haak Yip', 'Kwai Wai', 'No Mai Chee', 'Shan Chi', 'Mauritius', 'SweetCliff', 'Groff', 'Charley Tong'
Vietnam	'Vaithieu'

Typical colors include bright red ('Bengal'), dull red ('Wai Chee'), purple-red ('Haak Yip'), or pink-red ('Brewster'). The skin can be thick ('Wai Chee' 'Bengal' and 'Kwai May Pink') or thin ('Haak Yip' and 'Souey Tung'). Skin segments at full maturity can be smooth ('Haak Yip'), swelling ('Wai Chee'), or sharp-pointed ('Kwai May Red'), similar to the protuberances on each segment. Some cultivars ('Haak Yip' and 'Souey Tung') can be distinguished by the presence or absence of an obvious suture line. The texture, juiciness, taste, and aroma of the flesh can aid description; for example, 'Wai Chee' is watery, 'Kwai May Red' is firm, 'Kwai May Pink' is spicy, and 'Bengal' is very sweet.

BOTANICAL ASPECTS

The lychee (*L. chinensis* Sonn.) belongs to the family Sapindaceae, that include the members that produce soap berries. The Sapindaceae family includes longan (*Dimocarpus longan*), rambutan (*Nephelium lappaceum*), and mangosteen (*Garcinia mangostana*). It is regarded as a tropical to subtropical fruit. It is an evergreen tree that grows up to 10–20 m in height (Zhang, 1997). The lychee tree has a round, dense, compact, and symmetrical crown (Subhadrabandhu and Stern, 2005).

Phenological growth stages of lychee using the extended *Biologische Bundesantalt, Bundessortenamt, and Chemische Industrie* (BBCH) scale have been described by [Wei et al. \(2013\)](#). A total of seven primary growth stages were described for bud, leaf, and shoot development; inflorescence emergence; flowering; fruit development; and fruit maturity ([Figure 1](#)). In addition, 41 secondary growth stages were described. Lychee trees normally have a thick short trunk and brown gray bark. Lychee leaves differ in appearance at various points in the growing season or among different cultivars. They are 5–15 cm long and 3–5 cm wide, with colors ranging from copper-red or amaranth to copper-yellow or light green when young, which gradually turn to dark green with time. Under normal conditions, lychee trees undergo two to three batches of vegetative flushes each year. From June to November, lychee leaves produce large amounts of carbohydrates that accumulate in branches and trunks, with starch concentration the highest in small branches ([Chen et al., 2004](#)). This provides the necessary energy for floral formation and flowering in early spring. Terminal buds of the stem, and in certain conditions, the axillary buds (i.e., the occurrence of a killing flush or the failure of initial flowering) produce compound raceme panicles that are 10–40 cm long and contain 200–4000 functionally male and functionally female flowers, as well as a few hermaphrodite flowers. The number of flowers and their sex ratio depend on the cultivar and climatic condition. Additionally, lychee exhibits a flowering behavior called *dichogamy*, in which the peak time of functionally male flowers does not synchronize with that of the functionally female flowers.

The lychee fruit is drupe with variable size, shape, color, and weight, and is derived from a superior ovary. It consists of an aril, pericarp, carpopodium, pedicel, and five seed parts. Drupaceous fruit vary from round, ovoid, or heart-shaped, and fruit size can vary from 23 to 30 g. The ratio of the edible aril to seed is more important than large fruit size. The lychee fruit is approximately 5 cm long and 4 cm wide, depending on the cultivar. These characteristics have been described in detail by [Wu \(1998a,b\)](#), [Li and Huang \(2003\)](#), [Li \(2007\)](#), and [Wei et al. \(2013\)](#). Lychee fruit growth (code 700–709 on the BBCH scale) is customarily divided into three growth stages ([Joubert, 1986](#)). During the first growth stage, the pericarp, embryo, and seed coat develop. The endosperm is initially liquid and is absorbed by the developing embryo. The second stage of fruit growth is characterized by rapid growth of the embryo and beginning of aril development. During the third growth stage, rapid growth of the aril and maturation processes take place.

The shape of the lychee fruit differs from conical to spherical. At immature stages fruit are green, and at maturity the fruit develops a rough indehiscent red skin (pericarp). The red skin color is caused by anthocyanins. The pericarp has protuberances that can be used to identify different cultivars based on the protuberance type, texture, and arrangement. The succulent white mesocarp (aril) is the edible portion of the fruit, and the one seed is present in the center of the fruit. The color of the seed varies from chestnut brown to dark brown, and the shape is from ovoid to oblong (1.0–3.3 cm long and 0.6–1.2 cm wide) ([Subhadrabandhu and Stern, 2005](#)).

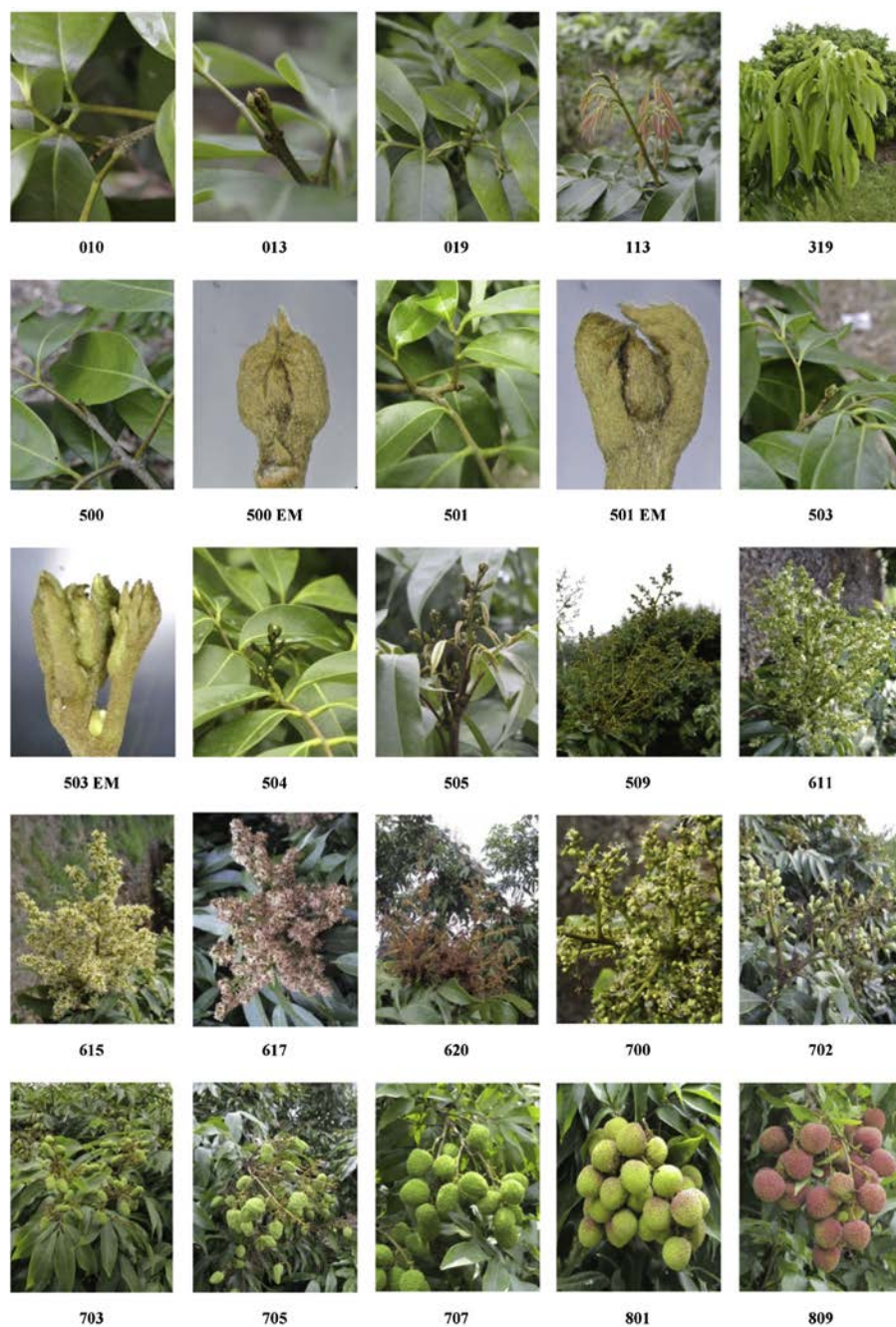


Figure 1 The important phenophases with the corresponding codes in southern China. For details please refer to [Wei et al. \(2013\)](#).

Table 2 Major constituents of the lychee fruit
Nutritional components **Value (100 g FW)**

Water	84
Protein (g)	0.7
Fat (g)	0.1
Carbohydrate (g)	15
Vitamin C (mg)	15
Thiamine (mg)	0.02
Niacin (mg)	1.1
Riboflavin (mg)	0.07
Phosphorus (mg)	32
Iron (mg)	0.7
Calcium (mg)	4

Source: Huang et al. (2005).

Generally lychee fruit takes 80–112 days to mature. However, the exact number of days to reach maturity stage for harvesting depends on the type of cultivar and weather (Menzel, 2001). During fruit development the color of the skin changes from green to reddish pink. The color change in the skin is the result of a decline in chlorophyll content and increase in anthocyanin (Underhill and Critchley, 1992). Lychee fruit does not ripen after harvest and produces low levels of ethylene, and was identified as nonclimateric fruit (Chen et al., 1986). A decline in the rate of respiration was observed during fruit development (Jiang et al., 1986). The respiration was decreased directly after harvest in the cultivar ‘Huaizhi’ and thereafter an increase was observed. However, there is a paucity of information available on the rate of respiration in other cultivars. The pulp (aril) growth begins 25 days after anthesis. The pulp grows continuously from about 4 weeks after flowering. In terms of the consumer’s view, lychee fruit typically has a pinkish to bright red peel, depending on the type of cultivar, a sweet and sour blend of flavor, and juicy, soft, and crisp aril (Nakasone and Paull, 1998). The fruit is high in sugar content and contains several vitamins and minerals (Table 2).

NUTRITIONAL AND BIOCHEMICAL COMPOSITION OF TRADITIONAL AND MODERN CULTIVARS

Studies conducted by Higgins (1917), Stahl (1935), Deullin and Trupin (1965), Wenkan and Miller (1965) and Kadman and Slor (1982), as quoted by Saucó and Menini (1989), showed that water is the main component of lychee, accounting for between 76% and 91% of the pulp. In the seed and skin, its proportion was 54% and 34%, respectively. Carbohydrates, fats, proteins, amino acids, phenols, pectins, minerals, vitamins, and flavor components are the major important constituents of lychee pulp. Nutritional and biochemical composition and variation among cultivars are described in the following sections of this chapter.

Sugars

Farooqui and Kaul (1963) reported that aril of lychee fruit contain glucose, fructose, and sucrose as free sugars; those in combination are arabinose, galactose, xylose, and a trace of rhaminose. The sugar content differs between different cultivar types (Wang et al., 2006). Major sugar components in lychee are sucrose, fructose, and glucose (Chan et al., 1975; Paull et al., 1984; Jiang et al., 2006). The total sugars in the edible portion differ from 55.9% to 61.4% on dry weight (DW) basis, with 41.5–43.5% reducing sugars (Cavaletto, 1980; Jiang et al., 2006). In the edible portion, the reducing sugars represent more than 70% of the total sugars (Jiang et al., 2006). The cultivar type, stage of maturity, and invertase activity determine the relative ratios between these sugars (Paull et al., 1984). Glucose is considered to be the major sugar in the fruit, with smaller amounts of fructose and sucrose; however, in some cultivars, such as ‘Shui Dong’, ‘Gui Wei’, and ‘Mi Selection’ the sucrose level is much higher than that of glucose (Paull et al., 1984). At full maturation, the sugar concentration declines as a result of increased water influx into the aril and a reduction in acid concentration, giving some cultivars a bland taste (Huang and Qiu, 1987). Sugar metabolism is associated with anthocyanin synthesis, which is evident from the simultaneous increase of soluble sugars, invertase activity, and color development.

The lychee aril accumulates sugars amounting to 15–20% of the fresh mass (FM), and the total amount of sugars (sucrose, glucose, and fructose) accumulated varies among 42 cultivars (Yang et al., 2013) (Figure 2). Cultivars ‘Wuyejiu’, ‘Liuyuexue’ and ‘Jinzhong’ were observed to accumulate significantly lower amounts of sugar (<100 mg/g FM) than the other cultivars, whereas ‘Guifeihong’, ‘Zhuangyuanhong’, ‘Qingpi’, ‘Jidi’, ‘Wanpu’, and ‘Feizixian’ accumulated more than 150 mg/g FM in the arils. Roughly, equal amounts of glucose and fructose were detected in the aril. The amounts of glucose and fructose were added together as hexoses, and the ratio of hexoses to sucrose was calculated to indicate sugar composition in the lychee aril. A significant differences in the hexose to sucrose ratio was observed among the 42 cultivars tested, which could be grouped into three types. The first type included cultivars with hexose to sucrose ratios less than 1, such as ‘Guifeihong’, ‘Wuheli’, and ‘Zhuangyuanhong.’ The second type included cultivars with hexose to sucrose ratios between 1 and 2, such as ‘Longyanben’, ‘Guinuo’, and ‘Xuehuaizi’. The third type included cultivars with hexose to sucrose ratios greater than 2, such as ‘Baipi’, ‘Jianye’, and ‘Wuye’. No visible relationship between sugar content and hexose to sucrose ratio was observed (Yang et al., 2013). Wang et al. (2006) classified lychee cultivars according to sugar composition into monosaccharide prevalent types, disaccharide prevalent types, and intermediate types. This difference in sugar composition between cultivars was ascribed to differences in the activity of certain key enzymes (Wang et al., 2006).

Storage temperature and duration also affect sugar content in different cultivars. Fruits that had been stored at 5°C and 90% relative humidity (RH) (vapor pressure deficit (VPD)=0.084 kPa) had a higher concentration of sucrose in cultivars ‘Kom’ and ‘Mauritius’, whereas the lowest concentration of sucrose was noted during storage at

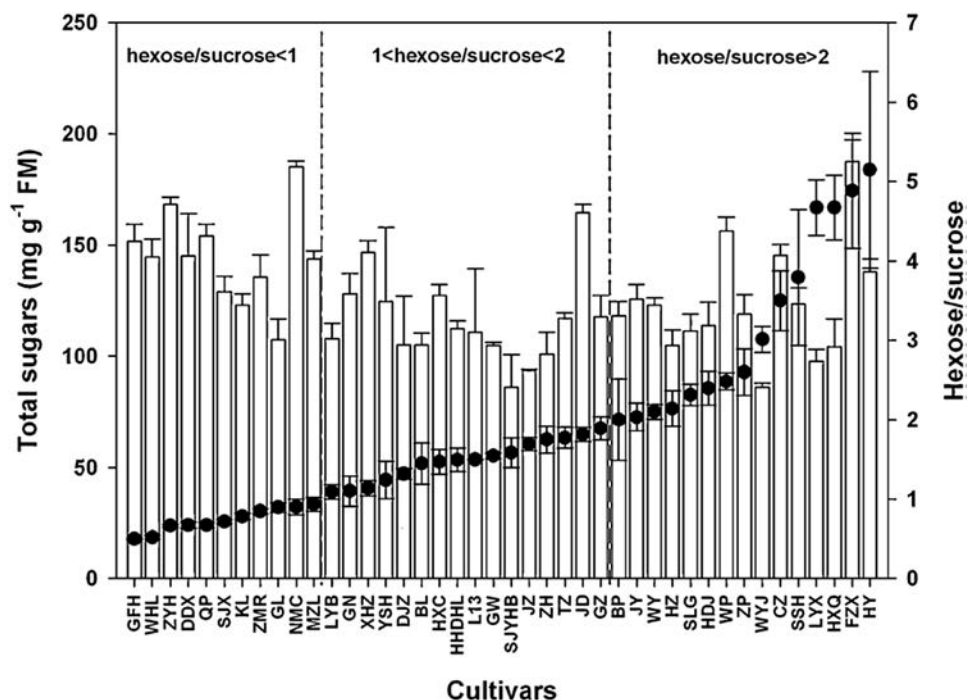


Figure 2 Total soluble sugars and hexose to sucrose ratios in the arils of 42 cultivars at maturity. The vertical bars represent the standard error of three replicates. For details and cultivar abbreviations refer to [Yang et al. \(2013\)](#).

13 °C and 80% RH (VPD = 0.274 kPa) ([Somboonkaew and Terry, 2010](#)). However, highest glucose and fructose levels were observed in both cultivars at 80% RH, irrespective of storage temperature ([Somboonkaew and Terry, 2010](#)).

Organic Acids

Succinic acid is the main organic acid present during the greater part of the fruit development ([Paull et al., 1984](#)). However, higher content of malic acid was observed at maturity. According to [Wang et al. \(2006\)](#), mature fruit contains malic acid but not succinic acid. In their studies, malic acid was the main organic acid, which increased during early aril development and decreased dramatically as the fruit approached maturity. Citric, succinic, levulinic, glutaric, malonic, and lactic acids are present as relatively minor acid components ([Cavaletto, 1980; Paull et al., 1984](#)). The citric acid level was found to be low during fruit development, with a slight increase toward full maturity ([Paull et al., 1984](#)).

The storage RH was reported to affect the organic acids in the aril of cultivars ‘Kom’ and ‘Mauritius’. The ‘Kom’ fruit at 100% RH and ‘Mauritius’ fruit at 95% RH retained higher malic acid levels, at 26.56 and 14.64 mg/g DW, respectively. Highest tartaric acid concentrations were observed in both cultivars at 90% RH, and concentrations of

organic acids were lower at 80%. Storage at lower temperature (5 °C) maintained the malic, tartaric, oxalic, and total acids in both cultivars better in than those stored at 13°C. The changes in sugar and organic acid concentrations explain the influence of RH, temperature, and VPD on carbohydrate use through respiration (Somboonkaew and Terry, 2010).

Ascorbic Acid

Lychee is recommended as good source of vitamin C (ascorbic acid). The average vitamin C content in lychee is 27.6 mg/100 g. The early maturing Hawaiian lychee cultivar ‘Kaimana’ showed an average vitamin C content of 33.2 mg/100 g, and the late-maturing cultivars ‘Groff’ and ‘Bosworth-3’ showed 21.2 and 22.5 mg/100 g, respectively (Wall, 2006). The vitamin C contents in cultivars ‘Mauritius’ and ‘McLean’s Red’ were 27.43 mg/100 g and 21.35 mg/100 g, respectively (Sivakumar et al., 2008). Luximon-Ramma et al. (2003) reported average ascorbic acid content of 13.8 mg/100 g fresh weight (FW) in pulp of an unidentified variety from Mauritius. Ascorbic acid content of lychee cultivars growing in different geographical locations is mentioned in Table 3. Ascorbic acid increases with total sugar, but declines slightly in mature fruit when sugar accumulation slows down (Gaur and Bajpai, 1979). In contrast, studies by Wang et al. (2006) revealed that ascorbic acid decreases with fruit development until 2 weeks before harvest, but then increases again slightly at full maturity.

Minerals

Lychee fruit is a good source of potassium (K) and nitrogen (N). The contents of N, phosphorus (P), K, calcium (Ca), magnesium (Mg), sodium (Na), and iron (Fe) differed significantly between the two South African cultivars ‘Mauritius’ and ‘McLean’s Red’, even though the two cultivars were grown under similar conditions in the same location (Sivakumar et al., 2008). This could be attributed to the different patterns of mineral absorption and distribution in metabolically active tissues (Shewfelt, 1990), which could be cultivar-dependent. The mineral contents of different lychee cultivars are given in Table 4.

Table 3 Ascorbic acid content in lychee cultivars grown in different geographical locations

Cultivar	Location	Ascorbic acid (mg/100 g FW)	References
Unidentified	Mauritius	12.3–15.3	Luximon-Ramma et al. (2003)
‘Bosworth-3’	Hawaii	21.0–24.0	Wall (2006)
‘Groff’	Hawaii	21.2	Wall (2006)
‘Kaimana’	Hawaii	30.7–36.0	Wall (2006)
‘Mauritius’	South Africa	27.4	Sivakumar et al. (2008)
‘McLean’s Red’	South Africa	21.2	Sivakumar et al. (2008)

Table 4 Mineral composition of some lychee cultivars

Cultivar	Country of study	Ca	P	Mg	Na	Fe	Cu	Zn	Mn	K	B	Pb	References
‘Bedana’	India	3.80	ND	ND	16.90	0.91	0.30	0.25	0.04	16.60	ND	0.10	Tripathi et al. (1987)
‘Calcuttia’	India	3.40	ND	ND	33.30	0.43	0.23	0.23	0.02	19.30	ND	0.10	Tripathi et al. (1987)
‘Deshi’	India	3.10	ND	ND	14.40	0.60	0.40	0.26	0.04	17.50	ND	0.10	Tripathi et al. (1987)
‘Groff’		7.16	5.76	5.08	ND	ND	ND	ND	ND	37.30	ND	ND	Paull et al. (1984)
‘Rose Scented’		4.50	ND	ND	13.80	0.60	0.32	0.26	0.03	12.00	ND	0.13	Paull et al. (1984)
‘Bosworth’	Hawaii	2.1–4.7	25.4–23.7	11.5–13.1	3.1–6.8	0.36–0.43	0.17–0.20	0.16–0.26	0.05–0.07	159.6–172.4	0.09–0.11	ND	Wall (2006)
‘Groff’	Hawaii	2.1–4.7	28.2	11.5–13.1	3.1–6.8	0.36–0.43	0.17–0.20	0.16–0.26	0.05–0.07	159.6–172.4	0.09–0.11	ND	Wall (2006)
‘Kaimana’	Hawaii	2.1–4.7	31.1–26.9	11.5–13.1	3.1–6.8	0.36–0.43	0.17–0.20	0.16–0.26	0.05–0.07	159.6–172.4	0.09–0.11	ND	Wall (2006)
‘Mauritius’	S. Africa	2.1–4.7	35.0	11.5–13.1	3.1–6.8	0.36–0.43	0.17–0.20	0.16–0.26	0.05–0.07	159.6–172.4	0.09–0.11	ND	Sivakumar et al. (2008)
‘McLean’s Red’	S. Africa	2.1–4.7	31.2	11.5–13.1	3.1–6.8	0.36–0.43	0.17–0.20	0.16–0.26	0.05–0.07	159.6–172.4	0.09–0.11	ND	Sivakumar et al. (2008)

B, Boron; Ca, calcium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; Na, sodium; ND, not determined; P, phosphorus; Pb, lead; Zn, zinc.

Fats, Proteins, and Amino Acids

These constituents vary a good deal with different cultivars. [Singh et al. \(1987\)](#) reported that fat content varies between 0.21% and 0.35% in the four Indian cultivars. However, [Saucó and Menini \(1989\)](#) quoted fat values from 0.5% to 1.6%. The protein content of ‘Early Large Red’, ‘Calcuttia’, ‘Bedana’, and ‘Muzaffarpur’ fruits ranged from 0.33% to 1.2% ([Singh et al., 1987](#); [Tripathi et al., 1987](#)). The major amino acids identified in lychee are methionine and tryptophane ([Table 5](#)). The occurrence of other amino acids such as glutamic acid, serine, alanine, threonine, tyrosine, leucine, isoleucine, lysine, and aspartic acid has also been reported ([Farooqui and Kaul, 1963](#); [Tripathi et al., 1987](#); [Singh et al., 1987](#)).

Phenolics and Antioxidants

Analysis of phenols in lychee fruit pericarp (LFP) indicates numerous compounds, but information existing on the phenolic composition is poor because of the lack of formal identification of the cited compounds. Studies have primarily been carried out by thin-layer chromatography (TLC) ([Prasad and Jha, 1978](#); [Jaiswal et al., 1987](#)) and then by high-pressure liquid chromatography (HPLC) ([Lee and Wicker, 1991](#)). In lychee skin, the anthocyanins have been the most studied compounds. The literature indicates the presence of cyanidin 3,5-diglucoside, cyanidin 3-glucoside, cyaniding 3-rutinoside ([Jaiswal et al., 1987](#); [Lee and Wicker, 1991](#)), cyanidin 3-galactoside ([Lee and Wicker, 1991](#); [Underhill and Critchley, 1994](#)), pelargonidin 3,7-diglucoside ([Prasad and Jha, 1978](#); [Jaiswal et al., 1987](#)), and malvidin 3-acetylglucoside ([Lee and Wicker, 1991](#)). Flavonols have been mentioned, but data are based only on their *R_f* on TLC and absorbance maxima ([Jaiswal et al., 1987](#); [Macheix et al., 1990](#); [Mazza and Miniati, 1993](#)). These authors reported quercetin 3-rhamnoside, quercetin 5-glucoside, and kaempferol. The presence of condensed tannins was demonstrated by [Le Roux et al. \(1998\)](#), who showed that polymeric proanthocyanidins in LFP are epicatechin units linked by both A- and B-type interflavanoid bonds.

LFP contains abundant phenolic compounds, and exhibits powerful activities against fat oxidation and hepatocellular carcinoma ([Wang et al., 2006](#); [Zheng et al., 2003](#)). The health promoting properties of LFP are related to the presence of phenolic compounds

Table 5 Amino acids (mg/100 g) in different Indian lychee cultivars

Cultivar	Tryptophane	Methionine	Tyrosine	References
‘Bedana’	13.0	2.8	1.4	Singh et al. (1987)
‘Calcuttia’	14.0	2.4	1.4	Singh et al. (1987)
‘Deshi’	NA	NA	1.9	Singh et al. (1987)
‘Early Large Red’	14.0	2.1	NA	Tripathi et al. (1987)
‘Muzaffarpur’	16.0	2.6	NA	Tripathi et al. (1987)
‘Rose Scented’	NA	NA	1.1	Tripathi et al. (1987)

(Zheng et al., 2003; Zhao et al., 2007). Oligonol, a polyphenolic product containing catechin-type monomers and lower oligomers of proanthocyanidin from lychee fruit, has proven to significantly increase lipolysis and have powerful antioxidant activity (Ogasawara et al., 2009). The pericarp, constituting about 15% in FW of the lychee fruit, is a good source of phenolics, including condensed tannins, procyanidins, anthocyanins, epicatechin, catechin, gallocatechin, and epigallocatechin (Zhang et al., 2000).

The pericarps of 10 lychee cultivars from two production seasons were studied for their phenolic concentrations and composition and activities of antioxidation (Wang et al., 2011). The total phenolic concentrations in dried LFP ranged from 51 to 102 g/kg. Different cultivars varied considerably in phenolic concentration and composition. Cultivars 'Nuomici' exhibited significantly higher concentrations of proanthocyanidins, flavonoids, phenolic acids, and therefore total soluble phenolics than the other cultivars, whereas 'Lanzhu' and 'Guiwei' had minor values in phenolics. The extracts of LFP exhibited considerably high ferric reducing antioxidant power (FRAP) and strong activities of 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging, lipid peroxidation inhibiting. The crude ethanol extracts of pericarp displayed significantly higher FRAP and stronger DPPH scavenging capacity than butylated hydroxytoluene and catechin. Among the tested 10 cultivars, concentrations of major phenolics had significant linear correlations with FRAP and DPPH scavenging activities. These results indicated that lychee pericarp is rich in natural antioxidant phenolic compounds, and different lychee cultivars differ considerably in phenolic concentration and antioxidant activities (Wang et al., 2011). Zhang et al. (2000) reported that epicatechin and proanthocyanidins are the main phenolics in the pericarp of 'Huaizhi' cultivar.

Low pressure chromatography, HPLC, ultraviolet-visible spectral analysis, mass spectrometry, and nuclear magnetic resonance studies have allowed the determination and quantification of the polyphenolic composition of LFP. Lychee skins contain significant amounts of polyphenolic compounds. The principal characteristic of the lychee skin's polyphenolic compounds is their *ortho*-diphenolic structure, which gives them high oxidability. Four major pigments were formally identified as cyanidin 3-rutinoside, cyanidin glucoside, quercetin 3-rutinoside (rutin), and quercetin glucoside. The tannin content was characterized after the depolymerization thiolysis reaction. Tannins (polymeric proanthocyanidins) are mainly constituted with epicatechin units linked by A- and B-type bonds. The different phenolic compounds of the lychee cultivar 'Kwai Mi' were quantified by HPLC. Condensed tannins were the most abundant (4 mg/g of fresh skin), followed by epicatechin and procyanidin A2 (1.7 and 0.7 mg/g of fresh pericarp, respectively). The amount of anthocyanins was found to be comparable to that of flavonols, with a value of 0.4 mg/g of fresh pericarp (Sarni-Manchado et al., 2000).

Studies on the phenolic content and antioxidant activity of lychee fruit are mainly focused on its by-products, pericarp (Sarni-Manchado et al., 2000) and seeds (Prasad et al., 2009c). In contrast, the most commonly consumed part, lychee pulp, is rarely mentioned in the literature. Both qualitative and quantitative knowledge of phenolics and

their antioxidant activity in the pulp are limited and incomplete. [Luximon-Ramma et al. \(2003\)](#) investigated the total phenolic content (TPC) and antioxidant activity of lychee pulp in northern 'Mauritius'. They reported $288 \pm 17 \mu\text{g}$ gallic acid equivalents (GAE)/g FW TPC, $94 \pm 6 \mu\text{g}$ quercetin/g FW total flavonoids, and $10 \pm 2 \mu\text{mol}$ Trolox/g FW total antioxidants in lychee pulp of unidentified variety. [Mahattanatawee et al. \(2006\)](#) detected glycosides of quercetin and kaempferol in lychee pulp from southern Florida. However, these studies only reported the free phenolics on the basis of the solvent-soluble extraction, and the bound phenolics and their contribution to antioxidant activity were not involved. There will be an underestimation of the phenolic content and antioxidant activity if the bound fraction is not included. Furthermore, many lychee cultivars mature at different times. Their phenolic compositions and activities are assumed to differ as a result of the differences in cultivation environment and varieties.

The phenolic profiles and antioxidant activity of lychee pulp of 13 varieties were investigated by [Zhang et al. \(2013\)](#). The free, bound, and TPCs were 66.17–226.03, 11.18–40.54, and 101.51–259.18 mg of GAE/100 g, respectively. The free, bound, and total flavonoid contents were 16.68–110.33, 10.48–22.75, and 39.43–129.86 mg of catechin equivalents (CAE)/100 g, respectively. Free phenolics and flavonoids contributed averagely 80.1% and 75% to their total contents, respectively. Six individual phenolics (gallic acid, chlorogenic acid, (+)-catechin, caffeic acid, (–)-epicatechin, and rutin) were detected in lychee pulp by HPLC. Significant varietal discrepancy in antioxidant activity was also found by FRAP and DPPH scavenging capacity methods. Antioxidant activity was significantly correlated with phenolic and flavonoid contents. Thus phenolics and flavonoids exist mainly in the free form in lychee pulp. There were significant varietal differences in phytochemical contents and antioxidant activity of lychee pulp ([Zhang et al., 2013](#)).

LFP accounts for approximately 15% by weight of the whole fresh fruit and contains significant amounts of phenolics, which are usually discarded as a waste in the process ([Zhao et al., 2006](#); [Li and Jiang, 2007](#)). There are discrepancies in the phenolic profiles of LFP reported in previous studies. Prasad et al. (2009) reported that the major flavonoid compounds extracted from LFP were epicatechin and epicatechin gallate. [Zhao et al. \(2006\)](#) identified the major flavonoid chemicals extracted from LFP as procyanidin B2, procyanidin B4, and epicatechin. [Liu et al. \(2007b\)](#) found that the main oligomeric procyanidins isolated from LFP were epicatechin, procyanidin A2, and A-type procyanidin trimer. The phenolic content of LFP reported by [Ruenroengklin et al. \(2008\)](#) is about sixfold different from that reported by Prasad et al. (2009). It is not clear whether the differences in these studies are attributable to genotype or environmental conditions ([Li and Jiang, 2007](#)). Moreover, little is known about the complete profiles of phenolic compounds and antioxidant activity of LFP of different varieties.

The phenolic profiles of the nine lychee varieties were analyzed by [Li et al. \(2012\)](#) ([Table 6](#)). The TPCs of the nine varieties ranged from 9.39 to 30.16 mg GAE/g FW, with an average of 16.27 mg GAE/g. The coefficient of variation of phenolic content in

Table 6 Total phenolics, total flavonoids, total anthocyanins, and total proanthocyanidins of different lychee cultivars

Cultivar	Phenolic acids	Total phenolics	Total flavonoids	Total anthocyanins	Total proanthocyanidins	References
	g/kg DW	g/kg DW	g/kg DW		g/kg DW	
‘Nuomici’	24.3	102.1	33.0		31.1	Wang et al. (2011)
‘Feizixiao’	18.4	62.3	25.8		14.2	Wang et al. (2011)
‘Guiwei’	12.7	62.8	24.6		17.9	Wang et al. (2011)
‘Heiye’	17.2	89.4	33.2		27.2	Wang et al. (2011)
‘Yuhebao’	21.3	75.0	28.4		16.8	Wang et al. (2011)
‘Baitangying’	19.2	85.1	21.9		14.7	Wang et al. (2011)
‘Baila’	20.4	81.9	17.7		22.1	Wang et al. (2011)
‘Huaizhi’	13.4	71.3	26.0		14.0	Wang et al. (2011)
‘Lanzhu’	10.3	65.4	20.8		13.3	Wang et al. (2011)
‘Wuye’	13.3	73.4	26.2		21.9	Wang et al. (2011)
		mg GAE/g FW	mg CAE/g FW	mg CGE/g FW	mg EPE/g FW	
‘Heiye’		30.16 ± 1.14	23.46 ± 1.59	18.60 ± 0.14	7.46 ± 0.16	Li et al. (2012)
‘Huaizhi’		25.22 ± 1.09	19.19 ± 1.46	20.94 ± 0.14	6.24 ± 0.15	Li et al. (2012)
‘Guiwei’		20.30 ± 1.46	16.22 ± 1.01	5.97 ± 0.13	6.55 ± 0.20	Li et al. (2012)
‘Feizixiao’		14.31 ± 1.19	11.90 ± 1.03	1.77 ± 0.14	3.94 ± 0.17	Li et al. (2012)
‘Dingxiang’		13.58 ± 0.89	10.99 ± 1.35	6.64 ± 0.16	3.93 ± 0.12	Li et al. (2012)
‘Jizui’		11.79 ± 1.05	7.12 ± 0.22	2.96 ± 0.12	1.71 ± 0.13	Li et al. (2012)
‘Nuomizi’		11.60 ± 1.11	11.35 ± 0.93	5.72 ± 0.14	6.16 ± 0.24	Li et al. (2012)
‘Yuhebao’		10.06 ± 1.16	7.49 ± 0.77	8.29 ± 0.13	3.43 ± 0.18	Li et al. (2012)
‘Chanchutou’		9.39 ± 0.74	7.69 ± 0.60	7.75 ± 0.16	3.98 ± 0.15	Li et al. (2012)
‘Feizixiao’		259.18	129.86 ± 5.31			Zhang et al. (2013)
‘Nuomici’		170.49	92.19 ± 3.76			Zhang et al. (2013)
‘Jizui’		151.61	72.85 ± 6.38			Zhang et al. (2013)
‘Heiye’		130.58	67.63 ± 0.82			Zhang et al. (2013)
‘Dingxiang’		146.94	68.5 ± 5.14			Zhang et al. (2013)
‘Baila’		127.81	61.09 ± 2.29			Zhang et al. (2013)
‘Huaizhi’		133.15	64.61 ± 3.3			Zhang et al. (2013)
‘Baitangying’		126.88	62.73 ± 0.08			Zhang et al. (2013)
‘Qingke’		124.89	52.34 ± 0.34			Zhang et al. (2013)
‘Zhuangyuan-hong’		118.11	67.27 ± 5.69			Zhang et al. (2013)
‘Guiwei’		111.23	47.66 ± 3.24			Zhang et al. (2013)
‘Yuhebao’		109.78	39.43 ± 0.60			Zhang et al. (2013)
‘Chanchutou’		101.51	46.79 ± 3.32			Zhang et al. (2013)

CAE, Catechin equivalents; CGE, cyanidin-3-glucoside equivalent; DW, dry weight; EPE, epicatechin equivalents; FW, fresh weight; GAE, gallic acid equivalent.

lychee varieties was 43.3%, indicating that there were significant genotype differences in phenolic contents among the lychee varieties. A 3.2-fold difference in phenolic content was found between the highest and lowest varieties, 'Heiye' and 'Chanchutou', respectively. The total flavonoid contents of the nine lychee varieties ranged from 7.12 to 23.46 mg CAE/g FW with an average of 12.82 mg CAE/g FW (Table 6). Like the TPCs, there were significant differences in the total flavonoid contents among varieties. 'Heiye' variety had the highest flavonoid content (23.46 mg CAE/g FW), with a 3.3-fold difference compared with the variety with the lowest flavonoid content ('Jizui'). The total anthocyanin contents of the nine lychee varieties ranged from 1.77 to 20.94 mg cyanidin-3-glucoside equivalents (CGE)/100 g FW with an average of 8.73 mg CGE/100 g FW (Table 6). 'Huaizhi' and 'Heiye' varieties had higher anthocyanin contents (20.94 mg CGE/100 g and 18.60 mg CGE/100 g, respectively), 11.8-fold and 10.5-fold higher when compared with the variety with the lowest anthocyanin content ('Feizixiao').

Studies also showed a difference in phenolic content in LFP, as reported by Prasad et al. (2009), with 16 mg/g DW in the 'Baila' variety, and by Ruenroengklin et al. (2008), with 100 mg/g DW in 'Feizixiao' variety. The phenolic levels of the 'Heiye', 'Huaizhi', 'Guiwei', 'Feizixiao', and 'Dingxiang' varieties were higher than the level of 13.90 mg/g reported by Duan et al. (2007b). These differences may be attributed to different cultivars or to the methodology used for phytochemical analyses.

The LFP and seed were found to have high level of phenolics, including gallic acid; flavonoids, such as epicatechin and epicatechin gallate; and pigments, such as anthocyanidins and procyanidins, contributing to their high antioxidant property (Lee and Wicker, 1991; Prasad et al., 2009a,b). Commercially grown Indian lychee cultivars 'Shahi' and 'China' were found to be a rich source of antioxidants and possess strong radioprotective ability. In fresh, nonirradiated 'Shahi' and 'China' lychee fruit juice, the DPPH radical scavenging activity was found to be 89% and 85% on day 0 in storage (Saxena et al., 2011).

Volatiles

The volatile constituents of lychee investigated by the combined technique of gas chromatography–mass spectrometry (GC–MS) revealed 48 different volatiles. The citrus flavor of lychee is mainly caused by limonene, geraniol, and neral, whereas its floral character is mainly attributed to β -phene ethyl alcohol and its derivatives. Also, certain terpenoids comprise the major portion of the volatiles (Johnston et al., 1980). Toulemonde and Beauverd (1985) identified 89 volatiles from headspace analysis of lychee. They considered methyl esters of various alcohols, as well as limonene, rose oxide, and nonanal, decanal, citronellyl, and geranyl alcohols and acetates to be responsible for the fruity flavor and citrus tones of lychee fruits. Neutral volatiles in lychee have been reported by Fröhlich and Schreier (1986). They identified 14 alcohols, 4 carbonyl compounds, 4 ethers, 3 esters, 14 hydrocarbons, and 1 furanone derivative by capillary gas

chromatography and Fourier transform infrared spectroscopy. Methyl-1-branched C4 alcohol was found to be a major compound among the lychee volatiles. Among the alcohols, a series of C6 compounds were detected, which are well known as secondary volatiles formed after cell disruption from unsaturated fatty acids, caused by lipoxigenase–hydroperoxide lyase activity. It is obvious that these volatiles could not be detected during the headspace analysis of the whole fruit, as done by [Toulemonde and Beauverd \(1985\)](#). Twenty-five volatile compounds, including an esters, 14 alcohols, 2 aldehydes, 4 acids, 2 ketones, and 2 terpenes were reported in a lychee cultivar from Taiwan ([Chyau et al., 2003](#)). Geraniol and geranial were found to be the major volatile compounds in Taiwanese lychee.

Fourteen volatile compounds, namely three alcohols, one ester, three monoterpenes, and seven sesquiterpenes, were detected at harvest in cultivars ‘Mauritius’ in South Africa. The cultivar ‘McLean’s Red’ showed 19 volatile compounds, namely 4 alcohols, 3 monoterpenes, 2 oxides, and 10 sesquiterpenes. In ‘Mauritius’, alcohols represented 50% of the main fraction, followed by sesquiterpenes (23%), monoterpenes (21%), an unknown component (6%), and the ester (0.7%). No ester was detected in ‘McLean’s Red’ ([Sivakumar et al., 2008](#)). Among the three alcohols, citrinelol and geraniol predominated in the aroma profile of ‘Mauritius’, conferring a characteristic ‘floral, rose, citrus, and fruity aroma’ to the fruit ([Chyau et al., 2003](#)). Limonene, rose oxide, citronellol, and geraniol were detected at relatively low levels in ‘Mauritius’, although rose oxide was not present in the latter. Zingiberene was the predominant sesquiterpene, and terpinolene the most abundant monoterpene in ‘Mauritius’ ([Sivakumar et al., 2008](#)).

[Fröhlich and Schreier \(1986\)](#) reported 34 aroma compounds in lychee (unspecified cultivars) imported from South Africa. [Johnston et al. \(1980\)](#) also reported myrcene, limonene, terpinolene, zingiberene, citronellol, nerol, and geraniol in an unspecified lychee cultivar. Rose oxide, citronellol, nerol, terpinolene, and geraniol were reported in the cultivar ‘No Mai Chi’ ([Ong and Acree, 1998](#)).

A comparative study of volatile components of nine lychee cultivars (10 samples) from southern China were carried out through GC–MS combined with headspace–solid-phase microextraction ([Wu et al., 2009](#)). A total of 96 volatiles were detected, 43 of which were identified, and another 53 that were tentatively identified: 35 terpenoids, 27 alcohols, 10 aromatic compounds, 9 aldehydes, 8 esters, 4 ketones, 2 sulfurs, and 1 organic acid ([Table 7](#)). Seventeen common volatiles in all the samples included linalool, *cis*-rose oxide, R-terpineol, β -citronellol, geraniol, p-cymene, ethanol, 3-methyl-3-buten-1-ol, 3-methyl-2-buten-1-ol, 1-hexanol, (E)-2-hexen-1-ol, 2-ethyl-1-hexanol, 1-octen-3-ol, 1-octanol, ethyl acetate, p,R-dimethylstyrene, and 3-tert-butyl-4-hydroxyanisole. Among these cultivars, ‘Guangxi Huaizhi’ contained the most, with 67 volatiles and ‘Jizuli’ contained the least, with 36 volatiles. Alcohols were the predominant volatile components in various cultivars, representing 35.1% (‘Guangdong Huaizhi’) to 81.6% (‘Jizuli’) of the main fraction ([Table 7](#)). Although the volatile composition and

Table 7 Mean and standard deviation (n = 3) of amounts of volatile components in 10 fresh lychee samples (µg/L)

Compound	'Xiangli'	'Guiwei'	'Heiye'	'Jizuli'	'Nuomici'	'Huaizi 1'	'Huaizi 2'	'Zhengfeng'	'Baila'	Feizixiao
Ethyl acetate	171.8 ± 4.4 b	342.0 ± 0.7 d	358.9 ± 6.8 d	59.0 ± 0.3 a	170.4 ± 3.6 b	268.4 ± 6.6 c	38.3 ± 7.5 a	364.4 ± 37.1 d	359.9 ± 2.4 d	197.7 ± 17.7 b
Ethanol	755.4 ± 9.5 c	569.7 ± 6.1 a	705.9 ± 26.1 bc	677.3 ± 4.5 bc	1454.8 ± 12.4 d	2680.3 ± 76.8 f	1810.0 ± 99.7 e	571.8 ± 6.9 a	621.7 ± 42.8 ab	643.8 ± 4.9 ab
Hexanal	1.0 ± 0.2 a	—	—	—	—	19.1 ± 4.7 b	44.4 ± 2.2 d	31.2 ± 1.7 c	4.9 ± 0.7 a	3.6 ± 0.6 a
Isoamyl acetate	—	NQ	2.8 ± 1.5	—	—	—	—	NQ	—	—
4-Methyl-	4.249 ± 0.003 b	—	—	2.7 ± 0.2 a	—	—	—	—	3.6 ± 0.4 b	NQ
2-hexanone	—	—	—	—	—	—	11.0 ± 0.7	—	—	—
1-Butanol	—	—	—	—	—	—	—	—	—	—
β-Myrcene	—	—	109.9 ± 12.8 b	—	65.3 ± 1.3 a	236.8 ± 13.7 c	—	—	—	—
2,6-Dimethyl-	1.49 ± 0.05 a	1.02 ± 0.09 a	0.88 ± 0.08 a	1.10 ± 0.15 a	—	—	8.3 ± 1.3 b	—	NQ	NQ
4-heptanone	—	—	—	—	—	—	—	—	—	—
4-Penten-1-yl	—	NQ	—	—	—	—	—	—	—	—
acetate	—	—	47.0 ± 1.6	—	NQ	NQ	—	—	2.5 ± 1.1	—
Limonene	—	24.10 ± 0.14 a	—	—	155.15 ± 0.04 c	—	211.2 ± 15.6 d	—	—	69.2 ± 2.2 b
3-Methyl-	—	—	—	—	—	—	—	—	—	—
2-butenal	—	—	—	2.11 ± 0.08	—	—	—	—	—	—
Isoamyl alcohol	0.06 ± 0.02 a	0.078 ± 0.008 a	—	0.082 ± 0.001 a	—	—	—	—	—	—
2-Hexenol	8.4 ± 0.3 a	11.20 ± 0.02 a	8.1 ± 1.2 a	—	7.6 ± 1.2 a	74.6 ± 1.7 b	154.9 ± 3.3 d	203.4 ± 1.0 e	103.9 ± 7.2 c	10.9 ± 1.4 a
(E)-2-Hexenal	NQ	NQ	NQ	NQ	NQ	—	—	—	—	—
3-Heptanol	—	—	7.65 ± 0.14	—	—	17.1 ± 0.7	NQ	—	—	—
(Z)-β-Ocimene	—	—	—	—	—	—	20.7 ± 3.2	—	—	—
1,3,5-Trimeth-	—	—	—	—	—	—	—	—	—	—
ylbenzene	—	—	—	—	—	—	—	—	—	—
3-Methyl-	19.6 ± 0.5 d	18.8 ± 0.3 d	8.47 ± 0.14 b	NQ	58.0 ± 0.2 f	77.4 ± 1.0 h	38.7 ± 1.8 e	14.3 ± 2.5 c	2.4 ± 0.5 a	64.0 ± 3.0 g
3-buten-1-ol	—	—	—	—	—	—	—	—	—	—
3-Methyl-	NQ	26.0 ± 0.2	—	—	NQ	—	—	NQ	—	—
2-buten-1-yl	—	—	—	—	—	—	—	—	—	—
acetate	—	—	18.3 ± 0.6 b	—	—	26.9 ± 1.1 c	24.5 ± 1.2 c	—	—	9.9 ± 1.7 a
(E)-β-Ocimene	11.10 ± 0.13 c	6.27 ± 0.03 ab	13.2 ± 0.5 d	5.42 ± 0.14 a	5.66 ± 0.05 ab	7.2 ± 0.6 ab	10.7 ± 0.6 c	10.9 ± 2.3 c	7.5 ± 0.6 b	6.8 ± 0.6 ab
p-Cymene	34.7 ± 0.6 e	12.17 ± 0.12 c	9.5 ± 0.2 b	35.6 ± 0.2 e	73.0 ± 3.4 f	0.87 ± 0.07 a	—	—	8.98 ± 0.11 b	15.6 ± 0.2 d
Acetoin	—	—	—	—	NQ	8.4 ± 0.3	11.9 ± 6.6	—	—	—
Terpinolene	—	—	—	—	—	NQ	—	—	—	—
2,4-Dithiapen-	—	—	—	—	—	—	—	—	—	—
tane	—	—	—	—	—	—	—	—	—	—
2-Heptanol	—	—	NQ	—	—	6.4 ± 0.0	4.6 ± 0.0	—	—	—

Continued

Table 7 Mean and standard deviation (n=3) of amounts of volatile components in 10 fresh lychee samples (µg/L)—cont'd

Compound	'Xiangli'	'Guiwei'	'Heiye'	'Jizuili'	'Nuomici'	'Huaizi 1'	'Huaizi 2'	'Zhengfeng'	'Baila'	Feizixiao
3-Methyl-2-buten-1-ol	19.0±0.4 d	42.90±0.05 e	16.28±0.02 cd	2.1±0.2 a	170.4±0.2 h	162.5±1.0 g	106.6±2.4 f	15.1±0.6 c	5.5±0.2 b	103.6±3.0 f
(E)-2-Heptenal	—	—	—	—	—	—	17.8±1.2	—	—	—
6-Methyl-5-hepten-2-one	NQ	0.34±0.02 a	—	0.42±0.04 a	1.2±0.4 b	1.214±0.001 b	8.1±0.5 c	0.54±0.01 a	0.42±0.08 a	0.80±0.07 ab
2,6-Dimethyl-4-heptanol	4.26±0.11 e	3.08±0.06 cd	3.45±0.11 de	3.5±0.3 de	2.51±0.03 bcd	—	10.7±1.3 f	2.09±0.04 abc	1.1±0.2 a	1.8±0.4 ab
1-Hexanol	13.60±0.11 d	10.27±0.09 bc	8.2±0.4 b	0.4±0.2 a	7.6±0.6 b	69.5±4.5 g	55.4±0.9 f	37.85±0.03 e	56.2±3.0 f	36.6±0.5 e
Cis-Rose oxide	4.83±0.07 a	8.7±0.2 b	15.2±0.8 c	12.8±2.4 c	5.1±0.2 a	22.3±1.5 d	42.8±4.1 e	4.2±0.4 a	2.70±0.07 a	5.9±0.6 ab
(E)-3-Hexen-1-ol	—	—	—	—	—	—	—	—	NQ	—
Trans-Rose oxide	2.43±0.03 a	4.18±0.05 b	6.3±0.3 c	6.1±1.1 c	2.29±0.07 a	9.1±0.6 d	23.6±1.6 e	1.9±0.2 a	—	2.5±0.3 a
(Z)-Alloocimene	—	—	6.55±0.12 a	—	—	11.7±0.4 c	8.7±0.2 b	—	—	—
(Z)-3-Hexen-1-ol	—	—	—	—	—	NQ	—	—	—	—
3-Octanol	—	—	0.19±0.04 a	—	NQ	8.4±0.2 b	12.5±0.9 c	—	NQ	NQ
Nonanal	NQ	NQ	—	NQ	—	—	NQ	NQ	—	—
Methyl benzyl ether	—	—	—	NQ	—	—	—	—	—	76.5±4.3
(E)-Alloocimene	—	—	8.1±0.3	—	—	9.2±0.4	NQ	—	—	—
(E)-2-Hexen-1-ol	32.3±0.4 c	56.92±0.12 d	21.5±1.0 b	11.2±0.8 a	11.0±0.3 a	50.6±0.4 d	26.7±0.2 bc	76.3±1.0 e	151.3±10.7 g	88.9±2.9 f
2-Octanol	—	—	—	—	—	0.23±0.01	Tr	—	—	—
(E)-2-Octenal	—	—	—	—	—	—	NQ	—	—	—
Ethyl octanoate	—	—	—	—	—	—	NQ	—	—	—
p,a-Dimethylstyrene	2.30±0.05 c	1.38±0.01 a	2.8±0.2 d	1.46±0.05 a	1.42±0.03 a	6.1±0.3 e	9.01±0.03 f	2.6±0.4 cd	1.88±0.16 b	1.45±0.12 a
1-Octen-3-ol	NQ	0.68±0.04 a	19.6±1.0 d	NQ	NQ	58.8±1.5 e	57.1±0.7 e	3.3±0.3 b	1.7±0.4 ab	11.5±0.8 c
1-Heptanol	—	—	—	—	NQ	1.5±0.2	3.69±0.08	—	—	NQ
Acetic acid	2.9±0.4 a	NQ	11.8±1.8 c	8.2±1.2 b	—	—	—	14.8±0.9 d	9.8±0.2 bc	—
6-Methyl-5-hepten-2-ol	—	—	NQ	—	NQ	1.4±0.1	NQ	NQ	NQ	NQ

<i>Trans</i> -Furan	4.42±0.01 a	16.04±0.07 cd	7.3±0.3 ab	10.7±0.2 bc	17.6±0.6 d	55.5±0.9 e	63.2±6.6 f	7.9±2.4 ab	6.3±0.5 ab	–
linalool oxide										
Nerol oxide	1.53±0.02 a	2.27±0.01 a	1.62±0.07 a	1.6±0.2 a	2.98±0.11 a	14.6±1.1 b	35.4±3.7 c	1.80±0.01 a	–	–
2-Ethyl-1-hexa- nol	0.8±0.2 ab	1.80±0.03 c	0.6±0.2 ab	0.30±0.01 a	1.44±0.11 bc	4.2±0.4 d	6.3±1.0 e	2.253±0.002 c	1.8±0.2 c	1.8±0.3 c
Methyl phenethyl ether	–	–	2.5±1.7 a	4.9±1.6 a	1498.0±47.5 b	1913.0±41.2 c	2219.9±122.1 d	–	–	68.3±13.0 a
α-Copaene	–	–	–	–	NQ	–	–	–	–	–
(E,E)-2,4-Hep- tadienal	–	–	–	–	–	NQ	–	–	–	–
(E)-2-Hepten- 1-ol	–	–	–	–	–	4.9±0.3	14.40±0.06	–	–	–
Benzaldehyde	–	–	–	–	–	NQ	–	–	–	3.25±0.01
Linalool	3.44±0.02 e	1.52±0.01 c	1.20±0.06 bc	0.26±0.06 a	4.5±0.2 f	10.9±0.5 g	19.4±0.3 h	2.5±0.2 d	0.92±0.07 b	2.58±0.07 d
1-Octanol	NQ	NQ	NQ	NQ	0.5±0.2 a	5.5±0.3 d	6.5±0.2 e	2.5±0.3 c	1.93±0.04 b	0.22±0.11 a
2,3-Butanediol	NQ	–	–	–	–	–	–	–	–	–
4-Terpinenol	5.1±0.2 c	8.80±0.03 e	NQ	–	3.5±0.2 b	7.5±0.4 d	11.6±0.2 f	1.51±0.12 a	NQ	NQ
(E)-2-octen- 1-ol	–	–	–	–	–	1.1±0.1	0.03±0.01	–	–	–
(E)-p-Mentha- 2,8-dienol	–	–	–	–	–	–	–	NQ	NQ	–
Ethyl decanoate	–	–	–	–	–	NQ	NQ	–	–	–
Menthol	–	–	–	–	–	NQ	–	–	–	–
γ-Elemene	–	–	–	–	8.1±1.0	NQ	5.4±3.4	–	–	–
1-Nonanol	NQ	NQ	NQ	–	NQ	NQ	NQ	NQ	0.30±0.14	NQ
1,2-Dimethoxy- 1-phenylethane	–	–	–	–	–	–	–	–	–	10.0±3.2
2,3,5-Trithia- hexane	–	–	–	–	–	NQ	–	–	–	–
Diethyl succinate	–	–	–	–	–	NQ	–	–	–	–
Neral	–	–	10.8±0.6 c	–	5.85±0.11 a	11.11±0.11 c	14.7±0.3 d	5.2±0.4 a	5.91±0.13 a	7.3±0.4 b
γ-Murolene	–	–	–	–	6.1±0.7	4.8±0.1	NQ	–	–	–
α-Terpineol	6.27±0.06 c	2.74±0.04 ab	1.41±0.04 a	NQ	8.8±0.3 d	16.6±1.0 e	33.2±2.3 f	5.6±0.7 c	2.44±0.06 ab	4.4±0.4 bc
Borneol	–	–	–	–	–	NQ	–	–	–	–
1,2-Dimethoxy- benzene	–	–	–	–	–	–	–	–	NQ	–

Continued

Table 7 Mean and standard deviation (n = 3) of amounts of volatile components in 10 fresh lychee samples (µg/L)—cont'd

Compound	'Xiangli'	'Guiwei'	'Heiye'	'Jizuli'	'Nuomici'	'Huaizi 1'	'Huaizi 2'	'Zhengfeng'	'Baila'	Feizixiao
α-Murolene	—	—	—	—	13.2 ± 2.1 ab	5.6 ± 0.3 a	34.9 ± 13.8 b	—	—	—
(Z)-Myrtanol	—	—	—	—	—	3.82 ± 0.15	—	—	—	—
Cis-Pyran	—	NQ	—	—	—	—	—	—	—	—
linalool oxide	—	—	—	—	—	—	—	—	—	—
Geranial	—	NQ	53.6 ± 5.0 d	—	2.1 ± 0.6 a	38.9 ± 1.3 c	93.8 ± 9.4 e	4.9 ± 1.5 a	9.1 ± 3.2 a	23.1 ± 3.7 b
β-Citronellol	NQ	NQ	156.8 ± 7.6 e	NQ	4.3 ± 0.5 a	26.5 ± 1.4 b	52.3 ± 3.7 c	11.5 ± 1.7 a	10.9 ± 1.5 a	72.4 ± 6.6 d
γ-Geraniol	—	—	0.5 ± 0.2 a	—	NQ	2.6 ± 0.4 b	6.1 ± 0.6 c	NQ	NQ	NQ
Ethyl	—	—	—	—	—	3.6 ± 1.6	—	—	—	—
phenylacetate	—	—	—	—	—	—	—	—	—	—
Nerol	—	NQ	12.9 ± 0.5 b	—	9.4 ± 0.3 ab	35.2 ± 1.8 d	47.3 ± 2.5 e	6.5 ± 0.3 a	7.4 ± 0.3 a	21.8 ± 2.2 c
Cis-Isogeraniol	—	—	6.54 ± 0.10 a	—	—	7.3 ± 0.2 ab	9.4 ± 0.4 c	—	—	7.8 ± 0.5 b
Trans-Isogera-	—	5.481 ± 0.004 a	21.9 ± 0.9 d	NQ	9.4 ± 0.3 b	26.4 ± 1.4 e	37.0 ± 2.7 f	5.8 ± 0.2 a	5.82 ± 0.01 a	14.5 ± 1.4 c
niol	—	—	—	—	—	—	—	—	—	—
p-Cymen-8-ol	4.2 ± 0.5 a	NQ	—	—	—	87.4 ± 37.0 b	120.1 ± 50.9 c	NQ	—	—
Geraniol	NQ	2.67 ± 0.02 a	349.8 ± 19.0 c	NQ	13.3 ± 1.2 a	648.2 ± 38.6 d	964.1 ± 39.6 e	47.9 ± 11.5 a	38.5 ± 5.8 a	125.5 ± 19.4 b
Geranylacetone	—	—	—	NQ	5.4 ± 0.4 a	—	12.1 ± 0.2 d	NQ	6.1 ± 0.2 b	6.9 ± 0.2 c
Cis-Carveol	—	—	—	—	—	—	NQ	—	—	—
Benzyl alcohol	—	—	—	—	—	98.7 ± 5.0	NQ	—	—	NQ
2-Phenylethanol	—	7.7 ± 0.2 a	—	—	62.2 ± 0.2 b	418.3 ± 22.4 d	247.6 ± 10.0 c	—	NQ	273.4 ± 35.5 c
Butylated	NQ	NQ	NQ	NQ	NQ	—	NQ	NQ	—	—
hydroxytoluene	—	—	—	—	—	—	—	—	—	—
1-Dodecanol	—	—	—	—	—	NQ	2.1 ± 0.3	—	—	NQ
Eugenol methyl	—	—	—	—	—	7.0 ± 1.8	NQ	—	—	—
ether	—	—	—	—	—	—	—	—	—	—
3-Tert-butyl-	8.4 ± 0.5 cd	6.5 ± 0.8 abc	6.70 ± 0.14 bc	6.96 ± 0.11 bc	6.85 ± 0.03 bc	10.2 ± 2.6 de	11.4 ± 2.7 e	5.0 ± 0.3 ab	3.79 ± 0.03 a	4.3 ± 0.4 ab
4-hydroxyani-	—	—	—	—	—	—	—	—	—	—
sole	—	—	—	—	—	—	—	—	—	—
2,4-Ditert-butyl	NQ	NQ	NQ	NQ	—	NQ	—	NQ	NQ	NQ
phenol	—	—	—	—	—	—	—	—	—	—
Dibutylhy-	—	—	—	—	—	—	38.0 ± 23.2	—	—	—
droxybenzalde-	—	—	—	—	—	—	—	—	—	—
hyde	—	—	—	—	—	—	—	—	—	—

Values (mean and SD, n = 3) of the same compounds followed by different letters are significantly different ($P < 0.05$). NQ, not quantified (detection limit < concentration < quantification limit).

Source: Wu et al. (2009).

concentration varied between these cultivars, the components with the highest odor activity values (OAVs) in most cultivars were still *cis*-rose oxide, *trans*-rose oxide, 1-octen-3-ol, and geraniol. Two ‘Huaizhi’ samples from two producing areas exhibited similar volatile profiles, but which were significantly different from other cultivars according to cluster analysis performed on amounts of major volatile components (Wu et al., 2009).

SUMMARY POINTS

- Lychee is a tropical to subtropical fruit originating in China and northern Vietnam. It grows commercially in more than 20 countries. China is top producer of lychee fruit, followed by India.
- There are various commercial varieties grown in different countries. These varieties have sizable variability for physical, chemical, nutritional, and phytochemical characteristics.
- Lychee fruits are good source of potassium and nitrogen. N, P, K, Ca, Mg, Na, boron (B), and Fe content differ significantly among the cultivars, even though they are grown under similar conditions in the same or different locations. Mineral content is varied with the cultivar.
- Lychee pericarp contains abundant phenolic compounds. The concentration and composition of phenolics is affected by genetic, agronomic, and environmental factors. Pronounced differences in phenolic contents and antioxidant activity have been reported in different lychee cultivars.
- Lychee cultivars contain about 96 volatiles. Common volatiles in most of the cultivars include linalool, *cis*-rose oxide, α -terpineol, β -citronellol, geraniol, *o*-cymene, ethanol, 3-methyl-3-buten-1-ol, 3-methyl-2-buten-1-ol, 1-hexanol, (E)-2-hexen-1-ol, 2-ethyl-1-hexanol, 1-octen-3-ol, 1-octanol, ethyl acetate, *o*, α -dimethylstyrene, and 3-tert-butyl-4-hydroxyanisole.

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CHAPTER 18

Nutritional Composition of Mandarins

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LIST OF ABBREVIATIONS

ABTS 2,2'-Azobis (3-ethylbenz-thiazoline-6-sulfonic acid) assay
AsA Ascorbic acid
DHA Dehydroascorbate
DPPH 2,2-Diphenylpicrylhydrazyl assay
FRAP Ferric ion reducing antioxidant potential
GAEq Gallic acid equivalents
ORAC Oxygen radical absorbance capacity
SS Soluble solids
TE Trolox equivalents

INTRODUCTION

Citrus fruit have been domesticated in Southeast Asia thousands of years ago and spread throughout the world by the migration movements of different cultures. The history of citrus fruit is full of controversy and legends (Liu et al., 2012). Small citrus fruit like mandarins are preponderant in China, India, Japan, and also very important in the Mediterranean region. China is one of the native areas of mandarin and has a cultivation story of more than 4,000 years. From ancestral times (around 2205 to 2197 BC), during the reign of Ta Yu, mandarins were considered a highly prized tribute and only available for the imperial court (Liu et al., 2012). The spread of mandarins to other continents was slow but constant, and nowadays this group of citrus is mostly cultivated worldwide. The introduction of mandarin to Europe is fairly recent; seeds were carried from China to England around 1805, and it was from here that the tree spread first to Malta, then to Sicily, and finally to continental Italy and other Mediterranean regions (Nicolosi, 2007).

Mandarin cultivation worldwide has increased around 70% from 1990 to 2013, and a similar increment was registered on fruit production. Total world production of mandarins is around 27 million tons (including clementines), with China being the leading producer with nearly 50% (13.6 million tons), followed by India, Spain, Brazil, Turkey, and Egypt (FAO, 2012). Production of mandarin differs from that of orange because it is mostly intended to the fresh market. Spain accounts for over 50% of the world's exports of fresh mandarins (mainly clementines). Regarding common mandarin, satsumas and 'hybrids' leading producers are China, India, and Japan, followed by Turkey and Egypt (FAO, 2012).

The name tangerine has often been used as a synonym of mandarin, especially in the USA, and it indicates easy peeling varieties. The following classification could be used to differentiate mandarins, and a detailed list of main varieties cultivated in the world is presented in Table 1.

BOTANICAL ASPECTS

Mandarins are small evergreen trees. In the absence of seasonal abscission, the leaves remain on the plant for a year or more. The leaves are arranged spirally around the stem and an axillary bud occurs in each leaf axil, consisting of an apical meristem of new shoots. Some varieties have thorns that are especially prominent on juvenile, vigorously growing shoots. The leaves have a winged petiole that is usually less prominent in mandarins than in oranges or grapefruits. Mandarins are usually grafted onto a rootstock. Different rootstocks impart different properties to the scion. Rootstock selection is also governed by the particular growing conditions in each region. Most of the commonly cultivated mandarin varieties are hybrids. New varieties are derived from a few ancestral species. However, the number and identity of wild progenitor species is difficult to determine and remains controversial (Liu et al., 2012; Wu et al., 2014).

Table 1 Mandarin varieties. Classification of the main varieties of common and Satsuma mandarin, and mandarin hybrids. Varieties of Clementine mandarin are considered in Chapter 7

					Hybrids		
Common mandarin			Satsuma		Tangor	Tangelo	Others
Admoni	Hinanit	Rishon	Aguzdera	Miyagawawase	Ariake	Baygold	Amaka (Encore mandarin × Kiyomi tangor)
Afourer	Idit	Rubidoux	Aoshima	Nepolitana	Amoa	Minneola	Ambersweet (<i>C. clementine</i> × <i>Orlando tangelo</i>)
Bower	Kara	Shani	Clausellina	Nucellar	Dweet	Orlando	Cami (<i>C. clementine</i> × <i>Avana</i>)
Butwal	Kashi	Shringar	Dobashi Beni	Owari	Ellendale	Page	Fallglo (Bower mandarin × Temple tangor)
Cami	Lee	Sigal	Hayashi unshiu	Selma	Harumi	Sampson	Fortune (<i>C. clementine</i> × <i>C. reticulata</i> cv. <i>Dancy</i>)
Changsha	Merav	Sikkim	Hasimoto	Silverhill	Kiyomi	Thornton	Fremont (<i>C. clementine</i> × <i>Ponkan mandarin</i>)
Coorg	Michal	Suhugan	Imamura	Sugiyama unshiu	King	Wekiwa	Encore (King mandarin × Mediterranean mandarin)
Daisy	Mudkhed	Sumithra	Iwasaki	Taikouwase	Niva		Kara (King mandarin × satsuma Owari)
Dalandan	Murcott	Tami	Kara	Ueno	Ortanique		Kinnow (King mandarin × Mediterranean mandarin)
Dancy	Nagpur	Tango	Kovano-Wase	Yamashitabeni	Rudy		Lee (<i>C. clementine</i> × <i>Orlando tangelo</i>)
Darjeeling	Nectar	Thai	Miyagawa		Tacle		Nankou (<i>C. unshiu</i> × <i>C. clementina</i>)
Elarbi	Novel	Vered			Tankan		Nova (<i>C. clementine</i> cv. <i>Fina</i> × <i>Orlando tangelo</i>)
Emerald	Nurit	Wiling			Temple		Orah (Temple tangor × Dancy mandarin)

Continued

Table 1 Mandarin varieties. Classification of the main varieties of common and Satsuma mandarin, and mandarin hybrids. Varieties of Clementine mandarin are considered in Chapter 7—cont'd

							Hybrids
Common mandarin			Satsuma	Tangor	Tangelo	Others	
Emperor	Odem	Winola				Osceola (<i>C.clementine</i> × <i>Orlando tangelo</i>)	
Fairchild	Or	Yafit				Robinson (<i>C. clementine</i> × <i>Orlando tangelo</i>)	
Fallglo	Ora	Yifat				Sunburst (Robinson × Osceola)	
Fremont	Orit					Tamami (Kiyomi tangor × Wilking mandarin)	
Hadas	Pixie					Wilking (King mandarin × Mediterranean mandarin)	

Mandarin fruit consists of an outer skin formed by the flavedo or exocarp (the colored part of the peel containing the essential oil glands) and the albedo (the white spongy tissue layer below the flavedo) that varies in thickness, and the central columnella, a complex network of vascular bundles. Small and densely packed sacs containing juice and seeds fill the internal membrane segments, which form the pulp that is the edible part of the fruit. Although flowering usually takes place in spring in most mandarin species, fruit ripening takes place from autumn to early spring with important differences between species and varieties. The botanical classification and taxonomical names presented here follow the classification of [Mabberley \(2004\)](#) and [Dianxiang and Mabberley \(2008\)](#).

Common Mandarin (*Citrus reticulata* Blanco)

There is a great diversity of common mandarins with different colorations, peel thickness, seeds, and juice content, as well as organoleptic and quality characteristics ([Goldenberg et al., 2014](#)). The most common mandarin varieties are: ‘Ponkan’ (cultivated in China, India and other south Asian countries, and Brazil), ‘Nagpur’ (very similar to ‘Ponkan’; common in India), ‘Coorg’ (similar to ‘Nagpur’, very common in India), ‘Kashi’ (Meghalaya, India; locally known as ‘Sikkim’ or ‘Kamala’ mandarin), ‘Darjeeling’, ‘Emperor’ (important in Australia), ‘Dancy’ (important in Florida), ‘Daisy’, ‘Murcott-Afourer’ group (popular in Morocco, California, Argentina, and Uruguay), and ‘Or’ and ‘Odem’ (common varieties in Israel). Other varieties are detailed in [Table 1](#). Recently, full genome sequence analyses of ancient, traditional, and modern mandarins and ancestral *Citrus* species have revealed much less genetic diversity among the traditional mandarins than was previously recognized and, more surprisingly, the absence of a pure type specimen of *Citrus reticulata* ([Wu et al., 2014](#)).

Satsuma Mandarin (*Citrus unshiu* Yu.Tanaka ex Swingle, Marcow)

Satsuma mandarin (*Citrus unshiu* Yu.Tanaka ex Swingle, Marcow), now considered to be a synonym of *C. reticulata* Blanco, is the most important and widely cultivated mandarin in Japan and is also widely grown throughout the main citrus production zones (Argentina, Australia, China, Peru, Spain, South Africa, and Uruguay). Satsumas are especially valued for their early harvest, easy peeling, and seedless characteristics. Of the many clones and varieties which have been produced, the most common are ‘Miyagawa’ and ‘Okitsu’ (early maturing varieties which are very popular in Japan, Italy, and Spain, as well as in Argentina, Uruguay, and South Africa). ‘Owari’ is a very common, midseason maturing variety, which is widely cultivated in Japan, Spain, Argentina, Uruguay, and South Africa. Other satsuma varieties are detailed in [Table 1](#).

Mediterranean Mandarin Willowleaf (*Citrus deliciosa* Ten)

Clementine varieties have replaced Mediterranean Mandarin Willowleaf (*C. deliciosa* Tenore), now considered to be a synonym of *C. reticulata* Blanco, varieties in most citrus

growing areas. Examples of this group are ‘Comun de Concordia’ (grown in the Entre Ríos region of Argentina and in Uruguay), ‘Avana’, and ‘Avana Tardivo’.

King Mandarin (*Citrus nobilis* Lour)

King mandarin (*C. nobilis* Lour), now considered to be a synonym of *Citrus* × *aurantium* L., originated in Southeast Asia and the Indo-China region (Malaysia, Vietnam, Cambodia); a typical variety of this group is ‘Kunenbo’ (present in Japan).

Clementine (*Citrus clementina* Hort)

Clementine (*C. clementina* Hort), now considered to be a synonym of *C. × aurantium* L., is the main cultivated mandarin in Spain and is very important worldwide due to its productivity, attractive flavor, easy peeling, and absence of seeds, characteristics which make it very popular with consumers and growers. Clementine mandarin is the focus of another chapter in this book and, therefore, is not treated here.

Hybrids

Spontaneous and deliberate crosses have led to a great diversity of mandarin hybrids. Two types of hybrids may be distinguished: ‘tangelo’, a cross between mandarin and grapefruit (*C. reticulata* Blanco × *Citrus paradisi* Macfad, now considered to be a synonym of *C. × aurantium* L.) and ‘tangor’, a cross between a mandarin (*C. reticulata* Blanco or *C. unshiu* Yu. Tanaka ex Swingle, Marcow, now considered to be a synonym of *C. reticulata*) and an orange (*Citrus sinensis* L. Osbeck, now considered to be a synonym of *C. × aurantium* L.). Among tangelos, the principal cultivated varieties are ‘Orlando’, ‘Minneola’, ‘Page’, ‘Baygold’, ‘Wekiwa’, ‘Sampson’, and ‘Thornton’. Among tangors, the most popular are ‘Ortanique’, ‘Nova’, ‘Tacle’, ‘Temple’, ‘Kiyomi’, ‘Ellendale’, ‘Dweet’, ‘Amoa’, ‘Rudy’, ‘Tankan’, ‘Harumi’, ‘Ariake’, and ‘King’. Besides tangors and tangelos, various crosses between them and mandarins, or between different types of mandarins, have generated a great variability of hybrids worldwide which are summarized in [Table 1](#).

COMPOSITION OF TRADITIONAL AND MODERN CULTIVARS

Citrus fruits are widely commercialized and consumed worldwide, with mandarins and oranges being the most important species ([FAO, 2012](#)). Mandarins are especially valuable and highly consumed due to the easy peeling and low seed number in most species and varieties. Therefore, mandarins fit the modern consumer preferences of easy-to-eat foods. The consumption per capita of mandarin in the USA has experienced a rapid increase from around 1 kg in 1995 to nearly 1.6 kg in 2005. Mandarins, as other citrus fruit, are especially rich in primary metabolites like organic sugars and acids, amino acids (AA), and vitamins (vitamin C, provitamin A, and vitamins of the B group, mainly folate), as well as present a great diversity of secondary metabolites such as carotenoids,

polyphenols (mainly flavonoids, flavanones, and flavones) and phenolic acids, limonoids, and volatile compounds that altogether provide their characteristic flavor and the nutritional and health-related benefits (Benjamin et al., 2013; Goldenberg et al., 2014).

In general, mandarin bioactive compounds are more abundant in the peel than in the pulp tissue (Xu et al., 2008b; Alós et al., 2014); however, since the flesh constitutes the edible portion of this crop, this tissue will be the main focus of the current review.

Sugars, Organic Acids, and Amino Acids

Sugars and organic acids are important components of citrus fruit flesh, and their ratio is used as a harvest maturity indicator. Moreover, this index is especially important in mandarins, since internal commercial maturity is normally acquired before the external color has been completely achieved (Lado et al., 2014). The taste of citrus fruit is mainly governed by sugars and acids levels in the juice sacs, and remarkable differences in both parameters exist among mandarins (Goldenberg et al., 2014; Table 2). Moreover, sugar and acid content in mandarin fruit are highly affected by many factors during fruit development, the scion–rootstock combination and temperature being among the most important (Benjamin et al., 2013). Fruit position in the tree and cultural practices (nutrition, irrigation, pruning, thinning, etc.) have also a direct impact on fruit sugar and acid content (Cronje et al., 2013). High temperatures during the fruit enlargement and ripening period cause lower formation of acids and higher sugar accumulation (Marsh et al., 1999), while higher light irradiance stimulates carbohydrate and total soluble solids accumulation (Cronje et al., 2013).

Carbohydrates are the main soluble components in mandarin pulp (75–80%), mainly sucrose, glucose, and fructose, as well as other sugars that are present in lower amounts. Sugar levels in mandarins range from 1–2% glucose, 1–3% fructose, and 2–6% sucrose.

Table 2 Nutritional profile in the edible portion of a generic mandarin fruit. Results are expressed in a 100 g basis

Nutrient	Concentration
Water (%)	83–90
Energy (KJ)	167–223
Protein (g)	0.80–2.1
Total lipids (g)	0.05–0.40
Ashes (g)	0.29–0.54
Carbohydrates (g)	9.0–13.0
Fiber (g)	0.3–2.3
TSS (°Brix)	9–16
Total acidity (%)	0.5–2.0
Total amino acids (μmol/g)	15–20

Adapted from Ladaniya (2008), USDA (2010), Matsumoto and Ikoma (2012), and Goldenberg et al. (2014).

During maturation of mandarin fruit, sucrose content increases, and it became the primary nonreducing sugar and the major translocable carbohydrate (Ladaniya, 2008). Total soluble solids content in the pulp varies notably among the different mandarins and ranges from 9.6% in 'Okitsu' or 11–11.7% in 'Owari' satsuma mandarins to 12% in 'Ponkan' or 15.8% in 'Fairchild' common mandarins (Xu et al., 2008a; Shen et al., 2013; Goldenberg et al., 2014). Soluble solids in 'Nagpur' common mandarin accounted for 9.5–10.5%, without showing any substantial changes after 75 days storage at 3.5 °C (Ladaniya, 2011). Total sugar content in juice sacs of 'Aoshima' satsuma mandarin accounts for 280 $\mu\text{mol/gFW}$, distributed mainly as sucrose (135 $\mu\text{mol/gFW}$), fructose (80 $\mu\text{mol/gFW}$), and glucose (70 $\mu\text{mol/gFW}$). Moreover, changes in sugar content are negligible during postharvest, independent of the storage temperature (Matsumoto and Ikoma, 2012).

Similarly to soluble solids, organic acids composition varies widely in the different mandarin varieties and among the fruit tissues, citric acid being the predominant in the pulp (70–90% of total acids), while malate is relevant in the peel and oxalate more abundant in the albedo. Other minor acids present in citrus juice are acetic, pyruvic, glutamic, formic, and succinic. Total content of acids has a direct impact on consumer acceptance, and only mandarins with acidity lower than 0.8% are fully accepted by consumers. Acidity levels, as soluble sugars, also vary notably among mandarins, from as low as 0.5% in common 'Odem' mandarin or 0.6–1.0% in 'Owari' satsuma, to 1.3% in 'Ponkan', and nearly 2.0% in common 'Vered' mandarins (Xu et al., 2008a; Shen et al., 2013; Goldenberg et al., 2014). Postharvest cold storage slightly reduced acidity, as exemplified in 'Nagpur' mandarin, in which a drop from 1.0% acidity to 0.7% occurred after 75 days at 3.5 °C (Ladaniya, 2011).

Mandarin juice sacs also contain nitrogenous compounds such as AAs, ornithine, glutamine, phenylalanine, tryptophan, tyrosine, isoleucine, leucine, valine, threonine, lysine, methionine, histidine, and γ -amino butyric acid being the most relevant in the satsuma mandarin (Matsumoto and Ikoma, 2012). Thus, in general, mandarin fruit provides eight of the nine essential AAs required for the human body. Total AA content in juice sacs of satsuma mandarins is 15 $\mu\text{mol/gFW}$, whereas the more abundant AAs are asparagine (3.5 $\mu\text{mol/gFW}$), arginine (2.4 $\mu\text{mol/gFW}$), aspartic acid (2.0 $\mu\text{mol/gFW}$), proline (1.5 $\mu\text{mol/gFW}$), and glutamine (1.0 $\mu\text{mol/gFW}$), the concentrations of other AA being lower than 1.0 $\mu\text{mol/gFW}$ (Matsumoto and Ikoma, 2012). In the juice of common mandarins, the main AA is proline (100 mg/100 mL), followed by arginine (85 mg/100 mL), asparagine (18–86 mg/100 mL), aspartic acid (24–50 mg/100 mL), glutamic acid (17–34 mg/100 mL), serine (12–26 mg/100 mL), alanine and phenylalanine (6–15 mg/100 mL), leucine (5–11 mg/100 mL), lysine (4–12 mg/100 mL), and valine (3–6 mg/100 mL) (Ladaniya, 2008). The composition of total free AAs varied during fruit ripening, proline and arginine being the AAs that experienced major changes (Ladaniya, 2008). Moreover, the content of total AA varies

more than that of sugars and acids in response to postharvest storage temperature, i.e., ornithine and glutamine are cold-responsive and increased at 5 °C, while phenylalanine, tryptophan, valine, lysine, and histidine were heat-responsive, and their content increased at 20 or 30 °C in three different satsuma varieties (Matsumoto and Ikoma, 2012).

Minerals

The most abundant mineral in mandarins, as in other citrus species, is potassium (K), which varies between 160 and 250 mg/100 g in the edible portion (Codoñer-Franch and Valls-Bellés, 2010). The pulp of ‘Ponkan’ mandarin presents nearly 140 mg/100 g FW of K, while sodium content is very low (1–3 mg/100 g FW) (Barros et al., 2012; Table 3). The balance between these two nutrients is important, since they are constituents of the fluids inside and outside the human cells, thus maintaining the osmotic balance and regulating blood pressure (Codoñer-Franch and Valls-Belles, 2010). Calcium (Ca) and magnesium (Mg) are also present in mandarin pulp, accounting for 14–47 mg/100 g and 11–12 mg/100 g FW of edible portion, respectively. In the ‘Ponkan’ mandarin, Ca and Mg content are 16 mg/100 g FW and 9.4 mg/100 g FW, respectively (Barros et al., 2012). These two nutrients are relevant in mitochondria and different enzymes related to energy transference and are also required with phosphorous (P) for bone structure. Phosphorous (P) is also an important component in mandarin pulp, with 10–30 mg/100 g FW of edible portion. Iron (Fe) is also present in mandarin flesh, however at lower levels (0.15–0.60 mg/100 g FW), as is zinc (Zn), 0.07–0.50 mg/100 g (Barros et al., 2012; Table 3). Copper is another mineral present in the juice, with 0.06–0.08 mg/mL in ‘Kinnow’ mandarin and 0.05 mg/100 g FW in ‘Ponkan’ pulp tissue (Barros et al., 2012). Similarly, the content of manganese (Mn) in the pulp of ‘Ponkan’ mandarin is around 0.05 mg/100 g FW (Barros et al., 2012). Iodine and selenium are also constituents of

Table 3 Mineral content in the juice and pulp of different mandarin varieties

Variety	K	Mg	Ca	Na	Fe	Cu	Mn	Zn
Ellendale (mg/L) ^a	1624	116	81	2.47	0.48	0.25	0.11	0.39
Ortanique (mg/L) ^a	2832	153	151	23.4	0.58	0.39	0.13	0.53
Nova (mg/L) ^a	1824	85	72	0.93	0.36	0.14	0.15	0.32
Generic mandarin (mg/100 g FW)	157–253	11–12	14–37	1–3	0.1–0.6			
Ponkan (mg/100 g FW) ^b	140	10	16	3.0	0.16	0.05	0.05	0.07

^aAdapted from Beltran et al. (2008) and USDA (2010).

^bAdapted from Barros et al. (2012).

mandarin flesh although at concentrations lower than 1 µg in 100 g. The concentration of each particular mineral element may differ considerably among the diverse mandarin species and varieties (Table 3) and consequently the mineral composition of the pulp and juice, the cultural practices and the growing regions being the key factors to explain that divergence (Beltran et al., 2008).

Polyphenols

Phenolic compounds have at least one aromatic ring with one or more hydroxyl groups attached and are classified as flavonoids and nonflavonoids. There is a growing acceptance that the polyphenols present in different fruits and vegetables exert beneficial effects in the prevention of degenerative diseases (Khan et al., 2014). Under this general classification are: simple phenols, hydroxycinnamic acid derivatives, flavonoids, coumarins, and the furanocoumarins (Codoñer-Franch and Valls-Belles, 2010). Mandarin fruits contain high amounts of extractable polyphenols (4.3–7.8 g/100 g), and the more relevant are the flavonoids (mainly flavanones and flavones) and the phenolic acids (Khan et al., 2014).

Flavonoids: Flavanones and Flavones

Flavonoids are important secondary metabolites present in citrus fruit at relatively high concentrations, mainly as conjugated molecules. Flavonoids commonly share the same generic structure, the flavan nucleus, consisting of two aromatic rings linked by a pyran ring. Differences in the location of the rings and their linkage are the criteria to distinguish between flavonoids (2-phenylbenzopyrans), isoflavonoids (3-phenylbenzopyrans), and neoflavonoids (4-phenylbenzopyrans), conforming a very complex group of compounds with important differences in the structure of the molecule and properties (Khan et al., 2014). Flavonoids are by far the most common compounds among this group found in citrus fruit, and their content increases to a maximum during early stage of fruit development to decline at the cell enlargement phase (Ladaniya, 2008). The flavonoid structure consists of 15 carbon atoms arranged in three rings and different variants ($C_6-C_3-C_6$) and substitutions of the C_{15} flavonoid molecule leading to flavonols, flavan-3-ols, isoflavones, anthocyanidins, flavones, and flavanones (Del Rio et al., 2013). Mandarins are particularly rich in flavonoids, which may account for up to 75% of total solids, and over 60 different compounds have been characterized (Codoñer-Franch and Valls-Belles, 2010) and in general, show important properties of anti-chronic diseases (reviewed in Codoñer-Franch and Valls-Belles, 2010 and in Khan et al., 2014). Total flavonoid content in the pulp of five common mandarins ('Fairchild', 'Dancy', 'Beauty', 'Suhugan', and 'Fizu') oscillates between 0.27 and 0.60 mg quercetin equivalents/gFW, 'Fairchild' being the highest and 'Dancy' being the lowest mandarins (Ramful et al., 2011). In the pulp of 'Ponkan' and 'Murcott' mandarins the concentration is around 11.0 mg/gDW (Wang et al., 2007), while in the same tissue of satsuma 'Owari', total

flavonoids account for 0.40 mg quercetin equivalents/gFW (Ramful et al., 2011). Total flavonoid content in the juice varies considerably among species and varieties, from 10 mg/L in ‘Afourer’ to 42 mg/L in ‘Nova’ mandarins (Goldenberg et al., 2014).

Among flavonoids, flavanones are the most relevant, while flavones are also present at lower amounts (Abad-García et al., 2014). Flavones differ from flavanones by a C₂—C₃ double bond (Khan et al., 2014). Other group of flavonoids of minor relevance as dietary components are the chalcones, dihydrochalcones, dihydroflavonols, flavan-3,4-diols, coumarins, and aurones (Del Rio et al., 2013). The flavanone class encompasses a wide array of compounds especially important in citrus fruit, since the flavanone class may account up to 87% and 97% of total polyphenols in the juice of mandarins (mainly as 7-*O*-glycosylflavanones), while flavones only represent between 0.3% and 9.8%. These percentages change slightly among different citrus species (Abad-García et al., 2014) (Table 4). Among flavanones, naringenin and hesperetin aglycones and their glycosides are of particular interest because of their high prevalence in foods. The most usual flavanones present in *C. reticulata* are hesperidin, narirutin, neoponcirin, didymin, isorhoifolin, and eriocitrin, while others such as taxifolin, naringin, neohesperidin, eridictyol, poncirin, and naringenin are present at lower levels (Nogata et al., 2006; Lafuente et al., 2011; Kelebek and Selli, 2014; Zhang et al., 2014). Hesperidin is a flavanone that is not bitter and is responsible for the cloudiness of juice and marmalade due to its precipitation in water. Hesperidin can be found in the segment membrane of fresh fruits in the form of white spots or crystals in freeze-damaged mandarins (Ladaniya, 2008). Hesperidin is by far the most common flavanone found in mandarins, fluctuating between 17 and 36 mg/gDW in the peel of *C. reticulata* mandarins, while the levels of narirutin and eriocitrin are nearly 10 times lower (Zhang et al., 2014). Didymin flavanone was also

Table 4 Main flavanones and flavones in the pulp of different mandarin varieties
Flavanones (mg/g FW)

Mandarin	Hesperidin	Narirutin	Didymin	Eriocitrin
Satsuma	7.52	7.6–15.9	1.68	0.18
Fortune	1.60	0.18	0.35	0.02
Ponkan	2.9–6.7	1.9	1.1	0.11
Murcott	0.54	n/d	n/d	n/d

Flavones (mg/g FW)				
	Diosmin	Luteolin	Sinensetin	Nobiletin
Satsuma	1.4	n/d	n/d	0.19
Ponkan	0.13	0.04	0.1	0.07
Murcott	0.14	0.05	0.1	nd

nd, no data.

Adapted from Nogata et al. (2006), Wang et al. (2007), Lafuente et al. (2011), and Xi et al. (2014).

described as a component of the juice of common mandarins and also in ‘Garbí’ and ‘Safor’ triploids, as well as in satsuma (Lafuente et al., 2011; Sdiri et al., 2012; Kelebek and Selli, 2014). Flavonoid composition may vary greatly among mandarin species and tissues. The highest concentration of flavanones is found in the peel as compared to the flesh and higher in segment membranes than in the juice vesicles (Nogata et al., 2006; Lafuente et al., 2011). Among flavones, sinensetin, nobiletin, and tangeretin are the most important compounds found in *C. reticulata* mandarins, accounting for 0.12–6.8 mg/g DW in peel extracts, depending on the mandarin variety (Zhang et al., 2014).

Regarding mandarin pulp, most flavonoids are concentrated in segment membranes as compared to juice vesicles (Nogata et al., 2006; Lafuente et al., 2011). Hesperidin is also the predominant flavanone in juice vesicles with 0.85–2.91 mg/g FW in ‘Ponkan’, 0.54 mg/g FW in ‘Murcott’, 0.24 in ‘Dancy’ common mandarins, 1.6 mg/g FW in ‘Fortune’, and 0.09–0.27 mg/g FW in satsuma (Nogata et al., 2006; Wang et al., 2007; Lafuente et al., 2011; Shen et al., 2013). Narirutin is the second most important flavanone in mandarin juice vesicles and reaches also the highest concentration in segment membranes (Nogata et al., 2006; Lafuente et al., 2011; Shen et al., 2013). The third relevant flavanone in mandarin segment membranes is neoponcirin, which is hardly or nondetected in juice vesicles of different mandarin species. In the hybrid ‘Fortune’ mandarin, didymin (0.35 mg/g FW) and isorhoifolin (0.53 mg/g FW), followed by narirutin (0.18 mg/g FW), are the most relevant flavonoids in the pulp (Lafuente et al., 2011).

Flavones are other class of flavonoids present at lower concentration in citrus fruit. The flavones apigenin-6,8-di-C-glucoside and diosmetin-6,8-di-C-glucoside account for 1.6–61 mg/L and 1.2–2.9 mg/L in juices of common and satsuma mandarins, respectively. Moreover, in the hybrid ‘Fortune’, the concentration of apigenin-6,8-di-C-glucoside (56 mg/L) is particularly high (Abad-García et al., 2014). Nobiletin is also present in juice vesicles and pulp of several mandarin varieties (Nogata et al., 2006; Xi et al., 2014). Other flavones are diosmin, luteolin, and sinensetin (Wang et al., 2007; Lafuente et al., 2011). Other flavones are typical of specific tissues, as tangeretin and isorhoifolin, which are only present in segment membranes of ‘Ponkan’ and ‘Dancy’ but not in satsuma (Nogata et al., 2006), or the flavonol aglycones quercetin and kaempferol, as well as the quercetin-3-O-glycoside or rutin, which are only present in the pulp of certain mandarins (Wang et al., 2007).

It is also noticeable that certain flavonoids are more characteristic or particularly abundant in certain citrus species and this property has been used for taxonomical classification of varieties and also as molecular markers for verification of fruit juice quality (Abad-García et al., 2014).

Nonflavonoids: Phenolic Acids

Among nonflavonoids are the C_6-C_1 phenolic acids, which are frequently bound to sugars or esters in citrus fruits. Chlorogenic acid is the main free phenolic acid in

mandarin fruit (Xu et al., 2008a,b). Total phenolics vary notably among mandarin species and varieties, and their content is always higher in the peel than in the pulp tissue, decreasing sharply as fruit ripen (Xu et al., 2008b).

Phenolic acids are found as extractable (soluble-free and free esters) or insoluble-bound, ferulic and caffeic acid, and *p*-coumaric acids being the more relevant cinnamic acids in most common mandarins. Differences in the relative abundance of each phenolic acid are usually detected between mandarin species and varieties (Xu et al., 2008a,b; Kelebek and Selli, 2014). The only free phenolic acid detected in both peel and pulp of mandarins is chlorogenic acid, accounting for 0.70 mg/g DW and 0.086 mg/g DW, respectively (Xu et al., 2008b). In fruit juice of 30 different common mandarins, total phenols vary from 380 to 650 mg Gallic acid equivalent (GAEq)/L (Goldenberg et al., 2014), while in 'Kinnow' mandarins, nearly 900 mg GAEq/L were detected (Al-Juhaimi and Ghafoor, 2013). Total phenolic acids were quantified in satsuma mandarin juice and were distributed as ferulic (67%), *p*-coumaric (9%), caffeic (5.5%), vanillic (5.5%), and sinapic (5.5%), and the protocatechuic and *p*-hydrobenzoic acid accounted for less than 3% (Xu et al., 2008a). In general, results indicate that variation in phenolic composition is dependent on the fruit type and also on the growing region. Moreover, total phenols (esterified, glycosides, or ester-bound) declined during fruit maturation (Xu et al., 2008b), but increased during postharvest cold storage (Qian et al., 2014)(Table 5).

Flavonoids and phenols are relevant nutritional components of citrus fruit and, together with carotenoids and ascorbic acid (AsA), have a relevant impact on fruit antioxidant properties. Total antioxidant capacity of the pulp also varied among mandarins, ranging from 1.5 to 6.3 μ MTE/g FW (Ramful et al., 2011; Goldenberg et al., 2014; Table 6). Experimental evidences indicate a positive and high correlation between total antioxidant activity (measured by ABTS, DPPH, FRAP, and ORAC methods) and the content of both flavonoids and phenolic compounds in mandarin juices (Kelebek and Selli, 2014) (Table 6). A study of the relationship among vitamin C, flavonoids, phenols, and carotenoids and the antioxidant capacity of the juice of

Table 5 Content of phenolic acids in the pulp of 'Ponkan' mandarin
Acid **Concentration (μ g/g DW)**

Ferulic	137.4
Chlorogenic	85.8
Caffeic	41.3
Sinapic	25.7
<i>P</i> -Coumaric	18.9
Vanillic	17.3
<i>P</i> -Hydroxybenzoic	12.7
Protocatechuic	4.12

Adapted from Xu et al. (2008b).

Table 6 Antioxidant capacity, determined by two methods, in the pulp extract of different mandarin varieties

Mandarin variety	TEAC $\mu\text{mol TE/g FW}$	FRAP $\mu\text{mol FE(II)/g FW}$
Satsuma Owari	4.3	4.6
Fairchild	4.4	6.3
Dancy	3.8	4.1
Beauty	3.7	4.5
Sughugan	2.9	3.3
Fizu	5.6	8.2
Tangor Ellendale	6.3	9.4
Tangelo Minneola	5.3	5.6

Adapted from [Ramful et al. \(2011\)](#).**Table 7** Concentration on main vitamins in the pulp of mandarin fruits

Vitamin	Concentration (mg/100 g FW)
Vitamin C	14–42
Thiamin	0.05–0.13
Riboflavin	0.02–0.06
Niacin	0.16–0.38
Total folate	16–36

Adapted from [USDA \(2010\)](#).**Table 8** Carotenoid content in the pulp of different mandarin varieties

Carotenoid ($\mu\text{g/g FW}$)	Satsuma mandarin	Mandarin hybrids (<i>Citrus reticulata</i>)	Tangor (<i>Citrus</i> $\times$ <i>aurantium</i>)
Phytoene	1.4–4.0	1.7–8.9	2.5–4.5
ζ -carotene	1.0–3.0	0.9–2.6	0.8–2.5
β -carotene	0.6–3.0	0.5–3.7	0.7–2.9
β -cryptoxanthin	13.0–19.5	3.0–13.3	9.7–13.8
Zeaxanthin	0.2–0.4	0.2–0.4	0.2–0.5
Violaxanthin	2.0–4.0	1.4–7.6	5.0–15.0

Adapted from [Yano et al. \(2005\)](#), [Kato et al. \(2007\)](#), and [Matsumoto et al. \(2009\)](#).

46 mandarins species allow a classification in two major subclusters: the first cluster includes common mandarins, satsumas, clementines, and Mediterranean mandarins, while the second includes additional common mandarins, ‘King’ mandarins, tangors, and tangelos ([Goldenberg et al., 2014](#)). Differences in these parameters not only affect antioxidant capacity, but also impact directly on flavor perception ([Goldenberg et al., 2014](#)).

Limonoids

Limonoids are a group of tetracyclic triterpenes found in the Rutaceae and Meliaceae families. Citrus limonoids are mainly represented by aglycones and glycosides, totalizing around 40 different aglycones and 21 glucosides (Manners, 2007). Among them, limonin and nomilin are the most common in citrus fruits. Several limonoids are extremely bitter at relatively low concentrations, which may originate consumer rejection. The physical disruption of juice sacs causes the transformation of a tasteless limonoid aglycone (limonate A-ring lactone) into the bitter limonin, a step that is catalyzed by the enzyme limonin D-ring lactone hydrolase at pH 6.5 or lower (Manners, 2007).

Nomilin is the common precursor of all known limonoids in citrus. Total limonoids increase with fruit ripening and decrease thereafter, but a high concentration is always maintained in the seeds. The enzyme limonoid glucosyltransferase is responsible for the conversion of limonoid aglycones to glycosides during maturation, consequently reducing the juice bitterness. Recently, a new limonoid was described in mandarin seeds named citrolide-A (Liao et al., 2012). The limonoid content in mandarins changes significantly among varieties, and many of them, such as as nomilin and limonin glucosides, are normally higher in segment membranes than in juice vesicles. Evidences indicate that citrus limonoids are biologically active, displaying anticarcinogenic, hypcholesterolemic, insecticidal, and antifeedant activity against insects. However, the antioxidant capacity of these compounds is very low (reviewed in Manners, 2007).

Volatile Compounds

Volatile components of citrus fruits are responsible for much of the aroma and flavor perceived by consumers of fresh fruits or their derivate products, directly impacting acceptability. Additionally, some of these volatiles are industrially valuable for the production of fragrances, pharmaceuticals, and agrochemicals for aphid pheromones. Fruit and flavor sensations derive from the combination of taste and aroma. Taste is mainly determined by the juice balance between sugars and acids, whereas fruit odor is strongly influenced by the content and composition of aroma volatiles (Tietel et al., 2012). The citrus aroma is complex and consists in a heterogeneous mix of different volatile compounds that are present in the essential oil, and most of them belong to the terpene family. In citrus fruit, this group is mainly composed by monoterpenes (C_{10}) and sesquiterpenes (C_{15}) and their derivatives (alcohols, esters, aldehydes, and ketones) (Moshonas and Shaw, 1997; Miyazaki et al., 2011).

Mandarin aroma is the result of a great number of volatile compounds, and recent analysis reported more than 100 volatiles, which are combined in suitable proportions to produce the distinguishable, fragrant, and highly valuable aroma characteristic of this fruit. Pioneer studies about the biochemical nature of mandarin aroma found that the main volatile constituents in mandarin and mandarin hybrid cultivars were the monoterpenes limonene, myrcene, linalool, and γ -terpinene (Moshonas and Shaw, 1997; Tietel et al., 2011), as can be seen in Table 9. As for other *Citrus* species, limonene is the most

Table 9 Main volatile composition in the pulp or juice of different mandarin species and varieties

		Common mandarin			Satsuma		Tangor		
		Dancy	Shatangju	Dalandan	Guoqing 1	Miyagawa Wase	Owari	Ortanique	Ellendale
Compound	Description	(mg L ⁻¹)	(%)	(%)	(μg g ⁻¹)	(μg g ⁻¹)	(μg g ⁻¹)	(mg L ⁻¹)	(mg L ⁻¹)
Alcohols									
Ethanol	–	520	–	–	0.71	0.17	1.15	–	–
Aldehydes									
Octanal	Tallowy, citrus-like	–	0.06	–	8.81	7.93	7.05		
Nonanal	Piney, floral, citrusy	0.039	–	0.4	–	0.98	–	0.004	0.008
Decanal	Beefy, musty, marine, cucumber	0.28	0.52	0.2	3.07	1.49	1.76	0.056	0.044
Monoterpenes									
α-terpineol	Floral, lilac-like	0.48	0.7	1.6	2.95	1.15	1.98	–	–
Limonene	Citrus-like, fresh	94	92.5	86.9	462.89	422.31	400.6	104	81
Linalool	Floral, green, citrus	1.5	0.62	0.8	50.54	26.45	36.36	0.12	0.11
α-phellandrene	Medicinal, terpeney, herbaceous	0.016	–	0.7	–	–	–	0.016	0.016
α-terpinene	Lemony, citrusy		–	–	–	0.55	–	–	–
γ-terpinene	Lemony, lime-like	0.6	–	1	21.12	19.1	17.3	0.013	0.013
Sabinene	Warm, oily, peppery, green	0.075	0.09	0.4	0.5	0.59	0.36	0.099	0.063

α -pinene	Pine-like, resinous	—	0.29	0.9	0.9	1	0.79	—	—
Myrcene	Musty, wet soil	0.43	1.67	0.5	8.95	8.41	7.76	1.9	1.6
β -pinene	Resinous, dry, woody	—	—	0.5	0.84	1.29	0.74	—	—
β -sinensal	Orange peel	—	—	—				—	—
<i>P</i> -cymene	Fresh, solvent, citrus	—	—	—				—	—
Terpinolene	Citrus, pine	—	—	0.7	1.28	1.56	1.02	—	—
Thymol	Sweet, medicinal, powerful	—	—	0.4	0.18	—	0.06	—	—
Geraniol	Flora, rose-like	—	—	—	0.27	—	0.15	—	—
Geranial	Citrus-like, flowery, fruity	0.0024	—	0.3	0.64	0.34	0.39	—	0.006
Nerol	Sweet, fruity, floral	—	—	—	0.37	—	—	—	—
Neral	Lemony, citrusy	0.0032	—	—	0.84	—	0.48	—	0.006
Citronellol	Rose-like, fresh	—	—	—	0.47	—	0.25	—	—
Citronellal	Powerful, floral, lemon	—	—	—	0.21	—	0.08	—	—
β -pinene	Resinous, dry, woody	—	—	0.5	0.84	1.29	0.74	—	—
Sesquiterpene									
β -elemene	—	—	0.11	—	0.39	0.31	0.19	—	—

Adapted from [Moshonas and Shaw \(1997\)](#), [Qian et al. \(2014\)](#), [Dharmawan et al. \(2007\)](#), and [Qiao et al. \(2007\)](#).

abundant volatile compound in all mandarin varieties, reaching up to 90% of total volatile content. However, mandarin fruit presents some characteristic key aroma-impacting compounds that are likely responsible for the particular flavor notes found in this citrus group. In this sense, it has been reported that the distinctive notes of the aroma of Mediterranean mandarins are due to the presence of methyl-*N*-methylantranilate (0.85%) and thymol (0.08%) (Ladaniya, 2008). In the peel oil of satsuma mandarins, sesquiterpenes (notably β -elemene and β -sesquiphellandrene) and acetate esters of geraniol, nerol, citronellol, and *p*-mentha-1,8-dien-7-ol were found to give the characteristic aroma of the fruit (Qiao et al., 2007). Contrastingly, the typical volatiles in Mediterranean mandarin are not present in satsuma, suggesting the existence of important differences in volatiles composition among mandarin species and varieties.

