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SALT, FAT AND SUGAR REDUCTION

SENSORY APPROACHES FOR
NUTRITIONAL REFORMULATION OF
FOODS AND BEVERAGES



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Sensory Approaches for
Nutritional Reformulation
of Foods and Beverages

MAURICE G. O'SULLIVAN



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Preface

Nutritional optimization of foods and beverages has always been a part of product innovation. However, in my long career as a food scientist, both in industry and as an academic, I cannot remember a period when this innovation has reached such intensity. A trip to the supermarket reveals a product range for celiacs far more diverse than at any other time. Processed meats have brand leading reduced salt and fat variants with some developed cured meats containing alternate or even organic nitrite sources. The number of vegans in Ireland and the United Kingdom increased fourfold between 2014 and 2019. Six percent of consumers in the United States claim to be vegans, a 600% increase in 3 years. Plant-based lifestyles have got the attention of producers with reduced meat or meat-free variants of main-stream products reaching the marketplace. Bioactive containing dairy and beverage products are widely available to assist in maintaining a healthy “microbiome.” In the spring of 2018, Ireland and the United Kingdom introduced a coordinated sugar tax on soft drinks. For producers in Ireland, this resulted in products containing between 5 and 8 g sugar/100 mL being levied at 20c/L, while those over 8 g/100 mL are levied at 30c/L. This resulted in dramatic increases in reformulation projects by the beverage sector.

This inertia to reformulate is being driven by consumers who are demanding products to provide their nutritional desires for healthier lifestyles and by government incentives devised to combat the civilization diseases obesity, diabetes, cardiovascular disease, and even cancer. This, in turn, has encouraged the industry to reformulate, through commercial necessity, and if they are to succeed, they must maintain safety, shelf life, and commercial viability. Salt, fat, and sugar are the main targets for reformulation in industry by reduction or replacement because of their contribution to the abovementioned civilization diseases, although this is easier said than done. Salt and sugar are tastants, preservatives, flavor enhancers, as well as functional ingredients; salt assists in water binding in meat, whereas sugar in baking is essential for cake volume. Fat is a functional ingredient and plays a vital sensory role in baked products, and for all fat-containing foods it contributes to flavor, mouthfeel, taste, aroma, appearance, structure, texture, and satiety. Modifying recipes thus has complex effects and interactions. However, food scientists have successfully risen to

the challenge as evidenced by the plethora of reformulated products available in our supermarkets across the product spectrum. This book outlines the background, issues, and challenges required in the reformulation of foods and beverages. This is presented with an emphasis on sensory- and consumer-driven strategies as ultimately the consumer demands healthier products that still taste great and have high acceptance and appeal.

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Understanding the requirement to reformulate; science, health, consumer demand, regulation, and capability

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Introduction

Nutritional optimization of processed foods is driven by four distinct processes. The first involves scientific understanding of the civilization diseases, such as hypertension, obesity, diabetes, and coronary heart disease (CHD), which result from the consumption of processed foods. The unhealthiness of too much fat, salt, and sugar in the human diet has been studied now for many years by virtually thousands of scientists. This scientific understanding is disseminated into the academic databases and journals, which ultimately filters through to the main stream media. This in turn propagates the second driver, which is consumer awareness and

understanding by the population in general of the scientific findings of the first driver. Stage three is the modification of processed food recipes by the industry because of consumer demand. This manifests as either a drop in sales of “unhealthy products” and the then essential need to reformulate or the capitalization of the industry to develop healthier processed food variants to meet consumer needs. The fourth stages are the government incentives to make foods healthier. This occurs through collaboration with industry to set realistic targets for unhealthy ingredient usage, for example, salt levels [the Food Standards Agency (FSA) and the Food Safety Authority of Ireland (FSAI) salt-reduction programs]. This results in gradual reduction in products over time and can be achieved through stealth, without the consumer really being aware of the reduction strategy. This is a very satisfactory approach for the industry as it means the gradual reduction of an ingredient can be well understood, achieved safely and without loss of commercial viability and most importantly sensory profile. The fourth stage can also be enforced by a government in order to achieve an immediate reduction of an “unhealthy” ingredient. The perfect example of this is the introduction of taxes. On May 1, 2018, Ireland introduced a sugar tax on soft drinks. Products containing between 5 and 8 g/100 mL sugar were levied at 20 c/L while those over 8 g/100 mL were levied at 30 c/L (Table 1.1). This resulted in dramatic increase in reformulation projects by the beverage sector in order for their business strategies to best fit with the new regulation. Again, such incentives are further driving the industry to reformulate, and if they are to succeed, this must be undertaken in a consumer-driven fashion while maintaining safety, shelf life, and commercial viability.



Salt

More than 90% of sodium in humans' diet is provided by salt (sodium chloride) (He, Campbell, & MacGregor, 2012), with excessive consumption associated with negative effects on human health, principally as elevated blood pressure ($\leq 140/90$ mmHg), where the prevalence exceeds 40% in most European countries (Kearney, Whelton, Reynolds, Whelton, & He, 2004; Strazzullo, D'Elia, Kandala, & Cappuccio, 2009). Elevated blood pressure is estimated to induce 7.5 million deaths annually,

Table 1.1 Sugar tax rates Ireland.

Sugar tax rates					
Lower rate			Higher rate		
Volume	Tax per pack	Plus VAT ^a	Volume	Tax per pack	Plus VAT ^a
330 mL	+ 5c	+ 7c	Volume	+ 8c	+ 10c
500 mL	+ 8c	+ 10c	330 mL	+ 12c	+ 15c
1.25 L	+ 20c	+ 25c	500 mL	+ 31c	+ 38c
1.5 L	+ 24c	+ 30c	1.25 L	+ 37c	+ 45c
1.75 L	+ 29c	+ 35c	1.75 L	+ 43c	+ 53c
2 L	+ 33c	+ 40c	2 L	+ 49c	+ 60c
4x330 mL	+ 22c	+ 26c	4x330 mL	+ 32c	+ 40c
6x330 mL	+ 32c	+ 40c	6x330 mL	+ 48c	+ 59c

^aValue Added Tax. <http://www.moneyguideireland.com/sugar-tax-ireland-much-will.html>.

equivalent to ~12.8% of all deaths worldwide as it is the major risk factor for cardiovascular disease (CVD) (strokes, heart attacks, and heart failure), the leading cause of deaths globally (World Health Organization (WHO), 2010). A diet rich in salt has also been linked to left ventricular hypertrophy (Kupari, Koskinen, & Virolainen, 1994; Schmieder & Messerli, 2000) progression of renal disease and albuminuria (Cianciaruso et al., 1998; Heeg, De Jong, Van Der Hem, & De Zeeuw, 1989; Swift, Markandu, Sagnella, He, & Macgregor, 2005), stomach cancer (Joossens et al., 1996; Tsugane, Sasazuki, Kobayashi, & Sasaki, 2004), bone demineralization (Devine, Cridle, Dick, Kerr, & Prince, 1995), colorectal cancer (WCRF, 2007) and hypertension in about 20% of the population with increased risk of CVD (Desmond, 2006; Paik, Wendel, & Freeman, 2005). With the increased consumption of processed foods, salt intake has increased to a level of 9–12 g salt per day in nearly all countries worldwide (Henderson, Gregory, Irving, & Swan, 2002) which is 40–50 times higher than the evolutionary intake (0.25 g salt per day) (Eaton & Konner, 1985). A sodium intake of less than 5 g/day is the recommended level (WHO, 2012). Changing consumer lifestyle patterns show a significant impact on consumer diets. A greater number of women are at work, people work longer hours, and spend more time on leisure activities (Hitchman, Christie, Harrison, & Lang, 2002), which has caused an increased demand for convenience foods, with most energy dense and poor in nutrition. After the bread and cereals group the largest source of sodium (salt) in the European diet is processed meat products (Kloss, Meyer, Graeve, & Vetter, 2015). Processed meat products contribute

20%–30% to the daily salt (NaCl) intake in industrialized countries amounting to between 9 and 12 g/day, a much larger value than the recommended value of <5 g/day (Desmond, 2006; Jiménez-Colmenero, Carballo, & Cofrades, 2001; WHO, 2003).

The reduction of salt in processed food causes technological challenges as salt has an essential function in meat products in terms of safety, taste, flavor, texture, and shelf life as well as being a preservative and functional ingredient for the binding of water (Desmond, 2006; O'Sullivan, 2017c; O'Sullivan & Kerry, 2008). Salt is basic to all meat curing mixtures and is the primary ingredient necessary for curing. Food manufacturers have to achieve satisfactory sensory quality in reduced-salt and reduced-fat products, which is challenging as salt and fat perform multipurpose roles in many processed foods and beverages. Salt is a preservative and imparts not only a salty taste but also enhances flavor, inhibits bitterness (Lindsay, 2007), and is important for yield in processed meats due to its water-binding functionality (Fellendorf, Kerry, Hamill, & O'Sullivan, 2018; Fellendorf, Kerry, & O'Sullivan, 2018; Fellendorf, O'Sullivan, & Kerry, 2015, 2016a, 2016b, 2017). Sodium chloride solubilizes myofibrillar proteins during manufacturing (Hamm, 1972), which are responsible for activation of the proteins to increase hydration and water-binding capacity, increase the binding properties of protein, and improve texture (Offer & Knight, 1988). As a consequence, a reduction of salt impacts all these processes with several researchers reported detrimental effects on water-binding capacity, texture, and flavor (Desmond, 2006; Totossaus & Pérez-Chabela, 2009). Also, salt reduction is difficult to achieve due to supermarket concerns about reductions in shelf life, as well as processing concerns pertaining to traditional product labels (Honikel, 2008).

Improving population diets plays an important role in preventing chronic noncommunicable diseases. Traditionally, strategies have focused on public campaigns and health education, despite these efforts, change has been slow (EPHAC, 2010). In addition, several studies found that Americans reported getting the majority of their health-related information from news media (Coleman, Thorson, & Wilkins, 2011). However, due to negative press and governmentally lead health campaigns, consumers are demanding products that are low in salt, fat, cholesterol, nitrites, and calories in general and contain in addition health-promoting bioactive components such as carotenoids, unsaturated fatty acids, sterols, and fibers (Weiss, Gibis, Schuh, & Salminen, 2010).

Some countries have taken a very progressive stance with regard to reducing salt in processed foods. The governments of the United Kingdom and Ireland are good examples. Cured and other processed meat products are the main contributors to salt intakes in the Irish population, followed by bread. FSA from the United Kingdom and the FSAI have agreed guidelines for the meat industry in order to reduce the salt content of several products, including bacon and ham. In the case of bacon products the FSAI agreed guidelines in 2012 were 3.3 g salt/100 g and the FSA salt targets for 2017 are 2.88 g/100 g. The FSA 2017 target for salt in ham products is 1.63 g/100 g (Delgado-Pando et al., 2018).

The food industry has already successfully started to implement processed foods low in salt and fat. Different strategies have been attempted to achieve this objective, including reducing the total amount of salt or by (partly) substitution of sodium chloride with salt replacer ingredients (Aaslyng, Vestergaard, & Koch, 2014; Aliño, Grau, Toldrá, & Barat, 2010; Aliño, Grau, Toldrá, Blesa, et al., 2010b; Fellendorf, Kerry, Hamill et al., 2018; Fellendorf et al., 2015, 2016a, 2016b, 2017; Gou, Guerrero, Gelabert, & Arnau, 1996; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2008; Tobin, O'Sullivan, Hamill, & Kerry, 2012a, 2012b, 2013).

Consumer surveys are a powerful tool, which can assist us in understanding how consumers view products and concepts. They can also tell us how effective scientific and government health campaigns are at disseminating important information regarding diet and nutrition to the consumer. Tobin, O'Sullivan, Hamill, and Kerry (2014) undertook a consumer study investigating European consumer attitudes on the associated health benefits of nutraceutical-containing processed meats using coenzyme Q10 as a sample functional ingredient. Of the 548 individuals surveyed, the majority of consumer attitudes toward processed meat indicate that they are unhealthy products. Most believed that processed meats contain large quantities of harmful chemicals, fat and salt (Tobin et al., 2014). In 2018 Fellendorf et al. (2018) published a paper on consumer attitudes on salt- and fat-reduced foods in the Republic of Ireland. The survey investigated how well consumers ($n = 1045$) in Ireland have assimilated the message of consuming healthier foods, including salt- and fat-reduced foods, into their diet. In Ireland, it seems that public health campaigns relating the importance of a balanced diet have reached the consumer in good order with them well informed of the health benefits of a balanced diet and the negative aspects over high salt consumption. Only a minority of those surveyed did not take care at all about maintaining a

balanced diet, independent of age, gender, and level of education; 59% of participants were very cognizant in maintaining a balanced diet with 38% of participants taking some care. Furthermore, an increase in the purchasing of salt-reduced food (43%) was observed. This displays to the processing industry that reformulation strategies appear to be having a positive effect on consumer behavior with the adoption of recognizable salt-reduced products and not just those produced over time by stealth through alignment with the government agency salt-reduction guidelines and program. Fat-reduced food products were already better accepted (64%) as determined from the data from this survey. In general, men, young adults (<30 years), and less educated people purchased less salt- and fat-reduced foods and took less care of consuming a balanced diet.

The majority of the participants (>90%) in the Fellendorf study (Fellendorf et al., 2018) were also aware of the health risks leading from a diet rich in salt and fat, although less participants transferred this knowledge into their diet. A very high demand for more salt and fat-reduced foods on the market was observed, although smaller product ranges and higher prices might diminish the level of acceptance. An increasing body of evidence shows that factors such as availability, accessibility, and price play more predominant roles in food choice. It is increasingly argued that improving diets will require change in the environments we live in and policy that supports making the healthy choice the easy choice (Foresight, 2007). Fellendorf, Kerry, Hamill, et al. (2018) and Fellendorf, Kerry, and O'Sullivan (2018) determined from the data of their survey that there was also no conflict for traditional foods reduced in salt and fat content when intrinsic character is kept. It has even been suggested that traditional food reformulation in the future may suffer from a less favorable attitude regarding health and nutritional aspects. The greatest threat for the future is seen in an insufficient adaptation to new requirements demanded by consumers (Jordana, 2000). The traditional food sector faces additional challenges of a potential discrepancy between the concept of traditional food and innovation (Guerrero et al., 2009; Stolzenbach, Bredie, & Byrne, 2013) which show an insufficient adoption of optimization strategies, possibly due the resistance to reformulate because of conservatism (Jordana, 2000). Stolzenbach et al. (2013) indicated that alterations in traditional foods without a clear understanding of the impact on consumers' perception and acceptance can potentially be more harmful than beneficial. Therefore insights in consumer requirements and expectations are imperative for a successful market launching of product innovations

(Grunert, Verbeke, Kügler, Saeed, & Scholderer, 2011). In Chapter 4, Reduced-salt products and challenges, and Chapter 5, Other nutritional modifications, consumer-driven product-development strategies for traditional food are presented through the use of coordinated affective and descriptive testing using novel rapid methods but validated by traditional consumer studies in order to determine product success.

Fellendorf, Kerry, Hamill, et al. (2018) and Fellendorf, Kerry, and O'Sullivan (2018) speculated that launching taxation and subsidies in tandem might counteract limited innovation regarding nutritional optimization and reformulation of traditional foods. On the one hand, food manufacturers might be encouraged in reformulating their products, and, on the other hand, it underlines to consumers the importance of a healthy diet. Furthermore, a user-friendly product labeling scheme is required so that consumers are able to make easier food choices (Fellendorf, Kerry, Hamill, et al., 2018; Fellendorf, Kerry, & O'Sullivan, 2018).

The use of salt in preserving processed food products was vital in the past, but the advent of modern packaging and refrigeration reduced its primary role and necessity (O'Sullivan & Kerry, 2008). This will be discussed in Chapter 12, Magnitude estimation—alignment of sensory and instrumental analysis, regarding the use of packaging innovations to compensate for the reduced shelf life and safety of low salt-containing products.



Fat

Overconsumption of fat is linked with, obesity, as well as high blood cholesterol and CHDs (Melanson, Astrup, & Donahoo, 2009; O'Sullivan, 2017a, 2017c; WHO, 2003). Also, obesity is a risk factor for many other diseases including high blood pressure, abnormal blood fat levels [affecting low-density lipoprotein (LDL) and high-density lipoprotein cholesterol and triglycerides], increased blood-clotting tendency, and raised blood insulin levels and type 2 diabetes mellitus (Department of Health & Children, 2005). The nonfatal but restricting health problems related with obesity include respiratory difficulties, chronic musculoskeletal problems, infertility, and skin problems, whereas the chronic health problems associated with obesity include cardiovascular problems (including hypertension, stroke, and CHD), conditions associated with insulin

resistance (e.g., noninsulin-dependent diabetes mellitus), cancer (especially the hormonally related and large-bowel cancers), and gallbladder disease (WHO, 2000). In addition, saturated fatty acids and cholesterol are linked in increasing the plasma LDL level. High LDL levels can lead to plaque buildup in arteries and result in CVDs (strokes, heart attacks, and heart failure) (Grundy & Denke, 1990).

Therefore low fat intakes are strongly recommended (WHO, 2003). This recommendation is addressed not only to the consumer but also requires the food industry to reduce sugar and fat in processed foods (Barclay et al., 2008).

Fat has an important role in human nutrition and is part of a normal balanced diet. Fats are required for hormone production (prostaglandins) and are used in blood clotting, oxygen transport, as well as the making of new cells and are required for energy production, without which muscles would cease to function. Animal fats play important functional, sensory, and nutritional roles in many food products, including processed meats (O'Sullivan, 2017c). Fat is also a functional ingredient and plays a vital sensory role in baked products where it contributes to flavor, mouthfeel, taste, aroma, appearance, and satiety. In the baking industry the presence of fat is vital for lubricity that facilitates processing steps such as sheeting and molding (O'Sullivan, 2017c). In processed meat production fat has important nutritional, sensory, and functional roles and is necessary in developing taste, texture, inducing mouthfeel, and lubrication (Dransfield, 2008; Giese, 1996; Hughes, Mullen, & Troy, 1998; Jiménez-Colmenero, 2007; Malone, Appelqvist, & Norton, 2003). It is very challenging for food processors to compensate for these qualities in fat-reduced food variants (O'Sullivan, 2015).

Strategies to reduce animal fat in meat products include formulating with leaner meats (partially defatted), substituting some of the fat with water, changing the fat profile with plant, fish and/or algal oils or utilizing fat replacers (categorized in fat substitutes and fat mimetics) (Weiss et al., 2010).

Generally there are two potential strategies that can be chosen with regard to fat reduction: (1) use sensory optimization studies to reduce the ingredient to determine the minimum fat levels beyond which sensory quality deteriorates and (2) use replacement ingredients such as fat substitutes, mimetics, or bulking agents that simulate the sensory properties of fat while also endeavoring to maintain maximum sensory quality. Fat replacers are ingredients used to mimic and replace fat in food products

(O'Sullivan, 2017c). The term “fat replacer” is a generic term which covers a very wide variety of materials such as starches, proteins, emulsifiers, hydrocolloids, and fibers (Atkinson, 2011). Fat substitutes are materials that simulate the chemical and physical properties of fats and oils and can directly replace fat on a weight to weight basis and take on board the processing characteristics of conventional fats and can be used in baking and frying. Examples of common fat substitutes include fat-based sucrose polyesters such as olestra (Olean), esterified propoxylated glycerol, fatty acid esters of sorbitol, and sorbitol anhydrides (Sorbestrin) (O'Sullivan, 2015). Fat mimetics also simulate the sensory properties of fat and can be composed of protein (e.g., gelatin, egg, milk, whey, soy, and gluten) or carbohydrate (modified starches, dextrins, and nondigestible complex carbohydrates) based materials. Similarly to fat substitutes, they have a much lower calorific level compared to conventional fats and oils and usually bind large volumes of water. Their processing characteristics are limited in reduced-fat foods as they cannot be used in products that are fried as they are poor carriers of fat-soluble flavors (O'Sullivan, 2015).



Sugar

High sugar intakes are associated with obesity, insulin resistance, diabetes mellitus type 2, dental caries, and fatty liver (WHO, 2003). Sugar has a major part to play in the sensory properties of confectionery products, such as cake and cake-like products and thus reducing sugar in these products presents a huge challenge for the food industry (Richardson et al., 2018a, 2018b). Sugar assists in incorporation of air cells, while creaming provides good grain structure, flavor, and texture to the product. It aids in retention of moisture, prolongs freshness, and promotes good crust color (Nip, 2007). In confectionary foods, sugar is responsible for sweetness, while fat contributes to the texture, mouthfeel, flavor, and aroma of food (Drewnowski & Almiron-Roig, 2010). The topic will be discussed in greater detail in Chapter 3, Reduced-fat products and challenges, where the difficulty in reducing sucrose, because of its functional properties in baking, will be discussed.

Sugar reduction or removal in confectionary products is an important research objective for the food industry, considering negative press,

consumer awareness around civilization diseases, and government strategies for sugar reduction in sugar-containing products. Recent research has investigated sugar particle size alteration, which affects the physical and sensory properties of chocolate brownies and could be used as a viable approach to reduce sugar in confectionery-type products (Richardson et al., 2018a, 2018b), whereas other studies have examined the use of clean label, novel sweetening ingredients (apple pomace, whey permeate, oligo-fructose, and polydextrose) as possible sugar replacers (Milner, Kerry, O'Sullivan, & Gallagher, 2019). The strategies used to date to reduce the amount of sucrose in food and beverage products have had limited success and will be discussed in detail in Chapter 2, Nutritional optimization—reduced sugar products (food and beverages) and challenges. Essentially, consumer concerns have been expressed about the safety of “artificial” sweeteners (Gardner et al., 2012; Pereira, 2012). Noncaloric artificial sweeteners (NAS) such as sucralose, aspartame, or saccharin are sugar replacers that have found ubiquitous use in the food industry in the production of calorie reduced food and beverage products. Saccharin, which is 300–400 times sweeter than sugar, has fallen out of favor with product developers mainly due to negative publicity, bans for use in some jurisdictions, followed by the lifting of bans and perhaps ambiguity and confusion now by the consumer as well as after taste issues with its use (metallic). Also, saccharin is associated with the potential risk of cancer of the bladder when used heavily (O'Sullivan, 2017c). Aspartame is also a controversial sugar replacer 200 times sweeter than sugar that has had a chequered past. Since 1981, when aspartame was first approved by the US Food and Drug Administration (FDA), researchers have debated both its recommended safe dosage (40 mg/kg/day) and its general safety to organ systems (Choudhary & Pretorius, 2017). Aspartame is permitted for use in Europe and is not a safety concern (EFSA, 2013). Acesulfame K exhibits significant bitter and metallic off taste essentially identical to that of saccharin (Miele et al., 2017). Suez et al. (2014) studied the bacterial populations of 400 people and found that in the guts of those who consumed NAS, there were significantly differences to those who did not. Suez et al. data indicate that NAS consumption may contribute to, rather than alleviate, obesity-related metabolic conditions, by altering the composition and function of bacterial populations in the gut. Therefore a clean label approach to sugar reduction is of significant interest to the food industry (O'Sullivan, 2017c).

In 2018 Richardson et al. (2018a, 2018b) undertook a consumer survey ($n = 1166$) to gain an understanding of the consumption behavior

of Irish consumers and to get an insight into their knowledge and belief toward sugar in foods and beverages, sugar-reduced food and beverage products and sugar substitutes (Richardson et al., 2018b). Richardson et al. (2018a) found that young adults (18–24) and those with a high school education were at a higher risk for overconsumption of free sugar through consumption of sugary beverages. Also, respondents within these demographic groups were very likely to say “Yes” when asked if they understood food labels, but these groups were also the most likely group to say “No” when asked if they knew the difference between NAS and natural sugar substitutes. These conflicting answers suggest confusion among the younger generation and highlights that much more needs to be done to educate young adults on food and nutrition and more specifically sugar, free sugar, and sugar substitutes. The consumption of NAS containing beverages was also observed to decrease with age, possibly due the consumer becoming better informed over time regarding health implications. Also, the difference between respondent’s likelihood to consume sugary foods (54.3%) and sugary beverages (4.2%) on a daily basis could suggest a growing awareness of negative health impact of sugar-sweetened beverages (SSBs) but not for confectionary. These findings stress that more awareness needs to be made of the excess amount of free sugar also present in food products, perhaps through media/health promotion outlets or taxation. The confusion regarding sugar replacers in this study is also a finding to be considered by the Irish food industry when reformulating products. This coupled with the inclination to purchase foods and drinks containing NAS specifically decreasing with advancing age and education perhaps justifies the need for a clean label approach (Richardson et al., 2018b).



Pricing

SSBs consumption in high-income countries are a contributor to socioeconomic inequalities regarding dental decay (Armfield, Spencer, Roberts-Thomson, & Plastow, 2013) and health outcomes such as obesity (Gearon, Backholer, Hodge, & Peeters, 2013). The presence of low-nutrient foods in most retail food outlets, especially SSBs, is ubiquitous, and their point-of-sale marketing strategies are carefully designed and

structured by manufacturers (Adjoian, Dannefer, Sacks, & Van Wye, 2014; Miller, Bodor, & Rose, 2012). Placing sodas on an end aisle display generated sales equivalent to discounting the beverage by 22%–62% (Nakamura, Pechey, Suhrcke, Jebb, & Marteau, 2014). Another prime location associated with impulse purchases is the check-out aisle (Miller et al., 2012). A larger amount of shelf-space and repeated exposures to products in multiple locations (called “multiplacements”) increases the odds that the product will attract the shopper’s attention (Cox, 1970). Also, possibly the most potent factor closely associated with purchase choices of SSBs includes pricing (Kotler and Keller, 2005). Blake, Lancsar, Peeters, and Backholer (2018) conducted an online discrete choice experiment with 2020 Australian consumers from difference economic backgrounds. Consumers were presented with 20 choice scenarios in a hypothetical convenience store setting where subjects chose between seven SSB and non-SSB beverage options or a no beverage option. These authors found that price increases for SSBs were likely to reduce demand across all income groups, more so for lower than higher, with an educational message having an additive effect (Blake et al., 2018). Richardson et al. (2018a, 2018b) in their survey of 1016 Irish consumers found that young adults (18–24) and those with a high school education were at a higher risk for overconsumption of free sugar through consumption of sugary beverages. Also, according to this study respondents within the young adults (18–24) group were the most likely to be affected by the implementation of a sugar tax, which could affect their purchasing habits and therefore significantly reduce their intake (Richardson et al., 2018b). Blake et al. (2017) found that a 20% SSB price increase in an urban Australian convenience store setting was associated with a 28% decrease in SSB volume sales (Blake et al., 2017). Similarly, Block, Chandra, McManus, and Willett (2010) found that a 35% SSB price increase in a hospital cafeteria setting (Boston, United States) was associated with 26% decrease in SSB purchasing, with an additional decrease when educational posters were displayed. SSB price increases represent an under explored tool for health promotion practitioners and dietitians promoting healthier foods in settings with limited healthy offerings (Blake et al., 2017). Blake et al. (2017) state that in addition to government regulation, there is the potential for retailers to independently alter SSB prices.

Colombia has a high prevalence of overweight (56%) and obesity (19%) among adults and is experiencing a growing trend in the prevalence of associated chronic conditions (Vecino-Ortiz & Arroyo-Ariza, 2018).

More than half of Colombian adults have a body mass index (BMI) greater than 25 (56%), and 19% are obese (BMI > 30) (ICBF, 2015). Vecino-Ortiz and Arroyo-Ariza (2018) applied a comparative risk assessment strategy to simulate the effect of an SSB tax on a nationally representative nutritional survey with 7140 adults. They found that a tax rate of at least 75 cents of Colombian peso (0.75 COP) per milliliter (24% of the average price) would need to be applied to have statistically significant effects on both overweight and obesity prevalence among lower economic group households. Thus the pricing of unhealthy products, such as SSBs, has a clear effect on purchase decision and the implementation of a tax on such products should improve the nutritional outcomes of a significant part of the population. In the next section taxes on the targeted ingredients, sugar, salt, and fat are discussed in detail.



Taxes

SSBs taxes are being considered and implemented around the globe to combat obesity, yet limited evidence has been gathered on the real-world impact of SSB taxes on purchasing behavior over time (Andreyeva, Long, & Brownell, 2010; Colchero, Popkin, Rivera, & Ng, 2016; Falbe et al., 2016). Beverage taxes may reduce SSB consumption and discourage unhealthy diets (Malik et al., 2010; Woodward-Lopez, Kao, & Ritchie, 2011). The implementation of sugar tax policies on SSBs is currently very topical due to recent implementations taken in Europe by the United Kingdom and Ireland. There are some suggestions that frequent SSB consumers may preferentially benefit from an intervention that increases the price of SSBs, given the dose–response relationship between SSB consumption and the risk of adverse health outcomes (Malik et al., 2010). The United Kingdom implemented a sugar tax on April 6, 2018, with SSB containing more than 8 g/sugar/100 mL taxed at 24 p/L, while drinks containing 5–8 g of sugar per 100 mL taxed at 18 p/L. Similarly, on May 1, 2018, Ireland introduced its own sugar tax on soft drinks with comparable rates (Table 1.1). Products containing between 5 and 8 g/100 mL sugar are levied at 20 c/L while those over 8 g/100 mL were levied at 30 c/L. The sugar tax has driven some United Kingdom drinks companies (e.g., A.G. Barr and supermarket chain Tesco) to reformulate (Lancet, 2017).

However, Ireland and the United Kingdom are not the first to implement such taxes. In the US beverage taxes have also been recently implemented (2017) in Albany, California; Oakland; Boulder, Colorado; Philadelphia, Pennsylvania, and more are being considered by other cities (Hinton & Svachula 2017). Mexico (2014), France (2012), Hungary (2012), and Finland (2016) have taxed sugary drinks while South Africa, the Philippines, Indonesia, and India are considering doing so. In addition, Hungary and Finland have also taxed some unhealthy foods (Briggs, 2016). Denmark implemented the world's first but short-lived fat tax in 2011. Bødker, Pisinger, Toft, and Jørgensen (2015) revealed that upon the launch of the saturated fat tax, food industry representatives fought against its introduction. In addition, the saturated fat tax suffered from significant shortcomings, especially because the tax did not reflect the actual saturated fat content in final product and gradually suffered a loss in popularity among politicians, health experts, and the general public. The Danish law put a surcharge on foods containing more than 2.3% fat. When it came to the fat tax, retailers complained that Danes simply went to Sweden and Germany, where prices are lower, to buy butter and ice cream (Strom, 2012). Consequently, 15 months later, the saturated fat tax was abolished, even when a lower consumption of saturated fat was beginning to appear among the Danish public. Bødker et al. (2015) concluded that the fat tax was more focused on a healthy economy than a healthier population. The sugar tax (\$0.01/ounce) implemented in Berkeley in the US state of California (March 2015) was shown to reduce frequency of SSB consumption by 21% within less than 6 months (Falbe et al., 2016).

Mexico has one of the highest prevalence rates for diabetes, overweight, and obesity in the world. More than 33% of young people aged 2–18 years are overweight or obese rising to 70% for adults. Heart disease and diabetes are the leading causes of mortality in Mexico with the latter having the highest level of any OECD (Organization for Economic Cooperation and Development) country (OECD, 2015). The rise in obesity and diabetes in Mexico is significantly linked to large increases in the consumption of SSBs with 163 L per capita consumed in 2011 (Barquera et al., 2010; Barquera, Hernandez-Barrera, & Tolentino, 2008; Colchero et al., 2016). Thus the reduction by the population of the consumption of SSBs became an important target by the Mexican government for obesity and diabetes prevention. In January 2014 the Mexican congress, as part of the federal budget, implemented an excise

tax of 1 peso/L on SSBs and a sales tax on several highly energy dense foods. This tax has proved highly successful with significant declines in consumption across all population groups, but particularly with the lower socioeconomic group with a 17% decline in consumption by December 2014 (Colchero et al., 2016).

One of the most draconian ingredient tax initiatives was implemented by Hungary in 2011 targeting foods with high fat, sugar, salt, caffeine content, and alcohol. The added levy on sugar-sweetened soft drinks was 16 c/L, 33 p/kg for prepackaged sweetened products, 67 p/kg for salty snacks and 84 p/L for energy drinks. These taxes were implemented by the Hungarian government to attempt to address a health crisis in its population; 19.5% of adult Hungarians self-reported as being obese in 2009 (Villanueva, 2011). Hungary has one of the lowest life expectancy rates at birth in the European Union with just 71.2 years for men and 78.7 for women (2011) compared with the European mean level (2009) of 76.6 years for men and 82.6 years for women (Daly, 2013). The overnight implementation of the tax came as a shock to the food industry in Hungary and forced them to implement reformulation strategies with immediate effect. Thus as a result, of this tax, 40% of manufacturers reformulated their products by reducing or ridding them of sugar and other unhealthy ingredients such as caffeine and salt (Lancet, 2017).



Capability

Rapid introduction of new products is an important consideration for companies because if a product has taken too long to get into the marketplace general trends or demographic consumer segments might change. However, this must be achieved without cutting corners. With any product-development project, there are risks and obstacles along the route, and after undertaking costly and resource consuming research and development projects there is no guarantee of success (O'Sullivan, 2017b). There are four golden rules that must be followed when reformulating products. Reformulated variants must be legal in the jurisdiction in which they are produced, and sold, and must meet benchmarked *Regulatory* compliance. Products must be *Safe* for human consumption.

This is especially important considering the reduction of preserving ingredients such as salt. Reducing salt to meet nutritional guidelines, even when sensory quality is maintained, must not be undertaken if the resulting product is in any way compromised with respect to safety. Once the first two rules are met, a projected product costing must be prepared to ensure that *least cost formulation (LCF)* protocols are utilized and the manufactured product is capable of actually making a profit within the target specification as set by the organization. These steps are usually undertaken as a precursor prior to entering a stage gate type product-development program which is also used extensively for reformulated product. *Technological capability* is the next evaluation step that must be undertaken. Can the facility actually make the product by having sufficient resources, including equipment and time to effectively produce the product within its designed technical and cost specifications. Many new products fail in the marketplace because product production and development does not focus systematically on consumer preferences and perceptions of sensory properties (O'Sullivan, Kerry, & Byrne, 2011). Developing products is easy, developing products that appeal to consumers is less so, and developing products that appeal to sufficient numbers of consumers and also achieve commercial success is very difficult (Stone & Sidel, 2007). It is well documented that more than 90% of all new product development in the food and beverage industries fail, some claim the figure is in fact closer to 98%. However, the 2% that is successful accounts for billions of pounds, dollars, yen, and euros worth of business every day, which begs the question: is the risk a worthy one? (Business Insights, 2004). However, despite the very low success rate, about 10% or less, companies continue to make the investment because of the enormous profit and reputation opportunities expected by the winners (Stone & Sidel, 2007).



Regulatory guidelines

Regulatory compliance must be carefully researched for new and reformulated products in order to ensure that the finished material is legally compliant in both the country of manufacture and sale. If, during reformulation, we are substituting fat or salt with replacer ingredients, we must ensure during our regulatory investigations that these ingredients are

allowed for use at the concentrations and applications utilized in the jurisdictions of sale. Another example is that of an ice cream made in the United Kingdom but produced for export to the United States. In the United Kingdom, ice cream is defined as a frozen food product containing a minimum of 5% fat which must contain no less than 2.5% milk protein (such as from skim milk powder). The fat source may be vegetable such as hydrolyzed palm kernel oil. The majority of the ice cream in the United Kingdom is made from nonmilk-fat ingredients, whereas in the United States as defined by the FDA, ice cream must contain at least 10% milk fat, below which it can only be called ice milk, and a minimum of 10% nonfat milk solids. As milk fat percentage increases from 10%, the nonfat milk solids may sequentially decrease such that the dairy fat and nonfat dairy ingredients balance at the 20% level (FDA, 2015; O'Sullivan, 2017d). Therefore our UK ice cream does not fit the definition of ice cream in the United States. The producer in this case will have to reformulate in order to specifically meet the FDA requirements. Another example is the production of a flavored alcoholic beverage for dual markets (European and United States). Flavoring ingredients in the EU may be nature identical, whereas those required to satisfy the regulator, the TTB (Alcohol and Tobacco Tax and Trade Bureau), in the United States must be natural flavors. Natural flavors can be far more expensive than nature identical flavorings, and this can also have major cost implications. Thus a legally compliant US variant could be sold in Europe, but the European variant manufactured with nature identical flavors cannot be sold in the United States (O'Sullivan, 2017m). Diageo, the world's largest drinks manufacturer, has undertaken a very pragmatic approach and consolidated its flagship cream liqueur brand, Baileys, by having only one universal formulation, made from natural flavors, that can be sold anywhere in the world.



Safety

Food safety is a default for any reformulation protocol. All products must be safe for human consumption across the specification of their use criteria. Microbiological safety can be determined by manufacturers by appropriate testing sufficient quantities of the product held at its normal

storage temperature. Samples tested should reflect the normal batch-to-batch variation of the product. This variation should include variation to component ingredients, within specification fluctuations in the manufacturing process and the sample should be contained in its specified packaging.

For food safety, it is important to determine how long a product is safe to consume within the designed storage parameters. In order to achieve this the product is stored at the recommended storage temperature and conditions until the maximum legally allowable limit for numbers of defined microflora is reached, and then manufactures subtract a further period of time to allow an additional safety margin by which the product can be consumed (O'Sullivan, 2017d). This margin of safety should be determined and applied by the manufacturer after examining all reasonably foreseeable conditions of processing and use (FSAI, 2014a). With microbial growth it is often useful to consider safety and spoilage separately although the controlling factors for both may be identical (Walker, 1994). The safety of foodstuffs is mainly ensured by a preventive approach, such as implementation of good hygiene practice and application of procedures based on hazard analysis and critical control point principles (EC 2073/2005). Such practices ensure the absence of pathogenic microorganisms during production and minimize the microbial load within the regulatory guidelines (O'Sullivan, 2017d).

Microbiological criteria have been set in legislation for various foods, including meat products and ready-to-eat foods (see Chapter 10: Validation and safety (Shelf Life testing). Commission Regulation (EC) No 2073/2005 (EU, 2005) sets guideline limits on various microorganisms at point of sale (EU, 2005). Cheeses made from milk or whey that has undergone heat treatment should have a limit for *Escherichia coli* of <100 cfu/g; precut fruit and vegetables (ready-to-eat) should have a limit for *E. coli* of 100 to 10^3 cfu/g and unpasteurized fruit and vegetable juices (ready-to-eat) should have a cutoff level set for *E. coli* bacteria of $>10^3$ cfu/g. Similarly limits for coagulase-positive staphylococci at point-of-sale for shelled and shucked products of cooked crustaceans and molluscan shellfish should be set at $>10^4$ cfu/g. Cheeses made from milk that has undergone a lower heat treatment than pasteurization and ripened cheeses made from milk or whey that has undergone pasteurization or a stronger heat treatment should have limits of between 20 and 10^4 cfu/g (O'Sullivan, 2017d).