In fruits of satsuma mandarin ('Kovano-Wase', 'Miyagawa-Wase', and 'Owari' varieties), limonene and β -myrcene are the main volatile compounds, followed by γ -terpinene, linalool, and β -elemene, while β -pinene and octanal are also present, contributing to a variation in overall aroma and flavor perception of this mandarin group. The levels of α -thujene and α -pinene could be used to differentiate some cultivars; these compounds separate oriental mandarin cultivars ('Owari' and 'Okitsu') from the Mediterranean. Mandarin hybrids show interesting differences compared to common mandarins: 'Ortanique' and 'Ellendale' tangors contain similar amounts of limonene compared to 'Dancy' common mandarin; however, myrcene is between four and five times higher in mandarin hybrids. Furthermore, linalool and γ -terpinene contents are considerably higher in 'Dancy' than in both tangors (Moshonas and Shaw, 1997). An analysis of qualitative and quantitative differences in the volatile composition of a population of 20 tangerine hybrids identified a total of 203 aroma volatiles, and most hybrids were distinguished from other samples by their lower number and/or quantity of volatile compounds (Miyazaki et al., 2011). In a complementary olfactometry and sensory study, including five hybrids with a distinct volatile profile, 49 aroma active compounds were found (Miyazaki et al., 2012). Aldehydes were the most important group with odor activity, as well as monoterpenes, esters, alcohols, and ketones. 1,8-Cineole, β -myrcene, (E,E)-2,4-nonadienal, hexanal, ethyl-2-methylbutanoate, and linalool were perceived with high intensity in most samples. Two clementine $\times$ 'Mineola' hybrids and one 'Fortune' $\times$ 'Murcott' hybrid with tangerine had sulfury and woody/spicy flavors and active compounds combined with terpene, fatty/vegetable, and metallic/rubber descriptors. However, as a general conclusion, there was not one unique compound characteristic of tangerine flavor (Miyazaki et al., 2012).

Volatile composition not only varies interspecifically, but also among mandarin varieties from the same group. It is the case of the satsuma group where three varieties ('Guoqing 1', 'Miyagawa Wase', and 'Owari') showed between 66 and 73 different volatile compounds, from which 29 were common, limonene, linalool, γ -terpinene, β -myrcene, α -pinene, and octanal being the most representative. Changes in the combination of these compounds contributed to the differences perceived in the overall aroma (Qiao et al., 2007).

Furthermore, thymol is a constituent found in ‘Dancy’ and ‘Dalandan’ common mandarins and not in other citrus species, like oranges or grapefruits (Dharmawan et al., 2007). Similarly, α -phellandrene and 1-terpineol were only found in ‘Dalandan’ common mandarins, but not in ‘Mosambi’ oranges (Dharmawan et al., 2007), while methyl-*N*-methylantranilate was only found in clementine mandarins but not in other citrus species. Recently, a comparative study of fruit quality parameters in 11 commercial mandarins, including some mandarin hybrids, has been performed in Spain. A total of 38 volatile compounds were identified, and the majority belong to the monoterpene type, 95% being limonene with respect to the total volatiles detected, followed by β -myrcene, α -pinene, decanal, *trans*-ocimene, and linalool (Simón-Grao et al., 2014).

During the ripening of the citrus fruit, important qualitative and quantitative changes are observed in the aromatic profile, highlighting a greater abundance of volatiles in the early stages of ripening. Immature fruits of different species have a higher proportion of oil glands than in mature fruits (Ladaniya, 2008). During mandarin ripening, the relative importance of limonene increased from 20% to 87%, while linalool decreased from 62% to 4.2%, and thymol decreased from 3.2% to 0.23%, as also occurred with α - and β -pinene, α - and γ -terpinene, and geraniol (Bourgou et al., 2012).

VITAMIN C AND CAROTENOIDS IN MANDARINS

Different vitamins are present in the flesh of mandarin fruit, and vitamin C provides important nutritional benefits and also contributes to total antioxidant activity (Barros et al., 2012; Goldenberg et al., 2014). Other vitamins present in mandarins are folate (mainly as reduced 5-methyltetrahydrofolate and polyglutamate derivatives) and provitamin A (by the presence of its precursors β -carotene and β -cryptoxanthin) (Codoñer-Franch and Valls-Belles, 2010). Mandarins usually contain lower AsA content than oranges and grapefruits in both peel and pulp tissues (Dhuique-Mayer et al., 2005; Martí et al., 2009; Alós et al., 2014). The average content of AsA in the pulp of oranges is around 50 mg/100 gFW, while nearly 20 mg/100 gFW was described in ‘Owari’ satsuma mandarin (Martí et al., 2009; Alós et al., 2014). Similarly, the pulp of other varieties of satsumas, such as ‘Guoqing No. 1’ and ‘Egan No. 2’, contain 27 and 36 mg/100 gFW, respectively. Mandarin juices were described to present around 40 mg/100 mL (Dhuique-Mayer et al., 2005), while slight variations may exist between cultivars. The concentration of AsA in juice of different mandarin cultivars may be very variable, but usually falls in the range between 15 and 50 mg/100 mL juice, and in general, it remains relatively constant during cold storage (Martí et al., 2009; Ladaniya, 2011). A profuse study of vitamin C content in the juice of several mandarin varieties described that AsA was relatively higher in tangor hybrids and common mandarins than in mandarins of the satsuma group (Beltran et al., 2008). Other mandarin hybrids such as ‘Ortanique’, ‘Nova’, and ‘Ellendale’ also contain higher AsA concentration than common mandarins (Sdiri et al., 2012).

AsA content in general increases in the peel, while it slightly decreases in the pulp as fruit maturity progresses, nearly being four to five times higher in the former tissue (Alós et al., 2014). Different mechanisms have been proposed to regulate AsA biosynthesis in both tissues, and diverse biosynthetic routes appears to contribute to AsA accumulation. The relative importance of each pathway depends mainly on the stage of fruit development (Alós et al., 2014). Dehydroascorbate, originated by AsA oxidation, was only present in green fruits and not found in mature mandarin fruit (Alós et al., 2014). Other vitamins, such as the vitamin B complex (folic acid or folate, thiamin, and B6 group pyridoxal, pyridoxamine, and pyridoxine), vitamin E, or tocopherol (0.15 mg/100 gFW) are also present in mandarins, although at lower levels compared to vitamin C (Table 7). However, provitamin A activity is usually higher in mandarins than in other citrus species, since it is tightly related to carotenoid composition, and the important presence of β -cryptoxanthin in mandarins favors this activity.

Mandarins are among the most highly pigmented citrus fruit species, due to their content and composition of carotenoids (Kato, 2012; Rodrigo et al., 2013). Carotenoids are isoprenoid compounds that can be divided in two groups: carotenes, which consist in a hydrocarbon structure, and xanthophylls, which contain oxygen atoms in their structure. Carotenoids play essential functions in plants and have also beneficial properties for human nutrition and health, preventing chronic and degenerative diseases (Rao and Rao, 2007). Carotenoids are recognized as relevant antioxidants, but more importantly, some of them are direct precursors of vitamin A (α - and β -carotene, and β -cryptoxanthin) (Turner, 2011).

Total carotenoids are higher in the peel than in the pulp of mandarins, varying from 25 to more than 300 $\mu\text{g/gFW}$ in the peel, and from 10 to 40 $\mu\text{g/gFW}$ in the pulp. Carotenoid content is usually higher in mandarin hybrids than in common mandarins. β -Xanthophylls usually represent between 68% and 90% of total carotenoid in the peel (Kato, 2012; Rodrigo et al., 2013), and β -cryptoxanthin (60–80%) predominates in the edible pulp (Kato et al., 2004; Matsumoto et al., 2009). Therefore, the preferential accumulation of β -cryptoxanthin in mandarin pulp is a common feature among mandarins and distinguishes it from other citrus fruits. During ripening of mandarin fruit, there is an important increase in xanthophylls (mainly β -cryptoxanthin and violaxanthin) content as well as smaller changes in β -carotene and phytoene in juice sacs, contributing to the changes in pulp color from pale orange to the more intense reddish coloration typical from mandarins. Despite the similar pattern of carotenoid accumulation in the pulp tissue during ripening, there are some differences on carotenoid composition among mandarins (Goldenberg et al., 2014). The biggest difference between common mandarins or tangors and those of the satsuma group is related to accumulation of xanthophylls. Satsumas usually present a higher content of the xanthophyll β -cryptoxanthin in the pulp (15–18 $\mu\text{g/gFW}$), followed by *cis*- and *trans*-isomers of violaxanthin (2–4 $\mu\text{g/gFW}$), phytoene (1.5–4.0 $\mu\text{g/gFW}$), and also β -carotene (1–3 $\mu\text{g/gFW}$) (Kato, 2012).

Other varieties, such as the hybrid ‘Amaka’, ‘Youko’, and ‘Saga’ mandarins presented lower β -cryptoxanthin (9.7–13.8 $\mu\text{g/gFW}$) but higher violaxanthin content (6.1–9.8 $\mu\text{g/gFW}$) than satsumas, but also contained phytoene (2.5–4.5 $\mu\text{g/gFW}$), ζ -carotene (0.8–2.5 $\mu\text{g/gFW}$), and β -carotene (0.7–2.9 $\mu\text{g/gFW}$). β -Cryptoxanthin content is variable among mandarins, being either lower (as the ‘Kiyomi’ tangor or ‘Ponkan’ and ‘Murcott’ mandarins) or higher (as in ‘Harumi’, ‘Ariake’, and ‘Tamami’ hybrid) respect to satsuma. However, some hybrids such as the ‘Tamami’ variety (‘Kiyomi’ tangor $\times$ ‘Wilking’ mandarin) present a higher carotenoid content in the pulp (35 $\mu\text{g/gFW}$) than the two parental. These differences are mainly explained by a three-times-higher content of β -cryptoxanthin (20 $\mu\text{g/gFW}$), phytoene (6.8 $\mu\text{g/gFW}$), and β -carotene (3.5 $\mu\text{g/gFW}$) (Kato et al., 2007; Wang et al., 2007). On the other hand, violaxanthin content in juice sacs was higher in the ‘Wilking’ parental mandarin (15 $\mu\text{g/gFW}$) than in both the ‘Tamami’ hybrid (5 $\mu\text{g/gFW}$) and ‘Kiyomi’ tangor (3.0 $\mu\text{g/gFW}$) (Kato et al., 2007). Thus, evidences indicate that differences on individual carotenoids among mandarin varieties are mainly related to changes in β -cryptoxanthin and violaxanthin contents (Table 8).

A profuse study of total carotenoids (determined as β -carotene equivalents) in juice of 46 mandarin varieties revealed notable differences and wide variability, i.e., ‘Fortune’ and ‘Ponkan’ mandarins are pale in color and contained only 3 mg of carotenoids/mL of juice, whereas ‘King’ mandarin and ‘Imamura’ satsuma are dark-orange, and the concentration of total carotenoids was nearly 30 mg/mL (Xu et al., 2008a; Goldenberg et al., 2014). However, other varieties of the satsuma group, such as ‘Wase’, contained only 7.3 mg β -carotene equivalents/mL (Xu et al., 2008a). β -Cryptoxanthin (10.7 mg/mL) is also the predominant carotenoid in the juice of common mandarins, followed by β -carotene (1.6 mg/mL) and violaxanthin (1.39 mg/mL), the former being responsible for the three-times-higher vitamin A value of its juice compared to other citrus species (Dhuique-Mayer et al., 2005). Despite the differences on carotenoid content among mandarin species and varieties, all of them shared a very close cluster aggrupation compared to other citrus species, based on juice carotenoid composition, mainly explained by the high β -cryptoxanthin content (Fanciullino et al., 2006).

SUMMARY POINTS

- Mandarins are characterized by an extremely high genetic diversity that leads to great phenotypic differences among species and varieties. Their production worldwide is mainly intended for the fresh market, and their consumption is gradually increasing. Mandarins are especially valuable and highly appreciated for being easy to peel and for the low seed presence in most of the commercial species and varieties.
- Mandarin fruits are a source of different compounds that exert relevant nutritious and nutraceutical properties. Among primary metabolites, soluble sugars, organic acids, AA, and vitamins (mainly vitamin C) are important constituents of all

mandarin species, and their contents notably vary between varieties. Mandarins are also a source of minerals, mainly potassium, magnesium, and calcium. Secondary metabolites are especially important in mandarins, being rich in carotenoids, flavonoids, and volatile compounds, which are crucial in the organoleptic quality of the fruit.

- Pulp of all species and varieties of mandarins contains high levels of β -cryptoxanthin, a carotenoid with provitamin A and antioxidant activity, and other health-related benefits.
- Flavanones hesperidin and narirutin are the most relevant flavonoids in mandarin pulps, while ferulic, chlorogenic, caffeic, *p*-coumaric, and sinapic phenolic acids vary their relative importance in different mandarin groups. Flavonoid, phenolic acids, and limonoids contents decrease in the pulp during fruit ripening, while carotenoid and volatiles contents increase.
- Some volatiles compounds such as thymol, α -phellandrene, and 1-terpineol methyl-*N*-methylantranilate are specific to mandarins, being responsible for the typical mandarin overall flavor perceived by consumers. Moreover, some of these volatiles mixtures or combinations with other main constituents are strongly related to consumer preferences.
- All these metabolites may vary among mandarin species and varieties, being more abundant in the peel than in the pulp and highly influenced by growing conditions, horticultural practices, and the environment. The unique composition of nutritional constituents (primary and secondary metabolites) in each mandarin drives to differences in sensory acceptance, and can be also used for taxonomical classification in order for phenotyping and to cluster the different species according to their nutritional composition. Moreover, the great diversity and complexity in these compounds among citrus species may be used as markers for fruit juice quality or as criterion for detection of adulterations.

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CHAPTER 19

Nutrient and Flavor Content of Mango (*Mangifera indica* L.) Cultivars: An Appurtenance to the List of Staple Foods

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LIST OF ABBREVIATIONS

DAH	Days after harvest
DAP	Days after pollination
FW	Fresh weight
PVC	Principal volatile component
RNS	Reactive nitrogen species
ROS	Reactive oxygen species
TA	Total acidity
TSS	Total soluble solids

INTRODUCTION

The population of the world is increasing at an alarming pace, and only a few crops, mostly cereals, have served as a common food till now. The increment, due to the Green Revolution in the main staple food crops like rice, wheat, and maize, has almost reached a plateau. The option that is available to feed the escalating population is to increase the production of these crops or to enhance the diversity in the crops to be consumed as food/nutritional crops. Fruit crops are a quirky choice, having comparatively better potential to grow in poor, marginal soils with fewer inputs, and they have the tendency to bear stress or climatic extremities and are nutritionally very important. The need of the hour is to continue research on the staple crops; however, simultaneously extensive research inputs are required for the horticultural crops. The fruit crop like mango (*Mangifera indica* L.) is really a worthy choice.

Mango, often called the “king of fruits,” is the most popular fruit throughout the world. It holds a high esteem in human minds, as it is considered a “heavenly fruit” or “super fruit.” Its nutritional importance, unique flavor, delicious and salubrious taste, and wholesomeness impart this status to the fruit. There are about 1000 cultivars reported to be present in India alone that reflect the diversity available in this fruit crop. Tropical and subtropical climates have mango as a major fruit crop, especially Asia, where mango has a tremendous importance in human life. However, fewer efforts are being made to improve its yield as compared to the staple food crops. The factors such as heterogeneity, alternate bearing (in certain varieties), extended juvenility, disease susceptibility, costly plantation, and evaluation time of trees in the field could be responsible for this. However, a substantial growth in mango produce in recent times might be due to some efforts in expansion of its abode, refined practices in the field of plantation, flowering, ripening, and storage, as well as in pest, insect, and disease management. However, more systematic research efforts using modern scientific approaches are needed in order to develop varieties with better nutritional and flavor qualities and morphometric traits.

Mango is considered as an important cultural and religious symbol of India. It is the oldest cultivated tropical fruit; it first appeared in the quaternary period with its origin in the Indian subcontinent, particularly in the Indo-Burma region and surrounding vicinity, as supported by the classical literature. Different names of mangoes used in various regions have been derived from the Sanskrit language, where it is referred to as ‘Amra’. The early travelers to India (Buddhist pilgrim Sung-Yun, Fa-Hien, Hsüan-tsang, and others) were considered to be responsible for the introduction of this fruit to the rest of the world. The detailed description of characteristics and taste of the mango fruit have been highlighted in historical literature, as old as the Ain-e-Akbari, the encyclopedia created during the reign of Akbar (Valavi et al., 2012; Richard, 1997).

BOTANICAL ASPECTS

Mango cultivation dates back at least 4000 years. There are about 69 *Mangifera* species (Kostermans and Bompard, 1993), most of which are restricted to tropical Asia, but extend as far north as 27° latitude and as far east as Caroline Islands in the northwestern

Pacific Ocean (Valavi et al., 2012). Species of *Mangifera* occur in the wild in India, Bangladesh, Sri Lanka, Myanmar, Sikkim, Thailand, Cambodia, Vietnam, Laos, southern China, Malaysia, Singapore, Indonesia, Brunei, Philippines, Papua New Guinea, Solomon Islands, and the Caroline Islands. According to De Candoll (1884), mango is undoubtedly native to South Asia and the Malay Archipelago. Various views have been proposed regarding the origin of the genus *Mangifera*, based on morphology, phytogeography, and fossil evidence. However, recent molecular evidence indicates that mango (*M. indica* L.) evolved within a large area of East Asia (including northwestern Myanmar, Bangladesh, and northeastern India). Despite the East Asian origin of the genus, the highest number of *Mangifera* species occur in Malaysia, especially in its peninsular region. Mango has become naturalized in many parts of India (Litz, 1997). Four main species of *Mangifera*, namely *M. indica* L., *Mangifera sylvatica* Roxb., *Mangifera odorata* Griff., and *Mangifera zeylanica* (Blume) Hook.f. have given rise to most of the cultivated varieties. The taxonomical classification of the common mango is:

Kingdom	–	Plantae
Class	–	Magnoliopsida
Phylum	–	Magnoliophyta
Order	–	Sapindales
Family	–	Anacardiaceae
Genus	–	<i>Mangifera</i>
Species	–	<i>indica</i>

Wild mangoes are found at the edge of their range in northeastern India, Bangladesh, and Myanmar. However, cultivation of unaltered wild varieties has been reported in Tirhoot (Bihar, India) and Malda (West Bengal, India) (Valavi et al., 2012). Wild mango trees yield small fruit with thin flesh and are of poor nutritional quality and taste. As a result of domestication and recent selection criteria, the fruit has undergone many changes especially with regard to texture, biochemistry, and nutritional content. However, semi-wild form can be found throughout the Indian subcontinent and Southeast Asia. Some primitive selections from Orissa, India with varied fruit shape and size are evidence of the early domestication of common mango (Richard, 1997). Within *M. indica*, it has been assumed that there are two domestication types, monoembryonic mangoes (Indian type) and polyembryonic mangoes (Indo-Chinese type). However, diversity analysis using Rapid Amplification of Polymorphic DNA (RAPD) markers indicate the presence of some polyembryonic mangoes in the western region of India, suggesting their introduction into the area from Southeast Asia (Ravishankar et al., 2004). There are almost 1500 cultivars of *M. indica*, of which about 350 are used commercially. Based on the geoclimatic locations of distribution and cultivation, Tharanathan et al. (2006) have classified mango into two major categories, Indian and Indo-Chinese. Most of the Indian cultivars have intense peel coloration and a strong aroma and are characterized by attractive fragrances, delicious taste, and high nutritional value. On the

other hand, Indo-Chinese cultivars are perceived as medicinal and have a turpentine flavor. Such variation is also seen among Indian and foreign cultivars (Lizada, 1993).

Wild mangoes are large trees (30–40 m and occasionally 54 m in height), the largest of which are emergent in the rainforests of South and Southeast Asia (Litz, 2009). They are evergreen and have long lives. Depending on variety and the amount of pruning, cultivated mango trees can vary in height from 3 to 30 m. Mature mango trees produce up to 1000 inflorescences, each bearing 500–6000 flowers. The flowers can be monoecious, hermaphrodite, or polygamous. The onset of flowering and vegetative growth is variable throughout the tropics and subtropics; variation occurs even within the Indian and southeast Asian region. Flowering in the subtropics is stimulated by cool temperatures. In the tropics, the age of the previous vegetative flush decides the onset of flowering in mildly cool or warm temperatures. The effect of temperature on flowering, sex of flowers, etc. is complex. Sukhuibul et al. (2000) found that inflorescence development only occurred on trees maintained at 20/10, 25/10, and 30/20°C. Higher temperatures generally increased inflorescence size, while there was an inverse effect on the number of flowers per inflorescence. Both wild mangoes and cultivars show variation in flowering patterns depending on the age of tree. Apart from biotic and abiotic factors, chemicals such as potassium nitrate are used to alter the flowering (and hence fruiting) season so that fruits can be harvested at particular times (Davenport, 2003). Despite abundant flowering, the fruit set is usually less than 10%, out of which only 0.2–0.3% of fruits reach harvesting stage. The fruit is a simple, large, more or less compressed, fleshy, resinous drupe (fleshy stone fruit), and an indehiscent climacteric. It varies in size, shape, color, fiber content, flavor, and taste. The pericarp consists of a smooth exocarp, fleshy mesocarp, and stony endocarp. The mesocarp provides the fleshy edible pulp, which is firm and can be fibrous or fiber-free, with a flavor ranging from turpentine to sweet. The endocarp develops into a thick, tough, leathery, glandular covering around the seed. The seed is exalbuminous. Fruit development can be divided into four stages: (1) juvenile stage (up to 21 days from the day of fruit set) leads to rapid cellular growth; (2) stage of maximum growth (21–49 days) results in cell enlargement and maturity; (3) maturation and ripening stage (49–77 days) during which respiration and ethylene production increases (the climacteric stage of fruit ripening); and (4) senescence stage (77th day onwards), the postripening stage, during which the fruit is prone to microbial attack and decay (Tharanathan et al., 2006). Mango fruits normally reach maturity about 4–5 months after flowering.

COMPOSITION OF MANGO CULTIVARS

Nutritional Composition of Mango

Fruits play a very important role in human nutrition by providing additional sources of energy, necessary growth factors, carbohydrates, dietary fibers, and antioxidants,

which are essential for maintaining normal health. The quality of any fruit is largely decided by its physicochemical and nutritional characteristics, which are gained during the process of ripening. The physiology of fruit ripening involves numerous physical activities such as loss of fruit weight and volume, changes in specific gravity, peel and pulp color development, and decline in fruit firmness. These are followed by a series of chemical changes, such as decline in acidity, starch, and insoluble solids, while there is an increase in total sugars and aroma-forming compounds (Gowda and Huddar, 2001). However, all these properties experience significant variation depending upon variety of fruit, environmental conditions during the growth, geographic location of cultivation, nutritional content of the fruit, stage of fruit maturity, postharvest treatment, and storage conditions. Mango is a major source of sugars (reducing and nonreducing), carbohydrates, fats, vitamins, minerals, dietary fibers, antioxidants, tannins, polyphenols, pigments, and flavor compounds with the high energy value of 250 kJ (60 kcal) per 100 g of common mango and thus is a commercially valuable food crop (Table 1). Fresh as well as processed forms of mango fruit are an important part of the human diet.

Although fruits usually portray low protein and fat content, Peruvian mango has high protein content, which ranges from 1.5 to 5.5%. Further, mango cultivars from Java show 1–2% protein content in the skin and 0.6–1% in the pulp of fruits. However, for Indian mango cultivars, it ranges approximately from 0.5 to 1%. Augustin and Ling (1987) studied variation in amino acid content in three different varieties (Table 2). The amino acid content of the fruit also varies depending upon the maturation level. For example, it has been reported that the peak stage of maturation shows the presence of only alanine, arginine, glycine, serine, leucine, and isoleucine, while all other amino acids are present in trace amounts (Tharanathan et al., 2006). The lipid content in peel and pulp of five mango varieties, including ‘Malgoa’, ‘Totapuri’, ‘Benishan’, ‘Sundari’, and ‘Neelam’, has been studied wherein; it ranged from 0.75 to 1.7% for peel and 0.8 to 1.36% for pulp (Pathak and Sarada, 1974). Elaborate analysis of fatty acid content in the ‘Alphonso’ mango during ripening showed a steady increase in its content until perfect ripe stage, with no significant change thereafter (Bandyopadhyaya and Gholap, 1973). A comparative study of lipid contents of ‘Alphonso’ and ‘Totapuri’ displayed a steep increase in the lipid content of ‘Alphonso’ during ripening, while no significant change in ‘Totapuri’ mango was evident (Gholap and Bandyopadhyaya, 1975). In addition, both these studies also explained a unique correlation between palmitic to palmitoleic acid ratio and the flavor character of mango cultivars. A recent analysis of total and neutral lipid content of ‘African Bush’ mango cultivar showed a much higher concentration of these compounds in ‘Bush’ mango as compared to the Indian cultivars (Olawale, 2010). Extensive fatty acid analysis was carried out on different mango cultivars, yielding qualitative and quantitative variation as listed in Table 3 (Ali et al., 1985; Sonwai and Ponprachanuvut, 2014).

Table 1 General nutritional content of mango fruit

Nutrient	Units	Value per 100 g of edible portion	Sample count	Std. error
Proximates				
Water	g	81.71	108	0.323
Energy	Kcal	65	0	—
Energy	kJ	272	0	—
Protein	g	0.51	79	0.025
Total lipid (fat)	g	0.27	47	0.039
Carbohydrate, by difference	g	17.00	0	—
Fiber, total dietary	g	1.8	0	—
Ash	g	0.50	66	0.033
Minerals				
Calcium, Ca	mg	10	27	0.850
Iron, Fe	mg	0.13	21	0.021
Magnesium, Mg	mg	9	20	0.580
Phosphorus, P	mg	11	41	0.746
Potassium, K	mg	156	24	8.441
Sodium, Na	mg	2	24	0.624
Zinc, Zn	mg	0.04	1	—
Copper, Cu	mg	0.110	17	0.009
Manganese, Mn	mg	0.027	17	0.002
Selenium, Se	µg	0.6	0	—
Vitamins				
Vitamin C, total ascorbic acid	mg	27.7	162	1.749
Thiamin	mg	0.058	35	0.005
Riboflavin	mg	0.057	36	0.004
Niacin	mg	0.584	36	0.070
Pantothenic acid	mg	0.160	0	—
Vitamin B-6	mg	0.134	1	—
Folate, total	µg	14	0	—
Folic acid	µg	0	0	—
Folate, food	µg	14	0	—
Folate, DFE	µg	14	0	—
Vitamin B-12	µg	0.00	0	—
Vitamin A	IU	3894	91	244.166
Vitamin A, RE	µg	389	91	24.417
Vitamin E	mg	1.120	0	—
Tocopherol, alpha	mg	1.12	0	—
Lipids				
Fatty acids, total saturated	g	0.066	0	—
4:0	g	0.000	0	—
6:0	g	0.000	0	—
8:0	g	0.000	0	—

Table 1 General nutritional content of mango fruit—cont'd

Nutrient	Units	Value per 100 g of edible portion	Sample count	Std. error
10:0	g	0.000	0	—
12:0	g	0.001	15	—
14:0	g	0.009	19	—
16:0	g	0.052	19	—
18:0	g	0.003	19	—
Fatty acids, total monounsaturated	g	0.101	0	—
16:1 undifferentiated	g	0.048	19	—
18:1 undifferentiated	g	0.054	19	—
20:1	g	0.000	0	—
22:1 undifferentiated	g	0.000	0	—
Fatty acids, total polyunsaturated	g	0.051	0	—
18:2 undifferentiated	g	0.014	19	—
18:3 undifferentiated	g	0.037	19	—
18:4	g	0.000	0	—
20:4 undifferentiated	g	0.000	0	—
20:5 n-3	g	0.000	0	—
22:5 n-3	g	0.000	0	—
22:6 n-3	g	0.000	0	—
Cholesterol	g	0	0	—
Amino acids				
Tryptophan	g	0.008	11	—
Threonine	g	0.019	2	—
Isoleucine	g	0.018	2	—
Leucine	g	0.031	2	—
Lysine	g	0.041	13	—
Methionine	g	0.005	13	—
Phenylalanine	g	0.017	2	—
Tyrosine	g	0.010	2	—
Valine	g	0.026	2	—
Arginine	g	0.019	2	—
Histidine	g	0.012	2	—
Alanine	g	0.051	2	—
Aspartic acid	g	0.042	2	—
Glutamic acid	g	0.060	2	—
Glycine	g	0.021	2	—
Proline	g	0.018	2	—

A considerable share of organic acids is reported from mango fruits, which includes citric, tartaric, oxalic, succinic, pyruvic, galipic, galacturonic, glucuronic, and muconic acids, of which citric acid occupies major part, with its content varying from 0.13 to 0.71% FW of fruits (Table 1) (Tharanathan et al., 2006). In a cultivar specific study, it

Table 2 Amino acid composition (g/100 g) in seed kernels of some mango cultivars

Amino acid		Harumanis	Siam Panjang	Unclassified variety	Chausa	Dusheri
Essential	Isoleucine	4.1	4.1	3.9	4.9	4.2
	Leucine	6.9	6.7	6.5	7.0	7.2
	Lysine	4.2	4.9	4.8	5.5	4.5
	Methionine	1.7	1.0	1.0	2.1	2.3
	Phenylalanine	3.9	3.8	3.2	4.9	4.2
	Tryptophan	a	a	a	1.7	2.0
	Valine	5.0	4.9	5.3	5.3	5.1
	Histidine	0.8	1.0	0.9	2.6	2.7
Nonessential	Alanine	5.0	5.4	5.3	4.5	4.7
	Arginine	9.0	7.9	9.6	8.8	9.2
	Aspartic acid	13.1	10.2	10.6	10.0	10.6
	Cysteine	a	a	a	2.3	2.3
	Glutamic acid	20.8	16.6	17.8	16.0	10.9
	Glycine	4.6	4.1	4.5	3.9	4.1
	Proline	5.1	4.3	3.9	B	B
	Serine	4.8	4.5	5.0	3.9	4.1
	Threonine	3.6	3.3	3.8	B	B
	Tyrosine	2.7	3.9	3.4	3.1	3.4

was shown that in ‘Keitt’ mangoes, citric and malic acids were the predominant organic acids followed by tartaric, oxalic, ascorbic, and α -ketoglutaric acids detected in minor quantities (Medlicott et al., 1986). In case of African cultivars, fruits showed moderate acid content ranging from 0.2 to 1.3 percent of citric acid. (Othman and Mbogo, 2009). Sugars are one of the most important compounds, from taste as well as nutrition point of view. Accumulation of sugars during ripening of mango has been positively correlated with the degradation of starch, a prominent component of mature unripe mango fruit (Bernardes-Silva et al., 2008). In African mango cultivars, the total sugar content varies from 10.5 to 32.4% (Othman and Mbogo, 2009), while the range is minimized to 10–12% in Sudanese cultivars (Nour et al., 2011). Grossly, mango fruit experiences increased accumulation of total sugars during ripening. Their concentration ranges from 11.5 to 35% of FW and mainly includes sugars such as glucose, fructose, maltose, and xylose. Among these, fructose was reported as dominant sugar during the development and preclimacteric periods of ‘Keitt’ mango, while sucrose accounted for 57% of total sugar content of ripe ‘Keitt’ mango (Bernardes-Silva et al., 2008). Similarly, ‘Baladi’ (Sharaf et al., 1989) and ‘Haden’ (Castrillo et al., 1992) mango cultivars showed dominance of sucrose (over 60% of the total soluble sugar) in their ripe fruit, with increased accumulation of fructose at the overripe stage of ‘Baladi’ mango. Yashoda et al. (2005) reported an increase in soluble sugar content (from 7 to 20%) during ripening of

Table 3 Fatty acid content in different varieties of mango

Fatty acid	Harumanis	Alphonso (% wt)	Siam Panjang	Brindaboni	Fazli	Kalabau	Kanchamitha	Kuipahari	Lakhanvoge	Lengra	Misrakanta	Kaew- Morakot	Nam Dokmai	Aok-rong
Lauric	—	0.3	—	—	—	—	—	—	—	—	—	0.04	0.03	0.07
Myristic	0.03	2.9	0.03	—	—	—	—	—	—	—	—	0.06	0.07	0.09
Palmitic	7.16	26.8	7.26	9.2	8.4	8.1	9.1	10.0	9.7	8.5	7.9	6.24	7.38	7.69
Margaric	0.17	—	0.14	—	—	—	—	—	—	—	—	—	—	—
Stearic	44.41	1.5	44.28	39.1	39.4	40.2	38.2	38.3	38.3	39.3	39.2	37.38	41.40	36.78
Oleic	41.71	19.4	42.13	41.1	42.5	41.5	43.0	41.3	41.7	42.4	43.8	45.72	42.85	46.79
Linoleic	4.93	2.2	4.54	7.6	7.3	7.3	6.3	7.1	6.9	6.8	6.0	5.89	4.26	4.43
Linolenic	Trace	14.9	Trace	0.7	0.7	0.6	0.9	0.9	0.7	0.7	1.0	0.55	0.39	0.42
Arachidic	1.59	—	1.63	2.3	1.7	2.2	2.5	2.5	2.6	2.2	2.0	1.67	1.40	1.55
Behenic	—	—	—	—	—	—	—	—	—	—	—	0.32	0.25	0.30
Lignoceric	—	—	—	—	—	—	—	—	—	—	—	0.39	0.23	0.36

Note that the unit for mango varieties in this table is percent area, except ‘Alphonso’, which is percent weight. (Ali et al., 1985; Sonwai and Ponprachanuvut, 2014; Bandyopadhyaya and Gholap, 1973).

‘Alphonso’ mango. A similar observation was also reported for ‘Dashehari’ (Kalra and Tandon, 1983), ‘Keitt’ (Medlicott et al., 1986), and ‘Tommy Atkins’ mangoes during ripening (Tasneem, 2004). Mango pulp is a rich source of pectin, which is an important component as a gelling sugar. Pectin content in mango increases after the fifth week of fruit set until the completion of stone formation. In case of ‘Dashehari’ mango, water-soluble pectin starts accumulating after 70 days of fruit set, with its peak accumulation at the complete mature stage of fruit development. However, the alkali soluble fraction of pectin (protopectin) increases up to 70 days after the fruit set and decreases thereafter until harvest (Kalra and Tandon, 1983). Similarly in ‘Alphonso’, unripe fruit shows an accumulation of pectin with the significant decrease in its molecular weight in the progress of ripening. This can be seen as a consequence of increased activity of pectin-solubilizing enzymes such as galactanase, β -galactosidase, and polygalacturonase during ripening (Prasanna et al., 2004). The variation in physicochemical characteristics in ripe and unripe fruits in four different varieties of mango studied by Ellong et al. (2015) is in harmony with ripening physiology of mango, as well as with the other climacteric fruits (Table 4). These investigations, apart from physiology, are very important for the processing quality. Vijayanand et al. (2015) have used the physiochemical characteristics of ‘Sindura’, ‘Mallika’, and ‘Totapuri’ mango cultivars to shed light on the change in fruit physiology after processing.

Mango fruit possesses various antioxidants, which are crucial in the prevention or scavenging of reactive oxygen species (ROS) and reactive nitrogen species (RNS). These include phenolic compounds, carotenoids, anthocyanins, and tocopherols. With the process of ripening, development of characteristic peel and pulp color involves a progressive loss of chlorophyll with an increased accumulation of carotenoids (Lizada, 1991). A total of 16 carotenoids are reported from mango, of which β -carotene has a dominant share (60%) with its maximum contribution to fully ripe fruit. Carotenoid synthesis generally produces many xanthophylls during early ripening, which include violaxanthin, antheraxanthin, and auroxanthin, followed by synthesis of β -carotene, α -carotene, ζ -carotene, and γ -carotene during late ripening stages (Gomez-Lim, 1997). All these collectively serve as chemoprotectants.

Different parts of the mango (fruit pulp, peel, seed kernel, leaves, and stem bark) are rich source of various polyphenols, with concentration of the individual polyphenols varying in different parts or missing totally in some parts. Polyphenol content is the highest during growth of mango fruit that decreases on ripening (Kalra and Tandon, 1983). The major polyphenols in the mango in terms of antioxidative capacity and/or quantity are: mangiferin, catechins, quercetin, kaempferol, rhamnetin, anthocyanins, gallic and ellagic acids, tannic acid, caffeic acid, ferulic acid, propyl and methyl gallate, benzoic acid, and protocatechuic acid (Masibo and Qian, 2008). These antioxidants were extensively studied in some Thai varieties of mango (Table 5) (Berardini et al., 2005).

Table 4 Physicochemical changes in mango upon ripening

Physicochemical characteristics								
Cultivar	Stage of ripening	pH	TA g/100 g	Starch g/100 g	Carbohydrates g/100 g	Vit. C mg/100 g	Total polyphenol mg/100 g	Total carotenoids µg/100 g
Bassignac	Unripe	3.52	1.45	5.50	19.46	16.00	95.58	2183.00
	Ripe	4.13	0.86	4.50	20.31	25.50	100.18	4138.50
Green	Unripe	3.58	1.62	6.55	14.42	28.20	86.40	276.17
	Ripe	4.45	0.70	0.60	14.33	17.05	79.10	805.13
Julie	Unripe	3.09	1.39	7.50	48.42	34.50	117.50	954.00
	Ripe	4.30	0.47	6.00	21.48	14.50	111.81	3647.50
Moussache	Unripe	4.23	0.42	12.90	23.53	30.85	57.00	449.33
	Ripe	5.25	0.13	3.27	23.99	6.85	66.13	603.35

Table 5 Polyphenol content in different varieties of mango

Compound	Tommy Atkins	Manila	Ngowe	R2E2	Kent	Jose	Mini- mango	Haden	Heidi	Kaew	Mon DuenGao	MahaChanock	Nam Dokmai	Chok Anan
Mangiferin	1263.2	43.5	775.8	82.9	13.9	983.6	449.9	11.2	108.9	313.6	68.0	973.9	78.1	1297.1
Isomangiferin	40.3	11.5	184.7	19.0	4.0	45.5	13.3	21.0	8.0	28.6	10.6	54.7	14.3	41.2
Mangiferingallate	87.3	7.8	377.4	—	—	25.2	31.6	—	—	43.0	8.7	166.1	24.1	89.9
Isomangiferingallate	12.3	3.0	127.1	—	—	—	—	—	—	—	—	22.3	—	—
Quercetin-diglycoside	55.1	145.9	29.7	—	—	40.3	—	—	25.9	6.1	10.1	—	38.8	—
Quercetin 3-O-gal	1217.3	430.6	797.6	116.5	944.5	1467.7	1147.1	1309.1	1275.7	76.5	121.3	396.1	185.2	146.1
Quercetin 3-O-glc	882.0	282.5	359.1	124.4	890.0	1045.3	767.8	912.7	814.5	77.4	83.0	339.0	103.7	92.4
Quercetin 3-O-xyl	239.5	39.2	100.9	17.8	150.7	278.6	10.2	179.1	225.7	14.7	16.9	42.2	14.0	19.1
Quercetin 3-O-arap	163.5	27.6	70.7	8.8	91.6	191.8	3.5	104.9	131.9	7.6	10.2	28.6	8.3	9.6
Quercetin 3-O-araf	152.4	17.9	56.8	8.2	84.8	119.6	—	70.5	123.5	6.8	5.5	19.8	6.1	8.2
Quercetin 3-O-rha	38.2	15.6	20.6	5.3	58.1	116.4	—	52.7	41.6	4.2	4.6	20.6	5.9	4.2
Kaempferol 3-O-glc	77.3	16.8	24.1	11.2	30.6	171.7	—	43.7	73.0	9.9	6.7	36.5	3.6	20.9
Rhamnetin 3-O-gal/glc	215.6	14.6	22.6	5.4	70.6	374.4	49.8	228.6	57.4	—	6.2	20.4	3.6	—
Quercetin	—	1.7	6.7	—	3.3	—	19.3	2.8	11.9	—	2.8	—	—	—

Abou Aziz et al. (1976) reported a considerably higher content of total phenolic compounds in the skin of 'Pairi' mango than the pulp, which tends to decrease with storage time. A detailed analysis of peel of raw and ripe stages of Indian cultivars: 'Raspuri' and 'Badami' (Ajila et al., 2007), and 'Dashehari', 'Chausa', and 'Fazli' (Nehra and Sharma, 2012) depicted maximum phenolics content in the peel of raw stages. Carotenoids and anthocyanin were the highest in ripe stages, with a quantitative abundance in 'Raspuri' and 'Badami' cultivars compared to the others. These studies pointed out the fact that mango peel, which is a by-product of the mango processing industry, is a major source of bioactive compounds and if processed properly, can be used as a source of functional food or a value-added component in the dietary system. Raw and ripe stages of six commercially important Indian mango cultivars, 'Deshi', 'Langra', 'Chausa', 'Mallika', 'Dashehari', and 'Amrapali', were analyzed for their phenolic acid content, which showed maximum contribution of total phenolics to the ripe fruits than the raw stage. Further, all the cultivars invariably showed a quantitative abundance of tannic acid followed by gallic and ferulic acid (Singh et al., 2004). Four distinct foreign cultivars, 'Haden', 'Tommy Atkins', 'Uba', and 'Palmer' were also analyzed for their phenolic and carotenoid content. The total content of phenolic compounds ranged from 48.40 mg 100 g⁻¹ ('Haden') to 208.70 mg 100 g⁻¹ ('Uba'), while total carotenoid ranged from 1.91 mg 100 g⁻¹ ('Haden') to 2.63 mg 100 g⁻¹ ('Palmer'). Among these β -carotene accounted for 661.27 μ g 100 g⁻¹ ('Palmer') to 2220 μ g 100 g⁻¹ ('Uba') of carotenoid share (Rocha Ribeiro et al., 2007). These values are comparatively higher than those in the Indian cultivars.

Vitamins contribute a major part of nutritional content of fruits. In the case of mango, the initial study for analysis of vitamins A, C, and D content was carried out in three cultivars, 'Alphonso', 'Cawajji Patel', and 'Shendrya' (Perry and Zilva, 1932). Among these, vitamin A and C were dominant in 'Alphonso', although minute quantities were detected in the other two cultivars. However, vitamin D was not detected in any of these cultivars. Among the vitamins present in mango, vitamin C has shown the exceptional antioxidant quality, and its concentration in ripe flesh of mango ranged from 1.5 to 175 mg 100 g⁻¹ (Table 1). So far in mango, the reduction in ascorbic acid concentration has been noted between 5 and 10 weeks after fruit set. Rocha Ribeiro et al. (2007) reported the total ascorbic acid content of 'Tommy Atkins' and 'Uba' mangoes as 9.79 and 77.71 mg 100 g⁻¹, respectively. Ascorbic acid content is specific to cultivar and stage of maturity. Spencer, Morris and Kennard (1956) showed that the ascorbic acid content of four different cultivars, 'Amini', 'Mullgoa', 'Pico', and 'Turpentine' was higher (88 mg 100 g⁻¹) in small size fruit (about 5 weeks mature) as compared to the fully mature fruit (22 mg 100 g⁻¹). In case of Indian cultivars, the maximum content of vitamin C was reported during initial stages of development in 'Pairi' (300 mg 100 g⁻¹), while it was higher during ripe stages in 'Dashehari' (Siddappa and Bhatia, 1954). Among the group of vitamin B, folic acid (vitamin B9) was reported as 3.6 mg 100 g⁻¹ in raw mango, along with vitamin B1 (thiamin) and B2 (riboflavin), ranging from 35 to 73 mg 100 g⁻¹ FW.

All these collectively put forth mango as a nutritional treasure, along with its delicious flavor attributes.

However, different researchers have considered varied parameters to assess the nutritional composition of some of the locally important mango cultivars. Mango seed kernel, which is the least regarded nutritional part, can be used in cattle feed, chapatti preparation, in toffee, and for some other products as a fortifying agent without ruining or affecting the quality after removal of the tannins. It can be used as a solid fat substitute and some oil replacement (Afifa et al., 2014; Ali et al., 1992; Hossain et al., 2001; Kansci et al., 2003; Leghari et al., 2013; Naz et al., 2014; Nixwell et al., 2013). Tabulation of available characteristics of such famous cultivars brings an insight into the variation in the nutritional composition at climatic and intercontinental level (Table 6). However, with the evolution of the technologies concerned with ionomics, metabolomics, and proteomics, more information would be generated, which may lead to better understanding of the nutritional composition of mango cultivars.

Biochemical and Molecular Analysis of Mango Flavor

Apart from being a nutritionally rich fruit, mango possesses a delicious and attractive flavor, a complex commodity collectively contributed by aroma, taste, and texture of any particular fruit/food. Among these, aroma has a significant impact on the flavor of any fruit and is perceived either by orthonasal (through the nasal cavity) or by retronasal (through the mouth cavity) route. As the aroma is a function of volatiles, many efforts have been dedicated to identify these aroma volatile compounds from mango (Pino and Mesa, 2006). These studies, as well as our own studies as discussed below, collectively put forth the fact that mango-like aroma is not a function of any single compound, but it is a collective effect of volatiles from various chemical classes, such as terpene-hydrocarbons, lactones, aldehydes, ketones, alcohols, and esters. India, being the center of the origin and diversity of the mango, harbors a large number of mango cultivars. However, they are largely unattended for studies of their volatile composition. Taking into account the vital role of these aroma volatiles in imparting characteristic flavor to mango cultivars, we initiated systematic biochemical and molecular studies to explore the volatile composition of mango pertaining to various aspects of volatile diversity and biosynthesis. These along with other efforts are discussed below.

Volatile Diversity of Mango Cultivars

We analyzed 27 mango cultivars, including 22 Indian and 5 non-Indian for their volatile composition (Pandit et al., 2009a). A total of 84 volatile compounds were detected, wherein the highest and the lowest qualitative abundance of volatiles was shared by 'Alphonso' and 'Pairi' cultivars, respectively. Moreover, the highest and the lowest quantitative abundance were also shared by Indian cultivars 'Langra' and 'Chandrama', respectively. It was clearly evident from the study that the volatile profile of mango cultivars

Table 6 Nutritional composition of some indigenous and foreign cultivars

Variety	pH	Acidity (%)	TSS	Total invert sugar (%)	Reducing sugar (%)	Nonreducing sugar	Moisture (%)	Ash (%)	Carbohydrates (%)	Proteins (%)	Fats (%)	Vitamin C (mg/100 g)	Total sugar	Fiber
Indian cultivars														
Alphonso	—	0.41	19.60	15.20	2.43	10.60	—	—	—	—	—	14.01	17.00	—
Prior	—	0.20	14.00	—	2.23	—	—	—	—	—	—	1.23	12.50	—
Muvandan	—	0.23	10.00	—	2.35	—	—	—	—	—	—	1.50	6.00	—
Neelum	—	0.46	16.00	—	2.29	—	—	—	—	—	—	18.70	12.80	—
Ratna	—	0.28	24.00	—	2.97	—	—	—	—	—	—	31.30	20.66	—
H-151	—	0.21	23.00	—	2.66	—	—	—	—	—	—	53.00	18.66	—
Desi	2.88	0.59	8.53	—	—	—	86.55	0.29	—	—	—	—	—	—
Sindhri	2.82	0.38	9.09	—	—	—	88.60	0.60	—	—	—	—	—	—
Langra	2.77	0.49	9.35	—	—	—	85.97	0.38	—	—	—	—	—	—
Chaunsa	3.01	0.38	7.33	—	—	—	85.72	0.45	—	—	—	—	—	—
Himsagar	5.37	0.26	19.0	—	2.65	—	—	—	—	—	—	—	—	—
Fazli	6.00	0.154	17.93	—	2.44	—	—	—	—	—	—	—	—	—
Amrapali	4.94	0.374	20.13	—	3.53	18.50	—	—	—	—	—	12.5	—	—
Langra	4.91	0.321	17.6	—	1.44	—	—	—	—	—	—	—	—	—
Ashwina	3.58	0.798	17.27	—	0.82	—	—	—	—	—	—	—	—	—
Totapuri	3.9	0.38	15.3	—	2.9	—	—	—	—	—	—	—	10.5	—
Foreign cultivars														
Saber	—	—	—	—	—	—	8.9	2.0	85.0	2.3	0.2	198.3	—	2.0
Peach	—	—	—	—	—	—	9.3	2.0	85.1	2.0	0.2	27.7	—	1.6
Mallika	4.9	0.60	20.70	—	8.00	15.13	—	—	—	—	—	9.6	—	—
Bishwanath	4.0	0.87	17.6	—	6.58	12.12	—	—	—	—	—	14.20	—	—
Palmer	—	—	—	13.4	—	—	—	—	—	—	—	—	—	—
Anwar Ratual	5.33	0.23	14.97	20.333	—	—	86.00	0.30	—	0.49	0.45	126.0	—	—
Aman Dusahri	5.40	0.26	15.63	18.333	—	—	83.83	0.13	—	0.51	0.41	136.3	—	—
Keitt	—	0.411	21.24	14.90	4.10	10.30	7.8	2.0	85.7	2.8	0.2	177.5	—	1.8
Tommy Atkins	—	—	—	—	—	—	9.1	2.0	85.2	2.4	0.2	67.1	—	1.7
Vhavenda	—	—	—	—	—	—	7.8	2.0	85.1	1.9	0.2	29.8	—	2.6
Sunshine	—	—	—	—	—	—	8.8	2.0	84.4	2.2	0.2	140.8	—	1.8
Pope	—	0.70	20.84	15.20	4.70	9.90	—	—	—	—	—	36.30	—	—
Momi-K	—	0.59	22.24	15.60	4.00	10.90	—	—	—	—	—	48.60	—	—
Zil	—	0.55	19.37	14.50	4.20	9.80	—	—	—	—	—	31.70	—	—

Continued

Table 6 Nutritional composition of some indigenous and foreign cultivars—cont'd

Variety	pH	Acidity (%)	TSS	Total invert sugar (%)	Reducing sugar (%)	Nonreducing sugar	Moisture (%)	Ash (%)	Carbohydrates (%)	Proteins (%)	Fats (%)	Vitamin C (mg/100 g)	Total sugar	Fiber
Sindri	—	0.42	18.82	15.30	4.60	10.20	—	—	—	—	—	34.70	—	—
Intikhab	—	0.37	20.83	14.40	4.20	9.60	—	—	—	—	—	38.60	—	—
Pohilot	—	0.52	22.81	14.60	3.80	10.21	—	—	—	—	—	31.80	—	—
Shah pasand	—	0.30	21.89	15.80	4.50	10.80	—	—	—	—	—	28.60	—	—
Banganpalli	—	0.49	23.20	14.50	4.30	9.10	—	—	—	—	—	35.40	—	—
SS-I	—	0.32	21.31	16.20	4.00	11.45	—	—	—	—	—	43.60	—	—
SS-II	—	0.58	21.41	15.30	4.80	10.00	—	—	—	—	—	35.90	—	—
Sanglakhli	—	0.80	21.14	14.10	3.90	9.70	—	—	—	—	—	180.20	—	—
Ghafoor-e-Wala	—	0.35	21.83	15.60	4.20	10.80	—	—	—	—	—	38.60	—	—
Neelum	—	0.56	19.90	16.60	5.10	10.80	—	—	—	—	—	38.40	—	—
Sensation	—	0.39	19.71	15.20	4.20	10.50	—	—	—	—	—	35.70	—	—
Fajri	—	0.31	21.00	14.00	3.87	9.60	—	—	—	—	—	60.00	—	—
Tamuria	—	0.20	23.20	14.80	4.12	10.20	—	—	—	—	—	48.00	—	—
S B Chaunsa	—	0.28	24.90	16.40	4.62	11.60	—	—	—	—	—	155.00	—	—
Yakta	—	0.42	20.34	18.00	5.57	11.70	—	—	—	—	—	40.90	—	—
Malda	—	0.31	17.34	17.20	5.35	9.80	—	—	—	—	—	42.60	—	—
Burma Surkha	—	0.48	19.94	14.50	2.90	9.90	—	—	—	—	—	37.10	—	—
Kensington	—	0.68	20.21	15.50	4.50	10.60	—	—	—	—	—	43.90	—	—
Tomiatkin	—	0.59	20.17	15.50	4.40	10.70	—	—	—	—	—	33.90	—	—
Maya	—	0.36	21.35	15.00	4.10	10.30	—	—	—	—	—	47.30	—	—
Wadia Muna	—	0.35	19.50	13.50	3.50	9.30	—	—	—	—	—	56.30	—	—
Syed														
Saleh Bhai	—	0.64	20.60	16.60	3.90	12.10	—	—	—	—	—	32.80	—	—
Zafran	—	0.68	25.00	12.00	3.70	7.71	—	—	—	—	—	102.90	—	—
Anmol	—	0.66	23.00	13.70	4.50	8.92	—	—	—	—	—	23.50	—	—
Gulab Khas	—	0.29	27.50	14.30	3.40	10.40	—	—	—	—	—	43.15	—	—
Sobe-de-ting	—	0.70	24.30	12.70	3.30	8.90	—	—	—	—	—	43.90	—	—
Swarnareeka	—	0.46	23.25	14.10	4.30	9.30	—	—	—	—	—	29.90	—	—

was dominated by terpene hydrocarbons, with 20 cultivars having monoterpene dominance, while 7 had sesquiterpene predominance. By far, the study was the first to display a group of mango cultivars with sesquiterpene hydrocarbon as their dominant class of volatiles. Nevertheless, cultivars were grouped into three distinct categories based upon the quantitative abundance of three monoterpenes: β -myrcene, (Z)-ocimene, and δ -3-carene. These compounds were termed as principle volatile components (PVCs) of cultivars. Most of the Indian cultivars had β -myrcene and/or (Z)-ocimene as their PVC, whereas non-Indian cultivars invariably had δ -3-carene as their PVC. This observation was supported by the earlier finding, which stated δ -3-carene as the only compound contributing mango-like notes to the western mango cultivars (Macleod and Snyder, 1985). 'Langra' was the only Indian cultivar with δ -3-carene as its PVC with concentration higher than any other non-Indian cultivar. Such clear dominance of volatile compounds was also reported for Australian, Sri Lankan, African, Floridian, Colombian, and Cuban mangoes (Lalel et al., 2003; Macleod and Snyder, 1988; Quijano et al., 2007). Variation in the PVCs in the Indian and the non-Indian cultivars implied distinct criteria used in the domestication or selection of these cultivars. Further, among the 27 cultivars, 'Alphonso' and 'SB Chausa' were found to have qualitative and quantitative dominance of lactones, respectively. These oxygenated volatile compounds are known for their sweet, fruity odor character, and low odor detection threshold, thereby significantly contributes to aroma of these mango cultivars. Moreover, Idstein and Schreier (1985) showed that the aroma of 'Alphonso' mango is contributed by 14 different γ - and δ -lactones. No other mango cultivar or other fruit is known to possess such a diversity of lactones. The volatile blend of 'Alphonso' was also shared by the highest quantities of furaneol and mesifuran, which are important contributors of caramellike sweet fruity flavor (Pandit et al., 2009a). Thus, 'Alphonso' is a unique mango cultivar with the abundance of both lactones and furanone in its ripe fruits. Among the set of 27 cultivars, the non-Indian cultivars showed only trace amount of lactones as compared to the Indian cultivars. These observations suggested that the Indian and the foreign cultivars have varied volatile composition and blend. Also, they might have undergone distinct selection criteria during domestication in the different parts of the world.

Spatial and Temporal Variations in the Volatile Composition of 'Alphonso' Mango

Alphonso, an Indian mango cultivar, is blessed with many attributes, such as delicious taste, pleasant aroma, attractive color, low fiber-containing pulp, and long shelf life. However, the popularity of 'Alphonso' at the Indian, as well as international, market is mainly attributed to its flavor. Its raw, as well as ripe, fruits are largely utilized in various cuisines and in food processing industries in India. Owing to this, various attempts were made to explore the chemical composition of 'Alphonso' aroma. Gholap et al. (1986) carried out an olfactory analysis of various ripening stages of 'Alphonso' mango, which

displayed the aroma of raw mango as more terpenic and earth-like, and that of ripe fruit was with an addition of coconut/almond like notes. The vast differences in the flavors of raw and ripe fruits of 'Alphonso' in terms of variations in the pattern of volatiles emitted during various developmental and ripening stages of 'Alphonso' were investigated in our group (Pandit et al., 2009b). Five developing and five ripening stages of 'Alphonso' fruits, along with its flowers and leaves, and mature raw and ripe fruits of 'cv. Sabja' were studied for their volatile composition. Fifty-five different volatile compounds were identified and analyzed throughout the data set, among which monoterpene hydrocarbons qualitatively and quantitatively dominated the volatile profile at all the stages, followed by sesquiterpene and lactones. Moreover, (Z)-ocimene, a monoterpene hydrocarbon, dominated the spatial as well as temporal volatile profile of the 'Alphonso' mango, along with the late ripening stages characterized by the de novo appearance of lactones and furanones. This is in congruence with an earlier finding, which stated that the aroma of ripe 'Alphonso' retains the odor character of raw fruit with the dominant addition of a sweet, fruity flavor. Further, quantitative and qualitative analysis of these compounds revealed fruits at 5 and 15 days after pollination (DAP) stage had the highest amount of volatiles, and thus, this was collectively termed as the jump start stage, as the concentration of these volatiles gradually decreased in the further stages. Similarly, fruits at 2 days after harvest (DAH) stage had the lowest share of volatile concentration and were considered as 0 DAH. Lactones and furanones, which are vital flavorants of ripe 'Alphonso' fruits, showed the highest share at 15 DAH stage. Similar work carried out on the 'Kensington Pride' mango also showed dominance of terpene hydrocarbons during ripening, with selective increase in the concentration of ethyl octanoate during the late ripening stages (Lalel et al., 2003). Only two cultivars, 'Keitt' (Macleod and Snyder, 1985) and 'Kensington Pride' (Bartley and Schwede, 1987) were monitored for their volatile content at the overripe stage, which showed synthesis of off-flavor alcohols in 'Keitt', whereas reduced levels of ethyl butanoate were observed for 'Kensington Pride'. In 'Alphonso', overripening was characterized by a reduction in the quantities of terpenes and lactones and an increase in the furanones (Pandit et al., 2009b). This work has collectively demonstrated important maturity and ripening indices based on the characteristic volatile profile during development and ripening. Further, it has also displayed the importance of lactones and furanones to the flavor of ripe 'Alphonso' fruits.

EFFECT OF GEOGRAPHIC VARIATION ON MANGO FRUIT FLAVOR

'Alphonso' mangoes are mainly propagated by an asexual method called as grafting; hence, they are genetically identical. Irrespective of similar genetic characteristics, cultivation practices and harvesting processes, this highly favored fruit shows variation in fruit quality, flavor, and texture with respect to localities. Locality-dependent variation in mango fruit sap (Hassan et al., 2009) and fruit quality (Hofman et al., 1997) was initially

studied in the Australian mango cultivar 'Kensington Pride'. These studies indicated that sap quality, quantity, fruit eating quality, and percentages of dry matter vary with change in growing localities. [Kulkarni et al. \(2012\)](#) carried out the extensive study on changes in flavor volatiles due to different geographic localities of 'Alphonso' cultivation. This work clearly depicted that the pulp of completely ripe fruits from one of the locations, Deogad, has a lower level of mono- and sesquiterpenes, with a high share of lactones and furanones as compared to the fruits from the other location, making Deogad fruits more fruity, creamy, and caramellike than the terpenic fruits from Dapoli. However, fruits from the third location, Vengurle, had average quantities of these aroma volatiles in comparison with the fruits from Deogad and Dapoli regions. This variation in the volatile composition of fruits from three cultivation localities can be seen as a result of phenotypic plasticity, which might be because of varied abiotic or environmental factors such as heat units received, humidity, soil quality, etc. In light of these observations, studies on molecular mechanisms regulating the biosynthesis of these volatiles would be ideal to reveal the differential behavior of these chemical compounds among the geographic localities.

EXOGENOUS ETHYLENE TRIGGERED RIPENING-RELATED PROCESSES AND METABOLITE CHANGES IN 'ALPHONSO' MANGO

Fruit ripening is a complex process, which involves fruit softening, generation of aroma volatiles, conversion of organic acids to sugars, chloroplast degradation, and chromoplast synthesis. Fruits, based on their ethylene production and respiration pattern during ripening, are classified as climacteric and nonclimacteric. For mango, being a climacteric fruit, ethylene plays an important role in its ripening. Various studies were carried out to understand the effect of exogenous ethylene treatment on different physiological processes during mango ripening ([Chourasia et al., 2008](#)), causing changes in volatile accumulation. However, organoleptic evaluation of 'Keitt' and 'Kensington Pride' mangoes with ethephon treatment led to reported improvement in their flavor ([Sergent et al., 1993](#); [Singh and Janes, 2001](#)). Because aroma volatiles are a crucial component of mango flavor, a comprehensive analysis of aroma volatiles from skin and pulp of ethylene treated and control 'Alphonso' mangoes was initiated in our laboratory. Qualitative and quantitative analysis of 24 volatiles in the present data set displayed the ripe stage (15 DAH) of control fruits with the highest concentration of volatiles, irrespective of tissue, skin, and pulp. This finding was in congruence with our earlier reports ([Kulkarni et al., 2012](#); [Pandit et al., 2009b](#)). The skin of 'Alphonso' has a dominance of terpene content, while the pulp is relatively lactone rich. This was also evident from the volatile composition of skin and pulp of green 'Thai' ([Tamura et al., 2001](#)) and 'Kensington Pride' mango ([Lalel et al., 2003](#)). Further, the early appearance of ripening-related compounds lactones and furanones suggests early ripening of fruits upon ethylene treatment. Thus, ethylene treatment had a notable effect on the volatile profile of 'Alphonso', which is comprised of

minimized terpene content and a significant increase in mesifuran concentration with not much variation in the lactone composition (Chidley et al., 2013). Since mesifuran imparts a sweet, fruity, caramellike flavor to ‘Alphonso’ fruits, ethylene-treated mangoes showed dominance of these characteristics in their flavor blend at the ripe stage. All of these might aid to achieve high success at the consumer end. However, it is important to note that ethylene also triggers various pathways leading to the cell wall hydrolysis (Chourasia et al., 2006), which eventually reduces their shelf life, minimizing the possibility of transport of ethylene-treated mango to distant market places.

FUTURE PROSPECTS OF MANGO RESEARCH AND PRODUCTION

Fruits are an integral part of healthy and nutritious food at the consumers’ table, amid which mango is always preferred due to its nutritive value, good flavor, delicious taste, and various ways by which it can be consumed. With ever increasing demand, it is necessary to produce highly nutritive, good flavored, and healthy fruits with an increased shelf life. In this view, substantial efforts should be directed to deal with low shelf life, alternate and irregular bearing, anthracnose susceptibility, malformed mangoes, and physiological disorders such as spongy tissue development. Moreover, commercially important Indian cultivars such as ‘Alphonso’, ‘Kesar’, and ‘Dashehari’ should be mined for their metabolite diversity and nutritional content. A prerequisite for such attempts would be analyzing their metabolome, transcriptome, and proteome, which will generate clues to decipher regulatory mechanisms behind such diversity. These omics-based approaches will require a priori understanding of genome sequence to unravel the mystery of metabolite diversity of mango cultivars. Such efforts will collectively fortify our knowledge of mango diversity in terms of their nutritional value. Mango breeders who develop better and nutritionally superior mango cultivars can also exploit such information. Further, appropriate postharvest treatment, transport, and handling practices would aid to receive fruits with desired flavor and nutrition quality at the consumer end.

SUMMARY POINTS

- Mango is popular throughout the world as a “king of fruits,” due to its nutritional and other important properties.
- The importance of unique characteristics, such as taste and flavor, has been highlighted in past literature and recent studies.
- All the *Mangifera* species have a natural distribution in tropical Asia and East, but the genus is considered to have thrived in eastern Asia.
- Most of the cultivated species and cultivars have been derived from the four main species of *Mangifera*, namely *M. indica*, *M. sylvatica*, *M. odorata*, and *M. zeylanica*.

- The process of ripening brings change in fruit qualities, such as physiochemical and nutritional characteristics.
- Profuse prominence of sugars, carbohydrates, fats, vitamins, minerals, dietary fibers, antioxidants, tannins, polyphenols, pigments, and flavor compounds have been observed in mango fruit and thus serve as an important part of human diet.
- Various antioxidants to scavenge ROS and RNS in mango fruit elevate its use in nutrition and folklore prescription.

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CHAPTER 20

Orange (*Citrus sinensis* (L.) Osbeck)

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LIST OF ABBREVIATIONS

CAE Citric acid equivalents
DPPH 2,2-Diphenyl-1-picrylhydrazyl
DW Dry weight
FRAP Ferric reducing antioxidant power assay
TA Titratable acidity
TSS Total soluble solids

INTRODUCTION

Citrus fruit is basically a modified berry that is called hesperidium, based on the Greek myth of the garden of Hesperides, where the “Golden apples” were growing under the supervision of the nymphs called the Hesperides. The acquisition of these “Golden apples” were the eleventh labor of Hercules and are now believed to have been oranges.

Besides the Greek myth, the various species of the genus *Citrus* are believed to originate from the tropical and subtropical regions of Southeast Asia (Webber, 1967). The first citrus species known to European civilization was citron, as it is mentioned by Theophrastus at about 310 BC (Webber, 1967). Many centuries later, the rest of the citrus species became known to the West. Oranges were introduced to southern Europe by the Portuguese explorers following the steps of Vasco de Gama’s expedition to the East after discovering the direct sea route around the Cape of Good Hope (Webber, 1967). Orange culture was thus spread from China to the east coast of Africa and later to Europe, soon after the Christian era had begun, presumably in Italy. One reference on a letter sent by the king of France Louis XI to the governor of the province of Languedoc on June 29, 1483, leaves the impression that the culture of oranges was known to southern Europe at that time (Webber, 1967). By the beginning of the sixteenth century, the sweet orange culture had been well established and had great commercial importance in southern Europe. Perhaps the Roman conquests, the Arab trade routes, the expansion of Mohammedanism around the Mediterranean Sea, and the Crusades were the key events that contributed most to the expansion of orange culture in these areas (Webber, 1967). In America, oranges were introduced during the middle of the sixteenth century after being highly valued by the Europeans (Webber, 1967). In America the orange culture was spread by the missionaries during the eighteenth century from Florida to Arizona and California, which are the main orange cultivation areas of Northern America (Webber, 1967). Nowadays, due to its wide cultivation for so long, the truly wild type of orange species is no longer known.

BOTANICAL ASPECTS

The genus *Citrus* belongs to the family *Rutaceae*. Orange or sweet orange, *Citrus sinensis* (L.) Osbeck, is one of the currently 30 species of *Citrus*.

C. sinensis is an evergreen tree or shrub of medium to large size (3–15 m) (Hume, 1954; Swingle, 1967). The tree has a rounded, spherical, compact canopy with regular branches, and angled twigs when young. The bark of the branches and trunk is grayish to dark brown. Thorns are generally present, especially when the tree is in its juvenile phase (Hume, 1954; Swingle, 1967). The leaves are of medium size (6.5–15 cm long and 2.5–9.5 cm wide), oval or oval-oblong, smooth, glossy, dark green on the upper surface, and slightly lighter green below. Leaf tips are pointed and leaf bases rounded, and margins are entire or very slightly serrate. The petioles are mainly narrowly winged (although sometimes the

wing is slightly broader), articulated with the leaf blade (Hume, 1954; Swingle, 1967). Oil vesicles occur throughout the entire leaf blade. The flowers emerge in either small clusters or singly and are medium in size (approximately 5 cm wide) with a sweet scent. They are hermaphrodite, with a cup-shaped calyx, comprising five small, triangular, thick greenish sepals, persistent on mature fruit (Hume, 1954; Swingle, 1967). The corolla has five white or light yellow, oblong, thick petals. Each flower has approximately 20–25 stamens with flattened filaments united at least at the base and free at the upper part, where yellow anthers are located. The ovary is superior, rounded-subglobose, with 10–14 locules; the style is long and slender and falls soon after fertilization (Hume, 1954; Swingle, 1967).

The fruits are medium to large (6.5–9.5 cm in diameter), round, globose, subglobose, or oval, and consist of an outer rind (epicarp or flavedo, usually yellow or light orange to reddish, with distinct minute glands bearing an essential oil), inner rind (mesocarp or albedo, a white spongy layer), and pulp (endocarp) (Hume, 1954; Swingle, 1967). The pulp is juicy, yellow, orange or light to deep red in color, and full of membranous juice sacs, which are spindle shaped, and tightly packed within 10–14 segments derived from the locules of the ovary. The pulp is subacidic, although cultivars with nonacidic pulp also exist. Seeds are absent, few, or many (two to four seeds per segment), oblong-ovoid or irregular in shape.

The preferred regions of cultivation are outside the tropics, where several problems with fruit quality emerge. *Citrus* species are considered to be subtropical (occurring in latitudes of approximately 20–40°) and not tropical. The limiting factor for cultivation of citrus trees is low temperature. Mature orange trees can tolerate temperatures as low as –6°C during cessation of growth in winter. Orange trees can grow well in a variety of soil types, but sandy, well-drained, fertile soils with low lime content are preferable. Orange can grow in a variety of pH values (5.8–8.0), depending on the rootstock used.

Orange trees in subtropical regions flower between mid- to late March and mid-April. Although the majority of cultivars flower at that time, their fruit maturation period differs significantly. There are cultivars with fruits that mature in October ('Hamlin'), whereas others mature in March–April ('Valencia' and its clones).

Principal criteria for choosing to cultivate a specific variety, apart from the characteristics of the tree itself, are mainly the size of the fruit, its taste, the ease of peeling, and the juice content. Nowadays, new criteria are being added, mostly concerning the functionality of the fruit consumed and the content of its nutraceuticals (phenolic compounds, amino acids, vitamins, carotenoids, and anthocyanins).

COMPOSITION OF TRADITIONAL CULTIVARS

Among the traditional cultivars cultivated worldwide, Valencia (or Valencia Late, according to some authors), its clones (the traditional ones, Valencia Campbell, Valencia Olinda, Valencia Frost, and Valencia Cutter) and Washington Navel are in prominent place. The data reported hereafter refer to fresh, hand-squeezed juice or fresh fruit.

Organoleptic Characteristics and Organic Acids in Traditional Orange Cultivars

The most widely grown orange cultivar is undoubtedly Valencia and its clones. The fruit of all clones is characterized by high juice volume of outstanding color and good flavor (although it sometimes may be slightly acidic), which make Valencia and its clones the most widely cultivated cultivars in the world and the leader of oranges preferred by the juice industry (Saunt, 2000).

Valencia parent oranges have been found to exhibit higher juice content than its clone Campbell (Hodgson, 1967), ranging from 39.59% to 64% by weight, depending on rootstock and cultural management and varying from year to year (Table 1) (Sinclair, 1961a). The total soluble solids (TSS) range from 9.14 to 15.44 °Brix with most of the cultivated clones presenting values around 11 (Sanchez-Moreno et al., 2003). The titratable acidity (TA) is quite high (ranging from 0.69 to 2.4 g citric acid/100 mL juice in Valencia and around 1.6 g citric acid/100 mL juice in most of its clones) (http://www.citrusvariety.ucr.edu/citrus/sweet_oranges.html, last visit on 25.04.14.). The TSS to TA ratio ranged from 6.3 to 15.2, but most of the clones presented values around 7 or slightly higher (Sinclair, 1961a). Citric acid has been detected in concentrations of 0.22–1.21% w/v, while succinic acid has been also found (ranging from 0.13 to 0.54% w/v) along with malic acid (ranging from 0.05 to 0.26% w/v) (Duarte et al., 2012; Liu et al., 2012; Ranganna et al., 1983; Sinclair, 1961b). Tartaric, malonic, and oxalic acids have been detected in Valencia Late clone at concentrations ranging from 30 to 36, 26.0 to 26.1, and 16.0 to 24.0 mg/100 mL, respectively (Duarte et al., 2012).

The other leading cultivar worldwide, Washington Navel or Bahia, is a table (dessert) orange. Navel oranges are characterized by early maturing (around November in the northern hemisphere), seedless fruits of quite large size, with a deep orange-colored skin (most of the cultivars) and a sweet, pleasant flavor (Saunt, 2000). Navel oranges juice is characterized by delayed bitterness (Saunt, 2000). The bitterness in navel orange is the result of the release of limonin in the juice during processing (Saunt, 2000). The concentration of limonin ranges from 2.3 to even 42 mg/L, giving bitter perception at concentrations above 5 mg/L (Ranganna et al., 1983). Washington Navel fruit is characterized by moderate juice volume (41.4–48.12% per weight) with a fine, rich, sweet flavor (Saunt, 2000) (Table 1). The TSS content is reported to range from 6.64 to 16.77 °Brix, while TA is reported to be between 0.69% and 1.28% w/v citric acid, producing thus a ratio of TSS to TA of 8–15.24 (Jones, 1961; Sinclair, 1961a; Topuz et al., 2005). The citric acid concentration in the juice is around 0.5–1.0% w/v (Sinclair, 1961b), although lower levels have also been detected (Liu et al., 2012; Ranganna et al., 1983), along with low levels of malic acid (0.04–0.28% w/v) (Ranganna et al., 1983) (Table 1).

Carbohydrates in Traditional Orange Cultivars

The carbohydrate found in highest concentration in orange juice is sucrose, is followed by fructose and glucose (Table 2) (Ladaniya, 2008; Sinclair, 1961a). Sucrose has been

Table 1 Organoleptic characteristics and organic acids of the juice of traditional orange cultivars

Cultivars	Juice (% by weight)	Total soluble sugars (°Brix)	Titrateable acidity (g citric acid/100 mL juice)	TSS:TA	Citric acid (g/100 mL)	Succinic acid (g/100 mL)	Malic acid (g/100 mL)
Valencia	39.59–64	9.63–15.44	0.69–2.4	7.91–15.2	0.22–1.17	0.13–0.54	0.05–0.26
Valencia Cutter	—	11.9	1.87	6.5	—	—	—
Valencia Frost	—	11.4	1.62	7.3	—	—	—
Valencia Campbell	—	10.9	1.55	7.1	—	—	—
Valencia Late	47.88–49.23	9.14–12.03	0.95–1.37	6.76–10.07	0.89–1.21	—	0.253
Valencia Olinda	—	10.5–11.5	0.704–1.85	6.3–14.91	—	—	—
Washington Navel	41.4–48.12	6.64–16.77	0.687–1.28	8–15.24	0.5–1.0	—	0.04–0.28

The table shows the range of juice volume per fruit weight, the organoleptic characteristics, and the concentration of the major organic acids found in traditional orange cultivars.

Sources: Duarte et al. (2012); Hodgson (1967); Jones (1961); Liu et al. (2012); Ranganna et al. (1983); Sanchez-Moreno et al. (2003); Saunt (2000); Sinclair (1961a,b); Topuz et al. (2005); Internet http://www.citrusvariety.ucr.edu/citrus/sweet_oranges.html, last visit on 25.04.14.

Table 2 Carbohydrate composition of the juice of traditional orange cultivars

	Glucose	Fructose	Sucrose	Sugars sum		
Cultivars	g/L				Suc: gluc	Gluc: fruct
Valencia late	12.52	14.62	73.1	100.24	5.83	0.85
Valencia olinda	19.15	21.78	39.61	80.55	2.07	0.88
Washington navel	—	—	44.7	—	—	—

The table presents the major carbohydrate composition of the juice of traditional orange cultivars, along with the ratios of the major carbohydrates detected.

Sources: [Cerdan-Calero et al. \(2012\)](#); [Ladaniya \(2008\)](#); [Niu et al. \(2008\)](#); [Sinclair \(1961a\)](#); [Topuz et al. \(2005\)](#).

quantified to 73.1 g/L in Valencia Late, 39.61 g/L in Valencia Olinda, and 44.7 g/L in Washington Navel ([Topuz et al., 2005](#)). Glucose has been detected in Valencia Late at 12.52 g/L and at 19.15 g/L in Valencia Olinda ([Niu et al., 2008](#)). Fructose, the second most abundant carbohydrate, has been found in Valencia Late at 14.62 g/L and in Valencia Olinda at 21.78 g/L ([Niu et al., 2008](#)). Thus the total sum of sugars is reported to range around 80 g/L. Based on the relative sweetness perception of carbohydrates (fructose is 2.3 and sucrose 1.35 times sweeter than glucose), the sweetest juice was that of Valencia Late (144.8) and the least sweet that of Valencia Olinda (122.7). Besides the above-mentioned carbohydrates, other minor carbohydrates have been detected in Valencia Late juice, such as myo-inositol at a concentration 0.76 g/L, scyllo-inositol at 0.73 g/L, and raffinose at 0.26 g/L ([Cerdan-Calero et al., 2012](#)).

Ascorbic Acid (ASA), Phenolic Compounds, and Antioxidant Activity (AA) in Traditional Orange Cultivars

Ascorbic acid (ASA) is the major vitamin present in orange juice followed by niacin, thiamin, and vitamin B6. ASA has been found in Valencia in concentrations ranging from 52.89 to 65.2 mg/100 mL ([Sinclair, 1961b](#)) while in its clones Valencia Late and Valencia Olinda it has been detected at concentrations close to 50 mg/100 mL and up to 86 mg/100 mL ([Table 3](#)) ([Duarte et al., 2012](#); [Niu et al., 2008](#)). Similar concentrations have been found also in Washington Navel (38.96–61.1 mg/100 mL) ([Sinclair, 1961b](#)).

Phenolic compounds contribute to the antioxidant potential of the fruit and to its overall flavor. On a survey of ours on various orange cultivars ([Roussos et al., 2013](#)), we have found that total phenolic compound concentration ranged from 32.3 (Valencia Campbell) to 35.7 (Valencia Cutter) mg tannic acid equivalents/100 mL juice. Washington Navel presented similar concentration. Flavonoids have been found in concentrations ranging from as low as 1.23 (in Washington Navel) to 6.37 (in Valencia Olinda) mg catechin equivalents/100 mL juice.

Among the main phenolic compounds found in orange juice is hesperidin (the most abundant one) and narirutin, followed by naringin and didymin ([Gattuso et al., 2007](#)).

Table 3 Phenolic compound composition of the juice of traditional orange cultivars

Cultivars	Total phenolics (mg gallic acid equivalents/100 g)	Flavovoids (mg catechin equivalents/100 mL)	NAR	HESP	NRN	DID	ASA	Antioxidant activity
			(mg/100 mL)					
Valencia	108.5–140.7	—	—	—	—	—	52.89–65.2	816.9 ^d
Valencia campbell	32.3 ^a	5.64	—	—	—	—	—	459 FRAP ^d
Valencia cutter	35.7 ^a	3.84	10 ^c	50 ^c	—	—	—	86.9 ^e
Valencia frost	33.4 ^a	5.31	—	—	—	—	—	487 FRAP ^d
Valencia late	99	425 ^b	—	—	—	—	46–86	91.6 ^c
Valencia olinda	33 ^a	6.37	—	—	—	—	50	307 FRAP ^d
Washington navel	85	460 ^b	7.36	16.07	0.56	0.14	38.69–61.1	93.2 ^e
	33.75 ^a	1.23						6.44TEAC ^d
								658 FRAP ^d
								90 ^e
								487–555 FRAP ^d
								73.5 ^e

The table shows the range of concentrations of the major antioxidant compounds, i.e., phenolic compounds, both individual and total ones (using different expressions of their concentration) and ascorbic acid, along with the antioxidant capacity of the juice, measured by different methods, in traditional orange cultivars. NAR, naringin; HESP, hesperidin; NRN, naringin; DID, didymin; ASA, ascorbic acid.

^amg Tannic acid equivalents (TAE)/100 mL.

^bmg Quercetin/100 g pulp.

^cmg/100 g juice.

^dμmol Trolox/100 mL juice.

^eDPPH inhibition (%).

Sources: Berhow et al. (1998); Camarda et al. (2007); Duarte et al. (2012); Gattuso et al. (2007); Niu et al. (2008); Roussos et al. (2013); Sanchez-Moreno et al. (2003); Sinclair (1961b).

Hesperidin has been detected in Washington Navel at 16.07 mg/100 mL juice and narirutin at 7.36 mg/100 mL, while naringin and didymin have been found at 0.56 and 0.14 mg/100 mL, respectively (Camarda et al., 2007). In Valencia Cutter, hesperidin and narirutin have been found at 50 and 10 mg/100 g juice (Berhow et al., 1998). Narin-genin is not usually found in orange juice, although there is reference where it was detected in Valencia Late juice at concentration of 3 mg/100 mL (Sanchez-Moreno et al., 2003). Some other minor phenolic compounds have been detected such as isorhoifolin, eriocitrin, neoeriocitrin, taxifolin, and acacetin in Washington Navel (Camarda et al., 2007; Gattuso et al., 2007) as well as poncirin, heptamethoxyflavone, nobiletin and tangeretin (in Valencia and Washington Navel), sinensetin, diosmin, and neo-diosmin (in Valencia) (Gattuso et al., 2007).

Based on ferric reducing antioxidant power assay (FRAP), Washington Navel exhibited high antioxidant capacity (487–555 μmol Trolox equivalents/100 mL juice), while Valencia Olinda presented the highest antioxidant capacity among Valencia clones (658 compared to 307 of Valencia Frost or 459 and 487 μmol Trolox equivalents/100 mL juice of Valencia Campbell and Cutter, respectively) (Roussos et al., 2013). Similar results were obtained when the scavenging of 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay was used (Roussos et al., 2013).

Amino Acids in Traditional Orange Cultivars

Orange juice is a valuable source of amino acids also. One of the main amino acids is proline, which can be found at concentrations of up to 832 mg/100 g of pulp (Table 4) (Niu et al., 2008). Valencia juice is characterized by a low concentration of proline (64–239 mg/100 mL juice), followed by asparagine, arginine, and aspartic acid (35–188, 73–121, and 31–114 mg/100 mL, respectively) (Gomez-Ariza et al., 2005). All other amino acids are found in concentrations below 100 mg/100 mL (Niu et al., 2008). High amounts of serine and arginine have been reported in Valencia Olinda juice (753 and 966 mg/100 g juice) (Niu et al., 2008). Washington Navel has lower amounts of amino acids than Valencia, with the most abundant being proline, followed by arginine (107–153 and 54–72 mg/100 mL) (Niu et al., 2008; Rockland, 1961).

Carotenoids and Volatiles in Traditional Orange Cultivars

The commonly found carotenoids of orange juice are listed in Table 5 (Dugo et al., 2009; Lee and Castle, 2001). The most abundant carotenoid found in Valencia Late is β -cryptoxanthin, detected at a concentration of 2.14 mg/L, followed by lutein at a concentration of 1.47 mg/L, with all other detected carotenoids being in concentrations lower than 1.0 mg/L (Cerdan-Calero et al., 2012; Sanchez-Moreno et al., 2003). Among the most abundant carotenoids found in Valencia are lutein, violaxanthin-laureate-myristate (C12:0, C14:0), violaxanthin-di-palmitate (C16:0, C16:0), violaxanthin-laureate-palmitate (C12:0, C16:0), *cis*-violaxanthin (C10:0, C12:0), *cis*-violaxanthin (C12:0, C12:0),

Table 4 Amino acid composition of the juice of traditional orange cultivars

	Valencia	Valencia late	Valencia olinda	Washington navel
Amino acids	mg/100 mL	mg/100 mL	mg/100 g	mg/100 mL
Alanine	9–22	8.6	136	12–17
Arginine	73–121	–	966	54–72
Asparagine	35–188	36.14	84	67
Aspartic acid	31–114	7.36	–	27–43
Cysteine	0.6	–	–	–
GABA	4–64	–	–	24–26
Glutamic acid	19–49	6.47	–	12–20
Glutamine	15–60	–	49	–
Glycine	2	0.93	20	2
Histidine	5	–	101	–
Isoleucine	Traces	0.065	9	–
Leucine	Traces	0.55	9	–
Lysine	6–22	–	16	3
Methionine	3	–	43	–
Phenylalanine	Traces	1.77	77	–
Proline	64–239	164.5	832	107–153
Serine	17–37	10.4	753	18–28
Threonine	Traces	0.98	–	–
Tryptophan	Traces	–	–	–
Tyrosine	Traces	–	54	–
Valine	Traces	1.08	28	2

The table shows the range of concentration of the major amino acids found in juice of traditional orange cultivars. Sources: [Gomez-Ariza et al. \(2005\)](#); [Niu et al. \(2008\)](#); [Rockland \(1961\)](#).

β -cryptoxanthin (C14:0), and β -cryptoxanthin (C16:0) ([Melendez-Martinez et al., 2007](#)). In Washington Navel, the most abundant carotenoids are violaxanthin-laureate-myristate (C12:0, C14:0), violaxanthin-laureate-palmitate (C12:0, C16:0), *cis*-violaxanthin (C12:0, C12:0), β -cryptoxanthin (C14:0), and β -cryptoxanthin (C16:0) ([Dugo et al., 2009](#); [Giuffrida et al., 2010](#)).

Some of the volatiles usually found in orange juice are listed in [Table 6](#) ([Cerdan-Calero et al., 2012](#); [Kelebek and Selli, 2011](#); [Perez-Cacho and Rouseff, 2008](#)). The most abundant in Valencia Late oranges is dl-limonene (limonene) followed by β -myrcene, ethyl butanoate, and others ([Buettner and Schieberle, 2001](#); [Cerdan-Calero et al., 2012](#)). Limonene has been found at concentrations of 26.42 and 85.59 mg/kg in Washington Navel and Valencia Late, respectively ([Buettner and Schieberle, 2001](#); [Cerdan-Calero et al., 2012](#); [Perez-Cacho and Rouseff, 2008](#)). Limonene odor is characterized as lemon, citrus, orange, and minty, while that of β -myrcene is characterized as lemon, grapefruit, musty, spicy, geranium-like, mossy, and ethyl butanoate as fruit, apple, and pineapple ([Perez-Cacho and Rouseff, 2008](#)). Other volatiles found in Valencia juice in considerable

Table 5 Carotenoid composition of orange juice

Most usually found carotenoids in orange juice				
β -Cryptoxanthin	Zeaxanthin	Lutein	Violaxanthin–laureate–myristate (C12:0, C14:0)	Violaxanthin–myristate–palmitate (C14:0, C16:0)
β -Carotene	Zeinoxanthin	α -Cryptoxanthin	β -Cryptoxanthin–palmitate (C16:0)	<i>cis</i> -Antheraxanthin–palmitate (C16:0)
Mutatoxanthin	lycopene	(<i>Z</i>)- β -cryptoxanthin	<i>cis</i> -Antheraxanthin–palmitate (C16:0)	
Neochrome	β -citaurin	ξ -Carotene	Luteoxanthin–palmitate (C16:0)	
Neoxanthin α/b	Auroxanthin	α -Carotene	Violaxanthin–caproate–palmitate (C10:0, C16:0)	
Phytoene	Luteoxanthin α/b	Violaxanthin–palmitate (C16:0)	Violaxanthin–di–palmitate (C16:0, C16:0)	
Violaxanthin	luteoxanthin+ (<i>9Z</i>)-violaxanthin	Violaxanthin–di–myristate (C14:0, C14:0)	Violaxanthin–laureate–palmitate (C12:0, C16:0)	
Carotenoids tentatively identified in orange juice				
9- <i>cis</i> - β -carotene	All trans luteoxanthin (C12:0, C16:0)	<i>cis</i> -Violaxanthin (C10:0, C12:0)	Trollichrome	β -Zeaxarotene
All trans luteoxanthin (C10:0, C10:0)	All trans luteoxanthin (C12:0, C16:0)	<i>cis</i> -Violaxanthin (C12:0, C12:0)	Violaxanthin–laureate–myristate (C12:0, C18:0)	
All trans luteoxanthin (C10:0, C12:0)	All trans violaxanthin (C10:0)	<i>cis</i> -Antheraxanthin	β -Cryptoxanthin (C16:0)	
All trans luteoxanthin (C12:0, C12:0)	All trans violaxanthin (C12:0)	ξ -Carotene	β -Cryptoxanthin (C12:0)	
All trans luteoxanthin (C12:0, C14:0)	All trans violaxanthin (C14:0)	Phytofluene	β -Cryptoxanthin (C14:0)	

The table shows the variety of carotenoids usually found in orange juices as well as some carotenoids that are tentatively identified in orange juice.

Sources: Arena et al. (2006); Cerdan-Calero et al. (2012); Dugo et al. (2009); Giuffrida et al. (2010); Lee and Castle (2001); Melendez-Martinez et al. (2007); Pupin et al. (1999); Qiao et al. (2008); Sanchez-Moreno et al. (2003); Seideneck and Schieberle (2011); Selli et al. (2004); Wang et al. (2007).

Table 6 Volatile composition of orange juice
Volatiles detected in orange juices

γ -Butyrolactone	4-Vinyl phenol	Geranial	Terpinene-1-ol
(E)-2-Hexenal	4-Vinyl-2-methoxy phenol	Geraniol	Terpinene-4-ol
(E)-3-Hexen-1-ol	Acetaldehyde	Geranyl acetate	Thymol
(E)-Linalool oxide	Acetic acid	Heptanol	trans, trans decadienal
(Z)-3-Hexen-1-ol	α -Pinene	Hexanal	<i>trans</i> -2-hexen-1-ol
(Z)-4-Decenal	Benzaldehyde	Hexanoic acid	<i>trans</i> -2-hexen-1-ol
(Z)-Linalool oxide	Benzyl alcohol	Isoamyl acetate	<i>trans</i> -2-hexenal
1,8 Mentha dien-4-ol	<i>cis</i> -carveol	Isoamyl benzoate	<i>trans</i> -furan linalool oxide
1-Butanol	<i>cis</i> -dihydrocarvone	Isobutyl alcohol	Valencene
1-Hexanol	Citronellol	Linalool	Vanillin
1-Pentanol	Decanal	Methanol	Z-3-Hexenal
1-Penten-3-one	Decanoic acid	Methylbutanoate	α -Cubebene
1-Pentenol	Diethyl succinate	n-Butyl-n-butanoate	α -Phellandrene
1-Propanol	DL-limonene	Neral	α -Terpineol
2,3-Butanediol	Ethyl acetate	Nerol	α -Terpinolene/octanal
2-Heptanol	Ethyl butanoate	Nonanal	β -Cadinene
2-Heptanone	Ethyl decanoate	Nonanoic acid	β -Myrcene
2-Hexanol	Ethyl hexadecanoate	Nootkatone	β -Ocimene
2-Methyl butanol	Ethyl hexanoate	Octanal	β -phellandrene
2-Methyl-3-buten-2-ol	Ethyl linolenate	Octanoic acid	β -Pinene
2-Pentanol	Ethyl octanoate	Octanol	β -Sinensal
3-Ethoxy-1-propanol	Ethyl propionate	Perillalcohol	β -Terpineol
3-Hydroxy-2-butanone	Ethyl-2-methyl propanoate	Perillaldehyde	γ -Terpinene
3-Methyl butanol	Ethyl-2-methyl-butanoate	Phenylethyl acetate	δ -3-Carene
3-Methyl propanol	Ethyl-3-hydroxy-butanoate	Phenylethyl alcohol	δ -Amorphene
3-Methyl-2-buten-1-ol	Ethyl-9-octadecenoate	p-mentha-1,8-dien-9-ol	δ -Cadinene
3-Penten-2-ol	Furfuryl alcohol	Sabinene	δ -Terpinene
Ethyl 3-hydroxy-hexanoate	Carvone	Isoamyl alcohol	<i>trans</i> -Carveol

The table presents the most abundant and common volatiles usually detected in orange juices.

Sources: Buettner and Schieberle (2001); Cerdan-Calero et al. (2012); Kelebek and Selli (2011); Perez-Cacho and Rouseff (2008).

amounts (significantly lower than limonene, though) are decanal (517–876 µg/L, odor: fruity, soap, balsamic, green, tallow, citrus, fatty), octanal (376–630 µg/L, odor: fruity, citrusy, fat, soap, lemon, green, geranium, floral), octanol (172–410 µg/L, odor: citrus-like, chemical, metal, burnt, herbal, green), valencene (10,748–19,200 µg/L, odor: citrusy, green, oil), γ -terpinene (565–1294 µg/L, odor: sweet, citrusy, gasoline, turpentine), δ -cadinene (520–1963 µg/L, odor: thyme, wood), β -pinene (1211–2845 µg/L, odor: piney, pungent, resin, turpentine, wood, terpene like), and δ -terpinene (2037–3548 µg/L, odor: pine, plastic) (Perez-Cacho and Rouseff, 2008). The odor given above characterizes the volatile compound but does not necessarily mean that this odor is being detected in the juice, since the odor threshold of each compound differs.

Mineral Elements in Traditional Orange Cultivars

The most abundant element in Valencia orange juice is potassium ([1720 mg/L]/[1676 mg/kg] juice), followed by nitrogen, phosphorus, and calcium (904, 320, and 90 mg/L, respectively) (Table 7)(Bitters, 1961). Potassium is the most abundant mineral element (1255 mg/L) in Washington Navel too, followed by phosphorus, magnesium, and calcium (157.5, 96.6, and 53.7 mg/L, respectively) (Topuz et al., 2005).

COMPOSITION OF MODERN CULTIVARS

Organoleptic Characteristics and Organic Acids in Modern Orange Cultivars

Workman Navel exhibits the lowest juice volume (24% by weight) while most of the varieties exhibit juice volumes around 38% of fruit weight (Table 8) (http://www.citrusvariety.ucr.edu/citrus/sweet_oranges.html, last visit on 25.04.14.). The average TSS content is approximately 11.8 °Brix, with Fisher Navel, Jincheng, Lima orange, Parson Brown, Pineapple, Robertson Navel, Rio Grande Navel, Skaggs Bonanza, Smiths Early, Tarocco, Trovita, Westin, Workman, and Xianfencheng presenting lower values than the average (http://www.citrusvariety.ucr.edu/citrus/sweet_oranges.html, last visit on 25.04.14.). The TA ranges from as low as 0.23% citric acid in Lima orange to as high as 2.4% in Valencia orange. The mean ratio TSS:TA is approximately 13.5, with Tarocco Messina exhibiting the lowest value (5.85) and I-02 Piralima orange the highest one (141.1) (Rapisarda et al., 2008; Tazima et al., 2009) due to its very low acid content, since it is characterized as an acidless cultivar.

Shamouti is characterized by high concentration of citric acid, as are Lane Late and Jincheng (http://www.citrusvariety.ucr.edu/citrus/sweet_oranges.html, last visit on 25.04.14.)(Ranganna et al., 1983). Low levels of citric acid have been detected in Parson Brown, Hamlin, and Washington Navel as well as in all acidless varieties (Tazima et al., 2009). Succinic acid and malic acid are also present in orange juice (Ranganna et al., 1983). Tartaric acid, malonic acid, and oxalic acid have been reported in some orange cultivars (Duarte et al., 2012; Legua et al., 2013).

Table 7 Mineral element composition of the juice of traditional orange cultivars

Cultivars		N	K	P	Ca	S	Mg	Na	Zn	Mn	Cu	Fe
Valencia	mg/L	904	1720	320	90	40	50	70	—	—	—	1
	g/Kg	11	12	1.6	3.7	—	1	—	0.01	0.0044	0.0055	0.021
	fruit DW											
	% w/w	—	1.28–1.32	—	0.06–0.07	—	0.090–0.01	0.05	—	—	—	—
Washington Navel	dry juice											
	mg/Kg	—	1676	183	82.8	—	106.6	8.6–9.3	0.33	0.22	0.35	0.72
	juice											
	mg/L	—	1255	157.5	53.7	—	96.6	12.7	2.34	0.05	0.56	—
Navel	% w/w	—	1.43	—	0.06	—	0.11	0.05	—	—	—	—
	dry juice											
	mg/Kg	—	1696	179	80.3	—	114.1	9.4	0.34	0.19	0.36	0.61
	juice											

The table shows the range of mineral element concentration in the juice of traditional orange cultivars expressed by different ways.

Sources: [Bitters \(1961\)](#); [Topuz et al. \(2005\)](#).

Table 8 Organoleptic characteristics of the juice of modern orange cultivars

Cultivars	Juice (% by weight)	Total soluble sugars (°Brix)	Titrateable acidity (g citric acid/100 mL juice)	Cultivars	Juice (% by weight)	Total soluble sugars (°Brix)	Titrateable acidity (g citric acid/100 mL juice)
Atwood Navel	33	11.82	1.21	Marrs Early orange	32	11.9	0.55
Blanca		14.5	1.1	Midknight Valencia	39	11.21	0.99
Burris Blood Valencia	49.18	13.28	1.0	Mollar	—	13.8	1.1 ^b
Cadenera	37–42	10.5–14.5	0.5–1.84	Moro	35.1–37	10.3–12	1.01–1.57
Capuchina	—	16.8	1.24 ^b	Navelate	35	10.5–11.53	0.56–1.07
Cara Cara	42.4	—	—	Navellina	47.4	10.08–13.6	1.0–1.17 ^b
Comun	—	14.2	1.6 ^b	Newhall	47.8 ^a	11.4–15.8	0.83–1.12
Comun Orihuela	—	15	0.98	Ovale	—	10.58	0.9 ^b
Condesa	—	12.2	1.1 ^b	Paradise Navel	41.97	12.1–13.7	0.79–0.85
Dom Joao Valencia	41	11.65	1.03	Parson Brown	33–56.7	8.56	0.59 ^b
Fisher Navel	42.4	10.04	0.95	Pera Orage	35–56.5	9.89–11.5	0.76–1.25
Folha Murcha	48.55–53.11	10.98–12.73	0.99–1.36	Pineapple	28–35	9.8–10	0.3–0.8
Frost Navel	33	11.38	0.73	Rhode Red	49.17–50.6	8.82–9.09	1.23–1.29
				Valencia			
Gillette Navel	34–42.63 ^a	10.78–13.02	0.68–0.95	Rio Grande Navel	34	9.92	1.0
Grano de Oro	—	13.6	0.1 ^b	Robertson Navel	34	8.9	0.85
Guasi	—	17.8	1.34 ^b	Salustiana	36–41	11	0.5–1.19
Hamlin	25–60.2	9.38–12.58	0.5–0.76	Sanguina rosada	—	13	1.16 ^b
I-02 Piralima	—	10.9	0.1	Sanguinello	38.9	12.6	1.34 ^b
I-03 Barao	—	11.6	0.9	Shamouti	30–42.22	9.87–11.89	0.875
I-11 Natal	—	13.6	1.3	Skaggs Bonanza	35–50.79	10.63–12.58	0.86–1.16
I-16 Hamlin	—	10.5	1	Smiths Early	42.94	10.46	1.05
I-17 Seleta	—	10.6	1	Tarocco Meli	—	8.62	1.4
Vermelha							
I-60 Natal	—	11.8	1.4	Tarocco Messina	—	8.07	1.38
Imperial	—	13.8	0.14 ^b	Thompson	—	14.8	1.00 ^b

Jincheng	—	8.7	0.574 ^b	Trovita	30	9.6–10.8	0.73
Johnson Navel	42.23	11.52	0.75	Valencia Americana	49.97	9.31	0.75
Kozan	40	11.8–12	0.911	Valencia Delta		9.7	0.512
Lane Late Navel	49.17	8.18–13.22	0.71	Verna		14.2	1.3 ^b
Leng Navel	40	11.75	1.23	Westin	46.83	10.71	0.95 ^b
Lima Orange	47.3 ^a	7.7	0.23	Workman Navel	24	11.0	1.63
Liubencheng	46.24	11.58	1.2	Xianfengcheng	39	10.3	1.19
Macetera		13	1.28 ^b	Yinzaocheng	43.64	11.33	1.38

The table presents the range of juice volume per fruit weight as well as some organoleptic characteristics found in the juice of modern orange cultivars.

^aPer volume.

^bg Citric acid/100 gFW.

Sources: Duarte et al. (2012); Legua et al. (2013); Pretel et al. (2004); Ranganna et al. (1983); Rapisarda et al. (2008); Tazima et al. (2009); Internet http://www.citrusvariety.ucr.edu/citrus/sweet_oranges.html, last visit on 25.04.14).

Pretel et al. (2004) have assessed 17 traditionally cultivated orange cultivars in Spain on their sensorial attributes, such as aroma, chewiness, segment firmness, and lack of bitterness. Blanca and Comun had the lowest aroma score and the lowest chewiness, along with Condesa, Sanguina Rosada, and Imperial. Verna and Condesa received the lowest scores concerning segment firmness, while all cultivars scored high on the lack of bitterness index. New Hall, Cadenera, Capuchina, Comun Orihuela, Guasi, Navellina, and Thompson received the highest scores on all sensorial characteristics assayed.