Least cost formulation

An LCF calculation should be one of the very first activities to be completed for reformulated products in order to ensure commercial viability. The cost of production of the concept product has to be considered as part of the approval process and can be relatively straight forward to determine. Weights or approximate values must be calculated for each component ingredient and multiplied by the optimal price at which the company can purchase that ingredient. This is simply performed as a paper exercise but more usually using spreadsheet software such as excel (Microsoft) (O'Sullivan, 2017b).



Technological capability

Technological capability essentially means “Is the organization capable of making the new product with current manufacturing resources?” There are four potential scenarios to this situation. (1) The existing process line resources can accommodate the potential manufacture of the new product. (2) The existing process line can technically produce the product but is currently operating at capacity or near capacity. If a process line is unable to accommodate the increased capacity requirements, then increasing the pressure further by introducing a new product for scheduling in the production rota will only lead to inefficiencies and downtime. Thus it might be necessary to (3) invest capital in developing a new line which adds further to the risk to the product optimization program success (O'Sullivan, 2017b). Option 3 also comes into play if the new product requires a bespoke process. Obviously, this is the riskiest scenario and potentially could be foolhardy. In this latter case the best solution might also be to take the lesser of two evils by muddling through with option 2 with existing resources and to invest in option 3 when the new or reformulated product has demonstrated a sufficient degree of commercial success. Option 4 involves contracting out production to a third party manufacturer which is potentially a lower risk solution when internal resources are limited (O'Sullivan, 2017b).



Line extensions

Line extensions can be considered reformulations that diversify an origin product. For reformulated products, this might include an ingredient modification to produce a reduced fat, salt, or sugar variant of an established product. Line extensions may initially be developed to cater for niche markets, but ultimately become significant brands in themselves. For example, diet drinks which have definitely established themselves as separate to their full sugar counterparts (O'Sullivan, 2017b).



Pre- and postapproval—shelf life testing

During the product-reformulation process, shelf life testing should be initiated at the earliest opportunity once products have passed through a defined stage and are allowed to progress through the development route (see Chapter 10: Validation and safety (Shelf Life testing)). Retention samples can be stored under defined storage conditions and tested periodically for perhaps, microbiological, sensory, and physico-chemical quality (O'Sullivan, 2017b). Modifications to ingredients such as salt, which have sensory and functional roles as well as preservative capabilities must be carefully monitored. Sequential reductions in salt content of a reduced-salt formulation might dramatically reduce shelf life and potentially even safety if compensatory measures are not implemented. This compensation strategy could be through additional “hurdle” type processes which make up for loss of preservative potency. This might include an antimicrobial process like a heat treatment such as retorting or high pressure processing in combination with an organic acid to synergistically retard microbial growth (Rodríguez-Calleja et al., 2012).

Accelerated storage tests are designed to reduce shelf life testing time by speeding up the deteriorative changes that occur in the product by exposure to factors such as high temperatures or humidity (O'Sullivan, 2011, 2016, 2017b). In this fashion a predicted shelf life may be determined or problems such as off-flavor development identified. After product commercialization and launch the product needs to be monitored, as with any commercial product, to ensure that it is performing satisfactorily

in the market and achieving the appropriate quality and shelf life criteria (O'Sullivan, 2017b).

References

- Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, 96(1), 47–55. Available from <https://doi.org/10.1016/j.meatsci.2013.06.004>.
- Adjoian, T., Dannefer, R., Sacks, R., & Van Wye, G. (2014). Comparing sugary drinks in the food retail environment in six NYC neighborhoods. *Journal of Community Health*, 39, 327–335.
- Aliño, M., Grau, R., Toldrá, F., Blesa, E., Pagán, M. J., & Barat, J. M. (2010b). Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science*, 85(3), 580–588.
- Aliño, M., Grau, R., Toldrá, F., & Barat, J. M. (2010). Physicochemical changes in dry-cured hams salted with potassium, calcium and magnesium chloride as a partial replacement for sodium chloride. *Meat Science*, 86(2), 331–336. Available from <https://doi.org/10.1016/j.meatsci.2010.05.003>.
- Andreyeva, T., Long, M. W., & Brownell, K. D. (2010). The impact of food prices on consumption: A systematic review of research on the price elasticity of demand for food. *American Journal of Public Health*, 100, 216–222.
- Armfield, J. M., Spencer, A. J., Roberts-Thomson, K. F., & Plastow, K. (2013). Water fluoridation and the association of sugar-sweetened beverage consumption and dental caries in Australian children. *American Journal of Public Health*, 103, 494–500.
- Atkinson, G. (2011). CH 14. Saturated fat reduction in biscuits. In G. Talbot (Ed.), *Reducing saturated fats in foods* (pp. 301–317). Woodhead Publishing Limited.
- Barclay, A. W., Petocz, P., McMillan-Price, J., Flood, V. M., Prvan, T., Mitchell, P., & Brand-Miller, J. C. (2008). Glycemic index, glycemic load, and chronic disease risk—A meta-analysis of observational studies. *American Journal of Clinical Nutrition*, 87, 627–637.
- Barquera, S., Hernandez-Barrera, L., & Tolentino, M. L. (2008). Energy intake from beverages is increasing among Mexican adolescents and adults. *Journal of Nutrition*, 138, 2454–2461. Available from <https://doi.org/10.3945/jn.108.092163>, 19022972.
- Barquera, S., Campirano, F., Bonvecchio, A., Hernández-Barrera, L., Rivera, J. A., & Popkin, B. M. (2010). Caloric beverage consumption patterns in Mexican children. *Nutrition Journal*, 9, 47–56. Available from <https://doi.org/10.1186/1475-2891-9-47>, 20964842.
- Bødker, M., Pisinger, C., Toft, U., & Jørgensen, T. (2015). The rise and fall of the world's first fat tax. *Health Policy*, 119(6), 737–742.
- Blake, M. R., Peeters, A., Lancsar, E., Boelsen-Robinson, T., Corben, K., Stevenson, C. E., Palermo, C., & Bacholer, K. (2017). Retailer-led sugar sweetened beverage price increase reduces purchases in a hospital convenience store, Melbourne, Australia: A mixed methods evaluation. *Journal of the Academy of Nutrition and Dietetics*, 118, 1027–1036.
- Blake, M. R., Lancsar, E., Peeters, A., & Backholer, K. (2018). The effect of sugar-sweetened beverage price increases and educational messages on beverage purchasing behavior among adults. *Appetite*, 126, 156–162.
- Block, J. P., Chandra, A., McManus, K. D., & Willett, W. C. (2010). Point-of-purchase price and education intervention to reduce consumption of sugary soft drinks. *American Journal of Public Health*, 100, 1427–1433.
- Briggs, A. (2016). Sugar tax could sweeten a market failure. *Nature*, 531, 551–551.

- Business Insights, Future Innovations in Food and Drinks to 2006: Forward-Focused NPD and Consumer Trends, 2004.
- Choudhary, A. K., & Pretorius, E. (2017). Revisiting the safety of aspartame. *Nutrition Reviews*, 75(9), 718–730. Available from <https://doi.org/10.1093/nutrit/nux035>, 2017 Sep 1.
- Cianciaruso, B., Bellizzi, V., Minutolo, R., Tavera, A., Capuano, A., Conte, G., & De Nicola, L. (1998). Salt intake and renal outcome in patients with progressive renal disease. *Mineral and Electrolyte Metabolism*, 24(4), 296–301.
- Colchero, M. A., Popkin, B. M., Rivera, J. A., & Ng, S. W. (2016). Beverage purchases from stores in Mexico under the excise tax on sugar sweetened beverages: Observational study. *British Medical Journal*, 352, h6704.
- Coleman, R., Thorson, E., & Wilkins, L. (2011). Testing the effect of framing and sourcing in health news stories. *Journal of Health Community*, 16, 941–954.
- Cox, K. K. (1970). The effect of shelf space upon sales of branded products. *Journal of Marketing Research*, 7, 55–58.
- Daly, S. (2013). Hungary tries a dash of taxes to promote healthier eating habits. *New York Times*. March 3, 2013. <<https://www.nytimes.com/2013/03/03/world/europe/hungary-experiments-with-food-tax-to-coax-healthier-habits.html>>.
- Delgado-Pando, G., Allen, P., Fischer, E., O'Sullivan, M. G., Kerry, J. P., & Hamill, R. M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. *Meat Science*, 139, 179–186. Available from <https://doi.org/10.1016/j.meatsci.2018.01.025>.
- Department of Health and Children. (2005). Obesity – The policy challenges. In *Report of the national taskforce on obesity, 2005* (pp. 1–132). The Report of the National Taskforce on Obesity. <<http://www.hse.ie/eng/health/child/healthyeating/taskforceonobesity.pdf>>.
- Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, 74, 188–196.
- Devine, A., Cridle, A. R., Dick, I. M., Kerr, D. A., & Prince, R. L. (1995). A longitudinal study of the effect of sodium and calcium intakes on regional bone density in postmenopausal women. *The American Journal of Clinical Nutrition*, 62, 740–745.
- Dransfield, E. (2008). The taste of fat. *Meat Science*, 80(1), 37–42.
- Drewnowski, A., & Almiron-Roig, E. (2010). Human perceptions and preferences for fat-rich foods. In J. P. Montmayer, & J. le Coutre (Eds.), *Fat detection: Taste, texture, and post ingestive effects* (pp. 243–264). Boca Raton, FL: CRC Press Taylor & Francis Group.
- Eaton, S., & Konner, M. (1985). Paleolithic nutrition. A consideration of its nature and current implications. *The New England Journal of Medicine*, 312(5), 283–289.
- EFSA (European Food Safety Authority). (2013). Scientific Opinion of the Panel on Food Additives and Nutrient Sources added to Food on a request from the European Commission for the re-evaluation of aspartame (E 951) as a food additive. *EFSA Journal*, 11(12), 3496.
- EPHAC. (2010). *Response to the reform of the CAP towards 2020 – Impact assessment*. <<https://ec.europa.eu/agriculture/sites/agriculture/files/cap-post2013/consultation/contributions/ephac-be.pdf>>.
- EU. (2005). EC 2073/2005. *On microbiological criteria for foodstuffs*. Commission Regulation. (EC) No 2073/2005. Microbiological criteria for foodstuffs. <https://www.fsai.ie/uploadedFiles/Consol_Reg2073_2005.pdf>.
- Falbe, J., Thompson, H. R., Becker, C. M., Rojas, N., McCulloch, C. E., & Madsen, K. A. (2016). Impact of the Berkeley excise tax on sugar-sweetened beverage consumption. *American Journal of Public Health*, 106, 1865–1871.

- FDA, 21CFR (Code of Federal Regulations) 135.110. Title 21-Food and Drugs. Chapter I-Food and Drug Administration. Department of Health and Human Services. Subchapter B-Food for Human Consumption. Part 135 e Frozen Desserts. Subpart B-Requirements for Specific Standardized Frozen Desserts Sec. 135.110 Ice Cream and Frozen Custard, 2015.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding sausages. *Meat Science*, 103, 75–82.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016a). Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings. *European Food Research and Technology*, 242, 2105–2118.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016b). Impact of using replacers on the physicochemical properties and sensory quality of reduced salt and fat black pudding. *Meat Science*, 113, 17–25.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2017). Effect of different salt and fat levels on the physicochemical properties and sensory quality of black pudding. *Food Science & Nutrition*, 5(2), 273–284.
- Fellendorf, S., Kerry, J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Science and Technology*, 92, 584–592.
- Fellendorf, S., Kerry, J. P., & O'Sullivan, M. G. (2018). Consumer attitudes on salt and fat reduced foods in the Republic of Ireland. *Food and Nutrition Sciences*, 9, 880–898. Available from <https://doi.org/10.4236/fns.2018.97066>.
- Foresight. (2007). *Tackling obesities: future choices – Project report* (2nd ed). London: Government Office for Science.
- FSAI, Guidance Note No. 18 Validation of Product Shelf-Life (Revision 2), 2014a, ISBN 1-904465-33-1.
- FSAI, Food Safety Authority of Ireland, Guidance Note No. 3 Guidelines for the Interpretation of Results of Microbiological Testing of Ready-to-Eat Foods Placed on the Market (Revision 1), 2014b, ISBN 0-9539183-5-1.
- Gardner, C., et al. (2012). Non-nutritive sweeteners: Current use and health perspectives. A Scientific Statement from the American Heart Association and the American Diabetes Association. *Diabetes Care*, 35, Aug 2012.
- Gearon, E., Backholer, K., Hodge, A., & Peeters, A. (2013). The mediating role of dietary factors and leisure time physical activity on socioeconomic inequalities in body mass index among Australian adults. *BMC Public Health*, 13, 1214.
- Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, 50, 78–83.
- Gou, P., Guerrero, L., Gelabert, J., & Arnau, J. (1996). Potassium chloride, potassium lactate and glycine as sodium chloride substitutes in fermented sausages and in dry-cured pork loin. *Meat Science*, 42(1), 37–48. Available from [https://doi.org/10.1016/0309-1740\(95\)00017-8](https://doi.org/10.1016/0309-1740(95)00017-8).
- Grundy, S., & Denke, M. (1990). Dietary influences on serum lipids and lipoproteins. *The Journal of Lipid Research*, 31, 1149–1172.
- Grunert, K. G., Verbeke, W., Kügler, J. O., Saeed, F., & Scholderer, J. (2011). Use of consumer insight in the new product development process in the meat sector. *Meat Science*, 89(3), 251–258.
- Guerrero, L., Guàrdia, M. D., Xicola, J., Verbeke, W., Vanhonacker, F., Zakowska-Biemans, S., & Hersleth, M. (2009). Consumer-driven definition of traditional food products and innovation in traditional foods. A qualitative cross-cultural study. *Appetite*, 52(2), 345–354.
- Guàrdia, M. D., Guerrero, L., Gelabert, J., Gou, P., & Arnau, J. (2008). Sensory characterisation and consumer acceptability of small calibre fermented sausages with 50%

- substitution of NaCl by mixtures of KCl and potassium lactate. *Meat Science*, 80(4), 1225–1230. Available from <https://doi.org/10.1016/j.meatsci.2008.05.031>.
- Hamm, R. (1972). Kolloidchemie des Fleisches. In R. Hamm (Ed.), *Das Wasserbindungsvermögen des Muskeleiweißes in Theorie und Praxis*. Berlin and Hamburg: Paul-Parey-Verlag.
- He, F. J., Campbell, N. R. C., & MacGregor, G. A. (2012). Reducing salt intake to prevent hypertension and cardiovascular disease. *American Journal of Public Health*, 32(4), 293–300.
- Heeg, J. E., De Jong, P. E., Van Der Hem, G. K., & De Zeeuw, D. (1989). Efficacy and variability of the antiproteinuric effect of ACE inhibition by lisinopril. *Kidney International*, 36(2), 272.
- Henderson, L., Gregory, J., Irving, K., & Swan, G. (2002). *The national diet and nutrition survey: Adults aged 19-64 years, . Energy, protein, carbohydrate, fat and alcohol intake* (Volume 2). London: TSO.
- Hinton, R., & Svachula, A. (2017). Soda taxes popping up around the U.S. Chicago Sun-Times. July 23, 2017. <<https://chicago.suntimes.com/news/soda-taxes-popping-up-around-the-u-s/>> Accessed 29.09.18.
- Inconvenience food. In C. Hitchman, I. Christie, M. Harrison, & T. Lang (Eds.), *The struggle to eat well on a low income*. London: DEMOS.
- Honikel, K. (2008). The use and control of nitrate and nitrite for the processing of meat products. *Meat Science*, 78, 68–76.
- Hughes, E., Mullen, A. M., & Troy, D. J. (1998). Effects of fat level, tapioca starch and whey protein on frankfurters formulated with 5% and 12% fat. *Meat Science*, 48(1–2), 169–180.
- ICBF (Instituto Colombiano de Bienestar Familiar), Tabla de Composición de Alimentos Colombianos, 2015. <https://www.icbf.gov.co/bienestar/nutricion/tabla-alimentos>.
- Jiménez-Colmenero, F. (2007). Healthier lipid formulation approaches in meat-based functional foods. Technological options for replacement of meat fats by nonmeat fats. *Trends in Food Science and Technology*, 18, 567–578.
- Jiménez-Colmenero, F., Carballo, J., & Cofrades, S. (2001). Healthier meat and meat products: Their role as functional foods. *Meat Science*, 59, 5–13.
- Joossens, J. V., Hill, M. J., Elliott, P., Stamler, R., Lesaffre, E., Dyer, A., & Kesteloot, H. (1996). Dietary salt, nitrate and stomach cancer mortality in 24 countries. European cancer prevention (ECP) and the INTERSALT cooperative research group. *International Journal of Epidemiology*, 25(3), 494–504.
- Jordana, J. (2000). Traditional foods: Challenges facing the European food industry. *Food Research International*, 33(3–4), 147–152.
- Kearney, P. M., Whelton, M., Reynolds, K., Whelton, P. K., & He, J. (2004). Worldwide prevalence of hypertension: A systematic review. *Journal of Hypertension*, 22(1), 11–19.
- Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union—A review. *NFS Journal*, 1, 9–19.
- Kotler, P., & Keller, K. L. (2005). *Marketing management* (12th ed., p. 2005). Upper Saddle River, NJ: PHI.
- Kupari, M., Koskinen, P., & Virolainen, J. (1994). Correlates of left ventricular mass in a population sample aged 36 to 37 years. Focus on lifestyle and salt intake. *Circulation*, 89(3), 1041–1050.
- Lancet. (2017). Sweet success: Will sugar taxes improve health? *The Lancet Diabetes & Endocrinology*, 5(4), 235, April 2017.
- Lindsay, R. (2007). Flavours. In S. Damodaran, K. L. Parkin, & O. R. Fennema (Eds.), *Fennema's food chemistry* (4th ed.). Taylor and Francis Group.

- Malik, V. S., Popkin, B. M., Bray, G. A., Després, J.-P., Willett, W. C., & Hu, F. B. (2010). Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes: A meta-analysis. *Diabetes Care*, 33, 2477–2483.
- Malone, M. E., Appelqvist, I. A. M., & Norton, I. T. (2003). Oral behaviour of food hydrocolloids and emulsions. Part 1. Lubrication and deposition considerations. *Food Hydrocolloids*, 17, 763–773.
- Melanson, E. L., Astrup, A., & Donahoo, W. T. (2009). The relationship between dietary fat and fatty acid intake and body weight, diabetes, and the metabolic syndrome. *Annals of Nutrition and Metabolism*, 55(1–3), 229–243.
- Miele, N. A., Cabisidan, E. K., Galiñanes Plaza, A., Masi, P., Cavella, S., & Di Monaco, R. (2017). Carbohydrate sweetener reduction in beverages through the use of high potency sweeteners: Trends and new perspectives from a sensory point of view. *Trends in Food Science and Technology*, 64, 87–93.
- Miller, C., Bodor, J. N., & Rose, D. (2012). Measuring the food environment: A systematic technique for characterizing food stores using display counts. *Journal of Environment and Public Health*, 2012, 707860.
- Milner, L., Kerry, J. P., O'Sullivan, M. G., & Gallagher, E. (2020). Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients. *Innovative Food Science and Emerging Technologies*, 59, 102235.
- Nakamura, R., Pechey, R., Suhrcke, M., Jebb, S. A., & Marteau, T. M. (2014). Sales impact of displaying alcoholic and non-alcoholic beverages in end-of-aisle locations: An observational study. *Social Science & Medicine*, 108, 68–73.
- Nip, W. K. (2007). Sweeteners. In H. Hui (Ed.), *Bakery products: Science and technology* (pp. 137–159). Chicago, IL: Blackwell Publishing.
- OECD. (2015). *Organization for economic cooperation and development health at a glance 2015* (2015). Poorkings Institution Press. Available from www.brookings.edu/research/books/2015/health-at-a-glance-2015.
- Offer, G., & Knight, P. (1988). The structural basis of water-holding capacity in meat. In R. Lawrie (Ed.), *Developments in meat science* (Vol. 4, pp. 173–243). London: Elsevier Science Publications.
- O'Sullivan, M. G. (2011). CH4. Sensory shelf-life evaluation. In J. R. Piggott (Ed.), *Alcoholic beverages: Sensory evaluation and consumer research*. Cambridge, UK: Woodhead Publishing Limited.
- O'Sullivan, M. G. (2015). Chapter 430. Low-fat foods: Types and manufacture. In *Encyclopedia of food and health*.
- O'Sullivan, M. G. (2016). CH18. The stability and shelf life of meat and poultry. In Subramaniam (Ed.), *The stability and shelf life of food*. Oxford, UK: Elsevier Academic Press.
- O'Sullivan, M. G. (2017a). CH6. Shelf life and sensory quality of foods and beverages. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 103–123). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017b). CH10. Sensory and consumer led innovative product development-from inception to the shelf (current and future methodologies). *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 197–222). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017c). CH11. Sensory properties affecting meat and poultry quality. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 225–257). United Kingdom: Woodhead Publishing Ltd.

- O'Sullivan, M. G. (2017d). CH12. *Sensory properties of dairy products. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 259–280). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017). CH13. *Sensory Properties of Beverage products. A Handbook for Sensory and Consumer Driven New Product Development: Innovative Technologies for the Food and Beverage Industry* (pp. 281–304). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G., & Kerry, J. P. (2008). CH 30, Sensory and quality properties of packaged meat. In J. P. Kerry, & D. A. Ledward (Eds.), *In Improving the sensory and nutritional quality of fresh meat* (pp. 585–598). Cambridge, UK: Woodhead Publishing Limited.
- O'Sullivan, M. G., Kerry, J. P., & Byrne, D. V. (2011). Use of sensory science as a practical commercial tool in the development of consumer-led processed meat products. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats*. United Kingdom: Woodhead Publishing Ltd.
- Paik, D. C., Wendel, T. D., & Freeman, H. P. (2005). Cured meat consumption and hypertension: an analysis from NHANES III (1988–94). *Nutrition Research*, 25, 1049–1060.
- Pereira, M. (2012). *Acting sweet: drivers, trends and forecasts in the sugar-free food and beverage market are explored*. CBS Interactive. Available from http://findarticles.com/p/articles/mi_m3289/is_1_175/ai_n26689456/.
- Richardson, A. M., Tyufin, A., Kilcawley, K. N., Gallagher, E., O'Sullivan, M. G., & Kerry, J. P. (2018a). Impact of sugar particle size manipulation on the physical and sensory properties of chocolate brownies. *LWT—Food Science and Technology*, 95, 51–57.
- Richardson, A. M., Tyufin, A., Kilcawley, K. N., Gallagher, E., O'Sullivan, M. G., & Kerry, J. P. (2018b). The knowledge, belief and consumption patterns of Irish consumers on the intake of sugary foods and beverages and sugar reduced/replaced foods and beverages. *Food Quality and Preference*. (Submitted).
- Rodríguez-Calleja, J. M., Cruz-Romero, M. C., O'Sullivan, M. G., & Kerry, J. P. (2012). High-pressure-based hurdle strategy to extend the shelf-life of fresh chicken breast fillets. *Food Control*, 25, 516–524.
- Schmieder, R. E., & Messerli, F. H. (2000). Hypertension and the heart. *Journal of Human Hypertension*, 14, 597–604.
- Stolzenbach, S., Bredie, W. L. P., & Byrne, D. V. (2013). Consumer concepts in new product development of local foods: Traditional versus novel honeys. *Food Research International*, 52(1), 144–152.
- Stone, H., & Sidel, J. L. (2007). CH13. Sensory research and consumer-led food product development. In H. Macfie (Ed.), *Consumer-led food product development* (pp. 307–320). Cambridge, UK: Woodhead.
- Strazzullo, P., D'Elia, L., Kandala, N.-B., & Cappuccio, F. P. (2009). Salt intake, stroke, and cardiovascular disease: Meta-analysis of prospective studies. *British Medical Journal*, 339(1), b4567.
- Strom, S. (2012). Fat tax' in Denmark is repealed after criticism. *New York Times*, November 12, 2012. Available from <https://www.nytimes.com/2012/11/13/business/global/fat-tax-in-denmark-is-repealed-after-criticism.html>.
- Suez, J., et al. (2014). Artificial sweeteners induce glucose intolerance by altering the gut microbiota. *Nature*, 514.
- Swift, P. A., Markandu, N. D., Sagnella, G. A., He, F. J., & Macgregor, G. A. (2005). Modest salt reduction reduces blood pressure and urine protein excretion in black hyper-tensives. A randomised control trial. *Hypertension*, 46, 308–312.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters.

- Meat Science*, 92(4), 659–666. Available from <https://doi.org/10.1016/j.meatsci.2012.06.017>.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, 91(4), 460–465. Available from <https://doi.org/10.1016/j.meatsci.2012.02.032>.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, 93(2), 145–152. Available from <https://doi.org/10.1016/j.meatsci.2012.08.008>.
- Tobin, B., O'Sullivan, M., Hamill, R., & Kerry, J. (2014). European consumer attitudes on the associated health benefits of nutraceutical-containing processed meats using Co-enzyme Q10 as a sample functional ingredient. *Meat Science*, 97(2), 207–213. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0309174014000114>.
- Totosaus, A., & Pérez-Chabela, M. L. (2009). Textural properties and microstructure of low-fat and sodium-reduced meat batters formulated with gellan gum and dicationic salts. *LWT—Food Science and Technology*, 42(2), 563–569.
- Tsugane, S., Sasazuki, S., Kobayashi, M., & Sasaki, S. (2004). Salt and salted food intake and subsequent risk of gastric cancer among middle-aged Japanese men and women. *British Journal of Cancer*, 90(1), 128–134.
- Vecino-Ortiz, A. I., & Arroyo-Ariza, D. (2018). A tax on sugar sweetened beverages in Colombia: Estimating the impact on overweight and obesity prevalence across socio economic levels. *Social Science & Medicine*, 209, 11–116.
- Villanueva, T. (2011). European nations launch tax attack on unhealthy foods. *Canadian Medical Association Journal*, 183(17), E1229–E1230. Available from <https://doi.org/10.1503/cmaj.109-4031>.
- Walker, S. J. (1994). The principles and practice of shelf life prediction of microorganisms. In C. M. D. Man, & A. A. Jones (Eds.), *Shelf life evaluation of foods* (pp. 40–51). London: Chapman and Hall.
- WCRF. (2007). *World Cancer Research Fund/American Institute for Cancer Research, . Food, nutrition, physical activity, and the prevention of cancer: A global perspective* (517). Washington, DC: American Institute for Cancer Research. Available from www.int/dietphysicalactivity/publications/trs916/summary/en/print.html.
- Weiss, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science*, 86, 196–213.
- Woodward-Lopez, G., Kao, J., & Ritchie, L. (2011). To what extent have sweetened beverages contributed to the obesity epidemic? *Public Health and Nutrition*, 14, 499–509.
- World Health Organization (WHO). (2000). *Obesity: Preventing and managing the global epidemic, . Report of a WHO consultation* (894, pp. 1–253). World Health Organization Technical Report Series, i–xii.
- World Health Organization (WHO). (2003). *Diet, nutrition and the prevention of chronic diseases, . Report of a joint WHO/FAO expert consultation* (919). WHO Technical Report Series 148 pp. Available from <http://www.who.int/dietphysicalactivity/publications/trs916/summary/en/print.html>.
- World Health Organization (WHO). (2010). *Global status report on non-communicable diseases*.
- World Health Organization (WHO). (2012). *Guideline: Sodium intake for adults and children*.

Further reading

- O'Sullivan, M. G., & Byrne, D. V. (2019). Traditional foods and beverages of Ireland. In K. Hadwiger, & S. Braun (Eds.), *Nutritional and health aspects of traditional and ethnic foods of Western Europe* (pp. 3–12). United Kingdom: Woodhead Publishing Ltd.

- O'Sullivan, M. G., & Kerry, J. P. (2011). Sensory quality of fresh and processed meats. In J. P. Kerry, & D. A. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh and processed meats* (pp. 585–598). Cambridge, UK: Woodhead Publishing Limited.
- Pennington, J. A. T. (1998). Dietary exposure models for nitrates and nitrites. *Food Control*, 9, 385–395.
- World Health Organization (WHO). (2013). *Mapping salt reduction initiatives in the WHO European Region* (pp. 1–64).

Nutritional optimization— reduced-sugar products and challenges

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Introduction

The World Health Organization (WHO) estimates that 80% of cardiovascular diseases (CVDs), 90% of type 2 diabetes (T2D), and 30% of all cancers could be prevented by a healthy diet (Mozaffarian & Clarke, 2009). About 35 million people die annually due to the noncommunicable chronic diseases (NCDs), obesity, CVDs, cancer, and diabetes, which accounts for 60% and 70% of death rates worldwide and in Europe, respectively. By targeting common risk factors such as unhealthy diet, physical inactivity, tobacco use, and alcohol consumption, 80% of T2D, coronary heart disease and stroke, and one-third of cancers can be avoided (EPHAC, 2010). Consumers have a basic understanding of nutrition in regards to sugar but what differentiates a healthy consumer from an unhealthy one is how they use their nutritional knowledge to make food choices (Yeon & Lee, 2016). “Reduced sugar” labels can be used to

describe products that contain at least 25% less sugar than the reference amount. However, consumers prefer the “no sugar added” claim to the “reduced sugar” claim, most likely because they assume that other ingredients are added in place of sugar in the latter (Patterson, Sadler, & Cooper, 2012).



Sugar

Honey was probably the first sweetener and source of sugars used by humans (O’Sullivan, 2017a), but sugars were more available to our ancestors in fruits and some vegetables. These energy-boosting sources of food were high in vitamins and minerals and consumed infrequently and thus not posing any negative health risks. However, the human body is evolved to recognize the fact that sugars are associated with energy and nutrients, producing a reward signal in our brains, which makes us happy. This embedded positive association with sugar has resulted in the development of some civilization diseases due to overconsumption and the ubiquitous availability and inclusion of refined sugars in the things we consume (Elding, 2013). Today, many plants have sugars in their tissues but only sugar cane, *Saccharum officinarum*, and sugar beet, *Beta vulgaris*, have been used to extract sugar in commercial quantities. Sugars vary in color from white to dark brown, increasing as the amount of molasses is retained during processing (Manley, 2011). Sucrose is included in foods not just to sweeten. It is an important preservative as it reduces the water activity of foods and beverages, making water unavailable for bacterial and fungal growth. In the age of reformulation, where sugar has been particularly targeted for removal from food and beverages, it must be remembered that when sugar is removed, it has to be replaced with another preservative, which is often less appealing to consumers (McCain, Kaliappan, & Drake, 2018). Sugar also has the additional roles in foods, such as, making foods more palatable, it acts as a bulking agent, increases viscosity, enhances flavor, adds texture and color, increases preservation, and inhibits protein coagulation (Davis, 1995; Silcock, 2017). Sugar binds moisture and increases the osmotic potential and prolongs the shelf life of baked goods. Liquid sugars can retain more moisture than brown sugar which in turn can hold more moisture than granulated white sugar. Also, the higher the sugar content the darker the crust in baked goods

(O'Sullivan, 2017a). As an ingredient, there are many varieties of sugars with different colors and crystal sizes which also confer different functionalities depending on how they are used. It is thus important to choose the appropriate sugar for the right formulation or baking application. In baked goods, different sugars and syrups play different roles such as improving texture crumb, grain, as well as providing a tenderizing effect. Fructose, invert sugar, and honey have the capacity to retain water and extend shelf life.

Sugar is not only a sweetener in baking but has a complex role by acting as a preservative and by adding volume, tenderness, texture, and color to the baked product. With the process of leavening, in bread making, the highly elastic gluten strands trap air in pockets contributing to the light texture of breads. During the mixing and kneading of the dough, gluten strands form as the flour proteins are hydrated, but above a certain level the gluten will begin to make the dough rigid and tough. Sugar also lightens cake batter and air pockets formed during creaming expand and lift the mix, causing it to rise during baking as well as binding moisture (Manley, 2011). Sugar plays an important role in this process by impeding gluten formation by competing with the gluten-forming proteins for water in the batter thus preventing full hydration of the proteins during mixing and preventing the dough becoming too tough (O'Sullivan, 2017a). This is particularly important for nonbread products such as cakes and muffins. Sucrose delays starch gelatinization and protein denaturation temperatures during cake baking so that the air bubbles can be properly expanded by the carbon dioxide and water vapor before the batter sets (Rosenthal, 1995). Sugar acts as a bulking agent for many foods and when it is replaced with an alternative bulking agent, this will also contribute calories to the product and thus defeating the purpose of removing the sugar in the first place (Cardoso & Bolini, 2008). Maltodextrin is a common sugar replacer and bulking agent and it contributes the same amount of calories as sugar (4 kcal/g) (McCain et al., 2018).

Sweetness in confectionary products is mainly due to the sugar content (Drewnowski, Nordensten, & Dwyer, 1998), but it also depends on the fat content and moisture. However, fat perception is more complex than sweetness. It depends on the fat content, the sugar content, texture, moisture, flavor, the nature of the food (liquid or solid), and mouthfeel (Abdallah, Chabert, Le Roux, & Louis-Sylvestre, 1998). The greater the degree of creaming, or the mixing and working of fat and sugar ingredients together, during batter formulation prior to baking is a critical step in

cake making. The friction of the sugar granules rubbing against the fat produces air bubbles in the fat which subsequently increase in size, causing the batter to rise due to the entrapment of leavening gasses and steam produced in the oven. Sucrose further affects textural properties by competing with gluten for available water during baking and therefore impeding the formation of a very strong gluten network making products that are softer in texture than other dry cereal-based products (Kweon, Slade, Levin, Martin, & Souza, 2009). The size of the sugar crystal will also affect the amount of air incorporated during creaming. Granulated sugar, because it is larger in crystal size, will incorporate more air into a batter than confectioner's sugar. Also, a confectioner's sugar also will dissolve quicker in the batter than granulated sugar because of a smaller particle size (O'Sullivan, 2017a). Also the size of the sucrose crystals, and therefore their rate of dissolution as the dough piece warms in the oven, affects the spread of short doughs as they bake and affect the appearance and crunchiness of baked biscuits (Manley, 2011).



Sweeteners and noncaloric artificial sweeteners

As will be seen in this book chapter the reduction of sucrose levels in a cake system will directly affect the structural and sensory properties of the final product (Frye & Setser, 1991). As a consequence of these complex structural, textural, and sensory functionality properties of sugar in baked products, obtaining good-quality low-sucrose products is also a difficult task. Sweetness can be balanced with high-intensity sweeteners while reducing calories, but the inherent functionality of sucrose is very difficult to simulate. Reformulation strategies with respect to sugar replacement in baked products need to consider the sweetening, the bulking effect, as well as many of the other critical functions in baked products. These include aeration, browning, crystallization, freezing point depression, glass formation, moisture retention, texturization, and whipping. Thus the replacement of sugar with other sources influences the baking regimes of these products. Therefore during reformulation, it is critical to assess the changes to the mixing and baking processes of the products (Martínez-Cervera, Sanz, Salvador, & Fiszman, 2012; O'Sullivan, 2017a).

There was an increase of more than 6000 products containing nonnutritive sweeteners (NNS) in the United States between 1999 and 2004

(Yang, 2010). Artificial sweeteners are not found in nature but are synthesized. Saccharin was the first artificial sweetener approved by the FDA in 1958 (Ajinomoto, Itasca, IL). The disadvantages of these sweeteners are that they are often artificial, which are not label friendly, and often carry metallic or bitter taste and aftertastes (Schiffman, Booth, Losee, Pecore, & Warwick, 1995). Alternative sweeteners are useful for reducing sugar, carbohydrate, and calorie content, but they have a different sweetness temporality compared with sucrose at a comparative sweetness intensity and may contain undesirable off-flavors such as bitter or metallic tastes (Kim & Kinghorn, 2002; Morais, Pinheiro, Nunes, & Bolini, 2014; Souza et al., 2013; Zorn, Alcaire, Vidal, Giménez, & Ares, 2014). NNS such as sucralose and stevia can also have metallic tastes and bitterness is another common problem with NNS, and food producers try to mask this by blending sweeteners (Pinheiro & Oliveira, 2005).

Noncaloric artificial sweeteners (NAS) such as sucralose, aspartame, or saccharin are sugar replacers that have found ubiquitous use in the food industry in the production of calorie-reduced food and beverage products (O'Sullivan, 2017a). Saccharin is 300–400 times sweeter than sugar but has fallen out of favor with product developers mainly due to negative publicity, banned for use in some jurisdictions, consumer confusion, as well as aftertaste issues (metallic). Also, saccharin is associated with the potential risk of cancer of the bladder when used heavily (Grenby, 1991; O'Sullivan, 2017a). Animal studies dating back many years to the 1970s linking the artificial sweetener saccharin to cancer and later studies with rats (2005) have been disproven but, nonetheless, the “unhealthy” perception of artificial sweeteners by the consumer has persisted (Kroger, Meister, & Kava, 2006). A recent US Mintel survey (Gardner et al., 2012; Pereira, 2012) found that 64% of respondents indicated that they were concerned about the safety of “artificial” sweeteners. The consumption of aspartame has been associated with migraines in human subjects (Newman & Lipton, 2001) and seizures in rats due to increased phenylalanine levels in the brain (Maher & Wurtman, 1987). Aspartame is usually limited to nonthermal applications due to its instability to elevated temperatures, high pH values, and high moisture contents (Bell & Hageman, 1994). Wetzel, Weese, and Bell (1997) investigated the sensory properties of sugar-free cakes sweetened with encapsulated aspartame and concluded that a consumer panel found no difference in acceptability between the freshly prepared no-sugar-added and full-sucrose cakes. Sucralose is synthesized from sucrose and as such is considered an artificial sweetener. It is

600 times sweeter, but without the calories. It is able to maintain sweetness, through a wide variety of food-processing conditions, pH, and over a long shelf life (Tate & Lyle, 2018). Martínez-Cervera et al. (2012) investigated the rheological, textural, and sensory properties of low-sucrose muffins reformulated with sucralose/polydextrose. They found that for a 50% sucrose replacement, the appearance, color, texture, flavor and sweetness, and general acceptability were similar to those of the control, but significantly less acceptable muffins were obtained with 100% sucrose replacement. Aggarwal, Sabikhi, and Sathish Kumar (2016) demonstrated that highly acceptable reduced-calorie biscuits can be produced by using dairy—multigrain composite flour with maltitol and fructooligosaccharides-sucralose (as sweetener) and polydextrose (as fat replacer).