Carbohydrates in Modern Orange Cultivars

Sucrose concentration ranges from 32.41 g/L in Jincheng to 59.34 g/L in Kozan (Table 9) (Kelebek et al., 2009; Niu et al., 2008). Fructose concentration ranges from 15.5 g/L in Lane Late (Legua et al., 2013) to 33.05 g/L in Dortyol (Kelebek and Selli, 2011), while the highest glucose concentration has been detected in Kozan with 32.2 g/L (Kelebek et al., 2009) and the lowest in Jincheng with 13.95 g/L (Niu et al., 2008). The highest total carbohydrate concentration has been found in Dortyol with approximately 110.44 g/L (Kelebek and Selli, 2011; Legua et al., 2013), while the lowest has been found in Jincheng with only 65.1 g/L (Niu et al., 2008). Based on the relative sweetness perception of carbohydrates, the sweetest juice is that of Kozan and the least sweet that of Jincheng.

Table 9 Carbohydrate composition of the juice of modern orange cultivars

	Glucose	Fructose	Sucrose	Sugars sum		
Cultivar	g/L				Suc: gluc	Gluc: fruct
Alanya	—	—	41.6	—	—	—
Dortyol	30.99	33.05	46.4	110.44	—	0.94
Finike	—	—	42.4	—	—	—
Hamlin	18.62	20.98	38.48	78.09	2.07	0.89
Jincheng	13.95	18.74	32.41	65.1	2.32	0.74
Kozan	32.3	28.55	59.34	—	—	—
Lane Late	15.2–21.7	15.5–21.5	37.7–55.2	73.7–98.4	—	—
Navel						
Pineapple	21.9	23.76	39.12	84.79	1.79	0.92
Salustiana	24.6–25.8	26.9–28.5	38.3–36.6	82.8–91.5	—	0.86–0.96
Shamouti	—	—	33.3	—	—	—
Trovita	22.16	24.13	42.43	88.6	1.91	0.92
Valencia	16.81	20.15	38.52	75.48	2.29	0.83
Delta						

The table shows the range of concentration and the ratios of the major carbohydrate found in the juice of modern orange cultivars.

Sources: Kelebek and Selli (2011); Kelebek et al. (2009); Legua et al. (2013); Niu et al. (2008); Roussos, 2011.

Ascorbic Acid (ASA), Phenolic Compounds, and Antioxidant Activity (AA) in Modern Orange Cultivars

The lowest concentration of ASA has been determined in Jincheng cultivar (30 mg/100 mL juice), while the highest ones have been shown in Pineapple and in Lane Late Navel (78.4 and up to 80 mg/100 mL juice, respectively) (Table 10) (Legua et al., 2013). In general, its concentration ranged between 30 and 80 mg/100 mL (Kelebek and Selli, 2011; Rapisarda et al., 2008).

Table 10 Antioxidant activity and ascorbic acid concentration of the juice of modern orange cultivars

Cultivars	Antioxidant activity	Ascorbic acid (mg/100 mL)	Cultivars	Antioxidant activity	Ascorbic acid (mg/100 mL)
Blanca	38 ^a	—	Moro	566 FRAP ^d 81.6 ^b	—
Cadenas	—	55.2	Navelate	465 FRAP ^d 78.8 ^b	—
Cadenera	54 ^a	—	Navellina	530 FRAP ^d 93.6 ^b	—
Capuchina	138 ^a	—	Parson brown	—	63.3
Carter Navel	—	61.7	Pera orange	1100 FRAP ^c	68.1
Comun	61 ^a	—	Pineapple	—	78.4
Comun	52 ^a	—	Salustiana	481 FRAP ^d 85.3 ^b	—
Orihuela	—	—	Sanguina	60 ^a	—
Guasi	79 ^a	—	rosada	—	—
Hamlin	60.24 ^c	62.38–68.2	Sanguinello	—	53.42
Jincheng	—	30	Shamouti	365 FRAP ^d 73.7 ^b	34.27–51
Lane Late Navel	—	50–80	Skaggs	50.92 ^c	53.93
Lima orange	1000 FRAP ^c	46.1	Bonanza	—	—
Liubencheng	60.13 ^c	61.41	Tarocco	—	67–72
Lue Gim	—	64.7	Thompson	77 ^a	64.7
Gong	—	—	Trovita	—	63.9
Macetera	48 ^a	—	Verna	130 ^a	58.5
Maltese blood	—	56.7	Yinzaocheng	47.82 ^c	47.47

The table shows the range of ascorbic acid concentration along with the antioxidant capacity of the juice of modern orange cultivars, measured by different methods.

^amg ascorbic acid/100 g juice.

^bDPPH inhibition (%).

^cμmol Trolox/100 g juice.

^dμmol Trolox/100 mL juice.

Sources: Kelebek and Selli (2011); Legua et al. (2013); Pretel et al. (2004); Rapisarda et al. (2008); Roussos et al. (2013).

Based on the various antioxidant assays used, Blanca presented the lowest AA (38 mg ASA/100 g), while Capuchina (138 mg ASA/100 g) and Verna (130 mg ASA/100 g) presented the highest (Pretel et al., 2004). In other assays, with the results expressed as μmol Trolox equivalents per 100 g juice (irrespective of the assay used), Pera orange (1100 μmol Trolox equivalents/100 g juice) and Lima orange (1000 μmol Trolox equivalents/100 g juice) exhibited the highest antioxidant activities. From a survey that we did on 11 orange cultivars, we found that Moro exhibited the highest antioxidant capacity based on FRAP assay and Navellina the highest based on DPPH assay, while Shamouti presented the lowest AA based on both assays (Roussos et al., 2013).

There were not any significant differences between the cultivars tested concerning the total phenol content of the juice, as all presented values from 28.4 (Moro) to 49.5 (Salustiana) mg tannic acid equivalents per 100 mL (Table 11) (Roussos et al., 2013). Hamlin presented high total phenol content (1499.71), while Skaggs Bonanza (1173.28) and Yinzaocheng (1245.59) presented the lowest one (all expressed as mg gallic acid equivalents per L) (Xu et al., 2008). Moro sanguine presented a high total flavonoid content (2.66 mg catechin equivalents per 100 mL) compared to Navelate, Navellina, New Hall, Salustiana, and Shamuti (1.22, 1.68, 1.43, 1.88, and 1.37 mg catechin equivalents per 100 mL, respectively) (Roussos et al., 2013).

Hesperidin, the most abundant phenolic compound in orange juice, was found in high concentrations in Yinzaocheng and Hamlin (53.26 and 48.96 mg/100 mL, respectively) while Moro and Sanguinello exhibited the lowest hesperidin concentrations (Xu et al., 2008). Skaggs Bonanza exhibited the highest narirutin concentration (13.67 mg/100 mL), while Moro exhibited the lowest one (Kelebek et al., 2008). Naringin has been found in Dortyol, Moro, Kozan, and Sanguinello in low concentrations (0.095, 0.26, 0.107–0.223, and 0.17 mg/100 mL, respectively) (Kelebek et al., 2008, 2009; Kelebek and Selli, 2011). Didymin has been detected in Sanguinello and Dortyol in low concentrations, as well as neohesperidin (Kelebek et al., 2008; Kelebek and Selli, 2011), which is also found in Liucheng (Wang et al., 2007). Phenolic acids have also been detected in orange juice, among which ferulic acid is the most abundant. It has been quantified from 4.01, 3.99, and 3.2 mg/100 mL in Yinzaocheng, Hamlin, and Skaggs Bonanza, respectively, to 1.98 in Sanguinello (Xu et al., 2008). Caffeic acid has been detected in Dortyol and Sanguinello, while *p*-coumaric acid is found in Dortyol, Hamlin, Yinzaocheng, and in Skaggs Bonanza (Kelebek and Selli, 2011; Xu et al., 2008).

Eriocitrin and gallic acid have been found in Sanguinello, while vanillic acid and *p*-hydroxybenzoic acid have been found in Dortyol, Skaggs Bonanza, and Yinzaocheng (Kelebek and Selli, 2011; Xu et al., 2008). Protocatechuic acid has been determined in Hamlin, Sanguinello, Skaggs Bonanza, and Yinzaocheng (Xu et al., 2008). Chlorogenic acid has been found in Sanguinello, while sinapic acid has been found in Hamlin, Sanguinello, Skaggs Bonanza, and Yinzaocheng (Xu et al., 2008). Other phenolic compounds detected in Liucheng edible portions are the flavones luteolin, sinensetin, the

Table 11 Phenolic compound composition of the juice of modern orange cultivars

Cultivars	Total phenolics (mg gallic acid equivalents per L)	Flavovoids (mg catechin equiv./100 mL)	Narirutin	Hesperidin
			(mg/100 mL)	
Bey	—	—	10 ^c	40 ^c
Dortyol	—	—	2.19	10.4
Fisher	—	—	10 ^c	50 ^c
Hamlin	1499.71	—	10.27	48.96
Homosassa	—	—	—	40 ^c
Kozan	—	—	3.99	17.11–23.3
Liubencheng	1462.52	—	8.94	50.64
McFadden	—	—	10 ^c	40 ^c
Moro	1230	2.66	0.75–2.98	14.32
	28.4 ^a			
Navelate	32.8 ^a	1.22	—	—
Navellina	30.9 ^a	1.68	—	—
New Hall	37.4 ^a	1.43	—	—
Ovale	639.9 ^b	—	—	—
Salustiana	49.5 ^a	1.88	7.14–7.72	23.64–26.13
Sanguinello	—	—	0.58–13.91	11.29–30.79
Shamouti	33.6 ^a	1.37	—	—
Skaggs Bonanza	1173.28	—	13.67	42.77
Smiths Early	—	—	10 ^c	40 ^c
Tarocco Meli	507.13 ^b	—	—	—
Tarocco Messina	523.74 ^b	—	—	—
Thompson	—	—	—	30 ^c
Yinzaocheng	1245.59	—	8.41	53.26

The table shows the range of phenolic compounds concentration, both individual and total ones, detected in the juice of modern orange cultivars.

^amg Tannic acid equivalents (TAE)/100 mL.

^bmg Catechin equivalents/L.

^cmg/100 g juice.

Sources: Abad-Garcia et al. (2012); Kelebek et al. (2008, 2009); Kelebek and Selli (2011); Roussos et al. (2013); Saunt (2000); Xu et al. (2008); Wang et al. (2007).

flavanols rutin, quercetin, and kaempferol as well as *p*-coumaric acid (Wang et al., 2007). More orange polyphenols are cited in the work of Abad-Garcia et al. (2012).

Anthocyanins have been found only in blood oranges such as Moro and Sanguinello (Kelebek et al., 2008). Some of the anthocyanins found are delphinidin-3-glucoside (0.26 mg/100 mL), cyanidine-3-glucoside (1.58 mg/100 mL), delphinidin-3-(6"-malonyl glucoside) (0.14 mg/100 mL), cyaniding-3-(6"-malonyl glucoside) (1.69 mg/100 mL), cyaniding-3-*o*-(6" dioxalyl glucoside) (0.46 mg/100 mL), and peonidin-3-(6" malonyl glucoside) (0.16 mg/100 mL), while the total anthocyanins were estimated at 4.3 mg/100 mL (Kelebek et al., 2008). There are, however, some exceptions to the above rule, where the pink to red coloring of the flesh is attributed to lycopene. Lycopene is

the major pigment found in Cara Cara, the red-fleshed navel orange from Venezuela, as well as of the pink-fleshed acidless variety Vainiglia Sanguigno and Sarah, a mutation of Shamuti from Israel (Saunt, 2000).

Amino Acids in Modern Orange Cultivars

Serine, proline, and arginine (508–892, 394–735, and 300–746 mg/100 g juice) are considered as the major amino acids in most of the cultivars listed in Table 12, while aspartic acid, glutamic acid, and glycine have also been found in high concentrations too (Liu et al., 2012; Roussos, 2011). Histidine, glutamine, asparagine, and alanine are found in concentrations below 100 mg/100 g. Hamlin, Jincheng, and Pineapple have similar total amino acid concentration, reaching approximately 1800 mg/100 g (Niu et al., 2008), significantly lower than that found in Trovita and Pineapple (approximately 2500 mg/100 g) (Niu et al., 2008). Salustiana has lower amino acid concentration than Shamuti, in which the predominant amino acid is aspartic acid (115 mg/100 mL) (Roussos, 2011).

Carotenoids and Volatiles in Modern Orange Cultivars

The major carotenoids found in oranges are listed in Table 5. In the cultivars Hamlin, Earlygold, and Budd Blood, the main carotenoid found was violaxanthin, followed by lutein, β -cryptoxanthin, zeaxanthin, and *cis*-antheraxanthin (Lee and Castle, 2001). In Moro, *cis*-Violaxanthin (C14:0, C16:0), *cis*-Violaxanthin (C14:0, C14:0), and *cis*-Violaxanthin (C12:0, C14:0) are the most abundant (Giuffrida et al., 2010). In Bionda cultivar, *cis*-Violaxanthin (C14:0, C16:0) and *cis*-Violaxanthin (C14:0, C14:0) are the most abundant (Giuffrida et al., 2010). In Brasiliana, *cis*-Violaxanthin (C14:0, C14:0) and β -Cryptoxanthin (C14:0) are the predominant; in Ovale, luteoxanthin (C14:0) and β -Cryptoxanthin (C14:0); in Sanguinello, which is quite rich in carotenoids, luteoxanthin (C14:0), *cis*-Violaxanthin (C12:0, C14:0), β -Cryptoxanthin (C12:0), *cis*-Violaxanthin (C14:0, C16:0) (the most abundant one), and β -Cryptoxanthin (C14:0) are the ones found in highest concentrations (Dugo et al., 2009; Giuffrida et al., 2010). *cis*-Violaxanthin (C14:0, C16:0) is the predominant carotenoid in Tarocco pigmented orange also (Giuffrida et al., 2010). In Pera Rio zeaxanthin, lutein, and β -cryptoxanthin were detected in high concentration, in Natal, in Hamlin, in Lima, and in Pera Coroa zeaxanthin was the main carotenoid (Pupin et al., 1999). In Liucheng zeaxanthin, lutein and β -cryptoxanthin were the predominant carotenoids (Wang et al., 2007).

In Kozan cultivar besides limonene, linalool, β -phellandrene, and terpinene-4-ol are the most abundant ones (Selli et al., 2004). In Moro, β -myrcene and methylbutanoate are the main ones, as in Tarocco, in which ethylbutanoate is also a major volatile (Arena et al., 2006). β -myrcene has been found in high concentration in Pera Rio orange (Seideneck and Schieberle, 2011). In Jincheng, besides limonene, linalool, terpinene-4-ol, and β -myrcene are in higher concentrations than the rest of the volatiles (Qiao et al., 2008).

Table 12 Amino acid composition of the juice of modern orange cultivars

	Hamlin	Jincheng	Pineapple	Trovita	Valencia delta	Salustiana	Shamuti
Cultivars	mg/100 g				mg/100 mL		
Alanine	46	43	54	70	133	—	36
GABA	—	—	—	—	—	0.49–3.74	—
Asparagine	73	28	79	61	46	15.42–17.96	—
Arginine	519	300	490	639	746	17.71–18.41	45
Aspartic acid	—	—	—	—	—	2.79–3.04	115
Cysteine	5	1	8	—	—	—	—
Glutamic acid	—	—	—	—	—	3.56–4.8	28
Glutamine	65	36	67	22	35	—	—
Glycine	9	12	11	16	18	7.93–13.68	—
Histidine	72	126	53	111	62	0.18–0.40	—
Isoleucine	5	6	5	6	7	0.56	—
Leucine	4	5	5	4	8	0.66–0.74	6
Lysine	16	19	13	5	14	1.56–1.92	10
Methionine	5	5	5	3	46	1.90–1.92	—
Phenylalanine	20	35	17	24	43	0.15–0.14	—
Proline	517	394	440	615	735	79–103.59	—
Serine	508	541	511	892	535	6.37–7.95	70
Threonine	20	20	22	28	—	1.02–1.39	—
Tryptophan	—	—	—	—	—	0.16–0.3	—
Tyrosine	16	30	20	30	38	1.23–1.34	—
Valine	13	15	15	17	26	1.82–1.83	12
Total AA	1810	1800	1817	2535	2495	153.85–168.53	—

The table shows the range of the major amino acids concentration in the juice of modern orange cultivars.
 Sources: Liu et al. (2012); Niu et al. (2008); Roussos (2011).

Mineral Elements in Modern Orange Cultivars

Potassium is the major element found in all cultivars presented in Table 13. Its concentration ranged from 1011 (Shamouti orange) to 1570 (Lue Gim Gong) mg/L or around 140 mg/100 mL pulp (Lima and Pera orange) (Barros et al., 2012; Roberts and Gaddum, 1937; Topuz et al., 2005). Lue Gim Gong exhibited higher phosphorus concentration than the other cultivars (300 mg/L, while in other cultivars phosphorus concentration ranged around 150 mg/L) (Roberts and Gaddum, 1937). Calcium is the third most significant nutrient of orange juices, found in concentrations around 100 mg/L (3–4 g/kg DW of fruit) (Paramasivam et al., 2000). Magnesium is found in similar concentrations to those of calcium in most cultivars, ranging from 50 mg/L in Lue Gim Gong to 102 mg/L in Alanya (Topuz et al., 2005). Sodium has been determined in low concentration at approximately 7 mg/L. Zinc, manganese, and copper have been found in higher concentrations in Finike cultivar (3.16, 0.11, and 2.77 mg/L, respectively) compared to Alanya and Shamuti (Topuz et al., 2005).

Organoleptic and Biochemical Differences Among Common, Navel, and Pigmented Orange Cultivars

Orange cultivars are classified into categories, as follows:

1. The common oranges or blond oranges.
2. The navel oranges, which are characterized by the presence of a second fruit at the apex of the fruit.
3. The pigmented or blood oranges, which are characterized by red color of the pulp and/or the peel.
4. The sugar or acidless oranges, which are characterized by very low levels of acids.

The majority of the cultivars cultivated worldwide nowadays belong to the first three categories. The most widely cultivated group of cultivars, that is, Valencia group, is classified as common orange, although these varieties, due to their specific characteristics, could be part of a subclass within the common oranges. Common oranges are characterized by their distinctive skin color, a combination of yellow and red, and by the thin peel. Some of these cultivars have low juice volume (below 40% per fruit weight), while the Valencia group (Valencia Cutter, Valencia Olinda, Valencia Campbell, Valencia Frost, Valencia Delta, Lue Gim Gong, and others) is characterized by higher juice volumes.

The Navel oranges besides the distinctive feature of a navel at the stylar-end of the main fruit are characterized by early maturation, seedlessness, deep orange color of the skin, which is easily peeled, and a sweet, pleasant taste. They are dessert oranges since they yield less juice than other cultivars and develop late bitterness due to the presence of limonin.

Pigmented or blood oranges are characterized by the light to deep red coloring of the skin and/or flesh, due to the presence of anthocyanins, with some exceptions, such as Vainiglia Sanguigno and Cara Cara (a navel orange), in which the color is attributed to the presence of lycopene.

Table 13 Mineral element composition of the juice of modern orange cultivars

Cultivars	Units	Mineral elements								
		K	P	Ca	Mg	Na	Zn	Mn	Cu	Fe
Alanya	mg/L	1364	150.1	94.7	102	7.7	1.7	0.02	0.54	–
Finike	mg/L	1107	125.2	93.3	99.1	7.3	3.16	0.11	2.77	–
Hamlin	g/Kg DW fruit	11.8	1.3	3.8	1	–	0.030	0.003	0.005	0.020
Jincheng	mg/Kg juice	1500	–	98.8	78.57	6.43	0.05	0.17	0.36	1.01
Lima Orange	mg/100 mL pulp	140	–	18.7	10.3	2	0.091	0.045	0.047	0.171
Lue Gim Gong	mg/L	1570	300	110	50	7	–	–	–	1
Parson Brown	g/Kg DW fruit	12	1.3	4.6	1.15	–	0.022	0.004	0.005	0.030
Pera Orage	mg/100 mL pulp	139	–	–	10.3	2.6	0.067	0.053	0.035	0.256
Pineapple	mg/Kg juice	1310	–	41	100.7	6.29	0.72	0.14	0.27	1.04
Shamouti	mg/L	1011	174.2	88	84	5.7	1.72	0.05	1.37	–
Trovita	mg/Kg juice	1419	–	33.7	90.04	12.8	0.80	0.01	0.24	0.96
Valencia Delta	mg/Kg juice	1565	–	43.1	129.9	2.43	0.51	0.09	0.51	0.68

The table shows the range of mineral element concentration in the juice of modern orange cultivars expressed by different ways.

Sources: Barros et al. (2012); Paramasivam et al. (2000); Roberts and Gaddum (1937); Topuz et al. (2005).

Canterino et al. (2012) working with five common oranges, five navel, and five pigmented ones found that juice content and TSS content did not differ significantly between categories. Common oranges exhibited values of 10.44 °Brix, while navel and pigmented oranges presented 10.22 and 10.28 °Brix, respectively. There were, however, significant differences concerning TA, with pigmented oranges presenting higher values (1.03% w/v citric acid) compared to navel (0.63% w/v citric acid) and common oranges (0.73% w/v citric acid). The analysis of phenolic compounds (hesperidin, narirutin, and rutin) did not produce any significant differences among the three orange categories, with hesperidin ranging from 21.53 (navel) to 24.55 (pigmented) mg/100 mL, narirutin from 24.38 (navel) to 24.95 (common) mg/100 mL, and rutin from 4.73 (common) to 4.85 (pigmented) mg/100 mL. There were significant differences concerning the total phenol content of the three categories, with pigmented oranges exhibiting higher concentration (126.17 mg gallic acid equivalent/100 g) compared to navel oranges (97.93 mg gallic acid equivalent/100 g), with common ones exhibiting average values of 119.99 mg gallic acid equivalent/100 g. The exact opposite was detected concerning ASA concentration, with navel oranges exhibiting higher values (66.05 mg/100 mL) compared to pigmented (56.7 mg/100 mL), with common ones exhibiting average values of 61.46 mg/100 mL. The AA was determined based on FRAP assay, which showed that common oranges are characterized by higher AA (14.18 mmol Fe⁺²/kg) compared to navel oranges (11.05 mmol Fe⁺²/kg), with pigmented ones presenting average values (12.77 mmol Fe⁺²/kg). The taste panel test revealed significant differences among the three orange categories as well as similarities. There were no significant differences concerning sweet or sour perception, although navel oranges proved to be less bitter and less astringent than pigmented ones as well as having less citrus flavor intensity.

Significant differences were detected in juice quality characteristics in 12 orange cultivars (Shamuti, Salustiana, New Hall, Washington Navel, Navellina, Navelate, Moro, Tarocco, Valencia Olinda, Valencia Frost, Valencia Campbell, and Valencia Cutter) belonging to the three previously mentioned categories (Roussos and Pazioudimou, unpublished data). Juice from Navel cultivars exhibited higher pH values (3.8) than those detected in pigmented (3.5) and common oranges (3.6), which was the result of the lower TA measured in Navel oranges (1.02 against 1.47 and 1.51 g citric acid/100 mL juice in common and pigmented oranges, respectively). Pigmented oranges exhibited lower TSS content (9.8 °Brix) than common oranges (10.96 °Brix), while the maturity index (TSS per TA) was higher in navel oranges (10.6) than in pigmented and common oranges (6.5 and 8.2, respectively). The total carotenoid concentration, expressed as β -carotene equivalents, was higher in common oranges (0.18 mg equivalents β -carotene/100 mL juice) compared to that of pigmented and navel ones (0.07 and 0.08 mg equivalents β -carotene/100 mL juice, respectively). Total phenols did not differ much among the three categories, ranging from 30.4 to

34.36 mg tannic acid equivalents/100 mL juice. Flavonoids, however, differ between orange categories, with navel oranges exhibiting lower concentrations than pigmented and common oranges (1.39, 3.15, and 3.51 mg caffeic acid equivalents/100 mL juice, respectively). The same was found with *o*-diphenol concentration, for which pigmented and common oranges exhibited higher values than navel oranges (7.88, 6.48, and 4.05 mg caffeic acid equivalents/100 mL juice, respectively). The antioxidant capacity of the juice did not differ significantly based on either FRAP assay, since it ranged between 487 (navel) to 675 (pigmented) $\mu\text{mol Trolox}/100\text{ mL juice}$ or DPPH assay (from 83.17 in navel to 87.9% DPPH inhibition, in common oranges).

When we proceeded to principal component analysis based on the three categories of oranges assayed, there was not any clear distinction between them. When valencia cultivars were used as a separate group then it was easy to distinguish between common, navel, pigmented, and valencia oranges. Common oranges (excluding Valencia group) were characterized based on principal component analysis, by low TA, total carotenoid content, total flavonoids, and total *o*-diphenols. Pigmented oranges were characterized by high AA, low pH, and low total phenol concentration. Navel oranges exhibited low TA, total carotenoid content, total flavonoids, total *o*-diphenols, and low AA, but high pH and total phenol content. Valencia cultivars were characterized by high TA, total carotenoid content, total flavonoids, and total *o*-diphenols.

SUMMARY POINTS

- The major carbohydrate in orange juice is sucrose, followed by fructose and glucose.
- The most abundant organic acid of orange juice is citric acid, while malic and succinic acid have been also detected.
- The main phenolic compound of orange juice is hesperidin, followed by narirutin.
- The major amino acids in orange juice are proline, serine, and arginine.
- Violaxanthin, β -cryptoxanthin, and lutein are major carotenoids of orange juice.
- Limonene is the predominant volatile of orange juice, followed by linalool, β -myrcene, and terpinene-4-ol.
- The major mineral element found in orange juice is potassium, followed by phosphorus and calcium.
- Anthocyanins are the major pigments present in the majority of blood oranges, with lycopene being the major one in only a few cultivars.

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CHAPTER 21

Composition of Papaya Fruit and Papaya Cultivars

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LIST OF ABBREVIATIONS

DW	Dry weight
FRAP	Ferric reducing antioxidant potency
FW	Fresh weight
GAE	Gallic acid equivalent
GAP	Good agricultural practices
GMP	Good manufacturing practices
OA	Organic acids
ORAC	Oxygen radical absorbance capacity
TA	Titrateable acidity
TPC	Total phenolics content
TSS	Total soluble solids
Vitamin C	Ascorbic acids

INTRODUCTION

Fruits are one of the foremost nutritional and health-sustaining food resources available to humans. It is a well-accepted fact that consumption of whole fruit or processed fruit products are capable of supplying adequate amounts of essential minerals, vitamins, soluble and insoluble dietary fibers. In fact, processed fruit products such as juice, jam, purees, fruit powder (as a supplement), and others are also considered to retain the

original organoleptic qualities and nutritional value. Although fruits can be of the climacteric or nonclimacteric type, their cultivation has been shown to improve and support the economy of the grower as well as the region. In addition, of late, certain underused and underexplored fruits are also gaining much importance (mainly owing to their nutraceutical values). The majority of fruits worldwide are seasonal, and hence, a continuous supply of these types of fruit is of prime importance. Freshly harvested fruits have a shorter shelf life, and applications of various storage methods are required to maintain the overall quality and appeal.

As early as 1535, the existence of the papaya tree (*Carica papaya* L.) was described by the Spanish author de Oviedo in his book *La natural hystoria de las Indias*. In this book, the author notified the Spanish king regarding papaya fruits that were grown in the regions of southern Mexico and northern parts of Nicaragua. In addition, it was indicated that papaya seeds from these places were taken to the Caribbean islands, Panama, and some South American regions. Furthermore, owing to the unique taste and gaining popularity, papaya planting spread throughout the tropical countries, especially in Africa and Asia (de Oliveira and Vitória, 2011).

Among a wide array of tropical fruits, the papaya is deemed to be one of the most economical fruits, which not only is cultivated roughly in 60 countries but also is marketed worldwide. The increase in demand and popularity of papaya fruit is also because of its pleasant flavor and mouthfeel of the edible pulp, nutritional value, and therapeutic values. Papaya fruits are consumed in various forms such as ripe, semi-ripe, or unripe/raw. In the tropical regions, raw papaya is used as a vegetable, a snack food, and an ingredient in jellies, curry, salad, and pickles (Adetuyi et al., 2008; Chaiwut et al., 2010; Workneh et al., 2012; Annegowda et al., 2014). Ripe papaya is generally consumed directly by consumers. However, commercially ripe fruits find potential applications in the preparation of syrups, dried fruit, yoghurt, jam, jellies, nectars, and candy, among other foods. Papaya juice is also one of the most popular refreshing beverages (Workneh et al., 2012; Nakamura et al., 2013). Apart from the fruit, there is a high demand for papain, a digestive enzyme obtained from papaya, which holds great value as an added ingredient in the pharmaceutical, cosmetics, and food industries (for such applications as brewing and meat tenderizing). In the international fruit market, the demand for papaya has increased tremendously. Papaya production and importation worldwide during the year 2010 reached around 11.8 million tons and 243 million US dollars, respectively (Udomkun et al., 2014). Considering the growing trend, the Food and Agriculture Organization estimated that tropical fruit production worldwide would reach 82 million tons in 2014. Over the years, India and Brazil have been leading producers of papaya, and the United States is expected to have an import market of 134,445 tons, and with European Union countries expected to reach around 12% (<http://www.freshplaza.com/article/101367/World-production-of-tropical-fruit-expected-to-increase-in-2014>; accessed 01.12.14.). Even though papaya fruits are a rich source of nutrients accompanied by high amounts

Table 1 Phytochemical composition of various parts of a papaya plant

Part	Composition	References
Leaf	Vitamin A, C, B ₁₂ , folic acid, alkaloids carpain, pseudocarpain, and carposide.	Krishna et al. (2008) and Imaga et al. (2010)
Papaya peel	Cysteine proteases, papain, chymopapain, glycyndopeptidase, and caricain.	Chaiwut et al. (2010)
Papaya fruit	Sugars such as fructose, galactose, xylose, mannose, and ribose. Vitamin C, phenolic acids, and flavonoids. Organic acids such as citric acid, fumaric acid, malic acid, tartaric acid, and succinic acid. Flavoring volatile oil components such as benzyl isothiocyanate, butyric acid, hexanoic acid, and octanoic acid.	Jiao et al. (2010) Spínola et al. (2015) Hernandez et al. (2009) Flath et al. (1990)
Barks	β-Sitosterol, glucose, sucrose, and xylitol.	Krishna et al. (2008)
Seeds	Alkaloids, steroids, triterpenoids, flavonoids, benzyl isothiocyanate, carpaine, benzylglucosinolate, benzylthiourea, hentriacontane, and caricin.	Pathak et al. (2000), Kermanshai et al. (2001) and Krishna et al. (2008)

of bioactive compounds (antioxidants), the production rate remains inadequate. It is worth noting that each part of the papaya plant has biological activity and importance. Some vital phytochemical compositions of various parts of the papaya plant are provided in Table 1.

BOTANICAL ASPECTS

Papaya (*Carica papaya* Linn. family Caricaceae) is a small tropical evergreen tree (plant), and is the only species in the genus *Carica* (Eustice et al., 2008). The leaves are broad and the plant contains latex. The plant's stem is a hollow cylindrical trunk and bears the leaves on the top (like an umbrella). Depending on the variety, the plant can grow up to a height between 5 and 20 ft. Once the old leaves fall, they leave behind a scar (similar to a coconut tree) at the base. Papaya fruits occur in clusters below the leaf canopy, at the tip of the trunk. The plant contains milky latex, which is a good source of cysteine endopeptidases (papain, chymopapain, glycyndopeptidase, and caricain) (Azarkan et al., 2003; Annegowda et al., 2014). The plant is trioecious and has three sex forms, including male, female, and hermaphrodite (self-pollinating). For the commercial production of papaya, hermaphroditic trees are usually preferred, as all of these trees produce fruit, whereas a female tree requires at least 6–10% male trees in a field for the pollination and production of fruit. Besides, hermaphroditic trees remain unaffected by extrinsic environmental factors such as temperature, soil moisture, etc. Fruits obtained from hermaphroditic trees are cylindrical in shape and possess a thick wall of firm flesh along with a small seed

cavity. This helps in withstanding the handling and shipping process. Female papaya trees bear round fruits with thin skin (Workneh et al., 2012). Irrespective of the tree type, papaya trees bear fruits within 9–12 months after seed germination, with each one producing approximately 800–1200 seeds (Eustice et al., 2008).

Papaya plants, although native to South America, are widely cultivated today and popular in India, Sri Lanka, Malaysia, Bangladesh, Australia, the Philippines, Africa, Taiwan, Jamaica, and other tropical countries (Varastegani and Yang, 2013; Azad et al., 2014). Even though world production varies from year to year, the total annual production of papaya fruit are estimated to range around 6 million tons, with Brazil being the world's leading producer (supplying nearly 25%) followed by Mexico (14%), Nigeria (11%), India and Indonesia (10%). In addition, China, Peru, Venezuela, Ethiopia, Thailand, and the Philippines are known to contribute <3% of the world production supply. The principal markets for papaya fruit are the United States and Europe (de Oliveira and Vitória, 2011; Jayavalli et al., 2011). Normally an average plant has a height of 4–5 m (Adetuyi et al., 2008).

Papaya plants require hot and humid temperatures in the range of 21–33 °C. The plants are extremely sensitive to cold temperatures (<15 °C) or frost. In addition, the growth, size, and sweetness of the fruit diminish at low temperatures (Workneh et al., 2012). However, prolonged dry periods can reduce the production rate of papaya fruit as well (de Oliveira and Vitória, 2011). Papaya plants exposed to low light intensity are reported to contain low levels of ascorbic acid (vitamin C) and sugars. Papaya plants require adequate irrigation (watering) to promote normal growth, development of fruit, and regular fruit yield. The required soil conditions are sandy loamy or porous loamy soil. Low or high irrigation can lead to sterility of the plant, as well as result in the production of irregularly shaped carpellocid fruit (Workneh et al., 2012). Under favorable environmental conditions, papaya fruits are capable of growing round the year. Depending on the cultivar or the variety, the fruit, which is an elongated berry, can be of various sizes. The color of the fruit flesh can also vary, from green, yellow, or red to orange color with a sweet, pleasant, mellow taste. Papaya fruit usually ripens from the inside out. The two important features that can influence consumers' acceptance are the aroma and phenolic compound content (Saeed et al., 2014). Papaya fruit composition depends mainly on the cultivar or the variety, climatic conditions, type and fertility of the soil, and harvesting time. Studies have indicated that the bioactive constituents (phenols, antioxidant compounds), aroma compounds, total soluble solids (TSS), and titratable acidity (TA) vary among different papaya cultivars (Gomez et al., 2002; Saeed et al., 2014). In Table 2, the composition and mineral contents of various cultivars of papaya of Bangladesh origin assigned as 'Local 1' and 'Local 2' varieties (Bari et al., 2006) are highlighted. Accordingly, the compositions of Local 1 and Local 2 papaya cultivars were found to have remarkable variations in fiber content, carbohydrates, and vitamin and mineral components. This study revealed the pronounced disparities between the mature and ripe papaya of the same cultivars. The amount of protein, carbohydrates, vitamins and minerals, as well as

Table 2 Composition and minerals content of various cultivars of papaya from Bangladesh

Components analyzed	Local 1		Local 2	
	Mature	Ripen	Mature	Ripen
Total titrable acidity (%)	0.025	0.04	0.05	0.04
pH	5.86	6.01	5.59	5.96
Fiber	1.3	1.01	1.05	0.9
Protein	1.14	2.01	1.01	1.9
Carbohydrates	16.0	23.5	17.9	20.3
Lipids	0.5	0.37	0.2	0.27
Ascorbic acid	8.09	31.0	7.3	29.4
Carotene	0.50	0.81	0.40	0.78
Thiamine	0.14	0.17	0.20	0.21
Calcium	20.0	31.0	18.7	28.5
Potassium	198	275	190	240
Magnesium	16.0	22.0	14.0	21.0

Total titratable acidity, pH, fiber, protein, carbohydrates, and lipid values were determined in 100 g edible portion of papaya fruit; ascorbic acid, thiamine, carotene, calcium, potassium, and magnesium were values in mg found in 100 g edible portion of papaya fruit.

Source: Bari et al. (2006).

pH increased in ripe fruit in comparison to mature fruits. Among the papaya cultivars evaluated, ripe fruit of Local 1 cultivar possessed higher amounts of components compared to Local 2 cultivar.

Abu-Goukh et al. (2010) studied the compositional variation and changes in respiration rate among the 'Ekstotika cultivars' I and II of Malaysia, along with the local 'Baladi' cultivar of Sudan. They reported that respiration rate of 'Baladi' cultivar was low among the three cultivars during all stages of growth and development. Hence, 'Baladi' cultivar with low respiration rates had higher flesh firmness with longer shelf life. The TSS of 'Baladi' cultivar was significantly lower compared to 'Ekstotika' cultivars I and II. The total sugars were recorded to be increased markedly in the fruits after 120 days (from anthesis), owing to the increase in starch hydrolysis or sugar conversion by papaya invertase and acid invertase enzymes. In this study, the amount of reducing sugars was recorded to be increased 3.0-, 3.2-, and 3.3-fold in the fruits of 'Baladi', 'Ekstotika-I', and 'Ekstotika-II' cultivars, respectively, at 140 days from anthesis. In addition, a threefold increase in the total proteins in all the three cultivars was recorded. A progressive decrease in the total phenolics content (TPC) throughout the growth and development and at 155 days from anthesis was recorded in 'Baladi', 'Ekstotika-I', and 'Ekstotika-II' cultivars (a 10.7-, 18.6-, and 27.8-fold decrease, respectively). The vitamin C content of 'Baladi' cultivar was found to be increased 2.3-fold in 'Ekstotika-I' as well as 'Ekstotika-II' cultivar (increased to 2.2-fold 15–155 days from anthesis).

Nwofia et al. (2012) reported on the proximate composition, mineral, and vitamin content of papaya pulp obtained from five morphotypes of 'Sunrise solo' papaya fruit cultivated in Nigeria. The results revealed (see Table 3) significant variations in the

Table 3 Composition, vitamins, β -carotene, and mineral content in various morphotypes of ‘Sunrise solo’ papaya fruit pulp

Components analyzed	Oblong red	Pear orange	Round orange	Oblong yellow	Round yellow
Fiber (%)	0.83	0.93	0.77	0.87	0.83
Protein (%)	0.40	0.90	0.59	0.99	1.17
Carbohydrates (%)	7.46	7.56	6.50	8.07	9.51
Lipids (%)	0.53	0.37	0.47	0.70	0.49
Vitamin C	41.07	39.31	39.89	36.37	43.41
Thiamine	0.28	0.26	0.30	0.24	0.27
β -Carotene (IU/100g)	6207.2	6112.8	6186.7	5173.3	5874.9
Calcium (mg/100 g)	34.73	22.71	22.71	21.38	30.73
Phosphorus (mg/100 g)	16.47	18.37	17.02	19.45	29.80
Magnesium (mg/100 g)	13.60	11.20	10.40	12.00	12.80

Source: Nwofia et al. (2012).

components analyzed among the five morphotypes. The round yellow type possessed noticeable amounts of protein, carbohydrates, vitamin C, and minerals, whereas the oblong red morphotype was rich in fiber content, with the round orange type being rich in thiamine. The oblong yellow type had higher lipid levels. From this study, the authors concluded that the same papaya cultivar with different morphologies can highly influence the composition of papaya fruit.

Furthermore, Santos et al. (2014) compared the peel flour of two cultivars of papaya fruit (‘Hawai’ and ‘Calimosa’) in regard to various components (see Table 4). Their study showed that the composition of various nutritional components and minerals varies significantly among the two cultivars. The TA protein, lipids, ascorbic acid, and minerals were found in significant amount in ‘Hawai’ cultivars in comparison to the ‘Calimosa’ cultivar, whereas, in the peel flour of ‘Calimosa’ papaya cultivar, the pH, fiber, and carbohydrates were present in significant amounts.

Recently, Kelebek et al. (2015) analyzed the ‘Tainung’ and ‘Sel-42’ papaya varieties from Turkey for vitamin C, phenolic compounds, and sugars, as well as for compounds responsible for aroma (see Table 5). Except for pH, all of the compounds analyzed (TA, TSS, total sugars, vitamin C, and total polyphenols) were present in substantial amounts in the ‘Sel-42’ variety when compared to the ‘Tainung’ variety. Besides, the sucrose levels were found to be low among all of the papaya varieties evaluated. From the work, 12 types of phenolic compounds were identified among both the varieties. However, total composition of phenolic compounds was significantly higher in the ‘Sel-42’ variety compared to the ‘Tainung’ variety. Regarding the compounds responsible for aroma, 46 and 42 aroma compounds from ‘Sel-42’ and ‘Tainung’ papaya varieties were identified, respectively. Esters, which are potent contributors to flavor in papaya fruit, were found in significant amounts in the ‘Sel-42’ cultivar. Among the esters, methyl benzoate

Table 4 Composition of papaya peel flour of 'Hawai' and 'Calimosa' papaya cultivars
Components analyzed^a

	Hawai	Calimosa
Total titrable acidity (%)	0.80	0.63
pH	4.55	4.69
Fiber	33.05	34.70
Protein	18.18	15.03
Carbohydrates	9.67	23.3
Lipids	2.44	2.07
Ascorbic acid	3.37	2.96
Calcium	337.5	296.3
Potassium	2046	2075
Magnesium	210.0	182.5
Phosphorus	547.5	526.9

^aTotal titrable acidity, pH, fiber, protein, carbohydrate, and lipid values were found in 100 g peel of papaya fruit; ascorbic acid, calcium, potassium, and magnesium content values are given in terms of milligrams found in 100 g of papaya peel.

Source: Santos et al. (2014).

Table 5 Composition of papaya 'Sel-42' and 'Tainung' papaya varieties
Components analyzed

	Sel-42	Tainung
Total soluble solids (TSS)	11.2 ± 0.00	10.0 ± 0.00
pH	4.03 ± 0.01	5.10 ± 0.01
Titrateable acidity (TA) (%)	0.115 ± 0.01	0.086 ± 0.00

Sugars (g/kg)

Sucrose	4.11 ± 0.01	5.19 ± 0.05
Glucose	40.78 ± 0.59	37.22 ± 0.31
Fructose	34.80 ± 0.03	28.72 ± 0.45
G/F	1.17 ± 0.02	1.30 ± 0.03
Total sugar	80.86 ± 0.62	72.42 ± 0.16

Organic acids (mg/100 g)

Ascorbic acid	71.70 ± 0.42	67.30 ± 0.08
Oxalic acid	9.75 ± 0.07	8.78 ± 0.06
Citric acid	379.49 ± 2.67	349.34 ± 2.46
Tartaric acid	9.95 ± 0.07	4.21 ± 0.03
Malic acid	292.46 ± 2.06	306.68 ± 2.23
Fumaric acid	14.37 ± 0.10	11.67 ± 0.62
Total phenolic compounds (mg/100 g)	171.7	119.8

Aroma compounds (identified and quantified using GCMS)

Esters	994.1	970.3
Alcohols	235.0	359.0
Terpenes	589.5	64.5

Source: The table is reproduced with kind permission from Elsevier, Rightslink: License Number: 3607520513211; Dated: April 15, 2015; Food Chemistry; Kelebek et al. (2015).

(responsible for the fruity flavor) was detected in significant amounts in the ‘Sel-42’ cultivar. Even the concentrations of terpenes such as linalool and its derivative (responsible for the aroma of papaya fruit) were present in significant amounts in the ‘Sel-42’ compared to ‘Tainung’ variety.

Harvesting time and maturity of the fruit is vital to achieve stability and quality. Apart from influencing the concentration of bioactive compounds or sugars, early harvested fruits can be prone to postharvest physiological disorders and can be susceptible to physical damage during handling and transportation, as well as premature shrinking, leading to inferior flavor on ripening. Traditionally, papaya fruits are harvested when the skin color changes from dark green to light green with the development of a thin yellowish colored tinge. In addition to the above, papaya fruits are harvested based on commercial requirements; for export purposes, fruit is harvested when 25% yellow color is developed, whereas for the local market, they are harvested when there is 50–75% yellow color (Gayosso-García Sancho and Yahia, 2010). Determining the maturity index is based on farmers’ traditional knowledge (in developing regions) or on scientific knowledge (in developed countries). In certain instances, the texture or the softness and change in latex color from white to watery are used as a ripening index (Udomkun et al., 2014).

However, the contents of the fruit depend directly on the maturity. For example, less mature papaya fruit contains low sugar content and ripens slowly. Of course, as compared to other fruits, during ripening, papaya fruit shows enhanced respiration rate and ethylene production accompanied by rapid softening of the fruit. In addition, the amount of carotenoids and ascorbic acids tend to increase during the maturation and ripening stages (Schweiggert et al., 2011). An overview of how pre- and postharvest factors can influence the phytochemical contents of fruit and vegetables is shown in Figure 1.

COMPOSITION OF TRADITIONAL OR ANCIENT CULTIVARS

Papaya fruit contains high amounts of ascorbic acid, vitamins A, B₁, B₂, and E, carotenoids, essential minerals (potassium, iron, calcium, phosphorous), dietary fiber, among other substances (Udomkun et al., 2014). With regard to composition, papaya fruit is composed of approximately 85–90% water, with 10–13% being total sugars (glucose, fructose, and sucrose). However, the fruit is low in protein (0.6%). Traditionally, fruit takes various forms, as highlighted earlier. Tropical fruits are reported to contain noticeable amounts of structural and nonstructural carbohydrates (nearly 50–70% of total weight) that can influence softening and ripening rates as well as storage life (Ali et al., 2004). In ripe papaya, 100 g of edible fruit contains 10% carbohydrates, which include glucose, sucrose, and fructose. During the early stages of fruit maturity, glucose was found in high concentrations, whereas sucrose was high during the time of ripening. Extended storage time of papaya fruits at elevated temperature can lead to a decrease in sugar levels, owing to their use as a substrate in the respiration process (Gayosso-García Sancho and Yahia,

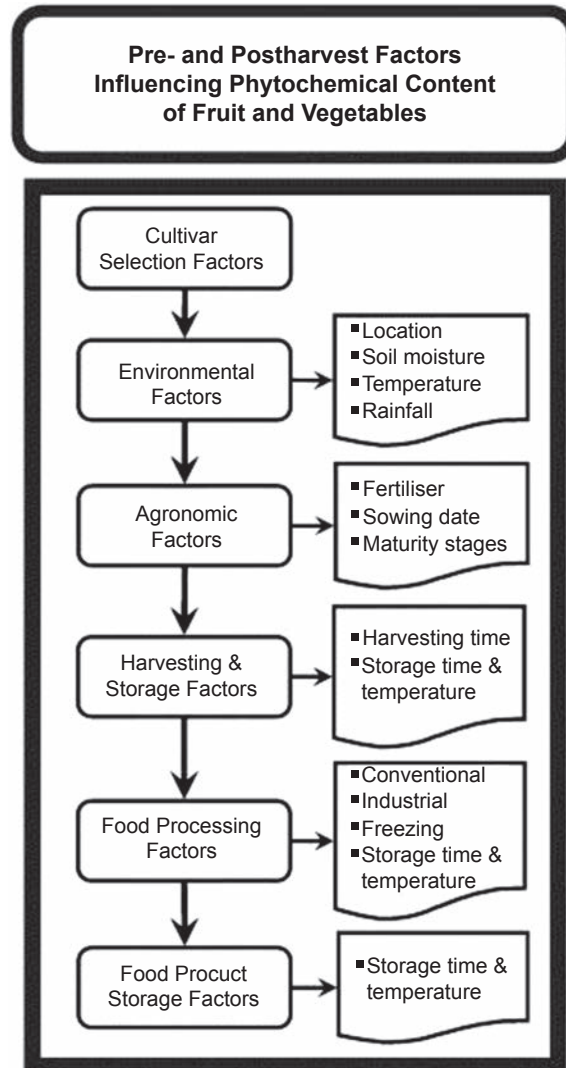


Figure 1 Pre- and postharvest factors influencing the phytochemical content of fruit and vegetables. Reproduced with kind permission from Elsevier, Rightslink: License number: 3519110341043; Dated: November 30, 2014; Food Research International, 2013; pp. 497–506.

2010). Degradation of starch in the ripe papaya mesocarp during ripening, accompanied by enzyme-influenced changes in cell wall structure and composition, contribute to softening of fruits. This leads to the formation of equal amounts of glucose and fructose (Lazan et al., 1995; Ali et al., 2004). Enzymes that influence changes in cell wall structure (wall-degrading enzymes) of papaya fruit includes endo-polygalacturonase (endo-PG), (1 → 4)-β-glucanase, β-galactanase, and pectin methylesterase (PME), and β-galactosidase

and pectinesterase. The activities of cellulase, β -galactosidase, and PME increase corresponding to various stages of ripening and decline on complete ripening (Rose and Bennett, 1999).

Papaya fruit pulp contains nonvolatile organic acids such as citric, fumaric, malic, malonic, succinic, and tartaric acids (pH 4.5–5.9). Furthermore, the level of organic acids fresh weight (FW) in ripe papaya (per 100 mg) contains the following: citric acid, 335 mg; L-malic acid, 209 mg, succinic acid, 52 mg, quinic acid, 52 mg, tartaric acid, 13 mg, oxalic acid 10 mg, and fumaric acid, 1.1 mg (Hernandez et al., 2009; Spínola et al., 2015). In addition, total acidity was found to increase during ripening and storage at ambient temperature. In ‘Solo’ papaya, total acidity level is reported to be increased from 0.34 to 1.04 g per 100 g fruit (Cámara et al., 1993). Ascorbic acid of papaya contributes to approximately 80% of the acidity value, whereas the remaining is owed to the presence of citric acid, malic acid, ketoglutaric acid, malonic acid, fumaric acid, and succinic acid. During ripening of papaya, ascorbic acid was found to increase by 20–30% (Bron and Jacomino, 2006).

Ripening of papaya fruit involves various changes in chemical composition, color, flavor, and texture of both peel and pulp. This is perceived by the formation of anthocyanins, carotenoids, and phenolic compounds with loss of chlorophyll. The carotenoids increased 5- to 10-fold during various stages of ripening of a yellow-flesh cultivar with the absence of lycopene. However, lycopene is the major pigment in red-fleshed cultivars such as ‘Solo’, ‘Farmosa’, and ‘Tailandia’, whereas β -cryptoxanthin contributes nearly 62% of the total carotenoids in a Brazilian papaya cultivar (Wills and Widjanarko, 1995; Schweiggert et al., 2011). These lipophilic carotenoids not only impart color and flavor to papaya fruits but also scavenge singlet oxygen and peroxy radicals and other reactive oxygen species. In addition, they also stimulate production of antioxidant enzymes such as superoxide dismutase, catalase, and glutathione S-transferase. Hence, papaya fruit can be considered as a main source of antioxidants (Gayosso-García Sancho et al., 2011).

The flavor of the papaya fruit is due to more than 100 different types of volatile flavoring compounds, which can be influenced by the location and the cultivar type. Linalool was found to be a major flavoring compound, along with minor compounds such as benzyl isothiocyanate, butyric acid, phenylacetone nitrile, hexanoic acid, and octanoic acid (Flath et al., 1990). In ‘Solo’ papaya cultivar, the percentage of linalool was 94%, the level of which varied based on the stages of ripeness. Ethyl butanoate, ethyl acetate, ethyl hexanoate, and ethyl-2-methyl butanoate present in papaya is accountable for the sweetness and aroma of the fruit (Flath et al., 1990). Results of Gas chromatography–Mass Spectrometry (GC–MS) analysis on the volatile compounds of four papaya cultivars from Indonesia and one from Brazil revealed the presence of butanoic acid, linalool, verbenone, phenylmethyl butanoate, D-octalactone, (Z)-linalool oxide, benzyl isothiocyanate, hexanal, (Z)-2-penten-1-ol, nonanal, and dimethyl sulfoxide (Ulrich and Wijaya, 2010).

Table 6 Relative concentrations of volatile components found in various cultivars of papaya, as determined by using GC–MS

Volatile components	Brazil	Burung	Bangkok
β -Pinene	—	0.303	0.013
α -Pinene	—	1.765	0.056
D-Limonene	—	0.083	—
Butanoic acid	—	0.769	0.009
Linalooloxide	0.026	0.564	0.029
Benzaldehyde	0.009	0.700	—
Butanonic acid	—	0.867	2.089
Furan methanol	0.140	0.337	—
Verbenone	0.025	0.829	0.038
<i>N,N</i> -Dibutyl formamide	0.073	1.203	0.034
Benzyl alcohol	0.004	0.697	0.014
Benzyl nitrile	0.061	1.610	0.263
Benzothiazol	0.017	0.614	—
δ -Octalactone	—	3.536	—
Isothiocyanatomethyl benzene	2.064	13.268	0.871

Concentrations of each compound were identified from GC–MS library, based on means of three replicates.

Source: Ulrich and Wijaya (2010).

(see Table 6). These researchers reported the presence of linalooloxide and verbenone (responsible for the flowery aroma) and δ -octalactone (responsible for the sweet and creamy odor) in the papaya fruits, which were much higher in the ‘Burung’ cultivar. Besides, the presence of high amounts of butanonic acid (responsible for the unpleasant odor) in the ‘Bangkok’ cultivar of papaya is also reported.

Recently, Pino (2014) used solid-phase microextraction and simultaneous distillation–extraction combined with Gas Chromatography–Flame Ionisation Detector (GC–FID), GC–MS, followed by aroma extract dilution and odor activity examination to analyze volatile compounds in papaya fruit cv. Red Maradol. The results showed the presence of 118 volatile compounds, with the composition including 50 esters, 19 alcohols, 10 acids, 20 terpenes, 15 ketones, 9 aldehydes, 7 *S*-compounds, 4 *N*-compounds, and 3 other compounds.

Papaya fruits have a very short shelf life and are prone to rapid postharvest loss. The fruits are susceptible to microbial contamination as well as bruising, owing to the high moisture and nutrient levels. Ripe papayas are highly susceptible to physical injuries (scratches and punctures) during handling and transportation, leading to wounds that result in loss of moisture and enhanced shriveling. Spoilage microorganisms infect papaya fruit, either by direct penetration or by intact cuticle or through wounds and natural openings on the surface (Paull et al., 1997; Tripathi et al., 2011). Anthracnose caused by the fungus *Colletotrichum gloeosporioides*, as well as other diseases caused by *Ascochyta caricae-papayae*, *Phomopsis caricae-papayae*, and *Phytophthora nicotiana* var. *parasitica* are common in papaya (Workneh et al., 2012).

Table 7 Phenolic content and antioxidant activity of papaya juice
Values

Phenolic contents	Imported	Local
Total hydroxycinnamic acids ^a	35.32	40.12
Hydroxybenzoic acids ^a	3.33	10.01
Flavones ^a	—	1.44
Total flavonols ^a	—	17.05
L-Ascorbic acid ^a	95.90	118.86
Total phenolic content ^b	127.85	159.7
Total flavonoid content ^c	15.30	20.47
Antioxidant activity (micromolar trolox equivalent antioxidant activity/100 g juice)		
ABTS ^d radical scavenging activity	906.5	946.8
Oxygen radical absorbance capacity	935.5	988.4

^amg/100 mL Fruit juice.^bmg Gallic acid equivalent/100 g juice.^cmg Quercetin equivalent/100 g juice.^d2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid).

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Various polyphenolic compounds (see Table 7) such as caffeic acid, caffeoylmalic acid, *p*-coumaric acid, quinic acid, pro-catechuic acid, ferulic acid, coumaryl glucaric acid, feruloylglucaric acid, feruloylmalic acid, quercetin, sinapic acid, methyl gallic acid, rutin, apigenin-O-pentoside, and isorhamnetin have been identified in papaya fruit. Besides, vitamin C content (in 100 mL of papaya juice) is reported to be 52 mg, with total hydroxycinnamic acids, hydroxybenzoic acid, flavones, and flavonols to be present in quantities of 40.12, 10.01, 1.44, and 17.05 g, respectively (Spínola et al., 2015).

COMPOSITION OF MODERN CULTIVARS

The various papaya cultivars available worldwide include 'Solo' from Brazil, 'Taiwan' varieties from Taiwan, 'Maradol' (Red Maradol) cultivar from Cuba and Mexico, 'Sekaki' cultivar from Hong Kong, 'Eksotika' variety from Malaysia, 'Khack Dum' variety from Thailand, and 'Sunrise', 'SunUp', 'Rainbow', and 'Kapoho' cultivars from Hawaii (Wall, 2006; de Oliveira and Vitória, 2011). In fact, cross-hybridization has also resulted in various papaya varieties from several countries.

Papayas of the 'Solo' varieties are pear or oval shaped, small, weigh between 400 and 600 g, and have desirable characteristics (sweetness and composition) and high commercial value. Since the size of this variety is about the right amount of fruit required for consumption by one person, it was given the name Solo. 'Solo' papaya harvested at 75% ripe stage can be stored for 21 days at 7 °C without any significant changes in the physicochemical parameters. If completely ripened papaya is stored at a temperature below 20 °C, it suffers from chilling injury, along with loss of quality (Workneh et al., 2012).

Table 8 Ascorbic acid, vitamin A, TSS, β -carotene, β -cryptoxanthin, and lutein content in different cultivars of papaya fruits grown in Hawaii

Contents	Papaya cultivars				
	Kapoho	Laie Gold	Rainbow	Sunrise	SunUp
Ascorbic acid ^a	45.4	51.3	60.4	64.5	45.3
Vitamin A ^b	29.9	48.2	54.3	72.5	20.4
β -Carotene ^c	145.9	256.7	370.6	410.3	97.4
β -Cryptoxanthin ^c	426.3	643.8	1034.4	920.0	294.9
Lutein ^c	238.2	146.8	317.6	129.5	93.3
TSS ($^{\circ}$ Brix)	12.1	12.5	14.3	12.9	10.9

^amg/100 gFW.^b μ g retinol activity equivalent/100 gFW.^c μ g/100 gFW.

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Dated: December 1, 2014; Journal of Food Composition and Analysis, Wall (2006).

The Taiwan variety of papaya is larger, pear to oblong in shape, weighs approximately 800–2000 g, has high amounts of sugar, and offers increased resistance during transportation (de Oliveira and Vitória, 2011). ‘Kapoho’, ‘Waimanalo’, ‘Sunrise’, and ‘Sunset’ cultivars of papayas have different distinct characteristics such as red flesh color for ‘Sunrise’ and yellow color for others (Tripathi et al., 2011).

A genetically modified papaya variety was developed in Hawaii (line 55-1) during 1998, which was resistant to papaya ringspot virus infection and is now commercially marketed worldwide (Nakamura et al., 2013). Papaya varieties of Hawaiian origin are harvested when the TSS is 11.5% and with 6% of surface coloration. Wall (2006) studied the amount of vitamin C, vitamin A, and minerals in various cultivars of papaya grown in Hawaii. From the study, it was concluded that ‘Sunrise’ cultivar possesses significant amounts of vitamin C, vitamin A, β -carotene, and β -cryptoxanthin, followed by the ‘Rainbow’ cultivar, ‘Laie Gold’ cultivar, and ‘Kapoho’, and ‘SunUp’ cultivars (see Table 8). The mineral contents also varied among the evaluated cultivars (see Table 9). Regarding the TSS, no significant differences were observed among these cultivars.

In the Thailand papaya cultivar, the fruit had a moisture content of 85.2 g water/100 g FW, while the TSS was 10.0 $^{\circ}$ Brix and TA of 0.1 g/100 g FW. Total phenolic content was 35.2 mg gallic acid equivalent (GAE), total lycopene content was 22.13, and β -carotene and β -cryptoxanthin were 1.71 and 1.14 (all mg/100 g DW), respectively. The antioxidant activity of papaya fruit in 2,2-diphenyl-1-picrylhydrazyl (DPPH), ABTS⁺ radical scavenging activity, and ferric reducing antioxidant potency (FRAP) were 7.3, 5.6, and 6.4, micromolar trolox equivalents/g DW of papaya fruit, respectively (Udomkun et al., 2014).

Golden papaya fruits, a variety, are normally harvested at five different maturity stages as follows: Stage 0: completely green fruit, Stage 1: fruit with 15% yellowish skin, Stage 2: fruit with 16–25% yellow skin, Stage 3: 26–50% yellowish skin, and Stage 4: skin completely yellow (Bron and Jacomino, 2006).

Table 9 Mineral content in different cultivars of papaya fruits grown in Hawaii

Minerals (mg/100 g FW)	Papaya cultivars				
	Kapoho	Laie Gold	Rainbow	Sunrise	SunUp
Phosphorus	8.0	6.2	8.8	8.0	4.9
Potash	89.7	152.9	203.7	221.4	170.1
Calcium	9.8	20.4	32.1	19.9	13.9
Magnesium	19.2	24.8	24.5	32.7	21.1
Sodium	5.6	8.9	24.3	14.0	6.9
Iron	0.29	0.44	0.66	0.46	0.46
Copper	0.11	0.06	0.14	0.08	0.06
Boron	0.13	0.14	0.21	0.20	0.11

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 Dated: December 1, 2014; Journal of Food Composition and Analysis, [Wall \(2006\)](#).

The total carotenoids in the Costa Rican papaya hybrid variety ‘Pococi’ were found to be enhanced from 0.13 to 5.42–6.21 mg/100 g FW during ripening. In the early stages of ripening, esterified β -cryptoxanthins were predominant whereas both β -cryptoxanthin esters and all-*E*-lycopene were predominant during later stages. In addition, abundant amounts of β -cryptoxanthins laurate and caprate were found during all the ripening stages along with the presence of trace amounts of their precursors like that of phytoene and phytofluene. The amount of vitamin A in fully ripe papaya was found to be 0.13–0.17 mg retinol equivalents/100 gFW of papaya. The TSS also markedly increased from 6.5° to 8.5°Brix during the ripening, and during postharvest storage the TSS recorded was as high as 10.5°Brix. To attain full ripening, fruit took 6–8 days during the postharvest stage, whereas the fruit took 10 days to ripen naturally on the tree. Moreover, the peel color, fruit firmness, nutritive values, as well as lycopene and vitamin A precursor contents did not differ significantly among the fruit, which were ripened by postharvest treatment or naturally on the tree ([Schweiggert et al., 2011](#)).

In the ‘Maradol’ papaya variety, the amount of lycopene, β -cryptoxanthin, and β -carotene increased during various stages of ripening and their amount was recorded to be 3.5, 1.06, and 0.5 mg/100 gDW, respectively. The increase in the amount of lycopene, β -cryptoxanthin, and β -carotene was around 10-, 5-, and 2-fold with respect to their values compared to initial stages of ripening ([Gayosso-García Sancho et al., 2011](#)). However, [Kimura et al. \(1991\)](#) reported a 2-fold increase in the lycopene content and 2- to 5-fold increases in β -carotene in the ‘Common’, ‘Solo’, ‘Formosa’, and ‘Tailandia’ varieties. The differences in the contents in different cultivars have been attributed to agricultural practices, time of exposure to sunlight, ripening, and harvest stage as well as to postharvest handling and storage ([Wall, 2006](#); [Rivera-Pastrana et al., 2010](#)).

At the advanced stages of ripening of ‘Maradol’ papaya cultivars, the phenolic acids (such as ferulic acid, caffeic acid, and *p*-coumaric acids) as well as TPC decreased. However, vitamin C content in this cultivar concurrently increased with ripening stage

(58.6 mg/100 g DW). A significant amount of vitamin C was found in the pulp in comparison with that of the skin portion of ripe papaya. The TA, pH, and TSS of ripened 'Maradol' papaya cultivar were 0.048, 6.4, and 9.66 °Brix. Antioxidant activity determined by the DPPH assay method showed a significant decrease (27%) in DPPH radicals in fully ripened papaya in comparison with fresh ripe fruit (Gayosso-García Sancho and Yahia, 2010; Gayosso-García Sancho et al., 2011).

Wall et al. (2010) conducted a study regarding the physicochemical, nutritional, and microbial quality of fresh cut and frozen fruits of various cultivars of papaya with internal yellowing disease (caused by *Enterobacter cloacae*). As an outcome of the study, it was observed that fresh cut papaya fruits contain high amounts of vitamin C, A, and β -carotene compared to the frozen fruit. The results of this study also showed 'Laie Gold' fruit and 'Rainbow' cultivars to possess high amounts of vitamin A. In addition, the 'Rainbow' cultivar showed higher resistance to the bacteria *E. cloacae*. With the presence of high amounts of sugars and lack of translucency, this variety has been recommended for use in preparation of various papaya products.

The transgenic cultivars of papaya transformed with replication gene: cultivar 'Mei Zhong Hong' (with red flesh) and cultivar 'Sui Zhong Hong' (with yellow flesh), and nontransgenic cultivars are reported to contain comparable amounts of flavoring volatile oil components, sugars (fructose, sorbose, galactose, xylose, etc.), organic acids, and carotenoids. However, significant variations in the chemical composition of these papaya cultivars were observed when harvested at different time intervals (Jiao et al., 2010).

Ozkan et al. (2011) evaluated the antioxidant activity of juice samples of papaya cultivars such as 'Sunrise Solo', 'Red Lady', and 'Tainung' (grown under greenhouse conditions in Turkey) and found that 'Sunrise Solo' contained significantly higher amounts of TPC (65 mg GAE/100 g FW). The DPPH, superoxide anion, and hydroxyl radical scavenging activities had IC₅₀ values of 52.1, 22.4, and 12.6 μ g/mL, respectively.

ADVANCED STUDIES ON PAPAYA

Papaya fruits need to be marketed immediately after harvest or when ripened, as storage remains a considerable challenge. Papaya fruits can spoil because of improper handling, packing, storage, or transportation. Sometimes size and maturity also matter. High demands are raised by consumers for minimally processed fruits with minimal use of chemicals and retention of same physiological states.

Several studies have been conducted on enhancing the shelf life of papaya. Extension of the shelf life and quality of freshcut papaya up to 19 days when packed and stored at 4 °C in a micro-perforated polyvinyl chloride container has been reported (Jayathunge et al., 2014). Under ambient conditions, papaya fruit has a storage life of 7 days if it is stored at an ambient tropical temperature (30 °C). The refrigeration storage temperature for various papaya cultivars may differ. However, at a temperature of 10–15 °C, papayas

can be stored for 16 days (Workneh et al., 2012). Recently, Tirkey et al. (2014) reported that the shelf life of freshcut papaya, packed in low-density polyethylene, vacuum sealed, and refrigerated, retained the physical, biochemical, and sensory qualities such as firmness, color, flavor, TSS, and microbiological stability up to 12 days. Storage of papaya fruit below 10 °C caused chilling injury. It was observed that the chilling injury occurred after 14 days for mature green papaya fruit, whereas it took 21 days for injury to occur in 60% yellow fruit (Workneh et al., 2012).

Adetuyi et al. (2008) evaluated the impact of waxing and nonwaxing of papaya fruit with “Shea butter” and studied the impact of storage of these treated papaya fruits at room temperature (27 ± 1 °C) and refrigeration temperature (10 ± 1 °C). Results of this study showed TPC, tannin, phytate, and vitamins to decrease significantly in both waxed and nonwaxed papaya stored at both refrigeration temperature and room temperature as the storage period increased. However, phytate, tannin, total phenol, and vitamins (vitamin E, C, and carotenes) were present in higher amounts in waxed papaya stored at refrigeration temperature compared to unwaxed papaya stored at room temperature.

Udomkun et al. (2014) evaluated the influence of air drying of papaya fruits (osmotically pretreated at different temperature and humidity) on bioactive constituents and antioxidant activities. The papaya fruits that were dried after osmotic pretreatments showed a significant decrease in moisture with an increase in TSS and TA. Regarding antioxidant activity, osmotically pretreated samples showed a slight decrease in DPPH and ABTS⁺ radical scavenging activities as well as FRAP values. However, the total lycopene, β -carotene, and β -cryptoxanthin were significantly reduced in the treated fruits in comparison with fresh fruit. Between the temperature and humidity tried, a drying temperature and humidity of 70 °C and 10 g/kg dry air was shown to be ideal to dry papaya products along with highest bioactive constituents.

Enhanced antioxidant activity is reported in freeze-dried raw and ripe papaya from Malaysia (Annegowda et al., 2014). Freeze-dried ripe papaya fruit extracts in ethanol and water showed significantly high levels of tannins (9.58 and 6.0 mgCAE/g), flavonoids (8.40 and 3.64 mgCAE/g), and total antioxidant capacity (1315 and 2167 mgAAE/g), as well as high inhibition of DPPH (91.8% and 93.0%) and ABTS radicals (87.1% and 97.5%), respectively (all values FW). The authors have suggested that freeze-dried ripe papaya can be used to find potential applications in the food industry to produce value-added food products to help both consumers and farmers.

FOCUSED AREAS OF RESEARCH/FUTURE SCOPE

By witnessing ongoing trends, papaya fruit or its products can be expected to gain high foreign exchequer for the growers and the growing regions. As a wealth of information is available on the nutritional composition and health-promoting substances present in

papaya fruit, further studies are warranted to incorporate the fruit powder in food products as a supplemental ingredient. Producing novel papaya-based food or health products can be of use to overcome micronutrient-associated malnutrition problems in susceptible communities. The actual harvest stage for each papaya cultivar based on the nutritional composition and phytochemical levels should be identified and documented. As papaya skin wastes are also known to encompass rich amounts of phytonutrients, they also need to be explored for commercial utilization. In vivo research should be encouraged as a basis for recommending the average daily dietary intake of these products. Owing to the low cost compared to the majority of other fruits, encouraging local populations to consume more papaya fruit as a snack food or a dessert can be beneficial. Educating farmers and food processors to select cultivars with high levels of bioactive compounds or phytochemicals should be encouraged.

The phytochemical profiles of papaya fruits have been well documented, which clearly indicate the presence of a wide range of biological activities. Hence, attempts can be made to commercially exploit these compounds for further use. Breeding experiments among different cultivars can also be productive. Encouraging the breeding of drought- and disease-resistant varieties is desirable. For example, interbreeding of high-yielding varieties with disease-resistant wild varieties can be of use in overcoming papaya ringspot virus problems. The hybrid 'Red lady' papaya cultivar is quite popular and can resist this virus.

Inter- and intrabreeding experiments can also be of use to enhance fruit size, yield, and nutritional qualities and can also help in the reduction of pre- or postharvest losses. Of late, genetically modified papaya cultivars have been well accepted in the majority of the countries worldwide. However, more efforts are still required by concerned authorities to address such issues as intellectual property rights and to promote consumer awareness. Good agricultural and farming practices as well as appropriate farm management can yield better outcomes for these crops. Application of modern, nonthermal food-processing treatments such as ionizing radiation, ultraviolet treatments, ultrasound treatments, and others are shown to enhance the bioactive compound levels in fruits. This concept can also be applied to papaya fruit or their processed products. Appropriate, reliable, and low-cost technologies should be developed to reduce postharvest loss of papaya fruit.

SUMMARY POINTS

- Papaya is a wholesome, nutritious fruit, and can fulfill some of the daily nutritional requirements in normal adults and children.
- Consumption of the whole fruit or their processed products is capable of supplying adequate amounts of ascorbic acid; essential minerals such as potassium, iron, calcium, phosphorous; carotenoids; vitamins such as A, B₁, B₂, and E; and soluble and insoluble dietary fiber.

- Papaya fruits contain adequate amounts of nonvolatile organic acids such as citric acid, fumaric acid, malic acid, malonic acid, succinic acid, and tartaric acid.
- Papaya plant parts (leaves, fruit, and seeds) are reported to possess antidengue, anti-cancer, antimicrobial, antiparasitic, anti-inflammatory, antioxidant, and antidiabetic activities.
- During ripening of the papaya, changes in chemical constituents, flavor, color, and texture of the peel and pulp occur. This is due to the loss of chlorophyll and concurrent development of carotenoids, anthocyanins, and enhancement of phenolic compounds.
- Papaya fruit has a low shelf life and needs to be preserved for export purposes. Many modern methods of preservation have been applied for extending shelf life.
- Many cultivars and varieties have been developed by breeding programs and by the application of genetic engineering, all aimed toward enhancing the quality and safety of papaya fruit.
- In conclusion, papaya fruit and its products are expected to gain huge amount of foreign exchequer if appropriate modes of cultivation, good agricultural and manufacturing practices, and preservation techniques are used.

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CHAPTER 22

Nutritional Composition of *Passiflora* Species

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INTRODUCTION

The genus *Passiflora* is part of the Passifloraceae family from the tropical American region; there are about 500 species, according Malacrida and Jorge (2012), while Ocampo Perez et al. (2007) indicate a number closer to 630. Negreiros et al. (2006) report that there are more than 150 native cultivars in Brazil, and reports by Borges and Lima (2007) confirm that the country has a leading role in world production of these fruits. Twenty of these species are edible; the most widely grown are the yellow passion fruit (*Passiflora edulis* f. *flavicarpa*), purple passion fruit (*P. edulis*), and sweet passion fruit (*Passiflora alata*). Despite the variety of edible fruits, 95% of commercial plantations only grown the yellow passion fruit (Malacrida and Jorge, 2012). According to Rana and Blazquez (2008), from the species identified in this family, *P. edulis* is considered the one with the most appealing taste. This species is native to southern Brazil, and because of the excellent quality of its juice, it has been introduced into many countries in South America, Africa, Asia, and others.

Plants of the genus *Passiflora* have been studied because they are very promising to the horticultural and pharmaceutical sector. The fruits of these strikingly beautiful

flowered plants have high commercial potential and bioactive phytochemical compounds of great value. In most of the species of *Passiflora*, flavonoid glycosides are present in high amounts; they differ widely in their content and concentration of substances originating from apigenin, saponins, cyanogenic glycosides, and harmala alkaloids (Ozarowski and Thiem, 2013). However, the main economic importance of the fruit is the processing of concentrates for juice and pulp for confectionery use, and to produce nectars and syrups to make ice cream and jams (Cerqueira et al., 2011).

The fruit of these plants exhibit an intense and characteristic aroma composed mainly of esters, terpenes, and some sulfur compounds (Conde-Martínez et al., 2014). Among others, tocopherols, carotenoids, and phenolic compounds have also been identified. These substances could have a great potential in the food, chemical, and pharmaceutical industries. The oils extracted from the seeds of these plants could be very useful as a raw material in industrial processes, food, detergents, cosmetics, vitamin supplements, and biodiesel fuels. Other plant products could also be a good source of natural antioxidants to help prevent a many diseases, and serve as a food additive to increase the stability and quality of food products (Malacrida and Jorge, 2012). These compounds can also contribute to prevent the oxidative damage to lipids; these antioxidants can be used to benefit human health issues related to aging prevention and the management of diseases, such as cancer and heart disease (Sousa et al., 2007).

The biological processes related to flowering, fertilization, fruit development, maturation, and fruit quality depend on relatively high temperatures, which must be between 21 and 25°C; in commercial crops of *Passiflora*, the plants develop best in temperatures between 23 and 25°C. However, in Brazil, *P. edulis* f. *flavicarpa* has been successfully grown in temperatures between 18 and 35°C. In this country, it is recommended that yellow passion fruit be grown at altitudes between 100 and 1000 m; the lower temperatures of plantations at inferior altitudes affect crop duration, reducing it in relation to the plantations at higher altitudes. In South Africa, for example, at altitudes between 1200 and 1400 m, plantations can be productive for 8 years because of the longer cycles, involving the increased longevity (Borges and Lima, 2007).

BOTANICAL ASPECTS

The family Passifloraceae includes about 18 genera and 630 species, distributed in tropical regions, mainly in South America, from sea level to 3800 m (in the páramo of the Colombian Andes). Colombia has the highest number of species (167 species) (Ocampo Perez et al., 2007). Most of the 58 endemic species in Colombia are found between altitudes of 1500 and 2500 m and belong mainly to the sections *Tacsonia* and *Decaloba*, in the genus *Passiflora*. Twenty-two of these species produce edible fruit, and nine are grown commercially in the country (Ocampo Perez et al., 2007). Recent molecular

phylogenetic studies support the grouping of the 23 subgenera of *Passiflora* into 3 major clades, namely: *Decaloba*, *Passiflora*, and *Astrophea*. However, based on the results of different types of molecular analysis in plants, this approach is still controversial (Muschner et al., 2003). Most species of *Passiflora* are diploid ($2n = 12$ or 18); however, it is possible to find a $2n$ ploidy equivalent to 14, 20, 22, 24, 36, 72, or 84 (Ferreira de Melo et al., 2014).

Dhawan et al. (2004) provide a fairly complete description of the genus *Passiflora*. The genus includes mainly tendril-climbing vines (lianes), shrubs, and herbs. The stems are either woody or herbaceous, the vast majority climbing, and only in some cases arborescent (e.g., *Passiflora arborea* Spreng, which forms a free-standing tree to 15 m). The leaves are alternate, simple, sometimes compound, entire, lobed or palmate, and sometimes unevenly pinnate (imparipinnate); stipules emerge at the base of the petioles and are rarely absent.

Escobar (1988) mentions that the leaves of this genus have been studied extensively because of the great diversity of available shapes; they can be simple, compound, whole or trilobate, heart-shaped, digitate, or transversely elliptical. Some species exhibit heteroblasty—with juvenile and mature leaves of very different shapes and sizes. Moreover, some species of the supersection *Tacsonia* have polymorphic leaves; that is, there are both whole and lobed leaves on the same plant. These plants have simple axillary tendrils originating from sterile pedicels. However, *Tryphostemmatoideis* plants produce branched tendrils; when plants are of reproductive age, they produce fruits on their lateral branches, while the plant uses its central branch for climbing (Escobar, 1988). *Passiflora* has a fairly shallow root system; it has been observed that about 60% of the roots are located within 30 cm of the soil (Borges and Lima, 2007).

Dhawan et al. (2004) describe the flowers as regular, bisexual, or unisexual. The floral receptacle is large, often hollow and cup-shaped, and has numerous filamentous or annular appendages between the corolla and stamens, which are brightly colored, forming a conspicuous crown with varied forms. The calyx comprises three to five imbricate, free, or connate sepals. The corolla has three to five free or basally connate petals, which are rarely absent. There are three to five stamens at the bottom of the perianth or at the base or top of the gynophore. The filaments are subulate or filiform, free or united. Anthers are versatile with longitudinal dehiscence. The ovary is superior, slightly stipitate, sessile in very few cases, and unilocular, with three to five united carpels that contain several or many anatropous ovules. Pistils may have a branched or straight appearance; in the latter case, three to five separate pistils are formed. Stigmas can be clavate or peltate. Anatropous ovules are numerous in a series of one to two, joined by a funiculus with three or five linear parietal placentas. The fruit can be a berry or an indehiscent capsule. Seeds are numerous, within a pulpy cupuliform saccate aril (Figure 1). Pollination is carried out by insects, for which the crown is remarkable and plays an important role in attracting pollinators.



Figure 1 External and internal appearance of fruits of *Passiflora edulis f. flavicarpa* (left) and *Passiflora ligularis* (right). Photo: Fánor Casierra-Posada.

COMPOSITION OF *PASSIFLORA* SPECIES

Nutrient Content

Technology development is necessary to increase productivity and yield of *Passiflora* crops, especially technology relating to the diagnosis of nutrient availability. Information on the nutrients available to the plants is essential for their proper sustenance and is crucial to achieving high productivity and yield (Carvalho et al., 2011). In the case of Brazil, to achieve a successful nutrient diagnosis, an important consideration is the low nutrient absorption of these plants from the time they are transplanted until 220–250 days of crop establishment; this occurs due to the low dry matter production in this period. However, once the fruits begin to appear (250–280 days after transplanting), the plants undergo exponential growth, which in turn increases their absorption of N, K, and Ca, and their micronutrient uptake, especially Mn and Fe (Borges and Lima, 2007).

Environmental supply, especially temperature, have a determining effect on plant nutrition; this is illustrated in a study by Borges and Lima (2007) that found that temperatures below 18°C delay the growth of *P. edulis f. flavicarpa*, which can significantly reduce nutrient absorption, as well as fruit production. Similarly, high relative humidity can hinder plant transpiration, triggering poor nutrient absorption; nutrients are normally absorbed by mass flow. Under these conditions, the plant becomes sensitive to disease, and the effectiveness of agrochemicals applied using sprinklers is decreased (Fischer et al., 2009).

Various authors have reported on the nutritional status of *P. edulis* plants to establish the optimal ranges of macro- and micronutrients in different regions where *Passiflora* is grown commercially. For example, in the region of Rio de Janeiro (Brazil), plants of *P. edulis f. flavicarpa* absorb N, K, and Ca in higher proportions than other nutrients, and follow in their order S, P, and Mg. Mn and Fe are the micronutrients absorbed in the

Table 1 Nutritional composition of passion fruits per 100 g of edible portion

Species	Calcium (g)	Phosphorus (mg)	Iron (mg)
<i>Passiflora edulis</i>	14	41	0.3
<i>Passiflora edulis</i> f. <i>flavicarpa</i>	4	25	0.4
<i>Passiflora ligularis</i>	7	30	0.8
<i>Passiflora tripartita</i> v. <i>mollissima</i>	4	20	0.4
<i>Passiflora quadrangularis</i>	10	22	0.6

From [Martin and Nakasone \(1970\)](#).

greatest amounts, followed by Zn, B, and Cu. As for nutrients removed from the crop in the harvested fruit, K removal occurs in the highest proportion (73.8 kg/ha), followed by N (44.6 kg/ha). Proportionately, smaller amounts of Mg, S, Ca, and P are also removed; however, contents of P and Mg removed with the fruit can reach 40% and 29%, respectively, in relation to the total of these elements taken by the plant. Mn is the micronutrient taken up by the whole plant in the greatest proportion; however, Zn and Cu are the most removed from the crop with the harvested fruit. Despite the large amount of Mn found in the fruit (180.2 g/ha), this nutrient makes up only 6.4% of the total nutrients taken up by the plant, whereas 34% of Zn, 32% of Cu, 13% of B, and 11% of Fe move toward the fruit and accumulate in them; as a result, these nutrients are removed from the crop with the harvested fruit ([Borges and Lima, 2007](#)). The nutritional value of fruits varies according to factors such as species and season, among others, which have been studied by [Martin and Nakasone \(1970\)](#). The results are shown in [Table 1](#). In this table, we can see that *P. edulis* had the highest contents of Ca and P, while *Passiflora ligularis* had the highest content of Fe. On the other hand, of the species tested, *P. edulis* f. *flavicarpa* and *Passiflora tripartita* v. *mollissima* had the lowest Ca content. The lowest amount of P was found in *Passiflora quadrangularis*, and the least amount of Fe was found in *P. edulis*.

[Menzel et al. \(1993\)](#) reported a decrease in N, P, and K in recently matured foliar tissue in plantations of purple and yellow passion fruit in Queensland (Australia) during October and December. Similarly, N and K decreased in April. These nutrient concentration declines were justified by high vegetative growth and by the fruit set occurring during those periods. There was a high concentration of Ca, Mn, Zn, Cu, and B between March and September. In contrast, Mg and Na concentrations in leaves decreased throughout the year, while Cl and Fe contents fluctuated with peaks in March, May, and October. They also reported that concentrations of N, P, K, Ca, Mg, Mn, Zn, Cu, and B stabilized between June and July related with vegetative growth; blooming and fruit set in this period were low. Another study by [Carvalho et al. \(2011\)](#) reported that productivity level (t/ha per year) of yellow passion fruit crops does not affect macro- and micro-nutrient content in the different plant phenological stages studied (slow fruit and blooming development, plant growth, intense blooming and fruit development, and fruit

development and harvest). However, the plants showed differences in the content of these nutrients according to the phenology.

Physicochemical Properties of Fruits

The physicochemical characteristics of the edible Passifloraceae fruit are vital for its genetic improvement. These characteristics enable the valuation the fruit's organoleptic properties and its flavor, which are factors that determine its quality for the in natura market and industrial use (Junqueira et al., 2004). With this purpose in mind, they are used to select more productive genotypes through conventional breeding of commercial with free-growing varieties or through mass selection to obtain new genotypes with economic potential (Junqueira et al., 2005). Junqueira et al. (2010) evaluated the physical and chemical characteristics of fruits as well as the yield of *Passiflora nitida* accessions from different states in the north and central regions of Brazil. They found that the access from Vale do Amanhecer had the best yield and could be used in a breeding program to introduce the *P. nitida* fruit into the market (Table 2). They also observed that accessions from the Brazilian savannas have more desirable physical characteristics and produced larger fruits with more pulp content.

Phytochemical Content

Most species of *Passiflora* have a distinctive and intense flavor, resulting mainly from the presence of volatile compounds such as esters, terpenes, alcohols, aldehydes, ketones, aromatic hydrocarbons, and sulfur compounds (Conde-Martinez et al., 2014). The attractive sensory properties of the products obtained from these plants, as well as their nutritional and therapeutic value, have significantly increased their consumption worldwide. There are nearly 294 volatile compounds that have been identified in various extracts of this fruit genre; more recently, 180 new compounds have been identified in yellow passion fruit (Chassagne et al., 1999). The presence of volatiles in several species of *Passiflora* has been determined through isolation and quantification during their release during acid or enzymatic hydrolysis. Table 3 shows a summary of the compounds that have been identified in several species of this genus.

Studies such as Chassagne et al. (1999) have identified monoglucosides and diglucosides that are aroma precursors in these species. Compounds such as α -L-rhamnopyranosyl- β -D-glucoside (rutinoside) and 6-O- α -L-arabinopyranosyl- β -D-glucopyranosides of linalool, benzyl alcohol, and 3-methyl-2-en-1-ol have been identified in *P. edulis*, *P. edulis* f. *flavicarpa*, and *P. ligularis*; α -L-arabinopyranosyl- β -D-glucoside and some phenolic compounds have been reported only in *P. edulis*. In addition, β -D-glucopyranosyl- β -D-glucoside or gentiobioside and α -L-rhamnopyranosyl- β -D-glucoside-mandelonitrile have been found in glycosidic fractions isolated in several species of yellow passion fruit (Chassagne et al., 1996b).

Table 2 Physicochemical characteristics of fruits and yield of *Passiflora nitida* accessions from north and central regions of Brazil

Accession	Fresh weight (g)	Longitudinal diameter (mm)	Transverse diameter (mm)	pH	Total soluble solids (°Brix)	Titrateable acidity (% citric acid)	Yield (t/ha)
“N. R. São José” (Chapada)	128.4	8.1	8.1	4.3	16.2	0.05	2.9
“N. R. São José” (Vereda)	99.2	7.2	7.5	4.3	16.0	0.04	3.4
“Vale do Amanhecer” (Vereda)	135.1	7.7	7.7	4.0	17.3	0.05	8.6
“Jardim Botânico” (Cerrado <i>Stricto sensu</i>)	75.7	7.0	6.5	4.3	15.3	0.04	1.6
“Silvânia” (Mata Ciliar)	94.4	7.2	7.0	4.3	14.3	0.04	1.5
“Silvânia” (Chapada)	117.6	7.7	7.0	4.3	14.7	0.05	3.4
“Itiquira 1” (Cerrado <i>Stricto sensu</i>)	99.2	6.7	7.0	3.7	16.7	0.07	0.5
“Alto Paraíso” (Chapada)	94.4	6.7	6.0	4.0	14.3	0.06	0.7
“Natividade” (Comunidade do Brejão - Chapada)	75.3	7.3	6.6	3.6	16.4	0.07	2.9
“Manaus 1” (Capoeira)	49.9	5.2	5.0	3.6	17.2	0.10	2.2

From [Junqueira et al. \(2010\)](#).

Table 3 Active compounds detected in extracts of fruits of the *Passiflora* species

	<i>Passiflora edulis</i>	<i>Passiflora edulis f. flavicarpa</i>	<i>Passiflora ligularis</i>	<i>Passiflora tripartita v. mollissima</i>
	µg/kg			
Alcohols and hydroxy compounds				
3-Methyl-but-3-en-1-ol	137	20	—	—
3-Methyl-but-2-en-1-ol	887	677	133	103
Hexan-1-ol	717	696	—	—
(<i>Z</i>)-3-Hexen-1-ol	475	72	—	115–1034
Heptan-2-ol	35	45	3	—
(<i>Z</i>)-3-Octen-1-ol	—	44	—	tr
Octan-1-ol	239	1235	—	136
Octan-1,8-diol	53	—	—	—
Methyl 3-hydroxyhexanoate	118	—	199	—
Ethyl 3-hydroxyhexanoate	tr	—	20	—
2,5-Dimethyl-4-hydroxy- 3-(2 <i>H</i>)-furanone	236	534	—	—
Terpenic alcohols and diols				
Linalool	1442	498	—	560
α-Terpineol	78	tr	—	—
Citronellol	112	430	—	—
Nerol	113	53	—	—
Geraniol	367	381	—	35
2,6-Dimethylocta-3,7-dien- 2,6-diol	163	—	—	—
2,6-Dimethylocta-2,7-dien- 3,6-diol	130	—	—	—
2,6-Dimethyl-1,8-octanediol	314	350	—	—
(<i>E</i>)-2,6-Dimethylocta- 2,7-dien-1,6-diol	121	152	—	—
(<i>Z</i>)-2,6-Dimethylocta- 2,7-dien-1,6-diol	782	753	—	81
C13 norisoprenoids				
3,4-Dihydro-3-oxoedulan	194	—	—	—
3-Hydroxy-β-damascone	—	84	—	—
3-Hydroxy-β-ionol	—	3158	—	—
3-Oxo-α-ionol	597	35	54	231
4-Oxo-β-ionol	710	169	51	131
4-Oxo-β-ionone	92	—	—	—
4-Oxo-7,8-dihydro-β-ionol	164	1134	173	29
3-Hydroxy-7,8-dihydro-β- ionol	—	917	—	—
3-Hydroxy-β-ionone	—	4176	—	482
3-Oxo-7,8-dihydro-β-ionol	443	482	310	367

Table 3 Active compounds detected in extracts of fruits of the *Passiflora* species—cont'd

	<i>Passiflora edulis</i>	<i>Passiflora edulis f. flavicarpa</i>	<i>Passiflora ligularis</i>	<i>Passiflora tripartita v. mollissima</i>
	µg/kg			
3-Oxoretro- α -ionol (1)	601	—	—	70
3-Oxoretro- α -ionol (2)	241	—	—	55
Dihydrovomifoliol	69	—	—	—
Aromatic compounds				
Benzaldehyde	16,039	16,261	209	—
Methyl salicylate	761	tr	306	75
Benzyl alcohol	13,609	639	733	—
2-Phenylethanol	1269	722	175	91
Eugenol	915	593	267	86
4-Ethylphenol	281	—	—	594
Cinnamyl alcohol	90	—	—	—
4-Allylphenol	1049	tr	—	—
Isoeugenol	46	—	—	—
Benzoic acid	255	—	—	69
Mandelonitrile	10,612	11,234	—	—
Cinnamic acid	908	3659	—	—

From Chassagne et al. (1999) and Conde-Martínez et al. (2014).

The mechanism of glycoside hydrolysis in *Passiflora* plants has been described by Günata et al. (1988). They report the activity of a specific glucosidase that produces a bond (one to six) between two units of α -D-glucose creating a β -D-glucoside. Subsequently, glucose and the aglycone are released by the action of a β -D-glucosidase. Then, glycoside hydrolysis of the different glucosides and diglucosides takes place according to the species. Differential hydrolysis is responsible for several enzymes such as α -L-rhamnopyranosidase, α -L-arabinofuranosidase, and α -L-arabinopyranosidase, which generate a high variability between volatile compounds in *P. edulis f. flavicarpa* and *P. ligularis* (Chassagne et al., 1997).

Other compounds reported for *P. edulis f. flavicarpa* and *P. edulis* are 2,5-dimethyl-4-hydroxy-3-(2H) furanone (Chassagne et al., 1998). Various terpene diols such as (*E*)-2,6-dimethyl-1,8-octanediol; (*Z*)-2,6-dimethylocta-2,7-diene-1,6-diol; 2,6-dimethylocta-3,7-diene-2,6-diol; and 2,6-dimethylocta-1,7-diene-3,6-diol, as well as significant concentrations of united aromatic alcohols have also been identified for both species (Chassagne et al., 1996a). Meanwhile, Li et al. (2011) isolated six flavonoid compounds from *P. edulis f. flavicarpa*, which were not detected in *P. edulis f. edulis*; these are lucenin-2, vicianin-2, isoorientin, isovitexin, luteolin-6-*C*-chinovoside, and luteolin-6-*C*-fucoside.

Yoshikawa et al. (2000a,b) confirmed the presence of some monomers in *P. edulis*. They identified triterpenoids, mainly, cycloartanes and its isolated saponins, including

two new compounds called cyclopassifloside XII (1) and XIII (2), along with six known triterpenoids cycloartanes, and cyclopassifloic acids E (1), F (2), and G (3), and their saponins, cyclopassiflosides VII (4), VIII (5), IX (6), X (7), and XI (8). Chassagne et al. (1999) also reported the existence of various derivatives of oxygenated β -Ionol in position 3 as the main norisoprenoids identified, while derivatives of oxygenated α -Ionol in position 3 appear to be characteristic in *P. ligularis*. According to their results, the cycloartane triterpenoid was one of the main compositions of *P. edulis* f. *edulis* and possess antidepressant-like activity.

Xu et al. (2013) reported four new 2,6-dideoxyhexose-C-glycosyl flavones in *P. edulis* that include (1) luteolin-8-C- β -digitoxopyranosyl-4'-O- β -D-glucopyranoside; (2) apigenin-8-C- β -digitoxopyranoside; (3) apigenin-8-C- β -boivinopyranoside; and (4) luteolin-8-C- β -boivinopyranoside.

Studies by Chassagne et al. (1999) on the composition of *Passiflora* indicate that geraniol was only found in *P. tripartita* var. *mollissima*. These authors also found small amounts of (Z)-2,6-dimethylocta-2,7-diene-1,6-diol in this genus and stated that the bound norisoprenoid content of *P. ligularis* and *P. tripartita* var. *mollissima* is low.

Studies by Conde-Martínez et al. (2014) on compounds in *P. tripartita* var. *mollissima* identified aliphatic and aromatic hydrocarbons, terpenes, aldehydes, ketones, esters (such as acetates, hexenyl, and hexyl esters), alcohols, and lactones as aroma components. The authors suggest that compounds such as linalool, hexyl acetate, 1,8-cineole, and butyl acetate are the aroma-generating compounds of this specie. Other compounds that contribute to the aroma of this plant are 2-methylpropyl acetate, (Z)-3-hexen-1-ol, and (Z)-3-hexenyl acetate. Sulfur compounds, 3-sulfanylhhexyl acetate and methional, were reported as aroma-active volatiles in *P. tripartita* var. *mollissima*.

Passiflora incarnata is another species of *Passiflora* that has been extensively studied in relation to its phytochemical compounds. The main phytoconstituents of this species are flavonoids; they represent the major phytoconstituents in this plant including apigenin, luteolin, quercetin, kaempferol, and 6- β -D-allopyranosyl-8- β -xylopyranosyl-apigenin; also C-glycosyl flavonoids vitexin, isovitexin, orientin, isoorientin, schaftoside, isoschaftoside, isovitexin-2"-O-glucopyranoside, isoorientin-2"-O-glucopyranoside, 2-glucosylapigenin, isoscoparin-2"-O-glucoside, 2"-O-glucosyl-6-C-glucosylapigenin, 6- β -D-glucopyranosyl-8- β -D-ribopyranosyl apigenin, and swertisin (Dhawan et al., 2004). Rahman et al. (1997) found flavone-C-glycosides; vicianin-2, lucenin-2, isoorientin 2"-O-glucoside, schaftoside, isoschaftoside, isoorientin, orientin, isovitexin 2"-O-glucoside, vitexin, isovitexin, and swertisin. They were identified in most samples, ranging from 0.3% to 2.85% of the total flavonoid content.

Indole alkaloids, β -carboline, and harman alkaloids such as harman, harmol, harmine, harmalol, and harmaline have been reported in this species (Pereira et al., 2014), as well as other various phytoconstituents as γ -benzo-pyrone (maltol) derivatives, and carbohydrates such as sucrose, D-glucose, and D-fructose. In addition, oils containing essential

hexanol, benzyl alcohol, linalool, carvone, *trans*-anethole, eugenol, isoeugenol, β -ionone, α -bergamotol, and phytol are also present, and fatty acids such as linolenic, palmitic, oleic, and myristic, as well as butyric and formic acids, coumarins, phytosterols (Sampath et al., 2011; Wohlmuth et al., 2010), and a cyanogenic glycoside called gynocardin. The presence of a core benzoflavone responsible for *P. incarnata* bioactivity is underscored.

From *P. alata*, two saponins and five C-glycosyl flavones derived from apigenin, luteolin, and chrysoeriol have been isolated and identified; in addition, several bioactive metabolites such as chrysin, apigenin, homoorientin, vitexin, luteolin, quercetin, kaempferol, isovitexin, orientin, isoorientin, schaftoside, isoschaftoside, harman, harmol, harmine, harmalol and harmaline, additionally, several bioactive metabolites of *P. alata* are saponins and C-glucoside flavonoids (Birk et al., 2005; Müller et al., 2005). A study of the aqueous extract (22%V/V) of *P. alata* leaves demonstrated that the triterpene quadrangulose is the main constituent of the saponin found in this species (Reginatto et al., 2001).

A chromatographic analysis of *Passiflora actinia* found isovitexin and the absence of the classical *Passiflora* β -carboline alkaloids or flavonoids such as vitexin, rutin, swertisin, hesperidin, and orientin. The extract obtained from the leaves of this plant showed the presence isovitexin but the absence of vitexin (Santos et al., 2006), whereas in *Passiflora suberosa*, 3-(6"-malonylglucoside) and 3-glucoside of cyanidin, delphinidin, petunidin, and pelargonidin were identified. Also, anthocyanins acylated with malonic acid constituted 27% of the total anthocyanin content in this species. In *Passiflora*, anthocyanins contribute to the spectacular color patterns of the flowers and the deep purple color of some of the fruits. Plants of the genus *Passiflora* have a high diversity of anthocyanins such as phytoconstituents, depending on the species (Kidøy et al., 1997).

Organic Acids

Besides its exceptional and distinguishing flavor, one of passion fruits juice's most distinctive characteristics is its high acid content, which is key in the formulation and processing of products containing this fruit. Organic acids play an important role because of their influence on the juice's organoleptic properties. Chan et al. (1972) reported the content of nonvolatile organic acids in *P. edulis* and *P. edulis f. flavicarpa* fruit juice. Citric acid was predominant in *P. edulis f. flavicarpa*, followed by malic acid. Other acids found in fruits of this species, but in much lower amounts, were lactic, malonic, and succinic acids. Although *P. edulis* contains the same acids as *P. edulis f. flavicarpa*, the relative content of these compounds was different. Citric acid was predominant in this species, followed by lactic, malonic, malic, and succinic acids (Table 4).

Sugars

The physiochemical composition of passion fruit can vary according to cultivar, environmental factors including climate and soil properties, and agricultural management (Ramaíya et al., 2013). The sugar content can influence the physiochemical properties of

Table 4 Organic acids found in yellow and purple passion fruit

Acid	<i>Passiflora edulis</i>	
	<i>f. flavicarpa</i>	<i>Passiflora edulis</i>
Meq/100 g fruit juice		
Citric	55.0	13.1
Malic	10.5	3.8
Lactic	0.5	7.4
Malonic	0.1	4.9
Succinic	tr	2.4
Ascorbic	0.06	0.05

From [Chan et al. \(1972\)](#).

Table 5 Sugar content in the juice of fruits from different passion fruit species

Species	Sucrose	Glucose	Fructose
	g/kg fresh weight		
<i>Passiflora edulis f. flavicarpa</i>	28.6	14.1	14.6
<i>Passiflora maliformis</i>	17.0	23.4	22.1
<i>Passiflora quadrangularis</i>	28.1	43.7	39.0
<i>Passiflora edulis</i> (yellow)	15.3	65.6	58.6
<i>Passiflora edulis</i> (pink)	45.5	30.1	31.3

From [Ramaïya et al. \(2013\)](#).

fruits and can provide valuable information on food wholesomeness ([Chinnici et al., 2005](#)). [Ramaïya et al. \(2013\)](#) found a significantly higher total sugar content in *P. edulis* and *P. edulis f. flavicarpa* than in other *Passiflora* species. Glucose and fructose content was higher in juice from vine-ripened fruits of *P. edulis*, *P. quadrangularis*, and *Passiflora maliformis*. On the other hand, sucrose content was significantly higher in the juice of non-vine-ripened fruits of *P. edulis* (pink) and *P. edulis f. flavicarpa* ([Table 5](#)).

POTENTIAL USES

Passiflora species have gained worldwide prominence because of their varied content of phytoconstituents of high therapeutic value that are potential raw material for the development of new drugs. One example is *P. edulis*; this species has acquired worldwide notoriety, not only because of the organoleptic characteristics of its fruit but also because its tea leaves are regularly used in Europe and the Americas and in traditional medicine for their sedative or tranquilizing effects. Recent research on the therapeutic properties of *Passiflora* plant part extracts have demonstrated their significant effects on the central nervous system; the extracts show anxiolytic, anticonvulsant, and sedative actions ([Benincá et al., 2007](#)).

At low doses, the organs of the aerial parts of *P. edulis* and *P. incarnata* can be used as an anxiolytic (anxiety reduction); at high doses, they can be used as a sedative ([Deng et al.,](#)

2010; Dhawan et al., 2001). These properties are attributed to their high content of flavonoids, especially, luteolin-6-*C*-chinovoside, luteolin 6-*C*-fucoside, isovitexin, and others (Li et al., 2011). *P. edulis* also has anti-inflammatory properties due to the presence of phenolic compounds possessing antioxidant activity that inhibit oxidative damage, therefore maintaining cell membrane stability. Among the phenolic compounds attributed with these properties, some forms of *C*-glucoside, orientin 2-rhamnoside, luteolin-6-*C*-chinovoside, and luteolin-6-*C*-fucoside have been identified (Cordova et al., 2013).

Ichimura et al. (2006) found that the rind of several species of *Passiflora* fruit have a variety of phytochemical constituents with antihypertensive effects and can therefore be used to treat circulatory system diseases. They found that polyphenols in the rind have a vasodilator effect, particularly the flavonoid, luteolin. These authors also found that the extracts of *P. edulis* rind, which is usually not consumed, decrease the activity of peroxidase, even more than pulp extracts. In addition, isoorientin quantification in the extracts showed that it has a correlation with the antioxidant activity because of their high flavonoid content.