NAS are currently consumed by approximately 28% of the American population and are very prevalent in beverages, ice cream, chewing gum, chocolate, jams/jellies, yogurt, and salad dressings (Antenucci & Hayes, 2014). Dietary alterations to the gut microbiome may benefit or harm individuals and potentially have long-term effects. Overconsumption of nonnutritive sugar substitutes may alter the microbiome (Daly et al., 2014). Feehley and Nagler (2014) suggest that artificial sweeteners induce glucose intolerance by altering the gut microbiota. Similarly, Suez et al. (2014) found that NAS consumption may contribute to, rather than alleviate, obesity-related metabolic conditions, by altering the composition and function of bacterial populations in the gut. These authors found that NAS consumption is correlated to elevated fasting blood-glucose levels and impaired glucose tolerance, which are disease markers linked to obesity (Suez et al., 2014). Therefore a clean label approach to sugar reduction is of significant interest to the food industry. Consumers often desire a more natural label and are willing to pay a premium for these foods as they are perceived as healthier (Parasidis, Hooker, & Simons, 2015). There is evidence that to a certain extent some consumers also reject the use of these NAS products and embrace a more “clean label” approach to reduced-calorie products. A recent US Mintel survey (Gardner et al., 2012; Pereira, 2012) found that 64% of respondents indicated that they were concerned about the safety of “artificial” sweeteners. Also, Richardson, O’Sullivan, and Kerry (2020), in a survey undertaken in Ireland from 1300 respondents on sugar and NAS sugar replacers in food and beverages, reported that 57% were wary of the latter NAS. Only 4% of participants said that they would drink sugary drinks on a daily basis and 52% of them said that they would not buy sugar-reduced and

NAS-containing sugar-free drinks. In addition, 92% of the people surveyed said that there is a greater need for information on the impact of a high sugar and fat diet in general.

Thus there are two principal approaches that can be taken with an NAS-avoidance strategy for the development of calorie-reduced foods. The first is the investigation of sugar reduction via alternate sugar sources (NAS) and sensory acceptance testing combined with ranking descriptive analysis incorporating sequential sugar reduction. The reduction of sugar in sweet baked products such as cake, muffins, and cookies is currently being studied in the SWEETLOW project funded by the Irish Department of Agriculture, Food and the Marine (SWEETLOW, 2016). This project funded as part of the food industry research measure is investigating sequential sugar reduction without replacement and also the use of alternative sugar sources, such as polyols, steviosides, polydextrose, and inulin/prebiotics and dietary fibers such as arabinoxylan oligosaccharides in sugar-reduction strategies. The application of emulsifiers and bulking agents is also being studied, in an effort to reduce the variance of the products being formulated (O'Sullivan, 2017a).

Numerous sweet and low-calorie compounds are available in nature; some of them are used commercially, for example, xylitol and stevioside (Nabors & Gelardi, 1986). The production of calorie-reduced products and NAS-avoidance strategies is (Suez et al., 2014) one route researchers are following to develop sensory-optimized reduced-sugar confectionary products. Such natural NNS are derived from plants and comprise natural compounds, typically sweet glycosides (Kim & Kinghorn, 2002). *Siraitia grosvenorii* (monk fruit) is a fruit native to southern China that contains sweet glycosides mogroside IV, mogroside V, and mogroside VI (Kinghorn & Compadre, 2001; Pawar et al., 2013). Inulin and isomalt substitution of sugar and fat in frozen yogurt has been reported to produce a similar sweetness and a reduction in fat with no added sugar in developed products (Isik, Boyacioglu, Capanoglu, & Nilufer Erdil, 2011). Stevia, another natural sweetener, is composed of sweet glycosides stevioside and rebaudioside A (Kinghorn & Compadre, 2001). Stevia is a commonly used sweetener used to partially or completely substitute for sugar in a range of products, particularly, in the sweetened beverage and bakery sectors. Stevia has delayed onset of sweetness with a long, persistent sweet and bitter aftertaste (DuBois & Prakash, 2012) with a metallic sensation (Pinheiro & Oliveira, 2005). Polydextrose, a glucose polymer, is widely recognized for its versatility as a bulking agent and texture enhancer and

provides only 1 kcal/g. It is commonly utilized with NNS such as sucralose and stevia. Stevia and inulin have found widespread applications as sweeteners, but the long-term effects are not fully understood and overconsumption may affect the microbiome as described by [Suez et al. \(2014\)](#) for NAS. Further studies must be undertaken to establish long-term effects.

The inclination for combination of nonnutritive sugar substitutes with sugar alcohols to produce a low-calorie bakery product has increased, with artificial sweeteners such as aspartame and sucralose providing sweetness and sugar alcohols providing the bulking properties ([Richardson et al., 2018](#)). Polyols are bulk sweeteners that can assist in retaining moisture in food and are utilized with the same concentrations as sucrose providing bulk and sweetness but contain less calories (2.4 kcal/g) ([Mariotti & Lucisano, 2014](#)). Polyols are sweet but have a lower intensity than sucrose and can have a cooling effect with good thickening and stabilizing properties. The main polyols include sorbitol, mannitol, maltitol, isomalt, xylitol, and erythritol. Polyols must be used with caution as they have laxative effects at high concentrations. Therefore using them as ingredients greater than 10% must carry a warning on the label ([Livesey, 2003](#)).

[Milner, Kerry, O'Sullivan, and Gallagher \(2020\)](#) examined the use of clean label, novel sweetening ingredients (apple pomace, whey permeate, oligofructose, and polydextrose) as possible sugar replacers. They observed that crumb cell structure was maintained: there was no significant difference observed between the control formulation and the reduced sugar cakes as shown by 2D and confocal imaging. Sensory trials revealed that the reformulated cakes were acceptable to panelists ([Milner et al., 2020](#)).

[Richardson et al. \(2018\)](#) investigated sugar reduction via sugar particle size manipulation. Chocolate brownies prepared with the smallest sugar particle size (459–972 μm) were the softest and moistest of all samples as supported by sensory, instrumental, and compositional analyses. This is an important finding as sugar within this size range could be employed to retain moisture and softness in low-sugar/low-fat confectionery-type products. Chocolate brownies formulated with the smallest sugar particles were perceived as the sweetest samples. Based on these findings, sugar particle size reduction would permit sugar reduction as sweetness perception is increased in samples with smaller sugar particles ([Richardson et al., 2018](#)) (Figs. 2.1 and 2.2).

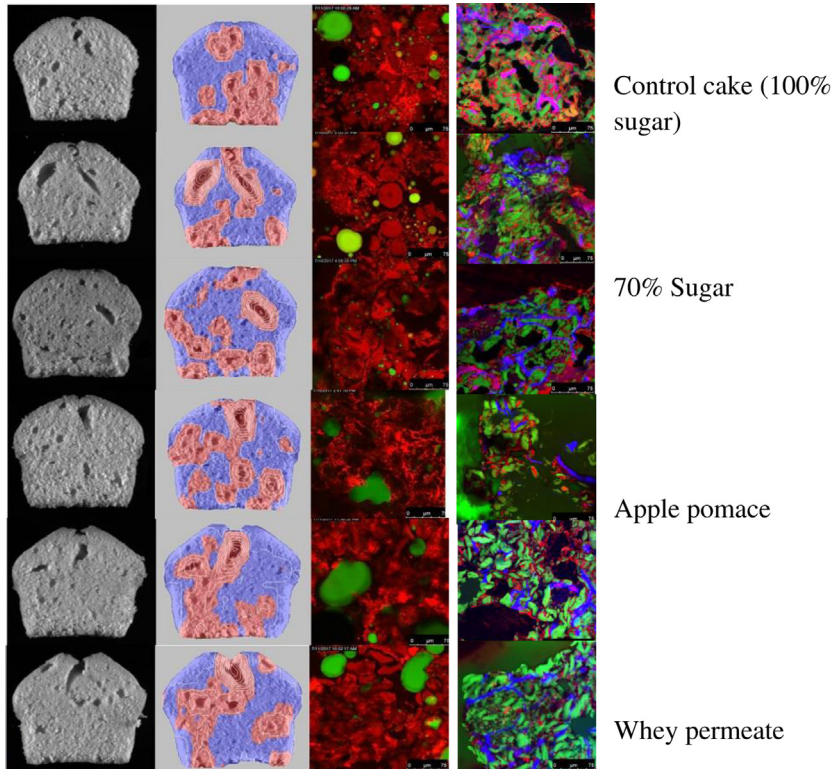


Figure 2.1 Milner et al. (2020) examined the use of clean label, novel sweetening ingredients (apple pomace, whey permeate, oligofructose, and polydextrose) as possible sugar replacers. Confocal microscopy was used to study the internal microstructure of the cakes. Images were recorded using a Leica SP5 confocal scanning laser microscope. The images were read at three different wavelengths (405, 488, and 633 nm), with three types of lasers (argon, blue diode, and helium neon). Samples of crumb microstructure are presented.



Dietary fiber

Dietary fibers are indigestible carbohydrates that are important for human gut health. They provide bulk to stools and thus speed transition of waste through the gastrointestinal tract and reduce the transition times of toxins. Dietary fiber can reduce the risk of CVDs (heart disease and stroke), T2D, and colorectal cancer. It is recommended to consume 25–30 g of fiber per day and thus the incorporation of fiber in regularly

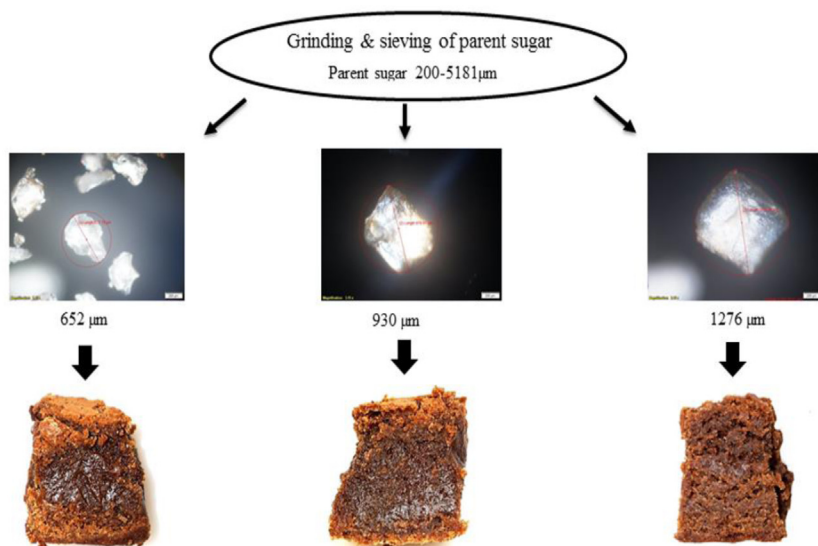


Figure 2.2 Richardson et al. (2018) investigated sugar reduction via sugar particle size manipulation. Chocolate brownies prepared with the smallest sugar particle size (459–972 μm) were the softest and moistest of all samples as supported by sensory, instrumental, and compositional analyses.

consumed foods, such as baked goods, is a strategy to increase fiber consumption (Figuerola, Hurtado, EsteveZ, Chiffelle, & Asenjo, 2005).

Dietary fiber is classified as either soluble or insoluble (Kale et al., 2011; Rodriguez et al., 2006) and is most suitable as a food ingredient in the ratio of 1:2 soluble/insoluble (Figuerola et al., 2005). Dietary fiber as well as being important for human nutrition has bulking properties and can be used as a functional ingredient in baking to mimic the thickening and bulking properties of sucrose and thus assist in replacement strategies. Dietary fiber can increase viscosity, form gels, have high water-holding capacity (Elleuch et al., 2011). Sources of dietary fiber can be cereal based which contain more insoluble fiber (cellulose, hemicellulose) or fruit based which contain more soluble fiber (pectin, gums). Sudha et al. (2007a) increased the fiber content of a biscuit formulation by replacing wheat flour with a number of different cereal brands. Sensory panelists ranked biscuits containing oat bran similar to the control in regards to color, texture, taste, and mouthfeel at low concentrations (10% and 20%). Singh et al. (2012) used corn bran to replace wheat flour in cake up to 30% (w/w) and reported no significant

differences between the control and the high-fiber cakes as determined by the sensory panel.

Fruit fibers are by-products from the juice-processing industry and thus are cheap and readily available. They are reported to confer a pleasant, sometimes fruity flavor in novel bakery formations (Rupasinghe et al., 2008). Fruit fibers also contain higher levels of total and soluble fiber than cereal-based fiber and thus can bind more water and oil while also having a lower calorific value without significantly altering moisture, fat, and ash (Figuerola et al., 2005; Rupasinghe et al., 2008).

Apple pomace is a waste product (30%) from apple juice pressing. Sudha et al. (2007b) incorporated finely ground apple pomace into cake in a study to boost the fiber levels of cake by 10%, 20%, and 30%, respectively. The cakes containing 20% apple pomace were scored as highly acceptable and had similar fat, protein, and moisture content to the control, but the total fiber content was significantly enhanced. Rupasinghe et al. (2008) found that the overall acceptability of the muffins containing dried apple skin pomace (ASP) at the concentrations of 8%, 16%, and 24% (w/w) was not significantly different from the control and that perceived sweetness increased with ASP incorporation.

Citrus fruits are a source of dietary fibers, with a high proportion of soluble fiber and by-products can be obtained from the processing of oranges, lemons, grapefruits, and mandarins. Nassar et al. (2008) found that there was no significant difference between the control formulation and biscuits containing 5% and 10% orange peel or pulp as ranked by the sensory panelists with regards to color, texture, flavor, and overall acceptability. Larrea et al. (2005) investigated adding extruded orange pulp (to increase the fiber content) and to replace wheat flour in cookies (5%, 15%, and 25% w/w replacement). There were no significant differences between the control and the biscuits containing 5% and 15% orange pulp in attributes as determined by a sensory panel.



Sensory properties of biscuits, cookies, cakes, and muffins

Biscuits have a long history. The word “biscuit” comes from the Latin “panis biscoctus” or twice-cooked bread and refers to bread rusks that were made from flour and water for mariners (ships biscuits) during

the Middle Ages. These were made by baking in an oven followed by further drying in a cooler oven to produce a low moisture very long shelf life product that could sustain sailors on long sea voyages (Manley, 2011).

Sugar and fat are two major ingredients in biscuits. They have crucial structural and textural properties during biscuit-dough preparation and baking, providing a typical shape and texture to the final product (Pareyt & Delcour, 2008). Biscuits can be classified according to their dough characteristics, soft, hard, or fermented. There are usually higher levels of fat and sugar in softer doughs which produce sweeter biscuits compared to harder doughs. Above a certain level, sugar softens dough by competing with sugar for free water. It also acts as a hardening agent by crystallizing as the biscuit cools, thus making the product crisp. Salt biscuits on the other hand use a fermented or hard dough with a low concentration of fat and sugar to create a cracker or puffed biscuit (Misra & Timwari, 2014). Biscuit doughs are generally a lot tougher than bread doughs because of a much lower water content that not only inhibits gluten action but also reduces the amount of water that needs to be cooked out during baking and for this reason they have a much harder and dryer finished texture. A variety of shapes and textures may be produced by varying the proportions of these ingredients (Maache-Rezzoug, Bouvier, Allaf, & Patras, 1998). Biscuits are typically baked on trays due to these tougher and dryer doughs, compared to cakes and breads, which require tins, because of their softer doughs. The fat-type content of biscuits is important for providing flavor, texture, and eating quality.

Sucrose in confectionary products promotes fat-crystal aggregates, which enhances air entrapment within the batter, leading to a greater stabilization of air bubbles during baking (O'Sullivan, 2017a). Sucrose not only sweetens but also contributes to color formation in both the crumb and crust of bakery products through Maillard browning and caramelization. Although sucrose is a nonreducing sugar, when it is heated, it is converted to fructose and glucose, both of which are reducing sugars and thus can participate in the Maillard reaction. Maillard browning is a chemical reaction that occurs between an amino acid and a reducing sugar that requires the addition of heat (Damodaran, Kirk, & Fennema, 2008; Varzakas, 2012). Maillard browning is responsible for the color and flavors in caramel, the browning of bread, cookies, and many other foods (Harrison & Dake, 2005). Also, the presence of sucrose is important for the overall structure of a biscuit or cookie as moderate amounts of sucrose act as a softening agent in cookies, due to the ability of sucrose to retain

water (Mariotti & Alamprese, 2012). Sucrose inhibits gluten development during dough mixing by competing with the flour for the available water in the formulation. Sucrose shifts the starch gelatinization point to a higher temperature thus allowing the dough more time to rise in the oven (Manley, 2011). As sugar is present in such significant quantities in biscuits and cookies, altering the level used will greatly affect dough consistency, rheology, baking regimes employed, and final product characteristics.

Pastry products are made from short doughs similar to biscuits. Puff pastry is made by encasing multiple laminated layers of fat and dough to produce a flaky texture on baking. Another major difference between breads and confectionary baked goods such as cakes, muffins, pastry, and biscuits is their very different sensory properties. The latter are sweet, high-calorie-baked products where sucrose not only contributes to the sweet taste but also acts as a bulking agent in the batter, aids in moisture retention and air entrapment, and creates a fine crumb grain in the products.

Sugar reduction in bakery products

Sugar is responsible for the sweetness in cakes and muffins and sucrose is the most commonly used sugar in cake making (Bennion & Bamford, 1973). Cake is a product that incorporates sugar as one of the primary ingredients and assists in incorporation of air cells while creaming, provides good grain structure, flavor, and texture to the product, aids in retention of moisture, prolongs freshness, and promotes good crust color (Nip, 2007). Due to the previously discussed complex functional properties of sucrose, obtaining sensory-optimized low-sucrose products is a difficult task. Also as discussed in Chapter 1, Understanding the requirement to reformulate: science, health, consumer demand, regulation, and capability, sugar reduction/replacement is very topical worldwide and with implementation of the sugar tax in Ireland/the United Kingdom, companies are shifting more and more toward sugar replacement/reduction strategies (Richardson et al., 2018).

In confectionary foods, sugar is responsible for sweetness, while fat contributes to the texture, mouthfeel, flavor, and aroma of food (Drewnowski & Almiron-Roig, 2010). Sugar also acts as a bulking agent, assists products in staying moist, reduces the swelling of starch to produce a finer texture end product, and contributes to the browning of the crust. The fat in cake batter not only helps the incorporation of air, but it also

produces emulsifying properties and holds considerable amounts of liquid to increase and extend cake softness and “shortens,” that is, it interrupts the protein particles to break gluten continuity to tenderize the crumbs (Bennion & Bamford, 1973). Fat contributes to the appearance and lubricity of baked goods and increases the feeling of satiety. For products such as muffins and cakes, these products are fat in water emulsions, where bubbles form the discontinuous phase, and the egg, sugar, fat, and water mixture forms the continuous phase, where the flour is also dispersed (Barcenilla, Román, Martínez, Martínez, & Gómez, 2016). Minute air bubbles are trapped in the cake batter by the surface-active proteins in the egg, fat, a suitable emulsifier, or a combination of all three to form an emulsified foam that forms a sponge on baking (Cauvain, 2011). Muffins, similarly to cakes, are characterized by a typical porous structure and high volume which confer a spongy texture. Sugar assists in incorporation of air cells in cakes and muffins while creaming and provides good grain structure, flavor, and texture to the product. To obtain such a final structure, a stable batter retaining many tiny air bubbles is required (Martínez-Cervera et al., 2012).



Sugar-reduction in dairy products

High sugar levels present a greater risk of obesity and T2D. The prevalence of obesity is increasing around the world and it is a significant public health problem in many countries (International Obesity Task Force, 2002). Overconsumption of fat and sugar is associated with many diseases, such as obesity, high blood cholesterol, and coronary heart diseases (Melanson, Astrup, & Donahoo, 2009; WHO, 2003). Sugar contributes to the energy density of foods and contains no essential nutrients (i.e., “empty calories”) and increases the risk of weight gain (World Cancer Research Fund, 2007). Sugar is not causally related to CVD or cancer; however, high sugar consumption is increasingly linked to obesity and T2D. Most international recommendations suggest that sugar should not exceed more than 10% of total energy intake (EPHAC, 2010). Several diseases are associated with a high level of sugar consumption, including obesity, insulin resistance, and diabetes mellitus type 2, as well as caries and fatty liver. Therefore low-sugar intake is strongly recommended (FAO/WHO, 2003). This recommendation is not only addressed

to the consumer but also requires the food industry to reduce sugar content in processed food (Barclay et al., 2008).

The targeting of sugar-sweetened beverages (SSBs) has been often regarded as a key action to cope with the obesity (Malik, Pan, Willett, & Hu, 2013); however, the importance of other product categories has been usually underestimated and sweetened dairy products deserve special attention (Yoo et al., 2017). In Europe, high intakes of sugar are observed more in children than adults in dairy products and beverages (Azaïs-Braesco, Sluik, Mailliot, Kok, & Moreno, 2017). A reduction in sugar is easier to perceive than a reduction in fat or salt content, making formulation of reduced-sugar dairy products a challenge (Biguzzi, Schlich, & Lange, 2014). Also, the health benefits of a dairy product cannot outweigh its sensory properties, and its acceptance depends on the degree of satisfaction given to the consumers (Bayarri, Carbonell, Barrios, & Costell, 2011). Dairy products are generally seen as a good source of essential nutrients vitamin A and calcium, but together with red meat they are the primary dietary source of saturated fat. There is evidence that suggests milk probably protects against some cancers, whereas cheese and diets high in calcium have been shown to increase risk of disease. Dairy products high in saturated fat are furthermore convincingly linked to NCDs (World Cancer Research Fund, 2007).

Lactose accounts for about 30% of the caloric value of whole milk but provides little sweetness. Thus enzymatic lactose hydrolysis is a method for sugar reduction in dairy foods (Fox & McSweeney, 2003; McCain et al., 2018). Lactose hydrolysis has also been used to reduce sugar content in ice cream either by hydrolyzing the mix or by using lactose-free skim milk powders (Abbasi & Saeedabadian, 2015).

Consumer demands for healthier products are driving a significant push for sugar reduction in dairy foods. Replacing sugar can have negative effects, making substitution inherently difficult (McCain et al., 2018). Food and dairy companies should offer consumers' healthy alternatives that could help reduce sugar consumption (Küster & Vila, 2017). Sweetened protein beverages with low carbohydrate content are an important category to consumers (Gerdes, 2012; Jacobson, 2015; Oltman, Lopetcharat, Bastian, & Drake, 2015). Direct sugar removal may negatively affect consumer liking as sweet taste is also a desirable attribute. A threshold for direct sugar removal between 25% and 40% has been demonstrated for various dairy products without negatively affecting consumer acceptance (Cadena, Cruz, Faria, & Bolini, 2012; Chollet, Gille, Schmid,

Walther, & Piccinali, 2013; Hoppert et al., 2013; Li, Lopetcharat, & Drake, 2015; Oliveira et al., 2015). However, below this threshold, NAS sweeteners can be used to replace sugar and maintain sweet taste (Parker, Lopetcharat, & Drake, 2018) and have been extensively discussed in the section on sweeteners.

A potential strategy is to gradually reduce sugar consumption to reduce the concentration of added sugar added to processed products (MacGregor & Hashem, 2014). This is a strategy used for salt reduction in processed foods in the UK Food Standards Agency (FSA) and in Ireland for reduction of salt in processed meats [Food Safety Authority of Ireland (FSAI), salt-reduction program]. Oliveira et al. (2016) explored the provision of recommendations for gradual sugar reduction in chocolate-flavored milk. They undertook consumer studies to determine difference thresholds for added sugar and evaluated consumer sensory and hedonic perception of reduced-sugar products. These authors found that sugar reduction (6.7%) in chocolate-flavored milk can be achieved without affecting consumers' perception and was easy to implement (Oliveira et al., 2016).

Parker et al. (2018) found that naturally sweetened protein beverages (sugar free or reduced sugar) must taste comparable with artificially sweetened or sucrose-sweetened products. Consumers will not compromise on sensory and hedonic quality of products even if products are healthier (Civille & Oftedal, 2012). Parker et al. (2018) investigated sucralose, sucrose, fructose, stevia, monk fruit as natural sugar replacers in ready to mix protein beverages. A label-conscious segment of consumers preferred beverages sweetened with natural blends when primed. A flavor-driven segment of consumers conceptually preferred naturally sweetened beverages but preferred sucralose-sweetened beverages when primed. The "all natural" label claim was most preferred across all consumers (Parker et al., 2018).

Sweetness can be increased by adding caramel, vanilla, or fruity aromas to products (Labbe & Martin, 2009; Labbe, Rytz, Morgenegg, Ali, & Martin, 2007). Thus the addition of aroma compounds can be an alternative to increase sweetness perception while reducing sugar concentration (Oliveira et al., 2016). Alcaire, Antúñez, Vidal, Giménez, and Ares (2017) investigated cross-modal aroma–taste interactions (added vanilla) and bulking agents (starch) for reducing the added sugar content of vanilla milk desserts. They found that, from a sensory perspective, they were able to totally and/or partially reduce sugar in formulations without using NNS (Alcaire et al., 2017).

Texture and fat in the food matrix play an important role in sugar-reduction studies because both highly influence sweet taste perception (McCain et al., 2018). Fat plays a critical role in the perception of sweet taste and, in emulsions with higher fat content sweetness is reduced (Bayarri, Taylor, & Hort, 2006; Zahn, Hoppert, Ullrich, & Rohm, 2013). Thicker dairy products such as chocolate milk texture actually prolong flavor perception during oral processing. Flavored milk has a pleasurable taste and provides essential nutrients equivalent to that of plain milk (Murphy, Douglass, Johnson, & Spence, 2008) and is popular among children and adults (Kim et al., 2013). Nonnutritive sweeteners are not really an option for flavored milks as they are artificial, are not label friendly, and often carry metallic or bitter taste and aftertastes (Schiffman et al., 1995). If an acceptable sweetness of chocolate milk could be achieved by hydrolyzing added lactose or a high-lactose dairy ingredient such as whey permeate, it would provide an alternative way of sweetening chocolate milk (Li et al., 2015). Li et al. (2015) investigated sugar reduction of skim chocolate milk through lactose hydrolysis. Lactose hydrolysis of added lactose was used to achieve the sweetness of sucrose in chocolate milk but required >7.5% (wt./vol.) added lactose. To a certain extent, this defeated the purpose as this contributed to undesirable calories, indicating that lactose hydrolysis may be more suitable for other dairy beverages that require less added sugar. As chocolate milks with higher fat content require higher sugar contents for sweet perception, regular consumers will be highly sensitive to a reduction in sugar (McCain et al., 2018). This is also true for ice cream, yogurt, or any dairy product, suggesting that sugar reduction in higher fat foods may be more challenging (McCain et al., 2018). Choi, Kim, and Chung (2013) determined that tagatose (5.9%), sucralose (0.009%), xylose (8%), and erythritol (8.3%) could be used to elicit the same sweetness strength when applied in banana-flavored nonfat and full-fat milk.

Yogurt is perceived as a healthy food because of the presence of live and active cultures. Also sugar is not only essential for the sweet taste of yogurt products, but it also contributes to the total solids of the product and provides texture, body, viscosity, and moisture retention (Popa & Ustunol, 2011). There is a demand for sugar reduction in yoghurt but the positive image should not be harmed by the use of artificial ingredients such as sweeteners (Chollet et al., 2013). NNS as a means of sugar reduction in yogurt were investigated by Pinheiro and Oliveira (2005). These authors reported that it was possible to produce a probiotic yogurt

successfully using sweeteners (sucrose, aspartame, aspartame + saccharin, and sucralose) without affecting the viability of the probiotic microorganisms (Pinheiro & Oliveira, 2005).

The addition of flavor compounds (strawberry aroma, vanilla aroma, benzaldehyde, and furaneol) in sweet model systems was found to enhance consumers' perception of sweetness (Labbe, Damevin, Vaccher, Morgenegg, & Martin, 2010; Tournier, Sulmont-Rossé, & Guichard, 2007). Chollet et al. (2013) investigated the influence of flavorings on hedonic and sweetness perception in consumer panels for strawberry-flavored (consumers = 192) and coffee-flavored (consumers = 197) reduced-sugar yoghurts. They found that consumers would accept flavored yogurts with 7% added sugar instead of 10%, but 5% sugar would be too low (Chollet et al., 2013).

Thaumatococcus is a nontoxic mixture of proteins from the fruit of the African shrub *Thaumatococcus daniellii* Benth, which has sweet taste and can be used as taste enhancer (Crammer, 2008; Glória, 2003; Hagiwara et al., 2005; Yebra-Biurrun, 2005). Oliveira et al. (2015) investigated vanilla flavor and thaumatococcus to attenuate the sensory changes caused by sugar reduction in probiotic chocolate-flavored milk. These authors found that a reduction in added sugar of 20% led to changes in sweetness intensity, which were perceived by both trained assessors and consumers with the latter also not diminishing in hedonic response by sugar reductions up to 40%. However, vanilla did not significantly increase sweetness perception in this product. It must be noted that thaumatococcus is not often used in soft drinks, even if approved, because it easily interacts with other beverage components, such as some coloring agents, losing its sweetening power (NPCS Board of Consultants & Engineers, 2008).



Sugar-reduction in beverages

Sensory properties of soft drinks and fruit juices

Fruit juices are made by pressing ripe fruit and collecting the juice. Juices can be sold clear as is the case for apple juice or cloudy like orange or grapefruit juices which contain fruit pulp (juice vesicles). Fruit juices can be sold either fresh or refrigerated, where they will have a shelf life of a few days. From a sensory perspective, any departure from the fresh juice

product will result in a partial loss of both nutritional and sensory quality due to thermal destruction of flavor components (O'Sullivan, 2017b). However, thermal processing remains the most widely employed method for shelf life extension and food preservation and concentration (Bhattacharjee, Saxena, & Dutta, 2017). Growth of yeasts can produce cloudiness and off-flavors and off-colors in fruit juices as well as CO₂ which can rupture containers. Typically, fruit juices are pasteurized, again refrigerated, where they are processed with either a short flash pasteurization heat treatment (85°C–90°C for 15–20 seconds) or an in-pack pasteurization process (70°C for 20 minutes) and can last for several weeks (O'Sullivan, 2017b). Pasteurization will rid juice of pathogens and other heat-sensitive microbes (bacteria, yeasts, and molds) and will reduce the microbial load substantially and extend the shelf life of the product (Tournas, Heeres, & Burgess, 2006). Pasteurization is used for products that have a pH value of 4.5 or less, where the acidic conditions effectively reduce the risk of growth of pathogenic organisms (Ashurst, 2011). Fruit juices can also be produced from concentrate that involves aseptically filled cartons of reconstituted juice which will have an ambient shelf life of around 1 year. The concentrate is generally produced through evaporation under heat and vacuum or through freeze concentration (Ashurst, 2011). However, the former process increases the risk of flavor degradation due to the thermal destruction of flavor compounds. Juice products packaged in clear containers can undergo bleaching or fading due to the action of sunlight and excessive thermal treatments can produce browning and cooked or off-flavors and losses of flavor volatiles which can diminish overall flavor quality (O'Sullivan, 2017b).

Membrane technology is a potential alternative to traditional thermal techniques for fruit-juice clarification and concentration as it requires less manpower and has greater efficiency and shorter processing times compared to conventional filtration (Bhattacharjee et al., 2017).

Fruit juices are important candidates for reformulation due to the negative contribution they make to diets of many young people. As fruit juices are obviously made from fruit, many consumers assume that they must also be healthy by containing important vitamins, in particular, and minerals. Proponents of juice argue that it helps children achieve fruit-intake recommendations and warn that limiting it will reduce vitamin C, folate, and potassium intake (Byrd Bredbenner et al., 2017). However, most nutrition researchers agree that whole fruit is nutritionally superior to juice because it contains more fiber and is less energy dense

(Herrick, Rossen, Nielsen, Branum, & Ogden, 2015; Heyman & Abrams, 2017). Fruit-juice products often contain high sugar and calorie levels and combined with high consumption frequencies; these facts negate any potential health benefits by a huge margin. Boehm, Read, and Schwartz (2018) have recently found evidence, in the United States, that fruit juice displaces milk and fruit in the school meal. In addition, such fruit-juice products contribute to the increased incidents of dental caries, again, particularly in younger consumers (Lim et al., 2008).

SSBs are generally described as nonalcoholic water-based beverages with added sugar and may include cordials, fruit drinks, flavored milks, sports drinks, energy drinks, vitamin waters, sweetened ice tea, as well as nondiet soft drinks (Blake, Lancsar, Peeters, & Backholer, 2018). Soft drinks are produced by diluting liquid pasteurized (85°C for 5 minutes) sugar syrup with potable water with the addition of preservatives, colors, and flavorings. They may be flavored with fruit juices, pulps, vegetable extracts, or flavors such as natural or artificial vanilla. The pH (2.5–4.0) is reduced, with generally citric or phosphoric acid and carbonated (1.5–4 vol.), both of which have an antimicrobial effects (O’Sullivan, 2017b). The standard carbohydrate used to sweeten soft drinks is sucrose, available as either granulated solid or as a concentrated syrup. Invert sugar (hydrolysis of sucrose to glucose and fructose) is rarely used in soft drinks. High-fructose glucose syrup is widely used in the United States, less so in Europe (Ashurst, 2016). Lower calorie variants may be produced by complete replacement of sugar with artificial sweeteners such as sucralose, aspartame, acesulfame K, or saccharin and for reduced-calorie drinks by the use of sucrose alternatives such as stevia (O’Sullivan, 2017b).

Saccharin is seldom used today to sweeten SSBs due to bitter after-tastes. Acesulfame K exhibits significant bitter and metallic off taste but is used in blends with aspartame and sucralose (Ashurst, 2016). Sucralose, the most popular sweetener of choice in the United States, is used in 73% of flavored sparkling waters (Tate & Lyle, 2018). Of the high potency naturally derived sweeteners stevia is also relatively widely used and permitted in flavored drinks at a level of up to 80 mg/L (Ashurst, 2016). Both sucralose and stevia can have metallic and bitter tastes and blending sweeteners is sometimes used to mask these tastes (Pinheiro & Oliveira, 2005). NAS have been used extensively to replace sugar in SSBs and have been discussed with respect to pros and cons in the section on sweeteners.

Soft drinks are of particular concern regarding sugar reduction and mainly contain water (~90%) and sweetener (~10%) added with small

amounts of coloring, flavoring, acidulants, carbon dioxide, and preservatives. Carbohydrate sweeteners (CHO) generally provide the natural sweetness of fruit juices and soft drinks. Again the standard carbohydrate used in soft drink is sucrose, available as either granulated solid or as a concentrated syrup (Miele et al., 2017).

SSBs, bread and cereals, confectionary, dairy products, and fruit products have been identified as the main sources of sugar intake among children and adolescents (Louie, Moshtaghian, Rangan, Flood, & Gill, 2016). SSBs, including soda, fruit-flavored drinks, and sport drinks, are one of the main sources of sugars in children's diets (Malik et al., 2013). Sugar contributes around 25% of the 2000 calories recommended in the daily western diet, which is far beyond the <10% daily sugar intake recommended by the WHO (Lustig, Schmidt, & Brindis, 2012). More worryingly, sugar-laden drinks account for 11% (224 kcal/day) (Wang, Bleich, & Gortmaker, 2008) and 9% (203 kcal/day) (Bleich, Wang, Wang, & Gortmaker, 2009) of the daily energy intake of young people and adults, respectively, making them the biggest sugar contributor to diet (Guthrie & Morton, 2000). Obesity is determined by the interaction of complex genetic, environmental, cultural socioeconomic, and behavioral factors; however, increased energy intake has been identified as a key contributor to the global growth in obesity (Prentice & Jebb, 2004; Swinburn et al., 2011). SSBs, such as flavored milk, soda, sport drinks, and sweetened tea, are the highest contributors to added sugar in American diets; in 2009, 13.8 billion gallons of SSBs were consumed (Wang, Coxson, Shen, Goldman, & Bibbins-Domingo, 2012). Excessive sugar consumption has been identified as the major cause of excessive caloric intake and the main dietary determinant of obesity among children and adolescents (Ambrosini, Johns, Northstone, Emmett, & Jebb, 2016; Te Morenga, Mallard, & Mann, 2012). Humans have built in preference for sweet taste, which has motivated the food industry to add sugar to processed products to increase the pleasure of eating and consequently their product sales (Yebra-Biurrun, 2005). In addition, consumers who consume more SSBs have a higher affinity for sweet taste, which further encourages companies to add more sugar into products until it reaches the consumers' "bliss point." This is the point at which the level of sugar sends consumers "over the moon" for the product, addicting them to the product and causing them to overeat (Mahar & Duizer, 2007; Moss, 2013). Studies with infants have shown that the sweeter a beverage is the more babies will consume it (Ganchrow, Steiner, & Daher, 1983; Yebra-Biurrun,

2005). Obesity accounts for over 1 million deaths (10%–13% of deaths) and 12 million ill-health life years each year in the WHO European Region (James et al., 2004). Approximately 22% of children aged 5–9 years are overweight (6% are obese) and 16% of children aged 13–17 years are overweight (4% obese) in Europe (EPHAC, 2010). Thus many parents desire reduced-sugar products for their children, and current studies emphasize the importance of developing healthy eating habits at a young age (Byrd-Bredbenner et al., 2016; Chan, Prendergast, Grønhoj, & Bech-Larsen, 2011).

Beverage producers have been exploring the use of alternative sources of sweetness with negligible calories (Tiban, Piližota, Šubarić, Miličević, & Kopjar, 2003). However, the delivery of sugar-like sweetness with partial or full sugar reduction is a challenging task as high-potency sweeteners typically display an unusual sensory characteristic (Moraes & Bolini, 2010). The drive to reformulate has been given much recent emphasis in Ireland and the United Kingdom due to the introduction of a coordinated sugar tax in both the countries. For both taxes, products containing between 5 and 8 g/100 mL sugar were levied at 20c/L in Ireland and 18p/L in the United Kingdom. For beverages over 8 g/100 mL the levies were 30c/L in Ireland and 24p/L in the United Kingdom. The sugar tax has driven UK companies (e.g., A.G. Barr and supermarket chain Tesco) to reformulate (Lancet, 2017).

There are two main strategies for sugar reduction without substitution: abrupt sugar reduction, which consists of reducing sugar in a single step, and gradual sugar reduction, which consists of consecutive small reductions (Lima, Ares, & Deliza, 2019).

Maintaining optimal hedonic flavor and texture of food and beverage products constitute a considerable challenge with respect to reformulation strategies (van Raaij, Hendriksen, & Verhagen, 2009). Sugar-containing beverages generally have a better mouthfeel compared to diet varieties because of the present sugar. Consumers frequently describe diet or sugar-free beverages as “thin” or “watery” and for many, these sensations are perceived as negative (Miele et al., 2017).

Again, a potential strategy for calorie reduction in SSBs is to gradually reduce added sugar stealthily over time (MacGregor & Hashem, 2014). The stealthy approach might be more effective than the abrupt sugar reduction, as consumers do not notice changes in the sensory characteristics of the products and slowly adapt to the lower sugar concentration. Reductions lower than the difference threshold for added sugar have been

recommended as they assure that the great majority of the consumers would not notice the change (MacGregor & Hashem, 2014). Sugar reduction by stealth would require several reduction steps to achieve the sugar-reduction target, which may not be practical and would take a long time (Lima et al., 2019). However, these strategies have proven very successful for salt reduction in processed foods in the United Kingdom (FSA) and in Ireland for reduction of salt in processed meats (FSAI, salt-reduction program). Oliveira et al. (2018) explored the provision of recommendations for gradual sugar reduction in nectars. No significant differences in overall liking were detected for fruit nectars with 20% sugar reduction. However, large heterogeneity in consumer hedonic reaction toward sugar reduction was found.