Among the properties that have given importance to *P. edulis* in the food industry sector is its high content of pectins, which are highly valued as juice stabilizing agents (Pinheiro et al., 2008). The total dietary fiber content (81.5 g/100 g) of this species is also of great importance, both soluble (35.5 g/100 g) and insoluble (46 g/100 g), and the ratio insoluble/soluble fiber (1.3) (Martínez et al., 2012). These values have wide applicability in food processing. Pectin is the methylated ester of polygalacturonic acid, which contains 1, 4-linked α -D-galacturonic acid residues (Azad et al., 2014) that contains residues of α -L-rhamnopyranosyl in its main chain and arabinan and galactan branches; its thin structure varies considerably (Shingthong et al., 2004).

Malacrida and Jorge (2012), in a study of the chemical and physical properties of *P. edulis* seeds, found high levels of unsaturated fatty acids (87.59%), including mainly linoleic (73.14%) and oleic (13.83%) acids, tocopherol (499.30 mg/kg), and phenolic compounds (1314.13 mg gallic acid equivalents (GAE)/kg). Meanwhile, Liu et al. (2008) reported significant amounts of sodium (2.980 ± 0.002 mg/g), magnesium (1.540 ± 0.001 mg/g), potassium (0.850 ± 0.001 mg/g), and calcium (0.540 ± 0.002 mg/g). These results demonstrate that the seed of this plant can be an alternative food source and potentially valuable, both for the industrial and pharmaceutical sector.

P. tripartita var. *mollissima* is an excellent source of vitamins A, B, and C (93 mg/100 g of fresh fruit), Ca, Fe, P, and K; it also has a high fiber content (Leterme et al., 2006). The edible part of the fruit has a high antioxidant potential and a high content of phenolic compounds, which contribute to an anti-inflammatory effect (Contreras-Calderón et al., 2011).

Gupta et al. (2012) have assessed the effect of *P. incarnata* extracts as a traditional treatment for diabetes. Their results showed that the methanol extract of this plant (200 mg/kg) significantly reduced blood glucose levels in fasting mice with streptozotocin-induced diabetes.

Differences in urine glucose levels evidenced the tolerance to oral glucose. Differences were also found in serum lipid and body weight profiles, compared with diabetic mice treated with drugs. Histopathological studies of these animals' pancreases showed considerable cell regeneration, induced by the *P. incarnata* extract after the cells were necrotic, due to the effect of the streptozotocin. These results suggest that the methanol extract of *P. incarnata* has an antihyperglycemic and hypolipidemic effect in the treatment of streptozotocin-induced diabetic mice, making this plant a promising source for the future treatment of diabetes in humans.

Moreover, studies of *Passiflora subpeltata* leaf tissue have become increasingly relevant because of the large amounts of total phenols and flavonoids in acetone extracts, as well as the presence of cysteine, glutathione, ascorbic acid, tocopherol, flavonoids, tannins, and aromatic amines (Saravan et al., 2014). However, the property that has gained the most interest is the ability to reduce and donate hydrogen ions. The results of these studies have shown that the extracts of *P. subpeltata* leaves contain potent inhibiting compounds that can act as primary antioxidants and react with DPPH radicals, as reported by Sasikala et al. (2011) in studies using *P. foetida*. Finally, Saravanan et al. (2014) found that extracts of *P. subpeltata* can also donate electrons. This finding increases the importance of this species for the pharmaceutical and industrial sectors because they can donate electrons to free radicals in biological systems or real food and maintain stable radicals.

SUMMARY POINTS

Mineral content differences have been found in the edible portion of the fruit of different species of *Passiflora*. It has been reported that *P. edulis* showed the highest contents of Ca and P, while the largest amount of Fe was found in *P. ligularis*. The lowest values of Ca content, in comparison with other species evaluated, was found in *P. edulis* f. *flavicarpa* and *P. tripartita* var. *mollissima*. The lowest P content was found in *P. quadrangularis* and the least amount of Fe was found in *P. edulis*.

The environmental characteristics of the regions from which the accessions of *Passiflora* originate produce significant differences in the physicochemical features of the fruits and affect their productivity. As a reference, in valuating several accessions of *P. nitida*, we found that the accession from Vale do Amanhecer showed higher productivity compared to the accessions from other areas. The accessions from the Brazilian Savannas showed the best physical condition of the fruit in terms of size and pulp content.

A high variability was observed between *Passiflora* species in regards to the presence and amount of active compounds in the fruit pulp. Furaneol was identified in bound form in *P. edulis* and *P. edulis* f. *flavicarpa*. Geraniol was found as the aglycone in *P. tripartita* var. *mollissima*. Terpenol was not identified in *P. ligularis* juice. Several terpene diols were found in both *P. edulis* and *P. edulis* f. *flavicarpa*, and small amounts of diols were identified in *P. tripartita* var. *mollissima*. Derivatives of α -Ionol seem to be characteristic of *P. edulis*,

whereas β -ionol compounds were the major norisoprenoids identified as the aglycone in *P. edulis* f. *flavicarpa*. The bound norisoprenoid content of *P. ligularis* and *P. tripartita* var. *mollissima* was low.

The juice of *Passiflora* species has a unique flavor because of their high acid content that differs between species. In *P. edulis* f. *flavicarpa*, citric acid was predominant. Other acids found in fruits of this species, but in much lower quantities, were malic, lactic, malonic, ascorbic, and succinic acids. *P. edulis* contains the same acids found in *P. edulis* f. *flavicarpa*, but the relative content of these compounds was different. In this specie, citric acid was predominant.

The variation in sugar content in the fresh juice of passion fruits depended mainly on the species or cultivars themselves. Higher contents of sucrose were found in *P. edulis* (pink) in comparison with *P. edulis* f. *flavicarpa*, *P. maliformis*, *P. quadrangularis*, and *P. edulis* (yellow). Similarly, *P. edulis* (yellow) had the highest content of glucose and fructose compared to other species and cultivars. Lower contents of sucrose, glucose, and fructose were found in *P. edulis* (yellow), *P. maliformis*, and *P. edulis* f. *flavicarpa*, respectively.

New alternatives to the sole consumption of the fruit in fresh form or processed for use in the food industry now exist; different plant tissues have high commercial potential because of bioactive compounds with a high phytochemical value.

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CHAPTER 23

PEACH (*Prunus persica* (L.) Batsch)

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LIST OF ABBREVIATIONS

FW	Fresh weight
GC-MS	Gas chromatography–mass spectrometry
OAV	Odor activity value
PCA	Principal component analysis
SSC	Solid Soluble Content
TA	Titrateable acidity
VOCs	Volatile organic compounds

INTRODUCTION

In spite of its botanical name, *Prunus persica* (L.) Batsch, from Persia, actually Iran, peach originally came from central Asia and was domesticated in China, where cultivation has been documented for more than 3000 years. The botanical name comes from the region of Asia Minor where Alexander the Great and the silk traders brought it from China in the third century BC. Thereafter, the Roman armies spread them around the Mediterranean basin and from then on all over Europe. It reached the Americas through Spanish and Portuguese exploration journeys from the sixteenth century.

Peach is a healthy and delicious summer fruit, cultivated in temperate regions, between 30° and 45° of latitude, in both hemispheres. Nowadays the top five producing

countries are China (46%), Italy (9%), Spain (7%), USA (7%), and Greece (4%), covering 1.5 million ha, totaling about 18 million tons. The production has doubled since 1980, due to the large increase in Chinese production. Peach is the third most important temperate tree fruit worldwide, behind apple and pear. More than 90% of the production is for the fresh market, while the canning industry requires appropriate cultivars with specific features of texture (nonmelting flesh) and color (yellow flesh, with no anthocyanins).

Many cultivars are grown all over the producing regions; they vary by shape (elongated/round or flat), flesh color (yellow or white), fuzzless skin (the nectarine group), flesh texture and pace of ripening, red pigments (anthocyanins, either on skin and/or flesh), etc. Given the Mendelian nature of most of the fruit traits, a countless combination of these traits has been obtained.

Classical breeding on rational bases was initiated less than one century ago, but since it can be easily propagated by seed, even because the juvenile phase is quite short (2–3 years from seed to fruit), many cultivars have been obtained after its domestication over the centuries.

Due to the relative easiness in obtaining new cultivars by classical cross-breeding, many breeding operations around the world have been started, since the first half of the twentieth century, with the US being in the forefront. These new cultivars display, besides a better fruit appearance, better horticultural traits (yield reliability over years and environmental adaptability, disease resistance/tolerance, etc.) and, most importantly, a better shelf life, allowing longer storage and shipping ability. As a consequence, the vast majority of local cultivars and landraces has now disappeared.

BOTANICAL ASPECTS

Peach (*P. persica* (L.) Batsch) belongs to the Rosaceae family, Amygdaloideae subfamily, *Prunus* L. genus, *Amygdalus* subgenus and *Euamygdalus* section. It can be distinguished from almond (*Prunus dulcis* (Mill.) D.A. Webb) because the mesocarp of the latter turns dry and splits at maturity, and the leaves of almond are more distinctly serrate.

Related interfertile species are *P. dulcis* (Mill.) D.A. Webb, *Prunus davidiana* (Carrière) Franch., *Prunus ferganensis* (Kostina & Rjabov) Y.Y. Yao, *Prunus kansuensis* Rehder, and *Prunus mira* Koehne. Their hybridization with *P. persica* produces fertile hybrids in most cases. Crosses with almond (*P. dulcis*) have produced several commercial rootstocks. All the above mentioned species are native to China, but some are found in Nepal, Tibet, and India (*P. mira*).

Prunus persica is diploid ($2n=16$). The tree can live up to 20–30 years, but in commercial orchards, the economic life is around 12–15 years, due to reduced productivity or cultivar replacement. Fruit production starts from the second to the third year.

Peach roots are orange with large lenticels; the roots can grow to a depth of 50–60 cm, depending on the type of soil and nutrients. The tree is medium-sized, up to approximately 8-m high, with many types of canopy architecture, for example, standard, arching, columnar, compact, open, spur, upright, and weeping. The trunk is straight and smooth with red-green bark in the first year, later turning gray-silver. One-year-old shoots are reddish-greenish, becoming gray-silver when older. The fruiting shoots are usually vigorous (50–100 cm), with flower buds along the axis and an apical vegetative bud. Fruit size is related to fruiting shoot vigor. Buds are formed at the nodes base of the leaves, in sets of three at each node: usually one vegetative bud in the center and two lateral flower buds. After winter dormancy, new shoot growth follows flowering. Leaves are lanceolate, glabrous and minutely serrate (serrulate), flat or wavy, broadest in the middle, and standard or narrow according to the width/length ratio; green or yellow glands are present (or not) at the blade base and at the petiole; the leaf veins are yellowish in cultivars with yellow-fleshed fruits and greenish-white in those with white-fleshed fruits.

Peach is insect-pollinated and self-fertile. Chilling and heat requirements, time of flowering, and ripening vary enormously among genotypes; in the northern hemisphere, the harvest season extends from mid-April to mid-November.

The flowers are hermaphrodite, normally with 5 petals and 20–30 stamens, and are pink, red, or white; the gynoecium is superior and glabrous in nectarines. Fruit growth is slower during pit hardening.

Fruit weight may vary from 50 to over 650 g, although commercial standards require 180 to 230 g. The fruit is a drupe, its shape may be round, oblong, or flat (doughnut-shaped); the peel (exocarp) is pubescent (standard peaches) or glabrous (nectarine fruit); the color may be greenish, white, yellow, orange, red, and purple, with many combinations of these characters. The flesh may be yellow or white. Xanthophylls and carotenoids are responsible for the yellow color, while anthocyanins are responsible for the red-blue colors and are present in either white or yellow fruit. They are located mainly under the skin or close to the tip, while in blood flesh types, almost all the flesh is red-stained. White flesh fruit accounts for higher amounts of volatile (hexanal, linalool, and decalactone) compounds responsible for the typical aroma. Ascorbic acid content is very low, around 10 mg/100 g fresh weight (FW), while the total organic acids account for around 0.9–1.6% of FW. Malic acid is the main carboxylic acid, followed by citric, quinic, and succinic. Low-acid phenotypes have 20–50% lower acid concentration than acidic phenotypes. Sugar content (mainly sucrose, glucose, fructose, and sorbitol) ranges from 9% to 15%, although it can be more than 20%.

In terms of flesh texture, at least four distinct types have been described so far, according to firmness and pattern of softening, and they are strongly affected by cell wall composition and calcium content. The melting type, the most common type, softens rather quickly along with physiological ripening. A subtype of it, called slow softening, has a slower pace of softening, allowing better management of the fruit in postharvest

operations; this texture is found in many recently developed cultivars, 'Big Top' nectarine being among the most popular.

The nonmelting type has firm flesh even at full ripening, with poor softening when overripe, becoming rather rubbery; this type is used by the canning industry. The fourth type, stony hard, is very firm and crispy and never melts, even when fully ripe; it never releases ethylene at ripening, its main distinct feature.

The stony endocarp is very hard, furrowed, and deeply pitted; it may adhere, or not, to the flesh.

COMPOSITION OF TRADITIONAL OR ANCIENT CULTIVARS

Although some local cultivars (by chance seedlings) or landraces (by seed propagation, given the high rate of self-pollination) are still cultivated in some places, their share of the world production is very small, for niche markets only.

Given a very limited amount of local/traditional cultivars/landraces treated in the scientific literature, these have been listed together with the modern, commercial ones, in Peach Chemical and Physical Attributes Section.

COMPOSITION OF MODERN CULTIVARS

Only modern cultivars, for example, obtained either by cross-breeding or from bud mutation, can be considered for the peach industry nowadays. Their economic relevance could depend on the country/region of cultivation, regardless of the time of their release from the breeding process.

As specified above, the modern cultivars have been considered with the local/traditional ones in Peach Chemical and Physical Attributes Section.

PEACH CHEMICAL AND PHYSICAL ATTRIBUTES

Traditional Aspects of Fruit Quality

Peach sensorial quality for the optimal consumer satisfaction is a combination of several factors, such as sugar and organic acid content, volatiles compounds, and flesh texture. The parameters related to these attributes, such as fruit firmness, soluble solid content, and titratable acidity (TA), are important drivers for consumer preference.

All these parameters greatly vary according to genotype, preharvest climatic condition, cultural practices, and ripening stages. Moreover, the ripening period strongly affects these attributes, and usually late and extra late cultivars are higher in flavor and sweetness than early ones. Maturity influences peach fruit quality, but also season-to-season differences should be taken into consideration (Kader et al., 1982; Cano-Salazar et al., 2013a), and sugar variation is less affected by the ripening stage than acidity and firmness (Meredith et al., 1989; Cano-Salazar et al., 2012).

Peaches are expected to be sweet, and they need to show more than 10 °Brix of soluble solids content (SSC). Currently there are selections or cultivars with SSC close to 20 °Brix, even if generally the SSC is assessed between 9.0 and 14.0. The main sugars are sucrose (54–75% of the total SSC), glucose (9–21%), fructose (3.25%), and sorbitol (4–11%). Sugar content depends, besides on genotype, on environmental and seasonal conditions, yield, position of the fruit in the canopy, and maturity (Brooks et al., 1993). Usually early ripening cultivars account for a lower level of SSC due to the shorter period of fruit development, while mid- or late ripening accessions always have the required minimum level of sugars. Most of the commercial cultivars are similar in sugar and acid content (Byrne et al., 1991), and generally white and nectarine fruit are characterized by a higher sugar content (Dagar et al., 2011) (Tables 2–4). From the literature available, the old standard yellow cultivars ‘Loring,’ ‘Dixilan,’ and ‘Federica’ show the best sugar levels of 16.5, 16, and 15.4 °Brix, respectively (Table 1). The white nectarines, ‘Arctic Queen,’ ‘Arctic Snow,’ and ‘Brite Pearl’ show the highest SSCs of 17.4, 17.1, and 16.4 °Brix, respectively (Table 4). Tavarini et al. (2008) reported a lower SSC of 8.0 °Brix in ‘Jerseyqueen’ yellow peach, even though if it is a mid-season cultivar, followed by the early ripening ‘Springbelle’ (8.6 °Brix).

The main organic acids are malic (over 50% of the total), citric, and quinic, well-correlated with TA. In low-acid cultivars, TA is three to five times lower and sucrose content higher than the acid cultivars (Byrne et al., 1991). Low-acid cultivars are preferred by the Asian markets compared to the acidic cultivars, traditionally preferred by European and North American markets.

The TA generally ranges from 0.07 to 0.14% in low-acid cultivars to 1.1–1.45% in the acidic ones, such as ‘Ruby Diamond,’ ‘Venus,’ and ‘Arctic Glow’ (Tables 1–4). TA shows a gradual decrease, and the sugar:acid ratio shows a significant increase at advanced maturity because the SSC is quite stable during ripening; the increase in perceived sweetness as it ripens is thus due to a decrease in acidity rather than an increase in SSC (Byrne et al., 1991; Cano-Salazar et al., 2012; Meredith et al., 1989).

Due to the Mendelian or oligogenic nature of the SSC and TA contents, very diverse sensorial phenotypes can be obtained by traditional cross-breeding and arranging high and low levels of sugars and acids in all combinations.

Fruit firmness is essential for efficient handling and marketing, and it depends mainly on flesh texture. Firmness decreases as maturity increases (Robertson et al., 1990; Remorini et al., 2008), and a value of 13 N or lower is considered acceptable for a consumer. The most traditional cultivars belong to melting and nonmelting flesh types. Nonmelting cultivars were released on the fresh market because they are firm enough to be harvested at a more mature stage, allowing a better quality and larger size (Bassols Raseira et al., 2012). However, the slow softening texture is the more successful flesh phenotype introduced more than 20 years ago in the USA, beginning with ‘Big Top’ nectarine and some yellow peaches, for example, the ‘Rich’ group (‘Rich

Table 1 Solid soluble content, titratable acidity, and firmness in yellow-fleshed peaches

Cultivar	°Brix	Titratable acidity (%)	Fruit firmness (N)
Autumn Flame	10.20	0.52	—
Autumn Red	11.3	0.5	62
Brittney Lane	10.7	0.75	—
Calanda (Calante)	13.2	—	64
Carolyn	10.7	0.5	34
Country Sweet	11.2	0.4	—
Cresthaven	14.3	0.62	61
Crimson Lady	10.7	0.62	57.9
Diamond Princess	10.0–10.5	0.44–0.65	—
Dixiland	16	0.6	41
Early Rich	10.4–10.5	0.98–1.00	40.8–43.9
Elberta	14	0.51	46
Elegant Lady	10.7–14.0	0.56–0.91	37.4
Fairtime	10.8	0.95	109.00
Fay Elberta	10.4–13.5	0.46–0.66	34.6–42.0
Federica	15.4	—	23
Fireprince	13.8	0.39	55
Flavorcrest	10.2–12.9	0.73	19.1–45.0
Flordaking	10.82	—	—
Flordaprince	10.6	—	24.5
Flordasun	11.8	—	—
Florida Prince	11.9	0.97	—
Glohaven	12.6	—	17
Goldilocks	11.5	0.25	—
Halford	14.1	0.5	35
Harvester	12.8–13.8	0.57–0.86	42.0–51.4
Jerseyqueen	8	0.72	53
July Flame	11.1	0.7	—
Kaweah	10	0.66	—
La Jewel	10.5	0.48	54
Leonforte	16.2	0.86	40
Lolita	10.9	0.63	57.8
Loring	16.5	0.68	46.00
Majestic	13.1	0.94	—
Maniace	9.2	0.76	38
Maria Marta	13	0.37	30
May Sweet	11.5	0.42	—
Maycrest	11.4	0.72	35.7
Miraflores	13.1	—	63
O'Henry	11.2–12.4	0.45–0.82	8.3
Ouachita Gold	14.8	0.6	44
Redhaven	9.9–15.5	0.07–0.36	21.0–91.0
Rich Lady	11.1–13.0	0.84–1.1	14.1–58.0

Table 1 Solid soluble content, titratable acidity, and firmness in yellow-fleshed peaches—cont'd

Cultivar	°Brix	Titratable acidity (%)	Fruit firmness (N)
Rich May	9.9–10.6	0.64–0.79	29.3
Riesi	9.8	0.84	36
Romea	12.2	—	16
Royal Glory	8.9–12.1	0.39	7.0–35.6
Ryan Sun	11.0–12.6	0.36–0.70	60
Sam Houston	12.7	0.14	42
San Lorenzo (Y. of August)	15.6	—	64
Saturn	11.9	0.33	—
September Sun	10.9–12.9	0.43–0.8	67.7–15.7
Springbelle	8.6–9.9	0.72	31.5–48.0
Spring Lady	9.6–12.6	0.87–0.89	10.8–41.0
Sudanell	14.8	—	57
Summer Zee	11.1	0.61	—
Suncrest	10.9–13	0.54	40.0–49.0
Super Rich	11.8	0.78	—
Suwanee	14	0.73	51
Sweet Dream	10.5–12.2	0.24–0.38	33.5–35.9
Sweet September	14.1	0.23	53.0–65.0
Tardibelle	11.1–12.1	0.70–0.79	58.1–65.0
Tra Zee	11.5	0.69	—
Tropic Beauty	10.6	—	18.40
Zee Lady	13.5	0.76	—
Calanda (Jesca)	12.5	—	58.00
Pamirskij	14.7	0.48	—
Saharanpur Prabhat	12.36	6.03	—

Data are means or ranges of means of different papers or years.

Lady,'Vista Rich,' etc.). Most probably, the slow-softening accessions will replace most of the melting peaches and nectarines in the near future, at least in the western peach industry.

Stony hard fruits are extremely rare in western markets; they are popular in Asian markets only.

Antioxidants and Bioactive Compounds

Peaches are important sources of antioxidants and bioactive compounds, which are beneficial in improving human health. These phytochemicals, thought to reduce the risk of cardiovascular and cancer diseases, comprise secondary metabolites and vitamins. There is a broad varietal variation in the content of these compounds (Tables 5–10), and antioxidant activity is strongly related to the genetic background. The

Table 2 Solid soluble content, titratable acidity, and firmness in white-fleshed peaches

Cultivar	°Brix	Titratable acidity (%)	Fruit firmness (N)
Bailey	11	0.63	—
Champagne	12.0–12.3	0.31–0.41	7.9–71.6
Ivory Princess	12.6	0.22	—
Klondike	11.2	0.31	—
Maria Bianca	12.9	—	25
Regina Bianca	15.66	0.81	—
September Snow	9.33–10.8	0.13–0.31	9.7–75.2
Snow Ball	10.6	0.32	57.8
Snow Brite	10.8	0.3	53.4
Snow Fire	13.6	0.3	—
Snow Giant	11.0–11.6	0.20–0.37	7.9–44.5
Snow King	11.6	0.24–0.27	11.3–59.6
Snow Kist	11.4	0.36	—
Spring Snow	10.6	0.4	—
Sugar Giant	9.8	0.28	47.6
Sugar Lady	11.7–12.6	0.27–0.40	55.6
Summer Sweet	11.8–12.1	0.20–0.34	5.3–46.3
Sunlit Snow	11.3	0.45	—
Sweet Scarlet	11	0.27	44
White Lady	11.0–12.5	0.25–0.34	60
Pamirskij	14.7	0.48	—

Data are means or ranges of means of different papers or years.

secondary metabolism is also influenced by environmental factors, training systems, horticultural management, biotic and abiotic stresses, ripening stage, and postharvest conditions. The phytochemicals reported in peach include carotenoids, phenolics, and vitamin C (Gil et al., 2002; Tomás-Barberán et al., 2001). Yellow-fleshed peaches can be a significant source of β -carotene, lutein, zeaxanthin, and β -cryptoxanthin (Dalla Valle et al., 2007). Carotenoids play an important role in vision, with lutein and zeaxanthin found to prevent age-related macular degeneration. A large array of phenolic compounds have been identified in peach, including several hydroxycinnamates such as chlorogenic acid and neochlorogenic acid, flavan 3-ols such as catechin and epicatechin, flavonols such as quercetin 3-glicoside and quercetin 3-rutinoside, and anthocyanins, primarily cyanidin 3-monoglucoside. Phenolic compounds are linked to both positive quality attributes like attractive visual appearance (color and pigmentation) and antioxidant capacity. However, there are also negative ones, like undesirable taste (astringency, bitterness) and browning potential. The antioxidant levels are highly correlated with total phenols, although not necessarily with anthocyanin content (Chang et al., 2000; Cevallos-Casals et al., 2005).

Table 3 Solid soluble content, titratable acidity, and firmness in yellow-fleshed nectarines

Cultivar	°Brix	Titratable acidity (%)	Fruit firmness (N)
Armking	10.4	—	16
August Fire	11.5	0.72	—
August Glo	12	0.71	—
August Red	13.4	0.98	12.65
Big Top	11.3–13.7	0.50–0.69	40.4–43
Crimson Gold	14.2	—	26
Diamond Bright	11.5	1.07	—
Diamond Ray	10.5	0.83	—
Fire Sweet	12.4–13.1	0.24–0.34	—
Grand Sweet	14.2	0.29	—
Honey Blaze	13.6	0.56	—
Honey Kist	12.0–13.2	0.46–0.53	65.8
Honey Royale	14.9	0.44	—
Laura	10.7	0.74	55.3
Maria Dolce	14.3	0.35	49.0–58.0
May Glo	8.0–11.3	1.01	7.2–42.4
Red Diamond	10.5	0.74	—
Red Jim	13.4	0.83	27.5
Rita Star	11.6	0.57	41.5
Rose Diamond	12.2	0.56	47.7
Royal Glo	10.6	0.82	—
Ruby Diamond	12.3	1.1	—
Ruby Sweet	12.5	0.46	—
September Free	13.7	0.77	—
September Red	11.2	0.51	9.7
Spring Bright	10.6–15.3	0.76–0.92	15.9
Spring Red	13.8	—	37
Red Gold	12.9–13.7	1.02	40.2–50.2
Summer Blush	13	0.87	—
Summer Bright	10.6	0.87	—
Summer Fire	10.8	0.4	—
Summergrand	12	1.08	—
Venus	11.2–11.6	0.69–1.10	52.9–68.0
Weinberger	12.6	0.64	54.1
Zee Glo	13.2	0.96	—

Data are means or ranges of means of different papers or years.

A work by [Gil et al. \(2002\)](#) on different nectarines and peaches has shown that phenolics are the only fruit constituents that correlate with antioxidant capacity. Therefore, the contributions of phenolic compounds and anthocyanins to the antioxidant activity of peaches is much more important than those of vitamin C or carotenoids ([Vizzotto et al., 2007](#); [Cantín et al., 2009](#)).

Table 4 Solid soluble content, titratable acidity, and firmness in white-fleshed nectarines

Cultivar	°Brix	Titrateable acidity (%)	Fruit firmness (N)
Arctic Glo	14.40	1.45	60.9
Arctic Jay	12.90	0.57	
Arctic King	12.10	0.97	42.3
Arctic Mist	12.11	0.36	
Arctic Queen	12.12	0.38–0.59	13.8–69.9
Arctic Rose	12.13	0.61	75.6
Arctic Snow	12.14	0.33–0.36	21.4
Arctic Star	12.15	0.29–0.46	15.0–44.9
Arctic Sweet	12.16	0.63	
Brite Pearl	12.17	0.21–0.33	28.0–56.5
Fire Pearl	12.18	0.37–0.58	14.1–58.3
Grand Pearl	12.19	0.49	
June Pearl	12.20	0.39	59.6
Ruby Pearl	12.21	0.31	
Silver King	12.22	0.67	40.4

Data are means or ranges of means of different papers or years.

Bioactive compound distribution is an important aspect of the overall phytochemical composition and antioxidant capacity. The peach skin is often not appreciated by consumers and discarded even if it is rich in these phytonutrients, which could contribute to the human diet intake. Peach peels contain two to three times the concentration of total phenolic compounds, compared to flesh and whole extracts. Given that much higher amounts of phenolics and carotenoids have been detected in the peel of both peaches and nectarines as compared to the flesh (Gil et al., 2002; Tomas-Barberan et al., 2001), discarding the skin may result in significant losses of these compounds.

Peach polyphenols include a wide range of compounds, namely hydroxycinnamates, flavonols, flavan 3-ols, and anthocyanins. The phenolic composition varies greatly among cultivars, although the phenol profiles are similar for both nectarines and peaches. No differences in individual compounds can be detected in such profiles between yellow- and white-flesh cultivars.

Hydroxycinnamic acid derivatives best characterized are represented by chlorogenic acid (5-O-caffeoyl-quinic acid) and neochlorogenic acid (3-O-caffeoyl-quinic acid), although cryptochlorogenic acid (4-O-caffeoyl-quinic acid) has been reported in some cultivars like ‘Summer Grand’ and ‘Bailey’ (Moing et al., 2003) (see Table 5 and Table 6).

In all cases, the amount of chlorogenic is larger than that of neochlorogenic acid, except in the flesh of ‘Summer Grand’ and ‘Fidelia.’ Peel contains always more chlorogenic acid than flesh; conversely, in the flesh of peaches and white nectarines, neochlorogenic acid content is often higher than in the peel. Among peaches, rich in chlorogenic acid in the flesh are the yellow-fleshed ‘Bolinha’ and ‘Spring Lady’ (10.94

Table 5 Hydroxycinnamic acid derivatives and flavonols (mean values) in yellow-fleshed peaches

Cultivar	Fruit tissue	Neochlorogenic acid (mg/100 g FW)	Chlorogenic acid (mg/100 g FW)	Other hydroxycinnamic acid derivatives (mg/100 g FW)	Total hydroxycinnamic acid derivatives (mg/100 g FW)	Quercetin 3-galactoside (tentative) (mg/100 g FW)	Quercetin 3-glucoside (mg/100 g FW)	Quercetin 3-rutinoside (mg/100 g FW)	Total flavonols (mg/100 g FW)
Andross	Whole	1.93	3.49				—	—	
	Peel	3.20	20.27				8.96	2.89	
	Flesh	4.15	7.03				—	—	
Bolinha	Whole	5.11	7.38				0.63	0.56	
	Peel	2.93	16.44				5.47	2.66	
	Flesh	7.83	10.94				—	—	
Corona	Whole	6.16	6.61				0.49	0.26	
	Peel	4.08	20.03				7.87	4.08	
	Flesh	5.68	6.00				—	—	
Flavorcrest	Peel	1.89	13.11	0.56	15.57	—	1.41	2.07	3.48
	Flesh	1.72	4.74	—	6.46	1.38	—	—	1.38
Halford	Whole	3.93	6.09				—	—	
	Peel	6.67	47.05				9.02	2.77	
	Flesh	2.87	3.87				—	—	
Kakamas	Whole	3.63	5.67				—	—	
	Peel	2.25	17.88				4.17	1.99	
	Flesh	3.19	7.79				—	—	
Leonforte	Peel	0.34	3.87		4.51	1.73	1.34	0.93	11.7
	Flesh	0.94	3.11		4.25	—	—	—	—
Maniace	Peel	—	0.26		0.26	2.64	2.15	0.69	13.2
	Flesh	—	0.03		0.11	—	—	—	—
Maria Marta	Whole		1.20				0.60		

Continued

Table 5 Hydroxycinnamic acid derivatives and flavonols (mean values) in yellow-fleshed peaches—cont'd

Cultivar	Fruit tissue	Neochlorogenic acid (mg/100 g FW)	Chlorogenic acid (mg/100 g FW)	Other hydroxycinnamic acid derivatives (mg/100 g FW)	Total hydroxycinnamic acid derivatives (mg/100 g FW)	Quercetin 3-galactoside (tentative) (mg/100 g FW)	Quercetin 3-glucoside (mg/100 g FW)	Quercetin 3-rutinoside (mg/100 g FW)	Total flavonols (mg/100 g FW)
O'Henry	Peel	5.42	19.19	1.50	26.11	0.27	1.27	2.81	4.35
	Flesh	5.28	7.93	—	13.22	1.84	—	—	1.84
Redhaven	Whole		1.9				0.71		
	Peel	2.80–4.13	10.80–13.6		13.73–17.73			2.4–3.6	4.27–13.6
	Flesh	3.33–4.13	4.13–4.8		7.47–9.07			0.13	0.53
Rich Lady	Peel	1.57	12.41	1.37	15.35	1.28	1.79	3.79	6.86
	Flesh	2.21	4.33	—	6.55	1.24	—	—	1.24
Riesi	Peel	2.64	9.69		12.33	3.09	5.05	0.96	15.3
	Flesh	1.24	1.31		2.73	—	—	—	—
Ross	Whole	4.83	6.17				—	—	
	Peel	6.56	32.51				9.69	8.13	
	Flesh	3.79	3.48				—	—	
September Sun	Peel	5.44	18.27	—	23.61	4.02	2.07	1.33	7.41
	Flesh	6.52	7.29	—	13.80	1.93	—	—	1.93
Springbelle	Peel	1.2–1.73	13.6–26		14.8–27.33			3.2–13.47	4.93–35.73
	Flesh	1.47–2.13	6.93–13.33		8.4–14.8			0.4	0.93–2.00
Spring Lady	Peel	4.41	29.46	0.85	34.74	2.09	2.13	2.83	7.05
	Flesh	4.47	12.61	—	17.08	1.92	—	—	1.92
Suncrest	Whole		1.3				0.52		
Walgant	Whole	1.83	4.62				—	—	
	Peel	4.51	18.69				3.80	1.68	
	Flesh	1.15	2.39				—	—	

Data are means or ranges (minimum–maximum or means of different years).

Table 6 Hydroxycinnamic acid derivatives and flavonols (mean values) in yellow-fleshed nectarines, white-fleshed peaches, and white-fleshed nectarines

Cultivar	Fruit tissue	Fruit type	Neochlorogenic acid (mg/100 g FW)	Chlorogenic acid (mg/100 g FW)	Other hydroxycinnamic acid derivatives (mg/100 g FW)	Total hydroxycinnamic acid derivatives (mg/100 g FW)	Quercetin 3-galactoside (tentative) (mg/100 g FW)	Quercetin 3-glucoside (mg/100 g FW)	Quercetin 3-rutinoside (mg/100 g FW)	Total flavonols (mg/100 g FW)
August Red	Peel	Nectarine, yellow	7.88	24.50	0.56	32.93	5.21	0.44	1.13	6.78
	Flesh		6.19	8.48	—	14.68	0.99	—	—	0.99
Big Top	Peel	Nectarine, yellow	0.53–4.00	4.8–15.07		5.33–19.06			2.00–3.73	2.00–19.2
	Flesh		1.2–3.07	3.2–4.27		4.4–7.2			0.13	0.13
Diamond Ray	Peel	Nectarine, yellow	1.07	4.67		5.73			—	—
	Flesh		0.67	2.93		4.13			—	—
Laura	Peel	Nectarine, yellow	2.13–5.73	10.13–22.8		12.40–28.67			3.07–11.47	5.60–25.20
	Flesh		2.67–6.93	3.07–11.87		5.33–18.80			0.27–0.53	0.27–0.93
May Glo	Peel	Nectarine, yellow	2.82	16.77	0.99	20.57	2.52	1.46	2.94	6.92
	Flesh		2.73	4.36	—	7.09	1.23	—	—	1.23
Red Jim	Peel	Nectarine, yellow	6.74	36.22	—	42.96	0.86	—	8.24	9.11
	Flesh		4.81	13.18	—	17.99	0.69	—	—	0.69
September Red	Peel	Nectarine, yellow	3.10	10.67	—	13.77	0.75	—	4.18	4.93
	Flesh		2.41	3.90	0.31	6.61	1.05	—	—	1.05
Spring Bright	Peel	Nectarine, yellow	5.98	24.10	1.70	31.79	1.53	1.67	5.69	8.89
	Flesh		5.89	8.43	—	14.31	2.11	—	—	2.11
Stark Red Gold	Peel	Nectarine, yellow	4.27–7.20	12.67–34.40		16.93–41.73			2.80–5.47	2.13–15.33
	Flesh		2.80–9.47	4.00–12.53		6.80–21.33			0.53	0.13
Summer Grand	Flesh	Nectarine, yellow	15.60	11.20						
Bailey	Flesh	Peach, white	22.13	40.93						
Champagne	Peel	Peach, white	8.77	18.59	0.54	27.90	0.96	0.52	1.49	2.97
	Flesh		6.04	4.15	—	10.19	1.04	—	—	1.04
Crizia	Peel	Peach, white	1.47–2.67	12.13–17.60		13.60–21.07			0.53–3.33	4.53–5.07
	Flesh		0.93–1.87	5.20–5.47		7.07–7.60			0.40	0.93

Continued

Table 6 Hydroxycinnamic acid derivatives and flavonols (mean values) in yellow-fleshed nectarines, white-fleshed peaches, and white-fleshed nectarines—cont'd

Cultivar	Fruit tissue	Fruit type	Neochlorogenic acid (mg/100g FW)	Chlorogenic acid (mg/100g FW)	Other hydroxycinnamic acid derivatives (mg/100g FW)	Total hydroxycinnamic acid derivatives (mg/100g FW)	Quercetin 3-galactoside (tentative) (mg/100g FW)	Quercetin 3-glucoside (mg/100g FW)	Quercetin 3-rutinoside (mg/100g FW)	Total flavonols (mg/100g FW)
Fidelia	Peel Flesh	Peach, white	2.27	11.20		13.47			3.60	4.53
			3.33	1.60		4.80			0.27	0.27
September Snow	Peel Flesh	Peach, white	6.41	10.72	—	17.13	1.01	—	2.69	3.70
			5.01	2.64	—	7.65	0.73	—	—	0.73
Snow Giant	Peel Flesh	Peach, white	7.50	17.67	1.07	26.24	0.83	1.04	1.52	3.39
			7.08	5.63	—	12.71	0.61	—	—	0.61
Snow King	Peel Flesh	Peach, white	4.78	43.47	1.59	49.85	—	2.06	2.71	4.77
			7.96	24.22	—	32.18	0.72	—	—	0.72
Summer Sweet	Peel Flesh	Peach, white	2.63	17.49	0.81	20.92	0.92	1.43	1.75	4.10
			3.10	6.89	—	9.99	1.14	—	—	1.14
Arctic Queen	Peel	Nectarine, white	4.81	24.05	1.37	30.23	1.36	1.99	2.93	6.27
	Flesh		4.43	8.44	—	12.90	1.02	—	—	1.02
Arctic Snow	Peel	Nectarine, white	6.35	18.90	0.99	26.24	0.43	1.67	2.44	4.54
	Flesh		7.62	9.03	—	16.65	1.05	—	—	1.05
Arctic Star	Peel	Nectarine, white	4.32	33.05	1.28	38.65	1.79	2.46	3.11	7.36
	Flesh		3.26	7.07	—	103.3	—	—	—	—
Brite Pearl	Peel	Nectarine, white	14.63	58.07	—	72.71	0.63	2.03	2.72	5.38
	Flesh		18.30	27.71	—	46.01	0.76	—	—	0.76
Fire Pearl	Peel	Nectarine, white	1.48	6.29	—	7.77	0.64	1.29	1.51	3.44
	Flesh		2.11	2.94	—	5.05	0.77	—	—	0.77
Silver Rome	Peel	Nectarine, white	6.13–15.07	38.13–54.67		44.67–69.60			1.73–19.73	3.20–26.00
	Flesh		10.67–17.07	12.93–14.27		24.27–37.87			0.67	0.93

Data are means or ranges (minimum–maximum or means of different years).

and 12.61 mg/100 g FW, respectively) and ‘Halford’ and ‘Ross’ for the peel (47.05 and 32.51 mg/100 g FW, respectively). High levels of chlorogenic acid are also reported in the white peaches, ‘Bailey’ (40.93 mg/100 g FW) and ‘Snow King’ (peel: 43.47 and flesh: 24.22 mg/100 g FW) and in the nectarines, in yellow-fleshed ‘Red Jim’ (peel: 36.22 and flesh: 13.18 mg/100 g FW) and in white-fleshed ‘Brite Pearl’ (peel: 58.07 and flesh: 27.71 mg/100 g FW). In contrast, the cultivars containing less chlorogenic acid are the yellow peaches ‘Maniace’ (peel: 0.26 and flesh: 0.03 mg/100 g FW) and ‘Maria Marta’ (1.2 mg/100 g FW), the white ‘September Snow’ (peel: 10.72 and flesh: 2.64 mg/100 g FW), the yellow nectarine ‘Diamond Ray’ (peel: about 4.67 and flesh: about 2.93 mg/100 g FW), and the white-fleshed nectarine ‘Fire Pearl’ (peel: 6.29 and flesh: 2.94 mg/100 g FW).

In peaches, high levels of neochlorogenic acid have been detected in the yellow-fleshed ‘September Sun’ and in the white-fleshed ‘Bailey,’ whereas among nectarines, the white ‘Brite Pearl’ and ‘Silver Rome’ and the yellow ‘August Red’ and ‘Summer Grand’ have the greatest amount of this compound.

Neochlorogenic and cryptochlorogenic acids are less important substrates for polyphenol oxidases than chlorogenic acid, and the ratio between the different hydroxycinnamic acid derivatives could play a major role in the control of browning. Moreover, a good correlation between browning and chlorogenic acid concentration has been reported in peaches (Moing et al., 2003).

With cinnamic acid derivatives, flavan 3-ols are the main class of phenolic compounds detected in ripe peach fruit. Catechin, epicatechin, procyanidin B1, and other dimeric procyanidins are the flavan 3-ols reported in various cultivars, with catechin being generally the main one (Tables 7 and 8). Catechin content is always higher in the peel, and the same applies to epicatechin, with the exception of the yellow nectarine ‘Spring Bright.’ In few cases, catechin and some dimeric procyanidins are not detected in the flesh. Among the yellow-fleshed peaches, ‘Halford’ has the greatest content of catechin and procyanidin B1 in the peel (27.00 and 43.40 mg/100 g, respectively), whereas the two compounds have the highest concentration in the flesh of ‘Spring Lady’ (7.91 and 23.43 mg/100 g, respectively). ‘Champagne’ and ‘Snow King’ are the white peaches containing the most catechin in the peel (31.89 and 31.16 mg/100 g, respectively), but ‘Snow King’ has also the highest amounts of procyanidin B1 in the peel (49.23 mg/100 g) and the highest levels of the two compounds in the flesh (19.67 mg/100 g of catechin and 33.31 mg/100 g of procyanidin B1). Among nectarines, the richest in catechin and procyanidin B1 are the yellow ‘Red Jim’ (peel: 23.78 and 25.30 mg/100 g; flesh: 8.10 and 11.43 mg/100 g, respectively), the white ‘Brite Pearl’ (catechin in the peel and in the flesh: 35.09 and 23.60 mg/100 g, respectively).

The cultivars containing higher amounts of epicatechin are the yellow peaches ‘September Sun’ and ‘O’Henry,’ the white peach ‘Snow Giant,’ the yellow nectarines ‘May Glo’ and ‘August Red,’ and the white nectarine ‘Brite Pearl.’

Flavan 3-ols are involved in the perception of astringency and bitterness. The ratio between monomers, oligomers, and polymers has a strong influence on these taste factors, since relative astringency increases and bitterness decreases with molecular weight (Moing et al., 2003). Moreover, catechin is a good substrate for polyphenol oxidases and may therefore contribute to tissue browning.

Flavonols, that is quercetin 3-glucoside, 3-rutinoside, and 3-galactoside are mainly accumulated at peel tissue level and only in trace amounts in flesh tissue, the concentration being frequently close to the detection limit (Tables 5 and 6). Cultivar variability is smaller than that of the other phenolic compounds previously considered. Quercetin 3-rutinoside (rutin) is generally the main flavonol in fruit, although yellow peaches contain often higher amounts of quercetin 3-glucoside (isoquercetin). Moreover, white-fleshed peaches and nectarines show similar concentrations of both compounds. Among yellow peaches, the richest in quercetin 3-rutinoside are 'Springbelle' (peel: up to 13.47 mg/100 g; flesh: 0.4 mg/100 g) and 'Ross' (peel: 8.13 mg/100 g), which has also a very high level of quercetin 3-glucoside (peel: 9.69 mg/100 g). 'Laura' is the yellow nectarine with a very high content of quercetin 3-rutinoside in both peel and flesh (up to 11.47 and up to 0.53 mg/100 g, respectively), whereas among white-fleshed cultivars, this compound accumulates mostly in the peel of the peaches 'Fidelia' and 'Crizia' (3.6 and up to 3.33 mg/100 g, respectively) and in the peel of the nectarine 'Silver Rome' (up to 19.73 mg/100 g).

Anthocyanins, like flavonols, are almost exclusively located in the peel (Tables 7 and 8). Nevertheless, anthocyanin pigments are also detected in small amounts in the flesh of some cultivars, owing to the red pigmentation mainly restricted to the area surrounding the stone. The concentration in the peel is generally in agreement with the percentage of red color of the epidermis. Two anthocyanins are reported in different cultivars, that is, cyanidin 3-glucoside, the main pigment, and cyanidin 3-rutinoside.

The peaches showing the largest anthocyanin content are the yellow 'Springbelle' (peel: up to 30.80 mg/100 g and flesh: up to 0.40 mg/100 g FW) and the white 'Crizia' (peel: up to 26.67 mg/100 g and flesh: up to 9.20 mg/100 g FW), while the nectarines containing the higher amounts of pigments are the yellow 'Summer Grand' (peel: 86.48 and flesh: 3.40 mg/100 g FW) and the white 'Silver Rome' (peel: up to 53.20 mg/100 g and flesh: up to 5.73 mg/100 g FW).

No clear differences are observed in the anthocyanin levels of white and yellow flesh of peaches and nectarines, depending on the pigmented area close to the stone. On the contrary, peel tissue of yellow peaches and nectarines contains generally more anthocyanins than the skin of the white cultivars (see Table 7 and Table 8).

Another class of pigments found in the fruit is that of carotenoids, which include carotenes α -, β -, and γ -carotene and xanthophylls (mono- or dihydroxylated carotenoids) zeaxanthin, lutein, β -cryptoxanthin, and violaxanthin. The predominant carotenoids are β -carotene and β -cryptoxanthin, followed by lutein (Tables 9 and 10).

Table 7 Flavan 3-ols, anthocyanins and total phenols (mean values) in yellow-fleshed peaches

Cultivar	Fruit tissue	Catechin	Epicatechin	Procyanidin	Other	Total flavan	Cyanidin-3-	Cyanidin-3-	Total	Total
		(mg/100g FW)	(mg/100g FW)	B1 (mg/100g FW)	proanthocyanidins (mg/100g FW)	3-ols (mg/100g FW)	glucoside (mg/100g FW)	rutinoside (mg/100g FW)	anthocyanins (mg/100g FW)	phenols (mg/100g FW)
Andross	Whole	1.09		1.36					—	49.80
	Peel	9.55		6.92					7.56	133.70
	Flesh	2.00		1.60					—	41.50
Bolinha	Whole	6.68		6.11					—	59.80
	Peel	22.50		24.60					4.58	121.00
	Flesh	5.39		4.45					—	58.50
Corona	Whole	7.47		11.29					1.78	59.70
	Peel	8.78		7.78					3.48	87.70
	Flesh	5.66		5.30					—	42.30
Flavorcrest	Peel	8.42	2.49	7.41	4.22	22.54	6.62	0.28	6.91	48.50
	Flesh	3.01	2.34	3.97	—	9.32	—	—	—	17.20
Halford	Whole	4.78		4.97					0.61	80.10
	Peel	27.00		43.40					—	189.60
	Flesh	5.39		2.27					—	76.50
Harvester	Whole									230.00
Kakamas	Whole	8.33		8.92					—	58.20
	Peel	6.96		5.31					—	126.30
	Flesh	—		6.46					—	60.70
Maria Marta	Whole	2.0–3.2								31.60–149.00
O'Henry	Peel	12.46	16.48	29.89	12.47	66.30	22.40	1.05	23.45	120.20
	Flesh	4.54	3.20	11.64	—	19.39	0.81	—	0.81	35.30

Continued

Table 7 Flavan 3-ols, anthocyanins and total phenols (mean values) in yellow-fleshed peaches—cont'd

Cultivar	Fruit tissue	Catechin	Epicatechin	Procyanidin		Total flavan	Cyanidin-3-glucoside	Cyanidin-3-rutinoside	Total anthocyanins	Total phenols
		(mg/100 g FW)	(mg/100 g FW)	B1 (mg/100 g FW)	Other proanthocyanidins (mg/100 g FW)	3-ols (mg/100 g FW)	(mg/100 g FW)	(mg/100 g FW)	(mg/100 g FW)	(mg/100 g FW)
Redhaven	Whole	2.0–3.4								73.30–103.60
	Peel	8.13–8.40	0.93–2.00		0.80–5.07	10.13–15.07	4.80–8.13			
	Flesh	2.40–5.20	0.67		0.27–2.00	5.07–5.47	0.13–0.40			
Rich Lady	Peel	16.33	9.56	19.11	9.84	54.84	26.44	0.92	27.36	104.40
	Flesh	5.98	2.86	9.60	–	18.43	–	–	–	26.20
Ross	Whole	2.86		2.50					–	54.50
	Peel	25.50		17.70					–	139.40
	Flesh	1.95		1.76					–	51.30
September Sun	Peel	18.71	15.87	24.06	50.3	63.67	16.89	0.69	17.58	112.30
	Flesh	5.89	5.92	15.83	–	27.64	0.37	–	0.37	43.70
Springbelle	Peel	2.93–7.73	1.20–3.33		1.73–6.67	7.73–13.07	17.07–30.80			
	Flesh	0.67–5.23	1.20		0.93–2.00	1.60–4.40	0.13–0.40			
Spring Lady	Peel	15.43	9.39	22.18	18.93	65.93	8.07	0.49	8.56	116.30
	Flesh	7.91	4.36	23.43	–	35.70	–	–	–	54.70
Suncrest	Whole	2.0–2.5								75.70–104.00
Walgant	Whole	2.20		1.77					–	46.70
	Peel	18.40		16.60					3.88	121.90
	Flesh	0.91		0.83					–	42.50

Data are means or ranges (minimum–maximum or means of different years).

Table 8 Flavan 3-ols, anthocyanins, and total phenols (mean values) in yellow-fleshed nectarines, white-fleshed peaches, and white-fleshed nectarines

Cultivar	Fruit tissue	Fruit type	Catechin (mg/100g FW)	Epicatechin (mg/100g FW)	Procyanidin B1 (mg/100g FW)	Other proanthocyanidins (mg/100g FW)	Total flavan 3-ols (mg/100 g FW)	Cyanidin-3- glucoside (mg/100 g FW)	Cyanidin-3- rutoside (mg/100g FW)	Total anthocyanins (mg/100g FW)	Total phenols (mg/100g FW)
August red	Peel	Nectarine, yellow	11.02	9.60	10.21	1.59	32.43	3.35	—	3.35	75.50
	Flesh		2.54	5.64	4.09	—	12.27	0.78	—	0.78	28.70
Big Top	Peel	Nectarine, yellow	1.07–3.47	2.00–3.20		1.33–2.13	4.27–8.93	6.27–20.00			
	Flesh		0.67–1.73	1.47–2.27		0.27–0.67	2.80–4.27	0.13–0.53			
Diamond Ray	Peel	Nectarine, yellow	1.20	—		—	1.20				
	Flesh		0.67	—		—	0.67				
Laura	Peel	Nectarine, yellow	3.33–5.20	1.20–6.13		3.07–13.33	7.60–24.67	10.93–17.6			
	Flesh		1.07–2.53	0.40–2.67		0.67–6.93	2.13–12.13	0.27–0.40			
May Glo	Peel	Nectarine, yellow	4.44	11.41	3.26	2.33	21.44	12.50	0.48	12.98	62.90
	Flesh		2.09	3.62	1.43	—	7.14	—	—	—	15.50
Red Jim	Peel	Nectarine, yellow	23.78	11.01	25.30	2.00	62.12	24.66	1.43	26.09	140.30
	Flesh		8.10	1.92	11.43	—	21.46	1.39	—	1.39	41.50
September Red	Peel	Nectarine, yellow	4.89	5.96	1.95	—	12.80	7.72	0.48	8.20	42.70
	Flesh		—	3.02	—	—	3.02	3.14	—	3.14	13.80
Spring Bright	Peel	Nectarine, yellow	5.34	2.24	5.83	5.21	18.61	22.36	1.27	23.64	82.90
	Flesh		2.44	4.38	3.62	—	8.00	0.32	—	0.32	24.70
Stark Red Gold	Peel	Nectarine, yellow	5.73–26.00	2.00		2.93–12.80	10.67–34.80	5.07–16.40		132	620.00
	Flesh		1.47–15.60	0.40–0.80		0.80–4.13	3.07–19.73	0.13–0.40		—	154.00
Summer Grand	Peel	Nectarine, yellow						86.48			
	Flesh		2.53			4.93		3.40			
Bailey	Peel	Peach, white						0.88			
	Flesh		11.07			16.13		4.13			
Champagne	Peel	Peach, white	31.89	12.77	35.43	5.99	85.80	5.35	0.36	5.71	122.40
	Flesh		8.49	3.83	15.74	2.92	30.98	0.64	—	0.64	42.90

Continued

Table 8 Flavan 3-ols, anthocyanins, and total phenols (mean values) in yellow-fleshed nectarines, white-fleshed peaches, and white-fleshed nectarines—cont'd

Cultivar	Fruit tissue	Fruit type	Catechin (mg/100g FW)	Epicatechin (mg/100g FW)	Procyanidin B1 (mg/100g FW)	Other proanthocyanidins (mg/100 g FW)	Total flavan 3-ols (mg/100 g FW)	Cyanidin-3- glucoside (mg/100 g FW)	Cyanidin-3- rutoside (mg/100 g FW)	Total anthocyanins (mg/100g FW)	Total phenols (mg/100g FW)
Crizia	Peel Flesh	Peach, white	4.53–6.67 1.47–2.40	5.60 2.13		6.93 1.47	4.53–19.20 2.40–5.20	13.73–26.67 2.13–9.20			
Fidelia	Peel Flesh	Peach, white	8.93 2.67	1.33 0.80		5.73 2.13	15.87 5.60	4.67 0.13			
September Snow	Peel Flesh	Peach, white	14.99 7.56	11.21 5.33	22.27 8.78	8.40 –	56.88 21.68	5.24 0.27	0.18 –	5.44 0.27	83.20 30.30
Snow Giant	Peel Flesh	Peach, white	27.00 13.88	15.16 5.19	32.21 25.09	33.93 9.55	108.30 53.70	13.28 –	0.97 –	14.26 –	152.20 67.00
Snow King	Peel Flesh	Peach, white	31.16 19.67	7.30 3.51	49.23 33.31	28.88 13.09	116.58 69.58	11.87 1.76	0.51 –	12.38 1.76	183.60 104.20
Summer Sweet	Peel Flesh	Peach, white	10.42 3.97	6.19 3.89	10.05 3.84	3.00 –	29.65 11.71	11.42 –	0.86 –	12.29 –	67.00 22.80
Arctic Queen	Peel Flesh	Nectarine, white	11.39 5.03	8.42 4.01	15.02 6.70	3.89 –	38.72 15.74	14.75 0.67	0.47 –	15.22 0.67	90.40 30.30
Arctic Snow	Peel Flesh	Nectarine, white	16.59 9.35	8.27 3.04	20.63 14.16	6.76 0.72	52.25 27.28	9.27 0.43	0.63 –	9.90 0.43	92.90 45.40
Arctic star	Peel Flesh	Nectarine, white	8.11 1.91	10.32 3.13	6.74 –	2.81 –	27.97 5.04	12.60 –	0.95 –	13.56 –	87.50 15.40
Brite Pearl	Peel Flesh	Nectarine, white	35.09 23.60	11.88 4.97	44.82 30.20	18.78 8.20	110.58 43.37	12.73 –	0.59 –	13.32 –	202.00 90.10
Fire Pearl	Peel Flesh	Nectarine, white	2.08 –	1.66 2.30	2.20 –	7.42 –	13.36 2.30	16.50 1.01	0.78 –	17.27 1.01	41.80 9.10
Silver Rome	Peel Flesh	Nectarine, white	1.20–35.07 2.53–13.60	0.93–5.20 0.40–1.86		16.67–28.93 13.47–17.73	25.20–36.00 14.13–25.20	10.00–53.20 1.07–5.73			

Data are means or ranges (minimum–maximum or means of different years).

Carotenoid compounds have been found to be more concentrated in the peel. The content and composition of these pigments vary greatly among cultivars. Given that carotenoids cause the yellow coloration in fruit, their total content is much higher in yellow-fleshed cultivars (Gil et al., 2002).

Among peaches very rich in carotenoids are ‘Rich Lady’ (β -carotene and β -cryptoxanthin: in the peel 379 and 36 $\mu\text{g}/100\text{g}$, respectively; in the flesh 81 and 16 $\mu\text{g}/100\text{g}$, respectively), ‘September Sun’ (β -carotene in the peel: 335 and in the flesh: 168 $\mu\text{g}/100\text{g}$), and ‘Kakamas’ (β -carotene and β -cryptoxanthin in the flesh: 68.20 and 339.10 $\mu\text{g}/100\text{g}$, respectively). High levels of these pigments are also reported in the nectarines ‘Spring Bright’ (β -carotene and β -cryptoxanthin: in the peel 307 and 31 $\mu\text{g}/100\text{g}$, respectively; in the flesh 85 and 21 $\mu\text{g}/100\text{g}$, respectively) and ‘August Red’ (β -carotene and β -cryptoxanthin: in the peel 273 and 27 $\mu\text{g}/100\text{g}$, respectively; in the flesh 128 and 14 $\mu\text{g}/100\text{g}$, respectively). Among white cultivars, the peach ‘Snow King’ and the nectarine ‘Arctic Star’ show a very high content of β -carotene in the peel (43 and 57 $\mu\text{g}/100\text{g}$, respectively).

Peach is also an important source of ascorbic acid (vitamin C) (Tables 9 and 10). The genetic background plays a much more important role than the climatic conditions and cultural practices in determining the ascorbic acid content in ripe fruits. Like the other bioactive compounds considered, skin tissues have more ascorbic acid to protect the fruit from oxidative stress caused by light and other environmental and biotic factors. Among peaches, the yellow cultivars showing high ascorbic acid levels are ‘Spring Lady’ (peel: 18.10 and flesh: 8.60 $\text{mg}/100\text{g}$), ‘September Sun’ (peel: 12.70 and flesh: 12.60 $\text{mg}/100\text{g}$), and ‘Hiley Belle’ (12.86 $\text{mg}/100\text{g}$), and the white one with a high amount is ‘Snow King’ (peel: 20.20 and flesh: 6.50 $\text{mg}/100\text{g}$). The yellow nectarines containing the most ascorbic acid in the peel and in the flesh are ‘Red Jim’ (peel: 13.00 $\text{mg}/100\text{g}$) and ‘August Red’ (flesh: 5.80 $\text{mg}/100\text{g}$), respectively, whereas the white nectarine richest in this vitamin is ‘Arctic Snow’ (peel: 20.00 and flesh: 12.20 $\text{mg}/100\text{g}$). There are no differences in ascorbic acid content between peaches and nectarines, while it is higher in white than in yellow-fleshed fruit (see Table 9 and Table 10).

Bioactive compounds and phytonutrients can contribute in determining the antioxidant activity of the fruit. As there are several different assays to determine antioxidant activity of biological samples, there are also different antioxidant indexes to evaluate this parameter. The data of antioxidant activity tests are obtained from different procedures and reported with different units. Therefore, the consequences are that the antioxidant values of different works cannot be effectively evaluated and compared. Consequently, it is possible to compare only few cultivars for their antioxidant capacity. The antioxidant potential has been reported to be mainly linked to total phenol content, whereas no clear correlation has been found with ascorbic acid and carotenoids (Gil et al., 2002). It is always higher in the peel, where the bioactive compounds are more concentrated (Tables 9 and 10). Peaches with very high levels of antioxidant activity are the yellow-flesh

Table 9 Carotenoids, ascorbic acid, and antioxidant activity (mean values) in yellow-fleshed peaches

Cultivar	Fruit tissue	Total carotenoids (µg/100 g FW)	β-carotene (µg/100 g FW)	β-cryptoxanthin (µg/100 g FW)	Lutein (µg/100 g FW)	Ascorbic acid (mg/100 g FW)	Antioxidant activity DPPH (AEAC) (mg/100 g FW)	
Corona	Flesh	107.55	130.80	57.9	22.28		31.30	
Crimson Lady	Whole		61.69	23.58				
Elberta	Whole					5.25		
Flavorcrest	Peel		324.00	20.00		11.50		10.40
	Flesh		53.00	6.00		6.00		
Golden Jubilee	Whole	109.45			27.11	6.13		
Halford	Flesh		186.90	103.50				
Hiley Belle	Whole					12.86		
Kakamas	Flesh		68.20	339.10				
Lolita	Whole		53.94	28.40				
Maycrest	Whole	84.96	37.98	22.68	24.30		110.70	
Mayflower	Whole					5.34		
O’Henry	Peel		265.00	8.00		7.20		39.80
	Flesh		81.00	8.00		3.10		
Rich Lady	Peel		379.00	36.00		9.20		60.40
	Flesh		81.00	16.00		4.70		
Rich May	Whole	84.77	39.47	24.23	21.06			
September Sun	Peel		335.00	—		12.70	79.00	
	Flesh		168.00	—		12.60		31.40
Springbelle	Whole		97.28	56.18		21.25	19,847	
Spring Lady	Whole		82.40	40.65		18.99	22.75	
	Peel	270.00		25.00	18.10	106.60		
	Flesh	70.00		10.00	8.60			43.20
Springcrest	Whole	92.77	44.05	21.28	27.43			

Data are means.

Table 10 Carotenoids, ascorbic acid, and antioxidant activity (mean values) in yellow-fleshed nectarines, white-fleshed peaches, and white-fleshed nectarines

Cultivar	Fruit tissue	Fruit type	Total carotenoids (µg/100 g FW)	β-carotene (µg/100 g FW)	β-cryptoxanthin (µg/100 g FW)	Lutein (µg/100 g FW)	Ascorbic acid (mg/100 g FW)	Antioxidant activity DPPH (AEAC) (mg/100 g FW)
August Red	Peel	Nectarine, yellow		273.00	27.00		11.80	45.90
	Flesh			128.00	14.00		5.80	15.90
Laura	Whole	Nectarine, yellow	49.90	20.21	14.38	12.35		
May Glo	Whole	Nectarine, yellow	63.63	34.83	14.69	14.10		
May Glo	Peel			192.00	25.00		11.90	27.70
	Flesh			58.00	8.00		6.10	6.20
Red Jim	Peel	Nectarine, yellow		187.00	24.00		13.00	98.10
	Flesh			73.00	14.00		5.50	31.70
Rita Star	Whole	Nectarine, yellow	64.42	30.03	12.40	14.18		
Rose Diamond	Whole	Nectarine, yellow	65.47	37.10	14.37	14.00		
Ross	Flesh	Nectarine, yellow		30.00	47.40			
September Red	Peel	Nectarine, yellow		199.00	28.00		7.80	28.30
	Flesh			131.00	15.00		5.30	12.00
Spring Bright	Peel	Nectarine, yellow		307.00	31.00		11.40	47.10
	Flesh			85.00	21.00		3.50	12.60
Weinberger	Whole	Nectarine, yellow	66.07	30.33	23.38	12.35		
Carman	Whole	Peach, white					8.82	
Champagne	Peel	Peach, white		31.00	7.00		13.60	127.50
	Flesh			7.00	—		6.10	47.90
Early Rose	Whole	Peach, white					7.18	

Continued

Table 10 Carotenoids, ascorbic acid, and antioxidant activity (mean values) in yellow-fleshed nectarines, white-fleshed peaches, and white-fleshed nectarines—cont'd

Cultivar	Fruit tissue	Fruit type	Total carotenoids (µg/100 g FW)	β-carotene (µg/100 g FW)	β-cryptoxanthin (µg/100 g FW)	Lutein (µg/100 g FW)	Ascorbic acid (mg/100 g FW)	Antioxidant activity DPPH (AEAC) (mg/100 g FW)
September Snow	Peel	Peach, white		30.00	6.00		11.20	62.40
	Flesh			4.00	—		4.80	40.30
Snow Giant	Peel	Peach, white		29.00	6.00		14.20	131.40
	Flesh			6.00	—		5.10	65.70
Snow King	Peel	Peach, white		43.00	7.00		20.20	178.90
	Flesh			8.00	—		6.50	100.60
Summer Sweet	Peel	Peach, white		11.00	14.00		13.40	53.00
	Flesh			4.00	12.00		5.70	14.60
Arctic Queen	Peel	Nectarine, white		17.00	3.0		16.00	55.30
	Flesh			10.00	—		7.80	14.50
Arctic Snow	Peel	Nectarine, white		31.00	5.0		20.00	98.40
	Flesh			4.00	—		12.20	40.20
Arctic Star	Peel	Nectarine, white		57.00	—		9.30	39.30
	Flesh			4.00	—		4.20	8.40
Brite Pearl	Peel	Nectarine, white		28.00	8.0		19.10	144.70
	Flesh			8.00	—		9.50	83.70
Fire Pearl	Peel	Nectarine, white		5.00	8.0		13.40	23.00
	Flesh			2.00	5.0		6.90	4.60
Silver King	Whole	Nectarine, white	21.65	12.32	4.22	5.11		

Data are means.

‘O’Henry’ and ‘Spring Lady’ and the white-fleshed ‘Snow King.’ High values are also reported in the yellow nectarine ‘Red Jim’ and in the white nectarine ‘Brite Pearl.’

Volatile Compounds and Sensorial Evaluation

The volatile composition and aroma in peach are important topics for the fruit industry, affecting consumer satisfaction.

Several methods are used to extract the volatile organic compounds (VOCs) in fruits, from static to dynamic headspace by several techniques (e.g., SPME, stripping by air or nitrogen stream on carbon trap, etc.); thus, extraction procedures and instruments settings are crucial in identifying VOCs. However, the data processing (internal or external standard, calibration curves, etc.) makes it difficult to compare outputs from different laboratories because the analytical methods are developed depending on specific aims. These factors influence greatly volatile identification; however, a lot of compounds have been determined on the bases of molecular weight, volatility, interaction among compounds, chemical affinity, etc. In 21 references, more than 200 compounds were found (Table 11).

In this work, in order to compare VOCs among various peach accessions and to try to tackle the problems above, VOCs with chemical affinity (acids, alcohols, aldehydes, esters, hydrocarbons, ketones, lactones, terpenes, and other molecules) were summed, considering both their own units and as percents on total VOCs (Table 12). Evaluating 27 peaches (25 yellow and 2 white flesh) and 8 nectarines (7 yellow and 1 white flesh), the amount of total VOCs ranges from 2 to 3 μg per kg of FW in nectarines (‘August Red,’ ‘Big Top,’ ‘Honey,’ and ‘Nectagala’) to 12–23 mg on kg FW in peaches, for example, yellow flesh ‘Bolero’ and ‘Early Rich’ (Cano-Salazar et al., 2013b and Eduardo et al., 2010). In particular, ‘Jinxu’ yellow peach shows a very high volatile content, varying from 15 to 32 g on kg FW, depending on the year (Xi et al., 2012a, 2012b).

Aldehydes, esters, and terpenes are among the more represented VOCs in headspace. It is very interesting to underline that single compounds show different odor thresholds; for example, small amounts of linanool or hexyl acetate can greatly affect fruit flavor, instead of larger amounts of benzaldehyde or (E)-2-hexenyl acetate are needed to reach similar results (Bononi et al., 2012 and Cano-Salazar et al., 2012).

About the use of sensorial evaluation, several works can be found in literature. The assessment is carried out by trained panels, for visual, olfactive, gustative, and tactile attributes recorded on a parametric structured or nonstructured scale (Table 13). Unfortunately, many results are given as radar, dendrogram, PCA, or other statistical representations, so the extrapolation of the numeric data is problematic. Among the more interesting outputs, ‘Big Top,’ ‘Honey Blaze,’ ‘Royale,’ and ‘Nectagala’ (yellow nectarines), ‘Elegant Lady,’ and ‘Ryan Sun’ (yellow peaches), and ‘Pesca Bivona Agostina’ and ‘Settembrina’ (white peaches) were among the more appreciated (Cano-Salazar et al., 2013b; Infante et al., 2011; Montevecchi et al., 2013; Lopez et al., 2011). Moreover, two of these accessions were appreciated for other attributes than aroma: ‘Big Top’ for crispness and ‘Pesca Bivona Settembrina’ for sweetness and flavor. The yellow peaches ‘Dourado’ and ‘Sweet

Table 11 List of volatile organic compounds found in references

Acids	Esters	Ketons
(<i>E</i>)-3-Phenyl-2-propanoic acid	(<i>E</i>)-2-Hexen-1-ol acetate	2,3-Butanedione
2-Methylbutanoic acid	(<i>E</i>)-2-Hexenyl acetate	Acetophenone
3-Methylbutanoic acid = isovaleric acid	(<i>Z</i>)-3-Hexen-1-ol acetate	<i>E</i> -3-Nonen-2-one
4-Oxo-pentanoic acid	(<i>Z</i>)-3-Hexenyl 3-methylbutanoate	
Acetic acid	(<i>Z</i>)-3-Hexenyl acetate	Lactones
Benzoic acid	(<i>Z</i>)-3-Hexenyl butanoate	6-Pentyl- α -pyrone
Decanoic acid	(<i>Z</i>)-3-Hexenyl hexanoate	γ -Decalactone
Dodecanoic acid	(<i>Z</i>)-3-Hexenyl octanoate	γ -Dodecalactone
Nonanoic acid	2-Hexenyl acetate	γ -Heptalactone
Olei acid	2-Hexenyl hexanoate	γ -Hexalactone
Salicylic acid	2-Hexenyl octanoate	γ -Nonalactone
Tetradecanoic acid	2-Methylbutyl 2-methylbutanoate	γ -Octalactone
	2-Methylbutyl 2-methylpropanoate	δ -Deca-2,4-dienolactone
Alcohols	2-Methylbutyl acetate	δ -Decalactone
(<i>E</i>)-2-Hexen-1-ol	2-Methylpropyl acetate = iso-butyl acetate	δ -Dodecalactone
(<i>E</i>)-3-Hexen-1-ol	2-Methylpropyl hexanoate	δ -Octalactone
(<i>Z</i>)-3-Hexen-1-ol	2-Methylpropyl octanoate	
1-Hexadecanol	2-Propenyl acetate	Terpenes-Terpenoids-Norisoprenoids-Other Compounds
1-Hexanol	3-Hexenyl acetate	(<i>E</i>)-theaspirane
1-Nonanol	3-Hexenyl heptanoate	(<i>E</i>)- β -ocimene
1-Pentanol	3-Methyl-2-butenyl acetate	(<i>E,E</i>)-Farnesyl acetone
2-Ethyl-1-Hexanol	3-Methylbutyl acetate	(<i>Z</i>)-6-dodecen-4-olide
2-Methyl-1-Butanol	3-Methylbutyl octanoate	(<i>Z</i>)-linanool oxide furanoid
2-Phenylethanol	Butyl 2-methylbutanoate	(<i>Z</i>)- β -ocimene
4-Allyl-2-Methoxyphenol = eugenol	Butyl acetate	1,2,3,4-Tetrahydro-1,1,6-trimethyl naphthalene
4-Allylphenol = Chavicol	Butyl hexadecanoate	1H-pyrazole
4-Vinylphenol	Butyl hexanoate	2,4-Di-tert-butyl phenol
Benzyl alcohol	Butyl octadecanoate	2,5-Furandione
Cyclohexanol	Butyl octanoate	2-Ethyl furan
Ethanol	Butyl propanoate	3,4-Dimethyl-2,5-furandione
	Cyclohexyl acetate	3,7-Dimethyl-1,5,7-octatrien-3-ol
Aldehydes	Ethyl 2-butenate	3-Hydroxy-5,6-epoxy- β -ionone
(<i>E</i>)-2-Hexenal	Ethyl 2-methylbutanoate	3-Hydroxy- β -damascone
(<i>E,E</i>)-2,4-Decadienal	Ethyl 2-octenoate	3-Methyl-2,5-Furandione

Table 11 List of volatile organic compounds found in references—cont'd

(<i>E,E</i>)-2,4-Heptadienal	Ethyl 3-decenoate	4-Hydroxy-3,5,5-Trimethyl-4-(3-oxo-1-butenyl)-2-cyclohexen-1-one
2-Ethyl-1-hexenal	Ethyl 3-methylbutanoate	5,6,7,7a-Tetrahydro-4,4,7a-trimethyl-2-(4H)-benzofuranone
7,11,13-Hexadecatrienal	Ethyl 4-heptenoate	8-Hydroxylinolal
7,11-Hexadecadienal	Ethyl 4-octenoate	Carvone
Acetaldehyde	Ethyl acetate	Dihydro-2,5-furandione
Benzaldehyde	Ethyl decanoate	Dihydroactinidiolide
Benzenacetaldehyde	Ethyl dodecanoate	Eucalyptol = 1,8-cineole
Decanal	Ethyl heptanoate	Furanal
Docosanal	Ethyl hexanoate	Geranyl acetone
Dodecanal	Ethyl nonanoate	Limonene
Eicosanal	Ethyl octanoate	Linalool
Heicosanal	Heptyl acetate	Longifolene
Hexacosanal	Hexyl 2-methylbutanoate	Nerol
Hexadecanal	Hexyl 3-methylbutanoate	Nerol oxide
Hexanal	Hexyl acetate	p-cymene
Nonanal	Hexyl benzoate	p-Menth-1-en-9-al
Octadecanal	Hexyl butanoate	Squalene
Phenylacetaldehyde	Hexyl hexanoate	Vanillin
Tetracosanal	Hexyl octanoate	α,α -Dihydro- α -ionone
Undecanal	Hexyl propanoate	α -Bisabolol
	Methyl 2-octenoate	α -Farnesene
	Methyl 4-octenoate	α -Ionol
Hydrocarbons (Alkanes-Alkenes)		
2,6,11-Trimethyldodecane	Methyl 9-decenoate	α -Ionone
C13 Tridecane	Methyl acetate	α -Pinene
C14 Tetradecane	Methyl decanoate	α -Terpineol
C14:1 Tetradec-3-ene	Methyl heptanoate	β -Cyclocitral
C15 Pentadecane	Methyl hexanoate	β -Damascenone
C16 Hexadecane	Methyl linoleate	β -Damascone
C17 Heptadecane	Methyl nonanoate	β -Ionone
C17:1 Heptadec-8-ene	Methyl octanoate	β -Myrcene
C18 Octadecane	Methyl tetradecanoate	
C19 Nonadecane	Methylethyl octanoate	
C21 Heneicosane	Methylethyl tetradecanoate	
C22 Dodecane	Nonyl acetate	
C23 Tricosane	Octyl acetate	
C24 Tetracosane	Pentyl acetate = n-amyl acetate	
	Pentyl hexanoate	
C25 Pentacosane	Propyl acetate	
C26 Hexacosane	Propyl hexanoate	
C27 Heptacosane		
C29 Nonacosane		

Table 12 Volatiles on the base of chemical affinity classes for peach accessions (units as reported in references and in percentage)

Cultivar	Fruit type	Acids	Alcohols	Aldehydes	Esters	Hydrocarbons	Ketones	Lactones	Terpenes	Total volatiles
August Red	Nectarine, yellow	602.4	147.8	215.6	852.4	—	395.0	—	61.8	2275.0
Azurite	Peach, yellow	703.7	620	2163.1	1195.2	2820.9	1.4	330.9	128.8	7964
Big Top	Nectarine, yellow	244.2	307.7	469	867.9	—	458.2	37.9	600.4	2985.3
Big Top	Nectarine, yellow	1477	537.7	3720	256.8	3616.3	—	135	101.8	9844.6
Bolero	Peach, yellow	824.9	42.1	6988.2	277.6	3585.2	1.6	274.2	63.4	12,057.2
Calanda Calante	Peach, yellow	—	33.5	325.8	176.7	47.1	—	626.6	59.8	1269.5
Calanda Jesca	Peach, yellow	—	41.8	120.1	98.2	26	—	232.8	63.6	582.5
Dixi Red	Peach, yellow	364	125.6	3907.1	315.5	2909.5	—	1085.5	222.4	8929.6
Doctor Davis	Peach, yellow	—	3.91	—	1106.78	67.69	—	132.6	9.76	1320.74
Early Rich	Peach, yellow	1879.4	141.8	5091.2	334.8	4124.5	—	657	215.4	12,444.1
Early Rich	Peach, yellow	863.3	711.5	1004.8	1749	—	274.1	167.6	38.3	4808.6
Elegant Lady	Peach, yellow	1382.7	196.4	1109.4	904.6	—	1503.3	91.3	6067.9	11,255.6
Fair Time	Peach, yellow	—	1.85	33.29	421.66	690.54	—	79.19	320.83	1547.36
Flaminia	Peach, yellow	—	3.75	57.73	540.97	2744.12	—	193.41	86.79	3626.77
Honey Blaze	Nectarine, yellow	494.4	217	305	1281.2	—	765.2	36.3	611.6	3710.7
Honey Royale	Nectarine, yellow	483.5	294	178.7	804.6	—	476.2	12.1	65.8	2314.9
Hujingmilu	Peach, white	—	—	—	—	—	—	42.5	—	42.5
Jinxu	Peach, yellow	—	0.333	0.835	30.9	—	—	—	—	32.068
Jinxu	Peach, yellow	—	—	—	—	—	—	15.06	—	15.06

	% Acids	% Alcohols	% Aldehydes	% Esters	% Hydrocarbons	% Ketones	% Lactones	% Terpenes	% Total volatiles	References
ng/kg (by calibration curves)	26.5	6.5	9.5	37.5		17.4		2.7	100	Cano-Salazar et al. (2013b)
µg/kg FW	8.84	7.79	27.16	15.01	35.42	0.02	4.15	1.62	100	Eduardo et al. (2010)
ng/kg (by calibration curves)	8.18	10.31	15.71	29.07		15.35	1.27	20.11	100	Cano-Salazar et al. (2013a,b)
µg/kg FW	15.00	5.46	37.79	2.61	36.73		1.37	1.03	100	Eduardo et al. (2010)
µg/kg FW	6.84	0.35	57.96	2.30	29.73	0.01	2.27	0.53	100	Eduardo et al. (2010)
µg eq. Ethyl nonanoate/g		2.64	25.66	13.92	3.71		49.36	4.71	100	Montero-Prado et al. (2013)
µg eq. Ethyl nonanoate/g		7.18	20.62	16.86	4.46		39.97	10.92	100	Montero-Prado et al. (2013)
µg/kg FW	4.08	1.41	43.75	3.53	32.58		12.16	2.49	100	Eduardo et al. (2010)
1 unit = 10 ⁶ area		0.30		83.80	5.13		10.04	0.74	100	Tabilio et al. (2013)
µg/kg FW	15.10	1.14	40.91	2.69	33.14		5.28	1.73	100	Eduardo et al. (2010)
ng eq. butyl benzene/kg	17.95	14.80	20.90	36.37		5.70	3.49	0.80	100	Cano-Salazar et al. (2012, 2013a)
ng eq. butyl benzene/kg	12.28	1.74	9.86	8.04		13.36	0.81	53.91	100	Cano-Salazar et al. (2012)
1 unit = 10 ⁶ area		0.12	2.15	27.25	44.63		5.12	20.73	100	Tabilio et al. (2013)
1 unit = 10 ⁶ area		0.10	1.59	14.92	75.66		5.33	2.39	100	Tabilio et al. (2013)
ng/kg (by calibration curves)	13.32	5.85	8.22	34.53		20.62	0.98	16.48	100	Cano-Salazar et al. (2013b)
ng/kg (by calibration curves)	20.89	12.70	7.72	34.76		20.57	0.52	2.84	100	Cano-Salazar et al. (2013b)
µg/g FW							100		100	Xi et al. (2012a)
g/kg		1.04	2.60	96.36					100	Xi et al. (2012b)
µg/g FW							100		100	Xi et al. (2012a)

Continued

Table 12 Volatiles on the base of chemical affinity classes for peach accessions (units as reported in references and in percentage)—cont'd

Cultivar	Fruit type	Acids	Alcohols	Aldehydes	Esters	Hydrocarbons	Ketones	Lactones	Terpenes	Total volatiles
Miraflores	Peach, yellow	—	0.2	16.4	14.5	1	—	36.6	40.8	109.5
Nectagala	Nectarine, yellow	628.7	331.9	318.4	1135.9	—	413.9	15.2	249.3	3093
Nonmelting (local cultivar)	Peach, yellow	321.2	2597.6	12,186.4	157.2	5396.7	128.4	2050	719.8	23,557.3
Oro A	Peach, yellow	—	—	—	—	—	—	—	—	—
Percoca Romagnola 7	Peach, yellow	—	12.68	36.24	753.5	733.34	—	222.34	182.67	1940.77
Redhaven	Peach, yellow	670.8	323.2	82.5	226.2	28.6	—	238.3	5429.5	6999.1
Redhaven Bianca	Peach, white	277.1	133.2	53.5	169.4	26	—	104	4513.9	5277.1
Romagna Big	Nectarine, yellow	133.9	991	1921	1262.6	2535.5	—	—	395.2	7239.2
Royal Glory	Peach, yellow	840.6	293.4	523.2	1596.6	—	940.4	71.4	399	4664.7
Royal Time	Peach, yellow	565.8	754.3	4278.4	1723.4	4091.5	—	671.5	393.8	12,478.7
San Lorenzo (Y. of August)	Peach, yellow	—	1.2	4	7.4	37.3	—	388.8	55	493.7
Sicilia Piatta	Peach, yellow	—	11.85	25	663.43	1376.14	—	194.66	145.08	2416.16
Springbelle	Peach, yellow	—	5467.1	2180.205	1994.2	—	—	74.9	49	9765.405
Sudanell	Peach, yellow	0.6	1.6	139.4	11.9	15.8	—	288.6	109.6	567.5
Sweet Dream	Peach, yellow	1181.5	311.3	493.3	5816.3	—	431.4	43.7	242.1	8519.6
Tardibelle	Peach, yellow	—	11.2	0.5	253.66	—	—	0.5	—	265.86
Venus	Nectarine, yellow	1293.8	894.1	1571.6	1649.8	—	1125.1	142.7	2899.5	9576.6
Wanmi	Peach, yellow	0	47.6	359	28	—	2.7	23.3	23.7	484.3
White nectarine (selection)	Nectarine, white	438.2	287.9	2613.7	1278.2	2769.7	—	145.7	428.9	7962.3

	% Acids	% Alcohols	% Aldehydes	% Esters	% Hydrocarbons	% Ketones	% Lactones	% Terpenes	% Total volatiles	References
µg eq. Ethyl nonanoate/g		0.18	14.98	13.24	0.91		33.42	37.26	100	Montero-Prado et al. (2013)
ng/kg (by calibration curves)	20.33	10.73	10.29	36.72		13.38	0.49	8.06	100	Cano-Salazar et al. (2013b)
µg/kg FW	1.36	11.03	51.73	0.67	22.91	0.55	8.70	3.06	100	Eduardo et al. (2010)
—		35.83	3.06	58.61			1.06	1.44	100	Bononi et al. (2012)
1 unit = 10 ⁶ area		0.65	1.87	38.82	37.79		11.46	9.41	100	Tabilio et al. (2013)
ng/g FW	9.58	4.62	1.18	3.23	0.41		3.40	77.57	100	Brandi et al. (2011)
ng/g FW	5.25	2.52	1.01	3.21	0.49		1.97	85.54	100	Brandi et al. (2011)
µg/kg FW	1.85	13.69	26.54	17.44	35.02			5.46	100	Eduardo et al. (2010)
ng eq. butyl benzene/kg	18.02	6.29	11.22	34.23		20.16	1.53	8.55	100	Cano-Salazar et al. (2012)
µg/kg FW	4.53	6.04	34.29	13.81	32.79		5.38	3.16	100	Eduardo et al. (2010)
µg eq. Ethyl nonanoate/g		0.24	0.81	1.50	7.56		78.75	11.14	100	Montero-Prado et al. (2013)
1 unit = 10 ⁶ area		0.49	1.03	27.46	56.96		8.06	6.00	100	Tabilio et al. (2013)
µg std/kg FW		55.98	22.33	20.42			0.77	0.50	100	Rizzolo et al. (2013)
µg eq. Ethyl nonanoate/g	0.11	0.28	24.56	2.10	2.78		50.85	19.31	100	Montero-Prado et al. (2013)
ng eq. butyl benzene/kg	13.87	3.65	5.79	68.27		5.06	0.51	2.84	100	Cano-Salazar et al. (2012)
µg/kg		4.21	0.19	95.41			0.19		100	Ortiz et al. (2010)
ng/kg (by calibration curves)	13.51	9.34	16.41	17.23		11.75	1.49	30.28	100	Cano-Salazar et al. (2013c)
µg equivalent of 3-octanol/kg FW		9.83	74.13	5.78		0.56	4.81	4.89	100	Wang et al. (2010)
µg/g FW	5.50	3.62	32.83	16.05	34.79		1.83	5.39	100	Eduardo et al. (2010)

Table 13 Sensorial parameters for peach accessions (expressed in percentage)

Cultivar	Fruit type	% Fibrousness	% Juiciness	% Sweetness	% Acidity/ Sourness		% Aroma/ Smell
						% Bitterness	
August Red	Nectarine, yellow	—	—	—	—	—	—
Big Top	Nectarine, yellow	0.0	46.0	60.7	28.0	—	—
Carson	Peach, yellow	—	—	—	—	—	—
Diamond Princess	Peach, yellow	—	53.1	50.1	47.0	—	44.6
Dourado	Peach, yellow	—	67.2	—	—	—	75.6
Early Rich	Peach, yellow	8.7	62.0	33.3	69.3	—	—
Elegant Lady	Peach, yellow	—	50.4	54.1	51.9	—	47.2
Fire Pearl	Nectarine, white	—	50.9	44.8	53.6	—	44.4
Honey Blaze	Nectarine, yellow	—	—	—	—	—	—
Honey Royale	Nectarine, yellow	—	—	—	—	—	—
Nectagala	Nectarine, yellow	—	—	—	—	—	—
P. Bivona Agostina	Peach, white	43.3	43.3	63.8	21.2	7.1	61.3
P. Bivona Bianca	Peach, white	30.8	46.3	64.2	40.8	26.3	65.0
P. Bivona Murtiddara	Peach, white	24.2	53.8	58.8	43.8	5.0	70.4
P. Bivona Settembrina	Peach, white	37.5	38.3	70.4	31.6	18.3	65.4
Ryan Sun	Peach, yellow	12.0	45.7	52.7	30.7	—	—
September Sun	Peach, yellow	—	—	—	—	—	—
Summer Bright	Nectarine, yellow	—	52.4	49.7	63.2	—	52.3
Summer Sweet	Peach, white	—	53.0	56.6	55.7	—	56.6
Sweet Dream	Peach, yellow	40.7	64.0	64.7	17.3	—	—
Venus	Nectarine, yellow	14.0	48.0	29.3	64.7	—	—

% Firmness/ Hardness	% Crispness	% Ease of breakdown	% Flavor	% Freshness	% Color	% Mealiness	% Satisfied consumers	References
—	—	—	—	—	—	—	53.0	Cano-Salazar et al. (2013b)
49.2	62.7	54.7	54.7	—	—	—	71.0	Cano-Salazar et al. (2013b,c)
—	—	—	—	—	—	—	58.3	Infante et al. (2011)
55.1	—	—	42.3	—	—	58.0	—	Obenland et al. (2005)
78.3	—	—	67.8	71.7	70.6	8.3	—	De Santana et al. (2010, 2011)
27.7	43.3	53.3	59.3	—	—	—	—	Cano-Salazar et al. (2013c)
52.4	—	—	48.2	—	—	62.9	70.0	Infante et al. (2011) and Obenland et al. (2005)
50.6	—	—	46.7	—	—	62.3	—	Obenland et al. (2005)
—	—	—	—	—	—	—	72.0	Cano-Salazar et al. (2013b)
—	—	—	—	—	—	—	75.0	Cano-Salazar et al. (2013b)
—	—	—	—	—	—	—	70.0	Cano-Salazar et al. (2013b)
33.3	—	—	64.6	—	—	—	69.6	Montevecchi et al. (2013)
32.9	—	—	55.4	—	—	—	61.7	Montevecchi et al. (2013)
33.3	—	—	62.9	—	—	—	62.1	Montevecchi et al. (2013)
40.4	—	—	73.3	—	—	—	72.9	Montevecchi et al. (2013)
59.6	42.7	49.3	45.7	—	—	—	75.5	Lopez et al. (2011)
—	—	—	—	—	—	—	41.5	Infante et al. (2009)
56.8	—	—	51.2	—	—	55.9	—	Obenland et al. (2005)
48.3	—	—	55.9	—	—	58.8	—	Obenland et al. (2005)
66.2	12.0	70.7	61.3	—	—	—	—	Cano-Salazar et al. (2013c)
78.5	34.7	60.7	34.7	—	—	—	53.0	Cano-Salazar et al. (2013b,c)

Dream' stand out for very high aroma, flavor, color, freshness, firmness, and juiciness (De Santana et al., 2011; Obenland et al., 2005), and for ease of breakdown and juiciness notes, respectively (Cano-Salazar et al., 2013c).

The assessment of volatile VOCs and sensory attributes is crucial, in particular for the fresh market. Unluckily, there are many methods for instrumental VOCs analysis, thus making it very difficult to compare results from different laboratories. Moreover, the panel test is an expensive method for sensorial evaluation because many trained panelists are needed, in order to obtain comparable and objective data, so it is seldom used for scientific purposes. The electronic nose and electronic tongue are going to be used to mimic in an objective fashion the sensor attributes.

The above-mentioned problems make it difficult to correlate VOCs and sensorial profile of fruit from different laboratories. There is a strong need to develop a standardized and official method for VOCs, from volatile extraction to the identification and quantification by GC-MS.

In addition, it would be interesting to develop a better relation between the aromatic bouquet and the respective chemical compounds. To this end, it is important to consider the odor activity value (OAV, the ratio between the content of an aromatic compound and the amount of its odor threshold); values less than one are not detected, while higher than one could be identified. The interactions among compounds on aroma perception should be further investigated to aid the fruit industry in understanding how to maintain fruit quality along the distribution chain.

SUMMARY POINTS

- A large number of peach cultivars are spread all over the producing regions; they vary in shape (elongated/round or flat), flesh color (yellow or white), fuzzless skin (the nectarine group), flesh texture and pace of ripening, red pigments (anthocyanins, either on skin and/or flesh), etc. Given the Mendelian nature of most of the fruit traits, a countless combination of these traits has been obtained.
- Peaches are expected to be sweet, and they need to show more than 10 °Brix of SSC. Currently there are selections or cultivars with SSC close to 20 °Brix, even if generally the SCC is assessed between 9.0 and 14.0. The main sugars are sucrose, glucose, fructose, and sorbitol.
- The main organic acids are malic, citric, and quinic, well-correlated with TA. In low-acid cultivars, TA is three to five times lower and sucrose content higher than the acid cultivars. Low-acid cultivars are preferred by Asian markets compared to the acidic cultivars, traditionally preferred by European and North American markets.
- Due to the Mendelian or oligogenic nature of the SSC and TA contents, very diverse sensorial phenotypes can be obtained by traditional cross-breeding and arranging high and low levels of sugars and acids in all combinations.

- Fruit firmness is essential for efficient handling and marketing, and it depends mainly on flesh texture. Firmness decreases as maturity increases, and a value of 13 N or lower is considered acceptable for a consumer. Most traditional cultivars belong to melting and nonmelting flesh phenotypes. However, the slow softening texture is the more successful flesh texture, introduced more than 20 years ago from the US. Stony hard fruits are extremely rare in Western markets, being popular in Asian markets only.
- Peaches are important sources of antioxidants and bioactive compounds. These phytochemicals comprise secondary metabolites and vitamins. The phytochemicals reported in peach include carotenoids, phenolics, and vitamin C. Yellow-fleshed peaches can be a significant source of β -carotene, lutein, zeaxanthin, and β -cryptoxanthin. A large array of phenolic compounds have been identified in peach, linked to both positive quality attributes like attractive visual appearance and antioxidant capacity, besides negative ones like undesirable taste, such as astringency, bitterness, and flesh browning. The contribution of phenolic compounds and anthocyanins to the antioxidant activity of peaches is much more important than those of vitamin C or carotenoids.
- Aldehydes, esters, and terpenes are among the more represented VOCs in headspace. There are many methods for instrumental VOCs analysis, thus making it very difficult to compare results from different laboratories. About sensorial evaluation, the assessment should be carried out by trained panelists, but it is an expensive method to obtain comparable and objective data, so it is seldom used for scientific purposes. The above-mentioned problems make it difficult to correlate VOCs and sensorial profile from different laboratories; thus, there is a strong need to develop a standardized and official method.

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CHAPTER 24

Nutritional Composition of Pear Cultivars (*Pyrus* spp.)

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LIST OF ABBREVIATIONS

AA	Ascorbic acid
CSP	Covalent soluble pectin
DM	Dry mass
DW	Dry weight
FW	Fresh weight
GC–MS	Gas chromatography–mass spectrometer
IDF	Insoluble dietary fiber
ISP	Ionic soluble pectin
ND	Not detected
RS	Reducing sugar
SDF	Soluble dietary fiber
SPME	The solid-phase microextraction
SSC	Soluble solids content
SSC/TA	Soluble solids content/titratable acidity
TA	Total titrated acid
TAA	Total amino acid
TAs	Total anthocyanins
TFs	Total flavonoids
TOA	Total organic acid
TPs	Total phenolics
TS	Total sugar
TTs	Total triterpenes
WSP	Water soluble pectin

INTRODUCTION

Pears belong to the family Rosaceae, subfamily Maloideae, and genus *Pyrus*. There are over 5000 known pear varieties grown around the world, but no more than 30 primary species have been widely cultivated. Pear (*Pyrus* spp.) fruit is one of the most widely consumed fruits for its juicy and delicious taste in the world. It is usually eaten fresh or used for production of processed foods such as juice, fruit wine, puree, jellies, and jams. In Asia, especially in China, Japan, and Korea, pear has also been used as a traditional folk remedy for relieving alcoholism, eliminating constipation, relieving cough, and moistening the lung for more than 2000 years. Pear is the fifth important temperate fruits species after banana, orange, apple, and grape, with a production of 23.9 million metric tons and a harvest area of about 1.61 million hm^2 . China produced the most (15.9 million t) with more than 1.0 million hm^2 of planting area, followed by Italy, the United States, Argentina, Spain, Turkey, and South Africa, which keep ranking top seven in the world during 2002–2011. Some other Asian countries, including India, Japan, and Korea have kept pear production ranging from 0.20 to 0.45 million during 2002–2011. ([Food and Agriculture Organization \(FAO\) of the United Nations, 2011](#)).

The study of the nutritional compositions of pear fruit, such as sugars, organic acids, amino acids, vitamins, volatiles, and so on, has been demonstrated ([Chen and Yan, 2004](#)).

Phosphorus, iron, potassium, calcium, magnesium, and other mineral nutrients are also important compositions contained in pears. Different pears possess different nutritional compositions and present different aromas and tastes. European pears (*Pyrus communis*) provide higher calories and sugar contents, while Asian pears (*Pyrus pyrifolia*, *Pyrus bretschneideri* Rehd.) are usually rich in water with less content of sugars and starch. Asian pears are characterized as a dietary or healthy fruit, and European pears are often used as delicious food ingredients. Malic and citric acids are the two major components of organic acids contained in pear fruit (Sha et al., 2011). Glucose, fructose, and sucrose in fruit are converted from sorbitol, and the composition of these four sugars plays a key role in sweetness of pear fruits. Phenolic acids and their derivatives are widely distributed in pear fruits, branches, and flowers. Many phenolic phytonutrients, such as hydroxybenzoic acids (chlorogenic acid, gentisic acid, syringic acid, and vanillic acid), hydroxycinnamic acids (coumaric acid, ferulic acid, and 5-caffeoylquinic acid), hydroxyquinones (arbutin), flavanols (catechin and epicatechin), flavonols (quercetin, isorhamnetin, and kaempferol), and anthocyanins have been identified in western and oriental pear fruits, which may account for the antioxidant and anti-inflammatory effects and coloring of pear fruits and their products (Lee et al., 2011; Li et al., 2014b). In addition, carotenoids such as beta-carotene, lutein, and zeaxanthin are also the important phytonutrients contained in pears.

BOTANICAL ASPECTS

The genus *Pyrus* belongs to the rose family (Rosaceae). There are at least 26 primary species and 10 naturally occurring interspecific hybrid taxa (Table 1), widely distributed in Europe, Asia, and North Africa (Aldasoro et al., 1996). More than 5000 cultivars have been named around the world. Many species are considered to have originated in East Asia and have been cultivated in China, Japan, Korea, etc. for at least 3000 years. Other major centers of diversity include the Mediterranean, Georgia, and Central Asia. Pears are thought to have been cultivated in Europe as early as 1000 BC. All species of *Pyrus* are capable of interspecific hybridization despite the wide geographic distribution of the genus. Hence, it is often difficult to differentiate between similar taxa and taxa which have been given species names in the past and are now considered to be either naturally occurring hybrids, subspecies, or varieties. Dispersal from the centers of origin is believed to have occurred both east and west along mountain chains (Bell, 1996). Kikuchi (1996) classified *Pyrus* species into three groups: small fruited species with two carpels, large fruited species with five carpels, and their hybrids with three to four carpels. There are about five primary small fruited species (also known as Asian pear species), mainly distributed in China, Japan and Korea, which are used for ornamental purposes or as rootstocks.

Pyrus communis L. is native to Europe and is the main species grown in Europe, North America, South America, Africa, and Australia. *Pyrus communis* cultivars ‘Bartlett

Table 1 Primary species of *Pyrus* and their geographical distribution and characteristics

Geographic group	Species	Distribution
European and North African species	<i>P. communis</i> L.	Western and Southeast Europe, Turkey, Spain
	<i>P. spinosa</i> Forssk. (syn. <i>P. amygdaliformis</i> Vill.)	South Europe, Anatolia, Turkey
	<i>P. cordata</i> Desv.	Southeast Europe
	<i>P. × canescens</i> Sprach	
	<i>P. × nivalis</i> Jacq.	Western and South Central Europe, Ukraine, France
	<i>P. bourgaeana</i> Decne (<i>P. manorensis</i> Trab.)	Mexico, Algeria
	<i>P. × complexa</i> Rubtzov	
	<i>P. × salvifolia</i> DC	Europe (Crimea)
	<i>P. cordata</i> Desv.	Southwest Europe
	<i>P. cossonii</i> Redher	Algeria
	<i>P. gharbiana</i> Trab.	Morocco, Algeria
	<i>P. mamorensis</i> Trab.	Morocco
	<i>P. calleryana</i> Decne.	Central And Southern China, Japan, North Korea
	<i>P. koehnei</i> C. K. Schneid.	Southern China, Taiwan
Asian pear species	<i>P. fauriei</i> Schneid.	Korea Peninsula
	<i>P. dimorphophylla</i> Makino.	Japan
	<i>P. betulaeifolia</i> Bunge.	Central, North And Southern Northeast China
		India, Nepal, Pakistan, Southern China
		China, Korea Peninsula, Japan, India, Pakistan
Medium-large fruited Asian species	<i>P. pashia</i> D. Don.	Japan
	<i>P. pyrifolia</i> Nakai.	Northern China, North Korea, Siberia
	<i>P. hondoensis</i> Nakai et Kikuchi	Mediterranean Region, Southern Europe
	<i>P. ussuriensis</i> Maxim.	Turkey, Southeast Europe, Ukraine
West Asian species	<i>P. amygdaliformis</i> Vill	Southern Iran
	<i>P. elaeagrifolia</i> Pall.	Iran, Russia
	<i>P. glabra</i> Boiss.	Northeast Africa, Israel, Iran
	<i>P. salicifolia</i> Pall.	Afghanistan, Russia
	<i>P. syriaca</i> Boiss.	
	<i>P. regelii</i> Rehd.	

Source: Prepared by the authors based on studies of Bell (1996) and Aldasoro et al. (1996). The authors thank all of them for the data.

(Williams' Bon Chrétien)' and 'Anjou' are the two most recognizable pear varieties in North America and Europe. 'Conference' is the most popular cultivar grown in Italy, the Netherlands, and other European countries, including the United Kingdom. *Pyrus bretschneideri* Rehder and *Pyrus ussuriensis* Maxim. ex Rupr. are the two main commercial

species in northern and central China. The most common cultivars of *P. bretschneideri* are ‘Zaosu’, ‘Dangshansu’, ‘New Zealand Red’, ‘Xuehua’, and ‘Jingbai’. ‘Nanguo’, ‘Qiu Zi Li’, ‘Jianba’, and ‘Jianbawang’ are the most common cultivars of *P. ussuriensis* widely cultivated in China. *Pyrus pyrifolia* (Burm. F) Nakai (including ‘Lvbaoshi’, ‘Jinhua’, ‘Dayexue’, ‘New Star’, ‘Atago’, ‘Gold Nijisseiki’, and other cultivars) is the main species in Japan, Korea, and southern and central China. In China, flowering and harvesting range from March to April and August to September, respectively. Most *P. communis* cultivars are harvested in late August to early September, while the entire harvest season ranges from July to November. Advanced storage technologies enable the availability of pears in markets all year round. Early cultivars are more profitable in China, so there is a trend for breeding earlier maturing cultivars in Asian countries.

COMPOSITION OF TRADITIONAL/ANCIENT AND MODERN CULTIVARS

The major old pear cultivars grown in North America are ‘Anjou’ and ‘Bartlett’, while other cultivars, including ‘Bosc’ and ‘Comice’ have captured small growing markets. The five dominating old European cultivars were ‘Conference’, ‘Blanquilla’, ‘Limónera’, ‘Williams’, and ‘Ercolini’. Most of the above cultivars were developed before the turn of the twentieth century. In Sardinia, ‘Butirru de Austu’ pears (*P. communis* L.) has been grown from ancient times, while ‘Coscia’ and ‘Precoce di Fiorano’ (‘Beurre Guiffard’ and ‘Coscia’) (*P. communis* L.) were introduced during the last century. Most cultivated pears native to Asia are mainly composed of five groups: ‘Ussurian’ pear (derived from *P. ussuriensis*), ‘Xinjiang’ pear (*Pyrus sinkiangensis* Yu, hybridized origin involved in Chinese white pears or Chinese sand pears and Occidental pears), Chinese white pear, Chinese sand pear (originated from wild *P. pyrifolia* Nakai), and Japanese pear. Since the first study in 1927, more than 300 volatile compounds, including esters, alcohols, hydrocarbons, aldehydes, and ketones, had been identified from pears. The volatile compounds are produced through metabolic pathways, ripening, harvest, postharvest, and storage and are influenced by species, variety, treatments, and so on (Qin et al., 2012; Li et al., 2014a). Aldehydes are the dominant volatile compounds, in *P. bretschneideri* and *P. pyrifolia*, followed by alcohols and esters, while, in the other three pear species, esters are the dominant volatile compounds. Up to now, *P. communis* is the only species having been investigated extensively (Qin et al., 2012). Main contributors to the aroma and contents of aroma in modern and ancient cultivars worldwide are summarized in Table 2.

‘Packham’s Triumph’ Pears

About 70 aroma compounds were identified in ‘Packham’s Triumph’ pears (Takeoka et al., 1992). Esters comprise 60–98% of total volatiles among the varieties. Takeoka et al. (1992) reported that ethyl 2-methylbutanoate, ethyl hexanoate, ethyl butanoate, ethyl 2-methylpropanoate, hexyl acetate, ethyl heptanoate, hexanal, ethyl pentanoate, and ethyl

Table 2 Main contributor to the aroma in modern and ancient cultivar cultivars and contents of aroma

Species and references	Amount of aroma compounds determined	Main contributor to the aroma	Content
Modern cultivars			
'Packham's Triumph' pears Takeoka et al. (1992)	70 aroma compounds	Hexyl acetate, butyl acetate and pentyl acetate	Esters comprise 60–98% of total volatiles
<i>Pyrus ussuriensis</i> Qin et al. (2012)	108 aroma compounds	Esters: ethyl acetate, ethyl butanoate, ethyl 2-methyl-butanoate, ethyl octanoate and ethyl hexanoate; Aldehydes: Hexanal and 2-hexenal were the predominant	Esters range from 0.34% to 83.47% Aldehydes range from 7.36–77.70% Alcohols ranged from 2.15% to 33.10% Hydrocarbons ~10%
'Pingxiangli' pear fruit (<i>Pyrus ussuriensis</i> Maxim.) Li et al. (2014a)	23 volatile compounds	Esters, hexanal, E-2-hexenal, ethyl butanoate, ethyl 2-methylbutanoate, ethyl hexanoate, and hexyl acetate	hexanal (307.74 µg/kg) Ethylene (122.16 nL/g/h) Ethylene (44.52 nL/g/h) Ethyl hexanoate (247.17 µg/kg) Ethyl butanoate (119.24 µg/kg)
Ancient cultivars			
'Yali' pear (<i>Pyrus bertschneideri</i> Reld) Chen et al. (2006b)	51 aroma compounds	Hexanoic acid, ethyl ester, butanoic acid, ethyl ester, α-farnesene, hexanal, acetic acid, ethyl ester, and acetic acid, hexyl ester	Ethyl ester (26.14%) Ethyl ester (16.62%) A-farnesene (15.57%) Hexanal (6.16%) Ethyl ester (3.68%) Hexyl ester (1.1%)
'Bartlett' pear Komes and Gani (2010); Jennings and Sevenants (1964)	68 aroma compounds	Ethyl (E, Z)-2,4-decadienoate and ethyl (E, E)-2,4-decadienoate	Ethyl (E, Z)-2,4- decadienoate (4.74–60 mg/L) Ethyl (E, E)-2,4- decadienoate (2.5–40.6 mg/L)
'Doyenne du Comice' López et al. (2001)	10 volatile components	Ethyl acetate, hexanal, and hexanol	Hexyl acetate and butyl acetate, more than 90% of the total amount of identified compounds

‘La France’ pear (<i>Pyrus communis</i> L.) Shiota (1990)	36 aroma compounds	Ethyl acetate, propyl acetate, butyl acetate and hexyl acetate	Butyl acetate and hexyl together accounted for 70.6%
‘Le Conte’ pear Omaima et al. (2010)	27 volatile compounds	Ethyl butanoate, ethyl hexanoate, hexyl acetate and ethyl-2-methyl butanoate	Esters of aliphatic acids (88.27%) Alcohols (8.07%) ethyl (E, Z)-2, 4-decadienoate (12.99%)
Wild varieties (<i>Pyrus amygdaliformis</i> Vill., namely ‘Pirastru’) Versini et al. (2012)	80 volatile compounds	Isoeugenol, ethyl benzoate and ethyl phenylacetate	Isoeugenol (0.186 g/hL a.a.), ethyl benzoate (0.388 g/hL a.a.), ethyl phenylacetate (0.12 g/hL a.a.)
Cultivated varieties (<i>Pyrus communis</i> L. cvs. ‘Coscia’, ‘Precoce di Fiorano’, and ‘Butirru de Austu’) Versini et al. (2012)	80 volatile compounds	Methyl and ethyl unsaturated decanoate isomers	Farnesene isomers (6.48 and 9.26 g/hL a.a.)
Asian Pear (<i>Pyrus serotina</i>) Takeoka et al. (1992)	72 aroma components	Ethyl 2-methylbutanoate, ethyl hexanoate, ethyl butanoate, ethyl 2-methylpropanoate, hexyl acetate, ethyl heptanoate, hexanal, ethyl pentanoate, and ethyl propanoate	Over 66% of the volatiles ethyl hexanoate (29.67%), hexyl acetate (14.34%), ethyl butanoate (4.65%)
‘Kuerle’ fragrant pear (<i>Pyrus</i> sp. <i>nr. communis</i>) Chen et al. (2006a)	43 aroma components	Ethanol, hexanal, ethyl acetate, ethyl propionate, ethyl butanoate, ethyl-2-methylbutanoate, ethyl hexanoate, hexyl acetate, ethyl octanoate, octyl acetate, and ethyl (E, Z)-2,4-decadienoate	Hexanal (17.80%), ethyl hexanoate (12.96%), ethyl butanoate (11.29%), α -farnesene (12.31%), ethyl acetate (9.69%), and hexyl acetate (2.94%)

Source: Summarized by the authors based on the references list in the table. The author thanks all of them for the data.

propanoate are important contributors to pear aroma. Hexyl acetate with fruity notes is the main contributor to the aroma of this variety of pear, followed by butyl acetate and pentyl acetate. Hexyl acetate was observed to be present as a major ester of pear, but a strong fruity note of pears is a result of the presence of butyl acetate and ethyl butanoate. The aromatic ester and 2-phenylethyl acetate were noticed to contribute a sweet, rose-honey-like aroma of pear. It was reported to be a flavor constituent of various fruits such as apple, plum, mango, strawberry, and apricot (Komes and Gani, 2010). Alcohols are profusely produced by the fruit, while they are poor contributors to their aroma. Straight-chain alcohols with two to eight carbons are present as the second largest group in the volatile profiles. Several aldehydes and ketones, as well as other aroma compounds, are also found in some other varieties but are present in very small amounts.

'Kuerle' Fragrant Pear (*Pyrus sp. nr. communis*)

'Xinjiang Kuerle' fragrant pears, belonging to super white pears, have been planted for more than 1300 years. They have been valued by consumers for their special fragrance, sweetness, juiciness, unique shape, jade green color, and scent. In the study of Chen et al. (2006a), gas chromatography-olfactometry (sniffing) was used to determine the compounds contributed to the aroma of 'Kuerle' fragrant pear. Forty-three compounds were obtained from solid-phase microextraction (SPME), such as ethanol, hexanal, ethyl acetate, ethyl propionate, ethyl butanoate, ethyl-2-methylbutanoate, ethyl hexanoate, hexyl acetate, ethyl octanoate, octyl acetate, and ethyl (E, Z)-2,4-decadienoate. The most important volatile compounds were hexanal (17.80%), ethyl hexanoate (12.96%), ethyl butanoate (11.29%), α -farnesene (12.31%), ethyl acetate (9.69%), and hexyl acetate (2.94%). α -Farnesene was a major compound in 'Kuerle' fragrant pear, which could be responsible for the fresh green odor (Shiota, 1990). Isopropyl palmitate was also found in 'Kuerle' fragrant pear, which probably originated from 'Kuerle' fragrant pear waxiness in the pear skin or from the SPME extraction course.

Pyrus ussuriensis

Thirty-three *P. ussuriensis* cultivars were evaluated by SPME with gas chromatography-mass spectrometer (GC-MS), and 108 volatile compounds were identified. Asters and aldehydes were the predominant volatile compounds, followed by alcohols and hydrocarbons. The composition and concentration of these volatiles differ greatly among different cultivars, and are affected by storage conditions and harvest maturity (Qin et al., 2012). The concentrations of volatile compounds among the cultivars ranged from 912.52 to 5264.04 $\mu\text{g/kg}$ fresh weight (FW). The contents of volatile compounds in the 'Shatangli', 'Reli', 'Hongbalixiang', 'Fuwxuixiang', and 'Long-xiang' cultivars were three- to fourfold greater than those in the 'Huangshan', 'Youyanchi', and 'Baihuagai' cultivars, and the earlier maturing cultivars, including 'Liuyuexian', 'Xiaobaixiao', 'Xiaoxiang-shui', 'Xiaohebai', and 'Zaoxiang' cultivars.

Esters with fruity notes were the major aromatic components found in the ripe fruit. Esters were important volatile compounds in all cultivars of the *P. ussuriensis*. The contents of esters in the 33 studied cultivars ranged from 0.34% in cultivar ‘Liuyuexian’ to 83.47% in the cultivar ‘Reli’, and the content of esters of 17 cultivars is over 50%. ‘Qiuxiang’, ‘Jinxiang’, ‘Daxiang-shui’, ‘Hongbalixiang’, ‘Baibalixiang’, and ‘Nanguoli’ cultivars are widely grown in northeast of China, and all have a characteristic ester flavor. Ethyl (E, Z)-2,4-decadienoate has been found in *P. pyrifolia* (Takeoka et al., 1992). In the study of Qin et al. (2012), ethyl (E, Z)-2, 4-decadienoate and methyl (E, Z)-2,4-decadienoate were identified in most of the *P. ussuriensis* cultivars and were considered to be important volatile components. The aromatic sulfur-containing esters ethyl 3-(methylthio)propanoate and ethyl 3-(methylthio)-(Z)-2-propenoate found in *P. pyrifolia* (Takeoka et al., 1992) were also found in *P. ussuriensis*, and an abundance of methyl 3-(methylthio)propanoate and methyl 3-(methylthio)-(Z)-2-propenoate were identified in *P. ussuriensis* cultivars. Besides these flavor constituents, many esters identified in *P. ussuriensis* have also been identified in other pears.

High concentrations of esters, aldehydes, alcohols, or hydrocarbons exert important influences on fruit aroma. Aldehydes are often derivative to alcohols and esters. The aldehydes are important volatile compounds in *P. ussuriensis*, with a relative content ranging from 7.36% in cultivar ‘Reli’ to 77.70% in cultivar ‘Liuyuexian’, while common values are around 30%. Hexanal and 2-hexenal are the predominant volatile aldehydes found in *P. ussuriensis*. Several alcohols were identified in the 33 *P. ussuriensis* cultivars. 1-Hexanol was identified in all cultivars, and (E)-2-hexen-1-ol was detected in most cultivars. The relative cumulative contents of alcohols ranged from 2.15% in the ‘Baihuagai’ cultivar to 33.10% in ‘Youyanchi’ cultivar. In *P. ussuriensis*, alcohols combined with aldehydes are important fundamental volatile compounds that impart a fresh, grassy, and fatty-green odor (Qin et al., 2012).

Ketones were detected in only few cultivars, and the relative cumulative contents of this class were less than 0.28% of total volatiles, so they might only contribute little to the flavor of *P. ussuriensis*. Hydrocarbons were found in all cultivars, with a relative cumulative contents of around 10%, except in cultivars ‘Fuanjianba’ (37.28%), ‘Longxiang’ (41.67%), ‘Guanhongxiao’ (34.25%), ‘Shanli24’ (39.90%), and ‘Wuxiangli’ (59.30%) (Qin et al., 2012).

‘Yali’ Pear (*Pyrus bertschneideri* Reld)

‘Yali’ pear (*P. bertschneideri* Reld) belongs to super white pear and has been grown in China for more than 2000 years. With few stone cells, it is popular with consumers for its unique fragrance, subtle aroma, sweetness, and crispness. (Chen et al., 2006b). Fifty-one compounds were obtained from SPME. The most important volatile compounds were hexanoic acid, ethyl ester (26.14%), butanoic acid, ethyl ester (16.62%), α -farnesene (15.57%), hexanal (6.16%), acetic acid, ethyl ester (3.68%), acetic acid, and hexyl ester (1.1%).

Isopropyl palmitate was also found in ‘Yali’ pear and probably originated from ‘Yali’ pear waxiness in the pear skin or from the SPME extraction procedure.

‘La France’ Pear (*Pyrus communis* L.)

Flavor components of ‘La France’ pear primarily consist of three categories: esters, aldehydes, and alcohols (Shiota, 1990; Tobitsuka, 2003). Aliphatic acetate esters especially butyl acetate and hexyl acetate are the main components closely related to aroma. The principal volatile components of ‘La France’ pear were various acetates of low molecular weight alcohols: ethyl acetate, propyl acetate, butyl acetate, and hexyl acetate, which together accounted for 70.6%, and hexyl acetate and butyl acetate were the highest in contribution, followed by acetaldehyde, hexyl aldehyde, and other acetic acid esters (Tobitsuka, 2003). Other components were mainly alcohols yielding the alkyl moiety of the acetates described above. Ethanol and propanol were not detected. Besides the aliphatic acetates and alcohols, monoterpenes such as limonene and α -terpineol were isolated as minor volatiles, which are abundant in citrus aroma concentrates. α -Farnesene was found as a relatively major component with a small amount of an isomer (Shiota, 1990).

Asian Pear (*Pyrus serotina*)

Asian pears (*P. serotina*) are a species completely distinct from the more common European-type pears (*P. communis* L.) such as ‘Bartlett’ and ‘La France’. The volatiles of Asian pear (‘Seuri’ cultivar) were studied by Takeoka et al. (1992) using the high-resolution gas chromatography (GC) and combined GC–MS.

A total of 72 volatile components have been identified. Esters were the main constituents (over 66%) of the volatiles, which included ethyl hexanoate (29.67%), hexyl acetate (14.34%), ethyl butanoate (4.65%), ethyl (E, Z)-2,4-decadienoate (3.40%), butylacetate (3.17%), and ethyl (Z)-4-decenoate (1.80%), methyl hexanoate (1.51%), and ethyl decanoate (1.49%). Besides, it is especially rich in α -pinene, β -pinene, myrcene, and limonene.

‘Bartlett’ Pear (*Pyrus communis* L.)

‘Bartlett’ pear is the most aromatic and favorite pear. The earliest study of its volatile compounds date back to 1927 by Harley and Fisher. Until now, 68 volatile compounds were identified in ‘Bartlett’ pears (Komes and Gani, 2010). The volatile compounds identified include ethanol, n-propanol, n-butanol, n-pentanol, n-hexanol, n-octanol; butyl, ethyl, n-propyl, n-butyl, n-pentyl; n-hexyl, n-heptyl, and n-octyl acetate; and the methyl and ethyl esters of n-octanoic, 3-hydroxyoctanoic, trans 2-octenoic, n-decanoic, cis 4-decenoic, trans 2-decenoic, 2-cis:4-decadienoic, and 2-trans:4-decadienoic acids. Among the esters in ‘Bartlett’ pears, hexyl acetate and ethyl (E, Z)-2, 4-decadienoate were character-impacting flavor compositions, but other esters, such as hexyl acetate,

2-methylpropyl acetate, butyl acetate, ethyl butanoate, butyl butanoate, pentyl acetate, and ethyl hexanoate also contributed to pear aroma (Jennings and Sevenants, 1964; Heinz and Jennings, 1966).

‘Doyenne du Comice’ Pear

Because of its unique taste, ‘Doyenne du Comice’ pear is often considered superior to the most available pear cultivars, and it is the third most important winter pear cultivar grown in the Pacific Northwest of the United States. Studies on volatile compounds associated with ‘Doyenne du Comice’ pear aroma are limited compared with other pears. Its volatile profiles were also characterized into five groups: esters, alcohols, hydrocarbons, aldehydes, and ketones. Low-boiling esters were the main compounds. There was an increase in the total aromatic volatile components of fruits under all storage conditions compared with the levels on the freshly harvested fruits. Hexyl acetate and butyl acetate were the major esters, and they amounted to more than 92% after storage. Among the alcohols, 1-butanol and 1-hexanol stand out quantitatively, followed by smaller quantities of ethanol, 1-propanol, 2-methyl-1-propanol, and 2-methyl-1-butanol (López et al., 2001).

Chinese Pear Cultivars

Ten dominant volatiles, including ethyl acetate, n-hexanal, 1-hexanol, ethyl propanoate, ethyl butyrate, butyl acetate, ethyl 2-methylbutanoate, ethyl hexanoate, hexyl acetate, and ethyl octanoates were detected by SPME-GC in five Chinese pear cultivars (Table 3). Ethyl acetate, hexanal, and hexanol were the most abundant compounds, which accounted for more than 90% of the total amount of investigated compounds. The levels of these volatiles differed along with species, ripening stages, and pear tissues. Among the five tested pear cultivars, ‘Bartlett’ pear and ‘Nanguo’ pear had the highest contents of esters; ‘Bartlett’ pear had much higher amounts of hexanol, while ‘Whangkeumbae’ pear and ‘Huangguan’ pear contained more hexanal than other three cultivars (Kou et al., 2012).

Wild and Cultivated Varieties in Sardinia

The aroma fraction of Italian distillates of one wild (*Pyrus amygdaliformis*, Vill., namely ‘Pirastru’) and three cultivated (*P. communis* L. cvs. ‘Coscia’, ‘Precoce di Fiorano’, and ‘Butirru de Austu’) pear varieties from the northern Sardinia Island was detected. Differences were found in the aromatic profile of all the distillates, depending on their varietal origin. For wild ‘Pirastru’ pear distillates, the richest aromatic constituents were in isoeugenol, ethyl benzoate, and ethyl phenylacetate, but the poorest were 1-hexanol, citronellol, Σ -farnesene isomers, and n-hexyl acetate. The distillates of this variety were also the poorest in methyl and ethyl unsaturated decanoate isomers, for example, 2-methyl-1-propanol, 2-methyl-1-butanol, and 3-methyl-1-butanol. In contrast, these compounds as characteristic aroma components of ‘Williams’ pear distillates were

Table 3 Concentrations of 10 volatile components detected by SPME-GC in eight pear cultivars

Compound	Ya	Nanguo	Whang keumbae	Huang- guan	Bartlett	Kuerle fragrant pear (% area)	Zaobaimi	Hong- xiangsu
							µg/kg	
Concentration in mg/L								
Ethyl acetate	2.43	8.35	1.78	3.74	7.90	9.69	—	—
Hexanal	5.10	2.33	6.28	6.86	2.77	17.80	35.8	44.0
1-Hexanol	1.38	0.65	0.44	0.66	2.48	0.80	1.5	3.6
Concentration in µg/L								
Ethyl propionate	14.53	85.38	18.55	9.44	49.38	0.17	ND	ND
Ethyl butanoate	3.36	18.85	6.32	9.21	39.66	11.29	ND	ND
Butyl acetate	14.24	35.55	19.49	1.40	92.58	—	0.3	ND
Ethyl 2-methyl- butyrate	4.27	9.58	30.80	37.90	38.75	0.07	ND	ND
Ethyl hexanoate	3.54	66.53	1.37	2.46	25.03	12.96	0.6	ND
Hexyl acetate	20.73	35.93	3.56	7.11	25.19	2.94	ND	0.3
Ethyl octanoate	0.80	0.95	0.76	0.83	4.89	0.39	ND	ND

Source: Summarized by the authors from [Chen et al. \(2006b\)](#) and [Kou et al. \(2012\)](#).

plenitudinous in ‘Coscia’ spirits, which together with ‘Precoce di Fiorano’, were also rich in farnesene isomers (Versini et al., 2012).

‘Pingxiangli’ Pear (*Pyrus ussuriensis* Maxim.)

Twenty-three volatile constituents produced during ripening stage, containing 16 esters, 2 alcohols, 3 aldehydes, 2 terpenes, and 1 acid, were identified in ‘Pingxiangli’ pear. Six volatiles contributed to the aroma of the ‘Pingxiangli’ pear fruit at different stages of ripening, including hexanal, E-2-hexenal, ethyl butanoate, ethyl 2-methylbutanoate, ethyl hexanoate, and hexyl acetate. Esters were the main class of compounds produced in ‘Pingxiangli’ pear during ripening, especially after the peak production of ethylene. Known to contribute sweet and fruity notes to the aroma of different types of fruit, the production of esters significantly increased during ‘Pingxiangli’ pear ripening, while that of aldehydes decreased. Similar changes have been found previously for other fruit, such as ‘Hayward’ kiwifruit. Among the four esters detected, ethyl esters were more abundant than hexyl esters. These esters were possibly synthesized from the corresponding acids and alcohols by the esterification, and the types of esters produced depend on the specificity of the alcohol acyltransferases and the availability of substrates (Li et al., 2014a).

‘Le Conte’ Pear

‘Le Conte’ pear is one of the most deciduous fruits widespread in Egypt. A total of 27 volatile components were identified using GC–MS, including 15 esters, 8 alcohols, 3 aldehydes, and 1 terpene. Volatile components varied considerably between fresh and stored samples, both quantitatively and qualitatively. Being the predominant constituents in headspace volatiles of all investigated pear samples, esters of aliphatic acids comprised 88.27% in the control sample. Ethyl butanoate, ethyl acetate, hexyl acetate, methyl propanoate, ethyl (E, Z)-2,4-decadienoate, ethyl-2-methyl butanoate, and ethyl hexanoate were the major esters in most samples. Among the above mentioned esters, ethyl hexanoate also became the major ester in all stored samples, while ethyl-2-methyl butanoate increased remarkably in most stored samples. Methyl and ethyl (E, Z)-2,4-decadienoate were rich in all samples, and ethyl (E, Z)-2,4-decadienoate reached 12.99% in an ascorbic acid (AA)-treated sample. Alcohols were the second major compounds in headspace volatiles of pear fruits, whose total yield amounted to 8.07%. Three aldehydes identified in all samples were (E)-2-hexenal, (E)-2-heptenal, and (E, E)-2, 4-decadienal. The major aldehyde was (E)-2-hexenal in the treated sample. α -Farnesene was the only sesquiterpene found in the tested pear samples (Omama et al., 2010).

Sensory

The sensory quality of fruits is critical for consumer acceptance and fruit consumption. For the pear, its sensory quality is determined by skin color, size, shape, scarring, bruising, firmness, aroma, flesh color, flesh moisture, flesh texture, grainy, juiciness, sweetness,

sourness, pear flavor, off-flavor, aftertaste (Table 4), and so on. Among them fruit color, texture, aroma, and taste are recognized as the most important sensory properties by consumers (Makkumrai et al., 2014).

Texture is partially related to changes in cell wall composition during ripening, such as water soluble pectin (WSP) and ethylene. WSP levels displayed a very strong positive correlation with some texture (butteriness, juiciness) and some taste (sweetness) attributes, whereas WSP levels were negatively correlated with crunchiness and firmness (Makkumrai et al., 2014). Increasing production of ethylene was associated with pectin degradation and an increase in WSP, which lead to a loss of firmness in ‘Passe-Crassane’ pears. Irradiation delays ripening of ‘Bartlett’ pears and slows the normal conversion of insoluble pectin to soluble form (Abolhassani et al., 2013).

Pear flavor is determined by its aromatic volatile compounds (we have summarized above). Taste is also a key factor of sensory attributes. The balance between sweet and sour taste affects consumer acceptance of pear fruit, which is mostly associated with the sugars (fructose, sorbitol, glucose, and sucrose) and acids (malic acid). Many studies show that the acceptable range of sweet/sour balance is 2–4, measured by soluble solids content/titratable acidity (SSC/TA) ratio in pear fruit. The kafirin coating not only extended the eat-ripe quality of the pears by 1–2 weeks but also affected the flavor by delaying the development of a sweet, pear-like aroma from day 7 to 10 (Makkumrai et al., 2014; Buchner et al., 2011).

NUTRITIONAL INGREDIENTS OF *PYRUS* SPP.

Fruits are not only a colorful and flavorful composition in our daily diet, but also a source of energy, vitamins, minerals, dietary fiber, and other nutrients, which play important roles in maintaining fruit quality and determining nutritive value (Chen et al., 2007). There are several studies that focus on certain chemical and nutritional composition of pear fruit, which has quantified parameters such as total sugars, TA, SSC, organic and fatty acids, amino acids, polyphenols, flavonoids, anthocyanins, fibers, and minerals (Tables 5 and 6). All these parameters were established to be the major bioactive and nutritional ingredients in different pear cultivars (Li et al., 2012b).

Ascorbic Acid (AA)

Ascorbic acid (AA) is a soluble antioxidant against reactive oxygen species in concert with other antioxidants such as glutathione and α -tocopherol in the ascorbate–glutathione cycle system. AA is not only very important during the plants’ growing and storage or shelf-life, but also for human health. In pears, there is a relationship between AA content and the susceptibility to brown during experimental storage under various brown core-inducing conditions. ‘Conference’ pears tend to develop tissue disorders, such as brown cores, when AA levels drop down below the thresholds, while the thresholds of ‘Conference’ pears vary

Table 4 Descriptors, scales, and definitions used to describe sensory properties of pears

Attribute (general category)	Definition
Green background (external appearance)	Refers to the depth of green color in the background of the skin of the pear
Yellow background (external appearance)	Refers to the depth of yellow color in the background of the skin of the pear
Presence of blemishes (external appearance)	Extent of black or brown blemishes on the outer surface of the pear
Wrinkled skin (external appearance)	Extent of wrinkled skin on the surface of the pear
Extent of ripeness (external appearance)	Extent of overall visual ripeness of the pear
White powdery appearance (external appearance)	Presence of white powdery deposits on the surface of the pear
Juicy appearance (internal appearance)	Extent of juicy appearance of the inner cut surface of the pear
Fruity (aroma)	Sweet aromatic, characteristic of ripe fruit
Apple (aroma)	Aroma associated with fresh apple
Pear (aroma)	Aroma note associated with fresh pears
Fermented/alcoholic (aroma)	Aroma associated with fermented fruits (sweet/alcohol)
Green stem (aroma)	Aroma associated with green wood stems; twiggy
Firmness (texture)	Amount of noise generated when chewing with the back teeth
Crunchiness (texture)	Amount of noise generated when chewing with the back teeth
Juiciness (texture)	Amount of wetness or juiciness released from the sample during the first three chews
Butteriness (texture)	Degree of smooth texture of the flesh with an absence of detectable particles, like butter
Fibrousness (texture)	Presence of fibers that are continuous filaments or are in discrete elongated pieces in the sample
Softness (texture)	Extent of softness of the pear while chewing
Sweetness (taste)	Basic taste on the tongue stimulated by sugar and high-potency sweeteners
Tartness (taste)	Sour taste stimulated by acids
Sour (taste)	A basic taste characterized by the solution of an organic acid, i.e., malic acid
Astringent (taste)	Associated with a dry feeling in the mouth as produced by grape skin
Fermented or alcoholic (taste)	Aroma associated with fermented pear/pear juice
Pear-like flavor (taste)	Pear-like flavor intensity associated with fresh ripe pear

Source: Prepared by the authors from [Makkumrai et al. \(2014\)](#) and [Buchner et al. \(2011\)](#).

Table 5 Ascorbic acid (AA, mg/100 g FW), carotenoids (mg/100 g FW ‘raw, edible’), soluble solids content (SSC, %), total titrated acid (TA, g malic acid/100 g), total sugar (TS, mg/100 g FW), total amino acid (TAA, mg/100 g of FW), total organic acid (TOA, mg/kg of fresh pears), minerals (mg/100 g of fresh pears), and dietary fiber (% of DW) in fruits of *Pyrus* species

Species	AA	Carotenoids	TSS	TA	TS	TAA	TOA	Mineral	Dietary fiber	Source	References
‘Yali’ pear (<i>Pyrus bretschneideri</i> Rehd cv.Yali)	3.40 ^a	—	8.09; 10.25	0.180	77	94	1619	Na 2.5, K897, Ca 20.5, Mg 35.5, Zn 0.15, Cu 0.31, Fe 0.48, Mn 0.11& B 2.43	WSP(14), ISP(0.9), CSP(41)	Beijing China; Zhao County, Hebei, China	Chen et al. (2007)
‘Kuerle’ fragrant pear (<i>Pyrus bretschneideri</i> Rehd cv. Kuerle Fragrant)	4.10 ^a	—	12.5	0.100	120	156.8	2171	Na 19.5, K 1085.0, Ca 22.5, Mg 94.5, Zn 0.11, Cu 0.41, Fe 0.79, Mn 0.18 & B 3.75	—	Beijing, China	Chen et al. (2007)
‘Dangshan’ pear (<i>Pyrus bretschneideri</i> Rehd cv. Dangshan)	2.21 ^a	—	8.60	0.140	86	278	3607	Na 12.0, K 1688, Ca 11.5, Mg 117.0, Zn 0.21, Cu 0.40, Fe 0.61, Mn 0.30 & B 7.17	—	Beijing, China	Chen et al. (2007)
‘Nanguo’ pear (<i>Pyrus ussuriensis</i> Maxim. cv. Nanguo)	4.55 ^a	—	8.90	0.160	97	154.6	2564	Na 12.5, K 1068, Ca 31.00, Mg 68, Zn 0.46, Cu 0.39, Fe 0.51, Mn 0.32 & -B 3.53	—	Beijing, China	Chen et al. (2007)

‘Jingbai’ pear (<i>Pyrus ussuriensis</i> Maxim. cv. Jingbai)	2.39 ^a	—	10.8	0.460	82	105.4	1881	Na 3.50, K 1050, Ca 44.50, Mg 92, Zn 0.28, Cu 0.28, Fe 0.98, Mn 0.47 & B 1.76	—	Beijing, China	Chen et al. (2007)
‘Ninomiyahaku’ pear (hybrid, <i>Pyrus bretschneideri</i> Rehd cv. Yali × Zhenyu)	3.85 ^a	—	9.00	0.150	65	155.5	1841	Na 4.45, K 1336, Ca 46.50, Mg 83, Zn 0.81, Cu 0.92, Fe 0.92, Mn 0.40 & B 1.02	—	Beijing, China	Chen et al. (2007)
‘Niitaka’ pear (<i>Pyrus pyrifolia</i> Nakai cv. Xingao)	1.30 ^a	—	9.56	0.250	71	181.7	1652	Na 4.50, K 990, Ca 32.0, Mg 76, Zn 0.35, Cu 0.46, Fe 0.73, Mn 0.23 & B 2.88	—	Beijing, China	Chen et al. (2007)
‘Wujiuxiang’ pear (hybrid, <i>Pyrus bretschneideri</i> Rehd cv. Yali × <i>Pyrus communis</i> Linn cv. Bali)	3.43 ^a	—	8.28	0.150	74	171.0	1721	Na 8.50, K 1098, Ca 16.00, Mg 67, Zn 0.24, Cu 0.30, Fe 0.56, Mn 0.17 & B 2.97	—	Beijing, China	Chen et al. (2007)
‘Anjou’ pear (<i>Pyrus communis</i> L.)	—	19–27(peel, μM/m ² , approximately 107 days after bloom)	—	—	—	—	—	—	—	Oregon State University	Li and Cheng (2009)

Continued

Table 5 Ascorbic acid (AA, mg/100 g FW), carotenoids (mg/100 g FW 'raw, edible'), soluble solids content (SSC, %), total titrated acid (TA, g malic acid/100 g), total sugar (TS, mg/100 g FW), total amino acid (TAA, mg/100 g of FW), total organic acid (TOA, mg/kg of fresh pears), minerals (mg/100 g of fresh pears), and dietary fiber (% of DW) in fruits of *Pyrus* species—cont'd

Species	AA	Carotenoids	TSS	TA	TS	TAA	TOA	Mineral	Dietary fiber	Source	References
'Conference' pear (<i>Pyrus communis</i> L. cv Conference)	30.60 ^b ; 42.8 or 45 ^b	—	11.5–12.3; 15.40	0.138–0.145; 35.43 ^c	—	—	—	—	—	Massy, France; Portugal; Picarra; Poland; Piedmont Region	Mrad et al. (2012)
'Laiyang' pear (<i>Pyrus bretschneideri</i> Reld cv. Laiyang)	2.44	—	—	40.21	—	—	—	—	—	Laiyang, Shandong, China	Contessa et al. (2013)
'Rocha' pear (<i>Pyrus communis</i> L. cv Rocha)	6.11–8.22(stored at –5 °C for 15 days)	—	—	—	—	—	—	—	—	Netherlands	Veltman et al. (2000)
'Williams' pear (<i>Pyrus communis</i> L. cv. Williams' Bon Chrétien.)	—	—	13.37	34.30 ^c	—	—	—	—	—	Piedmont Region	Contessa et al. (2013)
'Abate Fetel' pear (<i>Pyrus communis</i> L. cv. Abate Fetel)	—	—	14.47	33.70 ^c	—	—	—	—	—	Piedmont Region	Contessa et al. (2013)
'Améndoa' pear (<i>Pyrus communis</i> L. cv. Améndoa)	—	—	—	—	28.5(RS, 27.7) ^f	2.0 ^d	1.3 ^e	—	Fresh:14.2(SDF, 3.6; IDF, 10.3); Dried: 17.7(SDF, 32.4; IDF, 11.3)	Portugal	Barroca et al. (2006)
'Amorim' pear (<i>Pyrus communis</i> L. cv. Amorim)	—	—	—	—	35.6(RS, 36.5) ^f	2.6 ^d	4.0 ^e	—	Fresh:14.8(SDF, 4.0; IDF, 10.0) Dried: 15.9(SDF, 3.0; IDF, 13.7)	Portugal	Barroca et al. (2006)
'Carapinha Branca' pear (<i>Pyrus communis</i> L. cv. Carapinha Branca)	—	—	—	—	38.0(RS, 22.4) ^f	1.9 ^d	1.4 ^e	—	Fresh:15.3(SDF, 2.8; IDF, 14.3) Dried: 21.1(SDF, 4.1; IDF, 16.5)	Portugal	Barroca et al. (2006)

‘S. Bartolomeu’ pear (<i>Pyrus communis</i> L. cv. S. Bartolomeu)	—	—	—	—	21.7(RS, 22.5) ^f	1.9 ^d	3.4 ^e	—	Fresh:11.7 (SDF, 2.0; IDF, 8.1) Dried: 12.6(SDF, 2.0; IDF, 8.5)	Portugal	Barroca et al. (2006)
Pears (<i>Pyrus communis</i> L. var. Blanquilla)	—	—	—	—	—	—	—	—	Peel: 28.1 (SDF, 10.2; IDF, 17.9) Pulp: 21.3 (Soluble, 8.4; IDF, 12.9)	—	Leontowicz et al. (2003)
‘Cascade’ pear (<i>Pyrus communis</i> L. cv. Cascade)	—	0.93	14	—	93	—	16	—	—	Zhengzhou, China	Sun et al. (2014)
‘Mantianhong’ pear (<i>Pyrus pyrifolia</i> Nakai cv. Mantianhong)	—	0.7	11.4	—	99	—	13	—	—	Zhengzhou, China	Sun et al. (2014)
‘Meirensu’ pear (<i>Pyrus pyrifolia</i> Nakai cv. Meirensu)	—	0.625	12	—	—	—	—	—	—	Zhengzhou, China	Sun et al. (2014)
‘Rochado Oeste’ pear (<i>Pyrus communis</i> L. var. rocha)	—	β-Carotene (0.0013–0.0015); β-Cryptoxanthin (0.0009–0.0025); Lutein(0.0043–0.0088); Zeaxanthin, (ND–0.0018); Lycopene & α-Carotene, ND	—	—	—	—	—	—	—	Alcobaça	Dias et al. (2009)

Note: —, no research in the references; WSP, water soluble pectin; ISP, ionic soluble pectin; CSP, covalent soluble pectin; SDF, soluble dietary fiber; IDF, insoluble dietary fiber; DW, dry weight; FW, fresh weight; ND, not detected; RS, meaning ‘Reducing sugar’, expressed as a percentage of the dry mass.

^aAA (mg/100mL fresh pear juice).

^bAA (mg/100 g DW).

^cTitrate acidity (meq/L).

^dTotal protein of the fresh pears expressed as a percentage of the dry mass.

^eAcidity expressed as a percentage of the dry mass.

^fTotal sugar expressed as a percentage of the dry weight; total amino acid content (by HPLC): as the sum of individual amino acid.

Source: Summarized by the authors based on the references list in the table.

Table 6 Total phenolics (TPs, mg/100 g FW), total flavonoids (TFs, mg rutin/100 g FW), total anthocyanins (TAs, mg/100 g DW), and total triterpenes (TTs, mg/100 g DW) in fruits of *Pyrus* species

Species	TPs	TFs ^a	TAs	TTs	Source	References
‘Xuehua’ (<i>P. bretschneideri</i> Rehd. cv. xuehuali)	392.58	481.53	225	125	Yantai, Shandong, China	Li et al. (2011, 2012b)
‘Yali’ (<i>P. bretschneideri</i> Rehd. cv. yali)	244.08	473.66	170	110	Cangzhou, Hebei, China	Li et al. (2011, 2012b)
‘Shuijing’ (<i>P. pyrifolia</i> cv. Shisho)	347.35	609.54	—	—	Zhaoxian, Hebei, China	Li et al. (2011)
‘Fengshui’ (<i>P. pyrifolia</i> Nakai cv. Housui)	306.72	588.86	—	—	Mianyang, Sichuan, China	Li et al. (2011)
‘Xiang’ (<i>Pyrus</i> sp. nr. <i>Communis</i> cv. Xiang)	288.35	445.97	200	125	Kuerle, Xinjiang, China	Li et al. (2011, 2012b)
‘Dangshansu’ pear (<i>P. bretschneideri</i> Rehd. cv. Dangshansu)	140	125	151.6	209.24	Jixian, Tianjin, China	Li et al. (2012b)
‘Yuanpingsu’ pear (<i>P. bretschneideri</i> Rehd. cv. Yuanpingsu)	140	120	200	120	Jixian, Tianjin, China	Li et al. (2012b)
‘Nanguo’ pear (<i>P. ussuriensis</i> Maxim. cv. Nanguo)	823.3	790.8	225	170	Anshan, Liaoning, China	Li et al. (2012b)
‘Huangguan’ pear (hybrid, ‘Xuehua’ pear × ‘Xinshiji’ pear)	308.1	300.6	52	75	Cangzhou, Hebei, China	Li et al. (2012b)
‘Yantai’ pear (<i>P. communis</i> Linn. cv. Yantai)	124	80	175	149	Yantai, Shandong, China	Li et al. (2012b)
‘Laiyang’ pear (<i>P. bretschneideri</i> Rehd. cv. Laiyang)	Peel, 390; Flesh, 75	Peel, 710; flesh, 260	—	Peel, 250; flesh, 25	Liaocheng, Shandong, China	Li et al. (2014b)
‘Guifei’ pear (<i>P. communis</i> cv. Guifei)	Peel, 410; flesh, 750	Peel, 820; flesh, 620	—	Peel, 350; flesh, 50	Liaocheng, Shandong, China	Li et al. (2014b)
‘Qingpi’ pear (<i>P. communis</i> cv. Qingpi)	Peel, 590; flesh, 90	Peel, 1700; flesh, 160	—	Peel, 510; flesh, 240	South Africa	Li et al. (2014b)

'Hongpi' pear (<i>P. communis</i> cv. Hongpi)	Peel, 750; flesh, 365	Peel, 110; flesh, 625	—	Peel, 700; flesh, 340	South Africa	Li et al. (2014b)
'Yaguang' pear (<i>P. ussuriensis</i> Maxim cv. Yaguang)	Peel, 720; flesh, 190	Peel, 1550; flesh, 275	—	Peel, 660; flesh, 230	Langfang, Hebei, China	Li et al. (2014b)
'Jinqiu' pear (<i>P. pyrifolia</i> Nakai cv. Jinqiu)	Peel, 1120; flesh, 50	Peel, 710; flesh, 290	—	Peel, 700; flesh, 125	Shaoyang, Hunan, China	Li et al. (2014b)
'Lvbaoshi' pear (LBS, hybrid 'Xinshiji' and 'Zaosu' pear)	Peel, 300; flesh, 90	Peel, 510; flesh, 375	—	Peel, 250; flesh, 51	Liaocheng, Shandong, China	Li et al. (2014b)
'Mantianhong' pear (MTH, hybrid of 'Xingshui' and 'Huoba' pear)	Peel, 500; flesh, 120	Peel, 610; flesh, 460	—	Peel, 400; flesh, 70	Kunming, Yunnan, China	Li et al. (2014b)
'Meirensu' pear (MRS, hybrid of 'Xingshui' and 'Huoba' pear)	Peel, 700; flesh, 60	Peel, 490; flesh, 220	—	Peel, 500; flesh, 50	Kunming, Yunnan, China	Li et al. (2014b)
'Youran' pear (YRL)	Peel, 280; flesh, 30	Peel, 905 flesh, 230	—	Peel, 110; flesh, 25	Korea	Li et al. (2014b)
'Anjou' pear (<i>P.</i> <i>communis</i> L.)	—	—	0.05–0.62(peel, mM/m ² , approximately 107 days after bloom)	—	Oregon State University	Li and Cheng (2009)
'Conference' pear (<i>P. communis</i> L. cv. Conference)	254.90 ^b ; 30.33	—	12.83 ^c	—	Massy, France; Portugal, Picarra; Poland; Piedmont Region	Mrad et al. (2012)
'Williams' pear (<i>P.</i> <i>communis</i> L. cv. Williams' Bon Chrétien.)	47.93	—	2.70 ^c	—	Piedmont Region	Contessa et al. (2013)

Continued

Table 6 Total phenolics (TPs, mg/100 g FW), total flavonoids (TFs, mg rutin/100 g FW), total anthocyanins (TAs, mg/100 g DW), and total triterpenes (TTs, mg/100 g DW) in fruits of *Pyrus* species—cont'd

Species	TPs	TFs ^a	TAs	TTs	Source	References
'Abate Fetel' pear (<i>P. communis</i> L. cv. Abate Fetel)	60.30	—	8.67 ^c	—	Piedmont Region	Contessa et al. (2013)
'Cascade' pear (<i>P. communis</i> L. cv. Cascade)	—	17 (bagging)	0 (bagging)	—	Zhengzhou, China	Sun et al. (2014)
'Mantianhong' pear (<i>P. pyrifolia</i> Nakai cv. Mantianhong)	—	12 (bagging)	0 (bagging)	—	Zhengzhou, China	Sun et al. (2014)
'Meirensu' pear (<i>P. pyrifolia</i> Nakai cv. Meirensu)	—	13 (bagging)	0 (bagging)	—	Zhengzhou, China	Sun et al. (2014)

Note: —, no research in the references; DW, dry weight; FW, fresh weight.

^aTotal flavonoids (mg rutin/100 g FW).

^bmg GA/100 g DW.

^cTotal anthocyanins content (mg cyanidin-3-glucoside equivalents 100 g⁻¹ FW).

Source: Summarized by the authors based on the references list in the table.

between 2 and 6 mg/100 g FW depending on cultivar, picking date, and growing location. AA is chosen to be a very important quality parameter of fruits and should be kept at an appropriate level. In pear tissue, AA level tends to decrease during storage and can be very low; of 'Conference' pears grown in the Netherlands that reached 72 mg/kg FW at harvest (Veltman et al., 2000), AA level decreased to 23 mg/kg FW after 199 days of storage under a controlled condition. AA level in pear tissue differs depending on the cultivars and their maturity (Chen et al., 2007). AA levels of eight different pear cultivars grown in China were compared, and it was found that the AA level of these pear cultivars vary from 1.30 to 4.55 mg/100 ml in pear juice and 'Kuerle' fragrant pear, and 'Nanguo' pear had higher AA content (4.10 and 4.55 mg/100 ml pear juice), while the 'Niitaka' pear had the lowest AA level, with the value of 1.30 mg/100 ml pear juice.

Carotenoids

Carotenoids are a group of natural pigments present in fruits and vegetables, imparting their color from yellow to red. They are very important for human health and are related to actions such as provitamin A, antioxidants, cell differentiation and proliferation regulators, cell-cell communication stimulators, immune function, and carcinogen metabolism modulators. Many studies have shown strong correlations between carotenoid intake, the improvement of the immune system, and reducing the risk of some degenerative diseases, such as cancer, cardiovascular diseases, cataracts, and macular degeneration (Dias et al., 2009). α -Carotene, β -carotene, β -cryptoxanthin, lycopene, lutein, and zeaxanthin are the predominant carotenoids presenting both in serum and food in Europe. Dias et al. (2009) evaluated the above predominant carotenoids in 10 varieties of five fruit species, including orange, pear (*P. communis* L. var. Rocha), peach, apple, cherry, and six varieties of four leafy vegetable species (Portuguese coles, turnip greens, purslane, leaf beet, and beetroot leaves) cultivated in Portugal by High Performance Liquid Chromatography (HPLC). They found that the analyzed leafy vegetables were a very good source of lutein (0.52–7.2 mg/100 g) and β -carotene (0.46–6.4 mg/100 g), while the analyzed fruits had a relatively lower content of carotenoids (lutein, 0.0032–0.16 mg/100 g and β -carotene, 0.010–0.17 mg/100 g). The β -carotene, β -cryptoxanthin, lutein, and zeaxanthin content of pear (*P. communis* L. var. Rocha) were 0.0013–0.0015 mg/100 g, 0.0009–0.0025 mg/100 g, 0.0043–0.0088 mg/100 g, and 0.0011–0.0018 mg/100 g, respectively. All the results indicated that the carotenoid content could vary between species, varieties, geographical place of production (region, site), and state of harvest. The study of Sun et al. (2014) clearly indicated that the concentrations of carotenoids, chlorophyll, and flavonoids were influenced by the irradiance level of visible light.

Flesh Firmness, SSC, and TA

Flesh firmness, SSC, and TA are three important physical properties of fruit tissue, which directly affect taste quality and texture, and a change in flesh firmness may be due to the

modification of the chemical structure of the cell wall, depending on the storage conditions, harvest date, and the growing location (Chen and Yan, 2004). Chen et al. (2007) investigated eight commercial pear cultivars grown in China (Beijing) and found that 'Kuerle' fragrant pear and 'Jingbai' pear showed relatively higher level of soluble solids than other pears ('Yali', 'Dangshan', 'Nabguo', 'Ninomiyahaku', 'Niitaka', and 'Wujiuxiang' pears). It was noteworthy that 'Kuerle' fragrant pear had the highest soluble solids but the lowest acid content. The sugar/acid ratio of 'Kuerle' fragrant pear is 125.0, and it is an appropriate cultivar for eating when fresh. 'Kuerle' fragrant pear's firmness decreased very slowly during storage, and its SSC developed with fruit ripening and increased slowly from 1 month after storage, and the SSC total change was not remarkable; the results were in conformity with those of 'Yali' pear (Chen et al., 2006b), which suggested that even if 'Kuerle' fragrant pear fruit were stored for half year, SSC would only change slightly, so the flesh quality could be maintained during the storage period (Chen and Yan, 2004).

Sugars, Amino Acids, and Organic Acids

Sugars, amino acids, and organic acids contents not only have marked influence on the sensory quality of fruits, but also have exerted important influence in determining nutritive value. Based on this viewpoint, the nature and concentration of these constituents in fruit are of interest. There were several studies focusing on the changes of the individual sugar, organic acid, and amino acid in stored 'Yali' and 'Kuerle' fragrant pears (Chen and Yan, 2004, 2006b). The sugar, organic acid, amino acid, and fatty acid compounds of eight commercial pear cultivars from China were identified and quantified using HPLC with refractive index (RI) detector, UV detectors, and GC equipped with an FID detector (Chen et al., 2007). The results showed great quantitative differences in the composition of the pear cultivars. Malic, citric, quinic, and shikimic acids were the main organic acids, and the most predominant organic acid in the tested pears was malic acid. This is in accordance with the results of the contents of organic acids in fruits of 40 cultivars of four major pear species (*P. ussuriensis*, *P. bretschneideri*, *P. pyrifolia*, and *P. communis*) in China investigated by Sha et al. (2011). Fructose was the dominant sugar in the eight pear varieties, followed by glucose and sucrose. The total organic acid content of the 'Dangshan' pear was the highest, with a value of 3607 mg/kg of fresh pears, followed by that of the 'Nanguo' pear (2564 mg/kg of fresh pears), and the 'Kuerle' fragrant pear (2171 mg/kg of fresh pears), while the 'Kuerle' fragrant pear had a higher sugar to acid ratio than other pears. The organic acid content was commonly used to determine the sensory and flavor quality of fruit, which is consistent with the preference of consumers for 'Kuerle' fragrant pear. Asparagine and serine were the major amino acids in the tested eight pear varieties. There were some differences in different pear varieties, and total amino acid content (278 mg/100 g of fresh pears) in 'Dangshan' pear pulps was the highest. Although lysine and sulfur-containing amino acids are usually limited in proteins of

vegetal origin, sulfur-containing amino acids were still found in all eight pear varieties, and lysine was detected in 'Kuerle' fragrant, 'Dangshan' pear, 'Jingbai' pear, 'Ninomiya-haku', and 'Wujiuxiang' pear (Chen et al., 2007).

Minerals

It is well-known that trace minerals are important not only for plant nutrition, but also for human nutrition. Potassium is a mineral essential for controlling the salt balance in human tissues, and zinc is a trace mineral especially important for normal functioning of the immune system. Calcium is a mineral that is essential to bone structure and function. The content of nine kinds of minerals, including potassium, magnesium, calcium, sodium, zinc, copper, iron, manganese, and boron was detected by Chen et al. (2007). Potassium was the most abundant mineral in the eight commercial pear cultivars from China, such as in the 'Dangshan' pear (1688 mg/kg of fresh pears), 'Ninomiya-haku' (1336 mg/kg of fresh pears), and the 'Kuerle' fragrant pear (1085 mg/kg of fresh pears), followed by magnesium and calcium. Some species showed slightly higher calcium values than the indicated maximum value, except 'Dangshan' pear, while sodium values were below 30 mg/100 g in the eight pears.

Fibers

Fiber is classified into water-soluble and insoluble groups. The former is formed mainly by mucilage, gums, pectin, and hemicelluloses, whereas the latter consists of cellulose, lignin, and a wide range of hemicelluloses. Dietary fibers are associated with the prevention and treatment of many disorders, such as constipation, diabetes, cardiovascular diseases, diverticulosis, and obesity. The physiological effects of dietary fibers are related to their physicochemical and functional properties, which is mainly dependent on the source and the processing that pears undergo. It has been established that the fiber derived from fruits and vegetables has positive physiological effects, due to the higher proportion of soluble dietary fiber, while cereal fibers contain more insoluble cellulose and hemicelluloses (Barroca et al., 2006). Barroca et al. (2006) investigated the fiber properties of fresh and dried pears (*P. communis* L.) of the local varieties known as 'Améndoia', 'Amorim', 'Carapinha Branca', and 'S. Bartolomeu' from the center of Portugal. The results turned out that the content of dietary fiber of the four fresh pears ranged from 12% to 15% (dry mass), and the SDF/IDF ratios were between 1:2.5 and 1:5, while the total dietary fiber content and SDF/IDF ratio of the four pear varieties after dried maintained similarity to the fresh ones. It is generally accepted that the SDF/IDF ratio of the dietary fiber is also important for both dietary and functional properties, and those fiber sources are suitable for application as food ingredients when their SDF/IDF ratios are close to 1:2. Apparently, the SDF/IDF ratios of the four pears are higher than 1:2, but lower than that of other fruits such as grapefruit, lemon, orange, and apple. Pear peels proved to contain higher amounts of dietary fiber than its pulp (21.3 mg/g FW),

according to a study of [Leontowicz et al. \(2003\)](#). Pears have a higher dietary fiber level than those of some common fruits and vegetables, such as apples and citrus fibers. Furthermore, pears' fibers have better quality than other dietary fibers, due to the existence of associated bioactive compounds (flavonoids and polyphenols). Hence, pear is a good element to incorporate in fiber-enriched foods, and pears' fibers can be seen as a potential food additive ([Barroca et al., 2006](#)).

Total Phenolics (TPs), Total Flavonoids (TFs), Total Anthocyanins (TAs), and Total Triterpenes (TTs)

Apart from all the parameters mentioned above, total phenolics (TPs), total flavonoids (TFs), total anthocyanins (TAs), and total triterpenes (TTs) were also used as parameters to evaluate the nutritive value of pear fruits ([Table 6](#)).

Many studies reported the existence of different kinds of phenolic compounds in pear skins, pear flowers, and other parts of pear trees, which contain arbutin, chlorogenic acid, *p*-coumaroylquinic acid, *p*-coumaroylmalic acid, dicaffeoylquinic acids, vanillic acid derivatives, catechin, epicatechin, proanthocyanidins, cyanidin 3-O-galactoside, the 3-O-glycosides of quercetin, isorhamnetin, kaempferol, and some nonglycosylated flavones and flavonols ([Lin and Harnly, 2008](#)). There are much higher and more various phenolic contents in the pear peel than in its flesh, the polyphenol degraded during drying, and the rate increased along with increasing temperature ([Mrad et al., 2012](#)). [Lin and Harnly \(2008\)](#) analyzed the phenolic compounds in the peel of 16 pears (*Pyrus* spp.), using a standardized profiling method based on liquid chromatography with a diode array and electrospray ionization/mass spectrometric detection (LC-DAD-ESI/MS), and identified 34 flavonoids and 19 hydroxycinnamates. Arbutin and chlorogenic acid were recognized as major phenolic compounds in all of the pears tested. According to the pattern of distribution of the remaining phenolic compounds, [Lin and Harnly \(2008\)](#) suggested that the tested pears could be divided into four groups: group 1, composed of four Asian pears (Asian, Asian brown, Korean, and Korean Shinko), contained only arbutin and chlorogenic acid with only trace quantities of the remaining phenolics; in group 2, 'Yali' pear contained significant amounts of dicaffeoylquinic acids (such as caffeic acid); in group 3, fragrant pear contained significant quantities of quercetin glycosides as the main flavonoids and lesser quantities of isorhamnetin glycosides, the glycosides of luteolin, apigenin, and chrysoeriol; in group 4, the remaining 10 pears ('Bartlett', 'Beurre', 'Bosc', 'Comice', 'D'Anjou', 'Forelle', 'Peckham', 'Red', 'Red D'Anjou', and 'Seckel'; all belong to the cultivars or varieties of *P. communis* L.) contained significant quantities of isorhamnetin glycosides and malonates and lesser quantities of quercetin glycosides. [Salta et al. \(2010\)](#) compared the phenolic profile and the antioxidant activity of the 'Rocha' pear (a Portuguese pear cultivar) with the commercial pear varieties ('Comice', 'Abate', 'General Leclerc', and 'Passe Crassane'); it was found that the 'Rocha' pear (peel and flesh) presented the highest content of total

phenolics and chlorogenic, syringic, ferulic and coumaric acids, and arbutin and (–)-epicatechin were the major components. In addition, among the tested varieties, ‘Rocha’ pear exhibited the highest TPs content (164.3 mg/100 g FW) and presented the best antioxidant activity in the 2,2’-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging assay and ferric-reducing power assays. These features, allied to its unique flavor, made ‘Rocha’ pear a very promising source of natural antioxidants from food-stuffs. In accordance with all above studies, [Li et al. \(2012b, 2014b\)](#) also found that although the phenolic content varies greatly between different pear varieties (‘Xuehua’, ‘Ya’, ‘Dangshansu’, ‘Yuanpingsu’, ‘Nanguo’, ‘Huangguan’, ‘Yantai’, ‘Xiang’, ‘Laiyang’, ‘Yaguang’, ‘Jinqiu’, ‘Qingpi’, ‘Hongpi’, ‘Guifei’, ‘Lvbaoshi’, ‘Youran’, ‘Mantianhong’, and ‘Meirensu’ pears), arbutin, oleanolic acid, ursolic acid, chlorogenic acid, epicatechin, and rutin were the dominant components contained in all the pear varieties and the determined values of TPs, TFs, TAs, and TTs contents in peels were remarkably higher than those in flesh, approximately 6 to 20 times. The primary flavonoid in the tested pear fruits was arbutin, and the secondary flavonoid is catechin, followed by quercetin and epicatechin, which differed from the results of other researchers.

Systemic Isolation of Bioactive Compounds from *Pyrus* spp.

In order to fully clarify the chemical constituents of pear fruits, some work focusing on the separation of monomeric compounds from the plants have been carried out ([Figure 1](#); [Table 7](#)). Many polyphenol compounds with different types of structures ([Figure 1](#)) have been isolated from pear skins, pear flowers, and other parts of pear trees, including ferulic acid, caffeic acid, chlorogenic acid, epicatechin, and rutin ([Table 7](#)). Many of these polyphenol compounds were regarded as standards for the quality control of pear fruits. [Huang et al. \(2010\)](#) isolated two pentacyclic triterpene acids, oleanolic acid, and ursolic acid from the fruits of *P. bretschneideri* Rehd for the first time, and they were used as standards to identify and quantify the triterpene compounds of the fruits of 10 different commercial pear varieties by [Li et al. \(2012a, 2014b\)](#), which could provide more basic information on plant physiology and bioactivity. Recently, another three different triterpene compounds (tormentic acid, euscaphic acid, and 3-O-trans-caffeoyloleanolic acid) and three new phenolic compounds, including pashinin A, gastrodin-7-O-cis-caffeoyl ester, and gastrodin-7-O-trans-caffeoyl ester, were isolated and identified by [Zhao et al. \(2013\)](#) and [Cho et al. \(2013\)](#). Further systemic isolation and identification work is warranted to explore the nutritional components of the plants and fruits of *Pyrus* genus.

SUMMARY POINTS

- The nutritional investigations on pears (*Pyrus* spp.) have revealed volatiles, vitamins/AA, carotenoids, sugars, amino acids, organic acids, minerals, fibers, polyphenols, flavonoids, anthocyanins, and triterpenes as main nutritional constituents.

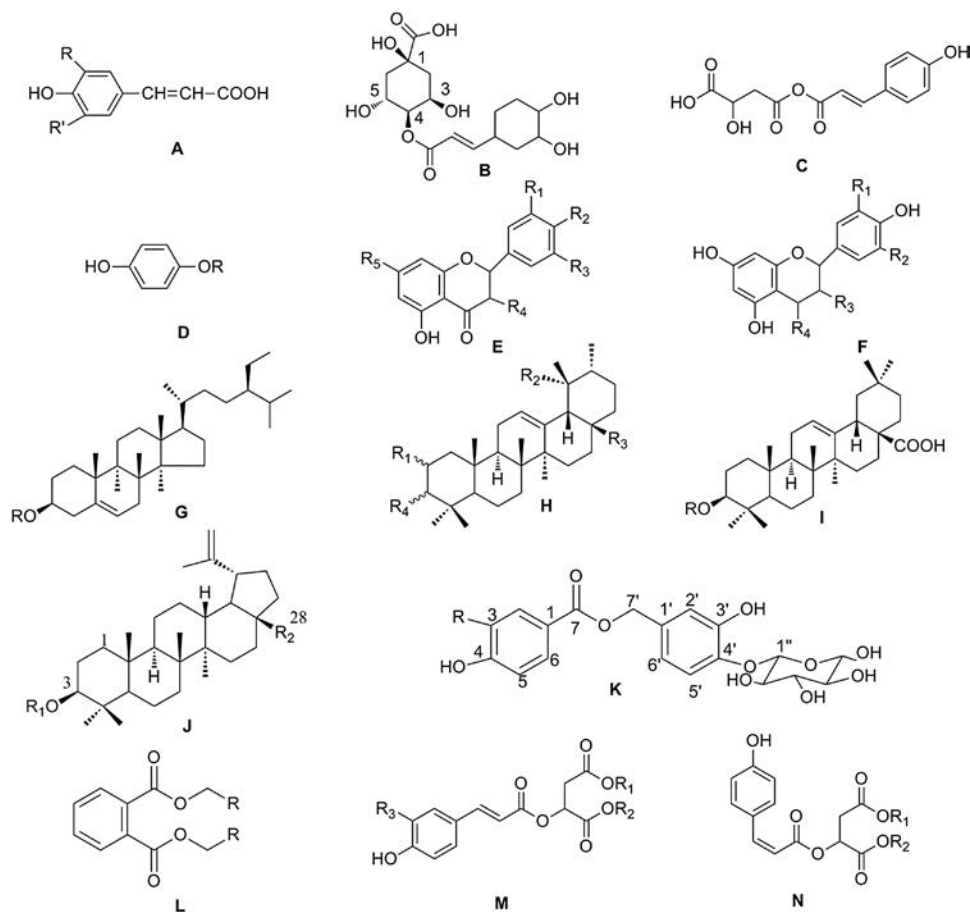


Figure 1 Mother nucleus types of compounds isolated from the plants of *Pyrus* species. Source: Summarized by the authors based on the references list in [Table 7](#).

- The content of these parameters differs with the pear cultivars and their maturity, which were established to be the major bioactive and nutritional ingredients in different pear cultivars.
- Studies on aroma of pear cultivars have been reported widely, and more than 300 volatile compounds (including alcohols, aldehydes, esters, acids, ketones, and hydrocarbons) have been identified in different pear cultivars, mainly cultivars of *P. communis*.
- However, a majority of research was focused on traditional or ancient cultivars. Only a few studies were focused on the modern cultivars, which might be new variants or hybrid varieties; therefore, research on the aroma of pear in modern cultivars should be encouraged.

Table 7 Chemical structures of compounds isolated from the plants of *Pyrus* species

Compound	Skeleton	Substituent	Source	References
Polyphenols (flavonoids, phenolic acids)				
Chlorogenic acid	B	R = OH	leaf of all <i>Pyrus</i> species	Sioud and Luh (1966)
<i>P</i> -Coumaroylquinic acid	B	R = H	leaf of all <i>Pyrus</i> species	Sioud and Luh (1966)
<i>P</i> -Coumaroylmalic acid	C		leaf of all <i>Pyrus</i> species	Oleszek et al. (1994)
Dicaffeoylquinic acid	B	4,5-dicaffeoylquinic acid	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)
Ferulic acid	A	R = OCH ₃ , R' = H	<i>Pyrus bretschneideri</i> Rehd.	Li et al. (2012b)
Caffeic acid	A	R = OH, R' = H	<i>Pyrus bretschneideri</i> Rehd.	Li et al. (2012b)
Cryptochlorogenic acid	B	4-caffeoylquinic acid	unknown	Sondheimer (1958)
Neochlorogenic acid	B	5-caffeoylquinic acid	unknown	Sondheimer (1958)
<i>P</i> -coumaric acid	A	R = R' = H	unknown	Li et al. (2012a)
Arbutin	D	R = glc	<i>Pyrus</i> cv. Kieffer	Durkee et al. (1968)
Quercetin	E	R ₂ = R ₄ = R ₅ = OH; R ₁ = R ₃ = H	<i>Pyrus bretschneideri</i> Rehd.	Sioud and Luh (1966) and Li et al. (2012a)
Quercitrin	E	R ₁ = R ₂ = R ₅ = OH; R ₄ = O-Rham R ₃ = H	<i>Pyrus communis</i> L. cv. Bartlett	Sioud and Luh (1966) and Li et al. (2012a)
Isoquercitrin	E	R ₁ = R ₂ = OH R ₃ = H; R ₄ = O-glu A; R ₅ = OH	<i>Pyrus communis</i> L. cv. Bartlett	Sioud and Luh (1966)
Kaempferol	E	R ₂ = R ₄ = R ₅ = OH; R ₁ = R ₃ = H	unknown	Li et al. (2014b)
Isoquercetin-3-O-glucoside	E	R ₄ = O-glc	<i>Pyrus communis</i> L. cv. Bon Chretien	Nortjé and Koeppen (1965)
Isoquercetin-3-O- rutinocide	E	R ₄ = O-rutinoside	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)
Isoquercetin-3-O- malonyl glucoside	E	R ₄ = O-malonyl glucoside	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)

Continued

Table 7 Chemical structures of compounds isolated from the plants of *Pyrus* species—cont'd

Compound	Skeleton	Substituent	Source	References
Isorhamnetin-3-O-glucoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-glc; R ₅ = OH	<i>Pyrus Communis</i> L. cv. Bon Chretien	Nortjé and Koeppen (1965)
Isorhamnetin-3-O-rhamno-glucoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-Rha; R ₅ = OH	<i>Pyrus Communis</i> L. cv. Bon Chretien	Nortjé and Koeppen (1965)
Isorhamnetin-3-O-rhamnoga-lactoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-Rha-Gal; R ₅ = OH	<i>Pyrus Communis</i> L. cv. Bon Chretien	Nortjé and Koeppen (1965)
Isorhamnetin-3-O- rutinoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-rutinoside; R ₅ = OH	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)
Isorhamnetin-3-O- galactor-hamnoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-Gal-Rha; R ₅ = OH	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)
Isorhamnetin-3-O-malonyl galactoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-malonyl galacto-side; R ₅ = OH	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)
Isorhamnetin-3-O-malonyl glucoside	E	R ₁ = H; R ₂ = OH; R ₃ = OCH ₃ R ₄ = O-malonyl gluco-side; R ₅ = OH	<i>Pyrus communis</i> 'Docteur Jules Guyot'	Oleszek et al. (1994)
Quercetin-7-O-xyloside	E	R ₂ = R ₄ = OH; R ₁ = R ₃ = H; R ₅ = O-xylose	<i>Pyrus communis</i> L. cvs. Bosc, D'Anjou, Bartlett, and Packham's Triumph pear	Oleszek et al. (1994)

Catechin	F	$R_1 = R_3 = \text{OH}; R_2 = \text{H}; R_4 = \text{H}$	<i>Pyrus communis</i> L. cv. Bartlett	Sioud and Luh (1966)
Epicatechin	F	$R_2 = R_3 = \text{OH}; R_1 = \text{H}; R_4 = \text{H}$	<i>Pyrus communis</i> L. cv. Bartlett	Sioud and Luh (1966)
Leucocyanidin	F	$R_1 = \text{OH}; R_2 = \text{H}; R_3 = \text{OH}; R_4 = \text{OH}$	<i>Pyrus communis</i> L. cv. Bartlett	Sioud and Luh (1966)
2-O-(<i>trans</i> -coumaroyl)malic acid	M	$R_1 = R_2 = R_3 = \text{H}$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
2-O-(<i>trans</i> -coumaroyl)malic acid 1-methyl ester	M	$R_1 = R_3 = \text{H}; R_2 = \text{CH}_3$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
2-O-(<i>trans</i> -caffeoyl)malic acid	M	$R_1 = R_2 = \text{H}; R_3 = \text{OH}$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
2-O-(<i>trans</i> -caffeoyl)malic acid 1-methyl ester	M	$R_1 = \text{H}; R_2 = \text{CH}_3; R_3 = \text{OH}$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
2-O-(<i>trans</i> -caffeoyl)malic acid 4-methyl ester	M	$R_1 = \text{CH}_3; R_2 = \text{H}; R_3 = \text{OH}$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
2-O-(<i>cis</i> -coumaroyl)malic acid	N	$R_1 = R_2 = \text{H}$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
2-O-(<i>cis</i> -coumaroyl)malic acid 1-methyl ester	N	$R_1 = \text{H}; R_2 = \text{CH}_3$	<i>Pyrus pyrifolia</i> Nakai	Lee et al. (2011)
Steroids				
β -sitosterol	G	$R = \text{H}$	<i>Pyrus bretschneideri</i> Rehd.; <i>Pyrus communis</i> L. var. <i>sativa</i>	Zuo and Liu (1997)
Daucosterol	G	$R = \text{glc}$	<i>Pyrus bretschneideri</i> Rehd.; <i>Pyrus communis</i> L. var. <i>sativa</i>	Zuo and Liu (1997)
Triterpenes				
2 β ,19 α -Dihydroxyursolic acid	H	$R_1 = \beta\text{-OH}; R_2 = \text{OH}; R_3 = \text{COOH}; R_4 = \beta\text{-OH}$	<i>Pyrus bretschneideri</i> Rehd.	Huang et al. (2010) and Li et al. (2012a)
Ursolic acid	H	$R_1 = R_2 = \text{H}; R_3 = \text{COOH}; R_4 = \beta\text{-OH}$	<i>Pyrus bretschneideri</i> Rehd.	Huang et al. (2010) and Li et al. (2012a)

Continued

Table 7 Chemical structures of compounds isolated from the plants of *Pyrus* species—cont'd

Compound	Skeleton	Substituent	Source	References
α -amyrin	H	$R_1 = R_2 = H$; $R_3 = CH_3$; $R_4 = \beta$ -OH	<i>Pyrus bretschneideri</i> Rehd.	Li et al. (2012a)
Tormentic acid	H	$R_1 = \alpha$ -OH; $R_2 = OH$; $R_3 = COOH$; $R_4 = \beta$ -OH	<i>Pyrus pashia</i> Buch.-Ham. ex D. Don	Zhao et al. (2013)
Euscaphic acid	H	$R_1 = \alpha$ -OH; $R_2 = OH$; $R_3 = COOH$; $R_4 = \alpha$ -OH	<i>Pyrus pashia</i> Buch.-Ham. ex D. Don	Zhao et al. (2013)
Oleanolic acid	I	$R = H$	<i>Pyrus bretschneideri</i> Rehd.	Huang et al. (2010) and Li et al. (2012a)
3-O- <i>trans</i> -caffeoyloleanolic acid	I	$R_1 = trans$ -caffeoyl	<i>Pyrus pyrifolia</i> Nakai. cv. Chuwangbae	Cho et al. (2013)
Lupeol	J	$R_1 = H$; $R_2 = CH_3$	<i>Pyrus communis</i> L. var. <i>sativa</i>	Zuo and Liu (1997)
Betulin	J	$R_1 = H$; $R_2 = CH_2OH$	<i>Pyrus communis</i> L. var. <i>sativa</i>	Zuo and Liu (1997)
Betulinic acid	J	$R_1 = H$; $R_2 = COOH$	<i>Pyrus communis</i> L. var. <i>sativa</i>	Zuo and Liu (1997)
Betulinic aldehyde	J	$R_1 = H$; $R_2 = CHO$	<i>Pyrus pyrifolia</i> Nakai. cv. Chuwangbae	Cho et al. (2013)
3-O- <i>cis</i> -caffeoylbetulinic acid	J	$R_1 = cis$ -caffeoyl; $R_2 = COOH$	<i>Pyrus pyrifolia</i> Nakai. cv. Chuwangbae	Cho et al. (2013)
3-O- <i>trans</i> -caffeoylbetulinic acid	J	$R_1 = trans$ -caffeoyl; $R_2 = COOH$	<i>Pyrus pyrifolia</i> Nakai. cv. Chuwangbae	Cho et al. (2013)
Lupeol ester				
Lup-20(29)-ene-3 β -yl eicosanoate	J	$R_1 = CO(CH_2)_{18}CH_3$; $R_2 = CH_3$	<i>Pyrus serotina</i> Rhed. cv. Shinko	Tomosaka et al. (2001)
lup-20(29)-ene-3 β -yl docosanoate	J	$R_1 = CO(CH_2)_{20}CH_3$; $R_2 = CH_3$	<i>Pyrus serotina</i> Rhed. cv. Shinko	Tomosaka et al. (2001)
lup-20(29)-ene-3 β -yl tetracosanoate	J	$R_1 = CO(CH_2)_{22}CH_3$; $R_2 = CH_3$	<i>Pyrus serotina</i> Rhed. cv. Shinko	Tomosaka et al. (2001)

lup-20(29)-ene-3 β -yl hexacosanoate	J	$R_1 = \text{CO}(\text{CH}_2)_{24}\text{CH}_3$; $R_2 = \text{CH}_3$	<i>Pyrus serotina</i> Rhed. cv. Shinko	Tomosaka et al. (2001)
lup-20(29)-ene-3 β -yl octacosanoate	J	$R_1 = \text{CO}(\text{CH}_2)_{26}\text{CH}_3$; $R_2 = \text{CH}_3$	<i>Pyrus serotina</i> Rhed. cv. Shinko	Tomosaka et al. (2001)
Phenolic acid esters				
protocatechuoylcalleryanin- 3-O- β -glucopyranoside	K	$R = R = \text{Glc}$	<i>Pyrus calleryana</i>	Nassar et al. (2011)
3'-hydroxybenzyl-4- hydroxybenzoate-4'-O- β -glucopyranoside	K	$R = \text{H}$	<i>Pyrus calleryana</i>	Nassar et al. (2011)
Others				
Dibutyl phthalate	L	$R = \text{CH}_2\text{CH}_3$	<i>Pyrus bretschneideri</i> Rehd.	Li et al. (2012a)
Diisobutyl phthalate	L	$R = (\text{CH}_3)_2$	<i>Pyrus bretschneideri</i> Rehd.	Li et al. (2012a)

Source: Summarized by the authors based on the references list in the table.

- Only several studies focused on the isolation of the bioactive compounds from fruits of pears, which could provide more basic information on plant physiology and quality control of fruits, as well as biological activity.
- Further systemic isolation and identification work is warranted to explore the nutritional components of the plants and fruits of *Pyrus* genus.

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CHAPTER 25

Nutritional Composition of Pineapple (*Ananas comosus* (L.) Merr.)

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LIST OF ABBREVIATIONS

ABTS 2,2-azino-bis(3-ethyl-benzothiazoline-6-sulfonic acid)

ADF Acid detergent fiber

ADL Acid detergent lignin

CEL Cellulose

CEQ Catechin equivalents

DPPH 1,1-diphenyl-2-picrylhydrazyl

DW Dry weight

FW Fresh weight

FRAP Ferric-reducing antioxidant power

GAE Gallic acid equivalents

HC Hemicellulose

HPLC High performance liquid chromatography

IDF Insoluble dietary fiber

MCC Metal chelating capacity

NDF Neutral detergent fiber

OD Optical density

RE Rutin equivalents

SDF Soluble dietary fiber

TA Titratable acidity

TDF Total dietary fiber

TF Total flavonoids

TP Total pectin, total phenolics

TSS Total soluble solids

WSP Water-soluble pectin

INTRODUCTION

Pineapple (*Ananas comosus* (L.) Merr.) originated in Latin America, particularly north of the Amazon river. Domesticated, cultivated, and selected by the Tupi-Guarani Indians, pineapple accompanied them in their northward migrations to the Antilles, northern Andes, and Central America. In 1493, on their second voyage to the Caribbean region, Christopher Columbus and his sailors discovered and were impressed by this large and delicious fruit. After that, pineapple was soon dispersed either accidentally or intentionally to America, Europe, Africa, and Asia ([Bartholomew et al., 2003](#))

The pineapple has served as both a food and a symbol throughout the human history of the Americans. Highly regarded for its intense sweetness, the “excellent fruit” was a staple of Indian feasts and rites. In Europe, it became a symbol of extravagance and hospitality. Visitors confronted with pineapple-topped food displays felt particularly honored by a host. The hospitality of a mansion was announced with carved wood or molded mortar pineapples on its main gate ([Levins, 1995](#)).

In the early 1500s, Europeans introduced and grew pineapple in greenhouses. The pineapple was a representation of the owners’ wealth but also a testimony to their gardening skill and experience. Into the 1600s, the pineapple remained so uncommon and coveted a commodity that King Charles II of England posed for an official portrait in an act then symbolic of royal privilege—receiving a pineapple as a gift ([Levins, 1995](#); [Johanna, 2010](#)).

As pineapple greenhouse cultivation expanded during the eighteenth and nineteenth centuries, many varieties were imported, mostly from the Antilles. Afterward, two of the most important varieties, ‘Smooth Cayenne’ and ‘Queen’, were taken from Europe to all of the tropical and subtropical regions ([Bartholomew et al., 2003](#)).

Pineapple is now widely cultivated in tropical and subtropical areas, being the fourth most cultivated tropical fruit crop and the third commercial tropical fruit in the world. It is grown mainly for fresh and for canned fruit and juice. It is the only source of bromelain, which is commonly used in pharmaceuticals. The total world production in 2012 was 23 million tons from 996,000 ha. The total world exported fresh and canned pineapple in 2011 were 3.15 and 1.23 million tons with exported values 172.7 and 130.7 million US dollars ([FAOSTAT, 2014](#)). Costa Rica, mainly operated by Del Monte Company, dominated the world fresh market. Thailand and the Philippines had been the largest producers and exporters of canned fruit and juice for several decades. Other main production areas include Brazil, China, Indonesia, and India.

The commercial production is mainly an intensive-based monoculture. Health and environmental risks are becoming a major concern for consumers. Consequently, pineapple producers, including large multinational companies, adopt more environmentally friendly practices and ensure good management practices with a series of certification systems adapted to agricultural production (ISO 14001, global GAP, Organic, HACCP, CO₂ footprint).

BOTANICAL ASPECTS

Pineapple belongs to the family Bromeliaceae. It is a perennial monocotyledon with a terminal inflorescence and a terminal multiple fruit. Adult plants of the cultivar ‘Queen’ are up to 1 m high and 0.5 m wide, and the cultivar ‘Smooth Cayenne’ can grow up to 1.5 m high and 1 m wide. The stem is short and thick, usually 25–50 cm long, with a diameter of 2–5 cm at the base, and supports 70–80 closely spaced leaves. The leaves are sword-like, waxy, and succulent, arranged spirally around the stem. Leaves sometimes bear short sharp spines along the entire margin or just at the tips. In some varieties, such as ‘Manzana’, the leaf is entirely smooth. The inflorescence, developed from the apical meristem, consists of 50–200 individual hermaphrodite flowers, each having a tubular corolla. Flowers are normally self-sterile, and fruit development is parthenocarpic. The fruit, formed by the fusion of individual parthenocarpic fruitlets, is a syncarp surmounted by a crown of leaves. The flesh of the fruit at maturity is both juicy and fleshy, and near white to yellow in color, depending on the variety.

Although some neighbor species such as *Aechmea* and *Bromelia* also yield edible fruits, only pineapple gives a fruit of economic importance. The most important commercial varieties belong to *A. comosus* (L.) Merr. The main cultivars produced for export are ‘Smooth Cayenne’ and the cultivar ‘MD-2’, although different spiny cultivars are very popular in Malaysia (‘Josapine’) and in China (‘Comte de Paris’ and ‘Shenwan’). ‘Queen’ and other spiny varieties are produced for export to Europe from South Africa and Réunion (‘Queen Victoria’). Brazil, one of the main producing countries for pineapple after Thailand, grows fruit for its domestic market from a number of spiny-leaved cultivars, including ‘Pérola’ and ‘Jupi’. Large programs of pineapple germplasm collection, conservation, and use are underway in Brazil, under the auspices of Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), and in the French West Indies in Martinique, where the CIRAD genebank contains more than 600 accessions, most of which are of edible varieties. Interestingly some species of pineapple have therapeutic properties; others produce fiber for cloth or ropes; and others are ornamental (e.g., *Ananas bracteatus* (Lindl.) Schult. & Schult. f. and *Ananas lucidus* Mill.). There are many therapeutic properties of pineapple fruit and of the plant, including use as a digestive aid, a wound-healing agent, and an inhibitor of platelet aggregation. Pineapple has anti-inflammatory and fibrinolytic activity, and modulates the activity of cytokinin and immune responses. Bromelain, a cysteine protease that is present in the flesh of pineapple (and in concentrations as high as 9 mg/ml in fresh pineapple juice, depending on the variety), is probably the main component contributing to medical applications.

Pineapple uses crassulacean acid metabolism, an adaptation that increases water use efficiency. The spirally arranged leaves collect water droplets and funnel water into the leaf axils, where the water is absorbed along with nutrients, making pineapple drought tolerant. The short thick stem, pliable leaves, and well developed roots make the plant wind resistant. It can tolerate high temperatures, but it is not frost hardy. The optimal temperature for growth is about 25 °C. Soils with good drainage and aeration, high organic matter, and pH between 4.5 and 5.5 are suitable for pineapple cultivation. Suckers, slips (small plantlets that grow at the base of the fruit on the fruit stalk), or the crown can be used as planting material. A period of 18 to 24 months is usually needed from planting to harvest. Pineapple can be harvested all year round using artificial flower initiation.

Nutrient Composition of Traditional Pineapple Cultivars

Fruit sugar content plays a key role in quality. It is the main component of fruit quality and flavor substances. Also, it is the raw material for the synthesis of pigments, amino acids, vitamins, aromatic substances, and other nutritional compounds. Organic acids in the pineapple fruit stabilize the pH value of the cell sap, and participate in photosynthesis, respiration, synthesis of phenols, amino acid metabolism, lipids metabolism, and aromatic substance metabolism (Ceng, 1992). High sugar content and the balance of sugar and acidity give pineapple excellent flavor. The variety and levels of sugars and acids are affected by genetic and environmental factors as well as fruit maturity (Py et al., 1987). The sugar and acidity content of some traditional pineapple cultivars reported by several authors are shown in Table 1. ‘Smooth Cayenne’, first collected in 1819 in French Guiana then rapidly spread to all tropical and subtropical regions and still widely cultivated in the world today, makes up about 90% of processed pineapple. It has also been frequently used as a parent for new-variety breeding. The cultivar has been the backbone of the global pineapple industry for more than a century (Bartholomew et al., 2003). Cultivars of the Cayenne group have a high content of total soluble sugar and acidity. ‘Nanglae’ content has the highest sugar and lowest acidity. Queen group pineapples, mainly cultivated for fresh consumption, have high sugar and moderate acid contents. Wijesinghe and Sarananda evaluated the quality of ‘Mauritius’ pineapple of seven commercial farms. The total soluble solids (TSS) was 17.3 °Brix, and titratable acidity (TA) was 0.54% when the fruit was harvested at the stage of 20% shell color yellow. Both sugar and acidity are low in Spanish group cultivars. There are few reports on fruit nutritional content of Pernambuco group and Perolera group pineapple cultivars. ‘Pérola’, widely cultivated in Brazil, is one of the most important cultivars of the Pernambuco group. Reinhardt et al. (2003) reported that more mature ‘Pérola’ fruits had a higher average TSS (14.6 °Brix) and a lower TA (0.37%), resulting in a ratio (41.5) that was 71.9% higher than that of green-ripe fruits. The sugar content of ‘Perolera’ was 14.1 °Brix, the acidity was 0.76%, and the ascorbic acid content was 29.89 mg/100 g (Cabot, 1987).

Table 1 Sugar and acidity contents of traditional pineapple cultivars

Group	Cultivar	TSS (°Brix)	TA(%)	Resources
Cayenne	Smooth Cayenne	12.6–17.4	0.73–1.3	Cabot (1987), Lieu et al. (2007), Sanewski (2008)
	Cayenne Lisa	13–19		Medina and García (2005)
	F180	14.7	0.5	Sanewski (2008)
	Sarawak	13–17	0.30–0.65	Wee (1972)
	Nanglae	16–20	0.3	Li et al. (2008)
	Fils de Chalvet	14.0	0.68	http://collections.antilles.inra.fr/initBRCCard.do?idBrc=2
	VraiAnanas	14.2	0.83	http://collections.antilles.inra.fr/initBRCCard.do?idBrc=2
Queen	Queen Mauritius	15.3–17.6	0.63–0.80	Lieu et al. (2007)
		15–17.3	0.4–0.6	Wee (1972) and Wijesinghe and Sarananda (2002)
	Moris	15.9	0.49	Chan (1993)
	Mac Gregor	13.0	0.53	http://collections.antilles.inra.fr/initBRCCard.do?idBrc=2
Spanish	Singapore Spanish	10–12		Medina and García (2005)
	Red Spanish	10–12		Li et al. (2008)
	Española Roja	12		Li et al. (2008)
	Nangka	7–10	0.2–0.5	Wee (1972)
	Gandul	8–15	0.15–0.46	Wee (1972) and Chan (1993)
Pernambuco	Pérola	14.6	0.37	Reinhardt et al. (2003)
Perolera	Perolera	12–14.1	0.76	Medina and García (2005)

The soluble sugar in pineapple fruit mainly includes fructose, glucose, and sucrose (Chen and Paull, 2000; Zhang et al., 2006). Pineapple fruit sweetness is related to both total sugar content and sugar composition. Zhang et al. (2007) reported that the major organic acids of pineapple fruit were citric acid and malic acid. The level of citric acid was the highest, accounting for 62% of the total organic acid. It was followed by malic acid (about 14%), tartaric acid, and acetic acid. Oxalic and malic acids were at a perceptible level.

We analyzed the composition and contents of soluble sugars and organic acids in 18 traditional pineapple cultivars by high performance liquid chromatography (HPLC). Ten of these cultivars belong to the Cayenne group, and others belong to the Queen group (Table 2). Total sugar contents of the Cayenne group varied from 77.59 to 132.29 mg/g fresh weight (FW), with an average content of 102.87 mg/g FW. Total organic acid content changed from 2.87 to 7.07 mg/g FW, with an average value of 5.16 mg/g FW. The Queen group had a

Table 2 Composition and contents of soluble sugar and organic acid in traditional pineapple cultivars (mg/g FW)

Cultivar	Fructose	Glucose	Sucrose	Total sugar	Citric acid	Malic acid	Quinic acid	Organic acid
Smooth Cayenne	21.03	24.25	64.76	110.05	4.44	1.61	1.02	7.07
Sarawak	21.97	26.43	77.70	126.10	3.96	1.12	0.66	5.73
Queensland Cayenne	13.08	13.74	69.88	96.71	3.80	0.80	1.22	5.83
Hilo	13.34	14.81	49.43	77.59	3.98	0.54	0.71	5.23
Giant Kew	22.65	23.25	60.41	106.32	4.44	0.53	0.93	5.90
Kallara Local	22.69	23.21	61.97	107.88	3.46	0.75	0.96	5.16
Nanglae	23.37	27.13	81.80	132.29	2.75	1.11	1.29	5.15
Chantaburi	13.93	15.57	50.63	80.13	1.69	0.52	0.66	2.87
Sriracha	17.05	21.31	52.29	90.65	2.60	0.81	1.13	4.54
Pattavia	23.81	25.06	52.12	100.99	2.18	0.98	0.92	4.08
Trad srithong	25.35	27.15	85.38	137.89	5.78	1.21	1.10	8.09
Phuket	20.24	22.60	89.46	132.30	4.80	1.05	1.23	7.08
Alexandria	14.35	17.82	73.30	105.46	2.37	0.46	0.65	3.49
Ripley	15.99	19.52	50.71	86.22	2.78	0.79	0.94	4.51
Moris	13.95	13.75	56.52	84.22	1.86	0.33	0.64	2.84
Mac Gregor	16.71	18.38	63.86	98.94	3.03	0.71	1.18	4.93
Comte de paris	31.41	33.60	60.65	125.66	3.37	0.90	0.50	5.09
Shenwan	20.07	23.34	70.39	113.80	4.97	1.05	1.32	7.34
Mean	19.50	21.72	65.07	106.29	3.46	0.85	0.95	5.27

The former 10 cultivars belong to the Cayenne group.

slightly higher average total sugar content, but the average organic acid content was nearly the same as that in the Cayenne group.

The fructose contents of different pineapple cultivars were observed to be relatively lower than other sugars. Fructose was the highest in 'Comte de Paris' (31.41 mg/g FW) and lowest in 'Queensland Cayenne' (13.08 mg/g FW). The glucose contents were also relatively lower, ranging from 13.74 to 33.60 mg/g FW. The highest was again in 'Comte de Paris' and the lowest in 'Queensland Cayenne'. The sucrose was the highest soluble sugar in the 18 pineapple varieties. It varied from 49.43 to 89.46 mg/g FW. 'Tradsrithong' and 'Phuket' had the highest sucrose contents, while 'Hilo' had the lowest.

The difference in organic acid content among the pineapple varieties was significantly different. Citric acid content was the highest among the organic acids. 'Tradsrithong' had the highest citric acid value (5.78 mg/g FW), followed by 'Shenwan' (4.97 mg/g FW) and 'Phuket' (4.80 mg/g FW), while 'Chantaburi' and 'Moris' contained much lower citric acid, 1.69 mg/g FW and 1.86 mg/g FW, respectively. The malic acid content of different pineapple varieties varied largely from 0.30 to 1.61 mg/g FW. 'Smooth Cayenne' and 'Tradsrithong' had higher malic acid content, and the lowest value was in 'Moris'. The quinic acid contents of the different pineapple varieties varied from 0.50 to 1.32 mg/g FW. 'Shenwan', 'Nanglae', 'Phuket', and 'Queensland Cayenne' had higher quinic acid content, while 'Comte de Paris', 'Moris', and 'Alexandria' had lower quinic acid value. All of the cultivars studied could be classified as citric acid-dominant fruits, based on their organic acid composition, similar to the results obtained by [Montafia Camara et al. \(1994\)](#) and [Saradhuldhath and Paull \(2007\)](#).

Dietary fiber is not digested and absorbed but is considered as an important nutrition element. Foods that have high dietary fiber concentration, low digestibility, and low caloric content are a good choice for modern human beings.

Some studies on the composition and contents of dietary fibers in pineapple have been done, but few of them compared the changes of dietary fibers among pineapple cultivars. [Li et al. \(2002\)](#) reported that the contents (fresh weight) of soluble dietary fiber (SDF), insoluble dietary fiber (IDF), and total dietary fiber (TDF) in the flesh of 'Smooth Cayenne' were 0.04 g/100 g, 1.42 g/100 g, and 1.46 g/100 g, respectively. [Ramulu and Rao \(2003\)](#) assessed the dietary fiber content of 25 different types of fruit purchased from local markets in India. Their results showed that the crude fiber, SDF, IDF, and TDF contents in pineapple pulp were respectively 0.5, 0.5, 2.3, and 2.8 g/100 g. [Chang et al. \(1998\)](#) analyzed 41 fresh fruits frequently consumed in Taiwan. The concentration of TDF in pineapple was 1.6%.

We analyzed contents of neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), cellulose (CEL), hemicellulose (HC), total pectin (TP), protopectin, and water-soluble pectin (WSP) in the pulp of 12 pineapple cultivars. Results are shown in [Table 5](#) and [Table 6](#). The differences in dietary fiber content among different cultivars were significant. 'Smooth Cayenne' from Hawaii

had a higher NDF of 37.54 g/100 g, while ‘Smooth Cayenne’ from Taiwan had the lowest NDF content, with a value of 20.77 g/100 g, which was 36.5% lower than the average. The concentration of ADF in ‘Smooth Cayenne’ from Hawaii was 39.8% higher than the average, and twice that observed in ‘Smooth Cayenne’ from Taiwan. The highest concentration of CEL, which was 47.3% higher than the average, has been observed again in ‘Smooth Cayenne’ from Hawaii; however, the content of CEL in ‘Smooth Cayenne’ from Taiwan and ‘Smooth Cayenne’ from Australia were lower than the mean. ‘Smooth Cayenne’ from Taiwan and ‘Smooth Cayenne’ from Hawaii had lower HC with a value of 6.77 g/100 g and 8.67 g/100 g, respectively. ‘Smooth Cayenne’ from Taiwan also had a lower ADL, with a value of 1.11 g/100 g (Table 5).

The TP contents measured in 12 cultivars ranged from 2.13 to 4.15 g/100 g. ‘Smooth Cayenne’ from Hawaii had a higher value of 4.01 g/100 g. TP in ‘Smooth Cayenne’ from Taiwan and ‘Smooth Cayenne’ from Australia were lower than the average. The WSP contents varied between 0.95 and 1.65 g/100 g. ‘Smooth Cayenne’ from Hawaii had a higher content of WSP, while ‘Comte de Paris’ exhibited a lower value. The contents of protopectin changed from 0.97 to 2.82 g/100 g. ‘Smooth Cayenne’ from Hawaii and ‘Comte de Paris’ showed a higher content of protopectin, while ‘Smooth Cayenne’ from Taiwan, ‘Smooth Cayenne’ from Australia had a lower content in protopectin (Table 6).

Nutrient Composition of Modern Pineapple Cultivars

Sugar and acidity contents of modern pineapple cultivars reported by different authors are shown in Table 3. Hybrid ‘MD-2’, developed by the Pineapple Research Institute of Hawaii, is a famous cultivar dominating the fresh pineapple market of the world. The average TSS of ‘MD-2’ is 1–2% higher than that of ‘Smooth Cayenne’. The acidity is lower than that of ‘Smooth Cayenne’ in all seasons of the year in Hawaii (Taniguchi et al., 2008). ‘CO-2’, a sibling of ‘MD-2’, is also an outstanding pineapple cultivar. It has a very aromatic flavor and generally has a good balance between sugars and acids. Fruit of ‘CO-2’ ripened in Hawaii had TSS of 15.0–16.7%, TA of 0.42–0.91 g/100 ml, and Vitamin C (VC) content of 30.8–55.5 mg/100 ml (3–4 times that of ‘Smooth Cayenne’). In Queensland, the acidity of ‘CO-2’ can be up to about 50% less than ‘Smooth Cayenne’ in winter (Taniguchi et al., 2008). ‘Dole-14’, a new hybrid of Dole Food Company, having a high carotenoid and VC content, improved aroma, and distinct sweet flavor, has a sugar content of 17.1 °Brix and acid content of 0.57% (Young and Gonzales, 2009). ‘Josapine’, a hybrid from Malaysia, is a hybrid between ‘Johor’ (‘Spanish’) and ‘Sarawak’. It has a sugar content between 17 °Brix on peat soil and 22 °Brix on mineral soil. This cultivar also has a high acid content (0.82%). These give ‘Josapine’ a very aromatic scent and excellent flavor (Bartholomew et al., 2003). ‘Imperial’ and ‘Vitória’, hybrids from Brazil, are new pineapple cultivars resistant to

Table 3 Sugar and acidity contents of modern pineapple cultivars

Cultivar	TSS (°Brix)	TA (%)	Resource
MD-2	12.6–16	0.45–0.70	Taniguchi et al. (2008) and Montero-Calderón et al. (2010b)
CO-2	13.6–17	0.4–0.91	Sanewski (2008) and Taniguchi et al. (2008)
Dole-14	17.1	0.57	Young and Gonzales (2009)
Tropical gold	14.6	0.69	Young and Gonzales (2009)
Josapine	16.8–22	0.63	Chan (1993) and Batholomew et al. (2003)
N36	14	0.8	Chan (2008)
Imperial	17.5	0.64	Cabral and Matos (2009)
Vitória	15.8	0.8	Ventura et al. (2009)
Tainung4	19.5	0.43	San and Lin (2003)
Tainung6	15.5	0.34	San and Lin (2003)
Tainung11	14.8	0.57	San and Lin (2003)
Tainung13	15.7	0.27	San and Lin (2003)
Tainung16	18.0	0.47	San and Lin (2003)
Tainung17	14.0	0.28	San and Lin (2003)
Tainung18	14.1	0.39	San and Lin (2003)
Tainung19	16.7	0.46	San and Lin (2003)
Flhoran41	15.2	0.76	CIRAD Germplasm, unpublished
Flhoran50	13.1	0.79	CIRAD Germplasm, unpublished
Flhoran53	14.4	0.59	CIRAD Germplasm, unpublished
Flhoran54	13.9	0.44	CIRAD Germplasm, unpublished
Flhoran55	16.8	0.68	CIRAD Germplasm, unpublished
Flhoran63	12.7	0.81	CIRAD Germplasm, unpublished
Scarlett	15–18		Chan (2008)
Ulam	18–22		Acosta et al. (2011)
Aus-Jubilee	16		http://pericles.ipaustralia.gov.au/pbr_db/plant_detail.cfm?AID=14879425
Aus-Festival	17		http://pericles.ipaustralia.gov.au/pbr_db/plant_detail.cfm?AID=14879426
Aus-Carnival	19		http://pericles.ipaustralia.gov.au/pbr_db/plant_detail.cfm?AID=14879424

Fusarios. ‘Imperial’ has a high TSS content (17.5 °Brix), moderate TA content (0.64%), high VC content (29.02 mg/100 g), and very good flavor (Cabral and Matos, 2009). TSS content of ‘Vitória’ was 15.8 °Brix, TA content was 0.8% (Ventura et al., 2009). ‘Ulam’, a cross of Cayenne x *A. bracteatus*, is an elite hybrid selection from the Philippines. The fruit has a pleasing taste, and good aromatic flavor. It is very sweet, with a sugar content of 18–22 °Brix (Acosta et al., 2011). ‘Tainung’ cultivars were

developed by the Chinese Taiwan breeding program. The common features of these varieties are low acid, high sugar, and fine quality, with a specific fragrance. ‘Smooth Cayenne × Perolera’ hybrids from CIRAD are resistant to *Fusarium subglutinans*. They all have the piping leaf. ‘Flhoran41’ fruit displays a strong red color at full maturity, with firm flesh and a good TSS of 15.2%, and medium acidity of 0.76%. ‘Flhoran53’ produces a cylindrical fruit, with TSS 14.4% and TA 0.59%, a very specific aroma, and firm flesh, which is considered a very good characteristic for processing; ‘Flhoran55’, with spherical yellow fruit, has a TSS commonly above 20% and moderate acidity (TA 0.68%).

The composition and contents of soluble sugars and organic acids in 16 modern pineapple cultivars were evaluated in our study. Results are shown in Table 4. Total sugar contents varied from 81.59 to 124.41.65 mg/g FW. The average value (108.14 mg/g FW) was higher than that in traditional cultivars (106.29 mg/g FW). However, the highest sugar content was lower than that in traditional cultivars (137.89 mg/g FW). This shows that there is a large variation in total sugar content in traditional cultivars. The total organic acid in modern cultivars ranged from 1.80 mg/g FW to 6.90 mg/g FW. The lowest, highest, and average contents of total organic acid in modern cultivars were lower than those in traditional cultivars.

The fructose contents of modern cultivars varied from 12.21 to 23.28 mg/g FW. Half of the cultivars had a fructose content of more than 20 mg/g FW. The highest and average content of fructose in modern cultivars was 18.71 mg/g FW and 23.28 mg/g FW, respectively. These values are somewhat lower compared to that in traditional cultivars (19.50 mg/g FW and 31.41 mg/g FW, respectively).

The glucose contents ranged from 14.07 to 27.55 mg/g FW. ‘Tainung20’ had the highest glucose content, but it is lower than that in the traditional cultivar ‘Comte de Paris’. ‘Tainung13’ also had higher glucose content, while ‘Tainung4’, ‘MD-2’, and ‘Comte de Paris mutant’ had lower values.

Sucrose is the most important soluble sugar in pineapple fruit. It was found to vary from 45.22 to 83.81 mg/g FW in modern cultivars. The average content (68.16 mg/g FW) was higher than in traditional cultivars. ‘New Phuket’ had the highest sucrose value among the modern cultivars, but it was lower than that in ‘Phuket’ (89.46 mg/g FW), which was the highest among traditional cultivars.

Citric acid content ranged from 0.90 to 4.63 mg/g FW, with a mean of 2.87 mg/g FW. ‘New Phuket’, ‘Comte de Paris mutant’, and ‘Fresh Premium’ had a higher citric acid value, while ‘Tainung13’, ‘Phetchaburi2’, ‘Tainung6’, and ‘Tainung18’ had the lowest content. The mean, highest, and lowest citric acid content in modern cultivars were observably lower than corresponding values in traditional cultivars.

The malic acid content of different modern pineapple varieties varied from 0.30 to 1.12 mg/g FW. ‘Tainung6’, ‘MD-2’, ‘New Phuket’, and ‘Fresh Premium’ content had

Table 4 Composition and contents of soluble sugar and organic acid in modern pineapple cultivars (mg/g FW)

Cultivar	Fructose	Glucose	Sucrose	Total sugar	Citric acid	Malic acid	Quinic acid	Organic acid
MD-2	13.06	14.63	78.99	106.67	2.88	1.05	0.94	4.88
Fresh Premium	22.27	24.81	75.83	122.91	4.03	1.03	1.26	6.32
Golden Winter Sweet	16.18	20.62	61.88	98.67	2.52	0.51	0.81	3.83
Comte De paris mutant	13.21	14.80	72.14	100.15	4.21	0.74	0.83	5.78
Zhenzhu	17.23	19.14	45.22	81.59	2.63	0.51	0.52	3.66
Tainung4	12.10	14.07	70.99	97.16	2.23	0.47	1.13	3.83
Tainung6	21.00	23.36	67.89	112.25	1.85	1.12	1.08	4.05
Tainung11	17.14	18.84	61.13	97.11	3.19	0.92	0.98	5.09
Tainung13	22.73	27.25	51.86	101.83	0.90	0.60	0.73	1.80
Tainung17	20.72	23.64	77.08	121.44	3.56	0.77	0.83	5.17
Tainung18	16.09	19.22	78.79	114.11	1.91	0.59	0.63	3.13
Tainung19	23.28	26.23	46.34	95.85	3.47	0.88	0.79	5.14
Tainung20	23.25	27.55	71.16	121.96	3.36	0.69	0.73	4.78
Tainung21	20.64	19.68	66.39	106.71	3.43	0.88	1.40	5.71
Phetcha-buri2	21.44	24.91	81.11	127.46	1.14	0.30	0.69	2.13
New Phuket	19.00	21.60	83.81	124.41	4.63	1.05	1.22	6.90
Mean	18.71	21.27	68.16	108.14	2.87	0.76	0.91	4.51

Table 5 NDF, ADF, CEL, HC, and ADL contents in various pineapples cultivars(g/100 g DW, [Shi, 2010](#))

Cultivars	NDF	ADF	CEL	HC	ADL
Smooth Cayenne from Taiwan	20.77j	14.14i	12.58h	6.77h	1.11f
Smooth Cayenne from Hawaii	37.54b	28.87a	24.99a	8.67g	3.00c
Smooth Cayenne from Australia	32.00f	19.66f	14.44g	13.00e	4.08b
Comte de Paris	30.00i	23.13c	19.49c	7.00h	2.99c
Yuecui	40.03a	25.13b	22.64b	15.03b	1.98de
Zhenzhu	36.33c	22.16d	15.33f	14.33cd	5.66a
Tainung6	31.00g	17.45h	10.51i	14.00d	5.56a
Tainung11	35.76d	21.00e	17.69d	14.76bc	2.41d
Tainung13	34.41e	18.06g	17.46de	16.41a	0.49g
Tainung16	34.00e	22.07d	17.24e	12.00f	4.01b
Tainung17	30.51h	17.69g	15.61f	12.82e	1.48ef
Tainung19	30.07i	18.47g	15.54f	12.07f	1.97de
average	32.70	20.65	16.96	12.24	2.98

Different letters in the same column mean significant differences at $P < 0.05$ by Duncan's multiple range test.

higher malic acid, while 'Phetchaburi2', 'Tainung4', 'Zhenzhu', and 'Golden Winter Sweet' exhibited lower malic acid content. The mean and highest malic acid content of modern cultivars were significantly lower than those values in traditional cultivars.