Such government incentives are further driving the industry to reformulate and if they are to succeed, this must be undertaken in a consumer-driven fashion while maintaining safety, shelf life, and commercial viability. Sensory, consumer-driven methodologies, for salt, fat, and sugar reduction in associated products have utilized similar approaches by combining hedonic analysis and descriptive analysis to identify optimal products (O'Sullivan et al., 2017a,b).



Sugar-reduction in alcoholic beverages

Cream liqueurs are typically composed of cream, sodium caseinate, sugar, alcohol, flavors, colors, and low-molecular-weight surfactants (Banks & Muir, 1988; Lynch & Mulvihill, 1997; O'Sullivan, 2011). As cream liqueurs typically contain 10%–20% sucrose, they have a high osmotic potential and between 10% and 15% alcohol by volume ethanol content. This creates a hurdle effect that prevents the growth of pathogenic organisms (O'Sullivan, 2017b). However, the high sugar content has meant that manufacturers are implementing sugar-reduction strategies as a contingency against sugar taxation penalties in the United Kingdom and Ireland.

Typical manufacture of a cream liqueur involves the preparation of a caseinate–trisodium citrate blend at 55°C–85°C, followed by the addition of cream and molten glycerol monostearate with continuous high-speed mixing to give the cream base. An aqueous–ethanol–sucrose solution is then added to the cream base and mixed thoroughly.

The blended preemulsion is normally homogenized twice at 45°C–55°C and 20–30 MPa (two-stage) using a standard radial diffuser homogenizer and cooled to 20°C (Dickinson, Narhan, & Stainsby, 1989; Lynch & Mulvihill, 1997; Muir & Banks, 1985, 1986; O'Sullivan, 2011). Various food grade thickeners may be added to contribute to the mouthfeel of cream liqueurs (Banks et al., 1981a). Homogenization is a crucial step in the manufacture of cream liqueurs in order to produce a finely dispersed emulsion with a long shelf life (Banks & Muir, 1988). During homogenization the size of the fat globules is decreased and sodium caseinate transfers from the serum phase to the newly exposed fat globule surface to stabilize the product. Viscosity of cream liqueurs will increase over time and as such viscosity can be used as an index of shelf life. Eventually, the viscosity will become a limiting factor to consumer acceptability. Viscosity can be quantified using a viscometer which has been discussed in more detail in the section covering instrumental analysis. High-quality cream liqueur can have shelf-lives of 2 years when stored in ambient conditions and can maintain their sensory quality even further when stored under refrigeration conditions. Another limiting factor to the sensory quality of cream liqueurs is the formation of negative ethyl esters that are formed from the reaction of fatty acids and alcohol (O'Sullivan, 2011).

Corn syrups, molasses, maltose, ribose, galactose, honey, lactose, sucrose, dextrin, modified starch, and glucose have been proposed for use as the carbohydrate source in cream/alcohol-containing beverages (Rule, 1983). The replacement/reduction of sucrose in the most popular brands of cream liqueurs will pose a major sensory and technological hurdle for manufacturers. As the sucrose in formulations contributes to high osmotic potential and viscosity reductions will impact flavor release due to changes in flavor partition coefficients as these are emulsion-based liquids. In addition, shelf life will be affected due to potential changes to viscosity and alternative bulking agents will change the physicochemical rate of viscosity change as well as of flavor formation due to the creation of ethyl esters. Also, alternative carbohydrate or NAS sources for sweetness can potentially deviate from signature flavor profiles compounding reformulation approaches to an even greater extent. The US FDA (2003) has approved the use of acesulfame K in alcoholic beverages as a general-purpose sweetener (US FDA, 2003). Saccharin is also permitted but the regulation states that amounts must be specified in the ingredient declaration (Kroger et al., 2006).

References

- Abbasi, S., & Saeedabadian, A. (2015). Influences of lactose hydrolysis of milk and sugar reduction on some physical properties of ice cream. *Journal of Food Science*, 52, 367–374.
- Abdallah, L., Chabert, M., Le Roux, B., & Louis-Sylvestre, J. (1998). Is pleasantness of biscuits and cakes related to their actual or to their perceived sugar and fat contents? *Appetite*, 30, 309–324.
- Aggarwal, D., Sabikhi, L., & Sathish Kumar, M. H. (2016). Formulation of reduced-calorie biscuits using artificial sweeteners and fat replacer with dairy—multigrain approach. *NFS Journal*, 2, 1–7.
- Alcaire, F., Antúnez, L., Vidal, L., Giménez, A., & Ares, G. (2017). Aroma-related cross-modal interactions for sugar reduction in milk desserts: Influence on consumer perception. *Food Research International*, 97, 45–50.
- Ambrosini, G. L., Johns, D. J., Northstone, K., Emmett, P. M., & Jebb, S. A. (2016). Free sugars and total fat are important characteristics of a dietary pattern associated with adiposity across childhood and adolescence. *Journal of Nutrition*, 146, 779–784.
- Antenucci, R. G., & Hayes, J. E. (2014). Non-nutritive sweeteners are not super-normal stimuli. *International Journal of Obesity*, 39, 1–6.
- Ashurst, P. (2011). CH19. The stability and shelf life of fruit juices and soft drinks. In D. Kilcast, & P. Subramaniam (Eds.), *The stability and shelf-life of food* (pp. 571–593). Cambridge, UK: Woodhead Publishing Limited.
- Ashurst, R. (2016). *Chemistry and technology of soft drinks & fruit juices*. Oxford, UK: John Wiley and Sons Ltd. (pp. 17e21; 131–134).
- Azaïs-Braesco, V., Sluik, D., Maillot, M., Kok, F., & Moreno, L. A. (2017). A review of total & added sugar intakes and dietary sources in Europe. *Nutrition Journal*, 16, 6–21.
- Banks, W., Muir, D. D., & Wilson, A. G. (1981a). The formation of cream based liqueurs. *The Milk Industry*, 83, 16–18.
- Banks, W., & Muir, D. D. (1988). Stability of alcohol-containing emulsions. In E. Dickinson, & G. Stainby (Eds.), *Advances in food emulsions and foams* (pp. 257–283). New York: Elsevier Science Publishing Co..
- Barcenilla, B., Román, L., Martínez, C., Martínez, M. M., & Gómez, M. (2016). Effect of high pressure processing on batters and cakes properties. *Innovative Food Science and Emerging Technologies*, 33, 94–99.
- Barclay, A. W., Petocz, P., McMillan-Price, J., Flood, V. M., Prvan, T., Mitchell, P., & Brand-Miller, J. C. (2008). Glycemic index, glycemic load, and chronic disease risk—A meta-analysis of observational studies. *The American Journal of Clinical Nutrition*, 87, 627–637.
- Bayarri, S., Carbonell, I., Barrios, E. X., & Costell, E. (2011). Impact of sensory differences on consumer acceptability of yoghurt and yoghurt-like products. *International Dairy Journal*, 21, 111–118.
- Bayarri, S., Taylor, A. J., & Hort, J. (2006). The role of fat in flavor perception: Effect of partition and viscosity in model emulsions. *Journal of Agriculture and Food Chemistry*, 54, 8862–8868.
- Bell, L. N., & Hageman, M. J. (1994). Differentiating between the effects of water activity and glass transition dependent mobility on a solid state chemical reaction: Aspartame degradation. *Journal of Agriculture and Food Chemistry*, 42, 2398–2401.
- Bennion, E. B., & Bamford, G. S. T. (1973). Baking fats. In A. J. Bent (Ed.), *The technology of cake making* (p. 25e47). Aylesbury: L. Hill.
- Bhattacharjee, C., Saxena, V. K., & Dutta, S. (2017). Fruit juice processing using membrane technology: A review. *Innovative Food Science and Emerging Technologies*, 43, 136–153.

- Biguzzi, C., Schlich, P., & Lange, C. (2014). The impact of sugar and fat reduction on perception and liking of biscuits. *Food Quality Preference*, 35, 41–47.
- Blake, M. R., Lancsar, E., Peeters, A., & Backholer, K. (2018). The effect of sugar-sweetened beverage price increases and educational messages on beverage purchasing behavior among adults. *Appetite*, 126, 156–162.
- Bleich, S. N., Wang, Y. C., Wang, Y., & Gortmaker, S. L. (2009). Increasing consumption of sugar-sweetened beverages among US adults: 1988–1994 to 1999–2004. *The American Journal of Clinical Nutrition*, 89(1), 372–381.
- Boehm, R., Read, M., & Schwartz, M. B. (2019). Juice displaces milk and fruit in high school lunches. *Journal of Nutrition Education and Behavior*, 51, 80–85. (Online).
- Byrd Bredbenner, C., Ferruzzi, M. G., Fulgoni, V. L., Murray, R., Pivonka, E., & Wallace, T. C. (2017). Satisfying America's fruit gap: Summary of an expert roundtable on the role of 100% fruit juice. *Journal of Food Science*, 82, 1523–1534.
- Byrd-Bredbenner, C., McKinley, J., Martin-Biggers, J., & Gager, E. (2016). Encouraging reductions in sugar-sweetened beverage consumption: HomeStyles Best Drinks for Families guide. *Journal of Nutrition Educational Behaviour*, 48, S11–S12.
- Cadena, R. S., Cruz, A. G., Faria, J. A. F., & Bolini, H. M. A. (2012). Reduced fat and sugar vanilla ice creams: Sensory profiling and external preference mapping. *Journal of Dairy Science*, 95, 4842–4850.
- Cardoso, J. M. P., & Bolini, H. M. A. (2008). Descriptive profile of peach nectar sweetened with sucrose and different sweeteners. *Journal of Sensory Studies*, 23, 804–816.
- Cauvain, S. P. (2011). CH23 The stability and shelf life of bread and other bakery products. In Kilcast (Ed.), *Food and beverage stability and shelf life* (pp. 657–682). Woodhead Publishing Limited.
- Chan, K., Prendergast, G., Grønhoj, A., & Bech-Larsen, T. (2011). Danish and Chinese adolescents' perceptions of healthy eating and attitudes toward regulatory measures. *Young Consumers*, 12, 216–228.
- Choi, J., Kim, K., & Chung, S. (2013). Relative sweetness and sweetness quality of low calorie sweeteners in milk and coffee model system. *Korean Journal of Food Science and Technology*, 45, 754–762.
- Chollet, M., Gille, D., Schmid, A., Walther, B., & Piccinali, P. (2013). Acceptance of sugar reduction in flavored yogurt. *Journal of Dairy Science*, 96, 5501–5511.
- Civille, C. V., & Oftedal, K. N. (2012). Sensory evaluation techniques—Make “good for you” taste “good”. *Physiology & Behavior*, 107, 598–605.
- Crammer, B. (2008). Recent trends in some natural sweet substances from plants. In R. Ikan (Ed.), *Selected topics in the chemistry of natural products* (pp. 189–208). Singapore: World Scientific.
- Daly, K., Darby, A. C., Hall, N., Nau, A., Bravo, D., & Shirazi-Beechey, S. P. (2014). Dietary supplementation with lactose or artificial sweetener enhances swine gut *Lactobacillus* population abundance. *British Journal of Nutrition*, 111(Suppl. 1), S30–S35.
- Damodaran, S., Kirk, L., & Fennema, O. (2008). *Fennema's food chemistry*. (4th ed.). Boca Raton, FL: CRC/Taylor & Francis Group.
- Davis, E. A. (1995). Functionality of sugars: Physicochemical interactions in foods. *American Journal of Clinical Nutrition*, 62, 170S–177S.
- Dickinson, E., Narhan, S. K., & Stainsby, G. (1989). Stability of cream liqueurs containing low-molecular-weight surfactants. *Journal of Food Science*, 54, 77–81.
- Drewnowski, A., & Almiron-Roig, E. (2010). Human perceptions and preferences for fat-rich foods. In J. P. Montmayeur, & J. le Coutre (Eds.), *Fat detection: Taste, texture, and post ingestive effects* (pp. 243–264). Boca Raton, FL: CRC Press Taylor & Francis Group.

- Drewnowski, A., Nordensten, K., & Dwyer, J. (1998). Replacing sugar and fat in cookies: Impact on product quality and preference. *Food Quality and Preference*, 9(1–2), 13–20.
- DuBois, G. E., & Prakash, I. (2012). Non-caloric sweeteners, sweetness modulators, and sweetener enhancers. *Annual Reviews in Food Science Technology*, 3, 353–380.
- Elding, C. (2013). *Why do humans crave sugar*. <<https://www.thehealthcloud.co.uk/why-do-humans-crave-sugar/>>. July 30, 2013.
- Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, 124, 411–421.
- EPHAC. (2010). Response to The reform of the CAP towards 2020—Impact Assessment. <<https://ec.europa.eu/agriculture/sites/agriculture/files/cap-post-2013/consultation/contributions/ephac-be.pdf>>.
- FAO/WHO. (2003). *Diet, nutrition and the prevention of chronic diseases. WHO technical report series 916* (pp. 1–149). Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO), Geneva, Switzerland.
- Feehley, T., & Nagler, C. T. (2014). The weighty costs of non-caloric sweeteners. *Nature*, 514.
- Figuerola, F., Hurtado, M. L., EsteveZ, A. M., Chiffelle, I., & Asenjo, F. (2005). Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment. *Food Chemistry*, 91, 395–401.
- Fox, P. F., & McSweeney, P. L. H. (2003). *Advanced dairy chemistry*. New York: Kluwer Academic/Plenum.
- Frye, A. M., & Setser, C. S. (1991). Optimizing texture of reduced calorie sponge cakes. *Cereal Chemistry*, 69, 338e343.
- Ganchrow, J. R., Steiner, J. E., & Daher, M. (1983). Neonatal facial expressions in response to different qualities and intensities of gustatory stimuli. *Infant Behavior and Development*, 6, 473–484.
- Gardner, C., Wylie-Rosett, J., Gidding, S. S., Steffen, L. M., Johnson, Rk, Reader, D., & Lichtenstein, A. H. (2012). Nonnutritive sweeteners: Current use and health perspectives: A scientific statement from the American heart association and the American diabetes association. *Circulation*, 126(4), 509–519.
- Gerdes, S. (2012). Consumers have a thirst for protein beverages. *Dairy Foods*, 113–122.
- Glória, M. B. A. (2003). Sweeteners | Others. In B. Caballero (Ed.), *Encyclopedia of food sciences and nutrition* (2nd ed., pp. 5695–5702). Oxford: Academic Press.
- Grenby, T. H. (1991). Intense sweeteners for the food industry: An overview. *Trends in Food Science and Technology*, 2, 2–6.
- Guthrie, J. F., & Morton, J. F. (2000). Food sources of added sweeteners in the diets of Americans. *Journal of the American Dietetic Association*, 100, 43–51.
- Hagiwara, A., Yoshino, H., Sano, M., Kawabe, M., Tamano, S., Sakaue, K., et al. (2005). Thirteen-week feeding study of thaumatin (a natural proteinaceous sweetener), sterilized by electron beam irradiation, in Sprague–Dawley rats. *Food Chemistry & Toxicology*, 43, 1297–1302.
- Harrison, T., & Dake, G. (2005). An expeditious, high-yielding construction of the food aroma compounds 6-Acetyl-1,2,3,4-tetrahydropyridine and 2-Acetyl-1-pyrroline. *The Journal of Organic Chemistry*, 70(26), 10872–10874.
- Herrick, K. A., Rossen, L. M., Nielsen, S. J., Branum, A. M., & Ogden, C. L. (2015). Fruit consumption by youth in the United States. *Pediatrics*, 136, 664–671.
- Heyman, M. B., & Abrams, S. A. (2017). American Academy of Pediatrics (AAP) Section on Gastroenterology, Hepatology, and Nutrition, AAP Committee on Nutrition. Fruit juice in infants, children, and adolescents: Current recommendations. *Pediatrics*, 2017(139), e20170967.

- Hoppert, K., Zahn, S., Janecke, L., Mai, R., Hoffmann, S., & Rohm, H. (2013). Consumer acceptance of regular and reduced-sugar yogurt enriched with different types of dietary fiber. *International Dairy Journal*, 28, 1–7.
- International Obesity Task Force (2002). *About obesity: Incidence, prevalence & co-morbidity*.
- Isik, U., Boyacioglu, D., Capanoglu, E., & Nilufer Erdil, D. (2011). Frozen yogurt with added inulin and isomalt. *Journal of Dairy Science*, 94, 1647–1656.
- Jacobson, J. (2015). Beverage survey finds “high protein,” “natural” are top trends. *Dairy Foods*, 116, 16–17.
- James, W. P. T., et al. (2004). *Comparative quantification of health risks: Global and regional burden of disease attribution to selected major risk factors*. Geneva: World Health Organization.
- Kale M., Pai D., Hamaker B., & Campanella O., (2011). Incorporation of fibers in foods: a food engineering challenge, In: Ajjigilera J.M., Barbosacanvas G.V., Simpson R., Weltchanes J., & Bermudezaguirre D. (Eds.), *Food Engineering Interfaces*.
- Kim, M. K., Lopetcharat, K., & Drake, M. A. (2013). Influence of packaging information on consumer liking of chocolate milk. *Journal of Dairy Science*, 96, 4843–4856.
- Kinghorn, A. D., & Compadre, C. M. (2001). Less common high potency sweeteners. In L. O. B. Nabors (Ed.), *Alternative Sweeteners* (third rev. ed, pp. 209–233). Boca Raton, FL: CRC Press.
- Kim, N. C., & Kinghorn, A. D. (2002). Highly sweet compounds of plant origin. *Archives of Pharmacal Research*, 25, 725–746.
- Kroger, M., Meister, K., & Kava, R. (2006). Low-calorie sweeteners and other sugar substitutes: A review of the safety issues. *Comprehensive Reviews in Food Science and Food Safety*, 5, 35–47.
- Küster, I., & Vila, N. (2017). Healthy lifestyle and eating perceptions: Correlations with weight and low-fat and low-sugar food consumption in adolescence. *Frontiers in Life Science*, 10, 48–62.
- Kweon, M., Slade, L., Levin, H., Martin, R., & Souza, E. (2009). Exploration of sugar functionality in sugar-snap and wire-cut cookie baking: Implications for potential sucrose replacement or reduction. *Cereal Chemistry*, 86(4), 425–433.
- Labbe, D., & Martin, N. (2009). Impact of novel olfactory stimuli at supra and sub threshold concentrations on the perceived sweetness of sucrose after associative learning. *Chemical Senses*, 34, 645–651.
- Larrea, M. A., Chang, Y. K., & Martinez-Bustos, F. (2005). Some functional properties of extruded orange pulp and its effect on the quality of cookies. *Lwt-Food Science and Technology*, 38, 213–220.
- Labbe, D., Damevin, L., Vaccher, C., Morgenegg, C., & Martin, N. (2010). Modulation of perceived taste by olfaction in familiar and unfamiliar beverages. *Food Quality and Preference*, 17, 582–589.
- Labbe, D., Rytz, A., Morgenegg, C., Ali, S., & Martin, N. (2007). Subthreshold olfactory stimulation can enhance sweetness. *Chemical Senses*, 34, 645–665.
- Lancet. (2017). Sweet success: Will sugar taxes improve health? *The Lancet Diabetes & Endocrinology*, 5(4), 235. Available from [https://doi.org/10.1016/S2213-8587\(17\)30070-0](https://doi.org/10.1016/S2213-8587(17)30070-0).
- Li, X. E., Lopetcharat, K., & Drake, M. A. (2015). Parents’ and children’s acceptance of skim chocolate milks sweetened by monk fruit and stevia leaf extracts. *Journal of Food Science*, 80, S1083–S1092.
- Lim, S., Sohn, W., Burt, B. A., Sandretto, A. M., Kilker, J. L., Marshall, T. S., & Ismail, A. I. (2008). Cariogenicity of soft drinks, milk and fruit juice in low-income African-American children: A longitudinal study. *The Journal of the American Dental Association*, 139, 959–967.

- Lima, M., Ares, G., & Deliza, R. (2019). Comparison of two sugar reduction strategies with children: Case study with grape nectars. *Food Quality and Preference*, 71, 163–167.
- Livesey, G. (2003). Health potential of polyols as sugar replacers, with emphasis on low glycaemic properties. *Nutrition Research Reviews*, 16, 163–191.
- Louie, J. C. Y., Moshtaghian, H., Rangan, A. M., Flood, V. M., & Gill, T. P. (2016). Intake and sources of added sugars among Australian children and adolescents. *European Journal of Nutrition*, 55, 2347–2355.
- Lustig, R. H., Schmidt, L. A., & Brindis, C. D. (2012). Public health: The toxic truth about sugar. *Nature*, 482(7383), 27–29.
- Lynch, A. G., & Mulvihill, D. M. (1997). Effect of sodium caseinate on the stability of cream liqueurs. *International Journal of Dairy Technology*, 50, 1–7.
- MacGregor, G. A., & Hashem, K. M. (2014). Action on sugar—Lessons from UK salt reduction programme. *Lancet*, 383, 929–931.
- Maher, T., & Wurtman, R. (1987). Possible neurologic effects of aspartame, a widely used food additive. *Environmental Health Perspective*, 75, 53–57.
- Malik, V. S., Pan, A., Willett, W. C., & Hu, F. B. (2013). Sugar-sweetened beverages and weight gain in children and adults: A systematic review and meta-analysis. *American Journal of Clinical Nutrition*, 98(4), 1084–1102.
- Manley, D. (2011). CH11 Sugars and syrups as biscuit ingredients. In D. Manley (Ed.), *Manley's technology of biscuits, crackers and cookies* (pp. 144–159).
- Martínez-Cervera, S., Sanz, T., Salvador, A., & Fiszman, S. M. (2012). Rheological, textural and sensorial properties of low-sucrose muffins reformulated with sucralose/polydextrose. *LWT—Food Science and Technology*, 45, 213–220.
- McCain, H. R., Kaliappan, S., & Drake, M. A. (2018). Invited review: Sugar reduction in dairy products. *Journal of Dairy Science*, 101, 8619–8640.
- Melanson, E. L., Astrup, A., & Donahoo, W. T. (2009). The relationship between dietary fat and fatty acid intake and body weight, diabetes, and the metabolic syndrome. *Annals of Nutrition and Metabolism*, 55(1–3), 229–243.
- Miele, N. A., Cabisidan, E. K., Plaza, A. G., Masi, P., Cavella, S., & Di Monaco, R. (2017). Carbohydrate sweetener reduction in beverages through the use of high potency sweeteners: Trends and new perspectives from a sensory point of view. *Trends in Food Science & Technology*, 64, 87–93.
- Maache-Rezzoug, Z., Bouvier, J. M., Allaf, K., & Patras, C. (1998). Effect of principal ingredients on rheological behaviour of biscuit dough and on quality of biscuits. *Journal of Food Engineering*, 35, 23–42.
- Mahar, A., & Duizer, L. M. (2007). The effect of frequency of consumption of artificial sweeteners on sweetness liking by women. *Journal of Food Science*, 72, S714–S718.
- Mariotti, M., & Alamprese, C. (2012). About the use of different sweeteners in baked goods. Influence on the mechanical and rheological properties of the doughs. *LWT—Food Science and Technology*, 48, 9–15.
- Mariotti M. & Lucisano M., Sugar and sweeteners, In: Zhou W. & U. Y. J. (Eds.), *Bakery products science and technology*, second edition, 2014, UK: Wiley.
- Milner, L., Kerry, J. P., O'Sullivan, M. G., & Gallagher, E. (2020). Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients. *Innovative Food Science and Emerging Technologies*, 59, 102235.
- Misra, N. N., & Timwari, B. (2014). Biscuits. In W. Zhou, & Y. H. Hui (Eds.), *Bakery products science and technology*. UK: Wiley.
- Moss, M. (2013). *Salt sugar fat: how the food giants hooked us*. Toronto, Canada: McClelland & Stewart.

- Muir D.D., & Banks W. (1984). From Atholl Brose to cream liqueurs: development of alcoholic milk drinks stabilized with trisodium caseinate, In: Galesloot T.E. and Tinbergen B.J. (Eds.), *Proceedings of the International Congress on Milk Proteins*, (pp. 120–128). Luxembourg, May 7–11.
- Muir, D. D., & Banks, W. (1986). Technical note: multiple homogenisation of cream liqueurs. *Journal of Food Technology*, 21, 229–232.
- Milner, L., Kerry, J. P., O'Sullivan, M. G., & Gallagher, E. (2020). Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients. *Innovative Food Science and Emerging Technologies*, 59, 102235.
- Moraes, P. C. B. T., & Bolini, H. M. A. (2010). Different sweeteners in beverages prepared with instant and roasted ground coffee: Ideal and equivalent sweetness. *Journal of Sensory Studies*, 25, 215–225.
- Morais, E. C., Pinheiro, A. C. M., Nunes, C. A., & Bolini, H. M. A. (2014). Multiple time-intensity analysis and temporal dominance of sensations of chocolate dairy dessert using prebiotic and different high-intensity sweeteners. *Journal of Sensory Studies*, 29, 339–350.
- Mozaffarian, D., & Clarke, R. (2009). Quantitative effects on cardiovascular risk factors and coronary heart disease risk of replacing partially hydrogenated vegetable oils with other fats and oils. *European Journal of Clinical Nutrition*, 63, S22–S33.
- Murphy, M. M., Douglass, J. S., Johnson, R. K., & Spence, L. A. (2008). Drinking flavored or plain milk is positively associated with nutrient intake and is not associated with adverse effects on weight status in US children and adolescents. *Journal of the American Dietetic Association*, 108, 631–639.
- Nassar, A. G., Abdel-Hamied, A. A., & EL-Naggar, E. A. (2008). Effect of citrus by-products flour incorporation on chemical, rheological and organoleptic characteristics of biscuits. *World Journal of Agricultural Sciences*, 4, 612–616.
- Nabors, O. L., & Gelardi, R. C. (1986). *Alternative sweeteners* (p. 1986) New York: Marcel Dekker.
- Newman, L. C., & Lipton, R. B. (2001). Migraine MLT-down: An unusual presentation of migraine in patients with aspartame-triggered headaches. *Headache*, 41(9), 899–901.
- Nip, W. K. (2007). Sweeteners. In H. Hui (Ed.), *Bakery products: Science and technology* (pp. 137–159). Chicago, IL: Blackwell Publishing.
- NPCS Board of Consultants & Engineers. (2008). *High-intensity sweeteners. The complete technology book on alcoholic and non-alcoholic beverages (fruit juices, whiskey, beer, rum and wine)*. Delhi, India: Asia Pacific Business Press Inc. (pp. 140e176).
- Oliveira, D., Antunez, L., Giménez, A., Castura, J. C., Deliza, R., & Ares, G. (2015). Sugar reduction in probiotic chocolate-flavored milk: Impact on dynamic sensory profile and liking. *Food Research International*, 75, 148–156.
- Oliveira, D., Reis, F., Deliza, R., Rosenthal, A., Giménez, A., & Ares, G. (2016). Difference thresholds for added sugar in chocolate-flavoured milk: Recommendations for gradual sugar reduction. *Food Research International*, 89, 448–453.
- Oltman, A. E., Lopetcharat, K., Bastian, E., & Drake, M. A. (2015). Identifying key attributes for protein beverages. *Journal of Food Science*, 80, S1383–S1390.
- O'Sullivan, M. G. (2017a). CH14. *Sensory properties of bakery and confectionary products. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 305–324). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017b). CH13. *Sensory properties of beverage products. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 281–304). United Kingdom: Woodhead Publishing Ltd.

- Oliveira, D., Galhardo, J., Ares, G., Cunha, L. M., & Deliza, R. (2018). Sugar reduction in fruit nectars: impact on consumers' sensory and hedonic perception. *Food Research International*, 107, 371–377.
- O'Sullivan, M. G. (2011). CH 4, sensory shelf-life evaluation. In J. R. Piggott (Ed.), *Alcoholic beverages: sensory evaluation and consumer research* (pp. 42–61). Cambridge, UK: Woodhead Publishing Limited.
- Pareyt, B., & Delcour, J. A. (2008). The role of wheat flour constituents, sugar, and fat in low moisture cereal based products: a review on sugar-snap cookies. *Critical Reviews in Food Science and Nutrition*, 48, 824–839.
- Pawar, R. S., Krynskiy, A. J., & Rader, J. I. (2013). Sweeteners from plants—with emphasis on *Stevia rebaudiana* (Berton) and *Siraitia grosvenorii* (Swingle). *Analytical and Bioanalytical Chemistry*, 405, 4397–4407.
- Parasidis, E., Hooker, N., & Simons, C. T. (2015). Addressing consumer confusion surrounding “natural” food claims. *The American Journal of Law & Medicine (AJLM)*, 41, 357–373.
- Parker, M. N., Lopetcharat, K., & Drake, M. A. (2018). Consumer acceptance of natural sweeteners in protein beverages. *Journal of Dairy Science*, 101, 8875–8889.
- Patterson, N. J., Sadler, M. J., & Cooper, J. M. (2012). Consumer understanding of sugars claims on food and drink products. *Nutrition Bulletin*, 37, 121–130.
- Pereira, M. (2012). *Acting sweet: Drivers, trends and forecasts in the sugar-free food and beverage market are explored*. CBS Interactive. <http://findarticles.com/p/articles/mi_m3289/is_1_175/ai_n26689456/>.
- Pinheiro, M., & Oliveira, M. (2005). The effect of different sweeteners in low-calorie yogurts—A review. *International Journal of Dairy Technology*, 58, 193–199.
- Popa, D., & Ustunol, Z. (2011). Sensory attributes of low-fat strawberry yoghurt as influenced by honey from different floral sources, sucrose and high-fructose corn sweetener. *International Journal of Dairy Technology*, 64, 451–454.
- Prentice, A., & Jebb, S. (2004). Energy intake/physical activity interactions in the homeostasis of body weight regulation. *Nutrition Reviews*, 62, S98–S104.
- Richardson, A. M., Tyuftin, A., Kilcawley, K. N., Gallagher, E., O'Sullivan, M. G., & Kerry, J. P. (2020). A study on the consumption patterns and behaviour of Irish consumers on the intake of sugar and associated replacers. *Journal TBC*.
- Richardson, A. M., Tyuftin, A., Kilcawley, K. N., Gallagher, E., O'Sullivan, M. G., & Kerry, J. P. (2018). Impact of sugar particle size manipulation on the physical and sensory properties of chocolate brownies. *LWT—Food Science and Technology*, 95, 51–57.
- Richardson, A. M., Tyuftin, A., Kilcawley, K. N., Gallagher, E., O'Sullivan, M. G., & Kerry, J. P. (2020). A study on the consumption patterns and behaviour of Irish consumers on the intake of sugar and associated replacers. *Journal TBC*.
- Rodriguez, R., Jimenez, A., Fernandez-Bolanos, J., Guillen, R., & Heredia, A. (2006). Dietary fibre from vegetable products as source of functional ingredients. *Trends in Food Science & Technology*, 17, 3–15.
- Rupasinghe, H. P. V., Wang, L. X., Huber, G. M., & Pitts, N. L. (2008). Effect of baking on dietary fibre and phenolics of muffins incorporated with apple skin powder. *Food Chemistry*, 107, 1217–1224.
- Rosenthal, A. J. (1995). Application of aged egg in enabling increased substitution of sucrose by litesse (polydextrose) in high-ratio cakes. *Journal of the Science of Food and Agriculture*, 68, 127–131.
- Rule, C. E. (1983). *Cream/alcohol containing beverages*. US patent no. 4,419,378.
- Schiffman, S. S., Booth, B. J., Losee, M. L., Pecore, S. D., & Warwick, Z. S. (1995). Bitterness of sweeteners as a function of concentration. *Brain Research Bulletin*, 36, 505–513.

- Silcock, P. (2017). *The basics: The functional role of sugar in food*. <<https://www.srasanz.org/sras/basics-sugar/functionsuses-food/>> Accessed September 2018.
- Singh, M., Liu, S. X., & Vaughn, S. F. (2012). Effect of corn bran as dietary fiber addition on baking and sensory quality. *Biocatalysis and Agricultural Biotechnology*, 1, 348–352.
- Souza, V. R., Pereira, P. A., Pinheiro, A. C. M., Bolini, H., Borges, S. V., & Queiroz, F. (2013). Analysis of various sweeteners in low-sugar mixed fruit jam: Equivalent sweetness, time-intensity analysis and acceptance test. *International Journal of Food Science and Technology*, 48, 1541–1548.
- Suez, J., et al. (2014). Artificial sweeteners induce glucose intolerance by altering the gut microbiota. *Nature*, 514.
- Sudha, M. L., Srivastava, A. K., Vetrmani, R., & Leelavathi, K. (2007a). Fat replacement in soft dough biscuits: its implications on dough rheology and biscuit quality. *Journal of Food Engineering*, 80, 922–930.
- Sudha, M. L., Baskaran, V., & Leelavathi, K. (2007b). Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. *Food Chemistry*, 104, 686–692.
- Sweetlow (2016). *Development of consumer optimised low carbohydrate irish confectionary products*. Project Coordinator: Dr Maurice O' Sullivan. Ref:14/F/812. <<https://www.agriculture.gov.ie/media/migration/research/firmreports/CALL2014ProjectAbstracts240216.pdf>>.
- Swinburn B.A., Sacks G., Hall K.D., McPherson K., Finegood D.T., Moodie M.L., et al., (2011). The global obesity pandemic: Shaped by global drivers and local environments, *Lancet* 378, 804–814.
- Tate, & Lyle. (2018). *Sucralose, sweetener, no-calorie sweetener, zero-calorie-sweetener*. <<https://www.tateandlyle.com/ingredient/splenda-sucralose>>.
- Te Morenga, L., Mallard, S., & Mann, J. (2012). Dietary sugars and body weight: Systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ*, 346, 7492.
- Tiban, N. N., Piližota, V., Šubarić, D., Miličević, D., & Kopjar, M. (2003). Influence of hydrocolloids and sweeteners on flow behaviour of peach nectar. *Acta Alimentaria*, 32, 383–393.
- Tournas, V. H., Heeres, J., & Burgess, L. (2006). Moulds and yeasts in fruit salads and fruit juices. *Food Microbiology*, 23, 684–688.
- Tournier, C., Sulmont-Rossé, C., & Guichard, E. (2007). *Flavour perception: Aroma, taste and texture interactions*. Isleworth, UK: Global Science Books Ltd.
- US FDA (2003). PART 172—FOOD ADDITIVES PERMITTED FOR DIRECT ADDITION TO FOOD FOR HUMAN CONSUMPTION. Federal Register/Vol. 68, No. 250/Wednesday, December 31, 2003/Rules and Regulations.
- van Raaij, J., Hendriksen, M., & Verhagen, H. (2009). Potential for improvement of population diet through reformulation of commonly eaten foods. *Public Health Nutrition*, 12, 325–330.
- Varzakas, T. (2012). *Sweeteners: nutritional aspects, applications, and production technology*. Boca Raton, FL: CRC Press.
- Wang, Y. C., Bleich, S. N., & Gortmaker, S. L. (2008). Increasing caloric contribution from sugar-sweetened beverages and 100% fruit juices among US children and adolescents, 1988–2004. *Pediatrics*, 121, 1604–1614.
- Wang, Y. C., Coxson, P., Shen, Y. M., Goldman, L., & Bibbins-Domingo, K. (2012). A penny-per-ounce tax on sugar-sweetened beverages would cut health and cost burdens of diabetes. *Health Affairs (Millwood)*, 31, 199–207.
- Wetzel, C. R., Weese, J. O., & Bell, L. N. (1997). Sensory evaluation of no-sugar-added cakes containing encapsulated aspartame. *Food Research International*, 30, 395–399.

- WHO. (2003). Diet, nutrition and the prevention of chronic diseases. In *Report of a joint WHO/FAO expert consultation, WHO technical report series 919*. 148 pp. <<http://www.who.int/dietphysicalactivity/publications/trs916/summary/en/print.html>>.
- World Cancer Research Fund. (2007). American Institute for Cancer Research. *Food, nutrition, physical activity, and the prevention of cancer: A global perspective*. Washington, DC, AICR.
- Yang, Q. (2010). Gain weight by “going diet?” Artificial sweeteners and the neurobiology of sugar cravings: Neuroscience 2010. *Yale Journal of Biology and Medicine*, 83(2), 101–108.
- Yebrá-Biurrun, M. C. (2005). *Sweeteners. Encyclopedia of analytical science* (pp. 562–572). San Diego, CA: Elsevier/Academic Press.
- Yeon, J. Y., & Lee, S. K. (2016). Perception of sugar reduction, nutrition education, and frequency of snacking in children by the self-perceived sweet dietary habits of mothers in Busan. *Nutrition Research and Practice*, 10, 546–554.
- Yoo, H. J., Machín, L., Arrúa, A., Antúnez, L., Vidal, L., Giménez, A., ... Ares, G. (2017). Children and adolescents’ attitudes towards sugar reduction in dairy products. *Food Research International*, 94, 108–114.
- Zahn, S., Hoppert, K., Ullrich, F., & Rohm, H. (2013). Dairy-based emulsions: Viscosity affects fat difference thresholds and sweetness perception. *Foods*, 2, 521–533.
- Zorn, S., Alcaire, F., Vidal, L., Giménez, A., & Ares, G. (2014). Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners. *Food Quality and Preference*, 36, 135–143.

Further reading

- Sakamoto, K., & Konings, W. N. (2003). Beer spoilage bacteria and hop resistance. *International Journal of Food Microbiology*, 89, 105–124.

Reduced-fat products and challenges

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Introduction

Of the three most targeted ingredients for reformulation (fat, salt, and sugar) in foods, fat is perhaps the one with the longest history. Since the 1950s, the conventional wisdom on obesity has been simple, that it is fundamentally caused by or results from a net positive energy balance, another way of saying that we get fat because we overeat (Taubes, 2013). The first correlations of high-fat diets to cholesterol occurred in the 1940s in the United States in that low-fat diets might prevent heart disease in high-risk patients. In the 1960s the idea was expanded to include the promotion of low-fat diets for the whole population. After 1980 the low-fat approach became an overarching ideology, promoted by physicians, the federal government, the food industry, and the popular health media (La Berge, 2008). The popularity of this antifat movement becomes increasingly evident in the types of products available in the US supermarkets: almost every product has a no-fat, low-fat, or reduced-fat counterpart

(Schessler-Jandreau, 2008). The argument whether the low-fat approach has actually been effective continues as we have never, as a population, been so aware of the nutritional consequences of how and what we eat, yet our citizens are proportionally getting more obese. Are populations getting fatter because they are eating more, or because the macronutrient composition of their diets is promoting fat accumulation. Attempts to blame the obesity epidemic, worldwide, on increased availability of calories typically ignores the fact that these increases are largely carbohydrates and those carbohydrates are largely sugar (Taubes, 2013). The debate rages on, but for many people the “lower fat product” category can assist in weight management or can form part of a healthy balanced diet. From a reformulation perspective, fat-reduced products are an appealing and desired product category by a significant proportion of the population and will continue to be optimized by the food industry. As science progresses, the knowledge and innovation in processes and ingredients drive the nutritional optimization of our foods, including those that contain fat.

Fat reduction in cakes

In cake and muffin manufactures, fat also plays a major structural role. These products are fat in water emulsions, where air bubbles form the discontinuous phase, and the egg, sugar, fat, and water mixture forms the continuous phase and where the flour is also dispersed. The fat in cake batter not only helps the incorporation of air but it also produces emulsifying properties and holds considerable amounts of liquid to increase and extend cake softness and interrupts the protein particles to break gluten continuity to tenderize the crumb (Bennion & Bamford, 1973). At first, the fat globules entrap air in the batter matrix during mixing, which aerates the product during processing that ultimately leads to a light fluffy texture on baking. Fat also has important emulsifying properties and can incorporate a large amount of liquid in the batter, which improves the softness of the cake (O’Sullivan, 2019). Minute air bubbles are trapped in the cake batter by the surface-active proteins in the egg, fat, a suitable emulsifier or a combination of all three to form an emulsified foam that forms a sponge on baking (Cauvain, 2011). The presence of fat also has a “shortening” effect on the crumb texture of cake and muffins, in that it interferes with the protein matrix, resulting in a “short,” more tender crumb. It is thus expected that a fat reduction process would result in lower overall volume (less aeration), increased crumb firmness (because

of a greater degree of starch swelling), and a reduced palatability (O'Sullivan, 2017a; Rodríguez-García, Sahi, & Hernando, 2014). It is again, fundamental, that an optimized fat level is determined through sensory and physicochemical (TPA, texture profile analyzer) analysis that can deliver fat-reduced products while maintaining optimal sensory characteristics (O'Sullivan, 2017a). Reduced-fat cake products are available on the market but their scarcity could be an indication of either the difficulty of producing them or of a lack of acceptance of the product by the consumer (Talbot, 2011). Changes in the matrix, due to fat reduction, change the fundamental sensory properties of the product. Thus fat reduction strategies with the aim of matching the sensory profile of a standard product are hard to achieve.

Cake shelf life can be up to 4 weeks (usually only 1); however, the use of additives such as preservatives (propionic, sorbic, and benzoic acids) and correct packaging conditions (correct heat sealing and modified atmosphere) can significantly prolong shelf (Barcenilla, Román, Martínez, Martínez, & Gómez, 2016).

Muffins are characterized by a typical porous structure and high volume, which confer a spongy texture similar to cakes. For muffins, sugar assists in the incorporation of air cells in cakes and muffins while creaming provides good grain structure, flavor, and texture to the product. It aids in retention of moisture, prolongs freshness, and promotes good crust color (Nip, 2007). To obtain such a final structure a stable batter retaining many tiny air bubbles is required (Martínez-Cervera, Sanz, Salvador, & Fiszman, 2012). As discussed in the previous chapter, sucrose plays a critical functional role as it not only contributes to the sweet taste but also acts as a bulking agent, assists products in staying moist, reduces the swelling of starch to produce a finer textured end product, and contributes to the browning of the crust. Multiple factors are linked to consumer perceptions of sweetness and fat. Sweetness is mainly due to the sugar content (Drewnowski, Nordensten, & Dwyer, 1998), but it also depends on the fat content and moisture. However, fat perception is more complex than sweetness. It depends on the fat content, the sugar content, texture, moisture, flavor, the nature of the food (liquid or solid), and mouthfeel (Abdallah, Chabert, Le Roux, & Louis-Sylvestre, 1998). American muffins are generally made with butter, but European varieties can be made with vegetable oil. The fat plays vital sensory and functional roles in these baked products. Using oil instead of butter lends greater volume to the final product, since the proteins in the flour are better wrapped in the fat

and, thus it is more difficult to develop the gluten network (Martínez-Cervera, Salvador, & Sanz, 2015). As a general principle, the reduction of saturate levels in a fat is brought about through an increase in the level of liquid oil in the product, as it is these liquid oils, such as rapeseed oil or sunflower oil, that have the lowest levels of saturated fats (Atkinson, 2011). The presence of fat also contributes to flavor or the combined perception of mouthfeel, taste, and aroma. It also contributes to the appearance and lubricity of baked goods and increases the feeling of satiety. The sensory properties of pastry products result from the use of saturated fats, particularly during their preparation and any reduction can reduce sensory quality (de Cindio & Lupi, 2011).

Martínez-Cervera et al. (2015) investigated sunflower oil, butter, and two types of sunflower oil cellulose emulsions that were used as fat sources in a muffin formulation. The oil cellulose emulsions were said to reduce final fat content by 49%. The author found that the oil muffins were the highest and with the most aerated texture. Sensory acceptability of the emulsion muffins was slightly lower than the other variants. The height and crumb bubble size of the cellulose emulsion muffins were found to be between those of the oil and the butter muffins (Martínez-Cervera et al., 2015).

Grigelmo-Miguel, Carreras-Boladeras, and Martin-Belloso (2001) investigated the addition of peach dietary fiber on the composition, physical properties, and sensory acceptability of reduced-fat muffins. These authors found that the addition of peach dietary fiber darkened the muffins, increased hardness and chewiness but did not affect acceptability compared to the control.

Devereux, Jones, McCormack, and Hunter (2003) investigated the consumer acceptability of various cookies and cakes (blueberry muffins, carrot cake, chocolate cake, lemon cheesecake) containing inulin and oligofructose. Generally, the fructan-containing products were rated highly for overall acceptability, although lower than their full-fat counterparts. Apart from cookies and chocolate cake, there were no differences between low- and full-fat variants for overall acceptability.

Jung, Kim, and Chung (2005) developed muffins in which corn bran fiber was substituted 10%, 30%, 50%, or 70% for fat. Sensory analysis yielded muffins with substitution of butter with corn bran considered to be as acceptable as the control. Kim, Yeom, Lim, and Lim (2001) replaced shortening in layer cake with maltodextrin (MD), amylopectin (AD), octenyl succinylated AD (OSAD), or mixtures (MD + AD and

MD + OSAD). Sensory results showed the cakes containing AD or OSAD had significantly higher firmness than the control, but the cakes containing a mixture of MD and AD had firmness, springiness, and overall flavor scores similar to that of the control cake.

Kaur, Singh, and Kaur (2000) studied the use of emulsifiers (glycerol monostearate and sodium stearyl-2-lactylate) and hydrocolloids (guar gum and aroxy methylcellulose) as fat replacers in bread, muffins, and cookies. Reduced-fat variants produced better quality products than the respective controls.

Martínez-Cervera, Salvador, Muguerza, Moulay, and Fiszman (2011) investigated cocoa fiber as a fat replacer in chocolate muffins. The sponginess and springiness of the samples with the lowest fat replacement were scored similar to the full-fat control formulation. Also, the muffins containing cocoa fiber were more cohesive, stickier, more difficult to chew and swallow as well as being more bitter the higher the level of cocoa fiber added.

Bosman, Vorster, Setser, and Steyn (2000) investigated the use of the fat mimetic Simplese as an oil replacer on the sensory and physical characteristics and microbiological quality of high-fiber muffins. These authors found that oil replacement with Simplese produced products with better stability toward batter refrigeration than the full-fat control muffins and that although the reduced-fat muffins were different from the freshly baked full-fat control muffins, they were still of comparable sensory quality. Pszczola (1994) reported that Simplese bakery blends did not affect the full-fat taste when they replaced fat up to 93% in cakes, muffins, and brownies. Armbrister and Setser (1994) showed that the replacement of 50% or 75% of fat by six protein- or carbohydrate-based fat mimetics, including polydextrose (Litesse), acid-treated cornstarch (Stellar, A.E. Staley, Decatur, IL), Slendid, mono and diglycerides, and Simplese and potato MD, produced products with different flavor characteristics compared to a full-fat control.

MD is spray-dried, soluble, hygroscopic powder with a slightly sweet to neutral taste. It is digested as a simple carbohydrate with a calorie content of 1 kcal/g and is converted to energy quickly (Prarikh, Agarwal, & Raut, 2014). Typically, it is produced industrially through enzymatic hydrolysis of starch (potato, tapioca, wheat, corn). It interacts with amylose resulting in the formation of gels, and therefore it can be used to replace fat in food matrices by thickening and stabilizing matrices (Forker, Zahn, & Rohm, 2012). MDs may be thus used as a fat substitute in cake

batters, but it can affect viscosity and air retention resulting in cakes with lower volume and firmer texture that can be improved upon with the further application of emulsifiers (Lakshminarayan, Rathinam, & KrishnaRau, 2006). Carbohydrate-based fat substitutes are thus often used for fat reduction in cakes and muffins.

Fat reduction in biscuits

Fat plays vital sensory, functional, and processing-aid roles in baked products and contributes to flavor, mouthfeel, taste, aroma, appearance, and lubricity of baked goods and increases the feeling of satiety. In the processing industry the presence of fat is essential as a lubricant for machinability such as sheeters, mixers, and dough molding equipment (O'Sullivan, 2019). Biscuits differ from cakes and breads in that they are baked on trays as they have tougher and dryer dough structure, compared to the latter, which require tins because of their softer dough consistency. They are principally made from flour, water, sugar, fat, and salt. A large variety of shapes and textures may be produced by varying the proportions of these ingredients (Maache-Rezzoug, Bouvier, Allaf, & Patras, 1998). The origins of biscuits in the literature go as least as far back as the Middle Ages where *panis biscoctus* (Latin for twice-cooked bread) or bread-type rusks composed of flour and water were used to sustain mariners on long sea voyages (O'Sullivan, 2017a). These were made by baking in an oven followed by further drying in a cooler oven to produce a low moisture, very long shelf life product that could sustain the sailors while at sea (Manley, 2011a). Fat plays an integral part in the development of flavor intensity and release in biscuit products. Fat acts as a lubricant, plasticizer and imparts a desirable flavor to the baked products. It coats the flour particles during mixing and prevents the development of the gluten network resulting in a brittle, crumbly product. In addition, for the manufacturing industry, fat is essential for machinability and dough molding properties. Biscuits are characterized as having a high-fat/sucrose to flour ratio with their respective doughs being tougher than bread doughs. This is due to the much lower water content that inhibits gluten action, which in turn is cooked out during baking. Thus biscuits have a much harder and dryer final texture (O'Sullivan, 2017a).

Hydrogenated vegetable oils, with their higher melting points, were commonly used in biscuit manufacture up to recently, but the presence of trans fats and the restriction of these compounds, as enforced by some

regulatory bodies, has resulted in a dramatic drop in their popularity. The consumption of these “trans fats” is thought to build up as plaque inside the arteries and has been linked to greater risk of coronary heart disease. Several countries, namely, Austria, Denmark, Hungary, Iceland, Norway, and Switzerland have set limits that virtually ban them from food products while the European Union is considering similar legislation for all the nation-states. In the United States the FDA require the levels of trans fat in foods to appear on nutritional labels. Palm oil is a high melting point (36°C) fat and that has extensively replaced hydrogenated oils in biscuit manufacture. Palm oil is highly saturated fat and therefore much less healthy than polyunsaturated oils such as rapeseed and sunflower oils. However, increased global demand is resulting in deforestation in countries such as Indonesia and Malaysia (O’Sullivan, 2017a).

Biguzzi, Schlich, and Lange (2014) found that a reduction in sugar content caused little change in perception of fat in biscuits, whereas a reduction in fat content sometimes induced a reduction in sweetness perception. The sucrose present in biscuit and cookie formulations affects the sweet flavor, dimensions/shrinkage, color, hardness, and surface finish. Sucrose inhibits gluten development during dough mixing by competing with the flour for the available water in the formulation and has been extensively discussed in Chapter 2, Nutritional optimization—reduced-sugar products and challenges.

Fat and sugar cannot be easily replaced, especially in a complex food system such as biscuits (Zoulas, Oreopoulou, & Kounalaki, 2002). Reductions of fat used in biscuit formulation will affect significant aspects of the product, for example, increased dough stiffness and less crispy/crumbly/brittle texture (i.e., more chewy). Reducing fat is an arduous job for the bakery industry as it is responsible for soft and crisp texture of biscuits and imparts flavor, lubricity, mouthfeel, aeration, and taste to the product (Aggarwal, Sabikhi, & Sathish Kumar, 2016). Also, achieving the optimum fat/sugar combinations is also crucial. The presence of fat and sugar combined plays an integral part in the development of flavor intensity and release with fat containing the more nonpolar flavors. Thus it is also very important for biscuit formulations that an optimized fat level is determined through sensory and physicochemical (TPA) analysis that can deliver fat-reduced products while maintaining optimal sensory characteristics (O’Sullivan, 2017a).

Cookies are soft-type biscuits whose textural characteristics are mostly provided by their high-fat content that provides flavor and mouthfeel and

also contributes to appearance, palatability, texture, and lubricity. Fat reduction results in several undesirable technological effects, such as toughening of the dough, increasing in cohesive, adhesive, and elastic dough properties, shrinkage of the final product, loss of color, and eating quality (Boobier, Baker, & Davies, 2006).

Polydextrose is a complex carbohydrate made from glucose, citric acid, and sorbitol, which forms a highly viscous gel-like matrix contributing to creaminess and mouthfeel (Mitchell, 1996). Moriano, Cappa Alamprese (2018) investigated polydextrose and resistant starch on reduced-fat soft-dough biscuit formulations. An optimized product obtained with 46.3% shortening reduction and 12.5% flour replacement had quality characteristics similar to those of full-fat biscuits.

Conforti, Charles, and Duncan (1996) investigated three fat substitutes derived from pectin, gums, and oat bran (Slendid, Kel-Lire BK, and Trimchoice-5) for baking biscuits, which were used to replace the fat at a level of 33%, 66%, and 100%. They concluded that tenderness decreased as substitute use increased when biscuits were rated by the sensory panel and consumer location testing rated the biscuits as moderately acceptable and indicated a desire for a product of this type to become available in the marketplace.

Zoulias et al. (2002) investigated the fat mimetics, Oatrim and Z-Trim, both derived from oats, in cookies which produced acceptable sensory characteristics at 50% fat replacement. However, lower quality resulted at higher levels of replacement. Zoulias et al. (2002) explored the use of the fat replacers Inulin (Raftiline, Orafit Active Food Ingredients, Oreye, France), Simplese (C*deLight, Cerestar, Brussels, Belgium), and polydextrose (Litesse, Pfizer, Inc. New York, NY, United States) for partial fat replacement and lactitol, sorbitol, and maltitol for sugar replacement in low-fat, sugar-free cookies. Cookies prepared with Simplese had the least acceptable flavor, while cookies prepared with C*deLight were rated as the most acceptable by a sensory panel (O'Sullivan, 2017b).

Laguna, Primo-Martín, Varela, Salvador, and Sanz (2014) studied the effects of partial fat replacement with inulin and hydroxypropyl methylcellulose (HPMC) in biscuits. Consumer studies revealed that fat replacement up to 15 g/100 g with inulin or HPMC provided acceptable biscuits, but higher replacement decreased the overall acceptability. Campbell, Ketelsen, and Antenucci (1994) managed to replace up to 25% of shortening in crisp oatmeal cookies using polydextrose (Litesse)

while maintaining physicochemical and sensory properties. Hydrolyzed oat flour (containing 5% β -glucan) has been used as a replacement for butter in baked desserts and for coconut cream in Thai desserts (Inglett, Maneepun, & Vatanasuchart, 2000).

The reduction of fat in sweet baked products such as cake, muffins, and cookies is currently being studied in the SWEETLOW project funded by the Irish Department of Agriculture, Food and the Marine (Sweetlow, 2016). This project funded as part of the Food Industry Research Measure is investigating the use of fruit and vegetable fibers as fat replacers as well as, alternative fat ratios in formulation matrices, emulsifiers, and bulking agents (O'Sullivan, 2017a). Fat replacement technologies are covered extensively in Chapter 9 of O'Sullivan (2017b).



Fat reduction in meat products

Excess intake of fat is linked to obesity as well as the concurrent civilization-associated diseases that can also occur with being overweight. Processed meat products are major sources of fats in the diet. Thus consumers are demanding meat products with lower levels of these components, and the industry has commenced product reformulation to meet this need. The use of salt, nitrates, and nitrites in preserving processed food products was vital in the past, but the enhancement of in-plant hygiene through effective implementation of hazard analysis critical control points and the advent of modern ingredients, packaging, and refrigeration have reduced their processing roles and necessity to some degree. Due to consumer demand for clean labeled meats, the demand for products made without added phosphate is also increasing. In addition, irrespective of public opinion, the processing of underutilized meat is necessary on ethical grounds alone as it is responsible for converting inedible material to a more palatable form, thereby reducing food waste and generating more protein-based food products that also present product diversity in the marketplace (Fellendorf et al., 2015).

Fats and oils play vital flavor and functional roles in processed meats and have a large impact in terms of eating quality as they interact with other ingredients and help to develop texture, mouthfeel and provide a lubricating effect (Javidipour, Vural, Ozbas, & Tekin, 2005; Webb, 2006; Wood, 1990). However, overconsumption of meat and meat products has

been linked with obesity, cancer, and cardiovascular diseases primarily due to the high amounts of sodium chloride and saturated fat present in processed products (Cross et al., 2007; Halkjaer, Tjønneland, Overvad, & Sørensen, 2009; Li, Siriamornpun, Wahlqvist, Mann, & Sinclair, 2005; Micha, Wallace, & Mozaffarian, 2010). For many years, researchers have been working on approaches to reduce animal fats in meat products (Delgado-Pando et al., 2011; Özvural & Vural, 2008; Prosslow, 2016). Thus this research area has received considerable focus for products such as frankfurters, breakfast sausage, beef patties, pork patties, bologna, black and white puddings, and corned beef (Fellendorf et al., 2015, 2016a, 2016b, 2018; Fellendorf, Kerry, Hamill, et al., 2018; Prosslow, 2016; Ruusunen et al., 2005; Tobin, O'Sullivan, Hamill, & Kerry, 2012a, 2012b, 2013a, 2013b; Ventanas, Puolanne, & Tuorila, 2010). Processing extends shelf life, improves texture, and enhances overall flavor but inevitably leads to products having higher amounts of salt, saturated fatty acids (FAs), and preservatives such as nitrates that have health implications (Barcellos, Grunert, & Scholderer, 2011). For this reason, processed meats have moved more into the public focus over the past 20 years, particularly with respect to health concerns (O'Sullivan, 2017c). Meat product suppliers have already commenced reformulating their recipes and now offer lower levels of nitrate, salt and fat, or even higher levels of polyunsaturated FAs in processed meat products on the market (Verbeke, Pérez-Cueto, De Barcellos, Krystallis, & Grunert, 2010). For meat, there are several methods to produce fat-reduced products such as using leaner meat, less fat and salt, more water, replacing parts of animal fat with plant oil, or the application of fat replacers (Fellendorf et al., 2015, 2016a, 2016b, 2018; Fellendorf, Kerry, Hamill, et al., 2018; Weiss, Gibis, Schuh, & Salminen, 2010).

Fat reduction can be achieved by using less fat in formulations or by using fat replacer ingredients that simulate the action of fat to varying degrees. The essential step in both approaches is to use consumer-driven, sensory evaluation processes, as described in the following sections.

Fat reduction without replacement

Many studies have investigated affective sensory-focused fat reduction, without utilizing replacement ingredients, in processed meats, including beef patties (Tobin et al., 2012a), breakfast sausage (Tobin et al., 2013a, 2013b), frankfurters (Tobin et al., 2012b) white pudding

(Fellendorf et al., 2015; Prosslow, 2016) and black pudding (Fellendorf, O'Sullivan, & Kerry, 2017; Prosslow, 2016). These studies involve sequentially reducing fat, without using alternative ingredients, in order to determine sensory optima while at the same time maintaining safety, functionality, and adequate product shelf life.

Tobin et al. (2012a, 2012b, 2013a, 2013b) explored the sequential reduction of salt and fat in beef patties, frankfurters, and breakfast sausage using a flash profiling methodology. In addition, Fellendorf et al. (2015, 2017) investigated salt and fat reduction in black and white puddings (sausage-style products) and corned beef (Fellendorf, Kerry, & O'Sullivan, 2018) by reduction without replacement using a sensory chemometric methodology that correlated acceptance testing [sensory acceptance testing (SAT)] and ranking descriptive analysis (RDA) (Richter, Almeida, Prudencio, & Benassi, 2010). These authors used these sensory methods to identify optimal formulations and found that different meat systems had varying optimization criteria. Both salt and fat reduction were shown, very importantly, not to negatively impact on consumer acceptability in patties and sausages, while only fat reduction could be achieved in frankfurters without negative assessor feedback (Tobin et al., 2012b, 2013a, 2013b). Fellendorf et al. (2015) found that white pudding samples containing 15% fat and 0.6% sodium were highly accepted ($P < .05$), thereby satisfying the sodium target (0.6%) set by the Food Safety Authority of Ireland (FSAI) (2011). In addition, black pudding samples (Fellendorf et al., 2017) containing 0.6% sodium and 10% fat displayed a positive ($P < .05$) correlation to liking of flavor and overall acceptability. This also meets the sodium target level set by the FSAI (2011). Fellendorf, Kerry, and O'Sullivan (2018) observed that corned beef samples low in sodium (0.2%, 0.4%) showed reduced ($P < .05$) saltiness perception but were positively correlated ($P > .05$) to liking of flavor and overall acceptability (O'Sullivan, 2017c). Reductions in salt content could also be optimized by using packaging technologies to compensate for loss of safety or shelf life stability of processed meat products (Fellendorf, O'Sullivan, & Kerry, 2018; Prosslow, 2016).

Fat reduction using replacement ingredients

The use of unsaturated oils such as vegetable or fish oils as a partial substitute to animal fat in meat products has received a great deal of attention. By replacing animal fat in processed meats with vegetable oils, the FA

profile can be nutritionally optimized as well as producing a lower fat- and/or cholesterol-containing products. Özvural and Vural (2008) reported that palm oil, palm stearin, cottonseed oil, hazelnut oil, and their mixes could be used to increase the ratio of unsaturated to saturated FAs and maintain product quality in processed meats. Also, Delgado-Pando et al. (2011) reported similar findings for olive oil, linseed oil, fish oil, and konjac oil. Both studies report that products scored as acceptable in consumer trials even with certain different physicochemical properties of these meat products (O'Sullivan, 2017c).

The use of ingredient replacers such as hydrocolloids (a range of polysaccharides and proteins) could also be utilized in the meat processing industry, as they have been used in processed meat products for many years to improve properties such as water binding and texture due to their ability to thicken, gel, bind, stabilize emulsions and pH (Andrès, Zaritzky, & Califano, 2006; Fellendorf et al., 2015, 2016a, 2016b, 2018; Fellendorf, Kerry, Hamill, et al., 2018). Hydrocolloids, based on animal proteins, include casein, whey, gelatin, and blood-derived protein. In addition, an enormous range of polysaccharides are available on the market, such as starches (corn, wheat, maize, potato, tapioca, pea), celluloses (carboxymethylcellulose), gums (guar, alginate, pectin, locust bean), fibers (β -glucan), chitin/chitosan, and xanthan derived from microorganisms (Cutter, 2006). Ingredients such as whey protein concentrate, sodium caseinate, lecithin, and a variety of other hydrocolloids such as gelatine and carrageenan are also commonly used in the meat industry (Andrès et al., 2006). Several researchers have reported the effectiveness of fat reduction using whey protein, soy protein, and surimi, respectively (Cengiz & Gokoglu, 2007; Murphy, Gilroy, Kerry, Buckley, & Kerry, 2004; Sampaio, Castellucci, Pinto e Silva, & Torres, 2004). As with oil incorporation, textural differences were detected in the finished product, but these changes did not have a negative impact on overall sensory acceptability.

Fat replacers are categorized into fat substitutes and fat mimetics. Fat mimetics show distinctly different chemical structures from fat—usually protein and/or carbohydrate based, though some of the physicochemical attributes and eating qualities of fat can be simulated such as mouthfeel, appearance, and viscosity (Dufloy, 1996; Fellendorf et al., 2016a, 2016b; Harrigan and Breene, 1989). The use of fat mimetics is, in general, more common. Chevance et al. (2000) achieved a fat reduction of 46% in salami, 60%–83% in frankfurters, and 55% in beef patties with tapioca starch and oat fiber or MD and milk protein.

On the contrary, fat substitutes display a chemical structure close to fats, have similar physicochemical properties and are generally low in calorie content or indigestible such as Olestra, Caprenin, and Salatrim (Fellendorf et al., 2016a, 2016b; Kosmark, 1996; Peters, Lawson, Middleton, & Triebwasser, 1997). With Salatrim the FAs attached to the glycerol backbone of the fat molecule are substituted with a combination of long-chain length (18–22 carbon chain), medium-chain length (6–10 carbon chain), and short (2–4 carbon chain) saturated fats. This changes the way this material is metabolized by the body and thus has only 5 cal per gram compared to 9 for standard fat (Atkinson, 2011).

Fellendorf et al. (2016b) explored the application of traditional and clean label ingredients as fat replacers in black pudding products (Fig. 3.1). These authors produced 22 black pudding variants through possessing different fat (10%, 5%) and sodium (0.6%, 0.4%) levels that were used as base formulations for 11 different salt and fat replacers. Compositional, physicochemical, and sensory analyses (SAT and RDA) were conducted. Black pudding samples with 5% fat and 0.6% sodium containing potassium chloride (KCl), potassium chloride and glycine mixture (KClG), and seaweed, respectively, and 10% fat and 0.4% sodium containing carrageen were rated higher ($P < .05$) for spiciness and saltiness. Samples with 10%

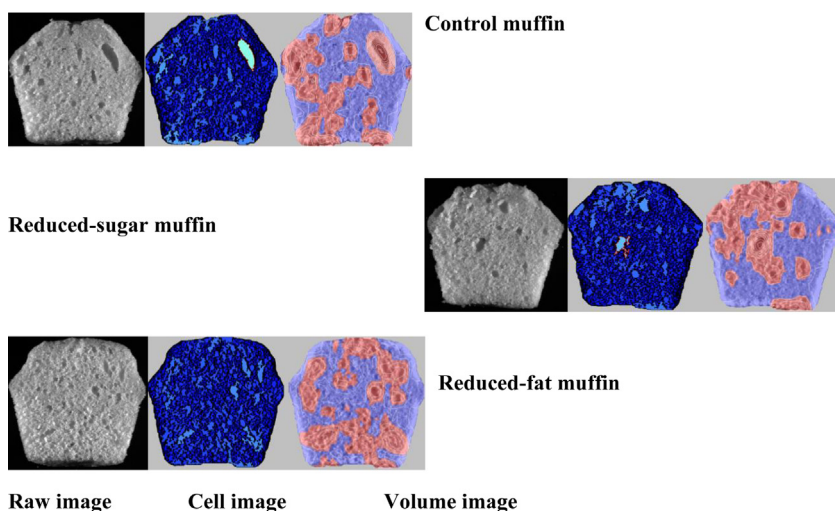


Figure 3.1 2D imaging of the crumb structure for reduced-fat muffins. From Milner, L., Kerry, J. P., O'Sullivan, M. G., & Gallagher, E. (2019). Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients. *Innovative Food Science and Emerging Technologies*.

fat and 0.4% sodium containing KClG were rated positively ($P < .05$) to fatness. Samples with 5% fat and 0.6% sodium containing pectin and a combination of potassium citrate, potassium phosphate and potassium chloride (KCPCI), as well as samples containing 10% fat and 0.4% sodium with waxy maize starch (WMS), were liked ($P < .05$) for flavor and overall acceptance. The Food Safety Authority of Ireland (FSAI) recommends a sodium target level of 0.6% and an even lower sodium level (0.4%) was achieved. In addition, [Fellendorf et al. \(2016a\)](#) produced 22 white pudding formulations that comprised two different fat (10%, 5%) and sodium (0.6%, 0.4%) levels and containing 11 different traditional and clean label ingredient replacers. Compositional, texture, and sensory analyses (SAT and RDA) were again conducted. Two formulations containing 10% fat and 0.6% sodium formulated with sodium citrate, as well as the combination of KClG, were found to have overall acceptance ($P < .05$) by assessors. These samples showed higher ($P < .05$) hardness values, scored lower ($P < .05$) in fatness perception and higher ($P < .05$) in spiciness perception. Hence, the recommended sodium target level of 0.6% set by the [FSAI \(2011\)](#) was again achieved for white pudding products, in addition to a significant reduction in fat level from commercial levels, without causing negative sensory attributes.

Numerous studies have lauded the benefits of human diets high in plant fiber on overall and digestive health through regular bowel movement. These include reduced risk of cancers, coronary heart disease, obesity, and diabetes ([O'Sullivan, 2017c](#)). Essentially, fiber is complex carbohydrate that can be incorporated into processed meat formulations as partial fat replacers and positively affects physicochemical properties of the resulting properties by potentially improving water binding, texture, cooking loss, and texture quality on sausages, puddings, bologna, and meatballs ([Borderías, Sánchez-Alonso, & Pérez-Mateos, 2005](#); [Fellendorf et al., 2015, 2016a, 2016b, 2017](#); [Fellendorf, Kerry, & O'Sullivan, 2018](#); [Fernandez-Ginés, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Álvarez, 2004](#)).

Stabilizers, emulsifiers, or thickeners are also added to meat to help maintain a uniform texture ([Fellendorf et al., 2016a, 2016b](#)). In addition, a diverse range of polysaccharides are available on the market, such as starches (corn, wheat, maize, potato, tapioca, pea), celluloses (carboxymethylcellulose), gums (guar, alginate, pectin, locust bean), fibers (β -glucan), chitin/chitosan, and xanthan derived from microorganisms ([Cutter, 2006](#)). [García-García and Totosaús \(2008\)](#) showed that starch

added with either K-carrageenan or locust bean gum could produce similar results in terms of texture as full-fat products. Ayo, Carballo, Solas, and Jiménez-Colmenero (2008) reported consumer acceptable low-fat products produced with walnut. Cold-set binders are of particular interest to the meat industry as they can affect the textural properties of a meat system without the application of heat, therefore keeping the meat product in its natural raw state. They also have application in the replacement of salt and fat and the production of healthier processed meats. Examples of cold-set binders include nonthermal gelatine, alginate, and fibrin (Boles, 2011). Commercially available cold-set binding systems include Fibrimex, alginate, and Activa.

Fellendorf, Kerry, and O'Sullivan (2018) investigated the impact of varying sodium levels (0.2%–1.0%) and salt replacers in corned beef on physicochemical, sensory, and microbiological properties. Samples formulated with CaCl_2 , MgCl_2 , and KCl scored higher ($P < .01$) in saltiness perceptions but correlated negatively ($P > .05$) to liking of flavor and overall acceptability. However, a sodium reduction of 60% in corned beef was determined to be achievable as assessors liked ($P < .05$) the flavor of the sodium-reduced corned beef containing 0.4% sodium and formulated with potassium lactate and glycine, even with the noticeable lower salty taste (O'Sullivan, 2017c).

In conclusion, highly accepted sensory-optimized products, based on commercial recipes, can be created with lower fat levels, but also with lower salt levels, which meet regulatory targets. This provides the processed meat industry with a blueprint on how to commercially develop stable, healthier processed meat products that consumers prefer and which meet regulatory requirements (Fig. 3.2).



Reduced-fat cheese

There are over 500 different varieties of commercially available cheese that have a wide range of visual, physical, and flavor attributes. The flavor of cheese is governed by three main biochemical pathways: glycolysis, lipolysis, and proteolysis. In general terms, the extent of each of these processes is characteristic of the individual cheese variety (Kilcawley & O'Sullivan, 2017). Cheese can be made from cows, sheep, goats, and even buffalo milk. The milk is acidified typically through the action of an

Black and white pudding, cryostat sections
Confocal scanning laser micrographs (protein = red, fat = green)

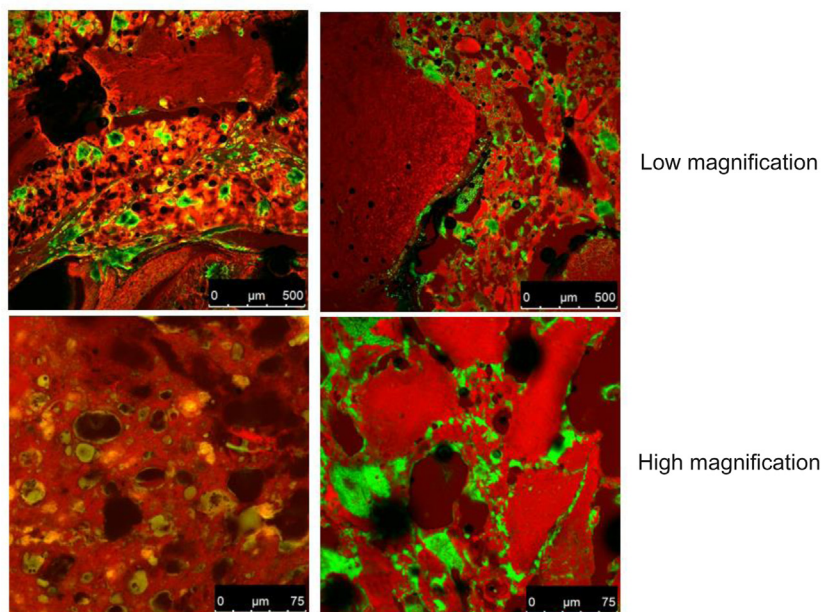


Figure 3.2 Protein and fat distribution in black (top) and white pudding (bottom). From Fellendorf, S., O'Sullivan, M. G., & Kerry J. P. (2016a). *Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings*. *European Food Research and Technology*, 242, 2105–2118; Fellendorf, S., O'Sullivan, M. G., & Kerry J. P. (2016b). *Impact of using replacers on the physicochemical properties and sensory quality of reduced salt and fat black pudding*. *Meat Science* 113, 17–25.

added starter culture of bacteria (lactic acid bacteria) that convert lactose into lactic acid. Rennet is then added, which is a complex mixture of enzymes containing chymosin, the main protease, extracted from the stomach of calves that curdles the casein in milk. The curds and whey are then separated with the curds typically formed into molds and ripened to make cheese. Cheese sensory properties can be categorized as taste, texture, and aroma/flavor properties, but color is also important for some varieties (Kilcawley & O'Sullivan, 2017).

Extensive research has been undertaken on reducing fat in cheese, as a means of providing insights for the development of reduced-fat cheeses with quality characteristics (flavor, texture, and cooking properties) as close as possible to the control cheese (McCarthy, Wilkinson, Kelly, & Guinee, 2016). In Europe a reduction of 30% of the fat content relative

to the reference full-fat cheese is required to use the term “reduced-fat” in the description of the product, according to European Council regulation No. 1924/2006 (Deegan, Holopainen, McSweeney, Alatossava, & Tuorila, 2014). The Food and Drug Administration (FDA) regulation mandates that food products claiming to be low fat must not contain more than 3 g of fat per reference amount (50 g), whereas reduced-fat labeling can be used for food that contains 25% less fat than the regular version (Amelia, Drake, Nelson, & Barbano, 2013; FDA-DHHS, 2002). Low-fat dairy products are in demand by consumers for exactly the same reasons as outlined for processed meats. Consumers wish to reduce their calorie, particularly saturated fat, intake and thus have driven the market to develop healthier reduced-fat variants of cheese, yoghurt, and milk products. Fat has an important sensory role in dairy products contributing to both flavor and texture and thus technological difficulties can be encountered when levels are reduced (Kilcawley & O’Sullivan, 2017). Reducing fat content of cheese leads to higher concentrations of protein, moisture and pH, and a reduction in moisture in nonfat substances (McCarthy et al., 2016).

Ritvanen et al. (2005) undertook sensory evaluation, chemical composition, and consumer acceptance of full-fat and reduced-fat cheeses (Havarti, Edam, and Emmental) in the Finnish market. These authors found almost all cheeses were considered pleasant, but differences in flavor and texture of full-fat and reduced-fat cheeses were detected. Stickiness and collapsed holes were more acceptable in reduced-fat cheeses, but lack of intense flavor was not.

Henneberry et al. (2016) investigated the sensory quality of mozzarella style cheeses with different fat, salt, and calcium levels. Reducing fat content significantly impaired sensory acceptability, mainly because of associated increases in firmness, rubberiness and chewiness, and reductions in fat flavor and cheese flavor in the unheated and heated cheeses. Reducing salt content had relatively minor effects. Reducing calcium content counteracted some of the negative sensory attributes associated with reduced-fat cheese (Henneberry et al., 2016). Cheeses such as cheddar and mozzarella become firmer and more rubbery on removal of fat, thus increasing in corresponding protein content. Flavor is particularly affected as the fat/protein matrix changes and affects flavor perception deleteriously. The greater the fat reduction the more negative the sensory flavor and texture quality. Some of the flavor defects mentioned included meaty, brothy, burnt, bitterness, low flavor intensity, and milk

fat flavor (Amelia et al., 2013; Banks, 2004; Drake & Swanson, 1995; Drake, Miracle, & McMahon, 2010; Kilcawley & O'Sullivan, 2017; Mistry, 2001).

Also, for mozzarella cheese, fat mimetics (McMahon, Alleyne, Fife, & Oberg, 1996) were investigated in a study with two protein-based fat replacers (Simplese D-100 and Dairy-Lo) and two carbohydrate-based fat replacers (Stellar 100X and Novagel RCN-15), although sensory investigations were not included.

Madsen and Ardö (2001) investigated the physiochemical, rheological, and sensory properties of Danbo cheese containing different fat levels. Sensory and rheological analyses confirmed that the low-fat cheeses had a firmer and more elastic texture.

Lamparski and Tobota (2007) compared the sensory quality of commercial semihard-type cheese and its reduced-fat version in Poland and found sensory hedonic scores for the reduced-fat variants significantly lower than the full-fat counterparts.

Fenelon, Beresford, and Guinee (2002) investigated the use of the adjunct *Lactobacillus helveticus* in combination with *Leuconostoc cremoris*, *Lactococcus lactis* var. diacetylactis, and *Streptococcus thermophilus* to a produce 50% fat-reduced cheddar cheese. The 50% fat-reduced cheddar had a higher preference score than a similar cheese made without the adjunct culture, although the flavor profile was clearly different from regular cheddar as burnt off-flavor notes were produced. Curd washing has also been investigated for the sensory optimization of reduced-fat cheese (Johnson, Steele, Broadbent, & Weimer, 1998).

Nelson and Barbano (2004) investigated flavor optimization of reduced-fat cheddar cheese by only removing the fat from regular-aged cheddar, once the flavor had fully developed. Sensory studies revealed that these products retained the same flavor intensity as the full-fat variety but the texture was quite different.

Kavas, Oysun, Kinik, and Uysal (2004) explored the use of the protein-based fat replacers, Dairy-Lo and Simplese D-100, and carbohydrate-based fat replacers Perfectamyl gel MB and Satiagel ME4 on the physicochemical and sensory properties of low-fat white pickled cheese. The low-fat cheeses, produced by adding Dairy-Lo, Perfectamyl gel MB, and Satiagel ME4, were highly acceptable compared to the low-fat cheese without fat replacers. The sensory panel did not detect differences between samples made using Simplese D-100 and full-fat cheese or low-fat cheese without fat replacer.