The quinic acid contents varied from 0.52 to 1.40 mg/g FW with an average value 0.95 mg/g FW. 'Tainung21', 'Fresh Premium', 'New Phuket', and 'Tainung4' had higher quinic acid values; however, 'Zhenzhu', 'Tainung18', and 'Phetchaburi2' had lower quinic acid.

A reasonably high level of sugars (16–18%) and low acid (0.3–0.6%) are very important criteria in pineapple breeding programs. The average sugar content in modern cultivars is higher, while the average acid is lower than that in traditional cultivars. However, the highest sugar and the lowest acid are not seen in modern cultivars.

On dietary fibers, the results of our study showed that the average contents of NDF, ADF, CEL, HC, and ADL were 32.70, 20.65, 16.96, 12.24, and 2.98 g/100 g, respectively. 'Yuecui', a hybrid from China, had the highest NDF, with a concentration of 40.03 g/100 g, which was 22.4% higher than the average value. The hybrid also had higher ADF, CEL, and HC values. 'Tainung13' had the highest HC concentration and the lowest ADL content. The highest ADL was found in 'Zhenzhu', followed by 'Tainung6', with values of 5.66 g/100 g and 5.56 g/100 g ([Table 5](#)).

The mean TP, WSP, and protopectin were 3.06, 1.16, and 1.91 g/100 g, respectively. 'Yuecui' had the highest concentration of TP, while 'Tainung19' and 'Zhenzhu' the lowest. 'Yuecui', 'Tainung16', and 'Tainung13' had higher content of WSP, while 'Zhenzhu' and 'Tainung17' exhibited the lower values. 'Yuecui' and 'Tainung13' showed a higher content of protopectin, while 'Tainung19' and 'Zhenzhu' had a lower content of protopectin ([Table 6](#)).

Table 6 TP, WSP, and protopectin contents in different pineapple cultivars (g/100 g DW, [Shi, 2010](#))

Cultivars	TP	WSP	Protopectin
Smooth Cayenne from Taiwan	2.13	1.16	0.97
Smooth Cayenne from Hawaii	4.01	1.21	2.80
Smooth Cayenne from Australia	2.41	1.19	1.22
Comte de Paris	3.21	0.95	2.26
Yuecui	4.15	1.65	2.50
Zhenzhu	2.32	0.98	1.34
Tainung6	2.95	1.05	1.90
Tainung11	3.33	1.12	2.21
Tainung13	3.51	1.23	2.28
Tainung16	3.41	1.32	2.09
Tainung17	3.12	0.99	2.13
Tainung19	2.21	1.03	1.18
Average	3.06	1.16	1.91

Compositions of Vitamins, Polyphenols, and Aroma in Pineapple Cultivars

Vitamins

Pineapple fruit is rich in vitamins. However, there are few research papers published on vitamins in pineapple, except some reports on vitamin C. [Achinewhu and Hart \(1994\)](#) compared the VC content of some pineapple varieties grown in the Rivers State of Nigeria. They found that the VC content of the fresh juice of *A. comosus* was the highest, with a concentration 33.5 mg/100 g, followed by *A. bracteatus* (30.3 mg/100 g), *Ananas ananassoides* (26.8 mg/100 g), and *Ananas erectifolius* (22.5 mg/100 g). [Ramsaroop and Saulo \(2007\)](#) found that the VC content in ‘MD-2’ flesh was 68 mg/100 g, although in the ‘Smooth Cayenne’ flesh, VC content was only 35 mg/100 g. [Wardy et al. \(2009\)](#) reported the VC contents of ‘MD-2’, ‘Sugarloaf’, and ‘Smooth Cayenne’ were 51.88, 42.11, and 21.04 mg/100 ml, respectively. [Montero-Calderón et al. \(2010b\)](#) reported that VC ranged from 305 to 351 mg/kg, with no statistical differences among the different parts of the ‘MD-2’ fruit.

We analyzed the vitamins content of 11 pineapple cultivars. The results are shown in [Table 7](#). Vitamin B₆ content varied between 0.0045 and 0.067 mg/g; it was the largest variation among these compounds. Vitamin C, vitamin A, and vitamin B₃ contents varied (0.10–0.23 mg/g, 0.0016–0.0038 mg/g, and 0.0038–0.024 mg/g, respectively). Vitamin B₁₂ in the fruit of ‘Comte de Paris’, ‘Tainung11’, ‘Golden Winter Sweet’, ‘Phuket’, and ‘New Phuket’ has not been detected, but in other cultivars the content varied between 0.0020 and 0.012 mg/g. The highest content of vitamin B₁₂ was in ‘Tainung19’. Vitamin B₃ and vitamin B₆ contents were the highest in ‘Golden Winter Sweet’, and the vitamin C and vitamin A in ‘Tainung11’ and ‘Smooth Cayenne’ were obviously higher than in other cultivars. According to these results, pineapple may be considered a good source of

Table 7 Vitamins content of different pineapple varieties (mg/g FW, [Li, 2012](#))

Cultivars	Vitamin A	Vitamin C	Vitamin B ₃	Vitamin B ₆	Vitamin B ₁₂
Comte de Paris	0.0038e	0.1778de	0.0089e	0.0069bc	—
Smooth Cayenne	0.0035d	0.0999a	0.0060c	0.0071c	0.0066c
Phuket	0.0025c	0.1860e	0.0049b	0.0066bc	—
MD-2	0.0024c	0.2239fg	0.0058c	0.0143e	0.0040b
Tainung19	0.0025c	0.1691d	0.0091e	0.0302f	0.0121e
Comte de Paris mutant	0.0016a	0.1769de	0.0090e	0.0049ab	0.0084d
Tainung11	0.0019b	0.2309g	0.0038a	0.0104d	—
Golden Winter Sweet	0.0018ab	0.1118b	0.0235f	0.0671g	—
Shenwan	0.0025c	0.2145f	0.0076d	0.0045a	0.0020a
New Phuket	0.0024c	0.1680d	0.0045b	0.0078c	—
Tainung17	0.0035d	0.1428c	0.0076d	0.0059abc	0.0120e
average	0.0025	0.1729	0.0082	0.0151	0.0041

Different letters in the same column mean significant differences at $P < 0.05$ by Duncan multiple range test.

vitamin A, vitamin C, and vitamin B₆. Some cultivars rich in vitamin B₁₂, such as ‘Tainung17’, ‘Tainung19’, and ‘Comte de Paris mutant’, can meet our need for vitamin B₁₂. The VC content in the fruit of ‘MD-2’ in this experiment was much lower than that reported by [Ramsaroop and Saulo \(2007\)](#) and [Wardy et al. \(2009\)](#). The difference may result from different growing environments.

Since vitamin contents among the cultivars analyzed were significantly different and some high vitamins contents have emerged, it would be interesting to breed for a high vitamin content variety for health-conscious consumers.

In addition to genotypes, large variability in vitamins content can be affected by multiple factors. Storage at room temperature for 2 weeks caused a reduction of 35–41% of the vitamin C ([Achinewhu and Hart, 1994](#)). [Wardy et al. \(2009\)](#) analyzed the VC content in the fruit of ‘MD-2’ at two different ripening stages, M1 (one-fourth of the shell color yellow) and M3 (three-quarters of the shell color yellow). VC in ‘MD-2’ at M1 was 54.17 mg/100 ml, and at M3 was 49.59 mg/100 ml. Vitamins content of the fruits of ‘Smooth Cayenne’ and ‘Comte de Paris’ ripened in summer and winter were compared by us. For the cultivar ‘Comte de Paris’, vitamins A and B₁₂ in summer fruit were much higher (0.29, 1.94 mg/g) than that in winter fruit (0.12, 0.20 mg/g). On the contrary, vitamins C and B₆ in summer fruit were much lower (15.07, 0.92 mg/g) than in winter fruit (29.49, 1.94 mg/g). There was no difference between vitamin B₃ content in summer and winter fruits with respective values of 1.25 mg/g and 1.53 mg/g. For the cultivar ‘Smooth Cayenne’, vitamin A and B₁₂ contents in summer fruit were much higher (0.29, 1.73 mg/g) than in winter fruit (0.14, 0.17 mg/g). There were no notable differences between vitamin C, B₃, and B₆ contents in summer and winter fruits, which were respectively 7.05, 1.04, 0.92 mg/g, and 9.51, 1.03, 1.09 mg/g.

Polyphenolic Compounds

Plants produce different scavenging and reducing compounds as well as enzymes as antioxidant defenses to maintain normal growth and metabolism (Pandhair and Sekhon, 2006). It has been reported that high consumption of fruits and vegetables has been associated with the possible management of many chronic diseases, such as cardiovascular disease and cancer (Leifert and Abeywardena, 2008; Bajpai et al., 2009). Plant compounds that contribute to the improvement of human health include the antioxidant polyphenolic compounds. Flavonoids, mainly present as pigments in plants, work also as potential antioxidants at various levels.

We evaluated the antioxidant properties and polyphenolic composition of 12 different genotype pineapples, and investigated the relationship of their antioxidant composition and antioxidant capacities by scavenging activity of 1,1-diphenyl-2-picryl hydrazyl (DPPH radical) and 2,2-azino-di-(3-ethylbenzothiazoline- sulphonic acid) (ABTS+ radical), reducing power, and metal-chelating capacity (MCC).

The total phenolic contents of pineapple samples were measured by using the Folin-Ciocalteu method, which relies on the electron transfer from phenolic compounds to the Folin-Ciocalteu reagent in alkaline media (Song et al., 2010). Total phenolic contents showed significant variations among the different genotypes, ranging from 25.71 to 72.57 mg GAE/100 g FW. 'MD-2' had the highest TP content (72.57 mg GAE/100 g), followed by 'Tainung4' (65.64 mg GAE/100 g), 'Fresh Premium' (46.76 mg GAE/100 g), and 'Smooth Cayenne' (40.42 mg GAE/100 g). The 'Red pineapple' had the lowest TP content (25.51 mg GAE/100 g). The results were similar to those reported in the study by Alothman et al. (2009). However, the total phenolic contents of the 12 pineapples in this study were lower than those obtained by Fu et al. (2011).

The total flavonoid (TF) contents of the pulp extracts showed significant differences, which varied from 10.40 to 50.57 mg RE/100 g FW. TF content for 'Ripley' was the highest, while 'Tainung17' was the lowest. Alothman et al. (2009) reported that the TF extracted by different solvents ranged from 1.37 to 4.14 mg catechin equivalent/100 g FW.

Phenolic acids exist in plants in different forms, such as aglycones (free phenolic acids), esters, glycosides, or bound complexes (Ross et al., 2009). The variation patterns of bioactive components and contents of different pineapple genotypes are listed in Table 8. The results provide direct evidence that phenolic compounds are genetically controlled. The pineapple samples investigated in our study had diverse phenolic acids profiles, among which catechin, epicatechin, and sinapinic acids were the predominant phenolic compounds. The difference between phenolic acids and other compounds reported in various studies could result from multiple factors, such as methodology (procedure of extraction, different susceptibilities to degradation, type of chromatography and quantification), genotypes, and growth environments (Ross et al., 2009; Pérez-Balibrea et al., 2011). The results obtained in this study indicated that 'Red pineapple' exhibited the highest total phenolic

Table 8 Concentrations of bioactive components in 11 pineapple cultivars

Genotypes	Contents of analysis (µg/g FW)											
	Garlic acid	Catechin	<i>p</i> -Hydroxybenzoic acid	Chlorogenic acid	Vanillic acid	Epicatechin	Cumaric acid	Ferulic acid	Erucic acid	Myricetin	Cinnamic acid	β-Carotene
New Phuket	0.76	80.68	0.39	0.02	—	7.89	—	0.05	35.44	0.10	0.007	1.72
Fresh premium	0.30	152.38	0.48	0.01	—	4.41	0.16	—	59.10	—	—	1.46
Ripley	0.48	122.24	0.31	0.03	—	4.40	0.22	0.14	—	—	0.03	1.90
Tainung17	0.14	43.57	0.21	0.03	—	10.15	—	0.003	2.48	0.38	0.07	2.44
Shenwan	0.30	24.00	0.16	0.19	0.08	—	—	0.10	26.63	0.33	—	0.31
Smooth Cayenne	0.54	63.33	0.57	0.04	—	3.70	—	—	38.20	0.08	0.08	1.15
Chenhuang	0.40	53.25	0.20	0.06	—	—	—	—	82.77	0.54	0.03	0.30
Comte de Paris	0.28	77.48	0.52	0.12	0.07	6.65	0.25	0.11	0.84	1.02	0.01	0.52
MD-2	0.24	80.94	0.68	0.06	0.13	2.14	0.11	0.20	1.36	0.71	0.05	0.40
Red pineapple	0.31	285.15	0.16	0.03	—	0.88	—	0.12	70.57	0.30	—	0.37
Josapine	0.43	91.70	0.48	0.01	0.13	6.90	0.26	0.07	84.89a	—	0.02	2.08

—, not detectable.

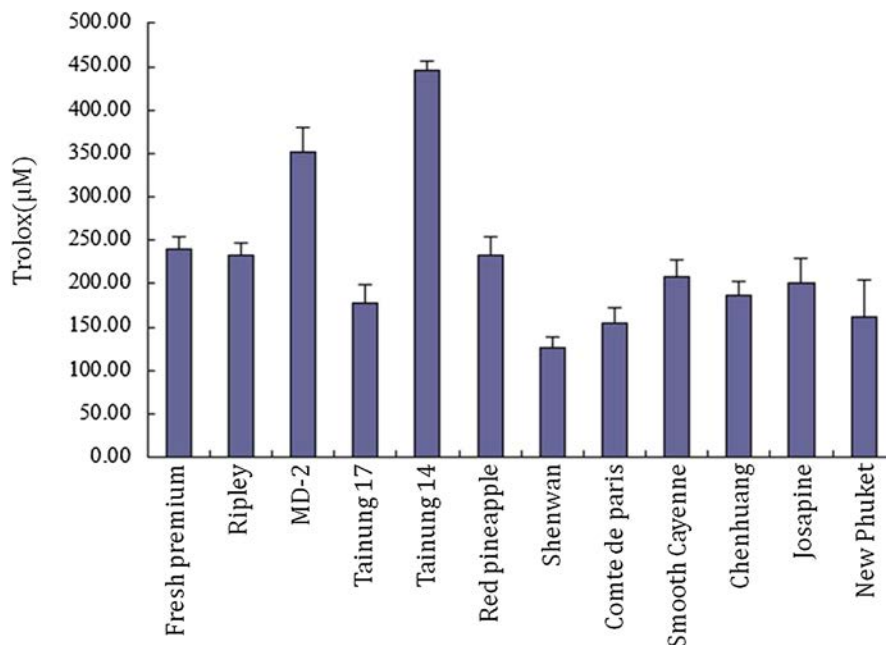


Figure 1 DPPH radical scavenging activity of different-genotype pineapples.

acids content ($357.52 \mu\text{g/g}$ FW), which was followed by ‘Fresh Premium’ ($216.86 \mu\text{g/g}$ FW), ‘Comte de Paris’ ($169.29 \mu\text{g/g}$ FW), and ‘Ripley’ ($127.85 \mu\text{g/g}$ FW), while ‘Shenwan’ was the lowest ($51.82 \mu\text{g/g}$ FW) among the samples studied (Table 8). Sinapinic acid was identified as a predominant phenolic acid in ‘Chenhuang’; catechin and sinapinic acids were detected as predominant phenolic acids in ‘Comte de Paris’, ‘Shenwan’, and ‘Josapine’, while the predominant compound in the other samples was catechin.

The summed phenolic acids determined chromatographically were not correlated with the total phenolic content. The difference could result from a lack of selectivity of the colorimetric Folin–Ciocalteu method. In addition, interference with other compounds (e.g., nitric compounds, saccharides) could occur during the determination of total phenol content (Siger et al., 2012).

Since the mechanisms involved in each method were different, the analysis provided only an estimate of antioxidant capacity. Thus, several methods have been developed to better estimate the antioxidant capacity of different plant materials. In our study, four different methods were used to evaluate the antioxidant capacity of the pineapple extracts (Figure 1). DPPH and ABTS methods depend on the spectrometric determination of OD by measuring the radicals’ scavenging ability but have different reaction mechanisms and conditions. The ferric-reducing antioxidant power (FRAP) assay is commonly used to study antioxidant capacity by reducing ferric iron to ferrous iron. The MCC method is used for evaluating the capacity of chelating ferrous iron.

The DPPH values of all pineapple extracts varied from 125 to 444 μM Trolox (Figure 1). ‘Tainung4’ had the highest DPPH value, followed by ‘MD-2’ (351.62 μM Trolox) and ‘Fresh premium’ (240.00 μM Trolox), while ‘Shenwan’ had the lowest (125.75 μM Trolox) among the extracts studied.

ABTS values ranged from 438 to 814 μM Trolox. ‘MD-2’ had the highest ABTS value, followed by ‘Tainung4’ (769 μM Trolox), ‘Ripley’ (683 μM Trolox), and ‘Fresh Premium’ (679 μM Trolox), and ‘New Phuket’ had the lowest ABTS value among the samples studied.

FRAP values ranged from 204 to 969 μM Trolox. FRAP value of ‘Tainung4’ was the highest, followed by ‘Shenwan’ (609.4 μM Trolox), ‘MD-2’ (519.5 μM Trolox), ‘Chenhuang’ (429 μM Trolox), ‘Smooth Cayenne’ (424 μM Trolox), and ‘Red pineapple’ (404 μM Trolox), while ‘Comte de Paris’ had the lowest antioxidant capacity among the extracts.

The MCC of fruit extracts varied from 4.9% to 13.3%. Their chelating ability from different genotypes in a decreasing value order was ‘Tainung4’ > ‘Tainung17’ > ‘Comte de Paris’ > ‘Red pineapple’ > ‘Smooth Cayenne’ > ‘New Phuket’ > ‘Shenwan’ > ‘Ripley’ > ‘Josapine’ > ‘Chenhuang’ > ‘Fresh Premium’.

Different fruits exhibit different antioxidant capacities according to polyphenol content, vitamin C, E, carotenoids, and flavonoids. Antioxidant activities depend on the plants’ genetic and environmental factors (Scalzo et al., 2005). The result obtained from this study showed that different genotypes had significantly different antioxidant capacities. The antioxidant activities of the tested samples were not in accordance with their polyphenolic contents. This may be the result of the presence of several individual bioactive compounds responsible for individual marked antioxidant activity as assayed through various in vitro modes (Amzad Hossain and Mizanur Rahman, 2011). The antioxidant capacities also depended on genetic and cultivation conditions.

Aroma Compounds

Distinct and pleasant flavor make pineapple an attractive fruit. The aroma of a fruit is a result of a specific blend of individual volatile components with a specific content of each of them. More than 280 compounds have been found among the volatiles of pineapples so far. Only a few of the volatiles have been identified as contributing to pineapple flavor. Tokitomo et al. (2005) reported that 29 odor-active compounds were detected in ‘Super Sweet’. Quantitative measurements by stable isotope dilution assays, and a calculation of odor activity values revealed 4-hydroxy-2,5-dimethyl-3(2H)-furanone, ethyl 2-methylpropanoate, ethyl 2-methylbutanoate, followed by methyl 2-methylbutanoate, and 1-(E,Z)-3,5-undecatriene as key odorants. Pino (2013) reported that 72 compounds were positively identified in ‘Red Spanish’ pineapple. Twenty odorants were considered as odor-active compounds, from which ethyl 2-methylbutanoate, 5-dimethyl-4-hydroxy-3(2H)-furanone, 1-(E,Z,Z)-3,5,8-undecatetraene, ethyl 3-(methylthio)

propanoate, 1-(*E,Z*)-3,5-undecatriene, ethyl hexanoate, and methyl hexanoate were the most odor-active contributors. [Elss et al. \(2005\)](#) showed that methyl 2-methylbutanoate, methyl 3-(methylthio)propanoate, methyl butanoate, methyl hexanoate, ethyl hexanoate, and ethyl 3-(methylthio)propanoate, as well as 2,5-dimethyl-4-methoxy-3(2H)-furanone and 2,5-dimethyl-4-hydroxy-3(2H)-furanone were major constituents. [Montero-Calderón et al. \(2010a\)](#) reported that 20 volatile compounds were identified and quantified in 'MD-2' pineapple. Among them, esters were the major components and accounted for 90% of total extracted aroma. Methyl butanoate, methyl 2-methylbutanoate, and methyl hexanoate were the three most abundant components, representing 74% of total volatiles, while the most odor-active contributors were methyl and ethyl 2-methylbutanoate and 2,5-dimethyl-4-methoxy-3(2H)-furanone. [Brat et al. \(2004\)](#) found that methyl 2-methylbutanoate, ethyl 2-methylbutanoate, and 4-hydroxy-2,5-dimethyl-3(2H)-furanone, methyl 3-(methylthio)propanoate, and ethyl 3-(methylthio)propanoate are impacting volatiles for Flhoran41. [Teai et al. \(2001\)](#) considered, however, methyl 3-(methylthio)propanoate; ethyl 3-(methylthio)propanoate; butanoic acid, 2-methyl-, methyl ester; butanoic acid, 2-methyl-, ethyl ester as major volatile components of the Polynesian pineapple.

Aroma profiles of six cultivars were analyzed by us using gas chromatography and mass spectrometry (GC-MS). The results are shown in [Table 9](#). A total of 83 volatile compounds were detected. In 'Smooth Cayenne', 26 aroma compounds were found, of which 3 were esters accounting for 11.1% of the total concentration, and 21 were alkenes and terpenes making up 65.1% of the total aroma content. In 'Queensland Cayenne', 17 volatiles were identified, of which 3 were esters holding 31.7% of the total aroma content; 7 were alkenes and terpenes taking 51.2% of the total aroma content. In 'New Phuket', 39 compounds were observed, including 8 esters holding 38.4% of the total aroma content, and 27 alkenes and terpenes sharing 61.1% of the total aroma content. Thirty-seven volatiles appeared in 'Shenwan', including 10 esters making up 35.1% of the total aroma content and 25 alkenes and terpenes accounting for 64.1% of the total aroma content. Forty-one aroma compounds appeared in 'Tainung17', including 12 esters holding 57.5% of the total aroma content and 29 alkenes and terpenes holding 42.5% of the total aroma content. Thirty-five aroma constituents were found in 'Tainung19', including 5 esters sharing 15.3% of the total aroma content and 30 alkenes and terpenes occupying 84.7% of the total aroma content. These results indicated that aroma components in 'Queen' group and hybrids were more diversified than those in the 'Smooth Cayenne' group.

Odor-active compounds of the six cultivars were selected using the odor activity value ([Table 10](#)). Two aroma components, decanal and butanoic acid methyl ester, were identified as odor-active compounds in 'Smooth Cayenne'. Five aroma components, decanal, nonanal, hexanoic acid methyl ester, γ -octalactone, and octanoic acid methyl ester were identified as odor-active compounds in 'Queensland Cayenne'. Four aroma

Table 9 Volatile compounds content in six pineapple cultivars

Volatile compound	Concentration($\mu\text{g/kg}$)					
	Smooth Cayenne	Queens-land Cayenne	New Phuket	Shen-wan	Tainung17	Tainung19
Butanoic acid, methyl ester	90.83					
Butanoic acid, 2-methyl-, methyl ester					766.92	
Butanoic acid, 2-methyl-, ethyl ester					217.69	
Hexanoic acid, methyl ester		143.04	623.86	332.55	1628.62	211.62
Hexanoic acid, ethyl ester			36.26	28.06	1080.39	8.75
3-(methylthio)propanoic acid methyl ester	52.97		134.47	67.24	72.25	
Hexanoic acid, 1-methylethyl ester			247.18	48.56		
3-(methylthio)propanoic acid ethyl ester					31.92	
4-Octenoic acid, methyl ester, (Z)-			72.40	40.14	137.59	15.34
Octanoic acid, methyl ester	48.79	274.69	743.21	310.70	749.27	86.01
Octanoic acid, ethyl ester				12.72		
n-Octanoic acid isopropyl ester				11.12	4.55	
Nonanoic acid, methyl ester			17.74	6.79	12.92	
Decanoic acid, methyl ester		29.09	175.32	53.35	260.93	35.82
Decanoic acid, ethyl ester					120.21	
2(3H)-Furanone, 5-butyldihydro-		14.14				
1,3,6-Octatriene, 3,7-dimethyl-, (E)-		20.25			91.21	39.20
D-Limonene		13.19		11.97	26.99	22.84
1,3,6-Octatriene, 3,7-dimethyl-, (Z)-		542.18	782.23	291.97	480.72	74.87
1,4-Cyclohexadiene, 1-methyl-4-(1-methylethyl)-			11.50		8.34	10.12
Cyclohexene, 1-methyl-4-(1-methylethylidene)-			11.64	6.34	3.27	14.78
(+)-4-Carene					12.92	
Bicyclo[4.1.0]hept-2-ene, 3,7,7-trimethyl-		5.06				
2,4,6-Octatriene, 2,6-dimethyl-, (E,Z)-		32.37	71.31	29.30	69.34	35.34
1-3,5,8-Undecatetraene	48.67	100.19	171.48	101.36	27.68	91.60
1-Decene				10.66		

Benzene, 1-methyl-4-(1-methylethenyl)- (<i>E,E</i>)-1,3,5-Undecatriene		8.08	8.82	3.57		4.30
(3 <i>Z</i> ,5 <i>E</i>)-1,3,5-Undecatriene	2.08					2.51
(-)-Aristolene	19.20					
Caryophyllene			78.01	34.89	116.00	
(+)-Cycloisosativene			106.09			90.99
Copaene			721.15			684.28
Naphthalene, 2,3,4,4a,5,6-hexahydro-1, 4a-dimethyl-7-(1-methylethyl)-						4.16
<i>cis</i> -(<i>-</i>)-2,4a,5,6,9a-Hexahydro-3,5,5,9- tetramethyl(1 <i>H</i>)benzocycloheptene					6.42	
1,2,4-Metheno-1 <i>H</i> -indene, octa- hydro-1,7a-dimethyl-5-(1-methyle- thyl)-, [1 <i>S</i> -(1 α .,2 α ,3 $\alpha\beta$,4 α ,5 α , 7 $\alpha\beta$,8 <i>S</i> *)]-				56.98	109.61	
Epizonarene	28.42					12.91
Cyclohexane,1-ethenyl-1-methyl- 2,4-bis(1-methylethenyl)-, [1 <i>S</i> -(1 α ,2 β ,4 β)]-	77.07		201.88	109.46	383.88	124.55
3-Carene						12.42
Bicyclo[4.1.0]heptane, 7-(1-methyle- thylidene)-				13.35		
2-Isopropenyl-4a,8-dimethyl- 1,2,3,4,4a,5,6,7-octahydronaphthalene	2.73					
Cycloisolongifolene						7.36
Caryophyllene	7.23			8.60		8.45
1 <i>H</i> -Cyclopropa[<i>a</i>]naphthalene, 1a,2,3,3a,4,5,6,7b-octahydro- 1,1,3a,7-tetramethyl-, [1 <i>aR</i> -(1 α ,3 $\alpha\alpha$,7 $\beta\alpha$)]-			102.29	62.76	160.85	70.68
10 <i>s</i> ,11 <i>s</i> -Himachala-3(12),4-diene	40.44					
α -Cubebene	160.94		3.00	335.22	1011.37	
1 <i>H</i> -Cyclopenta[1,3]cyclopropa[1,2] benzene, octahydro-7-methyl-3-meth- ylene-4-(1-methylethyl)-, [3 <i>aS</i> -(3 $\alpha\alpha$,3 $\beta\beta$,4 β ,7 α ,7 <i>aS</i> *)]-	15.62					

Continued

Table 9 Volatile compounds content in six pineapple cultivars—cont'd

Volatile compound	Concentration(µg/kg)					
	Smooth Cayenne	Queens-land Cayenne	New Phuket	Shen-wan	Tainung17	Tainung19
Isolongifolene, 4,5-dehydro-				14.21		
(+)-Epi-bicyclosquiphellandrene			84.54	44.87	118.52	60.07
Naphthalene, 1,2,4a,5,8,8a-hexahydro-			96.75	45.39		
4,7-dimethyl-1-(1-methylethyl)-, (1α,4aβ,8aα)-(.+/-.)-						
1,6,10-Dodecatriene, 7,11-dimethyl-	73.01					
3-methylene-, (E)-						
β-Guaiene					8.33	
Seychellene			8.84			
Cycloisolongifolene, 8,9-dehydro-					14.59	6.74
Naphthalene, 1,2,3,4-tetrahydro-	14.80					14.58
1,6-dimethyl-4-(1-methylethyl)-, (1S-cis)-						
Naphthalene, 1,2,4a,5,6,8a-hexahydro-4, 7-dimethyl-1-(1-methylethyl)-				168.92	284.76	
Naphthalene, 1,2,3,4,4a,5,6,8a-octa-	161.36		225.46			
hydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1α,4aα,8aα)-						
Neoisolongifolene			22.32			10.82
Azulene, 1,2,3,3a,4,5,6,7-octahydro-					65.64	24.41
1,4-dimethyl-7-(1-methylethenyl)-, [1R-(1α,3aβ,4α,7β)]-						
Naphthalene, 1,2,4a,5,6,8a-hexahydro-	256.99		291.52	187.56	430.86	267.26
4,7-dimethyl-1-(1-methylethyl)-, (1α,4aα,8aα)-						
Isolodene	17.20		23.12		15.43	24.84
α-Farnesene				16.31		
Bicyclo[3.1.1]hept-2-en@e,	56.38		39.05	18.08	53.99	50.88
2,6-dimethyl-6-(4-methyl-3-pentenyl)-						

1H-Cycloprop[e]azulene, 1a,2,3,4,4a,5,6,7b-octahydro-1,1,4,7- tetramethyl-, [1aR-(1a α ,4a α ,4a β ,7b α)]-	15.92		34.13	20.36	59.26	115.31
Naphthalene, 1,2,3,5,6,8a-hexahydro- 4,7-dimethyl-1-(1-methylethyl)-, (1S-cis)- (-)-Isoledene	87.64		90.99	55.12	97.54	81.41
Naphthalene, 1,2,4a,5,8,8a-hexahydro- 4,7-dimethyl-1-(1-methylethyl)-, [1S-(1a α ,4a β ,8a α)]-			13.23	8.77	31.36	
α -Calacorene	13.67				12.09	
Naphthalene, 1,2,3,4,4a,7-hexahydro- 1,6-dimethyl-4-(1-methylethyl)- β -Vatirenene	15.35		13.81		7.67	9.18
Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro- 4a,8-dimethyl-2-(1-methylethenyl)-, [2R-(2a α ,4a α ,8a β)]-			11.32		34.20	
Naphthalene, 1,6-dimethyl-4-(1- methylethyl)-	11.21		28.35			
Kaur-16-ene			14.43	9.97	16.00	5.15
1-Nonanol		32.21				
1-Octanol		9.15				
1,6,10-Dodecatrien-3-ol, 3,7,11- trimethyl-	403.89					
2,5-Dimethyl-4-hydroxy-3(2H)- furanone		9.47	5.02			
5,9-Undecadien-2-one, 6,10-dimethyl-, (E)-		26.34				
Nonanal		110.69				
Decanal	7.61	38.50	5.38	10.92		
Phenol, 4-(2-propenyl)-				11.14		
Benzene, 1,3,5-tris(1-methylethyl)-			9.81			
Hexanoic acid			6.68			
Sum	1730.01	1408.66	5344.62	2599.28	8842.09	2339.57

Table 10 Odor-active compounds in six pineapple cultivars

Aroma compound	Odor threshold ($\mu\text{g/kg}$)	Odor activity values					
		Smooth Cayenne	Queens-land Cayenne	New Phuket	Shen-wan	Tainung17	Tainung19
Butanoic acid, methyl ester	59 ^a	1.54					
Butanoic acid, 2-methyl-, methyl ester	2 ^d					383.46	
Butanoic acid, 2-methyl-, ethyl ester	0.15 ^d					1451.26	
Hexanoic acid, methyl ester	70 ^a		2.04	8.91	4.75	23.27	3.02
Hexanoic acid	3000 ^a			0.002			
Hexanoic acid, ethyl ester	0.76 ^a			47.72	36.92	1421.56	11.51
3-(Methylthio)propanoic acid methyl ester	180 ^b	0.29		0.75	0.37	0.40	
2,5-Dimethyl-4-hydroxy-3(2H)-furanone	10 ^d		0.95	0.50			
γ -Terpinene	1000 ^a			0.01		0.008	0.01
1-Octanol	190 ^a		0.05				
Cyclohexene, 1-methyl-4-(1-methylethylidene)-	200 ^a			0.06	0.03	0.02	0.07
3-(Methylthio)propanoic acid ethyl ester	7 ^f					4.56	
Nonanal	1 ^a		110.69				

Octanoic acid, methyl ester	200 ^a	0.24	1.37	3.72	1.55	3.75	0.43
1-(<i>E,E</i>)-3,5-Undecatriene	750 ^e		0.01	0.01	0.005		
Octanoic acid, ethyl ester	2 ^c				6.36		
Decanal	2 ^b	3.81	19.25	2.69	5.46		
γ -Octalactone	7 ^a		2.02				
β -Caryophyllene	64 ^a	0.11		1.22	0.68	1.81	0.13
3-Carene	770 ^a						0.02
Decanoic acid, ethyl ester	6300 ^d					0.02	

^aPino, J.A., Mesa, J., 2006. Contribution of volatile compounds to mango (*mangifera indica* L.) aroma. Flavor and Fragrance Journal 21, 207–213.

^bPlotto, A., Margaria, C.A., Goodner, K. L., Baldwin, E. A., 2008. Odor and flavor thresholds for key aroma components in an orange juice matrix: esters and miscellaneous compounds. Flavor and Fragrance Journal 23, 398–406.

^cGuth, H., 1997. Quantitation and sensory studies of character impact odorants of different white wine varieties. Journal of Agricultural and Food Chemistry 45(8), 3027–3032.

^dTokitomo et al. (2005).

^eBerger et al. (1985).

^fTakeoka et al. (1991).

components, decanal, hexanoic acid ethyl ester, hexanoic acid methyl ester, and octanoic acid methyl ester were identified as odor-active compounds in 'New Phuket'. Five aroma components, decanal, hexanoic acid, ethyl ester, octanoic acid, ethyl ester, hexanoic acid, methyl ester, and octanoic acid, methyl ester were identified as odor-active compounds in 'Shenwan'. Six aroma components, butanoic acid 2-methyl-ethyl ester, butanoic acid 2-methyl-methyl ester, hexanoic acid ethyl ester, hexanoic acid methyl ester, 3-(methylthio)propanoic acid ethyl ester, and octanoic acid methyl ester were identified as odor-active compounds in 'Tainung17'. Two aroma components, hexanoic acid ethyl ester and hexanoic acid methyl ester, were identified as odor-active compounds in 'Tainung19'. Furthermore, 1,3,5,8-undecatetraene content was higher in all six cultivars. [Berger et al. \(1985\)](#) considered that 1-(*E,Z,Z*)-3,5,8-undecatetraene, with extremely low odor detection thresholds, may contribute to the typical flavor of pineapple. [Soler et al. \(2006\)](#) found a relative intragroup homogeneity of aroma profiles for the different groups of pineapple. The most homogeneous group of cultivars, all giving almost identical aroma profiles, was the 'Queen' group, and the different 'Queen' varieties could not be differentiated using the Headspace solid phase microextraction (HS-SPME) extraction method. In our study, aroma composition and odor-active compounds of the two 'Queen' varieties, 'Shenwan' and 'New Phuket' were similar, but those of the two 'Cayenne' pineapples and of the two hybrids were obviously different. Some compounds are odor-active compounds of some varieties but may be not important to other varieties. For example 2,5-dimethyl-4-hydroxy-3(2H)-furanone was identified as a key odorant in 'Super Sweet', 'Red Spanish', and 'Flhoran41' ([Brat et al., 2004](#); [Tokitomo et al., 2005](#)) but was not detected in MD-2 ([Montero-Calderón et al., 2010a](#)).

Besides genotypes, volatile compounds are affected easily by fruit maturity and environmental factors. [Brat et al. \(2004\)](#) found that there was an increase in all classes of aroma compounds with the maturing, although their relative proportions were similar in the hybrid 'Flhoran41' and 'Smooth Cayenne' at full maturity. This may be explained by the release of free or glycosidically bound molecules during the ripening process by glycosidases.

SUMMARY

'Smooth Cayenne', accounting for 90% of processing pineapple, has been the backbone of the global pineapple industry for more than a century. Cultivars of the Cayenne group have a high content of total soluble sugar and acidity. Queen group pineapple, mainly for fresh consumption, contains high sugar and moderate acidity. Both sugar and acidity are low in Spanish group cultivars. 'Pérola' is one of the most important cultivars of the Pernambuco group, with a higher total soluble sugar (14.6°Brix) and a lower acidity (0.37%). The sugar content of 'Perolera' cultivar was 14.1°Brix and the acidity was 0.76%.

Hybrid 'MD-2' is a famous cultivar dominating the world fresh pineapple market. The average percentage of TSS in MD-2 is 1–2% higher than 'Smooth Cayenne'. The acidity is lower than that of 'Smooth Cayenne'. Total sugar contents in 16 modern pineapple cultivars varied from 81.59 to 124.41.65 mg/g FW. The average value (108.14 mg/g FW) was higher than that in traditional cultivars (106.29 mg/g FW). However, the highest sugar content was lower than that in traditional cultivars (137.89 mg/g FW). The values of total organic acid in modern cultivars changed from 1.80 mg/g FW to 6.90 mg/g FW. The lowest, highest, and average contents of total organic acid in modern cultivars were lower than those in traditional cultivars.

Total dietary fiber content varied from 1.46% to 2.80% FW. The average contents of NDF, ADF, CEL, HC, ADL, TP, WSP, and protopectin in 12 cultivars analyzed were 32.70, 20.65, 16.96, 12.24, 2.98, 3.06, 1.16, and 1.91 mg/100 g DW, respectively.

Vitamin C, vitamin A, vitamin B₃, and vitamin B₆ contents in 11 varieties changed between 0.10 and 0.23 mg/g, 0.0016–0.0038 mg/g, 0.0038–0.024 mg/g, and 0.0045–0.067 mg/g respectively. It seems that pineapple is a good source of vitamin A, vitamin C, and vitamin B₆.

Both total polyphenols and flavonoids could be the main components responsible for the antioxidant capacities in pineapple fruit. Total phenolic contents showed significant variations among different genotypes, ranging from 25.71 to 72.57 mg GAE/100 g FW. Catechin, epicatechin, and sinapinic acid were the predominant phenolic compounds. The TF contents of the pulp extracts had significant differences, which varied from 10.40 to 50.57 mg RE/100 g FW. 'MD-2' and 'Tainung4' exhibited higher antioxidant capacities than the other cultivars as determined by DPPH, ABTS, and FRAP methods.

Eighty-three volatile compounds were detected in six pineapple cultivars, including 15 esters and 57 alkenes and terpenes. Total concentration of aroma in 'Tainung17' was the highest (8842.09 µg/kg), while in 'Queensland Cayenne' it was the lowest (1408.66 µg/kg). Butanoic acid 2-methyl-methyl ester, butanoic acid, 2-methyl-ethyl ester, hexanoic acid methyl ester, hexanoic acid, ethyl ester, and decanal appeared to be the main odor-active compounds.

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CHAPTER 26

Plum (*Prunus domestica* L. and *P. salicina* Lindl.)

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LIST OF ABBREVIATIONS

3HCQ 3'-Hydroxycoumaroyl quinic acid
AA Ascorbic acid
CG Chlorogenic acid

CCG Cryptochlorogenic acid
Cy Cyanidin
DPPH 2,2-Diphenyl-1-picrylhydrazyl
DW Dry weight
FRAP Ferric reducing antioxidant power assay
FW Fresh weight
GAE Gallic acid equivalents
NCG Neochlorogenic acid
PCA Procyanidin A type dimer
PCB1 Procyanidin B1
PCB2 Procyanidin B2
PCB4 Procyanidin B4
Peo Peonidin
QGluc Quercetin-3-glucoside
QPH Quercetin pentosyl hexoside
Q3R Quercetin 3-rhamnoside
Q3X Quercetin 3-xyloside
RUT Quercetin 3-rutinoside
TA Titratable acidity
TSS Total soluble solids
TE Trolox equivalents

INTRODUCTION

Plum is one of the most important stone fruits, consumed mainly fresh and dried, although a small quantity is used for canning and beverages (Bhutani and Joshi, 1995). Plums are characterized by variation in many plant characteristics. The fruits may be small or large, round or oval, green, yellow, golden, black, purple, or blood red, with a variety of flavor, aroma, and texture (Bhutani and Joshi, 1995; Rieger, 2006). The tree may be characterized as a shrub-like one, while on the other hand it may have a strong canopy framework. The leaves may be delicate or coarse, and green or red (in landscape plums or in some rootstocks).

Wild plum trees are the symbols of independence, while plum flower is the national flower of Taiwan. Plum flowers are often found in ancient Asian art (Rieger, 2006).

The most commercially important species of plums are the European (*Prunus domestica* L.) and Japanese (*P. salicina* Lindl.) plums.

Prunus domestica is a relatively young species, said to originate from eastern Europe (presumably in the Balkan area) or western Asia in the Caucasus Mountains near the Caspian Sea (Faust and Suranyi, 1999; Rieger, 2006). It has been cultivated in Europe for almost 2000 years, based on the fact that *P. domestica* seeds were not found during the excavations of Pompeii, where seeds of most other known Old World fruits were discovered. It is hexaploid and is believed to have resulted from the hybridization of the diploid *P. cerasifera* with the tetraploid *P. spinosa*, either with subsequent spontaneous chromosome doubling or as a product of unreduced gametes from both parents

(Faust and Suranyi, 1999; Rieger, 2006). European plums were introduced to America by Spanish missionaries (west coast) and English colonists (east coast) (Faust and Suranyi, 1999; Rieger, 2006).

Prunus salicina is equally important to European plums, especially as fresh market fruit. In many countries (including European ones) Japanese cultivars are cultivated in higher ratio than European ones (Rieger, 2006). It is believed to have originated in China, where it was cultivated for thousands of years and transferred to Japan approximately 200–400 years ago, from where it was spread all over the world and took its name (Faust and Suranyi, 1999; Rieger, 2006). Many hybrids of this species have been made and used either as cultivars or rootstocks.

Recently, many hybrids between plum and apricot have been introduced, named either as ‘plumcots,’ in which plum and apricot genome contribute equally to the hybrid; ‘apriums’, with apricot contributing 75%; and ‘plumcots’ with plum contributing 75% to the genome (Rieger, 2006).

As with all stone fruits, plum leaves, flowers, and especially bark and seeds contain toxic compounds that generate cyanide, which can be toxic in large doses, whereas in smaller doses it is thought not to be toxic but, rather, therapeutic, especially for tumor treatment (Rieger, 2006).

China is the world leader in plum production, followed by the United States and some European countries, especially those from the Balkan region.

BOTANICAL ASPECTS

Plum belongs to the genus *Prunus*, in the subfamily Prunoidae of the family Rosaceae. Plums are classified in the subgenus *Prunophora*, section *Euprunus* (or “true plums”) and *Prunocerasus* (“plum cherries”) (Faust and Suranyi, 1999; Rieger, 2006). Nearly 200 species have been reported in the genus *Prunus*, and the most important plums are classified into three types: the European plum (*Prunus domestica* L.), the Japanese plum (*P. salicina* Lindl.), and hybrids of the latter (Faust and Suranyi, 1999).

Prunus domestica trees are taller, can reach 10–12 m in height, with more upright–erect habit, longer lived, more cold tolerant, and later blooming than Japanese plums (Faust and Suranyi, 1999; Rieger, 2006). The cultivated European plum varieties are characterized by straight spineless branches. The bark is dull brown, while the young twigs are dull and usually pubescent. Leaves are simple, quite large, 3–10 × 1.8–6 cm, thick, obovate to elliptical, crenate to serrate, glabrous and dull green in the adaxial surface, and densely pubescent to subglabrous in the abaxial surface, especially when they are young, with the hairs often restricted to the midrib and veins with leaf adulthood (Browicz, 1972; Webb, 1968). Flowers are white, large (15–25 mm in diameter), and usually formed in clusters of two to three, appearing simultaneously with the leaves in most cases. Leaf pedicel is about 5–20 mm in length, with white petals 7–12 mm length.

Fruits are drupes, 20–80 mm in length, ovoid or subglobose, smaller in size and more variable in color than Japanese plums, sweet to slightly acidic, and not astringent (Browicz, 1972; Webb, 1968). European plum fruits present both yellow and green ground colors with red and blue skins.

The European plum cultivars are classified into four groups (Bhutani and Joshi, 1995; Rieger, 2006), namely:

1. Prunes, the most commercially important group, with fruits characterized by high sugar content and freestone, which can be dried without removing the pit. Prunes are oval, dark blue or purple, firm, and thick.
2. Reine Claude, with fruits that are close to round in shape, green to yellow, slight red or gold color. The flesh is sweet and juicy, used mainly for fresh consumption or canning.
3. Yellow egg, with cultivars used mainly for canning. The fruit is large, long to oval in shape, with yellow skin and yellowish flesh.
4. Lombard, a group of large, oval, red to pink plums of fair quality, used for fresh consumption.

Japanese plum is a strong, growing, small tree with rough bark and numerous long-lived fruiting spurs. It is characterized by more precocious flowering than European plum, which makes it susceptible to late-winter or early-spring frosts (Bhutani and Joshi, 1995). The growth habit of the tree varies among cultivars from upright growth to a more spreading one. The leaves are simple, oblong to ovate, medium sized, sharp pointed, shiny, and almost free of pubescence. The flowers are white, emerging usually in groups of three mainly on spurs and less on 1-year-old wood. The fruit is variable in size, large, and quite firm. The fruit surface is covered by a light gray wax deposit, which makes the surface impermeable to water and protects the fruit from water loss (if undisturbed during harvest). The flesh and skin color of ripe fruits vary from yellow to deep red.

Plum is one of the few fruit trees able to withstand heavy soils and water logging, depending also on the rootstock used. Nevertheless, in deep sandy-loamy, well-drained soils with a pH of 5.5–6.5, plum grows better (Bhutani and Joshi, 1995; Rieger, 2006). Plums can grow in a variety of climatic conditions, assuming that the chilling requirements are fully covered (Japanese plums have relatively low chilling requirements, about 550–800 h, while European plums require more than 800 h) (Bhutani and Joshi, 1995; Rieger, 2006). Plum flower buds tolerate temperature in the range of -15 to -35°C when dormant, albeit with the wood suffering damages under lower temperatures (Bhutani and Joshi, 1995; Rieger, 2006). During flowering, open flowers or young fruitlets are killed after brief exposure to temperatures below -2.2°C , depending on, among other things, the cultivar.

In general, cold, wet, windy weather during the flowering period is harmful to the crop. Fruit matures approximately 3–6 months after flowering, depending on the cultivar.

Areas characterized by high rainfall or high relative humidity are not suitable for plum cultivation, since, in these areas, the cost of phytoprotection is quite high.

COMPOSITION OF TRADITIONAL PLUM CULTIVARS

Organoleptic Characteristics of Traditional Plum Cultivars

Total soluble solids (TSS) in traditional plum cultivars have been found to range from 9.5 °Brix in ‘Greengage’ to 15.5 °Brix in ‘Mariposa’ (Wills et al., 1983) (Table 1). Titratable acidity has been found in ‘Santa Rosa’ to range from 1.67 to 2.48 g malic acid equivalents 100 g⁻¹ FW (Daza et al., 2012). Wills et al. (1983) have found ‘Narrabeen’ to exhibit the lowest titratable acidity and ‘Santa Rosa’ the highest (13.7 and 39.5 meq H⁺ 100 g⁻¹ FW, respectively). ‘Gulfruby’ has also been found to exhibit high titratable acidity, reaching 39.5 mmol H⁺ L⁻¹ juice, while in ‘Shiro’ the titratable acidity has been measured at 21.5 mmol H⁺ L⁻¹ juice (Abdi et al., 1997).

Carbohydrate Composition of Traditional Plum Cultivars

The main carbohydrates detected in plum fruits are sucrose, glucose, fructose, and sorbitol (Table 2) (Cinquanta et al., 2002; Forni et al., 1992; Wills et al., 1983). Apparently there is not a specific carbohydrate prevailing, since sucrose, glucose, and fructose have been determined in similar concentrations. Sucrose has been found in concentrations ranging from 1000 to even 6270 mg 100 g⁻¹ FW in ‘Santa Rosa’ and ‘Sel D8 Dark’, respectively (Forni et al., 1992). Glucose is found in the lowest concentration in ‘Wilson’ (1700 mg 100 g⁻¹ FW) and in the highest one in ‘Sel D8 Dark’ (6020 mg 100 g⁻¹ FW). ‘Sel D5’ exhibits the lowest fructose concentration (760 mg 100 g⁻¹ FW), while the highest one is found in ‘Tradicotes light’ (5450 mg 100 g⁻¹ FW). Sorbitol, a common sugar alcohol in stone fruits, ranges from 1000 mg 100 g⁻¹ FW in ‘Blue Fre’ to 5330 mg 100 g⁻¹ FW in ‘Sel D8’ dark. The latter cultivar exhibited the highest total carbohydrate concentration (14,700 mg 100 g⁻¹ FW), with ‘Valor’ presenting the lowest one (7840 mg 100 g⁻¹ FW) (Forni et al., 1992).

Organic Acid Composition of Traditional Plum Cultivars

The major organic acid found in plums is malic acid (Table 3). It has been found in concentrations ranging from 1140 to 2540 mg 100 g⁻¹ FW in ‘Blood’ and ‘Santa Rosa’, respectively (Wills et al., 1983). Quinic acid is also present in significant amounts, ranging from 120 to 410 mg 100 g⁻¹ FW in ‘Greengage’ and ‘Wilson’, respectively. Citric acid is found in significantly lower concentrations, ranging from 18 to 44 mg 100 g⁻¹ FW in ‘Narrabeen’ and ‘Greengage’, respectively. The total organic acid concentration is higher in ‘Santa Rosa’ cultivar (2700 mg 100 g⁻¹ FW), followed by ‘Wilson’ (2100 mg 100 g⁻¹ FW) and ‘Mariposa’ (1600 mg 100 g⁻¹ FW), while ‘Blood’ and ‘Greengage’ exhibit similar concentrations (1500 mg 100 g⁻¹ FW) and ‘Narrabeen’ the lowest one (1400 mg 100 g⁻¹ FW) (Wills et al., 1983).

Table 1 Organoleptic characteristics of traditional and modern plum cultivars

Traditional			Modern								
Cultivar	TSS	TA g malic acid 100 mL ⁻¹	Cultivar	TSS	TA g malic acid 100 mL ⁻¹	Cultivar	TSS	TA g malic acid 100 g ⁻¹	Cultivar	TSS	TA g malic acid 100 g ⁻¹
Santa Rosa	11.2–13.8	2.48	Black Beaut	12.1	–	Angeleno	12.4–13.5	1.0	Larry-Ann	14.4–18.1	0.9
		meq H ⁺ 100 g ⁻¹	Edda	17.4	–	Avalon	15.8–18.4	2.3	Reeves	11.9–14.5	0.9
Blood	16.3	16.3	Elena	16.3	–	Black Amber	10–13.3	1.2	Songold	12.36–13	0.7
Greengage	9.5	16.5	Friar	13.4–14.9	1–1.4	Black Diamond	–	0.8	Souffriau	13	1.1
Mariposa	15.5	18	Jojo	9.1	–	Bluefre	10.3	–	Stanley	14.7	0.8
Narrabeen	12.5	13.7	Laetitia	11.7–13.8	1.0–1.8	Cacanska najbolja	11.4	–	TC Sun	–	0.7
Santa Rosa	11.5	30.5	Prime-time	11.6–13.4	1.3–2.7	Cacanska rodna	8.2	–	Tophit	15.7	1.1
Wilson	11	22.4	Red Beaut	9.2–11.9	1.6–2.2	Excalibur	13.5–14.6	0.9	Valor	12–18.3	1.1
		mmol H ⁺ L ⁻¹	Sapphire	12.6–14.8	1.0–1.9	Fortune	12.1–14.4	1.4	Victoria	15.1–15.7	1.4
Beauty	13.5	29.6	Show-time	10.3–13.8	1.0–1.3	Golden Globe	–	0.6			
Gulfruby	13–13.3	35.1–39.5	Souvenir	12.2–14.7	1.7–1.9	Golden Japan	9.4–10.5	1.6			
Ruby red	12.0	32.4	Wegierka	18.1	–	Hanita	16.2	1.8			
Shiro	11.4	21.5	Zwykła	10.3	–	Jubileum	13.4–16.3	1.1			
			Wickson								

The table shows the mean values as well as the range of total soluble solids concentration and titratable acidity of various traditional and modern plum cultivars. TA, titratable acidity; TSS, total soluble solids.

Adapted from [Abdi et al. \(1997\)](#), [Daza et al. \(2012\)](#), [Díaz-Mula et al. \(2009\)](#), [Gil et al. \(2002\)](#), [Karaman et al. \(2013\)](#), [Kristl et al. \(2011\)](#), [Meland \(2010\)](#), [Usenik et al. \(2009\)](#), [Vangdal et al. \(2007\)](#), [Walkowiak-Tomczak et al. \(2008\)](#) and [Wills et al. \(1983\)](#).

Table 2 Carbohydrate composition of traditional plum cultivars

Cultivar	Sucrose	Glucose	Fructose	Sorbitol	Total	Cultivar	Sucrose	Glucose	Fructose	Sorbitol	Total
mg 100 g ⁻¹ of FW											
Blood	2900	2300	1900	—	—	Sel B 30	4050	3580	1870	2940	9500
Blue Bel	3490	3690	2170	1760	9350	Sel D5	5920	4930	760	3120	11,600
BlueFre	3060	4050	2600	1000	9710	Sel D8 dark	6270	6020	2410	5330	14,700
D'Ente	3050	4020	2220	2280	9290	Sel D8 light	5030	4780	1780	2920	11,600
D'Ente 707	2150– 3790	4450– 5030	2390– 3590	2670– 2890	8890– 12,400	Stanley	3970– 4690	4170– 4880	2990– 3020	2380– 2560	11,800– 11,900
Greengage	3400	2300	2100	—	—	Tardicotes dark	2050	5460	5230	2770	12,700
Mariposa	2800	4900	1900	—	—	Tardicotes light	1960	5110	5450	3130	12,500
Narrabeen	2100	2000	2000	—	—	Tuleu Dulce	4460	4750	2950	3980	12,200
Prugna	4080	4720	3620	2370	12,400	Valor	2030	3430	2380	1670	7840
D'Argento	1000	2700	2200	—	—	Zucchella	5460	3680	780	2300	9992
Santa Rosa	2390–	2020–	940–1200	1810–	8040–						
Sugar	5060	4740		2470	10,100						
Wilson	3200	1700	900	—	—						

The table presents the mean concentration of the major carbohydrates detected in various traditional plum cultivars.
Adapted from Cinquanta et al. (2002), Forni et al. (1992) and Wills et al. (1983).

Table 3 Organic acids composition of traditional and modern plum cultivars

Traditional					Modern					
Cultivar	Citric	Malic	Quinic	Total	Cultivar	Citric	Malic	Shikimic	Fumaric	Total
mg 100g ⁻¹ of FW										
Blood	34	1140	340	1500	Cacanska Najbolja	—	940	5.28	0.78	—
Greengage	44	1370	120	1500	Cacanska Rodna	—	1620	4	1.27	—
Mariposa	36	1420	190	1600	Formosa	2.8	172.8	6.8	0.3	—
Narrabeen	18	1200	160	1400	Haganta	—	730.3	2.9	0.5	740
Santa Rosa	26	2540	170	2700	Jojo	—	672.6–2180	2.8–5.97	1.1–3.68	680
Wilson	30	1670	410	2100	Red Beaut genotype (606)	62	1970	6	—	21–40
					Shiro	25.2–27	198–202	—	—	—
					Valor	—	1090	6.27	0.8	—

The table shows the mean as well as the range of concentration of the major organic acids detected in the fruits of various traditional and plum cultivars. Adapted from Bae et al. (2014), Lombardi-Boccia et al. (2004), Melgarejo et al. (2012), Usenik et al. (2009, 2013) and Wills et al. (1983).

Phenolic Compound and Anthocyanin Composition of Fruits of Traditional Plum Cultivars

‘Sugar’ exhibited the highest total phenol concentration among traditional plum cultivars, reaching 3200 mg gallic acid equivalents (GAE) Kg^{-1} FW with the major phenolic compound being neochlorogenic acid ($195.3 \text{ mg } 100 \text{ g}^{-1}$ FW), followed by chlorogenic acid and rutin (Tables 4 and 5) (Piga et al., 2003). In the peel of ‘Santa Rosa’, the predominant phenolic compound was procyanidin B4, followed by procyanidin B1 and neochlorogenic acid (Tomás-Barberán et al., 2001).

Cyanidine-3-glucoside and cyanidine-3-rutinoside have been found in low concentrations in ‘Victoria’ (0.21 and $0.46 \text{ mg } 100 \text{ g}^{-1}$ FW, respectively) (Table 6) as well as traces of peonidine-3-rutinoside (Slimestad et al., 2009).

Vitamin Composition of Traditional Plum Cultivars

The major vitamin found in plums is ascorbic acid (vitamin C) (Table 7). Its concentration ranges from 4 (‘Santa Rosa’, ‘Narrabeen’) to $6 \text{ mg } 100 \text{ g}^{-1}$ FW (‘Wilson’, ‘Blood’) (Wills et al., 1983). Other vitamins found are thiamin, riboflavin, and niacin, with the latter present in higher concentration than the former two ones, lower though than that of vitamin C (Wills et al., 1983). Niacin has been found in concentrations ranging from 0.3 (‘Narrabeen’) to $0.9 \text{ mg } 100 \text{ g}^{-1}$ FW (‘Wilson’, ‘Santa Rosa’), while thiamin ranges from 0.02 (‘Narrabeen’) to $0.05 \text{ mg } 100 \text{ g}^{-1}$ FW (‘Greengage’) and riboflavin from 0.04 (‘Blood’, ‘Greengage’, ‘Mariposa’) to $0.05 \text{ mg } 100 \text{ g}^{-1}$ FW (‘Wilson’, ‘Narrabeen’, ‘Santa Rosa’) (Wills et al., 1983).

Carotenoid Composition of Traditional Plum Cultivars

The main carotenoid found in the fruits of traditional plum cultivars is β -carotene; β -cryptoxanthin and α -carotene have also been detected but in significantly lower amounts (Table 8) (Gil et al., 2002; Wills et al., 1983). β -Carotene has been found in concentrations ranging from $0.09 \text{ mg } 100 \text{ g}^{-1}$ FW in ‘Narrabeen’ to $0.225 \text{ mg } 100 \text{ g}^{-1}$ FW in ‘Blood’ (Wills et al., 1983). In ‘Santa Rosa’ flesh, Gil et al. (2002) determined only $0.049 \text{ mg } 100 \text{ g}^{-1}$ FW of β -carotene, with the peel being the richest fruit part, exhibiting $0.228 \text{ mg } 100 \text{ g}^{-1}$ FW. On the other hand, α -carotene was found in ‘Narrabeen’ at $0.005 \text{ mg } 100 \text{ g}^{-1}$ FW and β -cryptoxanthin in ‘Santa Rosa’ at 0.007 and $0.039 \text{ mg } 100 \text{ g}^{-1}$ FW in the flesh and peel, respectively. Overall, the total carotenoid content of plum fruits has been found to range from $0.26 \text{ mg } \beta$ -carotene equivalents 100 g^{-1} FW in ‘Santa Rosa’ to $0.778 \text{ mg } \beta$ -carotene equivalents 100 g^{-1} FW in ‘Mariposa’ (Wills et al., 1983).

Mineral Element Concentration in Traditional Plum Cultivars

Potassium is the most abundant macronutrient found in plum fruits, along with calcium, magnesium, and sodium (Table 9) (Ertekin et al., 2006; Wills et al., 1983). It has been determined in concentrations ranging from 120 to $190 \text{ mg } 100 \text{ g}^{-1}$ FW in ‘Narrabeen’ and ‘Mariposa’ cultivars, respectively. Calcium and magnesium are found in significantly lower concentrations. ‘Blood’ cultivar exhibited the highest Ca concentration

Table 4 Total phenolic compounds and antioxidant capacity of traditional and modern plum cultivars

Cultivar	Total phenols (mg GAE Kg ⁻¹ FW)	ABTS (mg AA g ⁻¹ FW)
Traditional cultivars		
Santa Rosa ^a	379	—
Sugar ^b	3200	—
Victoria	443	6.8 ^c
Modern cultivars		
Angeleno ^a	407	—
Augustinka	3020	3.5
Avalon	278	4.7 ^c
Bistrica	2313	—
Black Amber	2024	946.5
Black Beauty ^a	769	—
Bluma	3580	3.2
Bryska	3150	3.4
Durancie	4180	4.7
Elena	1742	—
Empress ^b	5600	—
Excalibur	197	3.2 ^c
Fortune	450	19.5 ^c
Haganta ^a	700	—
Hamanova svestka	3170	2.9
Jojo ^a	400	—
Jubileum	412	8.1 ^c
Kirkeho	2970	3.2
Kulovacka	3690	4.0
Larry Ann	1030	258.6
Pavluvka	4570	5.9
President ^b	7100	—
Red Beauty ^a	408	—
Reeves	184	2.9 ^c
Songold	1702	425.3
Stanley ^b	5200	—
Suplumeleven	945.4	645.8
Svestka Domaci	4950	6.1
Valor	420	7.5 ^c
Vlaska	2270	2.6
Wangenheimova	3480	3.6
Wickson ^a	220	—

The mean total phenol concentration and the antioxidant capacity of various traditional and modern plum cultivars are shown in the present table. GAE, Gallic acid equivalents; AA, ascorbic acid; TE, trolox equivalents.

^aThe total phenolic content was measured in plum flesh with no peel.

^bmg Kg⁻¹ of DW.

^cResults expressed as μmol Trolox equivalent (TE) g⁻¹ FW.

Adapted from Cinquanta et al. (2002), Gil et al. (2002), Karaman et al. (2013), Lozano et al. (2009), Piga et al. (2003), Rop et al. (2009), Slimestad et al. (2009) and Usenik et al. (2013).

Table 5 Phenolic compound composition of traditional and modern plum cultivars

Cultivars	NCG	CG	CCG	3HCQ	RUT	QGluc	PCB1	PCB4	PCB2	PCA	QPH	Q3X	Q3R
Traditional cultivars (mg 100 g⁻¹ of FW)													
Santa Rosa ^a	23.8	2.2	—	—	—	—	90	90.1	73.4	—	1.5	10.1	3.1
Sugar ^b	195.3	58.5	—	—	15.1	—	—	—	—	—	—	—	—
Victoria	—	137 ^c	—	6	0.7	0.1	—	—	—	—	—	—	—
Modern cultivars (mg 100 g⁻¹ of FW)													
African Delight	39.1	2.5	—	—	7.4	14.3	11.9	—	1.2	—	—	0.3	—
Angeleno ^a	4	—	—	—	—	—	80.6	52.1	339.9	477.4	—	5.7	1.8
Avalon	—	77 ^c	—	6	0.7	0.1	—	—	—	—	—	—	—
Black Amber	—	7.1	—	—	1.5	—	—	—	—	—	—	—	—
Black Beauty ^a	22.5	1.3	—	—	—	—	291.5	677.6	137.3	256.8	0.8	12.9	6.7
Excalibur	—	51 ^c	—	2	0.5	0.2	—	—	—	—	—	—	—
Fortune	—	32.8	—	—	0.4	—	—	—	—	—	—	—	—
Haganta ^d	3.7	1.7	—	—	1.87	—	—	—	—	—	—	—	—
Jojo ^d	2.3	1.1	—	—	1.2	—	—	—	—	—	—	—	—
Jubileum	—	124 ^c	—	8	1	0.1	—	—	—	—	—	—	—
Laetitia	36.7	—	—	—	6.6	6.9	10.8	—	0.8	—	—	0.5	—
President ^b	381.8	54.1	—	—	26.7	—	—	—	—	—	—	—	—
Red Beauty ^a	32.6	1.4	—	—	—	—	268.3	253.1	72.1	75.3	0.5	10.5	5
Reeves	—	28 ^c	—	4	0.1	0.02	—	—	—	—	22.6	—	—
Ruby Crunch	5.9	—	—	—	7.9	8.6	27.1	—	3.3	—	—	0.4	—
Ruby Red	40.1	—	—	—	2.8	8.9	6.3	—	5	—	—	0.9	—
Sapphire	—	—	—	—	2.3	6.3	8.7	—	5.4	—	—	0.7	—
Sun Breeze	21.8	—	—	—	—	1.9	20.4	—	1.6	—	—	0.5	—
Valor	—	158 ^c	—	15	0.8	0.14	—	—	—	—	—	—	—
Wickson ^a	13.5	0.6	—	—	—	—	539.9	484.8	—	77.6	0.6	9.5	3.6

The present table shows the mean concentration of the major phenolic compounds detected in the fruits of various traditional and modern plum cultivars. NCG, Neochlorogenic acid; CG, chlorogenic acid; CCG, cryptochlorogenic acid; 3HCQ, 3'-hydroxycoumaroyl quinic acid; RUT, quercetin 3-rutinoside (Rutin); QGluc, Quercetin-3-glucoside; PCB1, procyanidin B1; PCB4, procyanidin B4; PCB2, procyanidin B2; PCA, procyanidin A type dimer; QPH, quercetin pentosyl hexoside; Q3X, quercetin 3-xyloside; Q3R, quercetin 3-rhamnoside.

^aPhenolic compounds were measured in mature plum peel.

^bExpressed as mg 100 g⁻¹ DW.

^cCG is the total concentration of neochlorogenic acid + chlorogenic acid + cryptochlorogenic acid.

^dPhenolic compounds were measured in plum peel expressed as g/Kg FW.

Adapted from Karaman et al. (2013), Ozturk et al. (2012), Piga et al. (2003); Slimestad et al. (2009), Tomás-Barberán et al. (2001), Usenik et al. (2013) and Venter et al. (2013).

Table 6 Anthocyanin composition of traditional and modern plum cultivars

Cultivar	Cy-3-xyloside	Cy-3-glucoside	Cy-3-rutinoside	Peo-3-rutinoside	Peo-3-glucoside	Total anthocyanins
mg 100 g ⁻¹ FW						
Traditional						
Victoria	—	0.21	0.46	0.05	—	—
Ruby Red	—	45.68	7.88	—	—	—
Modern						
Avalon	—	0.50	1.15	0.09	0.01	—
Excalibur	—	0.15	0.29	—	—	—
Reeves	—	0.10	0.41	0.04	—	—
Jubileum	—	3.19	6.19	—	0.39	—
Valor	—	4.14	6.38	0.16	0.05	—
Laetitia	—	4.79	1.48	—	—	—
African Delight	—	8.21	1.51	—	—	—
Sapphire	—	22.26	5.32	—	—	—
Jojo	0.44	0.06	3.78	1.83	0.04	—
Valor	0.27	0.06	2.45	0.1	0.01	—
Cacanska Rodna	1.77	1.07	7.25	0.75	0.08	—
Cacanska	0.12	0.01	0.83	0.39	—	—
Najbolja	—	—	—	—	—	—
BY 8158.50	—	—	—	—	—	46.7
Methley	—	—	—	—	—	30.9
Black Amber	—	—	—	—	—	28.93
Suplumeleven	—	—	—	—	—	24.3
Fortune	—	—	—	—	—	23.78
Larry Ann	—	—	—	—	—	11.15
Haganta (peel)	—	193	273	75	25	570
Jojo (peel)	—	110	252	229	50	640

The present table shows the mean concentration of the major anthocyanins found in the fruits of various traditional and modern plum cultivars. Cy, cyanidin; Peo, peonidin.

Adapted from Cinquanta et al. (2002), Kim and Padilla-Zakour (2004), Lozano et al. (2009), Slimestad et al. (2009), Usenik et al. (2009, 2013) and Venter et al. (2013).

Table 7 Vitamin composition of traditional and modern plum cultivars

Traditional					Modern				
Cultivar	Vitamin C	Thiamin	Riboflavin	Niacin	Cultivar	Vitamin C	K1	α -tocopherol	γ -tocopherol
mg 100 g ⁻¹ FW					mg 100 g ⁻¹ FW				
Blood	6	0.03	0.04	0.8	Angeleno	4.2	—	—	—
Green- gage	5	0.05	0.04	0.6	Bistrica	9.79	—	—	—
Mariposa	5	0.04	0.04	0.7	Black Beaut	2.9	—	—	—
Narra- been	4	0.02	0.05	0.3	Elena	8.62	—	—	—
Santa	4	0.03	0.05	0.9	Red Beaut	10.2	—	—	—
Rosa	6	0.04	0.05	0.9	Red Beaut genotype (606)	47	—	—	—
Shiro					Shiro	1.6–2	9.7–12.6	0.411–0.585	0.068–0.117
Wilson					Wickson	9.0	—	—	—

The table presents the mean concentration of the major vitamins present in the fruits of several traditional and modern plum cultivars. Adapted from [Druzic et al. \(2007\)](#), [Gil et al. \(2002\)](#), [Lombardi-Boccia et al. \(2004\)](#), [Melgarejo et al. \(2012\)](#) and [Wills et al. \(1983\)](#).

Table 8 Carotenoid composition of traditional and modern plum cultivars

	β -carotene	β -cryptoxanthin	Phytoene	Lutein	Zeaxanthin	α -carotene	Total carotenoids
Cultivar	mg 100g ⁻¹ FW						
<i>Traditional</i>							
Blood	0.225	—	—	—	—	—	0.663
Greengage	0.095	—	—	—	—	—	0.453
Mariposa	0.210	—	—	—	—	—	0.778
Narrabeen	0.090	—	—	—	—	0.005	0.412
Santa Rosa	0.049–0.105	—	—	0.007	—	—	0.083–0.260
Wilson	0.155	—	—	—	—	—	0.313
<i>Modern</i>							
Wickson	0.040	0.005	—	—	—	—	0.087
Black Beauty	0.188	0.013	—	—	—	—	0.231
Red Beauty	0.064	0.003	—	—	—	—	0.087
Angeleno	0.057	0.003	—	—	—	—	0.113
Blackamber	—	—	—	—	—	—	0.762
Larry Ann	—	—	—	—	—	—	1.856
Shiro	0.068–0.117	—	—	—	—	—	—
Royal Rosa	—	—	—	—	—	—	0.55
Black Splendor	—	—	—	—	—	—	0.22
Ponterosa	0.218	0.05	0.131	0.133	0.049	—	—
Soldam	0.439	0.077	0.106	0.207	0.026	—	—

The table shows the mean concentration of the major carotenoids detected in the fruits of several traditional and modern plum cultivars.

Adapted from [Díaz-Mula et al. \(2009\)](#), [Gil et al. \(2002\)](#), [Lombardi-Boccia et al. \(2004\)](#), [Martínez-Espla et al. \(2014\)](#), [Wills et al. \(1983\)](#) and [Yano et al. \(2005\)](#).

Table 9 Fruit mineral composition of traditional and modern plum cultivars

	P	K	Ca	Mg	Na	Fe	Zn	Cu	Mn
Cultivar	mg 100 g ⁻¹ FW								
<i>Traditional</i>									
Blood	—	170	8	6	2	0.2	0.1	—	—
Greengage	—	140	6	6	1	0.2	0.1	—	—
Mariposa	—	190	7	7	2	0.4	0.1	—	—
Narrabeen	—	120	6	4	1	0.1	0.1	—	—
Santa	—	140	6	6	3	0.2	0.1	—	—
Rosa									
Wilson	—	160	7	6	0	0.2	0.1	—	—
<i>Modern</i>									
Augustinka	24.93	218.92	7.90	7.49	1.31	—	—	—	—
Bluma	27.16	161.91	10.62	6.44	1.74	—	—	—	—
Bryska	23.65	220.63	7.41	6.53	1.41	—	—	—	—
Durancie	33.07	264.97	10.88	10.88	1.42	—	—	—	—
Hamanova	22.15	196.18	9.65	8.95	2.05	—	—	—	—
svestka									
Kirkeho	27.87	159.63	7.86	9.65	2.04	—	—	—	—
Kulovacka	36.95	397.63	7.38	8.09	2.14	—	—	—	—
Pavluvka	25.50	257.19	11.42	10.24	2.12	—	—	—	—
Shiro	11.9–15.6	174–218	4.16–4.85	4.90–5.80	1–1.46	0.26–0.27	0.040–0.090	0.050–0.060	40–50
Stanley	26.34	231.77	7.13	9.37	1.94	—	—	—	—
Svestka	32.17	228.90	10.06	11.62	1.98	—	—	—	—
domaci									
Vlaska	29.88	190.35	8.19	9.09	1.82	—	—	—	—
Wangen-heimova	19.85	257.83	11.70	9.71	1.45	—	—	—	—

The mean concentration of several mineral elements found in the fruits of various traditional and modern plum cultivars is shown in the present table.

Adapted from [Ertekin et al. \(2006\)](#), [Lombardi-Boccia et al. \(2004\)](#) and [Rop et al. \(2009\)](#).

(8 mg 100 g⁻¹ FW) followed by ‘Mariposa’ and ‘Wilson’ (7 mg 100 g⁻¹ FW), whereas Greengage, ‘Narrabeen’, and ‘Santa Rosa’ presented the lowest Ca concentration (6 mg 100 g⁻¹ FW) (Wills et al., 1983). Mariposa was the cultivar with the highest Mg concentration (7 mg 100 g⁻¹ FW), while ‘Narrabeen’ presented the lowest one (4 mg 100 g⁻¹ FW). Sodium concentration ranged from 0 to 3 mg 100 g⁻¹ FW in ‘Wilson’ and ‘Santa Rosa’, respectively, while Zn was found at 0.1 mg 100 g⁻¹ FW in all cultivars tested (Wills et al., 1983). Iron was determined from 0.1 mg 100 g⁻¹ FW in ‘Narrabeen’ up to 0.4 mg 100 g⁻¹ FW in ‘Mariposa’.

Volatile Composition of Traditional Plum Cultivars

The predominant volatiles that have been detected in plum are listed in Table 10 (Crouzet et al., 1990; Gomez et al., 1993; Horvat et al., 1992; Krammer et al., 1991; Louw and Theron, 2012; Lozano et al., 2009; Melgarejo et al., 2012; Pino and Quijano, 2012; Sabarez et al., 2000; Williams and Ismail, 1981). Among them, in ‘AU-Amber’, ‘AU-Rosa’, ‘Byrongold’, ‘Methley’, and ‘Rubysweet’ cultivars, hexanal, butyl acetate, (*E*)-2-hexenal, butyl butyrate, hexyl acetate, linalool, γ -decalactone, and γ -dodecalactone were found to be the most abundant (Horvat et al., 1992). Krammer et al. (1991) have detected 31 compounds in ‘Nancy’ cultivar. In ‘Black amber’ and ‘Friar’, the volatiles’ profile has been found to be very similar, although ‘Black amber’ exhibited greater concentrations than ‘Friar’ of most of the identified compounds. In ‘Black amber’ cultivar, the most abundant compound was nonanal, followed by hexyl acetate and hexanol (Gomez et al., 1993), whereas in ‘Friar’, the most abundant compound was nonanal, followed by (*Z*)-3-hexen-1-ol, (*E*)-2-hexenal, and hexanol (Gomez et al., 1993).

COMPOSITION OF MODERN PLUM CULTIVARS

Organoleptic Characteristics of Modern Plum Cultivars

The lowest value of TSS has been determined in ‘Cacanska Rodna’, while the highest one is in ‘Avalon’ (8.2 and 18.4 °Brix, respectively) (Table 1) (Meland, 2010; Usenik et al., 2009) with the majority of the modern cultivars exhibiting TSS values higher than 11 °Brix and many higher than 14 °Brix (such as ‘Bistrice’, ‘Edda’, ‘Elena’, ‘Hanita’, ‘Larry Ann’, ‘Reeves’, ‘Stanley’, ‘Tophit’, ‘Victoria’, and ‘Wegierka Zwyczajna’) (Daza et al., 2012; Kristl et al., 2011; Meland, 2010; Walkowiak-Tomczak et al., 2008). Daza et al. (2012) have determined the lowest titratable acidity in ‘Sapphire’ and the highest in ‘primetime’ (1.05 and 2.72 g malic acid equivalents 100 mL⁻¹, respectively). ‘Avalon’ has also been found to have high titratable acidity (2.3 g malic acid equivalents 100 g⁻¹) (Vangdal et al., 2007), while ‘Golden Globe’ has been found to have low values of titratable acidity (0.58 g malic acid equivalents 100 g⁻¹) (Díaz-Mula et al., 2009). The majority of the

Table 10 Volatiles found in plum fruits

(<i>E</i>)-2,6-dimethylocta-2,7-die 1,6-diol	2,2,6-trimethylcyclohexanone	4-hydroxy- β -damascone	dehydrovomifoliol	nerolidol
(<i>E</i>)-2-hexen-1-ol	2,2,3-trimethyldecane	4-hydroxyacetophenone	Diethyl phthalate	Nonanal
(<i>E</i>)-2-hexenal	2,3-dimethyl-2-pentene	4-vinylguaicol	Dodecanoic acid	Octanoic acid
(<i>E</i>)-2-hexenal	2,4-dimethyl-2-decene	4-vinylphenol	Ethyl butyrate	Octyl acetate
(<i>E</i>)-2-hexen-1-ol	2,5-dimethyl-2-undecene	6,10,14-trimethyl-2-pentadecanone	Ethyl octanoate	Octyl octanoate
(<i>E</i>)-2-hexenyl butanoate	2,6-bis(1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione	6,10,14-trimethyl-5,9,13-pentadecatrien-2-one	Eugenol	Palmitic acid
(<i>E</i>)- α -hexenyl acetate	2,6-bis(1,1-dimethylethyl)-4-ethylphenol	6-Pentyl- α -pyrone	Geranylacetone	<i>p</i> -Damascenone
(<i>E</i>)-linalool oxide, furanoid	2,6-dimethyl-1,8-octanedione	7-Dodecalactone	Geranylacetone	<i>p</i> -Decalactone
(<i>E</i>)-linalool oxide, pyranoid	2-ethyl-1-hexanol	7-Nonalactone	Geraniol	Pentyl acetate
(<i>E</i>)- β -ionone	2-ethylhexanol	8-ionone	Hexanal	Phenol
(<i>E,E</i>)-2,4-heptadienal	2-hexanone	9-methyl-bundecene	Hexanoic acid	Phenylacetaldehyde
(<i>E,E</i>)-pseudoionone	2-hexenal	Acetic acid	Hexanol	<i>p</i> -ionone
(<i>E,Z</i>)-2,4-decadienal	2-phenylethanol	Acetophenone	Hexanol	Propyl octanoate
(<i>Z</i>)-3-hexen-1-ol	2-undecene	α -copaene	Hexyl acetate	<i>S</i> -Decalactone
(<i>Z</i>)-3-hexen-1-ol	3,dimethylundecane	α -terpineol	Hexyl butanoate	Styrene
(<i>Z</i>)-3-hexen-1-ol	3,7-dimethyloct-1-ene-3,7-d	Benzaldehyde	Hexyl hexanoate	Terpinolene
(<i>Z</i>)-3-hexenol	3-hexanone	Benzoic acid	Hexyl octanoate	Tetradecanal
(<i>Z</i>)-3-hexenyl acetate	3-hexenyl butanoate	Benzyl alcohol	Hotrienol	trans-linalool oxide
(<i>Z</i>)-3-hexenyl butanoate	3-hydroxy-2-butanone	BHT	Isobomeol	Tyrosol
(<i>Z</i>)-3-hexenyl hexanoate	3-hydroxy- β -ionone	Bomyl acetate	Isophorone	Vanillin
(<i>Z</i>)-linalool oxide, furanoid	3-hydroxy-5,6-epoxy- β -ionone	Butanoic acid	1,4-dimethylbenzene	Vomifoliol
(<i>Z</i>)-linalool oxide, pyranoid	3-hydroxy-7,8-dihydro- β -ionol	Butyl acetate	1-hexanol	γ -decalactone
(<i>ZE,6Z</i>)-3,7-dimethyl-2,6-octadiene-1,d-diol	3-hydroxy-8-ionol	Butyl butyrate	Limonene	γ -dodecalactone
1,2,3-trimethylbenzene	3-hydroxy-j3-damascone	Butyl hexanoate	Linalool	γ -Hexalactone
1,4-dimethyl benzene	3-methyl-1-butanol	Butyl octanoate	Limonene oxide	γ -Octalactone
1-butanol	3-oxo- α -ionol	C ₂₁ H ₄₄	Marmelolactone, I	α -terpineol
1-hexanol	3-tetradecene	C ₂₃ H ₄₈	Methyl eugenol	β -cyclocitral
1-methylcyclopentanol	4-(4-hydroxyphenyl)-2-butanone	Cinnamyl alcohol	Methyl salicylate	β -pinene
1-phenylethanone	4-hexen-1-ol-acetate	Decenal	Naphthalene	γ -decalactone
		Decyl acetate	Nerol	

The table presents the major volatile compounds detected in the fruit of various plum cultivars.

Adapted from Crouzet et al. (1990), Gomez et al. (1993), Horvat et al. (1992), Krammer et al. (1991), Louw and Theron (2012), Lozano et al. (2009), Melgarejo et al. (2012), Pino and Quijano (2012), Sabarez et al. (2000) and Williams and Ismail (1981).

Table 11 Carbohydrate composition of modern plum cultivars

	Sucrose	Glucose	Fructose	Sorbitol	Total
Cultivar	mg 100 g ⁻¹ FW				
Black Amber	650	—	4070	—	—
Formosa	272.8	343.2	342.3	33.5	—
Fortune	4160	—	2080	—	—
Haganta	2160–4350	2550–4220	1430–2350	3890–3460	10,030–14,390
Jojo	1500–3320	2570–4430	1600–2300	950–2410	6630–12,460
Larry Ann	4340	—	1820	—	—
Red Beaut	1440	2120	3940	—	7500
genotype (606)					
Shiro	1820–2750	1970–2110	1080–1380	960–1200	6270–7140
Songold	2030	—	3130	—	—
Suplumeleven	2410	—	4790	—	—
Suplumsix	3700	—	2180	—	—
Top taste	5530	4120	3030	4060	16,730
Tophit	4670	3300	2280	3460	13,710
Topstar	5660	2430	1650	1680	11,420
Top 2000	3600	4130	1420	2020	11,170
	mg 100 g ⁻¹ DW				
Angeleno	8100	25,300	22,100	10,400	—
Empress	14,600	26,100	6500	16,100	—

The table presents the mean as well as the range of concentration of the major carbohydrates found in the fruits of modern plum cultivars.

Adapted from [Bae et al. \(2014\)](#), [Lombardi-Boccia et al. \(2004\)](#), [Lozano et al. \(2009\)](#) and [Usenik et al. \(2013\)](#).

cultivars have been found to have titratable acidity ranging from 1.0 to 1.5 g malic acid equivalents 100 g⁻¹ ([Daza et al., 2012](#); [Kristl et al., 2011](#); [Vangdal et al., 2007](#)).

Carbohydrate Composition of Modern Plum Cultivars

‘Formosa’ exhibited the lowest carbohydrate concentration among the cultivars listed in [Table 11](#) ([Bae et al., 2014](#)). On the other hand, ‘Topstar’ had the highest sucrose concentration, followed by that of ‘Top taste’ (5660 and 5530 mg 100 g⁻¹ FW, respectively) ([Dugalic et al., 2014](#)). Glucose ranged between 343.2 mg 100 g⁻¹ FW in ‘Formosa’ and 4430 mg 100 g⁻¹ FW in ‘Jojo’, while in all other cultivars its concentration was close to or above 2000 mg 100 g⁻¹ FW ([Bae et al., 2014](#); [Dugalic et al., 2014](#)). Fructose was highest in ‘Suplemeleven’ (4790 mg 100 g⁻¹ FW), followed by ‘Black Amber’ (4070 mg 100 g⁻¹ FW) ([Lozano et al., 2009](#)). Sorbitol was detected in low concentration in ‘Formosa’ (33.5 mg 100 g⁻¹ FW) and as high as 4060 mg 100 g⁻¹ FW in ‘Top taste’, which exhibited

the highest total carbohydrate concentration among cultivars, reaching 16,730 mg 100 g⁻¹ FW (Bae et al., 2014; Dugalic et al., 2014).

Organic Acid Composition of Modern Plum Cultivars

Malic acid, the most abundant organic acid in plums, was found in very high concentration in 'Jojo' (up to 2180 mg 100 g⁻¹ FW), while in 'Formosa' it was found at 172.8 mg 100 g⁻¹ FW (Table 3) (Usenik et al., 2009). Citric acid was found in 'Red Beauty' (genotype 606), 'Shiro', in 'Formosa' (Bae et al., 2014; Lombardi-Boccia et al., 2004; Melgarejo et al., 2012), while quinic acid was found only in 'Shiro' by Bae et al. (2014) in very high concentration (275.1 mg 100 g⁻¹ FW), being the most abundant organic acid in this specific cultivar. Oxalic acid was also found in 'Shiro' (Bae et al., 2014), while fumaric acid was found in most of the cultivars, ranging from 0.3 mg 100 g⁻¹ FW in 'Shiro' (Bae et al., 2014) to 3.68 in 'Jojo' (Usenik et al., 2009).

Phenolic Compound, Anthocyanin Composition, and Antioxidant Capacity of Fruits of Modern Plum Cultivars

The total phenol concentration differs a lot among plum cultivars (Table 4) (Cinquanta et al., 2002; Gil et al., 2002; Karaman et al., 2013; Piga et al., 2003). 'Reeves' has been found to have low total phenol concentration, along with 'Excalibur', while the highest was determined in 'Svestka domaci' (184, 197, and 4950 mg GAE Kg⁻¹ FW) (Rop et al., 2009; Slimestad et al., 2009).

Neochlorogenic acid, chlorogenic acid, rutin, quercetin-3-glucoside, quercetin-3-xyloside, 3-hydroxycoumaroyl quinic acid, as well as procyanidin B1 and procyanidin B2 have been detected in plum fruits (Karaman et al., 2013; Ozturk et al., 2012; Piga et al., 2003; Slimestad et al., 2009; Venter et al., 2013), with the most abundant being neochlorogenic acid and procyanidin B1, ranging from 5.9 to 40.1 and from 6.3 to 27.1 mg 100 g⁻¹ FW (Table 5). The peel of pulp fruit is rich in procyanidins and especially procyanidin A type dimer, procyanidine B2, procyanidin B1, and procyanidin B4 (Tomás-Barberán et al., 2001).

Antioxidant capacity has been measured and expressed with different methods, thus making difficult any comparison between cultivars, as presented in Table 4.

The major anthocyanins found in plum fruits are cyanidine-3-rutinoside, cyanidine-3-glucoside, cynidine-3-xyloside, peonidine-3-rutinoside, and peonidine-3-glucoside (Table 6) (Kim and Padilla-Zakour, 2004; Lozano et al., 2009; Usenik et al., 2013, 2009). The major anthocyanin found was cynidine-3-rutinoside, which has been estimated from 0.29 mg 100 g⁻¹ FW in 'Excalibur' to 7.25 mg 100 g⁻¹ FW in 'Cacanska Rodna' (Usenik et al., 2009). 'Cacanska Najbolja' exhibited the lowest cyanidine-3-glucoside and cyanidine-3-xyloside concentration (0.01 and 0.12 mg 100 g⁻¹ FW, respectively), while the 'Sapphire' and 'Cacanska Rodna' the highest concentration (2.26 and 1.77 mg 100 g⁻¹

FW, respectively) (Usenik et al., 2009). The lowest concentration of peonidine-3-rutinoside has been determined in 'Reeves' ($0.04 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) and the highest in 'Jojo' ($1.83 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) (Slimestad et al., 2009; Usenik et al., 2009). 'Valor' and 'Avalon' have been found to have low concentration of peonidine-3-glucoside ($0.01 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ both), while the highest concentration has been determined in 'Jubileum' ($0.39 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) (Slimestad et al., 2009; Usenik et al., 2009).

The fruit portion containing the highest anthocyanin concentration is the peel, as has been clearly demonstrated with 'Haganta' and 'Jojo' by Usenik et al. (2013). Cyanidine-3-glucoside and cyanidine-3-rutinoside have been found at 193 and $273 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ in 'Haganta' peel, respectively, while 'Jojo' peel was richer in peonidine-3-rutinoside and peonidine-3-glucoside (229 and $50 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively) (Usenik et al., 2013). Total anthocyanin concentration has been found to be high in 'BY 8158.50' ($46.7 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) (Kim and Padilla-Zakour, 2004), while 'Larry Ann' exhibited only $11.15 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ (Lozano et al., 2009).

Vitamin Composition of Modern Plum Cultivars

'Red Beauty' genotype 606', 'Red Beauty', and 'Bitrica' were the three cultivars with the highest concentrations of vitamin C (47 , 10.2 , and $9.79 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively) (Table 7) (Družić et al., 2007; Gil et al., 2002; Melgarejo et al., 2012). Lombardi-Boccia et al. (2004) also detected vitamin K1, α -tocopherol, and γ -tocopherol in 'Shiro'.

Carotenoid Composition of Modern Plum Cultivars

β -Carotene is the most abundant carotenoid in plum fruits of modern cultivars (Table 8), followed by lutein, phytoene, zeaxanthin, β -cryptoxanthin, and all-trans-violaxanthin (Díaz-Mula et al., 2009; Gil et al., 2002; Lombardi-Boccia et al., 2004; Martínez-Esplá et al., 2014; Yano et al., 2005). The lowest β -carotene concentration has been found in 'Wickson' with the highest one in 'Soldam', at 0.04 and $0.439 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ (Gil et al., 2002; Yano et al., 2005). Yano et al. (2005) have detected in 'Soldam' and 'Ponterosá' phytoene (0.106 and $0.131 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively), lutein (0.207 and $0.133 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively), zeaxanthin (0.026 and $0.049 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively), and all-trans-zeaxanthin (0.04 and $0.096 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively). β -Cryptoxanthin was found to be low in 'Angeleno' ($0.003 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) (Gil et al., 2002) and high in 'Soldam' ($0.077 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) (Yano et al., 2005). 'Wickson' and 'Red Beauty' exhibited the lowest total carotenoid concentration ($0.087 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ both) (Gil et al., 2002), while 'Larry Ann' was the highest with $1.856 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ (Díaz-Mula et al., 2009).

Mineral Element Concentration in Modern Plum Cultivars

'Kulovacka' exhibited the highest potassium concentration ($397.63 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) among cultivars studied by Rop et al. (2009) (Table 9). 'Stanley', 'Wangenheimova',

‘Svestka domaci’, ‘Pavluvka’, ‘Bryska’, ‘Augustinka’, and ‘Durancia’ presented potassium values higher than $200 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, while potassium was determined in the lowest concentration ($159.63 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) in ‘Kirkeho’ (Rop et al., 2009). Phosphorus was the second most abundant mineral element in the former plum cultivars, reaching $36.95 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ in the fruits of ‘Kulovacka’. Calcium was highest in ‘Wangenheimova’, followed by ‘Pavluvka’ (11.70 and $11.42 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, respectively) and lowest in ‘Shiro’ (up to $4.85 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$). ‘Svestka domaci’ presented the highest magnesium concentration ($11.6 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$), while ‘Shiro’ had the lowest concentration (4.90 to $5.80 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$). Sodium ranged between 1.0 and $2.14 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$ (in ‘Shiro’ and ‘Kulovacka’, respectively). Minor elements were determined by Lombardi-Boccia et al. (2004) in Shiro, with iron ranging between 0.26 and $0.27 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, zinc between 0.04 and $0.09 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, copper between 0.05 and $0.06 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$, and manganese between 40 and $50 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$.

Volatile Composition of Modern Plum Cultivars

The main volatile compounds detected in ‘Angeleno’, ‘Larry Ann’, ‘Suplumeleven’, ‘Fortune’, and ‘Songold’ were guanidine, (*Z*)-3-Hexen-1-ol, 4-Hexen-1-ol-acetate, and hexyl acetate, with ‘Fortune’ being the cultivar with the highest volatile content and ‘Angeleno’ the cultivar with the lowest volatile content (Lozano et al., 2009) (Table 10). Sabarez et al. (2000) found only six volatile compounds in ‘D’Agen’, of which the major ones were hexanal, 2-hexenal, 1-hexanol, and nonanal. In ‘Horvin’ 148 volatile components were detected, among them butyl acetate ($3762 \mu\text{g Kg}^{-1} \text{ FW}$), hexyl acetate ($3404 \mu\text{g Kg}^{-1} \text{ FW}$), and 1-hexanol ($1739 \mu\text{g Kg}^{-1} \text{ FW}$) being most abundant (Pino and Quijano, 2012). In ‘Red Beauty’, the major compound was found to be terpinolene ($0.32 \text{ mg Kg}^{-1} \text{ FW}$), followed by nonanal (0.25 mg Kg^{-1}), α -terpineol ($0.19 \text{ mg Kg}^{-1} \text{ FW}$), and trans-linalool oxide ($0.11 \text{ mg Kg}^{-1} \text{ FW}$) (Melgarejo et al., 2012). Several other volatiles were present in very low amounts, such as limonene, phenylacetaldehyde, benzaldehyde, decenal, geraniol, and linalool (Melgarejo et al., 2012). In ‘Pioneer’, the major volatiles that have been detected are 2-hexenal, hexanal, and hotrienol, while those identified in ‘Laetitia’ are 1-hexanol and 2-hexenal (Louw and Theron, 2012).

Taste Panel of Modern Plum Cultivars

Sestras et al. (2007) performed a taste panel among five plum cultivars, evaluating the overall quality of these cultivars. ‘Vinete Romanesti’ was evaluated on a 1–5 scale, with 2 regarding its size but 5 regarding its firmness, taking the highest score on taste and flavor (Table 12). On the other hand, ‘Valor’ was evaluated as high in size (along with ‘Vinete de Italia’) but low in firmness and skin resistance, and moderate in flavor and taste. All cultivars were evaluated as highly juicy, except ‘R.C. d’Althan’, which got the lowest grade. ‘October Sun’ was highly appreciated for its flavor, aroma, and sweetness, while simultaneously characterized by low sourness (Crisosto et al., 2007). Among the

Table 12 Taste panel scoring of modern plum cultivar

Cultivar	Size	Skin color	Skin resistance	Firmness	Juiciness	Taste	Flavor	Sweetness	Sourness	Aroma
Tuleu Timpuriu Vinete Romanesti Vinete de Italia Valor R. C. d'Althan	Scale used							—	—	—
	1–5	1–5	1–3	1–5	1–3	1–12	1–3			
	3	4	3	5	3	10	2			
	2	5	3	5	3	12	3	—	—	—
	5	5	2	3	3	9	3	—	—	—
	5	4	2	3	3	9	2	—	—	—
	4	4	2	3	2	10	3	—	—	—
							Scale used			
							0–1	0–1	1–0	0–1
Betty Anne	—	—	—	—	—	—	0.34	0.13	0.16	0.58
Black Amber	—	—	—	—	—	—	0.56	0.36	0.33	0.45
Earliqueen	—	—	—	—	—	—	0.12	0.15	0.1	0.008
Fortune	—	—	—	—	—	—	0.018	0.61	0.8	0.78
Hiromi Red	—	—	—	—	—	—	0.12	0.24	0.31	0.2
Joanna Red	—	—	—	—	—	—	0.15	0.22	0.69	0.007
October Sun	—	—	—	—	—	—	0.89	0.76	0.97	0.92
Purple Majesty	—	—	—	—	—	—	0.57	0.49	0.93	0.16
Royal Zee	—	—	—	—	—	—	0.25	0.3	0.76	0.38

The table presents the scores of two independent taste panel tests of various modern plum cultivars, based on various attributes.

Adapted from [Crisosto et al. \(2007\)](#) and [Sestras et al. \(2007\)](#).

nine cultivars evaluated by [Crisosto et al. \(2007\)](#), ‘Earliqueen’, ‘Fortune’, ‘Hiromi Red’, and ‘Joana Red’ were characterized as poor in flavor, whereas ‘Earliqueen’ and ‘Betty Anne’ presented lower sweetness and higher sourness compared to the other tested cultivars.

EUROPEAN VERSUS JAPANESE PLUMS: COMPOSITIONAL DIFFERENCES AND SIMILARITIES

European plums are classified into the groups mentioned above, in which the majority of the cultivars categorized in them are used mainly after processing, especially after drying. Japanese plums, on the other hand, are preferentially consumed fresh. Thus, there are several similarities as well as differences between these two species of the genus *Prunus*. European plum cultivars are characterized by relatively high TSS concentration, ranging from 8.2 to 18.4 °Brix, with most cultivars exhibiting values over 13 °Brix ([Kristl et al., 2011](#); [Meland, 2010](#); [Walkowiak-Tomczak et al., 2008](#)). On the other hand, Japanese plums are characterized by lower TSS content, with the majority of the cultivars exhibiting values around 12 °Brix ([Abdi et al., 1997](#); [Daza et al., 2012](#); [Díaz-Mula et al., 2009](#); [Karaman et al., 2013](#); [Wills et al., 1983](#)). This is probably one of the reasons for the European plum cultivars to be processed in higher percentages than the Japanese plum cultivars, as fruits destined to be consumed dry must generally have high sugar content ([Bhutani and Joshi, 1995](#)). The titratable acidity of the European plums has been estimated around 1.0 g malic acid equivalents 100 g⁻¹ ([Kristl et al., 2011](#); [Meland, 2010](#); [Walkowiak-Tomczak et al., 2008](#)), while that of Japanese plums ranges between 0.58 and 2.48 g malic acid equivalents 100 g⁻¹ in ‘Golden Globe’ and ‘Santa Rosa’, respectively ([Díaz-Mula et al., 2009](#); [Wills et al., 1983](#)).

Carbohydrate composition of European plums is characterized by equal participation of sucrose, glucose, fructose, and sorbitol, with the dominant sugar being highly dependent on the cultivar. In ‘Top Taste’, the major carbohydrate found is sucrose, followed by glucose, sorbitol, and fructose (5.53, 4.12, 4.06, and 3.03 g 100 g⁻¹ FW, respectively) ([Dugalic et al., 2014](#)), while in ‘Tardicotes Dark’ the major sugar is glucose, followed by fructose, sorbitol, and last by sucrose (5.46, 5.23, 2.77, and 2.05 g 100 g⁻¹ FW, respectively) ([Forni et al., 1992](#)). In Japanese plums, sorbitol is usually detected in significantly lower concentration than the other three carbohydrates, as in ‘Angeleno’, in which sorbitol was estimated to be at 10.4 g 100 g⁻¹ DW when glucose and fructose were quantified to be 25.3 and 22.1 g 100 g⁻¹ DW, respectively ([Cinquanta et al., 2002](#)).

The vitamins present in both European and Japanese plums have been found at similar concentrations, with vitamin C ranging from approximately 2 to 9.8 mg 100 g⁻¹ FW in European plums and from 3 to 10.2 mg 100 g⁻¹ FW in Japanese plums ([Družić et al., 2007](#); [Gil et al., 2002](#); [Lombardi-Boccia et al., 2004](#); [Melgarejo et al., 2012](#); [Wills et al., 1983](#)). Nevertheless, [Melgarejo et al. \(2012\)](#) have reported quite a high concentration of

vitamin C in red Beauty genotype (606), reaching 47 mg 100 g⁻¹ FW. Thiamin, riboflavin, and niacin are found in similar concentrations in European and Japanese plums, at approximately 0.04, 0.04, and 0.7 mg 100 g⁻¹ FW, respectively (Wills et al., 1983).

European plums have been found to have higher concentrations of carotenoids compared to Japanese plums. β -Carotene, one of the most abundant carotenoids present in plums, has been detected in concentrations from 0.068 to 0.439 mg 100 g⁻¹ FW in 'Shiro' and 'Soldam', respectively, while the highest concentration determined in Japanese plums was 0.188 mg 100 g⁻¹ FW in 'Black Beauty' (Gil et al., 2002; Lombardi-Boccia et al., 2004; Yano et al., 2005). Similarly, β -cryptoxanthine has been quantified at 0.05–0.07 mg 100 g⁻¹ FW in European plums and at 0.005–0.013 mg 100 g⁻¹ FW in Japanese ones (Gil et al., 2002; Yano et al., 2005).

It is interestingly that the majority of European plums exhibit higher total phenolic compound concentrations compared to Japanese plums. The total phenol concentration in European plums has been determined between 443 and 4950 mg GAE Kg⁻¹ FW in 'Victoria' and 'Svestka Domaci', respectively (Rop et al., 2009; Slimestad et al., 2009), while in Japanese cultivars this concentration has been found to range between 450 and 2313 mg GAE Kg⁻¹ FW in 'Fortune' and 'Bistrica', respectively (Družić et al., 2007; Karaman et al., 2013).