Deegan et al. (2014) explored the physicochemical and textural changes of reduced-fat Emmental cheese made using a preprocessing step involving homogenization of milk. Samples were compared to full-fat Emmental cheese made with the same process. These authors found that the homogenization routine used in cheese making improved sensory aspects of the reduced-fat cheeses.

Ice cream

Ice cream is a sweetened frozen dessert that is typically flavored and eaten in the frozen state. It can contain dairy ingredients but can also be dairy free made with vegetable fat (O'Sullivan, 2017d). This fat source may also be vegetable such as hydrolyzed palm kernel oil. Frozen yoghurt can also be classed as ice cream. The Italian variety gelato is custard based and contains egg yolks (Clarke, 2004a, 2004b). In the United Kingdom, ice cream must have a minimum of 5% fat with no less than 2.5% milk protein (such as from skim milk powder) with the majority made from nonmilk fat ingredients. Higher value ice creams may contain up to 14% milk fat. In the United States, ice cream must contain at least 10% milk fat, below which it can only be called ice milk, and a minimum of 10% nonfat milk solids (as defined by the FDA). As milk fat percentage increases from 10%, the nonfat milk solids may sequentially decrease such that the dairy fat and nonfat dairy ingredients balance at the 20% level (FDA, 2015).

Fat reduction is another way the dairy industry is trying to decrease the energy density of ice cream (McCain et al., 2018). However, fat reduction initiates matrix changes that affect not only the mouthfeel of ice cream but can also lead to a change in flavor release and possibly sweetness perception (Karaca, Güven, Yasar, Kaya, & Kahyaoglu, 2009). It thus is a difficult challenge for food processors to reduce the fat content of ice cream and maintain the fundamental qualities that are integral for the formation of its microstructure. Fat increases the buttery and creamy notes as well as mouth coating in full-fat ice creams compared with low-fat ice cream (Koeferli, Piccinali, & Sigrist, 1996), and generally, low-fat ice creams have lower flavor and texture ratings when measured by sensory analysis and display textural defects such as coarseness, iciness, crumbliness, shrinkage on storage, and reduced flavor release (Marshall & Arbuckle, 1996). Fat presence is crucial for aeration and, as it stabilizes the air phase, freezing and is important as a carrier of lipophilic flavors and their subsequent release during consumption (O'Sullivan, 2017b).

Prindiville, Marshall, and Heymann (1999) decreased the fat content of chocolate ice cream and found this actually increased perceived sweetness. However, Roland, Phillips, and Boor (1999) reported that an increase in sweetness perception in vanilla ice cream when fat was used above 7%. In an effort to simulate the texture and flavor of fat-containing ice cream, the industry typically adds bulking agents and concentrated milk components to fat-free formulations (Roland et al., 1999). Carbohydrate bulking agents, such as MD and polydextrose, are currently used in low-fat formulations because they produce minimal negative effects on ice cream production, shelf life, and price (Roland et al., 1999; Schmidt, Lundy, Reynolds, & Yee, 1993). Rolon, Bakke, Coupland, Hayes, and Roberts (2017) found that differences regarding sweetness perception of vanilla ice cream when substituting MD for fat (6%–14% fat with 8%–0% MD, respectively) were not found using a consumer panel. However, a trained panel did detect a sweetness difference (Rolon et al., 2017).

Schaller-Povolny and Smith (1999, 2001) investigated inulin as a fat replacer in ice cream and found that it increased the viscosity and decreased the freezing point and produced a product with acceptable sensory qualities. Isik, Boyacioglu, Capanoglu, and Nilufer Erdil (2011) reported that substituting inulin and isomalt for sugar and fat in a product similar to ice cream, frozen yogurt, led to a similar sweetness and a reduction in fat with no added sugar. Prindiville et al. (1999) investigated the protein-based fat replacers, Dairy-Lo or Simplese in low-fat and nonfat chocolate ice creams made with 2.5% of milk fat and cocoa butter. Consumer acceptance was the same as for fresh ice creams. Simplese was more similar to milk fat than was Dairy-Lo on textural stability but was less similar in terms of thickness and mouth coating.

Yoghurt

Yoghurt is a very popular fermented milk that is produced all over the world by acid coagulation of milk without drainage (Sodini, Remeuf, Haddad, & Corrieu, 2004). Yoghurt is generally a healthy consumer product high in protein and calcium contents and is produced using skimmed milk or full-fat milk. It is no surprise that consumers have also driven a demand for low or even zero fat variants (O'Sullivan, 2017b). It is made in a variety of compositions (fat and dry-matter content), either plain or with added substances such as fruits, sugar, and gelling agents (Walstra, Wouters, & Geurts, 2006). Sweeteners (sugar, honey, and

aspartame), flavorings (vanilla and chocolate), and other ingredients (fruits, preserves, and stabilizers such as gelatine to improve the textural property) are added to modify the sensory characteristics of yogurt. The fat content of yoghurt comes from the fat content of the milk and milk-based products used in manufacture. According to UK regulations, fat levels must be less than 15% in yoghurt (CODEX, 2003). In the UK market, products range from fat-free to 10% fat for indulgence type products (Komorowski, 2011). The addition of flavors increases consumer appeal with strawberry being the most popular which also increases the functionality and antioxidant capacity of these dairy products (Trigueros, Pérez-Alvarez, Viuda-Martos, & Sendra, 2011). Probiotic and prebiotic yoghurt varieties are popular products with health-conscious consumers with many bacterial cultures linked to beneficial effects on the human microbiome (O'Sullivan, Thornton, O'Sullivan, & Collins, 1992).

Fat replacement in yoghurt has been explored by several researchers (Barrantes, Tamime, Davies, & Barclay, 1994; Barrantes, Tamime, & Sword, 1994; Tamime, Barclay, Davies, & Barrantes, 1994; Tamime, Barrantes, & Sword, 1996). The prebiotic polysaccharide inulin, most often extracted from chicory root, is a fructan or dietary fiber and has applications as a fat replacer in yoghurt. Srisuvor, Chinprahast, Prakitchaiwattana, and Subhimaros (2013) compared the effects of inulin and polydextrose on physicochemical and sensory properties of low-fat set yoghurt. Staffolo, Bertola, Martino, and Bevilacqua (2004) investigated inulin as a fat replacer in yoghurt and found that it produced a product with a stable color and water activity and syneresis did not prevail during storage.



Milk and flavored milk

Milk comprises sugars, proteins, and fat. Lactose imparts sweetness to milk and is a reducing sugar, also known as milk sugar. It contains about 4% fat, and this fat contains approximately 65% of saturated FAs (Komorowski, 2011). Lactose is the distinctive carbohydrate of milk and is a disaccharide composed of glucose and galactose. Milk fat consists of triglycerides (~98%), the vast majority of which are even-numbered saturated FAs esterified on glycerol. Bovine milk fat is present as emulsified globules surrounded by a thin membrane, called the milk fat globule

membrane, and imparts the creamy or rich flavor of milk (Kilcawley & O'Sullivan, 2017). Typically, milk fat contains 66% saturated FAs, 30% monounsaturated FAs, and 4% polyunsaturated FAs (Aigster, Sims, Staples, Schmidt, & O'Keefe, 2000). The easiest method of producing drinking milk with reduced levels of saturated fat is by decreasing the level of total fat in the milk. This is achieved through the use of centrifugal separators where the cream is diverted and the skim remains with a fat level of approximately 0.1%. Composition can then be standardized to any level by the readdition of cream (Komorowski, 2011). Reduced-fat milk has widespread appeal with consumers across many countries. In Denmark, and other countries in Scandinavia, reduced-fat varieties of milk outsell whole milk and the consumer appears to have adapted to and transitioned to lower fat option. For flavored milks, Kim, Lopetcharat, and Drake (2013) reported that fat content and sugar content (or intrinsic factors) were the biggest drivers of choice for adult consumers (of chocolate milk) and had a significant effect on consumer purchase habits. The intrinsic factors, brand name, and packaging labels were thus found to be less important than fat and sugar content. These authors also found that although consumers were aware of lower fat and lower sugar products, most still preferred a higher calorie product due to taste (Kim et al., 2013).

Butter and spreads

Butter, one of the oldest milk products, is a water-in-oil emulsion, generally containing a minimum of 80 g milk fat/100 g and a maximum of 16 g moisture/100 g, and milk solids not-fat 2 g/100 g (Lee et al., 2018). Its formulation is standardized across many countries, and the inclusion of milk fat with fat from other sources is prohibited (Australia New Zealand Federal Register of Legislative Instruments, 2005; EU, 2007; The People's Republic of China, 2010). Water forms the dispersed phase and oil forms the continuous phase. Butter is mostly made today by a continuous churn process as opposed to the batch approach. Different types of butter are available on the market such as sweet cream (salted or unsalted), cultured, and whipped butter (Kilcawley & O'Sullivan, 2017). It is a traditional food, which is widely consumed all over the world, directly or as an ingredient in processed foods such as pastries and convenience dishes. Its nutritional value, due to a high content of fats, vitamins, and minerals, and its unique and pleasant flavor make butter particularly appreciated by

consumers (Mallia, Escher, & Schlichtherle-Cerny, 2008). The nutritional, organoleptic, and rheological (hardness, spreadability, melting) properties of dairy products are largely dependent on the FA composition of milk, particularly polyunsaturated FAs (Hurtaud and Peyraud, 2007). The high ratio of saturated to unsaturated FAs in milk fat has been a concern because of the link between intake of saturated FAs and various biological markers for cardiovascular disease risk, such as elevated blood pressure, insulin resistance, and hyperlipidemia, particularly of low-density lipoprotein cholesterol (Rasmussen et al., 2006; Vessby et al., 2001), high cholesterol, atherosclerosis, and heart disease (Ulbricht & Southgate, 1991). As a consequence of this, there has been consumer concern regarding the consumption of milk fat compared to spread and margarine alternatives due to high levels of these saturated FAs. Modifying the FA composition of butter by decreasing the proportions of 12:0, 14:0, 16:0, and stearic acid (18:0) and increasing the proportions of unsaturated and short-chain FAs improves its spreadability (Bobe et al., 2007) and also potential health benefits.

The consumption of butter has increased in recent years, after the publication of scientific evidence on the nutritional benefits of some compounds found in butter (Lordan & Zabetakis, 2017). Recent reviews and metaanalysis have concluded that there is at least a neutral effect of milk intake on multiple health outcomes, and alternatively, cows' milk consumption may be beneficial in combating osteoporosis, cardiovascular disease, stroke, type 2 diabetes, and some cancers (Armas, Frye, & Heaney, 2016; Lamarche et al., 2016).

There are two potential approaches to reducing saturated fat in butter: the incorporation of unsaturated fats through dietary feeding or by fractionating the butterfat and using a less saturated fraction (Wilbey, 2009). A higher amount of fresh grass in the animal diet is reported to significantly increase the relative amount of α -linolenic acid (Dhiman, Anand, Satter, & Pariza, 1999) and CLA (conjugated linoleic acid) (O'Callaghan et al., 2016) in milk. Fresh grass feeding regimens, widely practiced in Ireland and New Zealand, produce a milk fat with higher proportions of unsaturated FA compared to those derived from total mixed ration indoor grass/maize/grain silage and concentrate feeding systems (Couvreur et al., 2006), extensively practiced in the United States, Asia, and parts of Europe. In addition, there is evidence that pasture feeding also produces a superior dairy product from a hedonic sensory perspective (O'Callaghan et al., 2016). As well as pasture feeding, a more healthful milk FA composition can be achieved by

altering the cow's diet by feeding supplemental fish oil or roasted soybeans, or by selecting cows with a more unsaturated milk FA composition (Bobe et al., 2007). However, the incorporation of polyunsaturated FAs into butter in this fashion will also increase the susceptibility to lipid oxidation. Also, modifying the FA composition of butter by decreasing the proportions of 12:0, 14:0, 16:0, and stearic acid (18:0) and increasing the proportions of unsaturated and short-chain FAs improves its spreadability (Bobe et al., 2007) and also potential health benefits.

The Codex Alimentarius defines dairy fat spreads as products exclusively obtained from milk, which have a fat content no less than 10 g/100 g and no more than 80 g/100 g and where the fat phase shall represent at least two-thirds of the dry-matter content of the product (FAO/WHO, 2007). "Three-quarter fat butter" is a product with a milk fat content between 60% and 62%. The term "reduced-fat" may also be used to describe these products, whereas "low-fat," "light," or "half-fat" butter may be used to describe products with a milk fat content of 39%–41%. The spread products with other milk fat contents should be described as "dairy spread X%" (EU, 1994). In the United States, light butter requires maximum levels of fat of 40 g/100 g and salt as 1.5 g/100 g, with the cream used meeting the requirements of cream acceptable for the manufacture of US Grade AA butter (USDA, 1995).

Blended spreads are composed of mixed milk fat (min 3%) and vegetable/animal fat products where total fat content is no more than 80% (FAO/WHO, 2007). Sources of vegetable fat might include olive oil or sunflower oil. However, in the European Union, the fat content in the blends and blended spreads shall be between 10 and 90 g/100 g of the total fat content (EU, 1994). Blends (> 80% total fat) or blended spreads (<80% total fat) are a mixture of butter and vegetable oils with a high content of unsaturated FAs (Lee et al., 2018) where milk fat must be greater than 3% (FAO/WHO, 2007). Margarine and fat spreads are made up of blends of vegetable and animal fat and contain less than 3% milk fat (EU, 1994).



Salad dressing and sauces

Consumers do not wish to sacrifice flavor quality for nutritional properties in products and thus the challenge for food technologists to produce acceptable products is great (O'Sullivan, 2017b). Liquid salad

dressings are oil-in-water emulsions, typically acidified with vinegar or lemon juice and stabilized by emulsifiers such as egg yolk or milk proteins. Due to their relatively high oil content, much attention has been directed to the development of low-fat variants, but because of this typically high oil content any decrease negatively affects emulsion properties and thus physicochemical and sensory characteristics. One of the simplest methods for reducing the total fat level of an emulsion is to replace some of the fat with an ingredient that has similar properties. In such a way, it may be possible to avoid complex changes to the manufacturing process (Talbot, 2011). Thickeners can also be used to stabilize reduced-fat salad dressings. Polysaccharides (carrageenan, xanthan, pectins, etc.) are usually incorporated in commercial salad dressing products, especially those of low oil content, to stabilize the oil droplets, prevent creaming, and compensate for the loss of thickening properties originating from their reduced oil content (Ma & Barbosa-Canovas, 1995; Parker, Gunning, Ng, & Robins, 1995). Xanthan gum, because it can form weak gels, is also often used in salad dressings (O'Sullivan, 2017b). Corn, waxy maize, wheat, potato, tapioca, rice, and waxy rice starches can be used as fat mimetics in dressings, sauces margarines, and spreads. Microcrystalline cellulose is used in reduced-fat salad dressings and maltodextrin has found applications in low-fat margarines, salad dressings, and sauces (O'Sullivan, 2017b). Fat mimetics such as Simplese can be used as fat replacers and texturizers in margarines, salad dressings, sauces, and soups. Trailblazer can be used as a texturizer in sauces and soups. Cooked starch may also be incorporated in these products since starch gelatinization results in the release of polysaccharides that may then act as emulsion stabilizers and thickeners (Mantzouridou, Karousioti, & Kiosseoglou, 2013).

References

- Abdallah, L., Chabert, M., Le Roux, B., & Louis-Sylvestre, J. (1998). Is pleasantness of biscuits and cakes related to their actual or to their perceived sugar and fat contents? *Appetite*, 30, 309–324.
- Aggarwal, D., Sabikhi, L., & Sathish Kumar, M. H. (2016). Formulation of reduced-calorie biscuits using artificial sweeteners and fat replacer with dairy–multigrain approach. *NFS Journal*, 2, 1–7.
- Aigster, A., Sims, C., Staples, C., Schmidt, R., & O'Keefe, S. F. (2000). Comparison of cheeses made from milk having normal and high oleic fatty acid compositions. *Journal of Food Science*, 65, 920–924.
- Amelia, I., Drake, M. A., Nelson, B., & Barbano, D. M. (2013). A new method for the production of low-fat Cheddar cheese. *Journal of Dairy Science*, 96, 4870–4884.

- Andr s, S., Zaritzky, N., & Califano, A. (2006). The effect of whey protein concentrates and hydrocolloids on the texture and colour characteristics of chicken sausages. *International Journal of Food Science & Technology*, 41(8), 954–961.
- Armas, L. A., Frye, C. P., & Heaney, R. P. (2016). *Effect of cow's milk on human health. Beverage impacts on health and nutrition* (pp. 131–150). Springer.
- Armbrister, W. L., & Setser, C. S. (1994). Sensory and physical properties of chocolate chip cookies made with vegetable shortening or fat replacers at 50% and 75% levels. *Cereal Chemistry*, 71, 344–351.
- Atkinson, G. (2011). CH 14. Saturated fat reduction in biscuits. In G. Talbot (Ed.), *Reducing saturated fats in foods* (pp. 301–317). Woodhead Publishing Limited.
- Australia New Zealand Federal Register of Legislative Instruments (2005). Butter. Australia New Zealand Food Standard Code 2.5.5. 2011.
- Ayo, J., Carballo, J., Solas, M. T., & Jim nez-Colmenero, F. (2008). Physicochemical and sensory properties of healthier frankfurters as affected by walnut and fat content. *Food Chemistry*, 107, 1547–1552.
- Banks, J. M. (2004). The technology of low-fat cheese manufacture. *International Journal of Dairy Technology*, 57, 199–207.
- Barcellos, dM. D., Grunert, K. G., & Scholderer, J. (2011). Processed meat products: Consumer trends and emerging markets. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 30–53). Oxford, Cambridge, Philadelphia, New Delhi: Woodhead Publishing Ltd.
- Barcenilla, B., Rom n, L., Mart nez, C., Mart nez, M. M., & G mez, M. (2016). Effect of high pressure processing on batters and cakes properties. *Innovative Food Science and Emerging Technologies*, 33, 94–99.
- Barrantes, E., Tamime, A. Y., Davies, G., & Barclay, M. N. I. (1994). Production of low-calorie yoghurt using skim milk powder and fat substitutes. 2. Compositional quality. *Milchwissenschaft*, 49, 135–139.
- Barrantes, E., Tamime, A. Y., & Sword, A. M. (1994). Production of low-calorie yoghurt using skim milk powder and fat substitutes. 3. Microbiological and organoleptic qualities. *Milchwissenschaft*, 49, 205–208.
- Bennion, E. B., & Bamford, G. S. T. (1973). Baking fats. In A. J. Bent (Ed.), *The technology of cake making* (pp. 25–47). Aylesbury: L. Hill.
- Biguzzi, C., Schlich, P., & Lange, C. (2014). The impact of sugar and fat reduction on perception and liking of biscuits. *Food Quality Preference*, 35, 41–47.
- Bobe, G., Zimmerman, S., Hammond, E. G., Freeman, A. E., Porter, P. A., Luhman, C. M., & Beitz, D. C. (2007). Butter composition and texture from cows with different milk fatty acid compositions fed fish oil or roasted soybeans. *Journal of Dairy Science*, 90, 2596–2603.
- Boles, J. A. (2011). Use of cold-set binders in meat systems. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats improving safety, nutrition and quality* (pp. 270–295). United Kingdom: Woodhead Publishing.
- Boobier, W. J., Baker, J. S., & Davies, B. (2006). Development of a healthy biscuit: An alternative approach to biscuit manufacture. *Nutrition Journal*, 5, 7–13.
- Border as, A. J., S nchez-Alonso, I., & P rez-Mateos, A. (2005). New applications of fibres in foods: Addition of fishery products. *Trends in Food Science & Technology*, 16, 458–465.
- Bosman, M. J. C., Vorster, H. H., Setser, C., & Steyn, H. S. (2000). The effect of batter refrigeration on the characteristics of high-fibre muffins with oil replaced by a protein-based fat substitute. *Journal of Family Ecology and Consumer Sciences*, 28, 1–15.
- Campbell, L. A., Ketelsen, S. M., & Antenucci, R. N. (1994). Formulating oatmeal cookies with calorie-sparing ingredients. *Food Technology*, 48, 98–105.

- Cauvain, S. P. (2011). Chapter 23, The stability and shelf life of bread and other bakery products. In Kilcast (Ed.), *Food and beverage stability and shelf life* (pp. 657–682). Woodhead Publishing Limited.
- Cengiz, E., & Gokoglu, N. (2007). Effects of fat reduction and fat replacer addition on some quality characteristics of frankfurter-type sausages. *International Journal of Food Science and Technology*, 42, 366–372.
- Chevance, F. F., Farmer, L. J., Desmond, E. M., Novelli, E., Troy, D. J., & Chizzolini, R. (2000). Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. *Journal of Agricultural and Food Chemistry*, 48(8), 3476–3484.
- Clarke, C. (2004a). *Ch1: The story of ice cream. The science of ice cream* (pp. 1–12). RSC Publishing.
- Clarke, C. (2004b). *Ch6: Measuring ice cream. The science of ice cream* (pp. 104–134). RSC Publishing.
- CODEX (2003). Codex standard for fermented milks (CODEX STAN 243–2003), Revised 2008. <<http://www.codexalimentarius.net/>>.
- Conforti, F., Charles, S. A., & Duncan, S. E. (1996). Sensory evaluation and consumer acceptance of carbohydrate-based fat replacers in biscuits. *Journal of Consumer Study and Home Economics*, 20, 285–296.
- Couvreur, S., Hurtaud, C., Lopez, C., Delaby, L., & Peyraud, J.-L. (2006). The linear relationship between the proportion of fresh grass in the cow diet, milk fatty acid composition, and butter properties. *Journal of Dairy Science*, 89, 1956–1969.
- Cross, A. J., Leitzmann, M. F., Gail, M. H., Hollenbeck, A. R., Schatzkin, A., & Sinha, R. (2007). A prospective study of red and processed meat intake in relation to Cancer risk. *PLoS Medicine*, 4(12), 345.
- Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, 74(1), 131–142.
- de Cindio, B., & Lupi, F. R. (2011). CH 15: Saturated fat reduction in pastry. In G. Talbot (Ed.), *Reducing saturated fats in foods* (pp. 301–317). Woodhead Publishing Limited.
- Deegan, K. C., Holopainen, U., McSweeney, P. L. H., Alatossava, T., & Tuorila, H. (2014). Characterisation of the sensory properties and market positioning of novel reduced-fat cheese. *Innovative Food Science and Emerging Technologies*, 21, 169–178.
- Delgado-Pando, G., Cofrades, S., Ruiz-Capillas, C., Solas, M. T., Triki, M., & Jiménez-Colmenero, F. (2011). Low-fat frankfurters formulated with a healthier lipid combination as functional ingredient: Microstructure, lipid oxidation, nitrite content, microbiological changes and biogenic amine formation. *Meat Science*, 89, 65–71.
- Devereux, H. M., Jones, G. P., McCormack, L., & Hunter, W. C. (2003). Consumer acceptability of low fat foods containing inulin and oligofructose. *Journal of Food Science*, 68(5), 1850–1854.
- Dhiman, T. R., Anand, G. R., Satter, L. D., & Pariza, M. (1999). Conjugated linoleic acid content of milk from cows fed different diets. *Journal of Dairy Science*, 82, 2146–2156.
- Drake, M. A., Miracle, R. E., & McMahon, D. J. (2010). Impact of fat reduction on flavour and flavour chemistry of Cheddar cheeses. *Journal of Dairy Science*, 93, 5069–5081.
- Drake, M. A., & Swanson, B. G. (1995). Reduced and low-fat cheese technology. A review. *Trends in Food Science and Technology*, 6, 366–369.
- Drewnowski, A., Nordensten, K., & Dwyer, J. (1998). Replacing sugar and fat in cookies: Impact on product quality and preference. *Food Quality and Preference*, 9(1–2), 13–20.

- Duflot, P. (1996). Starches and sugars glucose polymers as sugar/fat substitutes. *Trends in Food Science & Technology*, 7, 206.
- EU, 1994. European Union. Standards for spreadable fats. Council regulation No. 2991/94 of 5 December 1994. Off J Eur Commun 1994; L 316:2-7.
- EU, (2007). European Union. COUNCIL REGULATION (EC) No 1234/2007 establishing a common organisation of agricultural markets and on specific provisions for certain agricultural products. Off J Eur Commun 2007;L299:1-149.
- FAO/WHO. (2007). *Standard for fat spreads and blended spreads. CODEX STAN 256*. Rome: Food and Agriculture Organization of the United Nations.
- FDA, 2015. 21CFR (Code of Federal Regulations) 135.110. Title 21-Food and Drugs. Chapter I-Food and Drug Administration. Department of Health and Human Services. Subchapter B-Food for Human Consumption. Part 135—Frozen Desserts. Subpart B-Requirements for Specific Standardized Frozen Desserts Sec. 135.110 Ice Cream and Frozen Custard. <<https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=135.110>>.
- FDA-DHHS, 2002. 21CFR101.62b: Nutrient Content Claims for Fat, Fatty Acid, and Cholesterol Content of Foods. Food and Drug Administration Department of Health and Human Services, Washington, DC.
- Fellendorf, S., Kerry, J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Science and Technology*, 92, 584–592.
- Fellendorf, S., Kerry, J. P., & O'Sullivan, M. G. (2018). Consumer attitudes on salt and fat reduced foods in the Republic of Ireland. *Food and Nutrition Sciences*, 9, 880–898. Available from <https://doi.org/10.4236/fns.2018.97066>.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding sausages. *Meat Science*, 103, 75–82.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016a). Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings. *European Food Research and Technology*, 242, 2105–2118.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016b). Impact of using replacers on the physicochemical properties and sensory quality of reduced salt and fat black pudding. *Meat Science*, 113, 17–25.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2017). Effect of different salt and fat levels on the physicochemical properties and sensory quality of black pudding. *Food Science & Nutrition*, 5(2), 273–284.
- Fenelon, M. A., Beresford, T. P., & Guinee, T. P. (2002). Comparison of different bacterial culture systems for the production of reduced-fat Cheddar cheese. *International Journal Dairy Technology*, 55, 194–203.
- Fernandez-Ginés, J. M., Fernández-López, J., Sayas-Barberá, E., Sendra, E., & Pérez-Álvarez, J. A. (2004). Lemon albedo as a new source of dietary fiber: Application to bologna sausages. *Meat Science*, 67, 7–13.
- Forker, A., Zahn, S., & Rohm, H. (2012). A combination of fat replacers enables the production of fat-reduced shortdough biscuits with high-sensory quality. *Food and Bioprocess Technology*, 5, 2497–2505.
- FSAI, *Salt Reduction Programme (SRP)*, p. 85, 2011 to 2012.
- García-García, E., & Totosaus, A. (2008). Low-fat sodium-reduced sausages: Effect of the interaction between locust bean gum, potato starch and K-carrageenan by a mixture design approach. *Meat Science*, 78, 406–413.
- Griguelmo-Miguel, N., Carreras-Boladeras, E., & Martín-Belloso, O. (2001). Influence of the addition of peach dietary fiber in composition, physical properties and acceptability of reduced-fat muffins. *Food Science and Technology International*, 7, 425–431.

- Halkjaer, J., Tjønneland, A., Overvad, K., & Sørensen, T. (2009). Dietary predictors of 5-year changes in waist circumference. *Journal of the American Dietetic Association*, 109(8), 1356–1366.
- Harrigan, K. A., & Breene, W. M. (1989). Fat substitutes: Sucrose esters and Simplese. *Cereal Foods World*, 34, 261–267.
- Henneberry, S., O'Sullivan, M. G., Kilcawley, K. N., Kelly, P. M., Wilkinson, M. G., & Guinee, T. P. (2016). Sensory quality of unheated and heated Mozzarella-style cheeses with different fat, salt and calcium levels. *International Journal of Dairy Science*, 69, 38–50.
- Hurtaud, C., & Peyraud, J. L. (2007). Effects of feeding Camelina (seeds or meal) on milk fatty acid composition and butter spreadability. *Journal of Dairy Science*, 90, 5134–5145.
- Inglett, G. E., Maneepun, S., & Vatanasuchart, N. (2000). Evaluation of hydrolysed oat flour as a replacement for butter and coconut cream in bakery products. *Food Science and Technology International*, 6, 457–462.
- Isik, U., Boyacioglu, D., Capanoglu, E., & Nilufer Erdil, D. (2011). Frozen yogurt with added inulin and isomalt. *Journal of Dairy Science*, 94, 1647–1656.
- Javidipour, I., Vural, H., Ozbas, O. O., & Tekin, A. (2005). Effects of interesterified vegetable oils and sugar beet fibre on the quality of Turkish-type salami. *International Journal of Food Science and Technology*, 5(40), 177–185.
- Johnson, M. E., Steele, J. L., Broadbent, J., & Weimer, B. C. (1998). Manufacture of Gouda and flavour development in reduced-fat Cheddar cheese. *Australian Journal of Dairy Technology*, 53(2), 67–69.
- Jung, J. Y., Kim, S. A., & Chung, H. J. (2005). Quality characteristics of low-fat muffin containing corn bran fiber. *Journal of the Korean Society of Food Science and Nutrition*, 34(5), 694–699.
- Karaca, O. B., Güven, M., Yasar, K., Kaya, S., & Kahyaoglu, T. (2009). The functional, rheological and sensory characteristics of ice creams with various fat replacers. *International Journal of Dairy Technology*, 62, 93–99.
- Kaur, A., Singh, G., & Kaur, H. (2000). Studies on use of emulsifiers and hydrocolloids as fat replacers in baked products. *Journal of Food Science and Technology e Mysore*, 37(3), 250–255.
- Kavas, G., Oysun, G., Kinik, O., & Uysal, H. (2004). Effect of some fat replacers on chemical, physical and sensory attributes of low-fat white pickled cheese. *Food Chemistry*, 88, 381–388.
- Kilcawley, K. N., & O'Sullivan, M. G. (2017). In P. Papademas, & T. Bintsis (Eds.), *Cheese flavour development and sensory characteristics. Global cheesemaking technology: Cheese quality and characteristics*. Chichester: John Wiley & Sons Ltd.
- Kim, H. Y., Yeom, H. W., Lim, H. S., & Lim, S. T. (2001). Replacement of shortening in yellow layer cakes by corn dextrins. *Cereal Chemistry*, 78(3), 267–271.
- Kim, M. K., Lopetcharat, K., & Drake, M. A. (2013). Influence of packaging information on consumer liking of chocolate milk. *Journal of Dairy Science*, 96, 4843–4856.
- Koeflerli, C. R. S., Piccinalli, P., & Sigrist, S. (1996). The influence of fat, sugar and non-fat milk solids on selected taste, flavour and texture parameters of a vanilla ice-cream. *Food Quality and Preference*, 7, 69–79.
- Komorowski, E. S. (2011). Saturated fat reduction in milk and dairy products. *Reducing Saturated Fats in Foods*, 179–194. Available from <https://doi.org/10.1016/B978-1-84569-740-2.50009-9>.
- Kosmark, R. (1996). Salatrim: Properties and applications. *Food Technology*, 50, 98–101.
- La Berge, A. F. (2008). How the ideology of low fat conquered America. *Journal of the History of Medicine and Allied Sciences*, 63, 139–177.

- Laguna, L., Primo-Martín, C., Varela, P., Salvador, A., & Sanz, T. (2014). HPMC and inulin as fat replacers in biscuits: Sensory and instrumental Evaluation. *LWT e Food Science and Technology*, 56, 494–501.
- Lakshminarayan, S. M., Rathinam, V., & KrishnaRau, L. (2006). Effect of maltodextrin and emulsifiers on the viscosity of cake batter and on the quality of cakes. *Journal of the Science of Food and Agriculture*, 86, 706–712.
- Lamarche, B., Givens, I., Soedamah-Muthu, S., Krauss, R. M., Jakobsen, M. U., BischoffFerrari, H. A., Pan, A., & Després, J.-P. (2016). Does milk consumption contribute to cardiometabolic health and overall diet quality? *Canadian Journal of Cardiology*, 32, 1026–1032.
- Lamparski, G., & Tobota, G. (2007). Comparing sensory quality of full and reduced fat commercial cheeses. *Polish Journal of Food and Nutrition Sciences*, 57, 71–75.
- Lee, C. H., Liao, H. L., Lee, W. C., Hsu, C. K., Hsueh, F. C., Pan, J. Q., ... Chen, M. J. (2018). Standards and labeling of milk fat and spread products in different countries. *Journal of food and Drug Analysis*, 26, 469–480.
- Li, D., Siriamornpun, S., Wahlqvist, M. L., Mann, N. J., & Sinclair, A. J. (2005). Lean meat and heart health. *Asia Pacific Journal of Clinical Nutrition*, 14(2), 113–119.
- Lordan, R., & Zabetakis, I. (2017). Invited review: The anti-inflammatory properties of dairy lipids. *Journal of Dairy Science*, 100, 4197–4212.
- Ma, L., & Barbosa-Canovas, G. V. (1995). Rheological characterization of mayonnaise. Part II: Flow and viscoelastic properties at different oil and xanthan gum concentrations. *Journal of Food Engineering*, 25, 409–425.
- Maache-Rezzoug, Z., Bouvier, J. M., Allaf, K., & Patras, C. (1998). Effect of principal ingredients on rheological behaviour of biscuit dough and on quality of biscuits. *Journal of Food Engineering*, 35, 23–42.
- Madsen, J. S., & Ardö, Y. (2001). Exploratory study of proteolysis, rheology and sensory properties of Danbo cheese with different fat contents. *International Dairy Journal*, 11, 423–431.
- Mallia, S., Escher, F., & Schlichtherle-Cerny, H. (2008). Aroma-active compounds of butter: A review. *European Food Research and Technology*, 226, 315–325.
- Manley, D. (2011a). Chapter 1: Setting the scene: A history and the position of biscuits. In: Manley, D. (Ed.), *Manley's technology of biscuits, crackers and cookies* (pp. 1–9).
- Mantzouridou, F., Karousioti, A., & Kiosseoglou, V. (2013). Formulation optimization of a potentially prebiotic low-in-oil oat-based salad dressing to improve *Lactobacillus paracasei* subsp. *Paracasei* survival and physicochemical characteristics. *LWT, Food Science and Technology*, 53, 560–568.
- Marshall, R. T., & Arbuckle, W. S. (1996). *Ice cream* (5th ed., p. 349) New York: Chapman & Hall.
- Martínez-Cervera, S., Salvador, A., Muguerza, B., Moulay, L., & Fiszman, S. M. (2011). Cocoa fibre and its application as a fat replacer in chocolate muffins. *LWT e Food Science and Technology*, 44(3), 729–736.
- Martínez-Cervera, S., Salvador, A., & Sanz, T. (2015). Cellulose ether emulsions as fat replacers in muffins: Rheological, thermal and textural properties. *LWT – Food Science and Technology*, 63(2015), 1083–1090.
- Martínez-Cervera, S., Sanz, T., Salvador, A., & Fiszman, S. M. (2012). Rheological, textural and sensorial properties of low-sucrose muffins reformulated with sucralose/polysaccharide. *LWT – Food Science and Technology*, 45, 213–220.
- McCarthy, C. M., Wilkinson, M. G., Kelly, P. M., & Guinee, T. P. (2016). Effect of salt and fat reduction on proteolysis, rheology and cooking properties of Cheddar cheese. *International Dairy Journal*, 56, 74–86.
- McMahon, D., Alleyne, M., Fifé, R., & Oberg, C. (1996). Use of fat replacers in low fat Mozzarella cheese. *Journal of Dairy Science*, 79(11), 1911–1921.

- McCain, H. R., Kaliappan, S., & Drake, M. S. (2018). Invited review: sugar reduction in dairy products. *Journal of Dairy Science*, 101, 8619–8640.
- Micha, R., Wallace, S., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus. A systematic review and metaanalysis. *Circulation*, 121, 2271–2283.
- Milner, L., Kerry, J. P., O'Sullivan, M. G., & Gallagher, E. (2019). Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients. *Innovative Food Science and Emerging Technologies*, 59, 102235. Available from <https://doi.org/10.1016/j.ifset.2019.102235>.
- Mistry, V. V. (2001). Low fat cheese technology. *International Dairy Journal*, 11, 413e422.
- Moriano, M. E., Cappa, C., & Alamprese, C. (2018). Reduced-fat soft-dough biscuits: Multivariate effects of polydextrose and resistant starch on dough rheology and biscuit quality. *Journal of Cereal Science*, 81, 171–178.
- Mitchell, H. L. (1996). The role of bulking agent polydextrose in fat replacement. In: Roller, S., Jeong, J. Y., Lee, E. S., Choi, J. H., Lee, J. Y., Kim, J. M., Min, S. G., Kim C. J. (2007). Variability in temperature distribution and cooking properties of ground pork patties containing different fat level and with/without salt cooked by microwave energy. *Meat Science*, 75(3), 415–422.
- Murphy, S. C., Gilroy, D., Kerry, J. F., Buckley, D. J., & Kerry, J. P. (2004). Evaluation of surimi, fat and water content in a low/no added pork sausage formulation using response surface methodology. *Meat Science*, 66, 689–701.
- Nelson, B. K., & Barbano, D. M. (2004). Reduced-fat Cheddar cheese manufactured using a novel fat removal process. *Journal of Dairy Science*, 87, 841–853.
- Nip, W. K. (2007). Sweeteners. In H. Hui (Ed.), *Bakery products: science and technology* (pp. 137–159). Chicago, IL: Blackwell Publishing.
- O'Callaghan, T., Faulkner, H., McAuliffe, S., O'Sullivan, M. G., Hennessy, D., Dillon, P., ... Ross, P. (2016). Quality characteristics, chemical composition, and sensory properties of butter from cows on pasture versus indoor feeding systems. *Journal of Dairy Science*, 99, 9441–9460.
- O'Sullivan, M. G. (2017b). CH9. Nutritionally optimised low fat foods. *A handbook for sensory and consumer driven new product development: innovative technologies for the food and beverage industry* (pp. 177–196). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017c). CH11. Sensory properties affecting meat and poultry quality. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 225–257). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017d). CH12. Sensory properties of dairy products. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 259–280). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017a). CH14. Sensory properties of bakery and confectionary products. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 305–324). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2019). Nutritional optimisation through reductions of salt, fat and sugar using sensory and consumer driven techniques. In R. Vasilios (Ed.), *Reformulation as a strategy for developing healthier food products: Challenges and recent developments*. Springer.
- O'Sullivan, M. G., Thornton, G., O'Sullivan, G. C., & Collins, J. K. (1992). Probiotic bacteria: Myth or reality? *Trends in Food Science and Technology*, 3, 309–317.
- Özvural, E. B., & Vural, H. (2008). Utilization of interesterified oil blends in the production of frankfurters. *Meat Science*, 78, 211–216.
- Parker, A., Gunning, P. A., Ng, K., & Robins, M. N. (1995). How does xanthan stabilise salad dressing. *Food Hydrocolloids*, 9, 333–342.