In both European and Japanese plums, the major phenolic compound is neochlorogenic acid, followed by rutin, chlorogenic acid, and quercetin glucoside, while significant amounts of 3-hydroxycoumaroyl quinic acid have been found by Slimestad et al. (2009) in some European cultivars ('Avalon', 'Excalibur', 'Jubileum', 'Reeves', 'Valor', and 'Vicotria').

Anthocyanins are a significant group of phytochemicals responsible for the characteristic plum color, of both peel and pulp (in plums with dark-colored pulp). The overall anthocyanin concentration in European plums is considerable lower than that found in Japanese plums. Cyanadine-3-rutinoside, followed by peonidine-3-rutinoside, have been found to be the major anthocyanins present in European plums, in relatively low quantities though compared to Japanese plum. Cyanadine-3-rutinoside has been found to range from 0.29 to 7.25 mg 100 g⁻¹ FW in 'Excallibur' and 'Cacanska Rodna' European plums, respectively (Slimestad et al., 2009; Usenik et al., 2009), while in Japanese 'Laetitia' and 'Ruby Red', this chemical has been detected at 1.51 and 7.88 mg 100 g⁻¹ FW, respectively (Venter et al., 2013). Although cyanadine-3-glucoside is not a major anthocyanin in European plums (its concentration has been found to range between 0.01 and 4.1 mg 100 g⁻¹ FW in 'Cacanska Najbolja' and 'Valor', respectively) (Slimestad et al., 2009; Usenik et al., 2009), it has been detected in high concentrations in some Japanese cultivars (in 'Sapphire' 22.26 mg 100 g⁻¹ FW and in 'Ruby Red' 45.68 mg 100 g⁻¹ FW) (Venter et al., 2013), making this anthocyanin the major one in these cultivars.

The major mineral element found in both European and Japanese plums is potassium. Based on the data provided by Rop et al. (2009) and Wills et al. (1983) on several European cultivars, potassium is found in concentrations ranging from 140 to as much

as 397.63 mg 100 g⁻¹ FW (in ‘Greengage’ and ‘Kulovacka’, respectively), while the maximum concentration determined in Japanese cultivars has been found to be 190 mg 100 g⁻¹ FW in ‘Mariposa’. Magnesium, calcium, and sodium concentrations do not differ much between the two species (Rop et al., 2009; Wills et al., 1983).

There are not many great differences concerning the major volatiles found in European and Japanese plums. This could be partly due to the fact that within each species, there is already great difference of volatiles’ profile among cultivars. In general, esters are the main volatile compounds in European (Crouzet et al., 1990; Pino and Quijano, 2012) and Japanese (Gomez et al., 1993) plums. The predominant volatile compounds detected in European plums are hexanal, butyl acetate, (*E*)-2-hexenal, butyl butyrate, hexyl acetate, linalool, 1-hexanol, nonanal, γ -decalactone, and γ -dodecalactone (Horvat et al., 1992). In Japanese plums, the most abundant compounds that have been reported are nonanal, hexyl acetate, 1-hexanol, (*Z*)-3-hexen-1-ol, (*E*)-2-hexenal (Gomez et al., 1993), guanidine, 4-hexen-1-ol-acetate, as well as terpinolene, α -terpineol, and trans-linalool oxide (Melgarejo et al., 2012), hexanal and hotrienol (Louw and Theron, 2012).

SUMMARY POINTS

- Plums belong to two distinct different species, the European plums (*P. domestica*) and the Japanese plums (*P. salicina*), with many similarities concerning fruit composition and several differences.
- The TSS in the fruit have been found to be as high as 18.4 °Brix, with great differences among cultivars.
- Sucrose, glucose, and fructose are the main carbohydrates of plum fruits, with sorbitol being found in lower amounts. The relative concentration of the carbohydrates is strongly influenced by the cultivar tested.
- Malic acid is the dominant organic acid in the fruits, while citric, quinic, shikimic, and fumaric have been also found in lower concentrations.
- The major phenolic compounds found in plums are chlorogenic acid and neochlorogenic acid, with their concentration differing among cultivars. The peel is rich in procyanidins, such as procyanidin B1, procyanidin A type dimer, procyanidine B2, and procyanidin B4.
- The major anthocyanins of plums are cyanidin-3-glucoside and cyaniding-3-rutinoside, while low amounts of cyaniding-3-xyloside, peonidin-3-rutinoside, and peonidin-3-glucoside have also been found. The peel is the richest portion of the fruit in anthocyanins. The relative concentration of each anthocyanin depends greatly on the cultivar used and on the color of the flesh.
- Vitamin C is the most abundant vitamin found in plums, while thiamin, niacin, riboflavin, α -tocopherol, and γ -tocopherol have been also detected, in various concentrations, depending on the cultivar tested.

- β -Carotene is the major carotenoid in fruits, along with β -cryptoxanthin, while phytoene, lutein, zeaxanthin, and α -carotene have also been found in some cultivars.
- Potassium is the major mineral in plum fruits, followed by phosphorus.
- The volatile profile of plums consists of more than 100 compounds, among which the major are hexanal, butyl acetate, (*E*)-2-hexenal, butyl butyrate, hexyl acetate, linolool, 1-hexanol, nonanal, γ -decalactone, γ -dodecalactone, and (*Z*)-3-hexen-1-ol. The dominant one, as well as its concentration, differs among cultivars.

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CHAPTER 27

Pomegranate Cultivars (*Punica granatum* L.)

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ABBREVIATIONS

CE	Catechin equivalents
CGE	Cyanidin-3-glucoside equivalents
DFE	Dietary folate equivalents
EFSA	European Food Safety Authority
GC	Gas chromatography
GAE	Gallic acid equivalents
IPGRI	International Plant Genetic Resources Institute
PC	Phosphatidylcholine
PE	Phosphatidylethanolamine
QE	Quercetin equivalents
RAE	Retinol activity equivalents
WPI	Woody portion index

INTRODUCTION

Pomegranate (*Punica granatum* L.) belongs to Punicaceae family. Its name is derived from “*Pomuni granatum*,” Pomum (apple) granatus (grainy), which translates to “seeded apple” (Teixeira da Silva et al., 2013). The pomegranate family has a single genus, *Punica*, with two species, *P. granatum* and *Punica protopunica*. Pomegranate is one of the oldest known edible fruits, originating in Central Asia and Persia (modern-day Iran). Its domestication started in 3000–4000BC in the north of Iran and Turkey (Lye, 2008), from where it spread to other regions. Its cultivation later spread over ancient Egypt, India, Asia Minor, North Africa, and the Mediterranean coast. The Spanish introduced pomegranate to

Central America, Mexico, and South America in the 1500 and 1600s (LaRue, 1980). Traditionally, pomegranate usage was limited to the native regions, but its cultivation and consumption has now increased in other parts of the world as well. Since ancient times, pomegranate has been used in several medicinal systems, such as Ayurveda (India) and Unani (Middle East and India). Research on pomegranate as a medicinal and nutritional food source has grown recently. Studies have shown that pomegranate fruit, flowers, leaves, bark, and root contain several bioactive phytochemicals exhibiting potent physiological effects. The current total annual world production of pomegranate is estimated to be approximately 1.5 million tons, with India having the largest area and production. Spain ranks first (18.5 t/ha) in productivity, followed by the USA (18.3 t/ha), while Iran is the leading exporter of pomegranate (60,000 t/year) followed by India (35,176 t) (Teixeira da Silva et al., 2013). Pomegranate is consumed as fresh and/or juice, used in various cuisines, and in recent times has been used commercially in baked goods, candies, energy bars, yogurt, ice cream, salad dressings, pomegranate seed oil, skin care products, and health supplements. Pomegranate juice has become more popular in the western diet because of its diversely documented health benefits such as antioxidant properties (Çam et al., 2009), antiatherogenic effects (Aviram et al., 2000), anticancer activities (Seeram et al., 2005; Adams et al., 2006), antidiabetic effect and hypoglycemic activity (Katz et al., 2007), and antimicrobial properties (Salgado et al., 2009; Dahham et al., 2010).

BOTANICAL ASPECT

Pomegranate grows as a shrub or small tree that naturally tends to develop multiple trunks with a bushy appearance. It usually grows up to 5 m but can reach up to 10 m (Holland et al., 2009). The bark color changes from the initial pink, purple, or light green with pink-purple spots or stripes to dark gray with maturation (Goor and Liberman, 1956). The bark of the old tree tends to split and detach from the trunk, revealing the light yellow wood (Holland et al., 2009). Pomegranate trees are mostly deciduous; however, some evergreen cultivars are also reported particularly in India (Holland et al., 2009). Young branches are sometimes spiny. Young leaves are reddish in color, and upon maturation, they turn green. Leaves have an oblanceolate shape with an obtuse (rounded) apex and an acuminate (tapered) base. Mature leaves are simple, exstipulate (stipules usually absent), opposite or subopposite, bright green, entire, smooth, short-petioled, 2–8 cm long, glabrous (hairless), and glandular (Holland et al., 2009; Teixeira da Silva et al., 2013). Most varieties have leaves in pairs alternately crossing at right angles, whereas some varieties can have three leaves per node (arranged at 120°) and even four leaves per node (two opposite leaves per node) (Moreno, 2005).

Flowering occurs about 1 month after buds break on newly developed branches of the same year, mostly on spurs or short branches. In the northern hemisphere, flowering occurs in April–May and can continue until end of summer (Holland et al., 2009).

However, late flowering results in poorly matured fruits as the cold season causes dormancy in Mediterranean climatic conditions (Holland et al., 2009). Flowers can appear solitary on spurs along the branches, in pairs, or as terminal clusters. When young, the flower resembles a small pear with a greenish color on its basal part and reddish color on its apex, or entirely dark red. Upon maturity, the sepal color changes to orange-red or deep red, and the petals become usually orange-red or pink and, rarely, white. The color of the sepal is directly associated with the color of the fruit skin, with darker red flowers producing deep-red fruit skin (Holland et al., 2009). The sepals remain on the fruit as it matures, forming a prominent calyx. The calyx is tubular, 5–8 lobed, persistent, fleshy, and valvate with 5–7 petals inserted between the calyx lobes (Teixeira da Silva et al., 2013). The petals are obovate, very delicate, and slightly wrinkled. Pomegranate can have three types of flowers, namely hermaphrodite, male, and intermediate forms. Hermaphrodite flowers have a vase- or pitcher-shaped calyx, a fertile normal ovary capable of developing fruit, and the stigma is at or emergent above the anthers' height. This position of the stigma allows for self-pollination as well as pollination by insects. On the other hand, the male flowers have a campanulate (bell-shape) calyx, a poorly developed or no pistil, and atrophied ovaries containing few ovules, and they are infertile. Such flowers will drop without fruit set (Holland et al., 2009). The intermediate forms exhibit various degrees of ovary degeneration (Teixeira da Silva et al., 2013). Therefore, cultivars with higher vase-shape to bell-shape ratio will have a higher fruit yield potential (Holland et al., 2009). Both hermaphrodite and male flowers have numerous (more than 300) free stamens borne on the calyx tube. The stamens have an orange-red filament and yellow bilocular anthers that remain attached to the prominent calyx. Nectaries are located between the stamens and the ovary base. The flowers usually have eight superimposed carpels arranged in two layers and forming a syncarpic ovary (Holland et al., 2009).

Flowering and the consequent fruit set last about 1 month. The fruit is classified as a berry consisting of many closely packed red arils, and irregular segments separated by nonedible white piths and thin membranes. The multi-ovule chambers (locules) are separated by membranous walls (septum) and fleshy mesocarp. The chambers are filled with numerous seeds, surrounded by a juicy layer that develops entirely from outer epidermal cells of the seed. The seeds range in hardness from very hard to soft. The color of the edible juicy layer (arils) can vary from white to deep red, depending on the variety (Holland et al., 2009). The fruit size can vary from 6–12 cm in diameter and has a tough, leathery, brown to red, bitter skin (or peel or pericarp), which is easily peeled. The fruit is also known as 'balausta', formed by the union of the ovary with the receptacle of the thalamus (Nath and Randhawa, 1959). The fruit is connected to the tree with a short stalk. The color of the sepals in the developing fruit changes continuously from the initial orange-red to green and finally to the characteristic color of the ripened fruit. The skin color of a pomegranate fruit ranges from yellow, green, or pink overlain with pink to deep red or indigo to fully red, pink or deep purple cover, depending on the variety

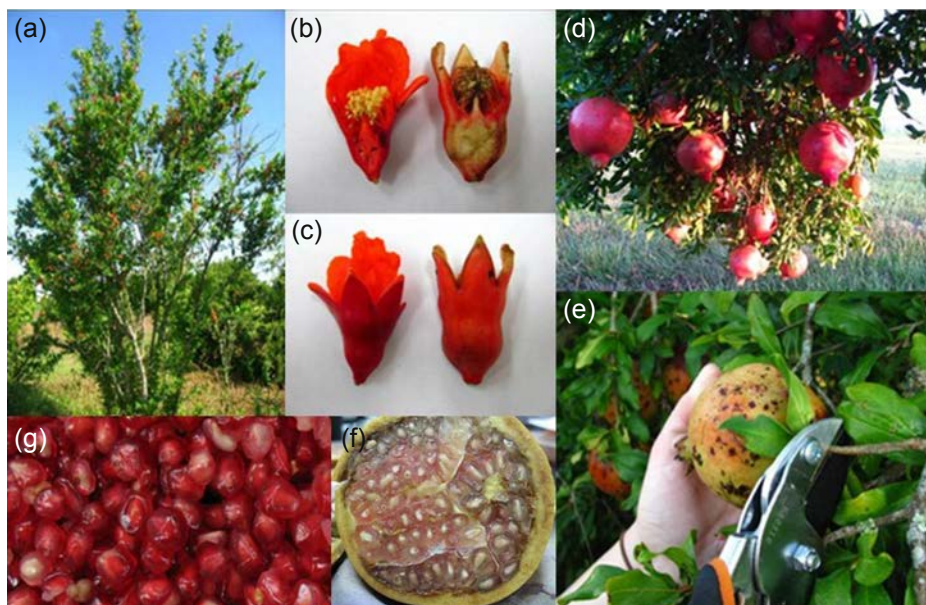


Figure 1 Different parts of pomegranate. (a) pomegranate tree. The exterior (b) and interior (c) of the male (left) and hermaphrodite (right) flower. (d) Fully ripe pomegranates. (e) Harvesting of pomegranates using clipping shears. (f) Interior of pomegranate fruit showing the membrane, pith, and arils. (g) Arils. [MacLean et al. \(2014\)](#), with permission

and stage of ripening ([Holland et al., 2009](#)). The fruit ripens 5–8 months after fruit set, depending on the variety. [Figure 1](#) shows the various parts of pomegranate.

Optimal conditions for the pomegranate exist in Mediterranean-type, arid climates with high exposure to sunlight, annual total precipitation of 170–560 mm, mild winters with minimal temperature not lower than -18°C , and long, hot, dry summers without precipitation during the last stages of the fruit development ([Teixeira da Silva et al., 2013](#)). It can easily withstand temperatures up to $45\text{--}48^{\circ}\text{C}$ combined with dry hot winds. Cold season adversely affects fruit set and quality. Rainfall during the final stages of fruit ripening can cause fruit splitting. Pomegranates grow well in a variety of soils, ranging from heavy clay to lime-rich soils, although the best soils for pomegranate cultivation are fertile, rich with humus, deep, medium density with good drainage, especially alluvial soils ([Teixeira da Silva et al., 2013](#)). Pomegranate is a light-loving plant and reacts negatively to excessive shading ([Chadha, 2005](#)), although occasionally too much direct sunlight along with high heat can cause the fruit to sunburn ([Sharma et al., 2006](#)). For higher fruit yield, regular irrigation is required. Water requirement and irrigation schedule varies with cultivars and the place of cultivation. Although pomegranate can be grown from seeds, hardwood cuttings are the most widely used propagation method. Since pomegranate is a nonclimacteric fruit that does not ripen off the tree even with ethylene treatment, it is

recommended to harvest it at a fully ripe stage. Some of the common diseases of pomegranate are wilt caused by *Fusarium oxysporium* (Chavan and Dake, 2001); black spot disease or *Alternaria* fruit rot caused by *Alternaria alternata* (Ezra et al., 2010), bacterial blight by *Xanthomonas* sp., and fruit rot caused by *Coniella granati* (Levy et al., 2011).

Although there are more than 500 pomegranate varieties known around the world, only 50 are commonly grown (IPGRI, 2001). Most of the pomegranate cultivars grown today are the result of human selection from naturally occurring varieties. Selection and breeding of new cultivars is done on the basis of market demands, preference traits, juice content, yield, disease resistance, and tolerance to the growing region, climate, and soil. Some of the popular cultivars are described in Table 1.

COMPOSITION

The composition of pomegranate varies largely based on the variety, agronomic practices, geographical location, storage, and processing. A number of studies have been carried out on the compositional analysis of different pomegranate varieties and also different parts of pomegranate such as peel, seed, juice, leaves, and flowers. The composition of the edible fraction of pomegranate determines its nutritional value and food applications. Some of the recent studies from different regions of pomegranate cultivation are discussed in this section. The nutritional composition of raw pomegranate fruit of 'Wonderful' cultivar is given in Table 2. The percent juice in pomegranate fruit is about 45–65% of the whole fruit or 76–85% of the arils (Poyrazoglu et al., 2002). The edible portion of pomegranate fruit represents on average 52% (w/w) of total fruit, comprising 78% juice and 22% seeds. The fresh juice is reported to contain 85.4% water (w/v), 10.6% (w/v) total sugars, 1.4% (w/v) pectin, 0.1% (w/v) acid (expressed as citric acid), 0.7 mg/100 mL ascorbic acid, 19.6 mg/100 mL free amino nitrogen, and 50 mg/100 mL ash (El-Nemr et al., 1990). The seeds contain 27.2, 13.2, 35.3, and 2.0% (w/w) total lipids, protein, crude fiber, and ash, respectively. Pomegranate seeds also contain 6.0% (w/w) pectin and 4.7% (w/w) total carbohydrates. The amount of iron, copper, sodium, magnesium, and zinc is higher in seeds than juice, except potassium (El-Nemr et al., 1990).

The edible part of the fruit contains a considerable amount of sugars, vitamins, polysaccharides, polyphenols, and minerals. The edible portion of the 'Taifi' cultivar from Saudi Arabia (57.5% of total fruit wt) comprised 63.6% of juice and 36.2% of seeds. Fresh juice from ripe fruits contained $83.7 \pm 0.4\%$ moisture, $14.6 \pm 0.5\%$ total sugar with glucose: fructose ratio of 1.16, $1.0 \pm 0.0\%$ protein, and $0.3 \pm 0.0\%$ ash. Total moisture and protein in seeds were 77.7 ± 3.4 and $4.5 \pm 0.7\%$, respectively. The predominant minerals were potassium (333.0 ± 15.8 mg/100 g in juice and 243.0 ± 21.7 mg/100 g in seed), sodium (72.1 ± 0.1 mg/100 g in juice and 95.7 ± 2.8 mg/100 g in seed), and calcium (24.5 ± 0.2 mg/100 g in juice and 59.3 ± 8.9 mg/100 g in seed) (Al-Maiman and Ahmad, 2002). Ten Iranian pomegranate varieties were classified into sweet (different clones of

Table 1 Comparative description of some of the pomegranates varieties around the world

Country	Variety	Fruit color	Taste	Seeds
Spain	Mollar	Red	Sweet	Nearly seedless Soft-seeded Very hard small seeds
Malta	Valenciana	Red	Sweet	
	Blanca	Whitish		
	Dulce Colourada	Red	Sweet	
Greece	Cagin	Red	Sour	Hard White hard seeds Seedless
	Patras Acide	Red	Sour	
Bulgaria	Patras Douce	Red	Sweet	
	Nikitski Rannii	Red	Sweet-sour	
Israel	Asmar	Dark purple-blackish		Small seeds Soft seeds Light seeds
Arabian Peninsula	Malissi			
	Cherabani	Red	Sour	
	Selimi	Red	Sweet-sour	
Turkey	Mellassi	Red	Sweet	Normal small
	Ak-anar	Yellowish-white		
Iran	Kizil-anar	Red	Sweet-sour	
	Shahvar (Saveh)	Red	Sweet	
Afghanistan	Kandahar large white	Yellowish	Sweet	Soft-seeded Soft-seeded
	Kandahar large red	Red	Sweet	
	Kandahar large black	Dark purple-blackish	Sweet-sour	
India	Ganesh	Yellowish red	Sweet	
	Bhagwa	Red	Sweet	Small, medium soft seeds
	Alandi	Red	Sweet-sour	
USA	Granada	Red	Sweet (very slight sour)	
	Wonderful	Bright red/dark red	Sweet-sour	
	Early Wonderful	Dark red	Sweet-sour	Soft-seeded
	Spanish Sweet	Pink	Sweet	
	Ruby Red	Purple red	Sweet-sour	

Ashton et al. (2006).

‘Alak-E-Shirin’, ‘Bihasteh’, ‘Syah’, ‘Agha Mohammad Ali Shirin’, and ‘Malase Shirin’), sweet-sour (clones of ‘Malase Torsh’ and ‘Pust Sefeede Shirin’), and sour varieties (‘Alak-E-Torsh’, ‘Tabestani’, and ‘Pust Sefeede Torsh’) (Fadavi et al., 2005). The sweet group comprised of the freshly consumed commercially viable varieties, whereas the sour group were commonly used for rootstock, ornamental, and industrial purposes. The moisture ranged from 71.3% in sour varieties to 75.5% in sweet varieties. The titratable acidity of sweet and sour varieties was 5.5 and 18.5 g/L, respectively, whereas Vitamin C varied from

Table 2 Nutritional composition of pomegranate fruit

Nutrient	Unit	Pomegranate
Proximates		
Water	g	219.76
Energy	kcal	234
Protein	g	4.71
Total lipid (fat)	g	3.3
Carbohydrate, by difference	g	52.73
Fiber, total dietary	g	11.3
Sugars, total	g	38.55
Minerals		
Calcium, Ca	mg	28
Iron, Fe	mg	0.85
Magnesium, Mg	mg	34
Phosphorus, P	mg	102
Potassium, K	mg	666
Sodium, Na	mg	8
Zinc, Zn	mg	0.99
Vitamins		
Vitamin C, total ascorbic acid	mg	28.8
Thiamin	mg	0.189
Riboflavin	mg	0.149
Niacin	mg	0.826
Vitamin B-6	mg	0.212
Folate, DFE	µg	107
Vitamin B-12	µg	0
Vitamin A, RAE	µg	0
Vitamin A, IU	IU	0
Vitamin E (alpha-tocopherol)	mg	1.69
Vitamin D (D2 + D3)	µg	0
Vitamin D	IU	0
Vitamin K (phylloquinone)	µg	46.2
Lipids		
Fatty acids, total saturated	g	0.338
Fatty acids, total monounsaturated	g	0.262
Fatty acids, total polyunsaturated	g	0.223
Cholesterol	mg	0
Other		
Caffeine	mg	0

Data for one raw pomegranate of four-inch diameter and 282.0g. Data based on samples of California Wonderful variety. DFE, dietary folate equivalents; RAE, retinol activity equivalents. [USDA National Nutrient Database for Standard Reference Release 26.](#)

0.13 mg/100 g in sweet varieties to 0.19 mg/100 g in sour varieties. Protein content in sweet varieties was 1.1% and 0.5% in sour varieties. Sweet varieties had 4.71% and 5.02% fructose and glucose, respectively, while the sour varieties contained 3.8% fructose and 3.7% glucose. Among minerals (mg/100 g), potassium concentration was the highest (142.0 in sour and 106.8 in sweet varieties) followed by sodium (28.5 in sweet and 19.6 in sour varieties), calcium (23.2 in sour and 17.2 in sweet varieties), magnesium, iron, zinc, copper, and manganese (Fadavi et al., 2005). The physicochemical properties and mineral content of some of the pomegranate varieties are given in Tables 3 and 4, respectively.

Pande and Akoh (2009) analyzed different fractions of six Georgia-grown (USA) pomegranate cultivars namely, 'R19', 'R26', 'Cvg-Eve', 'North', 'Crab', and 'Cranberry'. The predominant organic acid was citric acid, followed by malic acid. In all the cultivars, pulp fraction had the highest organic acids content (695.1–2235.3 mg/100 g) followed by peel (639.6–1857.9 mg/100 g), seeds (334.7–606.7 mg/100 g), and leaf (237.6–324.0 mg/100 g). The average malic acid content in pulp, peel, seed, and leaf was 157.5, 103.8, 95.0, and

Table 3 Physicochemical characteristics of pomegranate varieties juice
Varieties/cultivars

	Alak-E-Shirin ^a	Pust Safeeda ^a	Ciparski ^b	Wonderful ^c	Apaseo ^c
PH	4.20 ± 0.11	3.55 ± 0.04	3.4	2.9 ± 0.03	2.9 ± 0.1
TSS (°Brix)	14.0 ± 0.16	12.0 ± 0.09	14.8	17.8 ± 0.58	15.2 ± 0.18
TA (g/L)	5.6 ± 0.08	8.2 ± 1.6	9.0	15.8 ± 0.03	3.3 ± 0.02
Fructose (%)	4.50 ± 0.05	4.03 ± 0.03	8.3	8.90 ± 0.2	7.59 ± 0.1
Glucose (%)	4.80 ± 0.10	4.30 ± 0.11	7.4	8.94 ± 0.2	7.32 ± 0.2

TSS, total soluble solids; TA, titratable acidity.

^aFadavi et al. (2005).

^bGadze et al. (2013).

^cHerrera-Hernández et al. (2013).

Table 4 Major minerals in arils of pomegranate varieties (mg/100 g)
Varieties/cultivars

Organic acids	Wonderful	Ruby	Molla de Elche	Ganesh	Bhagwa
N	376.50	333.00	222.00	406.50	386.50
P	60.05	45.27	36.15	61.06	65.17
K	204.50	228.50	192.50	233.00	242.00
Ca	12.85	20.60	7.40	17.05	16.20
Mg	22.80	17.70	15.15	22.40	24.00
S	21.53	18.99	14.44	25.74	24.50
Cl	31.46	23.51	27.84	21.18	37.20
Na	2.14	2.45	2.46	2.11	2.14

Amos Fawole and Linus Opara (2012).

74.0 mg/100 g, respectively. The average citric acid content in pulp, peel, seed, and leaf was 1159.6, 980.5, 361.5, and 144.1 mg/100 g, respectively. The organic acid content of pomegranate varieties is given in Table 5. Pomegranate fruit, peel, seed, and leaves are rich in phenolic compounds, namely phenolic acids such as caffeic, *p*-coumaric, and ferulic acids, flavonoids like catechin, epicatechin, and quercetin, with the highest being hydrolyzable tannins including gallotannins, ellagic acid derivatives, and gallagyl tannins, which comprises mainly of punicalagin isomers and punicalin. Total polyphenols ranged from 89.2 mg/100 g in seeds to 164.4, 311.3, and 359.6 mg gallic acid equivalents (GAE)/100 g in pulp, peel, and leaves, respectively (Pande and Akoh, 2009). Peel fraction had the highest total hydrolyzable tannins content (4792.3–6894.8 mg/100 g). Individual phenolic compounds in different parts of pomegranate fruits are shown in Table 6. Overall, the highest antioxidant capacity was found in leaves, followed by peel, pulp, and seed. Pomegranate seeds had an average of 19.2% and fruit fraction had 0.3% total lipids content. Seed oil was rich in punicic acid (9*cis*, 11*trans*, 13*cis* octadecatrienoic acid, 81.0%). The other main fatty acids were oleic, palmitic, linoleic, and stearic acids. Table 7 shows the major fatty acid content of pomegranate seeds in some of the varieties across the world. No punicic acid was found in the lipids extracted from the fruit fraction (Pande and Akoh, 2009). The predominant fatty acids in fruit fraction were linoleic, palmitic, and oleic acids. Fruit fractions also had higher palmitic and oleic acid contents than the seeds. Pomegranate seed had a high content of α -tocopherol (average, 167.3 mg/100 g) and γ -tocopherol (average, 84.6 mg/100 g). The major phytosterol was β -sitosterol, ranging from 32.7 mg/100 g in fruit to 345.8 mg/100 g in seed. The other phytosterols were brassicasterol, campesterol, and stigmasterol. Pomegranate seed also contains phospholipids, mainly phosphatidylcholine (PC, 5.8–26.1 mg/100 g) and phosphatidylethanolamine (PE, 10.2–74.2 mg/100 g) (Pande and Akoh, 2009). In another study, the aril juice from 15 pomegranate cultivars grown in Georgia was extracted using the blender and mechanical press, and analyzed (Rajasekar et al., 2012). The cultivars were ‘Kaj-acik-anor’, ‘Rose’, ‘Don Sumner South Tree’, ‘Don Sumner North Tree’, ‘King’, ‘Crab’, ‘Thompson’, ‘Entek Habi Saveh’, ‘Afganski’, ‘Nikitski Ranni’, ‘Fleshman’, ‘Haku-Botan’, ‘Salavatski’, ‘Cranberry’, and ‘Pink’. The total soluble solids

Table 5 Organic acids of pomegranate varieties juice (ppm)

Organic acids	Varieties/cultivars				
	Wonderful ^a	Apaseo ^a	North ^b	Crab ^b	Cranberry ^b
Malic acid	1530	1510	1325	1641	1591
Citric acid	3290	940	4883	16,532	12,047
Oxalic acid	430	320	211	315	268
Ascorbic acid	88.2	75.4	365	611	558
Succinic acid	140	160	168	140	185

^aHerrera-Hernández et al. (2013).

^bPande and Akoh (2009).

Table 6 Phenolic composition of various parts of Georgia-grown pomegranates (mg/100 g)

Part	Cultivar	Hydrolyzable tannins	Caffeic acid	<i>p</i> -Coumaric acid	Ferulic acid	Catechin	Epicatechin	Quercetin
Seed	R19	36.3±2.3	2.8±0.3	1.4±0.9	0.8±0.3	nd	6.5±0.3	10.8±1.4
	R26	31.8±1.0	2.5±0.5	1.3±0.3	0.7±0.3	nd	6.2±0.5	11.2±1.2
	Cvg-Eve	26.6±0.5	3.1±1.2	2.1±0.2	0.5±0.0	nd	5.8±0.3	10.6±1.3
	North	22.8±1.3	2.1±0.4	2.8±0.2	0.5±0.3	nd	6.0±0.6	10.6±1.0
	Crab	30.7±1.3	3.4±0.3	3.2±0.1	1.1±0.3	nd	6.1±0.3	11.1±1.4
	Cranberry	36.6±0.6	3.2±0.3	3.6±0.8	1.3±0.3	nd	6.1±0.4	10.9±1.7
Pulp	R19	103.1±1.2	14.4±1.4	8.1±1.3	2.0±0.1	101.2±6.7	11.7±1.9	77.1±6.5
	R26	99.5±0.9	13.8±1.3	7.7±0.3	1.7±0.3	96.4±6.4	10.9±1.7	75.8±5.8
	Cvg-Eve	80.9±3.5	12.5±1.1	7.1±0.3	1.4±0.3	88.6±2.3	10.8±1.1	69.8±7.8
	North	71.2±2.2	12.3±1.2	6.6±0.6	1.3±0.2	82.7±5.3	9.6±1.6	66.7±5.7
	Crab	84.3±1.4	13.6±1.2	7.5±0.5	1.8±0.3	92.3±1.2	10.5±2.1	72.1±5.9
	Cranberry	100.6±1.3	14.1±1.4	8.0±0.1	2.0±0.3	98.5±4.5	11.7±0.7	76.3±5.3
Peel	R19	5759.5±61.3	19.7±2.7	4.3±0.9	17.7±2.3	118.3±6.8	26.1±3.4	94.3±8.3
	R26	5185.9±66.2	19.2±2.8	4.1±0.1	17.5±3.1	115.8±2.2	26.7±2.8	94.8±8.5
	Cvg-Eve	6076.3±24.8	19.8±2.0	4.7±0.9	17.8±0.3	120.6±5.7	27.7±2.4	95.8±8.6
	North	4792.3±35.5	18.9±2.7	3.8±0.3	17.1±0.3	110.7±7.7	25.4±2.8	92.1±8.5
	Crab	6894.8±12.6	21.4±3.8	5.1±0.3	18.9±1.6	126.7±7.1	29.5±3.1	99.2±7.2
	Cranberry	6780.9±18.4	20.7±2.2	5.2±0.3	18.6±3.0	125.6±6.3	28.3±3.5	97.8±7.2

Hydrolyzable tannins include gallotannins, ellagic acid derivatives, and gallagyl tannins which comprises mainly of punicalagin isomers and punicalin. nd, not detected. Pande and Akoh (2009).

Table 7 Major fatty acid composition of pomegranate seeds

	Varieties/ cultivars	Total lipid (%)	Fatty acids (%)						
			Palmitic	Stearic	Oleic	Linoleic	Punicic	Saturated	Unsaturated
USA ^a	R19	18.1 ± 0.3	4.2 ± 0.2	3.3 ± 0.2	3.6 ± 0.3	3.2 ± 0.2	83.4 ± 0.5	9.3	90.8
	CVG-Eve	20.7 ± 0.4	4.4 ± 0.2	3.1 ± 0.1	5.4 ± 0.2	3.5 ± 0.2	80.7 ± 0.5	9.4	90.2
	North	21.5 ± 1.1	4.1 ± 0.4	2.8 ± 0.0	7.5 ± 0.1	4.9 ± 0.0	78.3 ± 0.7	8.6	91.3
	Crab	18.3 ± 0.3	3.2 ± 0.1	2.4 ± 0.3	5.8 ± 0.2	3.3 ± 0.1	83.1 ± 0.3	7.0	93.0
Iran ^b	Abanmahi	14.6 ± 0.08	4.35 ± 0.2	2.99 ± 0.1	9.06 ± 0.3	8.11 ± 0.5	73.15 ± 0.4	8.01 ± 0.18	91.82 ± 1.19
	Malas	15.6 ± 0.09	4.46 ± 0.3	2.88 ± 0.2	8.31 ± 0.3	8.53 ± 0.4	73.31 ± 0.5	7.99 ± 0.07	91.76 ± 0.24
	Pust Sefid	16.9 ± 0.11	4.04 ± 0.1	3.00 ± 0.4	9.77 ± 0.3	8.13 ± 0.1	72.71 ± 0.4	7.73 ± 0.37	92.09 ± 0.8
	Shahvar	13.5 ± 0.08	4.41 ± 0.2	2.81 ± 0.1	9.36 ± 0.3	9.03 ± 0.3	72.07 ± 0.3	7.90 ± 0.16	91.94 ± 0.3
Spain ^c	Mollar de Elche 16	8.09 ± 0.19	3.83 ± 0.25	2.38 ± 0.39	5.91 ± 0.44	7.74 ± 0.32	66.76 ± 2.40	6.21 ± 0.73	80.41 ± 1.53
	Valencia 1	6.89 ± 0.19	3.63 ± 0.33	1.60 ± 0.15	5.23 ± 0.41	7.30 ± 0.45	78.50 ± 1.18	5.23 ± 0.24	91.03 ± 2.18
	Borde	10.49 ± 0.22	2.99 ± 0.47	1.64 ± 0.23	4.70 ± 0.33	4.98 ± 0.40	79.29 ± 1.90	4.63 ± 0.40	88.97 ± 2.76
	Albatera 1								
Tunisia ^d	Gabsi 3	21.45 ± 1.64	4.82 ± 0.05	3.15 ± 0.24	5.35 ± 0.01	7.51 ± 0.03	43.41 ± 7.33	10.18 ± 0.17	90.38 ± 0.15
	Mezzi 2	5.98 ± 0.82	11.82 ± 0.07	6.47 ± 0.05	12.14 ± 0.10	12.51 ± 0.09	12.45 ± 0.57	21.16 ± 0.37	80.54 ± 0.34
	Zehri 2	20.03 ± 0.42	6.61 ± 0.39	4.09 ± 0.07	11.34 ± 0.69	12.26 ± 0.78	40.42 ± 3.82	12.41 ± 0.64	88.46 ± 0.57
China ^d	Sichuan 2	15.03 ± 1.27	11.77 ± 0.34	15.64 ± 1.84	12.88 ± 0.69	13.92 ± 1.01	20.76 ± 1.72	28.61 ± 2.17	72.59 ± 2.18
	Shaanxi	15.71 ± 0.70	3.64 ± 0.08	3.24 ± 0.06	7.47 ± 0.18	7.80 ± 0.17	50.58 ± 15.63	8.77 ± 0.12	91.78 ± 0.11
	Sichuan 1	13.94 ± 0.07	3.21 ± 0.02	2.93 ± 0.16	6.50 ± 0.08	6.51 ± 0.07	47.58 ± 7.50	7.40 ± 0.33	93.11 ± 0.34
India ^e	Alandi	6.63 ± 0.18	6.0 ± 0.5	2.7 ± 0.2	6.3 ± 0.5	0.7 ± 0.2	83.1 ± 3.7*	9.9 ± 0.5	90.1 ± 3.7
	Vellodu	19.3 ± 0.15	7.5 ± 0.4	0.7 ± 0.1	10.7 ± 1.0	13.8 ± 2.0	66.3 ± 2.0*	9.2 ± 2.9	90.8 ± 2.8

*Reported as linolenic acid.

^aPande and Akoh (2009).

^bDadashi et al. (2013).

^cHernández et al. (2011).

^dElfalleh et al. (2011).

^eParashar et al. (2010).

content averaged 15.59°Brix in the blender and 14.94°Brix in mechanical press. The total monomeric anthocyanin levels ranged between 0.40 and 41.97 mg cyanidin-3-glucoside equivalents (CGE)/100 g. The total anthocyanins (mg/100 g FW) were 2.03 in the blender and 1.75 in mechanical press. The pomegranate juice contains six anthocyanin pigments, namely 3-mono- and 3,5-diglucosides of cyanidin, delphinidin, and pelargonidin, which are primarily from the arils and responsible for the intense red color. The major anthocyanin was delphinidin 3-glucoside. Overall, the blender was more efficient than mechanical press juice extraction in terms of yield, chemical composition, and antioxidant capacity of the juice. (Rajasekar et al., 2012)

Poyrazoglu et al. (2002) analyzed the organic acid and phenolic content in freshly prepared juices of 13 varieties of pomegranate from different regions of Turkey. The varieties (code) were '01-N-01' and '01-N-07' from Adana, '07-N-06' and '07-N-08' from Antalya, '31-N-01' and '31-N-07' from Hatay, and '33-N-11', '33-N-123', '33-N-15', '33-N-20', '33-N-23', '33-N-24', and '33-N-25' from İçel. The average total titratable acidity was 9.82 g/L, and total sugars were 148.75 g/L. Citric acid was the predominant organic acid (4.85 ± 2.83 g/L), followed by malic acid (1.75 ± 1.59 g/L). The main phenolic compounds in pomegranate juices were gallic acid, protocatechuic acid, chlorogenic acid, caffeic acid, ferulic acid, *o*- and *p*-coumaric acids, catechin, phloridzin, and quercetin. Pomegranate juices from nine Tunisian ecotypes (five ecotypes were for the variety 'Gabsi' and four ecotypes for the variety 'Tounsi') were analyzed for phenolics, flavonoids, anthocyanins, and tannins contents. Polyphenols ranged from 458 ± 19 to 3299 ± 103 mg GAE/L; flavonoids ranged from 135 ± 5 to 636 ± 24 mg quercetin equivalents (QE)/L; anthocyanins from 11 ± 1 to 178 ± 8 mg CGE/L, and tannins varied from 350 ± 20 to 2550 ± 90 mg catechin equivalents (CE)/L. The authors also suggested that the high concentrations of potassium (1042 ± 49 to 2226 ± 61 mg/L) and sodium (63 ± 2 to 164 ± 5 mg/L) may play a role in the adaptation of pomegranate to arid environments (El Kar et al., 2011).

A study dated 1930 analyzed the composition of different fruits of 'Wonderful' cultivar from different growing districts of California, USA, from three different years, namely 1925, 1926, and 1927. The mean soluble solids, acidity, and total sugars in fruits of year 1925 were 17.63, 1.90, and 13.82, respectively. For the year 1926, the average of soluble solids was 17.60, and acidity was 1.51. The average soluble solids, acidity, and total sugars for the harvest of year 1927 were 17.17, 1.85, and 13.56, respectively. The detailed composition of the 'Wonderful' pomegranate whole fruit (arils containing the juice sac) was also analyzed. The total sugars (%), pectic acid (%), citric acid (%), and ash (%) were 13.59, 0.072, and 1.02, respectively. Among minerals, phosphoric acid (mg/100 g), calcium oxide (mg/100 g), magnesium oxide (mg/100 g), potash (mg/100 g), chlorine (mg/100 g), and sulfur (mg/100 g) were 0.472, 27.55, 17.4, 17.1, 238.8, 50.3, and 5.72, respectively (Chace et al., 1930).

New cultivars are developed to obtain the best production and fruit quality. These new cultivars are developed to have higher adaptability to the growing region, its

climate, agronomic practices, and better yield. The new cultivars are often compared to well-established cultivars (such as ‘Wonderful’) or varieties in terms of their physical and chemical attributes to predict their selection and commercial applications. Four newly developed Mexican pomegranate cultivars (‘37–5’, ‘36–11’, ‘37–12’, and ‘33–17’) were compared to ‘Apaseo’, a Mexican cultivar and to ‘Wonderful’, the most commonly used commercial cultivar. Juice color of new cultivars was similar to that of the ‘Wonderful’ pomegranate. Two of the new cultivars had higher juice yield (~730 mL/kg arils) compared to ‘Wonderful’ pomegranate (703.7 mL/kg arils). All the new cultivars had similar TSS value as that of ‘Wonderful’ (17.8 °Brix) and higher than ‘Apaseo’ (15.2 °Brix). The organic acids identified were citric, malic, oxalic, tartaric, succinic, and quinic acids. ‘Wonderful’ and three new cultivars had higher citric acid than malic acid, whereas malic acid was the predominant acid in ‘Apaseo’ and one new cultivar. Three of the four new cultivars had similar glucose content as that of ‘Wonderful’ (89.4 g/L), while ‘Apaseo’ had lower glucose (73.2 g/L). In terms of fructose, two cultivars were similar to ‘Wonderful’ (89.4 g/L), whereas two were similar to ‘Apaseo’ (75.9 g/L). One of the cultivars had up to 56% higher vitamin C and 44% more punicalagins than ‘Wonderful’ juice. Pomegranate juices of the new cultivars and ‘Apaseo’ variety showed lower total soluble phenols compared to contents of ‘Wonderful’ (3806 mg GAE/L). ‘Wonderful’ juice had higher (888 CGE/L) anthocyanin content compared to juices produced from new cultivars and ‘Apaseo’ (469 CGE/L) (Herrera-Hernandez et al., 2013).

The chemical composition changes as the fruit matures. Generally, there is an increase in total soluble sugars and reduction in titratable acidity to obtain the optimum flavor. Kulkarni and Aradhya (2005) studied the chemical changes and antioxidant activity in pomegranate arils of common Indian variety, ‘Ganesh’, at different developmental stages, namely, 20, 40, 60, 80, 100, 120, and 140 days from the day of fruit set. They concluded that the content of total and reducing sugars increased significantly up to 100 days of fruit development, followed by a steady state in their rate of accumulation. The highest anthocyanin content (138 mg/100 g) was observed in 100-day-old fruit. There was a reduction of 76.2% and 71.7% in ascorbic acid and total phenolics, respectively, from 20 to 100 days of fruit development. The reduction in phenolics was accompanied by an increase in anthocyanin content, implying that phenolics were being metabolized for the biosynthesis of the flavylum ring during anthocyanin pigment formation. The antioxidant activity decreased as the content of vitamin C and phenolics decreased, but increased during the later stages as anthocyanins accumulated. The total protein content was highest in 20-day-old fruit (>200 mg/100 g) and rapidly decreased to <80 mg/100 g in the 80-day-old fruit. There was a 58.7% increase in total protein content between 80 and 120 days, after which it again decreased. After the period of 100 days, both the acidity levels and the amount of anthocyanins reduced, which may result in higher risk of internal browning in overripe fruits.

There are a very few studies on the amino acid content of pomegranate. [Tezcan et al. \(2013\)](#) analyzed the amino acids in commercial and fresh pomegranate juices to develop a fingerprint for adulteration of pomegranate juice with apple juices. The dominant amino acids (mg/L) of all the three freshly squeezed pomegranate juices were L-serine (641–846), L-proline (421–738), and L-alanine (252–545). The other amino acids were L-arginine (80.4–202), L-tryptophan (146–182), L-leucine (26.4–47.6), L-asparagine (90.6–137), L-glutamic acid (119–254), and L-aspartic acid (67–192). Among the D-isomers, only D-proline was detected in the fresh pomegranate juice (202–355 mg/L).

As with other fruit juices, total soluble sugars and titratable acidity are important parameters determining its flavor, acceptance, and also for predicting its maturation. Pomegranate varieties can be divided into sweet, sweet-sour, and sour varieties, based on the ratio of total soluble sugars to titratable acidity, also called the maturity index. Varieties having a maturity index of 31–98 are classified as sweet varieties, 17–24 as sweet-sour, and those having maturity index of 5–7 are sour varieties ([Martinez et al., 2006](#)). Maturity index helps in selecting the right time of harvest, which varies based on the cultivar and the growing region, and includes external skin color, juice color, acidity, and soluble solids content. The maximum titratable acidity for sweet varieties is 1% and for sweet-sour varieties is 1.5–2%. The variation in the minimum soluble solids can vary from 15 to 17% ([Elyatem and Kader, 1984](#)). The flavor of the fruit is dependent on the sugar/acid ratio. They vary among different cultivars, and the best possible values for sweetness and astringency are generally a soluble solids level above 17% and total phenolics content below 0.25% ([Elyatem and Kader, 1984](#)).

In a study based on a trained descriptive sensory panel, the flavor of pomegranate arils was described to be a combination of various tastes (sweet, sour, bitter), aroma (red wine and pomegranate fruity notes) and mouthfeel (astringency, juiciness, and seed hardness) sensations ([Mayuoni-Kirshinbaum et al., 2013](#)). Eighteen distinct pomegranate varieties from the Israel Pomegranate Breeding Collection at the Newe Ya'ar Research Center of Israel's Agricultural Research Organization were used. The varieties were numbered with a prefix P.G., as '119-20', '150-51', '218-229', '219-230', '128-29', '130-31', '160-61', '131-32', '213-224', '116-17', '118-19', '134-35', '234-245', '100-1', '112-13', '165-66', '162-63', and '127-28'. The high and low preferences based on these attributes are shown in [Figure 2](#). The overall taste of pomegranate juice is mainly governed by its sugar (sweetness), acid (sour), and polyphenol content (bitter notes). The major sugars present in pomegranate juice are glucose and fructose, with low amounts of other sugars such as sucrose, maltose, and arabinose ([Melgarejo et al., 2000](#)). It has also been suggested that the perceived sweetness depends on both the total amount as well as the relative proportion of sugars (mostly, glucose:fructose). Organic acids are the contributing factor to the sensation of sourness in pomegranates. As discussed earlier, the predominant acids in all varieties are citric and malic acids (in some varieties, citric acid is the dominant organic acid, while in some, it is malic acid) along with lower concentrations of succinic, oxalic, tartaric, and ascorbic acids ([Melgarejo et al., 2000](#)).

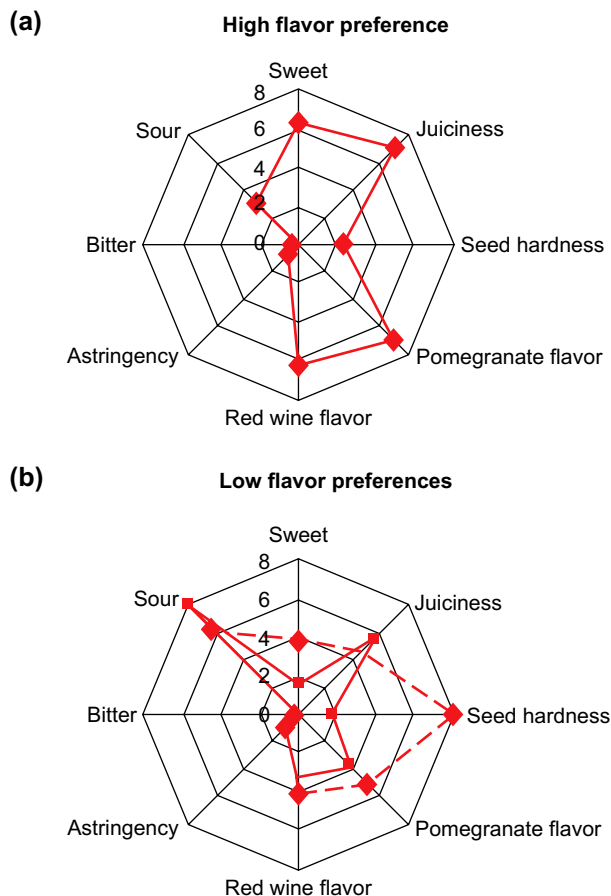


Figure 2 Flavor profiles and various attributes of high (a) and low (b) preferred pomegranate arils evaluated by a trained sensory panel consisting of 10 members. (a) is the average flavor profile of five highly preferred varieties, and (b) is the flavor profile of two different less preferred varieties. *Mayuoni-Kirshinbaum and Porat (2014), with permission*

Most fruits produce significant numbers of volatile compounds as the fruit ripens. These volatiles, along with sugars and acids, play an important role in flavor development and consumer acceptance of fruits. The aroma volatiles identified so far in pomegranate include alcohols, aldehydes, ketones, and terpenes. The three alcohols were hexanol (resin, floral, green), (Z)-3-hexenol (moss, fresh), and 2-ethylhexanol (floral). 6-Methyl-5-heptene-2-one (oil, herbaceous, green) was the only ketone identified in most varieties. The six aldehydes were hexanal (green, tallow, fat), (E)-2-hexenal (green, leaf), heptanal (fat, citrus, rancid), nonanal (fat, citrus, green), octanal (rancid, soapy), and (Z)-3-hexenal (green). The 11 terpenes can be divided into six monoterpenes, namely, α -pinene (pine, turpentine), β -pinene (pine, resin, turpentine), α -terpinene (lemon),

p-cymene (solvent, citrus), limonene (lemon, orange), and γ -terpinene (gasoline, turpentine); two oxygenated monoterpenes, mainly 4-terpineol (turpentine, must) and α -terpineol (oil, anise, mint); and three sesquiterpenes, which include α -bergamotene (wood, warm, tea), β -caryophyllene (wood, spice), and β -bisabolene (balsamic, herbaceous) (Mayuoni-Kirshinbaum and Porat, 2014; Vazquez-Araujo et al., 2011; Calin-Sanchez et al., 2011; Mayuni-Kirshinbaum et al., 2012; Melgarejo et al., 2011; Martinez et al., 2006). The core aroma volatiles determined in most of the varieties are hexanol, (Z)-3-hexenol, hexanal, nonanal, octanal, 6-Methyl-5-heptene-2-one, β -pinene, limonene, α -terpineol, and β -caryophyllene. Mayuoni-Kirshinbaum et al. (2012) used GC-olfactometry nasal impact frequency method to identify the aroma-active compounds (those volatiles present in concentrations equal to or greater than their odor thresholds limit) in the juice of the 'Wonderful' cultivar. The aroma-active pomegranate volatiles include one ester, three aldehydes, five terpenes, two alcohols, and one furan; namely, ethyl-2-methylbutanoate (fruity, apple), hexanal (green), β -pinene (pine, herbal), β -myrcene (woody, musty), *cis*-3-hexenal (green), limonene (fruity, musty), *cis*-2-heptenal (soapy, mushroom), *cis*-3-hexenol (earthy, grassy), 2-ethylhexanol (floral), β -caryophyllene (fruity, musty), 2(5H)-furanone (sweet, fruity), and β -sesquiphellandrene (terpene, almond). Unlike some fruits, such as banana (isoamyl acetate) and cherry (benzaldehyde), pomegranate does not have an individual character impact compound, but rather a complex mixture of several volatiles in different concentrations. The mouthfeel of pomegranate is based on astringency (as determined by the amount of hydrolyzable tannins, mainly punicalagin, present) and also the seed hardness (usually measured as woody portion index (WPI), which is the ratio of the woody portion of the seed to the entire aril) (Martinez et al., 2006). Pomegranate juice can be mainly described as having sour, sweet, musty/earthy, fruity aromatics, and an astringent mouthfeel. It has flavor characteristics of a combination of Concord grapes, cranberries, blackberries, cherries, currants, and raspberries, along with vegetable notes, such as beets and carrots (Koppel and Chambers, 2010).

FUNCTIONAL PROPERTIES

Pomegranate has gained attention due to its health beneficial properties, mainly antioxidant, anticancer, antitumor, antibacterial, and estrogenic properties. These health benefits are obtained not only from pomegranate juice, but also from its seeds, flowers, leaves, peel, and bark. A number of studies have been done to isolate and identify the health-promoting phytochemicals and study both *in vitro* and *in vivo* effects of pomegranate, its fractions, and different extracts. Plants produce a variety of compounds in addition to other essential metabolites, which are not directly involved in growth and development of the organism, but play an important role in reproduction, appearance, protection, and defense against pathogens, pests, and environmental stress. These compounds are known as secondary metabolites and can be grouped into terpenoids, alkaloids, and phenolic compounds.

Phenols, sometimes called phenolics, are a class of aromatic organic compounds consisting of one or more hydroxyl groups attached to an aromatic hydrocarbon group. Phenol is a benzene derivative and is the simplest member of the phenolic chemical. Polyphenols can be divided into various classes based on the number of phenol rings that they contain and also the structural elements that bind these rings to one another. The main groups of polyphenols are simple phenols, phenolic acids, coumarins, flavonoids, stilbenes, hydrolyzable tannins (polyesters of sugar moiety and phenolic acids), condensed tannins (also called proanthocyanidins), lignans, and lignins (Shahidi and Naczk, 2004). Phenolic acids are divided into two subclasses: (1) hydroxybenzoic acids, such as gallic acid and protocatechuic acids; and (2) hydroxycinnamic acid, such as coumaric, caffeic, and ferulic acids. Hydroxycinnamic acids occur more frequently as simple esters with carboxylic acids or glucose, whereas hydroxybenzoic acids are present as glucosides. Flavonoid represents the most common and widely distributed group of plant phenolics and consists of two aromatic rings linked through three carbons that usually form an oxygenated heterocycle. The variation in structure arises from the degree and pattern of hydroxylation, methoxylation, prenylation, or glycosylation. They can be subdivided into six classes: flavones, flavanones, isoflavones, flavonols, flavanonols, flavan-3-ols, anthocyanidins, and anthocyanins (Stalikas, 2007). Anthocyanins are the glycosylated derivatives of 3,5,7,3'-tetrahydroxyflavylium cation, whereas anthocyanidins are the nonglycosylated molecule (aglycone). The anthocyanins contain sugars and acylated sugars. The common sugars that are monosaccharides include glucose, galactose, arabinose, and rhamnose. The acyl substituents are *p*-coumaric, caffeic, ferulic, or sinapic acids, which are generally bonded to the C-3 sugar (Lee, 1992). The bright red color of pomegranate juice is due to its high content of anthocyanins, such as cyanidin-3,5-diglucoside, cyanidin-3-diglucoside, delphinidin-3,5-diglucoside, delphinidin-3-diglucoside, pelargonidin-3, 5-diglucoside, and pelargonidin-3-diglucoside. Pomegranate juice, due to its high phenolics, such as punicalagins, ellagic acid, and anthocyanins is considered to have several health benefits. Some of these important phenolic structures are shown in Figure 3. The other contributing factors are the lipid components of pomegranate seeds such as punicic acid. Punicic acid (C18:3-9*cis*, 11*trans*, 13*cis*) is an omega-5 long-chain polyunsaturated fatty acid and a conjugated linolenic acid isomer exhibiting several physiological benefits.

Commercial pomegranate juices showed an antioxidant activity three times higher than those of red wine and green tea, based on the evaluation of the free-radical scavenging and iron-reducing capacity of the juices. The commercial juice is extracted from whole fruits, thereby releasing some of the hydrolyzable tannins present in the fruit rind. Therefore, antioxidant activity was higher in commercial juices than in experimental juices obtained from the arils only (Gil et al., 2000). Pomegranate phytochemicals exhibit various biological activities, such as antioxidant activity by scavenging of free radicals, inhibiting oxidant enzymes, and inducing endogenous antioxidants; anti-inflammatory activities by inhibiting cyclooxygenase and lipoxygenase; antiatherogenesis effect by

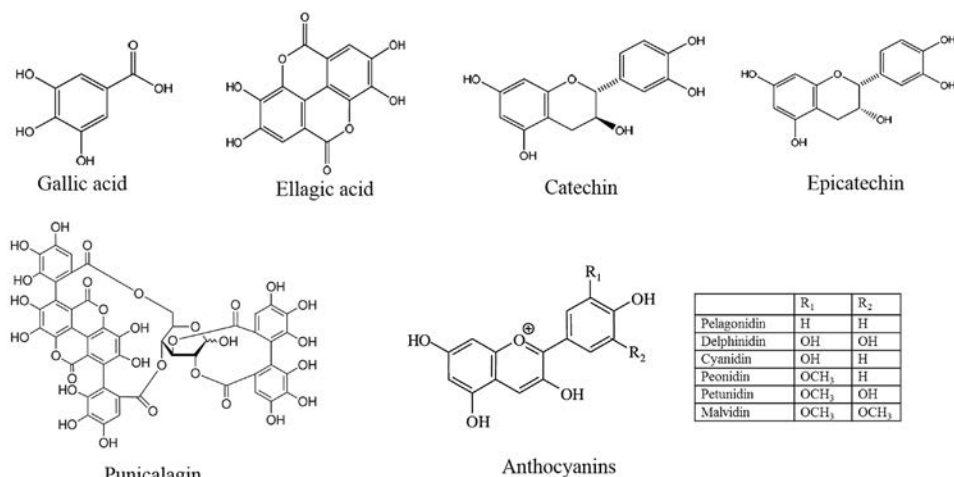


Figure 3 Physiologically important phenolics found in pomegranate.

inducing activity of paraoxonases 1 and 2 and defensive mechanism against oxidative stress; anticarcinogenic activity by inhibiting proinflammatory factors and tumor initiators, and also reduces cell proliferation (Akpinar-Bayazit et al., 2012).

Some studies have shown that supplementation with 40 g/day of pomegranate juice consisting of 2.1 g/100 g fiber, 15.6 g/100 g sugars, and 875 mg/100 g total polyphenols (875 mg/100 g) in type II diabetic patients significantly reduced total and LDL cholesterol, but had no effect on triacylglycerols and HDL-cholesterol levels (Esmailzadeh et al., 2004). In another study with pomegranate juice containing a high concentration of polyphenols (1979 mg/L of ellagitannins) but no fiber, a decrease in lipid peroxidation levels and cellular uptake of ox-LDL by monocyte-derived macrophages was observed in the diabetic patients (Rosenblat et al., 2006).

Several researchers have concluded that pomegranate phytochemicals, especially ellagitannins-derived compounds, such as ellagic acid, gallic acid, and their metabolites (urolithins A and B) have anticancer activities by inhibiting cancer cell proliferation (Seeram et al., 2005) and inflammatory cell signaling (Adams et al., 2006). Pomegranate extracts have also shown to be effective against oral bacteria in humans (Menezes et al., 2006). Pomegranate juice and pomegranate polyphenols were also effective against food-borne viral infectivity and have potential for preventing or reducing human norovirus infections (Su et al., 2010). Al-Zoreky (2009) reported that 80% methanolic extract of pomegranate peels was a potent inhibitor of *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli*, and *Yersinia enterocolitica*. Albrecht et al. (2004) showed that pomegranate seed oil, as well as polyphenols present in the pericarp, and fermented juice suppress proliferation and invasion of several human prostate cancer cells. Pomegranate seed oil has potential as a topical chemopreventive agent against skin cancer, mainly due to high punicalic acid content (Hora et al., 2003). Pomegranate seed oil has been shown to have

an anti-inflammatory effect (Boussetta et al., 2009) and protective effect on diet induced obesity and insulin resistance (Vroegrijk et al., 2011).

Commercial utilization of pomegranate as a functional food has increased in the last decade. Functional foods are those that include any food or food component that may provide additional physiological benefits beyond their basic nutritional functions. Several phytochemicals isolated from pomegranate plant have shown bioactivity and efficacy against chronic diseases. Some of them are anthocyanins, phenolics, and minerals in pomegranate juice; punicalic acid, tocopherols, and phytosterols in pomegranate seed oil; punicalagin, punicalin, and other phenolics in pomegranate peel and leaves; anthocyanin and phenolics in pomegranate flower; and phenolics and alkaloids in root and bark. Although there are a number of studies demonstrating the health benefits of pomegranates, in-depth, large, well-controlled studies are needed to investigate its bioavailability, safety, and nutritional value. The European Food Safety Authority panel also concluded that a cause and effect relationship has not been established between the consumption of punicalagin/ellagic acid in pomegranate/pomegranate juice and the maintenance of normal blood cholesterol concentrations, maintenance of normal erectile function, protection of lipids from oxidative damage, a sustained increase in appetite after unintentional weight loss leading to an increase in energy intake, and maintenance of normal blood glucose concentrations (EFSA, 2010). Recent studies have shown that the bioavailability of pomegranate phenolics, mainly ellagitannins (hydrolysis of ellagitannins releases ellagic acid, some of which is absorbed, and some is further metabolized to urolithins) varies and is affected by several factors (Seeram et al., 2008). Another aspect that needs further investigation is the interaction of pomegranate phytochemicals with other macro- and micronutrients in food, whether the phytochemicals affect/inhibit the metabolism and absorption of these other nutrients. Furthermore, some researchers have also reported that there may be a synergistic effect among pomegranate chemical constituents, as pomegranate extract or juice shows higher bioactivity than isolated individual phytochemicals (Lansky et al., 2005). Therefore, consumption of fresh fruit or juice in moderate amounts may be beneficial for health. Based on the traditional uses and recent scientific research demonstrating the pharmaceutical, pharmacological, and medicinal properties of pomegranate, the demand for pomegranate as a highly nutritious fruit crop and its commercial applications continue to increase.

SUMMARY POINTS

- Pomegranate is one of the oldest known edible fruits, originating in Central Asia and Persia.
- The pomegranate fruit is a berry with a leathery rind enclosing many several tightly packed juicy arils, which comprise the edible portion of the fruit.
- Some of the important traits determining consumer preference are pomegranate fruit size and color, arils color, seed harness, maturity, juice content, acidity, sweetness, and astringency.

- Various parts of the pomegranate plant demonstrate beneficial physiological activities, which can be attributed to its high content of phenolics, such as ellagitannins, punicalagin isomers, and anthocyanins.
- Pomegranate has a much higher antioxidant capacity than most of the commonly consumed fruits and fruit juices.
- Several in vitro and animal models, and few human clinical trials, have shown a positive effect of pomegranate on lowering or preventing the risk of many diseases. More human clinical studies are warranted to obtain stronger and definitive conclusions.

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CHAPTER 28

Nutritional Composition of the Prickly Pear (*Opuntia ficus-indica*) Fruit

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INTRODUCTION

Several members of the cactus family have strong cultural and economic significance throughout the Americas as crops in arid environments and for their alimentary, pharmaceutical, natural health, and forage products. Among these, the genus *Opuntia* Mill., commonly known as prickly pear cactus, includes a number of species that produce nutritious fruits and young, edible cladodes (stem pads, also called joints), which are used as a vegetable. They produce strong, vigorous plants in arid and semiarid climates in which few other crops can survive, protect against soil erosion, inhibit desert advancement, and protect wildlife, while functioning as commercial crops. *Opuntia* (subfamily Opuntioideae) and *Hylocereus* (A. Berger) Britton & Rose (subfamily Cactoideae) are among the most commonly domesticated and propagated cacti used as crops (Mizrahi et al., 1997). In addition, several columnar cacti, such as *Stenocereus pruinosus* (Otto ex. Pfeiff.) Buxb. (Bravo-Hollis, 1978), *Stenocereus queretaroensis* (F.A.C. Weber) Buxb. (Pimienta-Barrios and Nobel, 1994), and *Stenocereus stellatus* (Pfeiff.) Riccob. (Casas et al., 1997) are other species under controlled cultivation (Casas and Barbera, 2002).

Mexico is considered one of the major areas of genetic diversity of *Opuntia*, whose species prevail throughout the Americas, having adapted to many diverse habitats (Pimienta-Barrios and Nobel, 1995; Griffith, 2004). Conservatively, the genus *Opuntia sensu stricto*

(nopales, prickly pears) includes about 150 species (Stuppy, 2002). Although some species are distributed in areas with harsh winter conditions, both in the northern and southern hemispheres, the principal limitations to the cultivation of cactus for fruit are low temperatures in temperate regions or frost in other geographic areas because the ecotypes lack hardiness in freezing climates (Cota-Sánchez, 2002). Parish and Felker (1997) studied the performance of Mexican and Chilean *Opuntia* varieties in cold regions of Chile and found that Chilean varieties were most promising for the production of fruits with high sugar content and low seed weight, whereas Mexican varieties with high yields had low sugar content. In fact, several sources, for example, Inglese et al. (1995a) and Pimienta-Barrios and Muñoz-Urias (1995) suggest the need for better knowledge of the environmental influence on reproductive biology and fruit quality in cultivated cacti.

Opuntia ficus-indica (L.) Mill. (Figure 1) is quite likely the most agro-economically important cactus crop species (Bravo-Hollis, 1978; Kiesling, 1998; Griffith, 2004; Feugang et al., 2006). The fruits and joints are a popular food in Central and North America. In Mexican culture, for instance, the “nopaleras,” which are small to large cultivated areas or plantations of prickly pear cactus (Figure 2), have existed for thousands of years. In addition to fruit production, this cactus is farmed for the production of cochineal, a scale parasitic insect feeding on several species of *Opuntia*, from which the



Figure 1 A spineless plant of *Opuntia ficus-indica*, a domesticated cactus cultivated mainly as culinary source for its fleshy fruits. Note flat/paddle stems (cladodes) and the pear-like oval fruits. Photo: Patrick Griffith.

natural dye red carmine used to dye fabrics is extracted (Bravo-Hollis and Scheinvar, 2002).

Prickly pear was a popular fruit during the pre-Hispanic times (Kiesling, 1998; Inglese et al., 2002). The delicious fruits and the cladodes of this species are highly appreciated by humans, and the cladodes are also used as forage for livestock. The species has undergone human domestication since pre-Hispanic cultures. Both fruits and vegetative plant parts were introduced to Spain during the early voyages of Christopher Columbus (Bravo-Hollis, 1978; Kiesling, 1998). Cacti, in particular prickly pear cacti (*Opuntia* spp., also known as nopal), have had a long-term relationship with human culture. The cactus prickly pear fruit has long been cultivated in Latin America. There is evidence for the use of *Opuntia* in human diet at least 9000 years ago (Kiesling, 1998) or even as early as 12,000 years ago (Callen, 1967; reviewed in Griffith, 2004). It is also thought that nopaleras provided areas for centers of early human settlements in central Mexico, especially during the fructification period (Bravo-Hollis, 1978). In addition, drawings of prickly pear fruit

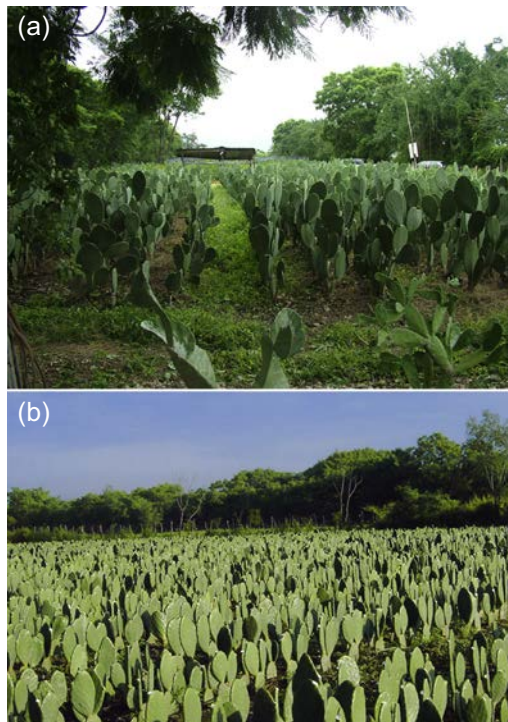


Figure 2 Nopaleras of *Opuntia ficus-indica*. (a) A nopalera in the state of Oaxaca (tended by a local community at Rancho La Nopalera in San Bartolo Coyotepec). The nopal is also called Tlapanocheztli, a compound Nahuatl term that refers to dye (tlapa) and nocheztli, for cochineal, the natural, pre-Columbian red dye that had a significant importance in the Spanish colonial economy. (Photo: Stephanie Wood.) (b) Modern cultivar of *O. ficus-indica* in northern Mexico. (Photo: VERALMEX®.)

(see below in common names) have been depicted in the Codex Mendocino (Código de Mendoza) in ca. 1540 and the Codex Florentine (Código Florentino) in ca. 1575 (Bravo-Hollis, 1978). *Opuntia* is also quite significant in modern Mexican culture and represents a national symbol depicted in the country's coat of arms (Aguilar-Enríquez et al., 2004).

According to Bravo-Hollis and Sánchez-Mejorada (1991) and Kiesling (1998), the different common names used for the prickly pear fruit are descriptive and make reference to its origin and distribution. The following accounts for vernacular names follow these two authors. First, the common name “tuna,” used mostly in Mexico and Central America, has a Caribbean origin and is thought to have originated with the Spaniards shortly after their arrival to the New World. According to Kiesling (1998), tuna is a word from the Taíno language used to refer mainly to the fruits, even though it is also used to denote the vegetative parts of *Opuntia* spp. Supposedly, the word “tuna” was used prior to any other names given to the prickly pear fruit. The word “nochtli” is the name in the Nahuatl language (also known as Azteca) for the prickly pear fruit and is currently used in the state of Oaxaca (Stephanie Wood, Oregon University, pers. com.). In turn, the term “nopal” is derived from “Nopalli” in Nahuatl and is used to designate several species of *Opuntia*. The first Spanish name is “Indian fig” (higo de las Indias), which alludes to its origin from the New East Indies, hence the origin of *Cactus ficus-indica* L., the first scientific name, but currently known as *O. ficus-indica*, a crop species that figures prominently in the modern folklore of ethnobotany (Griffith, 2004). Another common name is “tuna de Castilla” or “nopal de Castilla,” allegedly referring to Andalusia, the area in which it was first disseminated (Le Houérou, 1996; Kiesling, 1998). The Moors introduced the prickly pear to Africa when they left Spain and called it the “Christian fig.” To date, a spinescent hybrid called “tapia” (a name alluding to the use of this plant as a living fence) is frequently found in Morocco, while the spineless form is rare (Kiesling, 1998).

Given the high potential for use and consumption of *Opuntia* spp. products in conjunction with the prospective active nutrients and multiple properties of bioactive compounds in prickly pear, in this chapter the nutritional attributes of this fruit are reviewed and evaluated based on available literature. The prickly pear fruit is an excellent candidate for inquiry because of the high number of important nutrients relevant in the pharmaceutical industry, such as betalains, vitamins, minerals, amino compounds, and antioxidants. This chapter specifically examines published data to discuss the potential nutritional value and health benefits of the prickly pear fruit from *O. ficus-indica* (and other *Opuntia* species, whenever available). Also examined are the current trends in the increasing demand of nutraceutical and human health promoting products derived from fruits resulting from commercialization of this fruit, both in local markets and online.

BOTANICAL AND ANATOMICAL FEATURES OF THE PRICKLY PEAR FRUIT

Among all angiosperm families, few are as morphologically distinct as the Cactaceae, an important phytogeographic element of the American deserts and the second largest

plant family restricted to the New World, apart from one species in the genus *Rhipsalis* Gaertn., namely *Rhipsalis baccifera* (J.S. Muell.) Stearn, which is native in the New World and the Old World, but introduced to Madagascar, Mascarenes, Southern Africa, West and East Africa, and Sri Lanka (Cota-Sánchez and Bomfim-Patricio, 2010). It includes approximately 1500 species (Anderson, 2001) divided into four subfamilies (Anderson, 2001; Nyffeler, 2002). The family exhibits extreme levels of morphological diversity and physiological specialization. The stem structures have been variously modified to withstand severe xeric conditions and tropical or semitropical wet/dry seasonal habitats and have diverged significantly from a presumed leafy ancestor (Butterworth and Wallace, 2005). Cacti also exhibit extensive reproductive versatility and specializations in breeding systems (Cota, 1993; Anderson, 2001; Cota-Sánchez and Abreu, 2007; Almeida et al., 2013). The striking floral shapes, designed to attract a wide range of pollinators, act as a mechanism for cactus diversification by promoting genetic variability reinforced by outcrossing (Cota-Sánchez and Croutch, 2008).

The genus *Opuntia* belongs to the subfamily Opuntioideae, which includes several genera (Anderson, 2001). The genus *Opuntia* is used to refer to platyopuntias, that is, cacti with flattened cladodes or stem segments. In principle, the genus *Opuntia* s.s. includes nopales and prickly pears, but excludes *Consolea* Lem., and encompasses 150–180 species (reviewed in Majure et al., 2012). It is, therefore, the largest genus in the subfamily Opuntioideae and the most widely distributed genus in the cactus family ranging from southern Canada to Argentina (Anderson, 2001; Cota-Sánchez, 2002). As currently treated, *O. ficus-indica* represents a taxonomic complex of several clones originating from multiple lineages and is closely related to a group of arborescent plants from central and southern Mexico bearing fleshy prickly pear fruits (Griffith, 2004). The center of domestication for *O. ficus-indica* is located in central Mexico.

The spineless form of *O. ficus-indica* (Figure 1) is a horticultural cultivar. Based on coprolite data, the domestication of this species dates back from approximately 8000 (Bravo-Hollis and Sánchez-Mejorada, 1991) to 9000 (Callen, 1965, 1967) years ago. The origin of *O. ficus-indica* had remained a mystery until recently. According to Griffith's (2004) dispersal model based on molecular data (see his Figures 2, 3, and 6), the ancestors of *O. ficus-indica* were selected in central Mexico from tree-like (arborescent) taxa bearing fleshy fruits, including closely related species, such as *Opuntia hyptiacantha* F.A.C. Weber, *Opuntia leucotricha* DC., *Opuntia megacantha* Salm-Dyck, and *Opuntia streptacantha* Lem. Selective breeding for reduced spines and large fruits in *O. ficus-indica* quite likely involved various unique clones originating from several parental lines, thus forming a non-monophyletic group (Griffith, 2004). The cultivated plants were then distributed via trade markets throughout Mesoamerica and then to the Caribbean and conceivably into South America. It has been hypothesized that this species was transported to Europe by Christopher Columbus on his return voyage from the Americas in 1493 and then dispersed and naturalized in the Mediterranean area of Europe and North Africa and eventually across other arid and semiarid regions of the world. At present, *O. ficus-indica*

is cultivated for its fruits throughout the vast dry areas of the world, with Mexico, Algeria, Brazil, Chile, Sicily, and northern Africa being the most important producers (Barbera et al., 1992). Other species widely cultivated in northern and central Mexico for their large edible fruits are *O. robusta* J.C.Wendl. and *O. durangensis* Britton & Rose, two polyploid taxa (Griffith, 2004). The harvesting season of *Opuntia* spp. varies from April to August in the Americas (Scheinvar, 1995) and November to December in the Mediterranean basin (Le Houérou, 1996), with the fruits available unpeeled (Figure 3) and/or peeled (Figure 4) in local markets.

In order to understand the prickly pear fruit, it is necessary to discuss the structure of the cactus fruits first. The cactus ovary and fruit are extremely exceptional in that they are surrounded by vegetative tissues, which in most species consist of many nodes, internodes, axillary buds, and even rather ordinary leaves (Cota-Sánchez, 2004). Cactus flowers bear veins from the surrounding stem that enter at the top and sides of the ovary, spreading and extending to the style, ovules, and ovary. This unique vasculature provides evidence regarding the origin of the inferior ovary of a cactus flower from a stem that protrudes outward and engulfs the ovary. What we generally call a “fruit” is basically a combination of long-shoot coverings (the pericarpel) and the mature ovary, which is the actual botanical fruit. Consequently, when we eat the fleshy fruits of prickly pears or tunas, we are consuming mostly stem tissue (once the glochids and spines are removed—see Figure 3(b)). Because the pericarpel is composed of stem tissue, it forms conic leaves and areoles on its flanks, which, in turn, produce glochids and occasionally spines or even flower buds (reviewed in Rebman and Pinkava, 2001). The thick pericarp, covered with minute, barbed spines (also known as glochids), encloses a juicy pulp with 150–300 nonedible seeds. When eating the fruit, it is necessary to be very careful because the tiny glochids (see Figure 3, especially Figure 3(b)) can easily pierce the skin, causing pain and irritation.

The prickly pear fruit has an oval, elongated shape, like an oval apple or pear (Figures 1 and 3), and is technically a fleshy berry (Bravo-Hollis, 1978; Anderson, 2001).

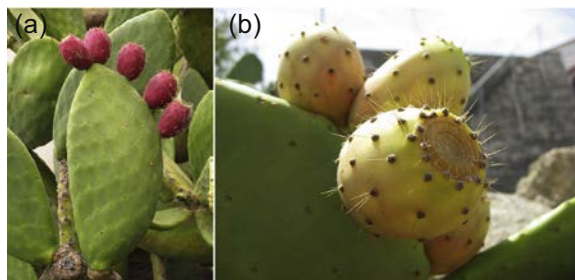


Figure 3 Prickly pear fruits from cultivated *Opuntia ficus-indica*. (a) Red pulp variety. (b) Yellow pulp variety. Photos: Valentina Saniccolo and Francesco Cepolina.

Its weight ranges from 67 to 216 g (Moßhammer et al., 2006). In the market, these fruits are available (peeled or unpeeled) in several attractive colors, such as white, green, yellow, orange, red, and purple (Figure 4(b)), which vary in relation to the amount of betalain pigment content (Anderson, 2001; Stintzing et al., 2005). Generally, cactus pear fruits may be divided into three components that may be exploited for commercial processing: seeds, peel, and pulp (reviewed in Moßhammer et al., 2006). The seeds of the prickly pear fruit are highly variable in form, size, structure, and testa color. Seeds are normally discarded (Feugang et al., 2006) but often eaten as part of the fresh fruit (pers. obs.). There are, however, a few varieties with few or no seeds; current selection focuses on reducing seed number and size while increasing fruit size (Bianchini et al., 1975). It has been suggested that for marketing strategies, one of the most important selective breeding objectives in prickly pear research should be the development of few-seeded varieties (Felker and Inglese, 2003). The fleshy prickly pear fruits have a short shelf life, varying from 2 to 3 and up to 4 weeks (Feugang et al., 2006), thus making marketing and long-term storage and worldwide distribution of fruits difficult (Kader, 2002). Efforts to diminish postharvest decay have been considered, taking into account decreasing



Figure 4 Prickly pear fruit, staple component of the Mexican and Central American diet culture. (a) Whole and longitudinal section of prickly pear fruit with rind (pericarp) attached. (b) Sample of the various colors of prickly pear fruits (resulting from different betalain pigments) for sale in a Mexican market in the state of Zacatecas. The rind (pericarp) has been removed from the fruits. (Photo B: Tomás Castelazo.)

microbial contamination while maintaining the consistency as well as the nutritional, palatable, and enticing properties of the fruit (Piga et al., 1996).

In Mexico and the southwestern US, the prickly pear fruit is relatively common and appreciated as a valuable supplemental food source. Its use is mainly restricted to fresh fruit consumption in its countries of origin (Sáenz-Hernández, 1995; Sáenz and Sepúlveda, 2001), but the fruit is also exported to the European fresh fruit market (Mizrahi et al., 1997; Sepúlveda, 1998). Occasionally, the fruit is processed and found canned or bottled as juice (Sáenz, 1996; Gurbachan and Felker, 1998; Bravo-Hollis and Scheinvar, 2002; Feugang et al., 2006). However, in spite of its popularity, there is still limited conclusive knowledge about the nutritional properties and human health benefits of this fruit.

NUTRITIONAL ASPECTS OF THE PRICKLY PEAR FRUIT

At present, there are no obvious references indicating a difference between traditional and modern crops of prickly pear used for fruit production. As indicated previously, most varieties originated from a small group of closely related species, from which the descendants, that is, spineless plants with large fruits, were further selected and propagated clonally. As a result, it is difficult to make a distinction between ancient and modern varieties. Consequently, the information below is based on fruit characteristics of *O. ficus-indica* (and other *Opuntia* spp.) from traditional and contemporary genotypes.

There is a plethora of studies dealing with the chemical characterization, antioxidant properties, and nutritional components of the prickly pear species and the fruit, and the information can be provocative and overwhelming. See also references in literature. In general, the prickly pear fruit contains approximately 85% water, 15% sugar, 0.3% ash, and less than 1% protein (Mohamed-Yasseen et al., 1996; Moßhammer et al., 2006). The fruit has no distinctive aroma, but the pulp is very sweet, and the sugar component is mainly glucose and fructose (in similar amounts), the concentration ranging from 10 ° to 17 °Brix (Stintzing et al., 2003; reviewed in Piga, 2004). This energy source in the form of sugar is absorbed by the organism and becomes readily available for brain and cell function. Considering the high water content, this fruit can reach a value of 50 kcal/100 g, an amount comparable to other fresh fruits like apricot, orange, and pear (Feugang et al., 2006). The seeds account for approximately 10–15% of the edible pulp (Feugang et al., 2006), or 3–7% on a weight basis, followed by the pericarp and mesocarp (36–48%), and the edible pulp (39–64%) (Gurrieri et al., 2000; Felker et al., 2002, 2005).

According to the United States Department of Agriculture and based on the amount of daily value (DV) provided in a 100 g serving, the *Opuntia* prickly pear fruit has a modest content of essential nutrients. The dietary fiber is 14% DV, and vitamin C content is 23% DV. Among minerals, magnesium has a 21% DV. The remaining components are not considered strongly significant for dietary supplements (Table 1). The concentrations

Table 1 A comparative synopsis of the chemical constituents of the different parts/products of the prickly pear fruit, primarily from *Opuntia ficus-indica*, obtained from different literature resources and the Food Composition Database (NDCB No. 09287) of the United States Department of Agriculture (USDA). Second value, whenever indicated, is from the USDA Website at <http://ndb.nal.usda.gov/ndb/>

Constituents	Fresh fruit pulp (%)	Fruit juice (mg/L) ²	Fresh fruit pulp (mg/100 g)
Water	84–90/87.5		
Carbohydrates	12–17/9.57		
Ashes	0.3–1/1.64		
Fiber	0.02–3.15/3.6		
Protein	0.21–1.6/0.73		
Lipids	0.09–0.7/0.51		
Free amino acid content			
Alanine		87.2	
Arginine		30.5	
Asparagine		41.6	
Glutamic acid		66.1	
Glutamine		346.2	
Glycine		11.3	
Histidine		45.2	
Isoleucine		31.2	
Leucine		20.6	
Lysine		17.4	
Methionine		55.2	
Phenylalanine		23.3	
Serine		174.5	
Threonine		13.3	
Tyrosine		12.3	
Tryptophane		12.6	
Valine		39.4	
Vitamin content (100 g)			
Niacin (Vit. B3)	Trace amounts		
Riboflavin (Vit. B2)	Trace amounts/0.06		
Thiamine (Vit. B1)	Trace amounts/0.014		
Vitamin C (total ascorbic acid)	12–81/14	12–81	
Vitamin E	111–115 µg		
Vitamin K ₁	53 µg		
Mineral content			
Calcium			12.8–59/56
Iron			0.4–1.5/0.30
Magnesium			16.1–98.4/85
Sodium			0.6–1.1/ND
Phosphorous			15–32.8/24
Potassium			90–220/220

Continued

Table 1 A comparative synopsis of the chemical constituents of the different parts/products of the prickly pear fruit, primarily from *Opuntia ficus-indica*, obtained from different literature resources and the Food Composition Database (NDCB No. 09287) of the United States Department of Agriculture (USDA). Second value, whenever indicated, is from the USDA Website at <http://ndb.nal.usda.gov/ndb/>—cont'd

Constituents	Fresh fruit pulp (%)	Fruit juice (mg/L) ²	Fresh fruit pulp (mg/100 g)
Selenium			ND/0.6
Sodium			ND/5
Zinc			ND/0.18
Antioxidant content (100 g)			
Ascorbic acid	12–81 mg ²		
Beta-carotene	1.2–30 µg		
Flavonols:	0.11–9 g		
Kaempferol derivatives			0.11–0.30
Quercetin derivatives			0.98–9
Isorhamnetin derivatives			0.19–2.48

ND or empty cells, no data; + symbol, includes kaempferol, quercetin, and isorhamnetin derivatives.

Additional data extracted and adapted from: Sáenz-Hernández (1995), Piga (2004), Stintzing and Carle (2005), Stintzing et al. (2001, 2005), Tesoriere et al. (2005), Feugang et al. (2006), Shedbalkar et al. (2010).

of the nutritional components of the fruit are dependent on the cultivation site, climate, and fruit variety (Sáenz-Hernández, 1995; Felker et al., 2005).

Several literature resources indicate that the prickly pear fruits are a source of different nutritional compounds (Sáenz-Hernández, 1995; Stintzing et al., 2001, 2005). There have been several studies, for example, Gurrieri et al. (2000), Stintzing et al. (2001), Piga (2004), Lee et al. (2005), and Feugang et al. (2006), that investigated the composition of pulp in the *Opuntia* fruit and considered its flesh as a good source of minerals, in particular calcium, magnesium, potassium, and phosphorous. Cactus pear fruits exhibit an ascorbic acid content of 20–40 mg/100 g fresh weight and a titratable acidity of 0.03–0.12% with pH values ranging from 5.0 to 6.6 (Feugang et al., 2006; but see data in their Tables 2–6 for more detailed information). The concentrations of these components are thought to be dependent on the cultivation site, climate, and variety (Sáenz-Hernández, 1995; Kader, 2002; Tesoriere et al., 2005; De Wit et al., 2010). Likewise, several types of amino acids, for example, alanine, arginine, and asparagine, are present in prickly pear fruit. In addition, Kugler et al. (2006) reported comparatively high amounts of aspartic and glutamic acids, estimated at about 200 mg/kg juice in *Opuntia ficus-indica*. Nutritionally important vitamins, such as vitamin C (ascorbic acid), E, K, and beta-carotenes (Tables 1 and 2), are also constituents of the cactus pear fruit. The antioxidant properties of both carotenes and vitamin E have been shown to ameliorate the stability of fatty oils (Ramadan and Mörsel, 2003a). Only trace amount of several types of vitamin B have been found in prickly pear fruits (Table 1).

Table 2 Detectable amino acid content in the fruit pulp of three varieties of *O. ficus-indica*.

Amino acid	Gymnocarpo	Morado	Apastillada	Mean value
Alanine	81.7	83.4	96.6	87.2
Arginine	37.1	21.2	33.2	30.5
Asparagine	45.5	35.5	44.2	41.7
Citrulline	14.2	5.9	28.7	16.3
Glutamic acid	83.0	42.5	72.8	66.1
Glutamine	574.6	288.8	175.1	346.2
Glycine	8.6	9.2	16.2	11.3
Histidine	50.0	32.3	53.3	45.2
Isoleucine	32.9	21.8	38.8	31.2
Leucine	21.3	nv	19.9	20.6
Lysine	18.3	16.5	nv	17.4
Methionine	76.9	56.3	32.5	55.2
Phenylalanine	23.9	24.1	22.0	23.3
Proline	1143.5	883.4	1768.7	1265.2
Serine	217.5	175.4	130.6	174.5
Taurine	407.3	323.6	572.1	434.3
Threonine	15.1	12.6	11.6	13.1
Tryptophane	11.2	9.2	17.5	12.6
Tyrosine	13.0	14.3	9.6	12.3
Valine	50.0	32.9	35.2	39.4

Data indicate that the prickly pear fruit is a fruit containing promising nutraceuticals and essential ingredients, such as amino acids, taurine, carbohydrates, calcium, magnesium, vitamin C, soluble fibers, and refreshing and pleasant flavor and colors.

Amounts expressed in mg/l; nv, not valid.

Adapted from [Stintzing et al. \(1999, 2001\)](#).

A significant amount of neutral lipid (87% of total lipids) is found in the seed oil from the prickly pear fruit, but the concentration of polar lipids is higher (52.9% of total lipid) in pulp oil ([Ramadan and Mörsel, 2003a,b](#); [Mannoubi et al., 2009](#)). Remarkably, 36.8 g of lipids per kg is found in the pericarp layer (or peel) ([Ramadan and Mörsel, 2003a](#)). Fat-soluble vitamins (alpha-, beta-, and delta tocopherols, beta-carotene, and vitamin K1) present in seed and pulp oils of the prickly pear fruit protect lipids from oxidative damage ([Feguang et al., 2006](#)). It is well-known that cacti produce alkaloids, which is a characteristic feature of the cactus family ([Gibson and Nobel, 1986](#); [Anderson, 2001](#)), but their role in human nutrition and health is still obscure.

Flavonoids (found in phenolic compounds) are another important constituent in *Opuntia* pulp fruits. The several flavonoids have an antioxidative effect ([Tesoriere et al., 2004, 2005](#); [Morales et al., 2012](#)) and are more effective than vitamins because phenolic compounds produce stable radicals, which in turn delay prooxidative actions on proteins, DNA, and lipids ([Aires et al., 2004](#)). Other antioxidants in prickly pear fruits include pectin, carotenes, betalains, ascorbic acid, quercetin, and quercetin derivatives. The fruits are a rich source of flavonoids, including kaempferol, quercetin, narcissin, dihydrokaempferol

(aromadendrin, 6), dihydroquercetin, and eriodictyol (Knishinsky, 1971; reviewed in Zou et al., 2005; Shedbalkar et al., 2010). Flavonoids are known to have positive health benefits (Knishinsky, 1971; Wang, 1988; Tesoriere et al., 2004).

Betalains are pigments characteristically red to violet (betacyanins) and yellow to orange (betaxanthins) present in different plant parts of members of the Caryophyllales, including the cactus family (Anderson, 2001). These pigments account for the gamut of fruit color of the prickly pear fruit and add important components to its nutritional nature. The concentration of these pigments is responsible for the differences and intensity in color types of the fruit, from deep red/violet and variations of pale green to yellow-orange (see Figures 3 and 4). The characterization of betalains in prickly pear fruits has revealed that these pigments have antioxidant properties (Butera et al., 2002; Stintzing et al., 2005; Tesoriere et al., 2005). Thus, the prickly pear fruit is an antioxidant-rich fruit with properties that can potentially prevent or delay cell damage in the human body. Overall, the general distribution of nutrients and antioxidants in the prickly pear fruit is an indication that the ingestion of the whole fruit is more beneficial from a health perspective because more potentially nutraceutical active ingredients are absorbed and used by our bodies.

The seeds of the prickly pear fruit are rich in minerals and sulfur amino acids (Sawaya et al., 1983a,b; reviewed in Feugang et al., 2006). In addition, several authors (Sáenz, 1996) claim that the composition of fatty acids in *O. ficus-indica* seeds have beneficial food properties, and the ground *Opuntia* seeds, with a chocolate/cumin taste, make an exceptional condiment, useful in culinary arts (Felker and Inglese, 2003). At present, prickly pear cacti extracts (from cladodes) are available in the market in powder or pill form and have been used as a dietary complement with suggested health benefits.

Considering the chemical components of the prickly pear cactus (Table 1), it could be said that the nutritional capacity of this fruit is relatively modest. There are, however, several aspects to consider this a promising fruit. Although the prickly pear fruit lacks proteins, fatty acids, vitamins, and certain required dietary supplement minerals, it does include several amino acids (Table 2), and it has strong antioxidant capacity attributed to flavonoid (Table 3) and carotenoid content (Table 4). Furthermore, it is worth mentioning, as pointed out by Piga (2004), that the popular and increasing trend in the demand for nutraceuticals is associated with an increased desire for natural ingredients and food products promoting health. The multiple functional properties of cactus pear, in conjunction with the antioxidant properties of the fruit, fit well with this trend. The data of Piga (2004, and sources therein) reveal the high content of some chemical constituents as well as betalains, taurine, calcium, magnesium, and antioxidants is significant, which adds value to this fruit on a nutritional and functional perspective (see Tables 2–5). In addition, the consumption of prickly pears provides promising nutraceuticals and essential ingredients, such as amino acids, taurine, carbohydrates, calcium, magnesium, vitamin C, and a significant contribution to the intake of fiber and total phenolics in human diets.

Table 3 Fractional and total content of flavonoids (kaempferol, quercetin, isorhamnetin) in prickly pear fruits from four species of *Opuntia* with different fruit skin colors. The last column includes the oxygen radical absorbance capacity (ORAC) value or antioxidant capacity in fruit extracts. The antioxidant capacity of cactus fruits can be attributed to their flavonoid, ascorbic acid, and carotenoid contents

Species and skin fruit color	Kaempferol	Quercetin	Isorhamnetin	Total flavonoids (μg/g fresh wt.)	ORAC (μl of TE/g)
<i>O. ficus-indica</i> (green-skinned)	2.2 ± 0.3	43.2 ± 2.5	24.1 ± 1.0	69.5 ± 3.8	26.3 ± 1.8
<i>O. lindheimeri</i> (purple-skinned)	1.1 ± 0.4	90.5 ± 11.5	1.9 ± 0.5	93.5 ± 12.4	49.2 ± 1.7
<i>O. streptacantha</i> (red-skinned)	3.8 ± 0.5	51.0 ± 4.6	nd	54.8 ± 5.1	25.2 ± 2.1
<i>O. stricta</i> var. <i>stricta</i> (yellow-skinned)	nd	9.8 ± 3.0	nd	9.8 ± 3.0	15.8 ± 1.6

Flavonol content expressed in (mg/g fresh weight). Mean ± standard deviation values are based on triplicate determination. nd, not detected; TE, trolox equivalent antioxidant capacity. Adapted from Kuti (2004).

Table 4 Biochemical composition of red-skinned prickly pear fruit from different wild species of *Opuntia* (*Opuntia stricta* and *Opuntia undulata*) in relation to commercial/modern *O. ficus-indica*.

	<i>O. ficus-indica</i>	<i>O. stricta</i>	<i>O. undulata</i>
Ascorbic acid (mg/100 g ff)	18.5 ± 2.0	23.3 ± 1.7	14.5 ± 1.5
Total phenolics (mg gallic acid equivalents/100 g ff)	218.8 ± 2.9	204.4 ± 4.2	164.6 ± 3.3
Total carotenoids (μg β-carotene equivalents/100 g ff)	2.58 ± 0.07	4.71 ± 0.10	6.68 ± 0.28
Betacyanins (mg betanin/100 g ff)	15.2 ± 0.8	80.1 ± 5.6	24.6 ± 2.1
Betaxanthins (mg indicaxanthin/100 g ff)	25.4 ± 1.9	nd	17.8 ± 0.9
Betalains (betacyanins + betaxanthins) (mg/100 g ff)	40.6 ± 2.7	80.1 ± 5.6	42.4 ± 3.0
Taurine (mg/100 g ff)	7.70 ± 0.46	6.80 ± 0.5	11.22 ± 0.74

Strongest antioxidant capacity and taurine content can be found in fruit extract of *O. ficus-indica*, whereas the fruits of *O. stricta* are the richest in ascorbic acid and total phenolics. The *O. undulata* fruits have the highest carotenoid content. Weight values are for fresh fruit (ff) and expressed in mean ± standard deviation of three separate estimations. nd, not detected.

Data adapted from Fernández-López et al. (2010).

Thus, nutritional and chemical properties of the prickly pear may not provide the required balanced diet for human nutrition, unlike major staple foods, such as cereals and legumes; nevertheless, the prickly pear fruit and derivative properties can certainly supplement human nutritional requirements.

Despite the difficulty in breaking cultural nourishment traditions, which in developing countries are often associated with nutritional imbalance and deficiencies, an assorted food

Table 5 Chemical composition for prickly pears of *O. ficus-indica* and *Opuntia dillenii*.

	<i>Opuntia ficus-indica</i>	<i>Opuntia dillenii</i>
Moisture (%)	82.27 ± 2.22	81.68 ± 2.42
Total fiber (%)	5.37 ± 0.87	9.49 ± 1.51
Protein (%)	0.90 ± 0.26	0.52 ± 0.12
Fat (%)	0.50 ± 0.13	0.71 ± 0.19
Ash (%)	0.39 ± 0.08	0.43 ± 0.06
pH	6.32 ± 0.17	3.34 ± 0.11
Ascorbic acid (mg/100 g)	17.2 ± 4.43	29.7 ± 2.95
Phenolics (mg/100 g)	45.2 ± 7.4	117 ± 10
Na (mg/kg)	6.25 ± 8.22	153 ± 162
K (mg/kg)	1583 ± 328	908 ± 251
Ca (mg/kg)	263 ± 76	535 ± 187
Mg (mg/kg)	251 ± 57	454 ± 102
Fe (mg/kg)	1.98 ± 0.57	1.53 ± 0.31
Cu (mg/kg)	0.38 ± 0.09	0.33 ± 0.05
Zn (mg/kg)	2.05 ± 0.51	1.29 ± 0.49
Mn (mg/kg)	3.03 ± 1.58	5.09 ± 3.80
Ni (mg/kg)	0.28 ± 0.10	0.20 ± 0.08
Cr (mg/kg)	0.11 ± 0.03	0.14 ± 0.03

There does not appear to be significant nutritional difference among fruits from different species. Most differences are due to human selection for larger size, more taste, and longer shelf-life in prickly pear fruits. No substantial difference was found between green and orange color pulp in fruits of *O. ficus-indica*, but according to [Díaz-Medina et al. \(2007\)](#), the consumption of prickly pears, in particular *O. dillenii*, represents a significant contribution to the intake of fiber, ascorbic acid, Mn, Cr, and total phenolics in human diets. Mean values expressed in mean ± standard deviation. Adapted from [Díaz-Medina et al. \(2007\)](#).

selection is relevant to sustain a balanced, quality diet to properly meet nutritional health benefits. Numerous sources, for example, [Bialostoky et al. \(2002\)](#), [Frison et al. \(2006\)](#), and references therein, indicate that macro- and micronutrient consumption and a holistic food-based approach are fundamental for ideal nutrition and ultimately optimum human health. Variety leads to a nutritionally adequate combination of macro- and micronutrients, even with a lack of specific nutritional knowledge ([Geissler and Powers, 2010](#)). In order to sustain a balanced diet, a person needs relatively larger amounts of macronutrients, that is, carbohydrates, proteins, and lipids (fats), with concomitant relatively smaller amounts of micronutrients, for example, vitamins, minerals, and antioxidants ([Geissler and Powers, 2010](#)).

USES AND HEALTH BENEFITS OF FRUIT AND OTHER PLANT PARTS OF THE PRICKLY PEAR

Cacti (*Opuntia* spp.) have been used for centuries as common vegetables and medicines by Native Americans and Mexicans to treat a variety of ailments and disorders ([Knishinsky, 1971](#); [Anderson, 2001](#); [Bravo-Hollis and Scheinvar, 2002](#); [Cota-Sánchez, 2002](#);

Tesoriere et al., 2004). The nutritional and medicinal properties of the fresh cladodes have long been known (Bravo-Hollis, 1978; Fernández et al., 1992; Cota-Sánchez, 2002). The bark is a tonic and diuretic, the fruits have cooling and tonic properties, and the young buds and the milky juice are astringent (Sedbalkar et al., 2010). A number of medicinal applications have been attributed to several cacti. Medicinally, prickly pear components and extracts have been used in treatments for diabetes, cholesterol, and immune system health (Knishinsky, 2004). Polysaccharides extracted from *O. ficus-indica* have been used to treat wounds and to protect the liver from dangerous organophosphorous pesticides (Ncibi et al., 2008). *Opuntia* species have been used to protect brain tissue from glucose and oxygen deprivation (Huang et al., 2008) and to treat hypoglycemic effects in diabetic patients by returning blood glucose to normal levels (Laurenz et al., 2003), and extracts of *O. streptacantha* have been shown to inhibit alpha-glucosidase activity (Becerra-Jiménez and Andrade-Cetto, 2012).

In Chinese medicine, cactus fruit is used as medicine to treat inflammation and pain and as a detoxification agent for snakebites (Wang, 1988). However, Arizona cactus pear extracts have been used to test anti-cancer effects. Zou et al. (2005) report that they inhibit cell growth in several cancer cell cultures, suppress tumor growth in nude mice, and modulate expression of tumor-related genes. While these effects were comparable to those of a synthetic retinoid currently used in chemoprevention trials, the mechanism of the anti-cancer effects of cactus pear extracts need further investigation and testing.

In summary, in spite of the several uses indicated above and the fact that the leaves, flowers, stems, and fruit are edible parts highly appreciated in prickly pear species, the use of *O. ficus-indica* is mainly restricted to fresh fruit consumption in their countries of origin (Sáenz and Sepúlveda, 2001). The fruit is typically eaten fresh, although it can be candied or made into juice and jams (pers. obs.). Fresh prickly pears are mainly available as food items in North American supermarkets serving Hispanic customers. The prickly pear fruit has been investigated as a new source of natural sweetener (Sáenz et al., 1998), and the pulp and seeds of *Opuntia jonocostle* F.A.C. Weber ex. Diguët and *Opuntia matudae* Scheinvar have been shown to be sources of bioactive compounds (phenolics, flavonoids, and tocopherols) (Morales et al., 2012).