- Peters, J. C., Lawson, K. D., Middleton, S. J., & Triebwasser, K. C. (1997). Assessment of the nutritional effects of olestra, a nonabsorbed fat replacement: introduction and overview. *Journal of Nutrition*, 127, 1539–1546.
- Prarikh, A., Agarwal, S., & Raut, K. (2014). A review on application of maltodextrin in pharmaceutical industry. *International Journal of Pharmacy and Biological Sciences*, 4, 67–74.
- Prindiville, E. A., Marshall, R. T., & Heymann, H. (1999). Effect of milk fat on the sensory properties of chocolate ice cream. *Journal of Dairy Science*, 82, 1425–1432.
- Prosslow (2016). Development of consumer accepted low salt and low fat Irish traditional processed meats. Project Coordinator: Dr Maurice O' Sullivan. Ref:11F026. <<https://www.agriculture.gov.ie/media/migration/research/firmreports/CALL2011ProjectAbstracts240216.pdf>>.
- Pszczola, D. E. (1994). Blends reduce fat in bakery products. *Food Technology*, 46, 168–170.
- Rasmussen, B. M., Vessby, B., Uusitupa, M., Berglund, L., Pedersen, E., Riccardi, G., ... Hermansen, K. (2006). Effects of dietary saturated, monounsaturated, and n-3 fatty acids on blood pressure in healthy subjects. *The American Journal of Clinical Nutrition*, 83(2), 221–226.
- Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, 21(6), 611–620.
- Ritvanen, T., Lampolahti, S., Lilleberg, L., Tupasela, T., Isoniemi, M., Appelbye, U., ... Uusi-Rauva, E. (2005). Sensory evaluation, chemical composition and consumer acceptance of full fat and reduced fat cheeses in the Finnish market. *Food Quality and Preference*, 16, 479–492.
- Rodríguez-García, J., Sahi, S. S., & Hernando, I. (2014). Functionality of lipase and emulsifiers in low-fat cakes with inulin. *LWT e Food Science and Technology*, 58, 173–182.
- Roland, A. M., Phillips, L. G., & Boor, K. J. (1999). Effects of fat replacers on the sensory properties, colour, melting, and hardness of ice cream. *Journal of Dairy Science*, 82, 2094–2100.
- Rolon, M. L., Bakke, A. J., Coupland, J. N., Hayes, J. E., & Roberts, R. F. (2017). Effect of fat content on the physical properties and consumer acceptability of vanilla ice cream. *Journal of Dairy Science*, 100, 5217–5227.
- Ruusunen, M., Vainionpää, J., Lyly, M., Lähteenmäki, L., Niemistö, M., Ahvenainen, R., & Puolanne, E. (2005). Reducing the sodium content in meat products: The effect of the formulation in low-sodium ground meat patties. *Meat Science*, 69(1), 53–60.
- Sampaio, G. R., Castellucci, C. M. N., Pinto e Silva, M. E. M., & Torres, E. A. F. S. (2004). Effect of fat replacers on the nutritive value and acceptability of beef frankfurters. *Journal of Food Composition and Analysis*, 17, 469–474.
- Schaller-Povolny, L. A., & Smith, D. E. (1999). Sensory attributes and storage life of reduced fat ice cream as related to inulin content. *Journal of Food Science*, 64, 555–559.
- Schessler-Jandreau, I. (2008). Fat America: A historical consideration of diet and weight loss in the U.S. Communication and Public Policy. In *Proceedings of the 2008 international colloquium on communication*. <<https://scholar.lib.vt.edu/ejournals/ICC/2008/ICC2008Schessler.pdf>>.
- Schmidt, K., Lundy, A., Reynolds, J., & Yee, L. (1993). Carbohydrate or protein based fat mimicker effects on ice milk properties. *Journal of Food Science*, 58, 761–763.
- Srisuvor, N., Chinprahast, N., Prakitchaiwattana, C., & Subhimaros, S. (2013). Effects of inulin and polydextrose on physicochemical and sensory properties of low-fat set yoghurt with probiotic-cultured banana purée. *LWT- Food Science and Technology*, 51, 30–36.

- Sodini, I., Remeuf, F., Haddad, S., & Corrieu, G. (2004). The relative effect of milk base, starter, and process on yoghurt texture: A review. *Critical Reviews in Food Science and Nutrition*, 44(2), 113–137.
- Staffolo, M. D., Bertola, N., Martino, M., & Bevilacqua, Y. A. (2004). Influence of dietary fiber addition on sensory and rheological properties of yogurt. *International Dairy Journal*, 14, 263e268.
- Sweetlow (2016). Development of consumer optimised low carbohydrate Irish confectionary products. Project Coordinator: Dr Maurice O' Sullivan. Ref:14/F/812. <<https://www.agriculture.gov.ie/media/migration/research/firmreports/CALL2014ProjectAbstracts240216.pdf>>.
- Talbot, G. (2011). CH1, Saturated fats in foods and strategies for their replacement: An introduction. In G. Talbot (Ed.), *Reducing saturated fats in foods* (pp. 1–28). Woodhead Publishing Limited.
- Tamime, A. Y., Barclay, M. N. I., Davies, G., & Barrantes, E. (1994). Production of low-calorie yoghurt using skim milk powder and fat substitutes. 1. A review. *Milchwissenschaft*, 49, 85–87.
- Tamime, A. Y., Barrantes, E., & Sword, A. M. (1996). The effect of starch based fat substitutes on the microstructure of set-style yogurt made from reconstituted skimmed milk powder. *Journal of the Society of Dairy Technology*, 49, 1–10.
- Taubes, G. (2013). The science of obesity: What do we really know about what makes us fat? An essay by Gary Taubes. *British Medical Journal*, 346, f1050. Available from <https://doi.org/10.1136/bmj.f1050>. (Published 17 April 2013).
- The People's Republic of China. (2010). Cream, butter and anhydrous milk fat. *National Food Safety Standard GB 19646-2010*.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, 4, 460–465.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, 92, 659–666.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013a). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, 93, 145–152.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013b). European consumer attitudes on the associated health benefits of nutraceutical-containing processed meats using co-enzyme Q10 as a sample functional ingredient. *Meat Science*, 97, 207–213.
- Trigueros, L., Pérez-Alvarez, J. A., Viuda-Martos, M., & Sendra, E. (2011). Production of low-fat yoghurt with quince (*Cydonia oblonga* Mill.) scalding water. *LWT e Food Science and Technology*, 44(6), 1388–1395.
- Ulbricht, T., & Southgate, D. (1991). Coronary heart disease: Seven dietary factors. *The Lancet*, 338(8773), 985–992.
- USDA, 1995. USDA Specifications for Light Butter. <https://www.ams.usda.gov/sites/default/files/media/lightbutter.pdf>
- Ventanas, S., Puolanne, E., & Tuorila, H. (2010). Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. *Meat Science*, 85(3), 410–419.
- Verbeke, W., Pérez-Cueto, F. J. A., De Barcellos, M. D., Krystallis, A., & Grunert, K. G. (2010). European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science*, 84(2), 284–292.
- Vessby, B., Uusitupa, M., Hermansen, K., Riccardi, G., Rivellese, A. A., Tapsell, L. C., ... Storlien, L. H. (2001). Substituting dietary saturated for monounsaturated fat

- impairs insulin sensitivity in healthy men and women: the KANWU study. *Diabetologia*, 44, 312–319.
- Walstra, P., Wouters, J. T. M., & Geurts, T. J. (2006). CH22: Fermented milks. In P. Walstra, J. T. M. Wouters, & T. J. Geurts (Eds.), *Dairy science and technology* (2nd ed., pp. 357–397). Boca Raton, London, New York: Taylor & Francis Group.
- Webb, E. C. (2006). Manipulating beef quality through feeding. *South African Animal Science*, 7, 5–15.
- Weiss, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science*, 86(1), 196–213.
- Wilbey, R. A. (2009). 'Butter', in Dairy fats and related products. In A. Y. Tamime (Ed.), *Society of Dairy Technology*. Wiley-Blackwell.
- Wood, J. D. (1990). Consequences for meat quality of reducing carcass fatness. In J. D. Wood, & A. V. Fisher (Eds.), *Reducing fat in meat animals* (pp. 344–397). London: Elsevier Applied Science.
- Zoulias, E. I., Oreopoulou, V., & Kounalaki, E. (2002). Effect of fat and sugar replacement on cookie properties. *Journal of the Science of Food and Agriculture*, 82, 1637–1644.



Reduced-salt products and challenges

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Introduction

Globally, the average daily dietary salt intake is more than double the recommended level (Zandstra, Lion, & Newson, 2016). Intake of dietary sodium has been linked to hypertension in about 20% of the population and consequently increased the risk of cardiovascular disease (CVD). The estimated cost of CVD to both the EU and US economies is €169B and \$403B, respectively (Desmond, 2006).

Consumers demand food products that are low in salt, fat, cholesterol, nitrites and calories, as well as potentially containing health-promoting bio-active components such as for example carotenoids, unsaturated fatty acids, sterols, and fibers (Weiss, Gibis, Schuh, & Salminen, 2010). Therefore many countries have begun with campaigns to reduce the dietary salt and fat consumption in their population (O'Sullivan & Byrne, 2019). Thus the demand for healthier food has already increased with consumers demanding healthier and more natural food, including convenience foods (Barcellos, Grunert, & Scholderer, 2011). Meat product suppliers have already commenced reformulating their recipes and now offer lower levels of nitrate, salt and fat, or even higher levels of polyunsaturated fatty acids in processed meat products on the market (Verbeke, Pérez-Cueto, De Barcellos, Krystallis, & Grunert, 2010). Also, the food-manufacturing industry has already lowered salt levels in many products using a “stealth” approach,

gradually reducing salt over years without actively informing consumers (Dötsch et al., 2009). For commercial foods, further reductions in the salt content must be achieved while also maintaining good taste, stability, and texture to ensure consumers will like (or even prefer) these reformulated products (Zandstra et al., 2016). Convenience food versions of traditional recipes are quite common across some less conservative EU countries and the demand for such products is steadily increasing (Brunner, van der Horst, & Siegrist, 2010). Thus many traditional food manufacturers are working on recipes low in salt, while in parallel public health campaigns are promoting the consumption of healthier foods (Fellendorf, Kerry, & O'Sullivan, 2018). European consumers demand safe traditional food products with optimal sensory properties, but also for a greater variety, with higher convenience, and nutrition with healthier options (Guerrero et al., 2009). This can be challenging as modifying traditional recipes can consequently negate their traditional status, particularly in conservative regions like Greece, France, and Italy, in particular (O'Sullivan, 2019). Fellendorf, Kerry, and O'Sullivan (2018) have investigated whether Irish consumers ($n = 1045$) have processed the message that they include healthier foods, including salt- and fat-reduced foods, in their diet. Their survey data showed that campaigns regarding the importance of a balanced diet were generally well accepted by respondents with more than half of the participants reporting that they followed a balanced diet carefully. In addition, an increase in the purchasing behavior of low-salt foods was observed, although fat-reduced food products were already better accepted. Moreover, there was no conflict for traditional foods that contain less salt and fat if their intrinsic sensory character is preserved (O'Sullivan & Byrne, 2019). Salt and fat-reduced processed meat has even been proposed as delivery systems for bioactive ingredients (Tobin, O'Sullivan, Hamill, & Kerry, 2014). However, there is still enormous potential to produce even healthier and more sensory-accepted products (Fellendorf, O'Sullivan, & Kerry, 2018). This chapter will discuss salt-reduction strategies for a wide range of products, including dairy, meat, bread, and convenience foods.



Salt in bread

Cereal and cereal products, such as breads, breakfast cereals, biscuits and cake, contribute approximately 30%–50% of the overall salt intake (World Health Organization, 2007). Bread is a good source of nutrients

and fiber. However, it is also the single largest contributor of sodium (Na) to the American diet ([Centers for Disease Control and Prevention, 2011](#)). This is primarily due to salt in bread but also due to quantities of consumption. Two of the top five sources of sodium in the US diet are bread and rolls, followed by meat products, pizza, poultry, and soups ([Mueller, Koehler, & Scherf, 2016](#)). Also, cereal products have been reported to be responsible for 30% of the overall salt intake in Ireland ([Lynch, Dal Bello, Sheehan, Cashman, & Arendt, 2009](#)).

Reducing the level of salt in bread would have a major impact on global public health. However, salt is a critical ingredient in bread production, and its reduction can have a deleterious effect on the production processes such as dough handling, as well as bread quality, shelf life, bread volume, and sensory characteristics ([Belz, Ryan, & Arendt, 2012](#)). Salt in bread is important in providing taste, affecting yeast activity, strengthening the gluten network, and thus the gas retention of dough ([Lynch et al., 2009](#)).

In the UK population, intake of salt from cereal is 38% and in Norway it is 22% ([Helsedirektoratet, 2011](#)). Salt performs four main functions in bread production. First to impart flavor, second to control yeast growth and fermentation rate. Third, the improvement of product texture and finally the reduction of spoilage, particularly mold spoilage ([Man, 2007](#)).

Sequential reduction of sodium in bread has been effective in some countries with gradual reduction over time without consumers noticing, essentially a steal approach ([Quilez & Salas-Salvado, 2012](#); [Silow, Axel, Zannini, & Arendt, 2016](#)). [Lynch et al. \(2009\)](#) produced breads without salt which resulted in products with sensory properties described as “sour/acidic,” “sourdough,” and “yeasty” flavor. These authors concluded that the production of bread containing lower salt levels (without replacement) is technologically feasible, but that the taste of the bread needs to be improved. [Rødbotten et al. \(2015\)](#) investigated the sensory profile and consumer preference in five European countries of barley bread with normal and low salt content. The control bread with no barley flakes or whole barley grains was the preferred bread by the Czech, Estonian, Scottish, and Spanish consumers, whereas the Norwegian consumers preferred the grainiest breads. The breads with low salt content were not preferred by the consumers. However, consumers were moderately positive to a salt reduction in breads even if they gave the breads with normal content salt a higher score for liking. [La Croix et al. \(2014\)](#) found that reducing Na levels by up to 30% in a sandwich bread did not affect

consumer liking or purchase intent of the product. Spina et al. (2015) investigated the partial replacement of NaCl in bread made from durum wheat (*Triticum turgidum* L. subsp. durum Desf.) with KCl and yeast extract. The experimental breads were packaged under modified atmosphere conditions (70% N₂/30% CO₂) and stored at 25°C for up to 120 days. These authors found no significant differences in bread samples for specific volume, crumb porosity, crust thickness, loaf firmness, and moisture content. The bread samples with low NaCl contents were acceptable when considering the main sensory attributes.

Replacers can maintain better technological quality during bread production but have sensory limitations due to bitterness in the case of potassium salts (Raffo et al., 2018; Salovaara, 1982). Better results can be achieved for brown bread using potassium, magnesium, and calcium salts (Charlton, Macgregor, Vorster, Levitt, & Steyn, 2007). Mueller et al. (2016) investigated sodium reduction in pizza crust without any topping, by sensory analyses. They found that it was possible to reduce sodium by 10% in one single step or to replace 30% of NaCl by KCl (potassium chloride) without a noticeable loss of salty taste. In addition, these authors investigated regional application of salt to enhance localized oral perception during consumption. This included late addition of coarse-grained NaCl (crystal size: 0.4–1.4 mm) to pizza dough and the aqueous salt solution to one side of the pizza crust. Both these strategies resulted in a sodium reduction of up to 25% while maintaining taste quality.

The combination use of sodium, potassium salts, and magnesium together with amino acids such as lysine have been patented to mask the taste defects of potassium chloride (Pansalt) (Silow et al., 2016). Raffo et al. (2018) substituted NaCl with a mixture of inorganic salts and taste enhancers present in Pansalt. This approach was only partially effective in maintaining saltiness, while producing perceptible increases in bitter taste and aftertaste in crust at an addition level of 3%.



Salt in processed meats

Fresh meat contains little sodium, but processed meat contains 2% added salt, a value that can increase up to 6% in dried products. Thus, processed meat products include one of the main sources of sodium in the diet in the form of sodium chloride (salt) (Desmond, 2006). Processed

meat is responsible for a relevant part of the average daily sodium intake by consumers and, therefore, the meat-processing industry is trying to develop low-salt meat products to address consumer issues and meet with government health recommendations (O'Sullivan, 2019). The clear association between meat consumption and the incidence of hypertension (Paik, Wendel, & Freeman, 2005) confirms the importance of meat technology in relation to salt intake. Apart from the recommendation to limit the consumption of salty foods and foods processed with salt (sodium) (WCRF, 2007), a possible association between cancer of processed meat and colon cancer cannot be ruled out. Ireland and the United States Kingdom's daily intake of sodium by adults is approximately three times the recommended daily amount and, therefore, public health and regulatory authorities recommend reducing dietary sodium intake to 2.4 g (6 g of salt) per day (Desmond, 2006).

Salt has an essential function in terms of taste, texture, and shelf life in meat products (Desmond, 2006) but is responsible for a variety of serious lifestyle diseases, if consumed at high intake levels. For this reason, several government agencies have set targets that the industry wants to achieve in order to gradually reduce the salt content of processed foods over time. The Food Safety Authority has recommended a salt reduction to 1.63 g (650 mg sodium) (Conroy, O'Sullivan, Hamill, & Kerry, 2018).

Meat suppliers have already started to reformulate their formulations and now offer lower nitrate, salt and fat levels, or even higher levels of polyunsaturated fatty acids in processed meat products on the market (Verbeke et al., 2010). There are two possible strategies for salt and fat reduction: reduction without using alternative ingredients and, second, using alternative ingredients such as salt/fat substitutes.

Many studies have focused on salt reduction without using substitute ingredients in processed meat. Tobin, O'Sullivan, Hamill, and Kerry (2012a) demonstrated that the most acceptable meat patty formulation in a salt and fat-reduction study was 20% fat and 0.5% salt. This is a 20% reduction in the fat content and a 50% reduction in the salt content of the average commercial patties. Additional studies demonstrating reduction without replacement ingredients for other processed meats include those for breakfast sausages (Tobin, O'Sullivan, Hamill, & Kerry, 2013a, 2013b), Frankfurter, white pudding (Fellendorf, O'Sullivan, & Kerry, 2015; PROSSLOW, 2016; Tobin, O'Sullivan, Hamill, & Kerry, 2012b), and black pudding (Fellendorf, O'Sullivan, & Kerry, 2016a; PROSSLOW, 2016). These studies essentially reduced

salt and fat sequentially, without using alternative ingredients to determine sensory optim, while maintaining safety, functionality, and adequate shelf life. The reduction of salinity could also be optimized through the use of packaging technologies to compensate for the loss of safety or durability (Fellendorf, O'Sullivan, & Kerry, 2017; PROSSLOW, 2016).

Sensory methods for salt/fat reduction also included the use of rapid sensory methods such as flash profiling (O'Sullivan, 2017) demonstrated for a variety of meat products, including French raw sausages (Rason, Lebecque, Ieger, & Dufour, 2003), meat empanadas (Tobin et al., 2012a), Frankfurter (Tobin et al., 2012b), and sausages for breakfast (Tobin et al., 2013a, 2013b). In addition, descriptive analyzes of the classification list and sensory acceptance tests have been carried out successfully for several other processed meat products, including white pudding (Fellendorf et al., 2015; Fellendorf, O'Sullivan, & Kerry, 2016b), black pudding (Fellendorf et al., 2016a, 2016b), and cured meat (Fellendorf, Kerry, & O'Sullivan, 2018; Fellendorf, Kerry, Hamill, & O'Sullivan, 2018).

Salt substitutes offer other options with respect to the reduction of salt in processed meat. The basis for the use of salt replacers is the reduction of sodium cations with potassium, magnesium, calcium, or to reduce chloride anions with ingredients such as glutamates and phosphates as a flavoring agent (Wheelock & Hobbiss, 1999). The most commonly used salt substitute is potassium chloride, although it is self-limiting due to its bitter and metallic taste when used above certain concentrations (Dzendolet & Meiselman, 1967). However, the perception of the bitter taste of potassium chloride can be suppressed by use in combination with other salt substitutes. Zanardi, Ghidini, Conter, and Ianieri (2010) successfully reduced the sodium content of Cacciatore salami, a typical Italian dry fermented sausage, using a mixture of KCl, CaCl₂, and MgCl₂. Other strategies for the replacement of ingredients included reducing the total amount of salt or the (partial) substitution of sodium chloride with potassium, magnesium and calcium chloride, glutamate, glycine, and potassium lactate (Aaslyng, Vestergaard, & Koch, 2014; Aliño, Grau, Toldrá, & Barat, 2010; Aliño, Gray, Toldrá, Blesa et al., 2010; Fellendorf et al., 2015, 2016a, 2016b; Fellendorf, O'Sullivan, & Kerry, 2017; Gou, Guerrero, Gelabert, & Arnau, 1996; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2008; Tobin et al., 2012a, 2012b, 2013a, 2013b). The most efficient result is the replacement of sodium with potassium to simultaneously increase potassium uptake.

Hydrocolloids have been used in meat products for many years to thicken, gel, bind, improve sensory properties, texture, emulsify, and stabilize pH levels (Andr s, Zaritzky, & Califano, 2006; Fellendorf et al., 2015, 2016b). Hydrocolloids based on animal proteins include casein, whey, gelatin, and blood proteins. In addition, there is a huge range of polysaccharides available on the market, such as starches (corn, wheat, corn, potatoes, tapioca, and peas), celluloses (carboxymethylcellulose), gum (guar, alginate, pectin, and carob), fibers (β -glucan), chitin/chitosan, and xanthan from microorganisms (Cutter, 2006). Recent studies have also highlighted the use of several types of edible seaweed (sea spaghetti, wakame, and nori) in meat products (Cofrades, L pez-L pez, Solas, Bravo, & Jim nez-Colmenero, 2008; Fellendorf et al., 2015; Jim nez-Colmenero, Carballo, & Cofrades, 2001; L pez, Cofrades, Yakan, Sola, & Jim nez-Colmenero, 2010). Seaweed is a rich source of minerals, trace elements, protein compounds, and flavorings (reducing sugars) that can act as flavor enhancers or even as reagents in the process of flavor development (Maillard reaction, caramelization) in processed meat. Seaweed also has a unique flavor profile that can replenish the loss of flavor of meat products processed with fat and salt (Hotchkiss, 2012). In addition, salt enhancers such as amino acids (glycine and glutamate), lactates, and yeast extracts have found application in processed meat. These substances in themselves do not have salty taste, although they may improve salty taste with sodium chloride combination (Desmond, 2006). The authors Gu rdia et al. (2008) successfully replaced 50% NaCl with a mixture of KCl and potassium lactate in small fermented sausages. Recently, dos Santos, Campagnol, Morgano, and Pollonio (2014) reported that cooked fermented sausages containing monosodium glutamate in combination with lysine, taurine, disodium inositol, and disodium guanylate masked the unpleasant sensory properties associated with 50% and 75% replacement of NaCl with KCl.

Phosphates are very effective water binders in processed meat and can dramatically improve cooking performance by increasing the ionic strength and releasing negative ion sites on the surface of the meat protein, thus increasing the binding of more water. Sodium polyphosphate and sodium tripolyphosphate are very effective water binders and contain sodium salts that partially contribute to the salty taste, but the addition rate to the formulations is usually less than 0.05%. Barbut, Maurer, and Lindsey (1988) found that sodium tripolyphosphate and other phosphates (sodium hexametaphosphate and sodium acid pyrophosphate) used at

0.4% addition improved the stability of the emulsion and the sensory properties of 20% and the 40% reduced turkey products. [Ruusunen, Särkkä-Tirkkonen, and Puolanne \(1999\)](#) believe that the NaCl content of cooked sausages with addition of phosphate can be reduced to 1.4% of the addition of NaCl without loss of flavor. In addition, these authors ([Ruusunen, Särkkä-Tirkkonen, & Puolanne, 2001](#)) reduced the salt content of cooked ham to 1.7% NaCl. However, as consumers demand clean labelled meat, there is an increasing demand for products manufactured without added phosphate ([O'Sullivan, 2017, 2019; O'Sullivan & Byrne, 2019](#)).

Many countries have their own traditional sausage recipes that vary depending on region, county, or even city of production. In Ireland and the United Kingdom, breakfast sausages are virtually identical and manufactured from pork or beef along with herbs or spices, cereals, or rusk. Traditionally, sausages are the main ingredients in the “Irish/English Breakfast” which also include bacon rashers, pork sausages, fried eggs, white pudding, black pudding, toast and also optionally a fried tomato, button mushrooms, baked beans, hash browns, and brown soda bread ([O'Sullivan & Byrne, 2019](#)). Other popular varieties include the Cumberland and Lincolnshire sausage, with their own unique flavors as derived from their respective traditional spice mixes ([O'Sullivan, 2019](#)).

Black pudding or blood sausage is a type of sausage produced from the blood of cattle, pigs, sheep, or goats, and regional varieties exist across the globe, from Europe, to the United States, to Asia ([O'Sullivan & Kerry, 2011](#)). Traditional blood sausages are popular in Ireland and England, where they are consumed typically sliced and fried as also a special feature of the traditional Irish and English breakfast. Black pudding, typical of those consumed in Ireland and the United Kingdom, contains lean pork meat, pork fat, pork blood powder, grains, onions, salt, and seasonings. In contrast, white pudding is manufactured without blood and contains generally a higher amount of cereal grains and spices. All ingredients are chopped and cooked in casings ([O'Sullivan & Byrne, 2019](#)). Salt and fat reduction using sensory acceptance testing combined with rapid profiling techniques have been successfully demonstrated for Black pudding ([Fellendorf et al., 2016b, 2017](#)). [Fellendorf et al. \(2016b\)](#) explored the application of traditional and clean label ingredients as salt and fat replacers in black pudding. These authors produced 22 black puddings possessing different fat (10%, 5%) and sodium (0.6%, 0.4%) levels which were used as base formulations for 11 different salt and fat replacers. Compositional,

physicochemical, and sensory analyses (hedonic and descriptive) were conducted. Black pudding samples with 5% fat and 0.6% sodium containing potassium chloride (KCl), potassium chloride and glycine mixture (KClG), and seaweed, respectively, and 10% fat and 0.4% sodium containing carrageen were rated higher ($P < .05$) for spiciness and saltiness. Samples with 10% fat and 0.4% sodium containing KClG were rated positively ($P < .05$) to fatness. Samples with 5% fat and 0.6% sodium containing pectin and a combination of potassium citrate, potassium phosphate, and potassium chloride (KCPCL), as well as samples containing 10% fat and 0.4% sodium with waxy maize starch were liked ($P < .05$) for flavor and overall acceptance. The Food Safety Authority of Ireland (FSAI) recommended a sodium target level of 0.6% and an even lower sodium level (0.4%) was achieved.

White pudding meat products are also popular in Ireland and in the United Kingdom and contribute a special feature of the traditional Irish and British breakfast (Ayto, 1990). Also called oatmeal pudding (white pudding), popular in Europe and America, is a processed meat product containing generally pork meat, fat, seasonings, bread, oatmeal, and other cereal grains. In general, it is manufactured from lean pork meat, pork fat, grains, onions, salt, and seasonings and is similar in nature to black pudding products but lacks the blood component present in the latter form. The fat content of commercial available white puddings range from 6.0% to 22.4% though the majority of the products contain between 12% and 18% fat (unpublished data, 2013; Fellendorf et al., 2015, 2016b). Fellendorf et al. (2016b) produced 22 white pudding formulations that were comprised of two different fats (10%, 5%) and sodium (0.6%, 0.4%) levels and containing 11 different traditional and clean label ingredient replacers. Compositional, texture, and sensory analysis were conducted. Adding replacers to low sodium and low fat white puddings showed a range of effects on sensory and physicochemical properties. Two formulations containing 10% fat and 0.6% sodium formulated with sodium citrate, as well as the combination of KClG, were found to have high overall acceptance ($P < .05$) by assessors. These samples showed higher ($P < .05$) hardness values, scored lower ($P < .05$) in fatness perception and higher ($P < .05$) in spiciness perception. Hence, the recommended sodium target level of 0.6% set by the Food Safety Authority of Ireland (FSAI, 2014) was achieved for white pudding products, in addition to a significant reduction in fat level from commercial levels, without causing negative sensory effects.

Salt is basic to all meat curing mixtures and is the primary ingredient necessary for curing. It acts by dehydration and alters the osmotic pressure, inhibiting bacterial growth and subsequent spoilage (Pearson & Tauber, 1984). Processed meats contribute 20%–30% to the daily salt (NaCl) intake in industrialized countries amounting to between 9 and 12 g/day, a much larger value than the recommended value of <5 g/day (Jiménez-Colmenero et al., 2001; WHO, 2003).

Cured meats can be divided in to two general categories, wet-cured and dry-cured with Wiltshire ham being an example of the latter. Irish traditional meat products that may contain nitrites include bacon, corned beef, and ham. Cooked cuts of salted/cured pork in Ireland are called bacon (O'Sullivan & Byrne, 2019). Due to their high contribution of the daily salt intake in the Irish population, the salt level of cured meat products, such as corned beef, has to be reduced. In addition, any optimized products must fulfill the sensory expectations of consumers. Fellendorf, Kerry, and O'Sullivan (2018) investigated the impact of varying sodium levels (0.2%–1.0%) and salt replacers in corned beef on physicochemical, sensory, and microbiological properties. Fellendorf, Kerry, Hamill, et al. (2018) employed an affective (hedonic) and descriptive sensory-driven sodium reduction strategy for corned beef. They investigated firstly sodium reduction and then used the same sensory methodology to further reduce salt, using salt replacers. Physicochemical and microbiological properties were also investigated to ensure that variants were still viable from a shelf life perspective. Potassium nitrite levels were kept constant for all variants and conformed to EU guidelines (Directive, 2006). Significant differences in color, hardness, and cooking loss were measured. Corned beef samples low in sodium (0.2%, 0.4%) showed reduced ($P < .05$) saltiness perception but were positively correlated to liking of flavor and overall acceptability. Samples formulated with the salt replacers CaCl_2 , MgCl_2 , and KCl scored higher ($P < .01$) in saltiness perceptions but correlated negatively ($P > .05$) to liking of flavor and overall acceptability. A sodium reduction of 60% in corned beef was achieved with products formulated with potassium lactate and glycine. This sensory-driven approach allowed the development of a healthier, reduced sodium, and consumer acceptable product while maintaining the traditional sensory characteristics, although the product was described as less-salty than the standard variety. Sodium reduction in corned beef (packaged under modified atmosphere) did not negatively impact on the microbiological shelf life (Fellendorf, O'Sullivan, & Kerry, 2017) (Fig. 4.1).

Black and white pudding, cryostat sections
 Light micrographs, stained with toluidine blue (protein = blue)

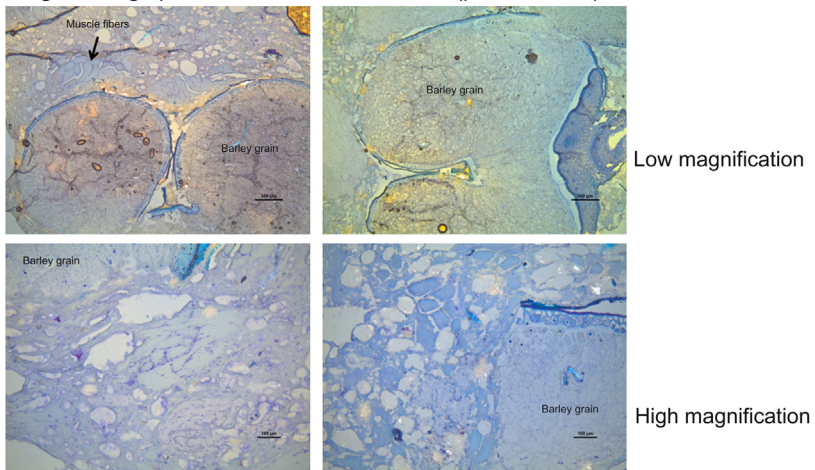


Figure 4.1 Light micrographs black pudding (top) and white pudding (bottom).



Salt in cheese

In cheese, salt (NaCl) directly impacts taste, acts as a flavor enhancer (FE), and influences structure and rheological properties of cheese. The extent of this impact on cheese flavor depends upon salt concentration, cheese composition, and the age of the cheese. The biochemical reactions in cheese are primarily initiated by the addition of microbial populations and/or exogenous enzymes during production. These biochemical reactions are in turn influenced by the milk (type, quality, and treatment), production equipment/processes, indigenous/exogenous microbial populations (selection and concentration), indigenous/exogenous enzymes (selection and concentration), salting (dry and brine), production processes and ripening regimes (time, temperature and humidity), all of which help contribute to the wide variety of cheeses available (Kilcawley & O'Sullivan, 2017).

The sensory properties of cheese depend on flavor, constituting taste and aroma, textural and rheological properties, and appearance (Delahunty & Drake, 2004). In addition, the acceptability of cheese to the consumer is influenced by many factors including sensory properties, functionality, convenience, price, and nutritional value (Henneberry et al., 2016).

Sodium chloride affects the compositional, water activity, microbial growth, enzymes activity, curd syneresis, solubility and hydration of protein during ripening, leading to the synchronized improvement in flavor and texture of the final product (Rulikowska et al., 2013). Extensive research has been undertaken for the development of reduced-fat or reduced-salt cheeses with quality characteristics (flavor, texture, and cooking properties) as close as possible to the control cheese (McCarthy, Wilkinson, Kelly, & Guinee, 2016). However, salt reduction in cheese is a major technological challenge as it contributes to flavor and affects microbial growth, enzyme activity, and syneresis, which in turn affects the cheese composition (Guinee & Fox, 2004). Salt reduction typically causes increases in moisture content, water activity, rate of lactose metabolism, extent of proteolysis, and a lower rate of starter cell autolysis. The fracture force and firmness of the unheated cheese are increased as is the flow and strength of the heated cheese is altered depending on the level of salt reduction (McCarthy, Wilkinson, Kelly, & Guinee, 2015). Reduction of salt also accelerates protein hydration that has a major influence on the physical properties and quality of cheese due to their influence on microstructure, rheology, and texture (McSweeney & Fox, 2009). Finally, low salt containing cheeses are normally pasty and have off flavor (Fox, 1975).

Cheddar cheese is extensively consumed as both a table cheese and as an ingredient in various culinary dishes in food service and in formulated foods products such as soups and sauces (Guinee, 2016). Cheddar is a hard cheese that varies extensively in consistency depending on how long it has been aged. Young cheddar is mild flavored and slightly soft and pasty becoming more crumbly in texture and more strongly flavored as it matures during ripening. Cheddar originated from the village of Cheddar, the south-west of Britain and is now among the most important cheeses made worldwide. It is made from pasteurized, standardized cow's milk using mesophilic starter cultures, and in large cheese factories, defined-strain starter systems are common (McSweeney, 2007). Increasing consumption of Cheddar cheese worldwide has concurrently resulted in an increase in the contribution of cheese to total dietary sodium (Khetra, Kanawjia, Puri, Kumar, & Meena, 2018). Cheddar cheese contains ~6 g Na/kg cheese and thus is considered as a high sodium-containing food (Beardsley, 2017). Salt replacers similar to those discussed in the previous section for processed meats also have applications in sodium reduction of cheeses including Cheddar. Replacers such as KCl and $MgCl_2$ may compensate for sensory and textural losses in cheese but similarly to

applications in processed meats have issues with metallic and bitter aftertastes in final products (Grummer, Karalus, Zhang, Vickers, & Schoenfuss, 2012). Bitter and metallic flavors as well as soft and pasty body are common defects of KCl applications for sodium reduction in cheddar cheese (Cruz et al., 2011). Similarly, Khetra et al. (2018) investigated sodium reduction in cheddar cheese by substituting 75% of sodium chloride (NaCl) with potassium chloride (KCl). However, to address the bitterness issue of using KCl they incorporated hydrolyzed vegetable protein and adenosine-50-monophosphate as bitter blocker in experimental variants. These authors found that the addition of these ingredients significantly improved the flavor, saltiness, and bitterness characteristics of the developed products. This study validated masking as a strategy for compensation for bitterness by using KCl in low or reduced sodium cheese. Grummer et al. (2012) investigated the use of CaCl_2 and MgCl_2 to reduce sodium in Cheddar-style cheese. Reduced-salt variants had flavor differences compared with the full-sodium control, and these flavors (bitter, metallic, earthy, unclean, soapy, and numbing)' these authors state, would not be desirable in high-quality cheese. Murtaza et al. (2014) investigated texture, flavor, and sensory quality of buffalo milk Cheddar cheese as influenced by reducing sodium salt content. These authors found that texture, hardness, toughness, and crumbliness lessened upon reducing the salt content and during the course of ripening. Reducing the sodium chloride content effected cheese composition, proteolysis, increased the raw, volatile flavor compounds content, but decreases the sensory quality (Murtaza et al., 2014).

Mozzarella is commonly consumed either in its natural form or heated as in the case when it is an ingredient of pizza. The different states yield fundamentally different products from a sensory perspective and thus it is important to understand both modalities when investigating reformulation studies with this product. Thus Henneberry et al. (2016) investigated the sensory quality of unheated and heated mozzarella style cheeses with different fat, salt, and calcium levels. These authors found that reducing salt content in the range studied (1.8%–1.0%, w/w) had little impact on the sensory properties of the cheese. This study is also discussed in the chapter on fat reduction, as this was also explored with this experiment.

Other popular regional cheeses have also been investigated with respect to salt reduction strategies. Halloumi, the brined goats and sheep cheese native to Cyprus, was investigated by Ayyash and Shah (2010). They partially substituted NaCl with KCl in the processing brine solutions

for the cheese. They found no significant difference between the chemical composition, lactic acid bacterial count, proteolysis and pH values of control and experimental, salt reduced, cheeses stored for similar periods. Gruyere cheese salt reduction was investigated by Lefier, Grappin, Grosclaude, and Curtat (1987) using a mixture of NaCl/MgCl₂. These authors found acceptable sensory properties, but reduced sodium variants resulted in final products with a slight bitterness and soft body. Coalho cheese is a traditional Brazilian “rennet” cheese highly appreciated for its sensory characteristics, such as soft aroma, compact, and soft texture (Bezerra et al., 2016). Coalho cheese has a high salt content (> 2%) which is necessary to prevent melting during heating, as it is typically cooked over a charcoal grill and eaten as a snack (Machado et al., 2011). Costa et al. (2018) investigated the partial substitution of NaCl by KCl in Coalho cheese over 60 days of refrigerated storage. They found that sodium replacement did not affect the physicochemical characteristics, pH, proteolysis indices, water activity or melting behavior of the cheeses. However, lower acceptance scores were observed for the substitution levels higher than 50%, which indicates this is an optimum threshold level for partial substitution. Prato, a semihard Brazilian cheese, is similar to the Danish cheese Danbo. Baptista, Araújo, da, Eberlin, and Gigante (2017) investigated the effect of salt reduction (25% and 50%) on proteolysis, firmness, and sensory acceptance of Prato cheese during 60 days of ripening. These authors found that the reduction of 25% was acceptable from a sensory perspective and that both the 25% and 50% salt content reduced variants did not lead to the formation of known bitter tasting peptides. Costa et al. (2018b) investigated the partial substitution of sodium chloride by salt substitutes in Prato cheese. They found that the sodium substitutes, KCl, Sub4salt, and Salona, did not interfere in the physicochemical, melting capacity, and texture profile of Prato cheeses and presented similar acceptance scores when compared to the control treatment.