FUTURE PROSPECTS

Cactus pear fruits are rich in betalains, taurine, minerals, and antioxidants (Moßhammer et al., 2005, 2006), fitting well with the current healthy nutraceutical trend of human society. This fruit is considered a promising future crop for commercial food applications, but a comprehensive knowledge of the physical and chemical attributes and their current and potential future uses of cactus prickly pears is still lacking. Many of the data are also contradictory. Despite the scanty figures on conclusive clinical studies and evidence (Moßhammer et al., 2006), numerous websites on the Internet claim that components of the prickly pear have contraindications, such as hypersensitivity, and that its use should be avoided

during pregnancy and lactation (<http://www.drugs.com/npp/prickly-pear.html>). Conversely, other websites claim a wide array of health benefits, such as treatment for type 2 diabetes, high cholesterol, obesity, colitis, etc., as well as side effects, including mild diarrhea, nausea, increased amount and frequency of stool, bloating, and headache. The fruit is also consumed purportedly to treat respiratory tract infections, arteriosclerosis, diarrhea, and sore throat (<http://www.mayoclinic.org/healthy-living/consumer-health/expert-answers/prickly-pear-cactus/faq-20057771>).

Because of the lack of rigorous research regarding the actual effect on human health of the prickly pear components, it is too early to call the cactus prickly pear a potential panacea fruit or superfood. Most importantly, the reader should keep in mind that many health claims available on the Internet are based on folklore or traditional or indirect scientific evidence and have not been validated by scientific research, which suggests a need to check the validity of herbal information available on this and other plants on the Internet. In fact, [Veronin and Ramirez \(2000\)](#) conducted a systematic survey of health claims of *Opuntia* and found that only 34% of the claims were addressed in the scientific literature and much of the evidence was conflicting. However, the prickly pear fruit is certainly popular in many areas of the world, particularly in Latin America, and can be part of a healthy diet because it is high in fiber, antioxidants, and carotenoids ([Piga, 2004](#); [Feugang et al., 2006](#), and references therein).

In a world with increasing interest in healthy food and lifestyle, it makes sense to market crops with potential health-promoting and nutritional benefits, such as cactus pears, which are increasingly gaining popularity from some health specialists and consumers worldwide. In brief, future research regarding further investigation of cactus pear chemistry and industrial utilization of the fruit as a raw material for foods is needed to accurately assess the benefits and wonders of this plant in human society, particularly regarding nutrition and health.

CONCLUDING REMARKS

To end this review, I would like to mention [Piga's \(2004\)](#) comment regarding a tale saying that people from some North African countries refer to the prickly pear fruit as “the bridge of life” because it is the only food and water resource for animals during the long dry seasons, and the hope is that this crop will substantially reward human exploitation in all parts of the world, particularly in arid and semiarid regions, where food and water supplies are limited. The nopal (*Opuntia* spp.) is a plant of manifold qualities ([Muñoz-de-Chávez et al., 1995](#)) and, at present, is a cash crop that is easy to tend and maintain in arid and semiarid regions ([Pimienta-Barrios, 1994](#); [Scheinvar, 1995](#); [Stintzing and Carle, 2005](#)). Its cultivation is expanding to new parts of the world because of its straightforward propagation and growth and, most importantly, the fact that it feeds both humans and livestock species in areas in which food resources may be limited. The seeds of

O. ficus-indica and most *Opuntia* species exhibit low germination rates due in part to the seed's sclerified (bony) aril. Thus, asexual reproduction is common in many opuntias. The most prevalent type of cloning of *Opuntia* is vegetative propagation by stem or cladode detachment (Rebman and Pinkava, 2001). It is through this mechanism that some opuntias are capable of forming large natural populations, which are the result of dense monocultures of clonal individuals, hence the ease of propagation as a crop plant.

Clearly, there are still numerous research needs related to the reproductive biology as well as productivity and orchard management of the prickly pear cactus crop. The gradual and improved information regarding the nutritional value of prickly pear fruit, in addition to the promising potential of *Opuntia* species to establish in marginal land, has promoted interest in preparing processed items to fulfill the need for diversification and improved fruit shelf life (Inglese et al., 1995b, 2002; Piga, 2004). One of the biggest challenges is fruit improvement, specifically the creation of large, tasty, seedless fruits of higher quality. In addition, increasing the consumer market is another shortcoming, but despite the fact that changing people's eating habits is difficult, it is feasible that more effective marketing strategies may enable this plant to go beyond ethnic markets to make the prickly pear fruit appealing to more consumers in larger cities. New marketing techniques should widely exploit the utilitarian possibilities of prickly pear fruits and pads.

In addition to human and animal food, crops of prickly pear cacti (*Opuntia* spp.) have been shown to have benefits for the environment. From this perspective, several *Opuntia* species have been successfully used in land reclamation and rehabilitation procedures (Le Houérou, 1996), and more recently *O. streptacantha* Lem. has been used as a bioaccumulator in lead-contaminated waters in bioremediation programs (Miretzky et al., 2008). In an excellent review, Shedbalkar et al. (2010) highlight the many characteristics of cacti, making them a suitable model crop to attain productivity and sustainability with minimal ecological or environmental impact to meet the growing world demand for food. The same idea applies to *O. ficus-indica* (and other *Opuntia* species), as these are alternative resources to meet food supply and nutritional health requirements. As a specialized and environmentally friendly crop, it withstands long periods of drought, a factor that may become significant in areas of the world with declining water resources and increasing desertification as a result of human population growth and global warming. Furthermore, these crops represent an effective food production system, including ecosystem services and the production of fruits and vegetable parts for human and livestock consumption.

In conclusion, this underexploited crop has the potential to provide food, beverages, and acceptable levels of nutrition in addition to significant pharmacological potential and promising active ingredients in human nutrition and health. To put it simply, the wide range of characteristics and applications of the prickly pear fruit (and plant) makes it an ideal element to explore and experience in different daily life activities, including nutritional diet and culinary arts, traditional and modern medicine, environmental land use and arid and semiarid agrosystems, and industry.

SUMMARY POINTS

- The cactus family has strong cultural and economic significance throughout the Americas and provides crops used for alimentary, pharmaceutical, natural health, and forage products. The genus *Opuntia*, commonly known as prickly pear cactus, includes a number of species that produce nutritious fruits and young, edible cladodes (stem pads, also called joints), which are used as a vegetable.
- The prickly pear fruit is also known as tuna, Indian fig, Christian fig, and tuna de Castilla.
- Mexico is considered one of the major areas of genetic diversity of *Opuntia*, and *Opuntia ficus-indica* is one of the most agro-economically important cactus crop species and is cultivated in arid and semiarid regions of the Americas, Mediterranean region, Australia, and Africa for its fruits. The spineless forms correspond to horticultural varieties.
- The cactus pear fruit has an oval, elongated shape, like an oval apple or pear, and is technically a fleshy berry. The fruits have several attractive colors, such as white, green, yellow, orange, red, and purple, which vary in relation to the amount of betalain pigment content.
- The prickly pear fruits may be divided into three components that may be exploited for commercial processing: seeds, peel, and pulp.
- The prickly pear fruit contains approximately 85% water, 15% sugar, 0.3% ash, and less than 1% protein. The flesh is a good source of minerals, in particular calcium, magnesium, potassium, and phosphorous. Several types of amino acids, for example, alanine, arginine, and asparagine, are present in prickly pear fruit. Important vitamins include vitamin C (ascorbic acid), E, K, and beta-carotenes. A significant amount of neutral lipid (87% of total lipids) is found in the seed oil. Flavonoids (found in phenolic compounds), effective antioxidants, are another important constituent.
- Red, yellow, and purple pigments (betalains) are characteristic in prickly pear fruit. These pigments have antioxidant properties, and their concentration is responsible for the differences and intensity in color types of the fruit.
- Overall, the general distribution of nutrients and antioxidants in the prickly pear fruit is an indication that the ingestion of the whole fruit is more beneficial from a health perspective because more potentially nutraceutical active ingredients are absorbed and used by our bodies. However, considering the chemical components of the prickly pear cactus, the nutritional capacity of this fruit is relatively modest and should be used as dietary complement.
- The prickly pear fruit can be considered as “the bridge of life” because it is the only food and water resource for animals during the long dry seasons in dry areas of the world. This crop can substantially reward human exploitation in all parts of the world, particularly in arid and semiarid regions where food and water supplies are limited.

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CHAPTER 29

Chemical Composition of Raspberry (*Rubus* spp.) Cultivars

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LIST OF ABBREVIATIONS

EA	Ellagic acid
FW	Fresh weight
HHDP	Hexahydroxydiphenic acid
IQF	Individually quick frozen
mDP	Main degree of polymerization
TPC	Total phenolic content

INTRODUCTION

Berries have been a part of human diet for centuries, while raspberries are among the most popular berries in the world. The place of origin of red raspberry (*Rubus idaeus*) has been postulated to be the Ida Mountains of Turkey (Jennings, 1988). The earliest account of raspberry domestication in Europe was provided by Romans in the fourth century. It is believed that Roman soldiers spread the cultivation of this plant throughout Europe.

Raspberries gradually grew in popularity over the centuries, and by the 1500s, *R. idaeus* was cultivated all over Europe. In 1829, 23 raspberry cultivars were listed in the “History of English Gardening” (Swanson et al., 2011). In the 1700s, raspberries were exported to the American colonies (Jennings, 1988).

Raspberries have been used in traditional medicine for their numerous healing properties (Hummer, 2010). Berries and leaves have been commonly used to treat a variety of ailments, including diseases of the alimentary canal and cardiovascular system, as well as fever, influenza, and diabetes. The leaves may also be applied externally as antibacterial, anti-inflammatory, and sudorific agents. Raspberry leaf extract has been reported to have antispasmodic and muscle-relaxant properties (Hummer, 2010).

Raspberries have always been attractive as fresh dessert fruits or for processing into various products. Fresh raspberry fruits are primarily sold in clamshell packages. The primary processed products include individually quick frozen (IQF) whole raspberries, IQF raspberry crumble, block frozen raspberries, and also pureed, juiced, canned, or dried raspberries. Currently, the leading commercial producers of red raspberries worldwide are Serbia, Russia, Poland, USA, and Chile. The cultivation of black raspberry (*Rubus occidentalis*) is mainly concentrated in the USA and in Korea (Swanson et al., 2011).

Raspberries are highly valued for their health-promoting and antioxidant substances, such as vitamin C and various polyphenolic compounds. The major phenolics found in raspberry fruits are ellagitannins and anthocyanins. The unique phenolic profile containing ellagitannins, which are complex hydrolysable derivatives of ellagic acid, as the major constituents, distinguishes raspberries from other common fruits. Ellagitannins and ellagic acid exhibit a wide range of biological effects such as antioxidant, antimutagenic, anticarcinogenic, and antiviral, suggesting that they could have beneficial effects on human health. In addition, ellagic acid is already included in the List of Existing Food Additives as a natural antioxidant in some countries, including Japan (Tasaki et al., 2008). Another important group of bioactive phytochemicals found in raspberries encompasses large spectra of natural pigments called anthocyanins, which are represented in *Rubus* berries, predominantly by cyanidin compounds. The variations in the content of ellagitannins and anthocyanins reported in raspberries are quite remarkable; these variations could be due to the differences in the applied analysis procedures or due to genetic factors.

Numerous genotypes of raspberries have been developed in different countries seeking to obtain commercial cultivars with increased productivity, higher content of valuable nutrients, stronger antioxidant potential, and other valuable characteristics. Therefore, regularly reviewing the studies reporting the composition of raspberry cultivars developed and grown in different countries all over the world becomes a useful task for growers, retailers, processors, dieticians, and researchers.

BOTANICAL ASPECTS

The genus *Rubus* comprises over 250 heterozygous species, which are subdivided into 12 subgenera (Mabberley, 2008). *Rubus* species are native throughout the northern hemisphere; however, the main center of diversity is in Asia. The domesticated subgenera include raspberries, blackberries, the Arctic raspberries, and flowering raspberries, all of which have been utilized in breeding programs. *Idaeobatus* (raspberries) is the most commercially important of the domesticated subgenera, while the most economically important raspberry species are the European red raspberry (*R. idaeus* L. subsp. *idaeus*), the North American red raspberry (*R. idaeus* subsp. *strigosus* (Michx.)), and the black raspberry (*R. occidentalis* L.). Both the red and the black raspberry have yellow- or apricot-colored natural or horticultural variants, resulting from the presence of recessive alleles that suppress red pigment production. Fruits from such plants are called yellow raspberries. Purple raspberries are hybrids between red raspberry (*R. idaeus*) and black raspberry (*R. occidentalis*).

Raspberries have perennial roots and crowns, while their stems or canes are biennial. There are two types of raspberries, floricanes-fruiting and primocane-fruiting. In floricanes (summer-bearing) raspberries, the first year primocanes are vegetative only, while the second year floricanes bear a crop in early summer. Primocane (fall-bearing or autumn fruiting) raspberries produce fruit on the top half of the primocanes in the fall, followed by fruiting on the bottom half of the floricanes in late spring or early summer.

A typical planting lifetime of red raspberries is 10–15 years, whereas black raspberries have a much shorter commercial lifetime, only two to three harvest seasons. Raspberry fruits ripen in three phases, and each phase lasts from 10 to 12 days. Ethylene production increases in the fruit when the fruit begins to change color and reaches maximum when it is fully ripe. Fruit mass of cultivated raspberries varies within a range from 2.5 to 5–6 g, but under certain conditions, the fruit can exceed 10 g (Jennings, 1988). Raspberries are an aggregate fruit, composed of individual drupelets, held together by almost invisible hairs. Each drupelet usually has a single seed (Graham and Woodhead, 2011).

COMPOSITION OF RASPBERRY CULTIVARS

Development and Distribution of Raspberry Cultivars

Many of the most important modern commercial red raspberry cultivars are derived from hybrids between *R. idaeus* and *R. strigosus* (Badjakov et al., 2006). In more recent years, parents with genes derived from *R. occidentalis* L. (black raspberry), in addition to *R. idaeus* and *R. strigosus* have been used in crosses. Important traits derived from *R. idaeus* are superior in fruit qualities including flavor, deep red color, and a single dominant gene resistance to raspberry mosaic virus complex. *Rubus*

strigosus is a source of genes for winter hardiness, resistance to cane diseases and to root rot. *Rubus occidentalis* is a source of genes for fruit traits, such as firmness, easy harvest, lower levels of susceptibility to rot, and late ripening (Daubeney, 2006).

Domestication has resulted in a reduction of both morphological and genetic diversity in red raspberry, with modern cultivars being genetically similar. Five parent cultivars dominate the ancestry of red raspberry: ‘Lloyd George’ and ‘Pynes Royal’, entirely derived from the European subspecies, and ‘Preussen’, ‘Cuthbert’, and ‘Newburgh’ derived from both European and North American subspecies (Badjakov et al., 2006). Therefore, concerted efforts are being made to broaden the genetic base of new raspberry cultivars (Fin et al., 2008).

The choice of raspberry cultivars for cultivation is determined by the environmental conditions and by the preferences of targeted market. Several raspberry cultivars developed in the mid-1900s have become standards of raspberry industry worldwide. For example, ‘Meeker’ and ‘Willamette’ are standard floricane red raspberries for the processing market, while ‘Tulameen’ is a standard floricane red raspberry for the fresh market, which is particularly suited for production under protected structures, including plastic tunnels and greenhouses, providing out-of-season fruit supply. ‘Boyne’ and ‘Newburgh’ are standard floricane red raspberry cultivars for challenging winter areas or wet sites. Other commonly grown floricane raspberry cultivars are ‘Glen Ample’, ‘Glen Lyon’, ‘Cowichan’, ‘Coho’, ‘Chilliwick’, ‘Malahat’, and ‘Qualicum’. (Fin et al., 2008; Janick and Paull, 2008).

‘Heritage’ is a standard primocane red raspberry for the fresh market. Other commonly grown primocane-fruited raspberry cultivars are ‘Autumn Bliss’, ‘Autumn Britten’, ‘Caroline’, ‘Nova’, and yellow-fruited ‘Anne’. The early primocane cultivars ‘Polka’ and ‘Polana’ are common in central Europe and Scandinavia because of the cold climates and short summers in those areas. ‘Munger’ and ‘Jewel’ are standard black raspberry cultivars for the processing and fresh markets, while ‘Mac Black’ is the main new black raspberry cultivar for the fresh market (Fin et al., 2008; Janick and Paull, 2008).

Red raspberry cultivars continue to be developed in order to meet the expanding needs of growers, processors, and consumers worldwide. In addition to high yields and excellent fruit quality, the objectives that are addressed in breeding programs are root rot and raspberry bushy dwarf virus resistance. Additional goals are focusing around traits based on the use of the fruit, and adaptation to specific local environments (Fin et al., 2008).

Only a few cultivars of black raspberry have been developed over the past several decades. However, the rising interest in their nutraceutical value is driving a need to develop better cultivars (Fin et al., 2008).

Raspberry Nutrients

In the last decade, the worldwide popularity of raspberries has increased, due to the numerous scientific reports on potential health benefits of highly colored berries.

Table 1 Nutrient composition of fresh red raspberries per 100 g (Rao and Snyder, 2010)

Proximates		Minerals		Vitamins	
Water (g)	85.75	Calcium (mg)	25	Vitamin C (mg)	26.2
Energy (kcal)	52	Iron (mg)	0.69	Thiamin (mg)	0.032
Protein (g)	1.2	Magnesium (mg)	22	Riboflavin (mg)	0.038
Total lipid (g)	0.65	Phosphorus (mg)	29	Niacin (mg)	0.598
Carbohydrate (g)	11.94	Potassium (mg)	151	Pantothenic acid (mg)	0.329
Dietary fiber (g)	6.5	Sodium (mg)	1	Vitamin B ₆ (mg)	0.055
Sugars (g)	4.42	Zinc (mg)	0.42	Folate (μg)	21
Sucrose (g)	0.2	Copper (mg)	0.09	Choline (mg)	12.3
Glucose (g)	1.86	Manganese (mg)	0.67	Vitamin A, RAE (μg)	2
Fructose (g)	2.35	Selenium (μg)	0.2	Lutein – zeaxanthin (μg)	136
				Vitamin E, α-tocopherol (mg)	0.87
				Vitamin K, phyloquinone (μg)	7.38

Raspberries are a good source of many nutrients, including essential minerals, vitamins, and fatty acids, as well as a wide range of polyphenolic phytochemicals.

A nutrient profile of red raspberries is shown in Table 1. Raspberries are rich in dietary fiber (6.5 g/100 g) and fructose (>50% of total sugars), both of which regulate blood sugar levels by slowing digestion, whereas fiber also contributes to a satiety effect. Raspberries are a good source of manganese and vitamin C; 100 g of berries provide almost 50% of the recommended daily allowance of vitamin C (Rao and Snyder, 2010). Vitamin C and manganese are important antioxidant nutrients that protect against oxidative stress. Raspberries are also recognized as a good source of riboflavin, folic acid, niacin, magnesium, potassium, copper, and iron.

Red raspberry seed was reported to contain 11–23% oil, consisting of 54–55% linoleic acid (18:2), 29–31% α-linolenic acid (18:3), 10–12% oleic acid (18:1), and 3–4% saturated fatty acids. The percentage of α-linolenic acid in raspberry seed oil is similar to hemp, black currant, and cranberry oils. The oil of raspberry seeds has a low ratio (1.6–1.7/1) of ω-6 and ω-3 fatty acids (Bushman et al., 2004). Other lipophilic nutrients in red and black raspberry seed oils are tocopherols (dominating γ-tocopherol) and carotenoids enduing with natural sun protection factor and anti-inflammatory capabilities. Therefore, raspberry seeds are a promising raw material in the growing cosmeceuticals market (cosmetic products with biologically active ingredients).

Raspberry Phytochemicals

Phytochemicals can be specifically defined as the bioactive nonnutrient components of fruits and vegetables that have been linked to reducing the risk of major chronic diseases

(Stoner et al., 2008). Phytochemicals can be classified into groups, such as carotenoids, phenolics, alkaloids, nitrogen-containing compounds, and organosulphur compounds. Phenolic compounds of berry fruits include flavonoids (anthocyanins, flavonols, flavones, flavanols, catechins, flavanones, and isoflavonoids), stilbenes, tannins, lignans, and phenolic acids (Szajdek and Borowska, 2008). The content of phenolic compounds in berries is determined by many factors, such as genotype, cultivation conditions, weather conditions, ripeness, harvesting time, storage time, and storage conditions.

In addition to beneficial biological functions, phenolic compounds, as well as some other phytochemicals, are closely associated with the sensory attributes of berries and other plant foods. Contribution to color by anthocyanins and carotenoids is well-known. The involvement of some phenolic substances in flavor development and taste is also documented.

Total Phenolics Content (TPC) of Raspberries

Considerable variation in total phenolic content (TPC) was reported among the red raspberry cultivars. For instance, the TPC values of red raspberry genotypes grown in USA were from 322 mg/100 g in cultivar ‘Dascade Delight’ to 645 mg/100 g in cultivar ‘Encore’ (Weber et al., 2008), in 17 cultivars grown in Lithuania—from 279 mg/100 g in cultivar ‘Pokusa’ to 504 mg/100 g in cultivar ‘Glen Moy’ (Bobinaitė et al., 2012), in 12 cultivars grown in Finland—from 192 mg/100 g in cultivar ‘Gatineu’ to 359 mg/100 g in cultivar ‘Ville’ (Anttonen and Karjalainen, 2005), and in 8 cultivars grown in Hungary—from 160 mg/100 g to 336 mg/100 g (Lugasi et al., 2011). Some of the red raspberry cultivars were analyzed in various countries by different scientific groups (Table 2), and it is interesting to note that, considering numerous factors that may influence the TPC, the differences determined for the same raspberry cultivar grown in different countries are not very significant.

The TPC values for black raspberries were reported to be approximately 1.2 to 2.5-fold higher than for red raspberries (Gansch et al., 2009; Bobinaitė et al., 2012). For instance, the TPC of 10 black raspberry genotypes grown in USA varied from 489 mg/100 g in cultivar ‘Black Hawk’ to 875 mg/100 g in cultivar ‘Hanover’ (Gansch et al., 2009). It has been frequently reported that darker colored raspberries contain higher TPC and stronger antioxidant activities. However, it was demonstrated that the yellow raspberry cultivars can also exhibit remarkable antioxidant activities and high levels of TPC and flavonoids, while being low in anthocyanins (Gansch et al., 2009). In different studies, the TPC values in yellow raspberry genotypes were reported to vary between 168 and 485 mg/100 g FW (Anttonen and Karjalainen, 2005; Weber et al., 2008; Gansch et al., 2009; Lugasi et al., 2011; Bobinaitė et al., 2012).

Besides the fact that TPC is influenced by the raspberry genotype, it was also reported that late harvest berries of some cultivars contained significantly higher TPC. For instance, significantly higher TPC was found in the second harvest of the

Table 2 Total phenolic content (mg/100 g FW) in raspberry cultivars grown in different countries

Cultivar	Color	TPC	Country	Reference
Meeker	Red	389	Lithuania	Bobinaitė et al. (2012)
		444	USA	Weber et al. (2008)
		360–420	New Zealand	Connor et al. (2005)
Haida	Red	325–363	New Zealand	Connor et al. (2005)
		484	Finland	Anttonen and Karjalainen (2005)
Chilliwick	Red	484	USA	Weber et al. (2008)
		325–363	New Zealand	Connor et al. (2005)
Tulameen	Red	386	USA	Weber et al. (2008)
		246–277	New Zealand	Connor et al. (2005)
Ottawa	Red	383	Lithuania	Bobinaitė et al. (2012)
		330	Finland	Anttonen and Karjalainen (2005)
Polana	Red	315	Lithuania	Bobinaitė et al. (2012)
		226	Hungary	Lugasi et al. (2011)
Bristol	Black	715	Lithuania	Bobinaitė et al. (2012)
		715	USA	Weber et al. (2008)

autumn-bearing red raspberry cultivars ‘Heritage’ and ‘Autumn Bliss’, whereas no differences between the harvest period were detected in the yellow raspberry cultivar ‘Fall-gold’, bearing fruit twice a year ([Pantelidis et al., 2007](#)). In addition, when the annual variation in the TPC of raspberries was investigated, significant differences between harvesting seasons were observed ([Lugasi et al., 2011](#)).

[Wang and Lin \(2000\)](#) investigated black and red raspberry juices obtained at three maturity stages of the berry, namely green, pink, and ripe; the TPC values decreased from the green to the pink stages and then significantly increased from the pink to the ripe stages. However, other scientists reported no significant changes in the TPC of raspberries during their maturation process ([Bobinaitė et al., 2013a](#)). Significantly lower amounts of TPC were found when raspberry fruits with removed seeds were analyzed as compared to the whole berries with seeds. The TPC in the berry pulp of ripe red raspberry ‘Glen Moy’ with removed seeds was 35% lower, and in yellow raspberry ‘Beglianka’, 40% lower than in corresponding raspberries with seeds ([Bobinaitė et al., 2013a](#)). The antioxidant capacity of cultivated red and black raspberries was shown to be directly related to the TPC of berries ([Pantelidis et al., 2007](#); [Gansch et al., 2009](#); [Bobinaitė et al., 2012](#)). However, no evident correlation was found between the TPC and radical scavenging activity of wild raspberry (*R. idaeus*) fruits collected in different habitats of Lithuania ([Dvaranauskaitė et al., 2006](#)).

Phenolic Profile of Raspberries

In general, the major phenolic compounds found in raspberries are ellagitannins and anthocyanins, whereas hydroxycinnamic acids and flavonols are the minor phenolic

constituents (Määttä-Riihinen et al., 2004). In addition to anthocyanins, which will be discussed in the next section, raspberries contain small amounts of other flavonoids. The primary flavonol glycosides in raspberries are quercetin-3-glucuronide and kaempferol-3-glucuronide (Figure 1), accounting for 1.1 and 0.6 mg/100 g FW, respectively (Rao and Snyder, 2010). Quercetin-3-glucoside and quercetin-3-rutinoside were also reported in red raspberries (Mullen et al., 2002). (+)-Catechin was reported as a major flavan-3-ol at a concentration of 2.4 mg/100 g FW (Rao and Snyder, 2010).

The concentration of quercetin and kaempferol derivatives decreased over the ripening period of raspberries (Wang et al., 2009), and the environment also had a significant effect on the content of quercetin in red raspberries (Anttonen and Karjalainen, 2005). It is interesting to note that the concentration of the powerful antioxidant quercetin was reported to be remarkably lower in raspberry samples with high TPC than in the samples demonstrating lower TPC values (Anttonen and Karjalainen, 2005).

The concentration of phenolic acids in raspberries was reported to be in the range of 26–29 mg/100 g FW; however, the percentage of soluble (free) phenolic acids was lower than 10% of the total content of phenolic acids. For instance, bound gallic acid was reported to comprise 78% of all phenolic acids detected after hydrolysis (Matilla et al., 2006). Other phenolic acids reported in raspberries include *p*-hydroxybenzoic, caffeic, ferulic, and *p*-coumaric (Türkben et al., 2010), cinnamic, sinapic, and vanillic acids (Matilla et al., 2006). Proanthocyanidins, which are also known as condensed tannins (oligomers or polymers of flavan-3-ol linked through an interflavan carbon bond), were also reported in *Rubus* fruits (Määttä-Riihinen et al., 2004; Beekwilder et al., 2005). Proanthocyanidins are decomposed to anthocyanidins through an acid-catalyzed oxidation reaction upon heating in acidic alcohol solutions. Hellstram et al. (2009) determined 78.8 mg/100 g FW of proanthocyanidins in red raspberries, which is higher than previously reported value of 30.2 mg/100 g FW (Gu et al., 2004). However, many other well-known berries such as black currants, blueberries, bilberries, chokeberries, cranberries, grapes, or lingonberries accumulate higher amounts of proanthocyanidins than *Rubus* fruits (Gu et al., 2004; Hellstram et al., 2009).

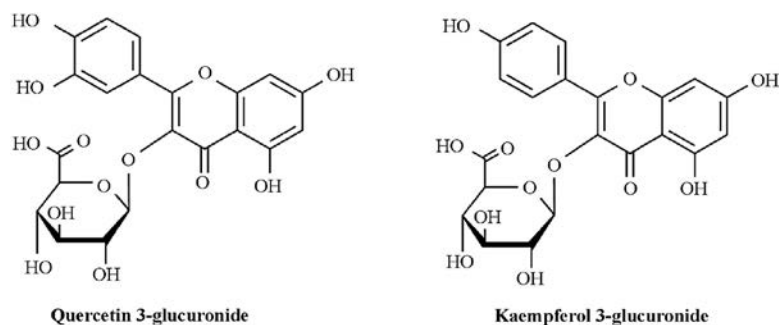


Figure 1 Structures of the main flavonol glycosides found in raspberries.

Ellagitannins and Ellagic Acid

Tannins are water-soluble phenolic compounds with molecular weights between 300 and 3,000 Da. Hydrolysable and condensed tannins are widely distributed in the plant kingdom and are thought to be biosynthesized and accumulated as defensive compounds against microorganisms, herbivores, and oxidative stress (Barbehenn et al., 2006). Ellagitannins have often been identified as the active principles in medicinal plants. However, the occurrence of ellagitannins and ellagic acid in commonly consumed plant foods is limited to a few fruits, such as raspberries, blackberries (*Rubus* sp.), cloudberries (*Rubus chamaemorus*), strawberries (*Fragaria* × *ananassa* D.), pomegranates (*Punica granatum* L.), muscadine grapes (*Vitis rotundifolia*), and some nuts (walnuts and pecans) (Bakkalbasi et al., 2009; Quideu, 2009).

Free ellagic acid levels are generally low in *Rubus* fruits, whereas the main part of ellagic acid is present in the form of water-soluble ellagitannins within the vacuoles of plant cells (Määttä-Riihinen et al., 2004). The relative amount of free ellagic acid in red raspberries was reported to constitute only 1–2.2% of the total ellagic acid content (Koponen et al., 2007; Bobinaitė et al., 2012). Wada and Ou (2002) reported remarkably higher levels of free ellagic acid (40–50%) of the total ellagic acid present in all analyzed berries, including red raspberries; however, extraction procedure used to determine free ellagic acid in their study was performed at 100 °C during 24 h. Ellagitannins are complex derivatives of ellagic acid, and they contain one or more hexahydroxydiphenic acid (HHDP) moieties esterified to a polyol (usually glucose). HHDP moieties are constituted by oxidative biaryl coupling (C—C coupling) between suitably orientated neighboring galloyl residues (Clifford and Scalbert, 2000). Ellagitannins can be hydrolyzed with acids or bases to release hexahydroxydiphenoyl units, which spontaneously form ellagic acid (Figure 2); this reaction is commonly used for the detection and quantification of food ellagitannins (Koponen et al., 2007; Vekiari et al., 2008; Vrhovsek et al., 2008). Free ellagic acid and its glycosides are analyzed without hydrolysis and subtracted from the total ellagic acid value to obtain the true content of ellagitannins.

Various ellagic acid derivatives, such as acylated and/or glycosylated compounds, have also been identified in raspberries, e.g., ellagic acid 4-acetyl-xyloside, ellagic acid

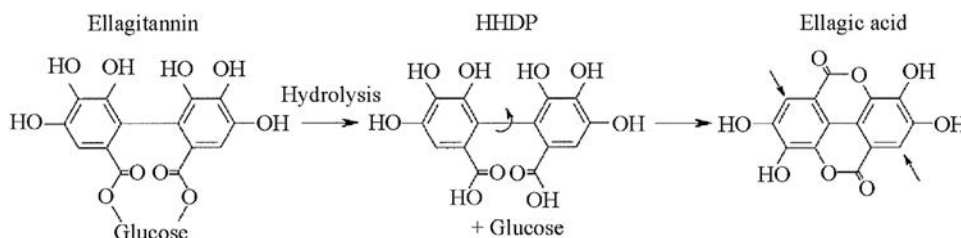


Figure 2 Hydrolysis of ellagitannin to form ellagic acid through the production of hexahydroxydiphenic acid (HHDP), which spontaneously lactonize to ellagic acid (EA) (Vekiari et al., 2008).

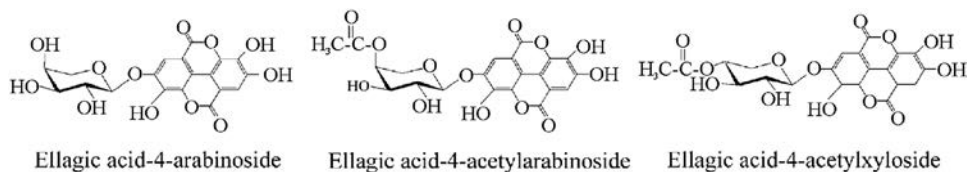


Figure 3 Structures of ellagic acid sugar conjugates in raspberries (Mullen et al., 2003).

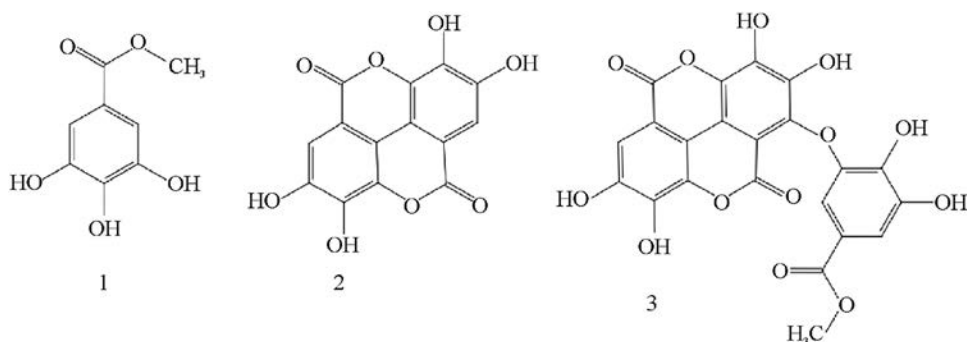
4-arabinoside, and ellagic acid 4-acetyl-arabinoside (Figure 3) (Zafrilla et al., 2001), two ellagic acid-pentose conjugates and two methyl ellagic acid-pentose conjugates (Mullen et al., 2003). The complexity of ellagitannin molecules makes it difficult to determine the precise structures of these compounds and their amounts in foods. There is a lack of commercial standards of ellagitannins; therefore, their analysis requires more advanced equipment such as different types of nuclear magnetic resonance (NMR) and mass spectrometers (MS). Due to that, the majority of quantitative evaluation reports on ellagitannins in *Rubus* fruits are based on hydrolyzed ellagitannins (Table 3). The main reasons for the large variation in ellagitannin contents, most likely could be attributed to the differences in growing conditions and raspberry genotypes analyzed. These variations may also partly depend on the differences in the applied extraction conditions and hydrolysis procedures. For instance, the reported ellagitannin concentrations for raspberries are generally lower in earlier studies (published before 2004) compared to the more recent results, because earlier studies quantified ellagic acid as the only ellagitannin hydrolysis product, while later it was observed that berry ellagitannins are degraded by acid hydrolysis into ellagic acid and some other derivatives shown in Figure 4 (Määttä-Riihinen et al., 2004; Vrhovsek et al., 2006), which were also taken into account in the calculations of the total ellagitannin content in more recent studies.

An enormous structural variability is characteristic to ellagitannins due to the different possibilities for the linkage of HHDP residues with the glucose moiety and strong tendency to form dimeric and oligomeric derivatives (Bakkalbasi et al., 2009). The main degree of ellagitannin polymerization (mDP) provides information on the ratio of non-tannin and tannin ellagic acids, as well as on the structures of simple and oligomeric ellagitannins. The mDP in various raspberry cultivars was between 1.61 and 1.86, which confirms the presence of a mixture of monomers and low oligomers (Vrhovsek et al., 2008). It was concluded that the average structure of ellagitannins is quite similar in different *Rubus* genotypes, while they differed in the absolute concentrations. Furthermore, it was noted that the mDP assumed significantly higher values in the floricanes than in the primocane raspberries (Vrhovsek et al., 2008).

Five red raspberry cultivars, namely 'Benefis', 'Pokusa', 'Polana', 'Polesie', and 'Polka', were analyzed in the studies carried out in Italy and Lithuania; the content of ellagitannins in the cultivars from Italy was 128.5, 111.6, 111.2, 130.0, and 135.9 mg/100 g FW, respectively, whereas the berries of the same cultivars from Lithuania contained 169.0,

Table 3 Ellagitannins content in raspberries (expressed as ellagic acid equivalents after hydrolysis)

Berry	mg/100 g (FW)	Reference
Red raspberry <i>Rubus idaeus</i>	20.7–24.4	De Ancos et al. (2000)
	51.0–66.0	Häkkinen et al. (2000)
	160.0	Mattila and Kumpulainen (2002)
	190.0	Määttä-Riihinen et al. (2004)
	38.0–118.0	Anttonen and Karjalainen (2005)
	263.7–330.9	Koponen et al. (2007)
	94.2–174.3	Vrhovsek et al. (2008)
	72.8–135.0	Türkben et al. (2010)
	117.7–307.2	Bobinaitė et al. (2012)
Red raspberry, wild	270.0	Määttä-Riihinen et al. (2004)
Black raspberry, <i>Rubus occidentalis</i>	329.6	Vrhovsek et al. (2008)
	319.7	Bobinaitė et al. (2012)

**Figure 4** Raspberry ellagitannin hydrolysis products formed after acid hydrolysis in methanol; methyl gallate (1), ellagic acid (2), and methyl sanguisorboate (3) (Vrhovsek et al., 2006).

117.7, 180.0, 183.9, and 175.5 mg/100 g FW, of ellagitannins, respectively (Vrhovsek et al., 2008; Bobinaitė et al., 2012). Considering numerous factors that may have an influence on the content of ellagitannins, the differences determined for the same raspberry cultivars by different authors do not seem remarkable. Furthermore, Lithuanian researchers used direct extraction—hydrolysis of the whole homogenized berries (including the seeds), while Italian researchers hydrolyzed berry extracts. This could be a reason for slightly higher ellagitannin values reported by Lithuanian scientists.

When intact ellagitannins were analyzed in red raspberries and blackberries, the sanguin H-6 dimer (MW = 1870 Da) and lambertianin C trimer (MW = 2804 Da) were reported as the main ellagitannins (Figure 5) (Beekwilder et al., 2005), with their sum representing 81% and 67% of the total ellagitannins in raspberries and blackberries, respectively (Gasperotti et al., 2010). In addition to sanguin H-6 and lambertianin C, Gasperotti et al. (2010) identified 10 more ellagitannins in red raspberries. The strong positive correlation between TPC and ellagitannins of raspberries was reported in

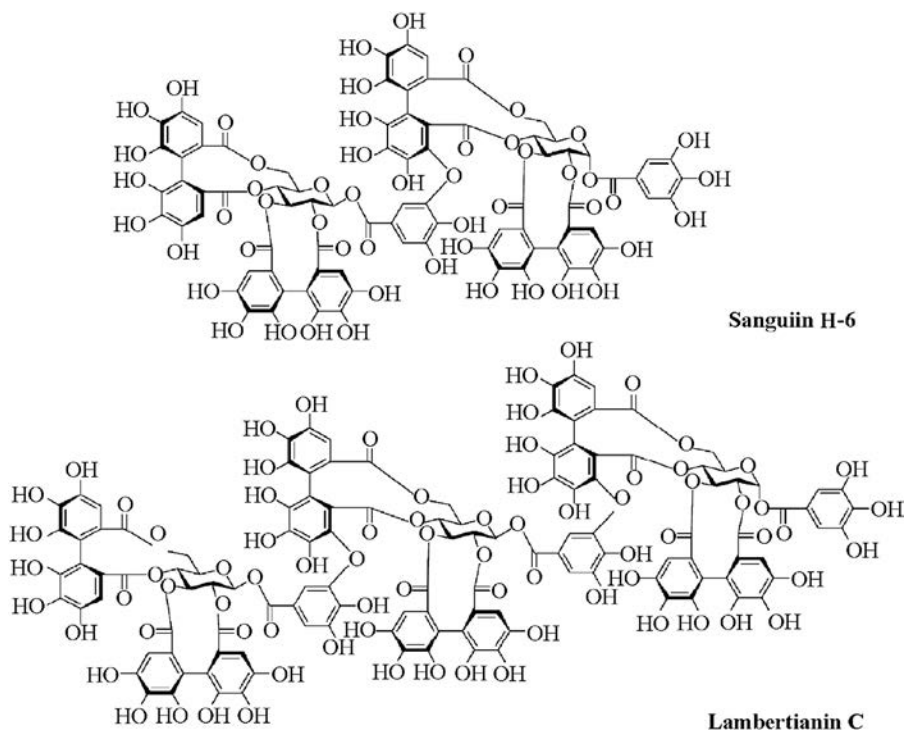


Figure 5 Structures of the main ellagitannins in raspberries (Mullen et al., 2003).

different studies, showing that raspberry cultivars with a higher TPC contain higher amounts of ellagitannins (Anttonen and Karjalainen, 2005; Bobinaitė et al., 2012).

Proanthocyanidin-like tannins and ellagitannins were reported to decrease three- to eightfold during raspberry fruit ripening, from stage one representing small, immature green fruits to stage five representing ripe, red fruits. The content of procyanidins was found even more remarkably reduced during the last ripening stage, while the content of ellagitannins remained almost unchanged (Beekwilder et al., 2005). In addition, the relative contribution of the different classes of compounds to the total antioxidant capacity significantly changes during raspberry fruit ripening (Beekwilder et al., 2005).

Ellagitannin-rich foods exhibit high in vitro free radical scavenging activity. The antioxidant efficiency of ellagitannins and ellagic acid is directly correlated with their degree of hydroxylation and decreases with the presence of a sugar moiety (Bakkalbasi et al., 2009). For example, ellagic acid has the highest antioxidant activity among the isolated ellagic acid derivatives in red raspberry (Zafrila et al., 2001). Ellagitannins were found to contribute from 30% to 60% of the total antioxidant capacity of *R. idaeus* fruits in a study of 14 cultivars (Beekwilder et al., 2005). In general, strong correlation between antioxidant capacity of raspberry fruits and their ellagitannis/total ellagic acid content was reported (Anttonen and Karjalainen, 2005; Bobinaitė et al., 2012).

Significant year-to-year variation in total ellagic acid concentration was reported for some strawberry cultivars, thereby suggesting that its concentration in fruits may be environmentally influenced (Atkinson et al., 2006). The total ellagic acid content in red raspberries harvested in different years in Finland was 263.7 and 330.9 mg/100 g FW (Koponen et al., 2007).

The total ellagic acid content, estimated after acid hydrolysis, in the seeds of red and black raspberry was 879 and 670 mg/100 g, respectively. In another study, the phytochemical composition of fruit, pulp, and marc extracts of various raspberry cultivars was reported; it was determined that the content of ellagitannins was higher by 63–80% in the raspberry marc extracts than in the pulp extracts (Bobinaitė et al., 2013b). These findings indicate that raspberry seeds are very rich in ellagitanins.

Total ellagic acid content in frozen red raspberries was reduced by 14–30% after long-term (9–12 months) storage at -20°C (De Ancos et al., 2000; Häkkinen et al., 2000). Türkben et al. (2010) reported that the ellagic acid content in red raspberries was reduced up to 50% during 6 months of frozen storage at -22°C , and they suggested that the decline in the total amount of ellagic acid during storage may be due to the metal chelating capacity and ability of ellagic acid to react with free radicals, as well as to the presence of polyphenol oxidase, which may be released with cellular disruption in berry fruits and oxidize polyphenols to quinones.

The content of free ellagic acid increases twofold during raspberry jam processing and continues to increase during the first months of storage at room temperature, followed by a slight decrease during the remaining storage period (Zafrilla et al., 2001). These changes were related either to the release of ellagic acid from ellagitannins during processing and storage or to an easier extractability of ellagic acid from processed products.

Anthocyanins

Anthocyanins are the most abundant flavonoid constituents in many fruits and vegetables, and they comprise the largest and most important group of water-soluble pigments in nature. Anthocyanins are conjugated anthocyanidins, which are accumulated in cell vacuoles and are responsible for diverse colors, from orange to red, purple, and blue in flowers, fruits, and vegetables. Approximately 95% of all anthocyanins are derived from six anthocyanidins (aglycones): cyanidin, peonidin, pelargonidin, malvidin, delphinidin, and petunidin. Glucose and rhamnose are the more common sugar moieties attached to the aglycone, but galactose, arabinose, xylose, rutinose, sambubiose, and other sugars are also frequently found (Bobinaitė and Viškelis, 2013).

The major anthocyanins in raspberries and blackberries are derivatives of cyanidins, which commonly exist in nonacylated forms. Red raspberries contain a wide spectrum of anthocyanins, with the major constituents being cyanidin-3-sophoroside, cyanidin-3-glucosylrutinoside, and cyanidin-3-glucoside (Figure 6), while cyanidin-3-xylosylrutinoside,

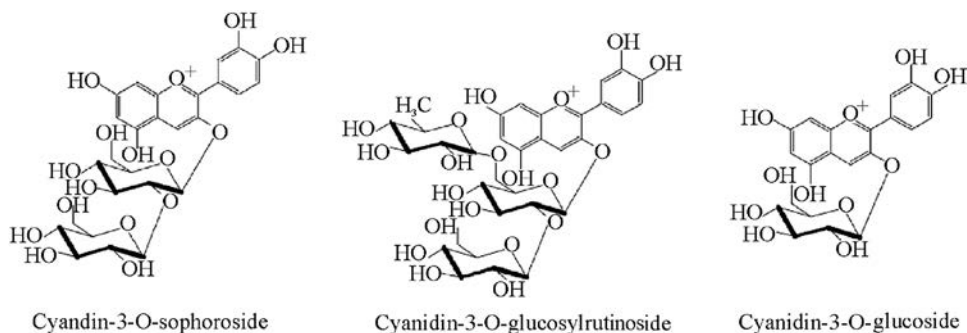


Figure 6 The major anthocyanins present in red raspberries.

cyanidin-3,5-diglucoside, cyanidin-3-rutinoside, cyanidin-3-sambubioside, pelargonidin-3-sophoroside, pelargonidin-3-glucosylrutinoside, pelargonidin-3-glucoside, and pelargonidin-3-rutinoside are found in smaller quantities. For instance, pelargonidin glycosides were reported to constitute less than 2% of the total anthocyanin content in red raspberries (Rao and Snyder, 2010). When the inheritance of anthocyanins in various *Rubus* species was studied, it was noted that some degree of orange color is imparted to progenies when pelargonidin pigments are incorporated (Jennings, 1988).

Significant differences in relative amounts of individual anthocyanins were reported among the studied raspberry cultivars (Rao and Snyder, 2010). Moreover, significant year-to-year variations in the content of anthocyanins were also determined (Koponen et al., 2007; Lugasi et al., 2011). Low and high temperatures have long been considered to promote and reduce, respectively, anthocyanin synthesis in fruits and berries. The total anthocyanin content is one of the main criteria used to differentiate between the species of *R. idaeus* and *R. occidentalis*. Black raspberries accumulate considerably higher amounts of anthocyanins than red raspberries, blackberries, and some black currant and blueberry genotypes. Anthocyanins in black raspberry consist mainly of cyanidin-3-xylosylrutinoside and cyanidin-3-rutinoside, with smaller amounts of cyanidin-3-glucoside, cyanidin-3-sambubioside, and pelargonidin-3-rutinoside (Bobinaitė and Viškelis, 2013). The concentration of anthocyanins in raspberries is low at the beginning of fruit ripening (green fruit), with only cyanidin-3-glucoside present and some traces of cyanidin-3-rutinoside. When raspberry fruits turn pink, small amounts of cyanidin-3-sophoroside and cyanidin-3-glucosylrutinoside are produced. By the time the fruit is red, the quantity of these anthocyanins sharply increases, and pelargonidin glycosides begin to form the last (Beekwilder et al., 2005).

Anthocyanin contents greatly vary depending on raspberry variety. Weber et al. (2008) analyzed 64 raspberry genotypes grown in the USA and found that some of the red raspberry genotypes accumulate rather low total anthocyanin contents (up to

40 mg/100 g) in comparison with others (up to 100 mg/100 g). The red raspberry cultivars comprising the highest content of anthocyanins were reported to be 'Chilliwick', 'Titan', 'Encore', 'Amity', 'Ruby', and 'Summit'. A similar tendency was noted by [Lugasi et al. \(2011\)](#); they grouped Hungarian-grown red raspberry cultivars based on those accumulating less than 45 mg/100 g or larger than 55 mg/100 g of anthocyanins. The total anthocyanin content of red raspberry cultivars grown in Lithuania varied from 29 to 131 mg/100 g. The highest content of anthocyanins was reported in fruits of 'Glen Moy', 'Polesie', 'Sputnica', 'Zorinka', 'Norna', 'Polana', and 'Polka' ([Bobinaitė et al., 2012](#)). The total anthocyanins content in four Spanish-grown red raspberry cultivars ranged from 37 to 116 mg/100 g. Furthermore, it was noted that anthocyanin concentration was higher in the late harvest cultivars, e.g., 'Zeva' and 'Rubi' ([Rao and Snyder, 2010](#)). The total anthocyanin values in red raspberry cultivars grown in Finland were somewhat lower and varied from 19 mg/100 g in 'Preussen' to 51 in 'Gatineau' ([Anttonen and Karjalainen, 2005](#)). The content of anthocyanins in 'Glen Ample' fruits grown in Scotland was reported to be 50 mg/100 g ([Rao and Snyder, 2010](#)). Generally, the total anthocyanin content in red raspberries is typically between 20 and 100 mg in 100 g of fresh fruit ([Rao and Snyder, 2010](#)).

The total anthocyanin content of black raspberries may reach up to 687 mg/100 g FW ([Rao and Snyder, 2010](#)). In a study reported by [Gansch et al. \(2009\)](#), the total anthocyanin content in black raspberry cultivars varied from 315.9 to 458.7 mg/100 g; the highest amounts were found in 'Mac Black', 'Munger', 'Plum Farmer', and 'Hanover' cultivars. Quite similar amounts, from 337 in 'Haut' to 400 mg/100 g in 'Bristol' were reported by [Weber et al. \(2008\)](#). 'Bristol' fruits grown under Lithuanian agroclimatic conditions accumulated slightly lower content of anthocyanins, 326 mg/100 g ([Bobinaitė et al., 2012](#)). In general, the between-study variation in reported concentrations of anthocyanins in raspberries is much lower than that of ellagitannins. Furthermore, the between-study variation in anthocyanin concentration reported for the same raspberry cultivars do not seem to be remarkable, although slightly higher than total phenolics content ([Tables 2 and 4](#)).

Anthocyanins are the second largest group of phenolic antioxidants found in red raspberry fruits, which were reported to contribute to the total antioxidant activity of red raspberries, approximately 25% ([Beekwilder et al., 2005](#)) or 16.5% ([Borges et al., 2010](#)). In black raspberries, two major anthocyanins, namely cyanidin-3-rutinoside and cyanidin-3-xylosylrutinoside, have been reported as the most important phenolic antioxidants ([Tulio et al., 2008](#)).

The fruit color of raspberries is also determined by the cellular environment in which the anthocyanins are suspended. [Melo et al. \(2000\)](#) suggested that the coloration of raspberries is not based on copigmentation but is mainly due to effects of the pH in vacuoles. Because of these pH effects, berries with the same anthocyanin constitution may exhibit different fruit colors.

Table 4 Anthocyanins content (mg/100 g FW) in raspberry cultivars grown in different countries

Cultivar	Color	Anthocyanins	Country	Reference
Autumn Bliss	Red	57–78	Hungary	Lugasi et al. (2011)
		72	USA	Weber et al. (2008)
		35–39	Greece	Pantelidis et al. (2007)
		75	USA	Wang and Lin (2000)
Meeker	Red	44	Lithuania	Bobinaitė et al. (2012)
		54	USA	Weber et al. (2008)
		43	Greece	Pantelidis et al. (2007)
Malling Exploit	Red	23	Hungary	Lugasi et al. (2011)
		37	USA	Weber et al. (2008)
Ottawa	Red	42	Lithuania	Bobinaitė et al. (2012)
		33	Finland	Anttonen and Karjalainen (2005)
Polana	Red	84	Lithuania	Bobinaitė et al. (2012)
		55	Hungary	Lugasi et al. (2011)
Heritage	Red	79	USA	Weber et al. (2008)
		48–49	Greece	Pantelidis et al. (2007)
Glen Ample	Red	46	Hungary	Lugasi et al. (2011)
		50	Scotland	Rao and Snyder (2010)
Bristol	Black	409	USA	Weber et al. (2008)
		326	Lithuania	Bobinaitė et al. (2012)

In a study reported by [Viskeliš et al. \(2012\)](#), the color of homogenized raspberries of five different cultivars was measured by the CIELab method. Authors reported a very strong negative correlation ($r = -0.89$) between the total anthocyanin content of the raspberries and the lightness coordinate L^* . Negative correlations were also found between the total anthocyanin content and the redness coordinate a^* , as well as between the total anthocyanins content and the chroma (color saturation) parameter C^* ($r = -0.84$ and -0.83 , respectively). It was concluded that lightness coordinate (L^*) was sufficiently accurate for screening the anthocyanin concentrations of raspberries. However, in another study, when the color of the surface of the raspberry fruit was measured, the color parameters were not found to represent good indicators of the anthocyanin levels of raspberries ([Viskeliš et al., 2012](#)).

SUMMARY POINTS

- A large number of red raspberry cultivars have been developed and cultivated.
- Raspberries are good source of bioactive phytochemicals.
- Phytochemicals in raspberries depend mainly on genotype and also on growing zone.
- Total phenolic content in fresh red raspberries is in the range of approximately 200–500 mg/100 g.

- Ellagitannins and anthocyanins are the most abundant phytochemicals in raspberries.
- The content of ellagitannins is highly variable in the studied raspberry cultivars.
- The content of anthocyanins is less variable group of phytochemicals in raspberries.
- Black raspberries accumulate remarkably larger amounts of anthocyanins than red ones.

ACKNOWLEDGMENT

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CHAPTER 30

Strawberry: Phytochemical Composition of Strawberry (*Fragaria* × *ananassa*)

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LIST OF ABBREVIATIONS

AOC	Antioxidant capacity
FRAP	Ferric reducing antioxidant power
FW	Fresh weight
G	Gram
GAE	Gallic acid equivalent
GH	Greenhouse
HPLC	High performance liquid chromatography
OF	Open field
ORAC	Oxygen radical absorbance capacity
PT	Plastic tunnel
TAC	Total antioxidant capacity
TEAC	Trolox equivalent antioxidant capacity
TMA	Total monomeric anthocyanin
TPC	Total phenolic content
TSS	Total soluble solid
μmol TE	Micromole trolox equivalent

INTRODUCTION

The commercial strawberry, *Fragaria* × *ananassa*, originated about 250 years ago when a few New World clones of *Fragaria chiloensis* and *Fragaria virginiana* accidentally hybridized in European gardens (Wilhelm and Sagen, 1972). Thomas A. Knight began the systematic breeding of strawberries in England in 1817, but had at his disposal only a small number of native and cultivated clones.

Likewise, North American genetic improvement began in the mid-1800s with a restricted group of European $F \times \textit{ananassa}$ cultivars, South American *F. chiloensis* and North American *F. virginiana* (Luby et al., 2008). The cultivars originating from this background played the predominant role in the most public and private breeding programs for the next 100 years (Hancock et al., 2005). In all fields where strawberry cultivation is done, it proves a wide variety in its own kind as it is grown for different time cycles and different reasons in the same ecologies. There are breeding programs in many areas of the world acting for these purposes. By applying modern growing techniques, such as greenhouse, drippage and irrigation, and mulching, and varying cultivation forms, species improved by these breeding programs is necessary to be subjected to adaptation studies in accordance with the different areas.

This review focuses on the nutrient and phytochemical contents of strawberry and on factors affecting the composition of this fruit.

BOTANICAL ASPECTS

There have been several attempts to sample fruits from natural populations of the world's strawberry species; some of these species have been utilized in breeding programs. Since the formation of the cultivated strawberry ($F \times \textit{ananassa}$ Duchesne) in the eighteenth century, strawberry culture has become increasingly limited to clones of this hybrid species (Galletta and Himelrick, 1990). In 1766, a classic book describing many aspects of strawberries at that time was published in Paris, France. The book was the result of several years of strawberry research by its young author Antoine Nicolas Duchesne, a student of the noted French botanist Bernard de Jussieu. Duchesne concluded that the new large-fruited hermaphroditic strawberry $F \times \textit{ananassa}$ was a hybrid between the North American species *F. virginiana* and *F. chiloensis* from South America (Duchesne, 1766). The genus *Fragaria* belongs to the family Rosaceae, an economically important family containing many fruit crops (e.g., *Malus*, *Pyrus*, *Prunus*, and *Rubus*) and ornamentals (e.g., *Rosa* and *Sorbus*). *Fragaria* is a member of the subfamily Rosoideae and consists of approximately 20 species that are variously diploid, tetraploid, hexaploid, or octoploid (Table 1). These include many wild diploid species such as *Fragaria nubicola* (Lindl. ex Hook. f.) *Lacaita* and *Fragaria vesca* L., and the cultivated strawberry, $F \times \textit{ananassa}$ Duchesne ($2n = 8x = 56$) (Sargent et al., 2006). Mabberley (2002) suggested that because morphological, genetic, and DNA evidence show that *Fragaria* is nested in *Potentilla*, these two should be reunited. However, this view is not maintained by The Plant List ver. 1.1 which keeps *Fragaria* separate from *Potentilla*, citing the Rosaceae database (RBG Edinburgh) (Anonymous, 2015). *Fragaria* are perennial herbs, with leaves and flowers in a basal tuft producing prostrate stems or runners. Leaves are trifoliate with membranous stipules and cuneate-obovate serrate leaflets. Flowers are white, borne in cymes on a naked scape. Calyx persistent, bearing five bractlets, alternate with the calyx lobes. Petals are obovate, short-clawed. Stamens are about 20. Pistils are numerous

Table 1 World species of *Fragaria* (strawberry)

Species	Native area	Fruit characters
Diploids (2n = 14)		
<i>Fragaria vesca</i> L.	Circumpolar	Long ovate variable, bright red, raised seeds, very aromatic, very soft flesh
<i>Fragaria viridis</i> Duch.	Europe to Eastern to Central Asia	Small, firm, pink-red, aromatic, seeds set in pits
<i>Fragaria nilgerrensis</i> Schlect	Southeast Asia	Small, round, pink, tasteless to unpleasant, many seeded sunken
<i>Fragaria daltoniana</i> J. Gay	Himalayas, 10,000–15,000 ft	Elongate-ovoid, bright red, tasteless
<i>Fragaria nubicola</i> Lindl ex. Lacaita	Himalayas, 5000–13,000 ft	Resembles vesca
<i>Fragaria iinumae</i> Makino	Japan, mountains	Ovoid, 1.5 cm long, achenes sunken, resembles <i>F. daltoniana</i>
<i>Fragaria nipponica</i>	Japan	—
Tetraploids (2n = 28)		
<i>Fragaria moupinensis</i> (French.) Card	Tibet, China	Small, similar to <i>F. nilgerrensis</i>
<i>Fragaria orientalis</i> Losink	Siberia, Korea	Soft, conical to round, slight aroma, seeds sunken
Hexaploids (2n = 42)		
<i>Fragaria moschata</i> Duch.	Northern Europe to Siberia	Light to dark dull purplish red, soft, irregular to ovoid, musky or vinous, aromatic, raised achenes, strongly reflexed calyx
Octoploids (2n = 56)		
<i>Fragaria virginiana</i> Duch.	Eastern North America	Twice the size of vesca, soft, light to deep red or scarlet, white flesh, tart, aromatic, sunken seeds, subglobose to ovoid
<i>Fragaria chiloensis</i> (L.) Duch.	Pacific beaches of North America, Chile, Argentina, Hawaii	Dull red brown, white flesh, mild, firm, round to oblate, small to large, achenes raised or sunken
<i>Fragaria ovalis</i> (Lehn.) Rydb. (<i>Fragaria virginiana glauca</i> Staudt)	Rocky Mountains to west coast	Round, pink, small, flavorful
<i>Fragaria mandschurica</i> Staudt	Manchuria	G. Staudt, 1959
<i>Fragaria inturupensis</i> Staudt	Island North of Japan	G. Staudt, 1973
<i>Fragaria</i> × <i>ananassa</i> Duch.	Cultivated	Large, red, variable in all traits

Source: Adapted from [Scott and Lawrence \(1975\)](#).

and distinct (separate), borne on an elevated convex receptacle; styles are lateral. Berry-like fruits are formed on the enlarged succulent receptacle, which bears the minute seed-like achenes (Galletta and Himelrick, 1990).

Composition of Ancient Cultivars of Strawberry

One of the most crucial purposes of commercial cultivation and breeding programs is efficiency and fruit quality characteristics. Nowadays, studies are focused on the fruit quality concept, and they are even widened to balancing nutritive value. The fruit quality properties is usually a complex process and it is difficult to define it objectively. It is expressed that these features are controlled as genetic or environmental and they prove varieties. Fruit size, fruit pulp rigidity, fruit shape, total soluble solids (TSS), TSS/acid ratio, amount of sugar (glucose, fructose, saccharose) are substantial quality features (Hancock, 1999; Connar et al., 2002; Scalzo et al., 2005a). Another crucial quality criterion of strawberry is the color. Anthocyanin is influential in color formation, which is used as quality criteria of identifying the maturity date in strawberry fruit (Koşar et al., 2004).

Nowadays, consciousness of consuming healthy food for a healthy life is becoming more and more widespread. In terms of health, small fruit has great importance in fruit species, as they contain flavonoids and phenolic acid in high rates, and these substances are known for their anticarcinogenic, antimutagenic, and antioxidant characteristics. It is possible to increase the level of antioxidants in fruit species, thanks to breeding for providing more consumption of fruit and vegetables, which are consumed less. This approach can only be successful if fruit species antioxidants' feature variety and phenotypic variation are stated. The regulation of newly developed species fruit quality and antioxidant features are directly related to protecting the health of consumers. Besides, the consumption of healthy fruit will bring new approaches, which regulate the human health (Scalzo et al., 2005a).

Breeding programs are not only focused on long existence of fruit on shelf but also on transportation, resistance to diseases, and high yield. Objectives, such as adaptation of growing systems, resistance to diseases and pests, and the regulation of fruit shape and yield are coming into question in breeding programs, which also include small fruit. Determining criteria of fruit quality is usually a complex process because it is not easy to define the fruits in an objective way. Sensual features, such as shape and color, are limited quality criteria for appearance of the products. Fruit firmness, total acidity, sucrose ingredients, and nutritive value are among critical factors which decide the quality of fruit. Studies are focused on term of fruit quality nowadays and have reached up to the regulation of nutritive value (Scalzo et al., 2005a).

In the last years, there has been an increasing interest in determining antioxidant properties of red fruits, due to their rich dietary sources of antioxidant phenolics and anthocyanins (Moyer et al., 2002). Epidemiological studies suggested that consumption of red fruit juices such as grape, different berry juices, and pomegranate correlate with a

reduced risk of coronary heart disease, stroke, certain types of cancers, and aging (Malik and Mukhtar, 2006). For this reason, it is believed that the consumption of fruit and vegetables that are rich in bioactive compounds may increase the resistance against such diseases (Sandra, 2004). The beneficial effects of fruit and vegetables are becoming increasingly appreciated. Among the fruit species, antioxidant activities of berries are very important as a potential cancer preventive (Seeram, 2008). Strawberries are a common and important fruit in the Mediterranean diet because of their high content of essential nutrients and beneficial phytochemicals, which seem to have relevant biological activity in human health (Giampieri et al., 2012).

Strawberries contain many important dietary components including vitamins, minerals, folate, and fiber, and are a rich source of phytochemical compounds, mostly represented by polyphenols.

According to its nutrient profile (Table 2), the strawberry represents a healthy food choice.

The phytochemicals that have been studied most extensively are the phenolic compounds. Phenolic compounds are products of plant metabolism that likely serve many functions essential to the growth and survival of the plant. It is now clear that these compounds are also bioactive in animals and humans who consume them (Sandra, 2004). Phenolic compounds are known to be important antioxidant compounds in strawberry (Aaby et al., 2012). Phenolic compounds are composed of one or more aromatic rings bearing one or more hydroxyl groups. They are found in foods in a range of sizes, from simple molecules to very large oligomers. Frequently, the phenolic compounds in foods occur as glycosides. The attached sugars make these compounds more water-soluble (Kähkönen et al., 2001). A major class of phenolic compounds in the strawberry is represented by the flavonoids (mainly anthocyanins, with flavonols and flavanols providing a minor contribution), followed by hydrolyzable tannins (ellagitannins and gallotannins), and phenolic acids (hydroxybenzoic acids and hydroxycinnamic acids), with condensed tannins (proanthocyanidins) being the minor constituents (Aaby et al., 2005).

Anthocyanins are water-soluble vacuolar pigments that may appear red, purple, or blue, depending on the pH. Red-colored fruits which means anthocyanins in strawberries and other small fruits, are considered one of the most important quality assurance parameters. Phenolic compounds, including anthocyanins, exhibit strong antioxidant activity, and they have been shown in many studies to contribute significantly to the total antioxidant capacity. Specifically, phenolic-rich fruits with an anthocyanin pigment are often found to contain the highest antioxidant capacities. Also, there have been strong correlations between total phenolics (TP), anthocyanins, and antioxidant capacity. A notable variability was found among the anthocyanin concentrations in samples of the same variety and harvest date, indicating the strong influence of the degree of maturity, climatic factors, and postharvest storage on anthocyanins (Lopes da Silva et al., 2007). Polyphenol composition is reported in strawberries in Table 3.

Table 2 Nutrient composition of fresh strawberries (Giampieri et al., 2012)

Type	Nutrient	Per 100g
Proximates	Water (g)	90.95
	Energy (kcal)	32.00
	Protein (g)	0.67
	Ash (g)	0.40
	Total lipid (g)	0.30
	Carbohydrate (g)	7.68
	Dietary fiber (g)	2.00
	Sugars (g)	4.89
	Sucrose (g)	0.47
	Glucose (g)	1.99
	Fructose (g)	2.44
Minerals	Calcium (mg)	16.00
	Iron (mg)	0.41
	Magnesium (mg)	13.00
	Phosphorus (mg)	24.00
	Potassium (mg)	153.00
	Sodium (mg)	1.00
	Zinc (mg)	0.14
	Copper (mg)	0.05
	Manganese (mg)	0.39
	Selenium (μg)	0.40
Vitamins	Vitamin C (mg)	58.80
	Thiamin (mg)	0.0240
	Riboflavin (mg)	0.0220
	Niacin (mg)	0.3860
	Pantothenic acid (mg)	0.1250
	Vitamin B6 (mg)	0.047
	Folate (μg)	24.00
	Choline (mg)	5.70
	Betaine (mg)	0.20
	Vitamin B12 (μg)	0.00
	Vitamin A, RAE (μg)	1.00
	Lutein + zeaxanthin (μg)	26.00
	Vitamin E, α-tocopherol (mg)	0.29
	β-tocopherol (mg)	0.01
	γ-tocopherol (mg)	0.08
	δ-tocopherol (mg)	0.01
	Vitamin K, phyloquinone (μg)	2.20

Antioxidants neutralize the molecules that occur after metabolism of products in the human body. They are short-lived, but have negative effects and are named free radicals. If free radicals are overproduced, they give damages in cystoblast degree; they may cause tumors that cause cancer as a result of some kind of enzymes activation (Özgen, 2006).

Table 3 Polyphenol composition reported in strawberries (Giampieri et al., 2012)

Class	Group	Compound
Flavonoids	Anthocyanins	Cyanidin-3-glucoside Cyanidin-3-rutinoside Cyanidin-3-malonylglucoside Cyanidin-3-malonylglucosyl-5-glucoside Pelargonidin-3-galactoside Pelargonidin-3-glucoside Pelargonidin-3-rutinoside Pelargonidin-3-arabinoside Pelargonidin-3,5-diglucoside Pelargonidin-3-malylglucoside Pelargonidin-3-malonylglucoside Pelargonidin-3-acetylglucoside Pelargonidin-disaccharide (hexose þ pentose) acylated with acetic acid 5-Pyanopelargonidin-3-glucoside
	Flavonols	Quercetin-3-glucuronide Quercetin-3-malonylglucoside Quercetin-rutinoside Quercetin-glucoside Quercetin-glucuronide Kaempferol-3-glucoside Kaempferol-3-malonylglucoside Kaempferol-coumaroyl-glucoside Kaempferol-glucunoride
	Flavanols	Proanthocyanidin B1 (EC-4,8-C) Proanthocyanidin trimer (EC-4,8-EC-4,8-C) Proanthocyanidin B3 (C-4,8-C) (þ)-Catechin
Phenolic acids	Hydroxycinnamic acids	<i>p</i> -Coumaroyl hexose
Hydrolyzable tannins	Ellagitannins	Ellagitannin Bis-HHDP-glucose Galloyl-HHDP-glucose HHDP-galloyl-glucose Galloyl-bis-HHDP-glucose Dimer of galloyl-bis-HHDP Sanguin H-6 Methyl-EA-pentose conjugates Ellagic acid pentoside Ellagic acid

Thus, consumption of rich nutrition with regard to antioxidant content has been claimed to be able to decrease this risk (Sandra, 2004). Strawberry flavonoids are an important source of phenolic compounds which have antioxidant features, such as anthocyanins and phenolic acids (Beattie et al., 2005; Lopes da Silva et al., 2007). Antioxidant activity has received the most attention, although few genetic studies have been conducted in strawberries that characterize its inheritance in breeding populations. Moreover, several methods are currently used in various programs to quantify antioxidant activity (for example, oxygen radical absorbance capacity (ORAC), Trolox equivalent antioxidant capacity (TEAC), ferric reducing antioxidant power (FRAP), and others), and comparisons among published results are difficult (Pattison, 2011).

Organic acids are minor components of strawberry fruit, but they are important attributes of flavor that, in combination with sugars, have an impact on the sensory quality of strawberry fruit. There were distinct differences in organic acid content among the genotypes examined (Wang et al., 2002). According to Gündüz and Özdemir (2014), two major organic acids were found within the cultivars studied: malic and citric acid. Citric acid was the major acid and accounted for 82.7% (in the growing year 2008) and 84% (in the 2009 growing year) of the total acid content, similar to other data found in the literature (Crespo et al., 2010). Sugar content is an important taste attribute for strawberries and is highly correlated with consumer acceptance (Jouquand et al., 2008). Glucose, fructose, and sucrose are by far the most abundant soluble components in strawberries. Gündüz and Özdemir (2014) found that levels of sucrose were found to be very low and were not presented. Wang et al. (2002) also reported that strawberry fruit contains lower sucrose concentrations compared to fructose and glucose. The amounts of fructose and glucose in the fruit were quite different among genotypes. 'Ebru', 'Osmanlı', and 'Kaşka' had the highest total sugar (Gündüz and Özdemir, 2014). Similar results have been reported by Kafkas et al. (2007).

Composition of Modern Strawberry Cultivars

Fruit nutritive value is substantially affected by fruit structure (shape, corpulence), species, and diversity in species. Also, growing circumstances (environmental and cultural procedures) are effective on nutritive value. Quality and antioxidant features showing diversity among genotypes are known in strawberries. In research about the effect on total antioxidant capacity of plant genotype and phenolic content, it has been identified that wild strawberries have more antioxidant content than the strawberries that are in the culture process (Scalzo et al., 2005b). Factors affecting antioxidant capacity are genetic diversities, maturation, greengrocer lifetime, and duration (Connar et al., 2002).

Effects of various substrates on efficiency and quality for cultivation of landless culture in strawberry have been researched by Wang and Lin (2000). In the research, they have grown 'Allstar' and 'Honeoye' strawberry species by using different environments: 100% land, 50% land and 50% sand, 50% land and 50% compost, and 100% compost.

As a result of the research, 50% land and 50% compost implementation has been proved to be more successful with regard to efficiency, quality, and corpulence than the other implementations. Compost has increased the content of organic acid (malic acid and citric acid), sucrose (fructose, glucose, and overall sucrose), TSS, and tittered acid substance in the fruit.

Hakala et al. (2002) has searched quality criteria of six strawberry species kept as frozen fruit ('Jonsok', 'Korona', 'Polka', 'Honeoya', 'Bounty', and 'Senga Sengana'), including shape, color, sucrose proportion, mineral elements, and vitamin C content. Researchers announced that species' sucrose substances change in the range of 5.4–11.0 g/100 mL, total organic acid substance 1.2–1.8 g/100 mL, and vitamin C substances 32.4–84.7 mg/100 g.

Montero et al. (1996) has researched the change of organic acid, resolvable sucrose substances, tittered acidity, pH, reducing sucrose, phenolic composites, and pectic materials since the beginning of growing large amounts of fruit until the maturity phase in 'Chandler' strawberry species. The researcher has stated that sucrose found in strawberry fruit is much less when compared to glucose and fructose.

Sone et al. (1999) has searched the relationship between ascorbic acid ingredients in harvest seasons and some fruit quality criteria. The researchers grew 293 genotypes in 1995 and 149 genotype in 1996 in open areas and under the covering, and they took fruit samples four times in 1995 and seven times in 1996. They announced that the ascorbic acid ingredient changes between 15.9 and 114.8 mg/100 g FW, but the average ascorbic acid ingredient stays at 59.1 mg/100 g. Ascorbic substances of strawberry genotypes have proven differences in various harvest dates as well. The researchers have declared that there is a strong correlation between ascorbic acid substances of strawberry fruit and TSS, but TSS has a weak relationship with malic acid and other organic acids. In the light of acquired data, it has been concluded that strawberry species, which have high TSS substances, have high ascorbic acid substances at the same time.

Strawberries are rich in respect to glucose, fructose, and sucrose (seriatim; 1.89–4.52 g/100 mL, 2.14–4.14 g/100 mL, 0.90–3.87 g/100 mL), which are basic sucrose compounds, and citric and malic acid (0.73–1.58 g/100 mL; 0.22–0.69 g/100 mL), which are kinds of organic acid beside phenolic compounds (Kallio et al., 2000).

Hakkinen and Törrönen (2000) have researched phenolic acids (ellagic, *p*-coumaric, caffeic, and ferulic acid) of six strawberry species in terms of organic and classic cultivation. In conclusion, they have not seen any differences between the fruit which was acquired from organic or classic cultivation in terms of overall phenolic acid proportion. And it has been identified that phenolic proportion changed between 42.1 mg/100 g and 54.4 mg/100 g with respect to species and cultivation areas.

Törrönen and Maatta (2002) have stated that anthocyanins constitute 44% of phenolic compounds in strawberries, and ellagitanins and ellagic acid derivation of ellagitanins constitute 41% of them (Figure 1).

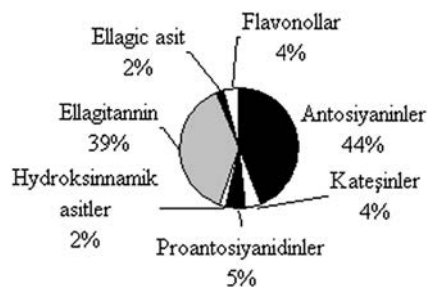


Figure 1 The proportion of phenolic compounds in a fresh strawberry fruit (Törrönen and Maatta, 2002).

‘Jonsok’ and ‘Honeoye’ were grown using an organic method in Finland. After the research, it was identified that sucrose proportion with respect to species changed between 5.40 and 11.00 g/100 mL, organic acid proportion changed between 1.20 and 1.80 g/100 mL, and vitamin C proportions changed between 32.40 and 84.70 mg/100 g. When the growing techniques (classic and organic growing) were compared, researchers could not identify any differences between two techniques in comparison with features mentioned above (Hakala et al., 2002).

In their research with 12 strawberry species, Schöpplein et al. (2002) identified that fruit size changes between 13.2 and 24.6 g, TSS between 8.9–11.2%, acid changed between 0.76–1.24%, TSS/acid rate between 8.7–12.4, and ascorbic acid substance changed between 29.7 and 68.2 mg/L; TEAC which was analyzed by high performance liquid chromatography (HPLC) method was identified as 8.4–16.5 mmol/trolox; among the species, 1717–2535 mg/L; overall phenol capacity, 68–225 mg/L; anthocyanin proportion. The highest antioxidant capacities were derived from the ‘Andana’, ‘Cirona’, and ‘Elsanta’ species in the research.

Tsao et al. (2003), in their 3-year study about phytochemical proportion, which has described antioxidant features in strawberry genotypes of untamed origins in Canada, identified an average of 2023 µg GAE/g overall phenolic substance, 543 µg PGE/g overall anthocyanin substance in 26 genotype in 2000, average 1994 µg GAE/g overall phenolic substance, 471 µg PGE/g overall anthocyanin substance in 34 genotypes in 2001, an average of 2010 µg GAE/g overall phenolic substance, and 316 µg PGE/g overall anthocyanin substance in 71 genotypes in 2002. In untamed strawberry genotypes, they identified an average of 2613 µg GAE/g overall phenolic substance, 477 µg PGE/g overall anthocyanin substance in 26 genotypes in 2001, an average of 2630 µg GAE/g overall phenolic substance, and 662 µg PGE/g overall anthocyanin substance in 43 genotypes in 2002. It was found that untamed genotypes were higher than cultured species in terms of both overall phenolic substance and anthocyanin substance. The researchers stated that there was a positive correlation between antioxidant capacity and phenolics; genotypes which had high antioxidant features could be grown by means of breeding programs.

In their study about the change of fruit quality features during the maturation of the 'Cigaline' strawberry cultivar, [Menager et al. \(2004\)](#) searched some fruit quality criteria (fruit color, fruit firmness, sucrose and organic acid compounds, aroma compounds TSS, acidity, and TSS/acid) throughout six maturation periods (white, pink, one-half red, three-quarters red, four-quarters red, and dark red). As the maturation period of study kept progressing, an increase in TSS and TSS/acid proportion but a decrease in tittered acidity and firmness of pulp was identified. While a rapid increase in saccharose, glucose, and fructose substances during commercial maturity period (three-quarters red) was being observed. While a decrease was being observed in citric acid substance during the maturity period, there was not any change observed in malic acid substance. In three-quarters red periods, which are accepted as commercial maturity, average saccharose, glucose, and fructose substances were identified as 1.43 g/100g, 2.5 g/100g, and 2.6 g/100g; citric acid and malic acid substances were determined as 0.6 g/100g and 0.4 g/100g.

[Koşar et al. \(2004\)](#) searched the phenolic substance of 13 different paragenetic genotypes with the help of the HPLC method by making use of 'Camarosa', 'Dorit', 'Chandler', and 'Osmanlı' strawberry species. As the highest anthocyanin quantity was being taken from mature fruit in the study, the basic compound of the green fruit happened to be ellagic acid. The researchers identified that those phenolic compounds in strawberry fruit change according to genotype, growing place, and maturity degree.

In their research, [Ferreyra et al. \(2007\)](#) searched the effect of 10 growing periods (small green, huge green, white, 5% red, 25% red, 50% red, 75% red, 100% red, 100% shiny red, and 100% dark red) upon antioxidant capacity in the 'Selva' strawberry, and stated that there was a correlation between antioxidant capacity and overall phenols, but there was no correlation with anthocyanins.

In their research about 'Osmanlı' and 'Camarosa' strawberry cultivars in different maturity periods and hybrid genotypes ("2," "3," "5," "6," "8," "11," "12," "13," and "17") and the quality features of genotypes, [Kafkas et al. \(2007\)](#) announced that with regard to cultivars and hybrid genotypes, tittered acidity changes between 6.02 and 9.73 g/kg, TSS substance changes between 71.3 and 108.7 g/kg, total sugar substance changes between 45.0 and 69.6 g/kg, and total organic acid substance changes between 11.9 and 23.5 g/kg. The researchers, at the same time, declared that formation of organic acid, ascorbic acid, and water-resolvable sugar depends substantially on genotypes.

In their research, by using three cultivars ('Camarosa', 'Gaviota', and 'Sweet Charlie') which came from an American breeding program, known locally in Turkey as 'Osmanlı', six genotypes that came from the Italian breeding program, six genotypes that came from Cukurova University (Turkey)'s breeding program, and three wild *F. vesca* kinds available in Turkey, [Özgen et al. \(2007\)](#) researched TP and antioxidant capacity. In the research, they determined that TP substances average in the cultivars that came from the American breeding program as 2318 µg GAE/g FW, in the selections that came from Italy breeding program as 2397 µg GAE/g FW, in the hybrids that

came from Cukurova University breeding program as 2467 $\mu\text{g GAE/g FW}$, and in the wild as 7914 $\mu\text{g GAE/g FW}$. They also declared antioxidant capacity in the cultivars that came from the American breeding program as 19.9 $\mu\text{molTE/g FW}$, in the selections that came from Italy breeding program as 22.0 $\mu\text{molTE/g FW}$, in the hybrids that came from Cukurova University breeding program as 21 $\mu\text{molTE/g ta}$, and in the wild as 70.2 $\mu\text{molTE/g FW}$.

In their research by using nine strawberry genotypes with the intention of determining the effect of genotypes on antioxidant capacity, Tulipani et al. (2008) stated that genetic structure played a significantly important role on the antioxidant capacity of strawberry fruit. Also in the study, it was determined that there was a strong correlation ($r = 0.95$, $p < 0.0001$) between FRAP and TEAC, which were among the methods used for determining antioxidant capacity, and it was detected that the correlation between total antioxidant capacities (TEAC, FRAP) and vitamin C was not considerable.

Capocasa et al. (2008) searched quality parameters of firmness, color, water-soluble dry matter ingredient, and titrated acidity with total antioxidant capacity and total phenolic content (TPC) in 20 strawberry cultivars and hybrid genotypes that they obtained from the *F. virginiana* ssp. *glauca* kind, and cross-combination on the subject of nutritional ingredient, which was among the fruit quality features. In conclusion, it was stated that genotypes and growing conditions in strawberries had significant effect on nutrition quality. Yet, the change of nutrition quality in commercial growing (especially nutrition parameters) does not have a wide variety. Researchers stated that fruit nutrition ingredient was hereditary, and it was not possible to improve this with breeding programs. Hence, fruit nutrition quality of *F. virginiana* spp. *glauca* as being a significant genetic source was detected.

Crespo et al. (2010) searched organic sucrose, organic acid, anthocyanin, and vitamin C in four new strawberry cultivars ('Antea', 'Asia', 'Clery', and 'Matis') on two growing areas of Switzerland. It was detected that genotypes were effective, rather than growing areas, according to the findings acquired. While pelargonidin-3-glucoside was determined as anthocyanin in all cultivars, it was seen that the other pelargonidin amount was dependent on cultivars. Vitamin C substances showed differences between the cultivars approximately two times. The researchers stated that they took high yields from the cultivars in high elevation areas, but fruit quality features were in low capacity.

Jin et al. (2011) researched the effect of cultural systems and storage heat on antioxidant enzyme activity in two strawberry cultivars ('Earlyglow' and 'Allstar'). Organic and inorganic fruit samples were stored at 0, 5, and 10 °C in the research. Antioxidant enzyme activity was found high in organic strawberries as a result of the research. Furthermore, antioxidant activity and capacity were identified as higher in the strawberries stored in high heat than the strawberries stored in low heat.

Tulipani et al. (2011) searched the effect of environment and genetic factors upon the components of fruit quality in strawberries. In the research, total antioxidant capacity, vitamin C, phenolics, protein, and allergen components were evaluated one by one for

2 years on four strawberry genotypes ('Adria' and 'Sveva' with the Marche Polytechnic University strawberry breeding program, and "AN94.414.52" and "AN00.239.55"). High TAC (total antioxidant capacity) on the red fruit term and with phenolic and flavonoid components, a low-allergen component on degree for the 'Sveya' kind was detected. The maximum effect to nutritional and nonnutritional features on 'Sveya' and "AN00.239.55" genotype was year-after-year temperature differences. These findings show that genotypes, antioxidant, and phenolic components differ with the effect of environmental conditions; in different years allergens on strawberry fruit may emerge.

In their research by using 27 strawberry cultivars to define phenolic composites on Norway strawberries with HPLC-DAD-MSⁿ, [Aaby et al. \(2012\)](#) stated that there were two to three times (for instance, 57–133 mg/100 g FW) differences among the cultivars with respect to TP ingredients. Cinnamoyl glucose, (0.6–24.9 mg/100 g FW), the biggest variation among the cultivars, was determined. The anthocyanin ingredient, which constitutes the biggest group of phenolic composites, showed changes among the cultivars between 8.5 ('Marlate') and 65.9 mg/100 g ('Rondo'). The lowest anthocyanin ingredient was taken from 'Marlate' and 'Carisma' cultivars, but the highest anthocyanin ingredient was taken from 'Rondo' and 'Babette'.

In their research done in Brazil by using strawberry kind called 'Camino Real', [Pineli et al. \(2012\)](#) tried to identify the effects of different harvest dates on fruit quality by taking fruit samples in three different harvest dates: May 5th, July 8th, and September 15th. They concluded that different harvest dates have effects on fruit, among all fruit quality features, after they researched the amount of TP substance, the amount of total anthocyanin, the ascorbic acid ingredient, and antioxidant capacity assets. In the research, they reached the highest assets, with respect to TP substance amounts, in July and September harvest terms, with the total anthocyanin ingredient in the September harvest term and antioxidant capacity and ascorbic acid ingredient in the July harvest term. In general, it was emphasized that lower outcomes were taken from the fruit having been harvested in May harvest term than the other harvest terms in the way of phytochemical substance amounts.

[Pincemail et al. \(2012\)](#) intended to identify the effects of different harvest terms upon phytochemical substances on strawberry fruit. In the research, the strawberry kind called 'Elsanta' was used, and TP substance, ascorbic acid, and antioxidant capacity were determined in the fruit harvested in different terms. According to the findings acquired in the research, it was stated that in different harvest terms, the amount of TP substance changed between 245 and 557 mgGAE/100 g FW, the amount of ascorbic acid 33.7–115.5 mgAA/100 g FW, and antioxidant capacity 2338–9480 $\mu\text{molTE}/100\text{ gFW}$.

[Akhatou and Fernández-Recamales \(2014\)](#) researched the effect of cultivation systems on fruit quality parameters by using different strawberry cultivars in soilless and soil cultivation. In the research, mineral substance, fructose, and glucose quantity among the cultivars in both cultivation systems showed diversity. 'Tamar' and 'Camarosa' cultivars were determined as sweeter than the other cultivars in soilless and soil cultivation.

In a research done by [Saracoglu \(2013\)](#), suitable planting time, performances with respect to efficiency and quality of some neutral and short day cultivars were searched in terms of pomological, chemical, and phytochemical features. The highest amounts of water soluble dry matter types were determined with 10.38 and 10.27%, respectively, as 'Festival' and 'Rubygem'. The highest values in terms of TP amount and antioxidant capacities were acquired from the 'Fer' type. 'Camarosa' came to prominence in total anthocyanin amount. In the research, fresh consumed fruit was detected to have a vitamin C average of 23% more from the frozen (-20°C) fruit, 47% more from the fruit preserved in the cold ($+1^{\circ}\text{C}$) environment, and 14 times more from the fruit preserved in consumption circumstances (20°C). While the higher values were acquired from the fruit which had secondary and tertiary positions in terms of acidity, sugar, and phytochemical matters in general, the king fruit was reported to have lower amounts.

[Gündüz and Özdemir \(2014\)](#) researched the effects of 13 strawberry genotypes and their production areas on phytochemical features by using three breeding areas (glass greenhouse, GH; plastic tunnel greenhouse, PT; and grown in open field, OF). Genotypes met 71% in the first production year and 72% in second year of total variance on total anthocyanin substance. As for total phenol substance, it was found to be 12% in the first production year and 13% in the second year. As a result, it was announced clearly that genotypes had been proved effective more than the production areas on bioactive substance. The effect of genotype and growing conditions on fruit bioactive compound was tested by comparing the total monomeric anthocyanin (TMA), TPC, and TAC (FRAP and TEAC), organic acids and organic sugar contents of 13 genotypes, grown in GH, PT, and OF production systems ([Tables 4–6](#)).

In 2008, mean values for TMA ranged between 95.1 mgPg-3-glucose/kg FW (GH) and 120.7 mgPg-3-glucose/kg FW (OF), whereas in the year 2009, the means ranged between 84.9 mg Pg-3-glucose/kg FW (GH) and 101.4 mg Pg-3-glucose/kg FW (PT and OF) ([Table 4](#)). Growing conditions had a significant effect on TPC in 2008, and the highest TPC was obtained for OF and PT (2311 and 2254 mg GAE/kg FW). Growing conditions did not have a significant effect on total acid content. The highest value for total sugar content was in PT (7.94 g/100 g), while the lowest value was in GH (5.22 g/100 g).

In 2008 for TMA, the 'Ebru' and 'Marlate' showed the highest values (149.7 and 148.9 mgPg-3-glucose/kg FW); the lowest TMA was observed in the 'Osmanli' cultivar (10.2 mgPg-3-glucose/kg FW). In 2008, TPC was highest in 'Camarosa' (2488 mg GAE/kg FW) and 'Type 5' (2349 mg GAE/kg FW), followed by 'Gaviota'. The lowest TPC was in the 'Cigouletta' and 'Osmanli' cultivars. TAC (FRAP and TEAC) was highest in 'Camarosa' (11.1 and 8.9 mmolTE/kg FW), followed by 'Type 5' (10.0 and 8.1 mmolTE/kg FW) and 'Gaviota' (9.9 and 8.4 mmolTE/kg FW). 'Osmanli' (1.13 g/100 g) showed the highest total acid content, followed by 'Cigouletta' (1.08 g/100 g). 'Sweet Charlie' had the lowest acid content. 'Ebru' had the highest value in terms of total sugar content, followed by 'Osmanli', and the lowest value was observed in 'Camarosa' and 'Gaviota' ([Table 4](#)).

Table 4 Effect of genotype and growing conditions on nutritional fruit quality characteristics of strawberries grown in the year 2008

Source	TMA ^a	TPC ^b	AOC		Organic acids ^e			Individual sugars ^f		
			FRAP ^c	TEAC ^d	Malic acid	Citric acid	Total acids	Glucose	Fructose	Total sugars
Growing conditions										
GH	95.1	1628 b	8.1	6.0	0.21	0.78	0.99	3.30	1.92 c	5.22 c
PT	104.9	2254 a	8.6	7.4	0.14	0.76	0.91	5.06	2.88 a	7.94 a
OF	120.7	2311 a	9.0	7.7	0.12	0.78	0.90	4.45	2.68 b	7.13 b
Genotype										
Sweet Charlie	80.9 ef	1929 bcd	7.9 bcd	7.1 bcde	0.12 c	0.50 f	0.62 f	3.50 def	2.18 def	5.68 def
Camarosa	115.9 bcd	2488 a	11.1 a	8.9 a	0.17 abc	0.72 de	0.88 de	2.93 f	1.82 f	4.75 f
Gaviota	103.1 cde	2282 abc	9.9 abc	8.4 ab	0.19 a	0.71 de	0.90 de	3.02 f	1.85 f	4.88 f
Whitney	56.8 f	2251 abcd	8.8 bcd	7.1 bcde	0.18 ab	0.65 e	0.83 e	3.28 ef	2.05 ef	5.33 ef
Cigouletta	127.2 abc	1764 d	7.6 d	6.5 cdef	0.18 a	0.90 ab	1.08 ab	4.54 bc	2.56 bcde	7.10 bcd
Marlate	148.9 a	1842 cd	7.4 d	5.9 ef	0.16 abc	0.86 bc	1.02 bc	4.75 bc	2.73 bc	7.48 bc
Alba	122.8 abc	2006 abcd	7.6 d	6.6 cdef	0.15 abc	0.76 cde	0.91 cde	4.50 bc	2.58 bcd	7.08 bcd
MT 99	125.6 abc	2234 abcd	8.7 bcd	7.5 abcde	0.15 abc	0.81 bcd	0.96 bcd	3.87 cdef	2.27 cdef	6.14 cdef
121 9	90.3 de	2001 abcd	9.6 abcd	7.7 abcd	0.14 abc	0.73 cde	0.87 cde	4.15 cde	2.48 cde	6.63 cde
Type 3	113.4 bcd	2349 ab	10.0 ab	8.1 abc	0.17 abc	0.79 bcde	0.96 bcde	4.34 cd	2.60 bcd	6.94 cd
Ebru	149.7 a	2043 abcd	7.8 cd	6.7 cde	0.19 a	0.79 bcde	0.98 bcde	6.44 a	3.49 a	9.93 a
Kaska	144.8 ab	1870 bcd	7.4 d	6.1 def	0.15 abc	0.83 bcd	0.97 bcd	4.79 bc	2.71 bc	7.51 bc
Osmanli	10.2 g	1779 d	7.4 d	5.0 f	0.12 bc	1.00 a	1.13 a	5.38 b	3.07 ab	8.45 b

Values in the same column that are followed by different letters are significantly different ($p \leq 0.05$) using Tukey's comparison test.

TA, total anthocyanin; TP, total phenol content; FRAP and TEAC, total antioxidant content; GH, greenhouse; PT, plastic tunnel; OF, open field.

^aTMA were determined by the pH-differential method of Giusti and Wrolstad (2005). Values are expressed as mg Pg-3-gl/ kg FW, by spectrophotometer.

^bTP contents were estimated by the Folin-Ciocalteu assay of Singleton and Rossi (1965). Values are expressed as mg gallic acid equivalents (GAE)/kg FW, by spectrophotometer.

^cTEAC values were determined by the method of Özgen et al. (2006). Values are expressed as mmolTE/kg FW, by spectrophotometer.

^dFRAP values were determined by the method of Benzie and Strain (1996). Values are expressed as mmolTE/kg FW, by spectrophotometer.

^eOrganic acids were determined by the method of Shui and Leong (2002). Values are expressed as mg/100 g FW, determined by HPLC.

^fOrganic sugars were determined by method of Bartolome et al. (1995). Values are expressed as mg/100 g FW, determined by HPLC.

Table 5 Effect of genotype and growing conditions on nutritional fruit quality characteristics of strawberries grown in the year 2009

Source	TMA ^a	TPC ^b	AOC		Organic acids ^e			Individual sugars ^f		
			FRAP ^c	TEAC ^d	Malic acid	Citric acid	Total acid	Glucose	Fructose	Total sugars
Growing conditions										
GH	84.9	2088	6.4	7.8	0.15	0.72	0.87	1.27	1.26	2.53
PT	101.4	2432	6.9	7.9	0.12	0.53	0.65	1.92	1.83	3.75
OF	101.4	2348	6.8	7.6	0.11	0.71	0.82	1.72	1.66	3.38
Genotype										
Sweet Charlie	61.8 de	1972 c	6.7	7.5	0.11 cd	0.41 c	0.52 d	1.45 bcd	1.38 cde	2.84 bcd
Camarosa	76.4 cd	2601 a	5.9	8.2	0.13 abc	0.54 bc	0.68 cd	1.13 d	1.08 e	2.21 d
Gaviota	86.8 bcd	2625 a	7.2	8.1	0.12 abc	0.51 bc	0.63 cd	1.29 cd	1.22 de	2.50 cd
Whitney	39.4 e	2075 bc	7.3	8.4	0.10 cd	0.53 bc	0.63 cd	1.12 d	1.01 e	2.13 d
Cigouletta	121.3 a	2143 bc	6.3	7.5	0.16 a	0.93 a	1.08 a	1.55 bcd	1.48 b-e	3.03 bcd
Marlate	136.1 a	2255 abc	6.2	7.7	0.13 abc	0.63 bc	0.75 bcd	1.83 ab	1.89 ab	3.72 b
Alba	111.7 ab	2155 bc	6.1	7.6	0.13 abc	0.67 bc	0.80 bcd	1.80 b	1.73 bc	3.52 b
MT 99	130.3 a	2302 abc	6.5	7.9	0.12 abc	0.62 bc	0.75 bcd	1.74 bc	1.68 bcd	3.42 bc
121 9										
Type 3	90.0 bc	2403 ab	7.1	7.9	0.11 bc	0.59 bc	0.71 cd	1.74 bc	1.63 bcd	3.37 bc
Type 5	133.4 a	2272 abc	6.9	7.8	0.16 a	0.76 ab	0.92 abc	1.64 bc	1.62 bcd	3.27 bc
Ebru	130.9 a	2410 ab	6.9	7.5	0.15 ab	0.71 ab	0.86 abc	1.83 ab	1.82 bc	3.65 b
Kaska	119.1 a	2223 abc	6.6	8.1	0.14 abc	0.64 bc	0.78 bcd	1.86 ab	1.76 bc	3.62 b
Osmanli	9.6 f	2322 abc	7.3	7.0	0.07 d	0.96 a	1.03 ab	2.30 a	2.29 a	4.58 a

Values in the same column that are followed by different letters are significantly different ($p \leq 0.05$) using Tukey's comparison test.

TA, total anthocyanin; TP, total phenol content; FRAP and TEAC, total antioxidant content; GH, greenhouse; PT, plastic tunnel; OF, open field.

^aTMA were determined by the pH-differential method of [Giusti and Wrolstad \(2005\)](#). Values are expressed as mg Pg-3-glucose/kg FW, by spectrophotometer.

^bTP contents were estimated by the Folin-Ciocalteu assay of [Singleton and Rossi \(1965\)](#). Values are expressed as mg gallic acid equivalents (GAE)/kg FW, by spectrophotometer.

^cTEAC values were determined by the method of [Özgen et al. \(2006\)](#). Values are expressed as mmolTE/kg FW, by spectrophotometer.

^dFRAP values were determined by the method of [Benzie and Strain \(1996\)](#). Values are expressed as mmolTE/kg FW, by spectrophotometer.

^eOrganic acids were determined by the method of [Shui and Leong \(2002\)](#). Values are expressed as mg/100 g FW, determined by HPLC.

^fOrganic sugars were determined by method of [Bartolome, Ruperez and Fuster \(1995\)](#). Values are expressed as mg/100 g FW, determined by HPLC.

Table 6 Variance component of genotype and growing conditions on nutritional fruit quality characteristics of strawberries grown in the years 2008 and 2009

Variance Component	AOC				Organic acids			Individual sugars		
	TMA	TPC	FRAP	TEAC	Malic acid	Citric acid	Total acids	Glucose	Fructose	Total sugars
2008										
GC	145 (7) ^a	138644 (50)	0.12 (4)	0.76 (24)	0.00 (54)	0.00 (0)	0.00 (4)	0.78(36)	0.25 (43)	1.89 (39)
G	1487 (71)	33147 (12)	1.07 (31)	0.91 (29)	0.00 (8)	0.01 (39)	0.01 (31)	0.88(41)	0.20 (34)	1.91 (39)
GC*G	195 (9)	43395 (16)	0.80 (23)	0.50 (16)	0.00 (6)	0.00 (0)	0.00 (0)	0.04(2)	0.02(4)	0.13 (3)
Error	280 (13)	63048 (23)	1.43 (42)	0.95 (30)	0.00 (31)	0.02 (61)	0.03 (65)	0.44(21)	0.10 (18)	0.96 (20)
2009										
GC	73 (3)	28698 (18)	0.01 (1)	0.00 (0)	0.00 (28)	0.01 (20)	0.01 (20)	0.10 (33)	0.08 (28)	0.37 (31)
G	1521 (72)	20743 (13)	0.07 (8)	0.05 (7)	0.00 (32)	0.02 (38)	0.02 (34)	0.09(28)	0.10 (35)	0.37 (31)
GC*G	78 (4)	13229 (8)	0.37 (46)	0.10 (15)	0.00 (30)	0.02 (35)	0.02 (39)	0.02 (5)	0.02 (7)	0.07 (6)
Error	447 (21)	96290 (61)	0.36 (45)	0.50 (77)	0.00 (9)	0.00 (6)	0.00 (7)	0.11(34)	0.09 (31)	0.38 (32)

GC, growing conditions; G, Genotype; TA, total anthocyanin; TP, total phenol content; FRAP and TEAC, total antioxidant content.

^aNumbers in parenthesis show the variation percentage.

In 2009, ‘Marlate’, ‘Type 5’, ‘Ebru’, ‘MT 99 121 9’, ‘Cigouletta’, and ‘Kaşka’ were most prominent for TMA. The lowest TMA was observed in ‘Osmanli’ as it was also in the first year (Tables 4 and 5). In 2009, TPC was highest in ‘Gaviota’ (2625 mg GAE/kg FW) and ‘Camarosa’ (2601 mg GAE/kg FW), followed by ‘Ebru’ and ‘Type 3’. ‘Cigouletta’ showed the highest total acid content (1.08 g/100 g), followed by ‘Osmanli’ (1.03 g/100 g). In 2009, ‘Osmanli’ also was most prominent for total sugar content (Table 5).

The proportion of variability obtained from genotype and growing conditions on bioactive compound is given in Table 6. Genotypes had a very large effect upon TMA (71 and 72%, respectively) in both years (Table 6). Genotypes had a significant effect on TAC in the first year, whereas in the second year, no significant effect was observed. Genotypes had a modest, significant effect on organic acids (31 and 34%, respectively) in both years. The effect of genotype and growing conditions on total sugar content were similar and high for both years (Table 6).

The importance of nutritional quality of fruits is steadily increasing. People are becoming more and more aware of the need to consume healthy food for a healthy life. It is necessary to establish new growing systems to protect fruit quality characteristics as well as developing new strawberry cultivars having high quality. In fact, it is important to know the effect of growing conditions on the fruit quality of each strawberry cultivar developed by a breeding program. In the study, the effect of growing conditions on fruit quality characteristics was not as important as genetic effects; however, PT and OF gave more quality fruits than GH did. Among the growing conditions, TMA was highest in OF and the lowest in GH.

SUMMARY POINTS

- Berries, including strawberries, have an important role among fruits because of their high phytochemical content.
- Recent studies have focused on the nutrient and phytochemical contents of the strawberry and on factors affecting the composition of this fruit.
- These studies have included genotype, environmental factors, and cultural systems.
- The importance of nutritional quality of fruits is steadily increasing. People are becoming more and more aware of the need to consume healthy food for a healthy life. It is necessary to establish new growing systems to protect fruit quality characteristics.

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Nutritional Composition of Fruit Cultivars



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Nutritional Composition of Fruit Cultivars documents valuable information on the nutritive values of cultivars, providing a comparative benchmarking between historical and modern varieties.

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