Salt in convenience foods

Convenience foods are defined as any fully or partially prepared foods in which significant preparation time, culinary skills, or energy inputs have been transferred from the home kitchen to the food processor and distributor, they include ready-meals, fast food, meals from restaurants

or takeaways (Traub & Odland, 1979). Ready-meals are in turn defined as preprepared main courses that can be reheated in their container, requiring no further ingredients, and needing only minimal preparation before consumption (Remnant & Adams, 2015). For some time-poor consumers, there is little time to prepare meals from fresh ingredients in the home. Thus there is a segment of the population that has a strong demand for products that are convenient and quick to prepare in addition to being fresh, tasty, and safe to eat (Gelabert, Gou, Guerrero, & Arnaud, 2003; Mitchell, Brunton, & Wilkinson, 2011). Ready-meals tend to contain high levels of fat and saturated fat (Celnik, Gillespie, & Lean, 2012). Thus consumption of ready-meals has been linked to higher body weight in consumers of these products (van der Horst, Brunner, & Siegrist, 2011). Remnant and Adams (2015) examined the nutritional content of 166 ready-meals from 41 stores in the United Kingdom. These authors found that supermarket ready-meals do not have a healthful nutritional profile and overall ready-meals were high in saturated fat and salt, and low in sugar.

Mitchell, Brunton, and Wilkinson (2009) investigated the effect of salt levels on the sensory acceptability of a model frozen chicken curry ready meal. In collaboration with an industry partner, a control sample containing 0.6% salt and chicken curry ready meal variants containing between 0.2% and 1.5% salt were prepared. Sensory trials (paired comparison, triangle, preference, and ranking tests) indicated that salt levels in a chicken curry ready meal could be reduced to a level of 0.4% without detecting a difference in saltiness when compared to the commercial control containing 0.6% salt. The further incorporation of salt substitutes (KCl and yeast based) allowed a further reduction in salt levels to 0.2% without panelists detecting a noticeable difference in saltiness.

Mitchell et al. (2011) investigated salt reduction in ready-meals without replacement or also by using salt substitutes. These authors found from their sensory trials indicated that salt levels in a commercial chili con carne ready-meal could be reduced by up to 40% without a difference in taste being detected. Alternatively, they found that a commercial nucleotide yeast extract, compensated for loss in flavor, brought about by a reduction in salt and allowed for a salt reductions of up to 60%. Also any bitter notes contributed by KCl would be masked by a strongly flavored product like chili con carne.

Pizza is of Italian origin and now ubiquitously consumed as a food product, available in restaurants, supermarkets as a FMCG (fast moving

consumer goods) fresh or frozen product and sometimes made at home from constituent ingredients. It can also be considered a ready meal when available in supermarkets in the fresh or frozen format. Generally, pizza is composed of a leavened wheat-based dough base layered with tomato sauce, mozzarella cheese as the essential ingredients and then it is covered with a large assortment of vegetable, meat, or even fruit-based toppings. Its high consumption rates thus can contribute significantly to dietary fat and sodium, especially in the youth (Drewnowski & Rehm, 2013; Powell, Nguyen, & Dietz, 2015). Also, its ranking as third within the top five sources of sodium in the United States, makes pizza a major contributor to dietary intake, which makes it an important target for sodium reduction (Mueller et al., 2016).

References

- Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, 96(1), 47–55.
- Aliño, M., Grau, R., Toldrá, F., & Barat, J. M. (2010). Physicochemical changes in dry-cured hams salted with potassium, calcium and magnesium chloride as a partial replacement for sodium chloride. *Meat Science*, 86(2), 331–336.
- Aliño, M., Grau, R., Toldrá, F., Blesa, E., Pagán, M. J., & Barat, J. M. (2010). Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science*, 85(3), 580–588.
- Andrés, S., Zaritzky, N., & Califano, A. (2006). The effect of whey protein concentrates and hydrocolloids on the texture and colour characteristics of chicken sausages. *International Journal of Food Science & Technology*, 41(8), 954–961.
- Ayyash, M. M., & Shah, N. P. (2010). Effect of partial substitution of NaCl with KCl on Halloumi cheese during storage: Chemical composition, lactic bacterial count, and organic acids production. *Journal of Food Science*, 75, C525–C529.
- Ayto, J. (1990). *The Glutton's glossary: A dictionary of food and drink terms* (1st ed). London: Routledge.
- Baptista, D. P., Araújo, F. D., da, S., Eberlin, M. N., & Gigante, M. L. (2017). Reduction of 25% salt in Prato cheese does not affect proteolysis and sensory acceptance. *International Dairy Journal*, 75, 101–110.
- Barbut, S., Maurer, A. J., & Lindsey, R. C. (1988). Effects of reduced sodium chloride and added phosphates on physical and sensory properties of turkey frankfurters. *Journal of Food Science*, 35, 62–66.
- Barcellos, de M. D., Grunert, K. G., & Scholderer, J. (2011). Processed meat products: Consumer trends and emerging markets. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 30–53). Cambridge, New Delhi: Woodhead Publishing Limited.
- Beardsley, R.J. (2017). *Growth of E. coli in reduced salt cheddar cheese* (Doctoral dissertation). Pretoria, South Africa: University of Pretoria.
- Belz, M. C. E., Ryan, L. A. M., & Arendt, E. K. (2012). The impact of salt reduction in bread: A review. *Critical Reviews in Food Science and Nutrition*, 52(6), 514–524.

- Bezerra, T. K. A., Araujo, A. R. R. de, Nascimento, E. S. do, Paz, J. E. de M., Gadelha, C. A., Gadelha, T. S., et al. (2016). Proteolysis in goat “coalho” cheese supplemented with probiotic lactic acid bacteria. *Food Chemistry*, 196, 359–366.
- Brunner, T. A., van der Horst, K., & Siegrist, M. (2010). Convenience food products. Drivers for consumption. *Appetite*, 55(3), 498–506. Available from <https://doi.org/10.1016/j.appet.2010.08.017>.
- Celnik, D., Gillespie, L., & Lean, M. E. J. (2012). Time-scarcity, ready-meals, ill-health and the obesity epidemic. *Trends in Food Science & Technology*, 27(1), 4–11.
- Centers for Disease Control and Prevention. (2011). Usual sodium intakes compared with current dietary guidelines – United States, 2005–2008. *MMWR Morbidity and Mortality Weekly Report*, 60, 1413–1417.
- Charlton, K. E., Macgregor, E., Vorster, N. H., Levitt, N. S., & Steyn, K. (2007). Partial replacement of NaCl can be achieved with potassium, magnesium and calcium salts in brown bread. *International Journal of Food Sciences and Nutrition*, 58, 508–521.
- Conroy, P. M., O’Sullivan, M. G., Hamill, R. H., & Kerry, J. P. (2018). Impact on the physicochemical and sensory properties of salt- and fat-reduced traditional Irish breakfast sausages on various age cohorts acceptance. *Meat Science*, 143, 190–198.
- Cofrades, S., López-López, I., Solas, M. T., Bravo, L., & Jiménez-Colmenero, F. (2008). Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emulsion meat systems. *Meat Science*, 79, 767–776.
- Costa, R. G. B., et al. (2018). Manufacture of reduced-sodium Coalho cheese by partial replacement of NaCl with KCl. *International Dairy Journal*, 87, 37–43.
- Costa, R. G. B., et al. (2018b). Sodium substitutes in prato cheese: impact on the physicochemical parameters, rheology aspects and sensory acceptance. *LWT-Food Science and Technology*, 90, 643–649.
- Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, 74(1), 131–142.
- Cruz, A. G., Faria, J. A., Pollonio, M. A., Bolini, H., Celeghini, R., Granato, D., et al. (2011). Cheeses with reduced sodium content: Effects on functionality, public health benefits and sensory properties. *Trends in Food Science and Technology*, 22, 276–291.
- Delahunty, C. M., & Drake, M. A. (2004). Sensory character of cheese and its evaluation. In P. F. Fox, P. L. H. McSweeney, T. M. Cogan, & T. P. Guinee (Eds.), *Cheese: Chemistry, physics and microbiology, general aspects* (Vol. 1, pp. 455–487). Oxford: Elsevier.
- Desmond, E. (2006). Reducing salt: A challenge for the meat industry. *Meat Science*, 74, 188–196.
- Directive (2006). Directive 2006/52/EC of the European Parliament and of the Council of 5 July 2006 Amending Directive 95/2/EC on Food Additives Other than Colours and Sweeteners and Directive 95/35/EC on Sweeteners for Use in Foodstuffs, O.J. L204 of 26.7.2006.
- dos Santos, B. A., Campagnol, P. C. B., Morgano, M. A., & Pollonio, M. A. R. (2014). Monosodium glutamate, disodium inosinate, disodium guanylate, lysine and taurine improve the sensory quality of fermented cooked sausages with 50% and 75% replacement of NaCl with KCl. *Meat Science*, 96, 509–513.
- Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Mueller, R., et al. (2009). Strategies to reduce sodium consumption: A food industry perspective. *Critical Reviews in Food Science and Nutrition*, 49(10), 841–851.
- Drewnowski, A., & Rehm, C. D. (2013). Energy intakes of US children and adults by food purchase location and specific food source. *Nutrients*, 5, 1840–1855.
- Dzendolet, E., & Meiselman, H. L. (1967). Gustatory quality changes as a function of solution concentration. *Perception & Psychophysics*, 2, 29–33.

- Fellendorf, S., Kerry, J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Science and Technology*, 92, 584–592.
- Fellendorf, S., Kerry, J. P., & O'Sullivan, M. G. (2018). Consumer attitudes on salt and fat reduced foods in the Republic of Ireland. *Food and Nutrition Sciences*, 9, 880–898. Available from <https://doi.org/10.4236/fns.2018.97066>.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding sausages. *Meat Science*, 103, 75–82.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016a). Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings. *European Food Research and Technology*, 242, 2105–2118.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016b). Impact of using replacers on the physicochemical properties and sensory quality of reduced salt and fat black pudding. *Meat Science*, 113, 17–25.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2017). Effect of different salt and fat levels on the physicochemical properties and sensory quality of black pudding. *Food Science & Nutrition*, 5(2), 273–284.
- Fox, P. F. (1975). Influence of cheese composition on quality. *Irish Journal of Agricultural and Food Research*, 14, 33–42.
- Food Safety of Ireland (FSAI). (2014). *Monitoring of sodium and potassium in processed foods period: September 2003 to July 2014*.
- Gelabert, J., Gou, P., Guerrero, L., & Arnau, J. (2003). Effect of sodium chloride replacement on some characteristics of fermented sausages. *Meat Science*, 65, 833–839.
- Grummer, J., Karalus, M., Zhang, K., Vickers, Z., & Schoenfuss, T. C. (2012). Manufacture of reduced sodium Cheddar-style cheese with mineral salt replacers. *Journal of Dairy Science*, 95, 2830–2839.
- Guerrero, L., Guàrdia, M. D., Xicola, J., Verbeke, W., Vanhonacker, F., Zakowska-Biemans, S., & Hersleth, M. (2009). Consumer-driven definition of traditional food products and innovation in traditional foods. A qualitative cross-cultural study. *Appetite*, 52(2), 345–354.
- Gou, P., Guerrero, L., Gelabert, J., & Arnau, J. (1996). Potassium chloride, potassium lactate and glycine as sodium chloride substitutes in fermented sausages and in dry-cured pork loin. *Meat Science*, 42(1), 37–48.
- Guàrdia, M. D., Guerrero, L., Gelabert, J., Gou, P., & Arnau, J. (2008). Sensory characterization and consumer acceptability of small calibre fermented sausages with 50% substitution of NaCl by mixtures of KCl and potassium lactate. *Meat Science*, 80(4), 1225–1230.
- Guinee, T. P. (2016). Protein in cheese products: structure-function relationships. In P. L. H. McSweeney, & S. A. O'Mahony (Eds.), *Advanced dairy chemistry. Vol. 1B. Proteins, applied aspects* (pp. 347–415). New York: Springer Science + Business Media.
- Guinee, T. P., & Fox, P. F. (2004). Salt in cheese: Physical, chemical and biological aspects. In P. F. Fox, P. L. H. McSweeney, T. M. Cogan, & T. P. Guinee (Eds.), *General aspects: Vol. 1. Cheese e chemistry, physics, and microbiology* (3rd ed., pp. 347–360). London, UK: Elsevier Academic Press.
- Helsedirektoratet (Norwegian Directorate of Health). (2011). *Kostråd for å fremme folkehelsen og forebygge kroniske sykdommer. Metodologi og vitenskapelig kunnskapsgrunnlag (Dietary Advice to Promote Public Health and Prevent Chronic Diseases. Methodology and Scientifically Based Knowledge)*. Report published by The Norwegian Directorate of Health. Available from www.helsedirektoratet.no.
- Henneberry, S., O'Sullivan, M. G., Kilcawley, K. N., Kelly, P. M., Wilkinson, M. G., & Guinee, T. P. (2016). Sensory quality of unheated and heated Mozzarella-style cheeses

- with different fat, salt and calcium levels. *International Journal of Dairy Science*, 69, 38–50.
- Hotchkiss, S. (2012). Edible Seaweeds. A rich source of flavor components for sodium replacement. *Agro Food Industry Hi Tech*, 23(6), 30–32.
- Jiménez-Colmenero, F., Carballo, J., & Cofrades, S. (2001). Healthier meat and meat products: Their role as functional foods. *Meat Science*, 59, 5–13.
- Khetra, Y., Kanawjia, S. K., Puri, R., Kumar, R., & Meena, G. S. (2018). Using taste-induced saltiness enhancement for reducing sodium in Cheddar cheese: Effect on physico-chemical and sensorial attributes. *International Dairy Journal*, 91, 1–7.
- Kilcawley, K. N., & O'Sullivan, M. G. (2017). Cheese flavour development and sensory characteristics. In P. Papademas, & T. Bintsis (Eds.), *Global cheesemaking technology: Cheese quality and characteristics*. Chichester: John Wiley & Sons Ltd.
- La Croix, K. W., Fiala, S. C., Colonna, A. E., Durham, C. A., Morrissey, M. T., Drum, D. K., et al. (2014). Consumer detection and acceptability of reduced-sodium bread. *Public Health Nutrition*, 18, 1412–1418.
- Lefier, D., Grappin, R., Grosclaude, G., & Curtat, G. (1987). Sensory properties and nutritional quality of low-sodium Gruyere cheese. *Lait*, 67, 451–463.
- López-López, I., Cofrades, S., Yakan, A., Sola, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International*, 43(5), 1244–1254.
- Lynch, E. J., Dal Bello, F., Sheehan, E. M., Cashman, K. D., & Arendt, E. K. (2009). Fundamental studies on the reduction of salt on dough and bread characteristics. *Food Research International*, 42, 885–891.
- Machado, G. D. M., Costa, R. G. B., Costa Júnior, L. C. G., Sobral, D., Taveira, L. B., & Souza, B. M. De (2011). Aspectos físico-químicos de queijo de coalho fabricado com o uso de ácido láctico. *Alimentos e Nutrição*, 22, 421–428.
- Man, C. M. D. (2007). Technological functions of salt in food products. In D. Kilcast, & F. Angus (Eds.), *Reducing salt in foods* (pp. 157–173). Cambridge: Woodhead Publishing Limited.
- McCarthy, C. M., Wilkinson, M. G., Kelly, P. M., & Guinee, T. P. (2015). Effect of salt and fat reduction on the composition, lactose metabolism, water activity and microbiology of Cheddar cheese. *Dairy Science and Technology*, 95, 587–611.
- McCarthy, C. M., Wilkinson, M. G., Kelly, P. M., & Guinee, T. P. (2016). Effect of salt and fat reduction on proteolysis, rheology and cooking properties of Cheddar cheese. *International Dairy Journal*, 56, 74–86.
- McSweeney, P. L. H., & Fox, P. F. (2009). Advanced dairy chemistry. *Lactose, Water, Salts and Minor Constituents*, 3, 1–201.
- McSweeney, P. L. H. (2007). *Cheese problems solved* (pp. 214–229). Woodhead Publishing Series in Food Science, Technology and Nutrition.
- Mitchell, M., Brunton, N. P., & Wilkinson, M. G. (2009). Optimization of the sensory acceptability of a reduced salt model ready meal. *Journal of Sensory Studies*, 24, 133–147.
- Mitchell, M., Brunton, N. P., & Wilkinson, M. G. (2011). Current salt reduction strategies and their effect on sensory acceptability: A study with reduced salt ready-meals. *European Food Research and Technology*, 232, 529–539.
- Mueller, E., Koehler, P., & Scherf, K. A. (2016). Applicability of salt reduction strategies in pizza crust. *Food Chemistry*, 192, 1116–1123.
- Murtaza, M. A., Huma, N., Sameen, A., Murtaza, M. S., Mahmood, S., Mueen-ud-Din, G., & Meraj, A. (2014). Texture, flavor, and sensory quality of buffalo milk Cheddar cheese as influenced by reducing sodium salt content. *Journal of Dairy Science*, 97, 6700–6707.

- O'Sullivan, M. G. (2017). *CH11. Sensory properties affecting meat and poultry quality. A Handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 225–257). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2019). Nutritional optimisation through reductions of salt, fat and sugar using sensory and consumer driven techniques. In R. Vasilios (Ed.), *Reformulation as a strategy for developing healthier food products: Challenges and recent developments*. Springer.
- O'Sullivan, M. G., & Byrne, D. V. (2019). Traditional foods and beverages of Ireland. In K. Hadwiger, & S. Braun (Eds.), *Nutritional and health aspects of traditional and ethnic foods of Western Europe* (pp. 3–12). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G., & Kerry, J. P. (2011). Sensory quality of fresh and processed meats. In J. P. Kerry, & D. A. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh and processed meats* (pp. 585–598). Cambridge, UK: Woodhead Publishing Limited.
- Paik, D. C., Wendel, T. D., & Freeman, H. P. (2005). Cured meat consumption and hypertension: An analysis from NHANES III (1988–94). *Nutrition Research*, 25, 1049–1060.
- Pearson, A. M., & Tauber, F. W. (1984). *Processed meats. CH3 curing* (pp. 46–68). Westport: AVI Publishing Co. Inc.
- Powell, L. M., Nguyen, B. T., & Dietz, W. H. (2015). Energy and nutrient intake from pizza in the United States. *Pediatrics*. Available from <https://doi.org/10.1542/peds.2014-1844>.
- PROSSLOW (2016). Development of consumer accepted low salt and low fat Irish traditional processed meats. Project Coordinator: Dr Maurice O' Sullivan. Ref:11F026. <<https://www.agriculture.gov.ie/media/migration/research/firmreports/CALL2011ProjectAbstracts240216.pdf>>.
- Quilez, J., & Salas-Salvado, J. (2012). Salt in bread in Europe: Potential benefits of reduction. *Nutrition Reviews*, 70, 666–678.
- Raffo, A., Carcea, M., Moneta, E., Narducci, V., Nicoli, S., Peparao, M., & Turfani, V. (2018). Influence of different levels of sodium chloride and of a reduced-sodium salt substitute on volatiles formation and sensory quality of wheat bread. *Journal of Cereal Science*, 79, 518–526.
- Rason, J., Lebecque, A., leger, L., & Dufour, E. (2003). Delineation of the sensory characteristics of traditional dry sausage. I – Typology of the traditional workshops in Massif Central. In *The 5th Pangborn sensory science symposium*, July 21–24, Boston, MA.
- Remnant, J., & Adams, J. (2015). The nutritional content and cost of supermarket ready-meals. Crosssectional analysis. *Appetite*, 92, 36–42.
- Rødbotten, M., Tomic, O., Holtekjølén, A. K., Grini, I. S., Lea, P., Granli, B. S., et al. (2015). Barley bread with normal and low content of salt; sensory profile and consumer preference in five European countries. *Journal of Cereal Science*, 64, 176–182.
- Rulikowska, A., Kilcawley, K. N., Doolan, I. A., Alonso-Gomez, M., Nongonierma, A. B., Hannon, J. A., & Wilkinson, M. G. (2013). The impact of reduced sodium chloride content on Cheddar cheese quality. *International Dairy Journal*, 28, 45–55.
- Ruusunen, M., Särkkä-Tirkkonen, M., & Puolanne, E. (1999). The effect of salt reduction on taste pleasantness in cooked bologna type sausages. *Journal of Sensory Studies*, 14, 263–270.
- Ruusunen, M., Särkkä-Tirkkonen, M., & Puolanne, E. (2001). Saltiness of coarsely ground cooked ham with reduced salt content. *Agricultural and Food Science in Finland*, 10, 27–32.
- Salovaara, H. (1982). Sensory limitations to replacement of sodium, with potassium and magnesium in bread. *Cereal Chemistry*, 59, 427–430.

- Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016). Current status of salt reduction in bread and bakery products e a review. *Journal of Cereal Science*, 72, 135–145.
- Spina, A., Brighina, S., Muccilli, S., Mazzaglia, A., Rapisarda, P., Fallico, B., et al. (2015). Partial replacement of NaCl in bread from durum wheat (*Triticum turgidum* L. subsp. durum Desf.) with KCl and yeast extract: Evaluation of quality parameters during long storage. *Food and Bioprocess Technology*, 8(5), 1089–1101.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, 4, 460–465.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, 92, 659–666.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013a). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, 93, 145–152.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013b). European consumer attitudes on the associated health benefits of nutraceutical-containing processed meats using co-enzyme Q10 as a sample functional ingredient. *Meat Science*, 97, 207–213.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2014). Effect of cooking and in vitro digestion on co-enzyme Q10 in processed meat products fortified with co-enzyme Q10. *Food Chemistry*, 150, 187–192.
- Traub, L. G., & Odland, D. D. (1979). *Convenience foods and home-prepared foods: Comparative costs, yield and quality*. Agricultural Economic Report No. 429. Washington, DC: US Department of Agriculture.
- van der Horst, K., Brunner, T. A., & Siegrist, M. (2011). Ready-meal consumption. Associations with weight status and cooking skills. *Public Health Nutrition*, 14(2), 239–245.
- Verbeke, W., Pérez-Cueto, F. J. A., De Barcellos, M. D., Krystallis, A., & Grunert, K. G. (2010). European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science*, 84, 284–292.
- WCRF. (2007). *World Cancer Research Fund/American Institute for Cancer Research. Food, Nutrition, Physical Activity, and the Prevention of Cancer: A Global Perspective* (p. 517). Washington, DC: American Institute for Cancer Research.
- Weiss, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science*, 86, 196–213.
- Wheelock, V., & Hobbiss, A. (1999). *All you ever wanted to know about salt but were afraid to ask*. Skipton, Yorkshire: Verner Wheelock Associates, Skipton, Yorkshire. Verner Wheelock Associates.
- World Health Organization, 2003. *Diet, nutrition and the prevention of chronic diseases* (p. 148).
- World Health Organization. (2007). Reducing salt intake in populations. In *Report of a WHO forum and technical meeting*, October 5–7, 2006. Paris, France.
- Zanardi, E., Ghidini, S., Conter, M., & Ianieri, A. (2010). Mineral composition of Italian salami and effect of NaCl partial replacement on compositional, physicochemical and sensory parameters. *Meat Science*, 86(3), 742–747.
- Zandstra, E. H., Lion, R., & Newson, R. S. (2016). Salt reduction: Moving from consumer awareness to action. *Food Quality and Preference*, 48, 376–381.



Other nutritional modifications

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Introduction

It is clear that certain segments of the population could benefit from food specifically designed to meet not only their nutritional but also sensory requirements, with the latter being paramount. If foods or beverages do not have acceptable sensory properties, no matter how healthy or advantageous they are for the consumer, they will not be consumed. The health benefits of a product cannot outweigh its sensory properties, and its acceptance depends on the degree of satisfaction given to the consumers (Bayarri Taylor, & Hort, 2006). In addition, sensory optimized food can have a cumulative effect, particularly with some groups. Taking the example of the elderly, which will be discussed in greater detail in this chapter, sarcopenia can be a disease that can ultimately result in increased mortality outcomes as well as reduced quality of life parameters. Sarcopenia is the loss of skeletal muscle mass and physical function (muscle strength or physical performance) that occurs with advancing age (Shaw, Dennison, & Cooper, 2017). High-protein intakes have been related to the preservation of skeletal muscle mass and a reduction in the reduction of this condition (Chernoff, 2004; Millward, Layman, Tomé, & Schaafsma, 2008). Thus improved meat consumption, by improving sensory properties, could prevent weight loss in this at-risk group and reduce the risk of other associated diseases and increase mortality which comes with such weight

loss. Modifiable behavioral factors such as diet could influence the development of sarcopenia, and improving diet and nutrition may be effective for both prevention and treatment of this condition, and promoting health in later life (Bloom, Shand, Cooper, Robinson, & Baird, 2018; Robinson, Cooper, & Aihie Sayer, 2012). Also, pregnancy is a critical period where food consumption can have a positive outcome for both mother and infant. Maternal diet during pregnancy and diet during infancy are associated with child's health outcomes (Bunyavanich et al., 2014; De Silva et al., 2014). Understanding pregnant women's eating and noneating behaviors from a psychosocial and behavioral economic approach, such as the study of food versus nonfood reinforcement, may provide insight into effective strategies to improve the health of the mothers and their offspring (Kong et al., 2018).

Childhood obesity is of major concern in first-world countries. The contribution of diet and exercise is the only effective means of reversing current trends. Thus the consumption of healthier foods and beverages by children, while also satisfying their sensory expectation, could assist in alleviating this problem. In general, consumers have a basic understanding of nutrition in regards to sugar, but what differentiates a healthy consumer from an unhealthy consumer is how they use their nutritional knowledge to make food choices (Yeon & Lee, 2016). Sugar-sweetened beverage (SSB) modifications, considering children as consumers, are covered in the sugar-reduction beverages section in Chapter 2, Nutritional optimization—reduced sugar products and challenges.

Another group of individuals, who benefit greatly from sensory optimized foods that meet their specific nutritional requirements, are those suffering from gluten intolerance or full-blown celiac disease. For many years the avoidance of gluten meant eating bland gluten free bread with properties not really comparable to normal bread with sensory expectations fulfilled by consuming biscuit-type products. This results in a diet potentially with a high GI (glycemic index) and high in saturated fatty acids and sugars while lacking in other nutrients such as dietary fibers, iron, zinc, magnesium, calcium, B12 vitamin, and folate.

Reformulation using sensory consumer-driven approaches is an important objective to meet the needs of these selected consumer groups with specific nutritional requirements to stay healthy. The reduction of sugar, fat, and salt can benefit these groups as a whole as well as the general population. While sensory studies can also be used to optimize the diet of celiac to provide nutritionally more balance bread-type products

and allowing them to reduce consumption of more unhealthy biscuit-type products.



Gluten-free products

Gluten is a protein complex that functions as the main storage proteins in wheat, rye, and barley and from a technological perspective is responsible for the viscoelastic properties of dough in bread making (O'Sullivan, 2017). It is the gluten in the dough process which during kneading traps air bubbles that are inflated by the gasses produced during leavening and cooking. This results in the aerated structure of bread and is fundamental in contributing to the sensory properties of bread. However, gluten is a problem for a segment of the population (~1%) as these individuals suffer from celiac disease. Sensitivity to gluten triggers an immune response that damages the mucosal layer of the small intestine and prevents absorption of nutrients (Pahlavan, Sharma, Pereira, & Williams, 2016). Celiac disease is an immune-mediated enteropathy caused by the ingestion of gluten in genetically susceptible individuals and is one of the most common lifelong disorders (Biagi, Klersy, Balducci, & Corazza, 2010; Fasano & Catassi, 2012). It is a permanent intolerance to ingested gluten that damages the small intestine by inducing villous atrophy (Fasano & Catassi, 2012). The source of this gluten is from foods made from wheat (i.e., all *Triticum* species), rye, and barley (and sometimes oats) (Masure, Fierens, & Delcour, 2016). The symptoms of gluten intolerance or celiac disease include diarrhea, constipation, weight loss, chronic tiredness, anemia, failure to thrive in children, chronic mouth ulcers, stomach pain and bloating, indigestion, bone pain, moodiness or depression, infertility, and recurrent miscarriages (Coeliac Society of Ireland, 2016). Celiac disease may develop at any time in life but is most prevalent at childhood ages with a high-expected ratio between undiagnosed and diagnosed cases (Lionetti, Gatti, Pulvirenti, & Catassi, 2015). As an autoimmune disease, celiac disease may play a role in some organ-related complications such as autoimmune thyroid disease, hepatitis, type I diabetes, psoriasis, Addison's disease, and dermatitis herpetiformis (Nenna et al., 2016).

To provide for the safety of gluten-sensitive consumers the Codex Alimentarius, European Commission Regulation, and the US Food and Drug Administration have specified 20 mg/kg as the maximum threshold

of gluten in foods labeled gluten-free (Pahlavan et al., 2016). At present the only available treatment for celiac disease is a strict gluten-free diet (Fasano & Catassi, 2012; Masure et al., 2016; Pahlavan et al., 2016).

It is important to find “gluten-free” alternatives in order to feed celiacs (Di Cairano, Galgano, Tolve, Caruso, & Condelli, 2018). The celiac population have driven the growth of the “gluten-free” product sector with companies producing a diverse range of sensory acceptable products from breads to confectionary, pasta, and even meat products traditionally produced with cereals such as sausages (Tobin, O’Sullivan, Hamill, & Kerry, 2013) and black and white puddings (Fellendorf, O’Sullivan, & Kerry, 2015; Fellendorf, O’Sullivan, & Kerry, 2016a; 2016b) (O’Sullivan, 2017). However, quite often, the diet of celiacs is unbalanced due to high intake of saturated fatty acids and sugars and lacking in different nutrients such as dietary fibers, iron, zinc, magnesium, calcium, B12 vitamin, and folate (Jnawali, Kumar, & Tanwar, 2016; Naqash, Gani, Gani, & Masoodi, 2017; Vici, Belli, Biondi, & Polzonetti, 2016). Gluten-free products, due to their starch-based composition, often have a high GI which is a concern for those afflicted with obesity and diabetes (Di Cairano et al., 2018).

Masure et al. (2016) have thoroughly examined current and future approaches to research into the production of gluten-free bread. Many different avenues have been followed to produce acceptable bread products without the use of gluten. However, it is known that the lack of gluten has a significant influence on the dough’s rheology, resulting in a bread with a crushed texture, a poor color, an unsatisfactory taste, and a low specific volume with a shelf life (Houben, Hochstotter, & Becker, 2012). Gluten-free ingredients have been reviewed in detail for alternative ingredients such as cereals (Comino et al., 2013; Huttner & Arendt, 2010), flours (Campo, del Arco, Urtasun, Oria, & Ferrer-Mairal, 2016; Paciulli, Rinaldi, Cirlini, Scazzina, & Chiavaro, 2016; Turkut, Cakmak, Kumcuoglu, & Tavman, 2016), starches (Matos & Rosell, 2013), probiotics (Capriles & Arêas, 2013), hydrocolloids (Anton & Artfield, 2008), proteins (Shevkani, Kaur, Kumar, & Singh, 2015), pseudocereals (Alvarez-Jubete, Auty, Arendt, & Gallagher, 2010), and sourdough (Arendt, Ryan, & Dal Bello, 2007). In order to make the end baked product more palatable, dairy, egg, soybean, and pea proteins have been used in their manufacture. These proteins improve the perceived quality by enhancing Maillard browning and flavor, improving texture, reducing rate of staling, and increasing water absorption (Arendt, Morrissey, Moore, & Dal Bello, 2008). Sourdough has been used to improve dough machinability, as well

as nutritional and sensory properties while also prolonging shelf life compared to yeasted breads (De Vuyst & Neysens, 2005; Hammes & Ganzel, 1998). Campo et al. (2016) investigated the effect of the addition of teff flour and sourdoughs on the consumer quality of gluten-free breads. They found that teff (10%) combined with cereal sourdough (rice or buckwheat) enhanced bread aroma, increasing the fruity, cereal, and toasty notes and bread combining 10% teff and rice sourdough was preferred in terms of flavor.

The growth of the gluten-free sector has expanded even further with normal consumers choosing to avoid gluten (Capriles, dos Santos, and Arêas, 2016). From 2013 to 2015 the gluten-free industry enjoyed a growth of 136%, far outpacing CD awareness and increases in prevalence (Norelle & Reilly, 2016). In addition, the gluten-free retail market has expanded rapidly from \$1.7bn in 2011 and will reach \$4.7bn by 2020, Euromonitor forecasts (Financial Times, 2017). Approximately 13% of young adults valued gluten-free food, a characteristic most strongly related to valuing food production practices (e.g., organic, locally grown) (Christoph, Larson, Hootman, Miller, & Neumark-Sztainer, 2018). These individuals, who are in good health, believe that gluten-free products are a “healthier” option, and it is an effective way of weight control and/or minimizing future risk of gastrointestinal diseases, although there is no scientific evidence to support these beliefs (Brouns et al., 2013; Gobetti et al., 2018; Pszczola, 2012).

Bespoke foods for pregnancy

Diet during pregnancy is one of the most important factors that may be adjusted in order to deal with the continuous challenges that women face during gestation (Costa-Rodrigues, Sá-Azevedo, Balinha, & Ferro, 2018). The pregnant woman's diet must also include high hygiene standards, avoid potentially toxic molecules (and alcohol), provide adequate amounts of energy and macronutrients and satisfy the needs (sometimes increased) of vitamins and minerals (Agnoli et al., 2017; Melina, Craig, & Levin, 2016; Nyaradi, Li, Hickling, Foster, & Oddy, 2013; Wennberg et al., 2016). A diet rich in vegetables, fruit and berries, whole grains, fish, and low-fat dairy products is associated with lower odds of excessive gestational weight gain and low gestational weight of the child (Hillesund, Bere, Haugen, & Øverby, 2014). Malnutrition during pregnancy has been connected with coronal heart disease and obesity in adulthood (Painter,

Roseboom, & Bleker, 2005; Roseboom, van der Meulen, & Osmond, 2000). Fetal organ development can be inhibited by inadequate nutrient intake in early pregnancy such as folic acid deficiency which increases the risk of neural tube defects (De-Regil, Fernandez-Gaxiola, Dowswell, & Pena-Rosas, 2010). Excess vitamin A increases the risk of central–neural–crest defects (Rothman et al., 1995). Many pregnant women fail to meet food and nutrient recommendations, especially for fruits, vegetables, grains, folate, and iron (Rifas-Shiman, Rich-Edwards, Kleinman, Oken, & Gillman, 2009). Also, iodine deficiency during pregnancy is associated with a subsequent low child intelligence quotient (Bath, Steer, Golding, Emmett, & Rayman, 2013). Thus following a healthy and balanced diet is of utmost importance during pregnancy. For example, overweight or obese pregnant individuals are at increased risk of developing gestational diabetes and hypertension, and a higher likelihood of requiring a cesarean birth (Dodd, Grivell, Nguyen, Chan, & Robinson, 2011; Galtier-Dereure, Boegner, & Bringer, 2000; Stotland, Hopkins, & Caughey, 2004; Thrift & Callaway, 2014). Excess gestational weight gain can also be detrimental to the health of the newborn child and has been identified as a strong predictor of macrosomia, large for gestational age neonates, and low Apgar (appearance, pulse, grimace, activity, and respiration) scores (Gante, Amaral, Dores, & Almeida, 2015). Food cravings are a significant barrier to healthy eating in pregnant women with craving frequency accounting for as much as one-third of the variance in excess weight gain during pregnancy (Goodrich, Cregger, Wilcox, & Liu, 2013; Orloff et al., 2016). The most frequent cravings are dairy, sweet foods, chocolate, fruit, and fruit juice, and pregnant women also report cravings for salty and savory foods (Bayley, Dye, Jones, DeBono, & Hill, 2002; Hook, 1978; Pope, Skinner, & Carruth, 1992). In the first trimester, pregnant women tend to have cravings for these savory substances (Belzer, Smulian, Lu, & Tepper, 2010). Cravings for sweets reach a peak intensity in the second trimester (Bowen, 1992), and cravings for salty substances occur later in pregnancy (Bowen, 1992; Crystal, Bowen, & Bernstein, 1999; Skinner, Pope, & Carruth, 1998). Thus by understanding pregnant women's eating and noneating behaviors from a psychosocial and behavioral economic approach may provide insight into effective strategies to improve the health of the mothers and their offspring (Kong et al., 2018). Many of the topics discussed in this book regarding the development of foods and beverages with lower levels of sugar, fat, and salt are also of direct benefit to pregnant women provided that the frequency of

consumption of such products is also controlled. A high intake of fat or salt during pregnancy perturbs placental function, alters fetal development, and predisposes offspring to metabolic disease in adult life (Reynolds, Vickers, Harrison, Segovia, & Gray, 2014). Reynolds et al. (2014) found that maternal high-fat diet significantly decreased body weight in both male and female fetuses. These authors also found that diets high in fat and/or salt affect maternal metabolic parameters, fetal growth and development, metabolic status, and adipoinsular axis in the weanling. The products discussed in the next section, designed for the elderly, are also relevant for pregnant consumers. However, the difficulty comes in the evaluation of specific sensory preferences using pregnant individuals for ethical and also for consistent data collection. It is not recommended to include females who may be pregnant as their dietary needs can exclude them from being able to assess some products for dietary and safety reasons, and also, their sensory response may also be skewed due to hormonal imbalances (O'Sullivan, 2017b). Pregnant women have been shown to have significantly lower overall gustatory sensitivity scores (Kölbe, Hummel, von Mering, Huch, & Huch, 2001). Pregnancy also alters taste responses and feeding patterns in women. Chief among these changes is increased sensitivity to bitter stimuli and feelings of nausea in response to bitter foods (Kölbe et al., 2001; Nordin, Broman, Olofsson, & Wulff, 2004; Sipiora, Murtaugh, Gregoire, & Duffy, 2000). Taste plays an important role as it can ensure proper growth and development through acquired nutrients, as well as the avoidance of harmful toxins. Toxic foods are often bitter, and this rejection by pregnant mothers is a defense mechanism against ingestion (Breslin, 2013). The ability of pregnant women to discriminate between different salt concentrations is also significantly less than nonpregnant women (Brown & Toma, 1986; Kölbe et al., 2001). Also, Reynolds et al. (2014) state that there is potential for maternal nutritional intervention strategies that may be employed to modify the metabolic disease risk in adult offspring during later life.

Specific foods and beverages for children

Children do not like bitter foods, and this is because they appear to follow the maternal–fetal nutritional strategy of avoiding toxins. This is why children are sometimes loathe to eating vegetables that are dense in micronutrients and phytonutrients but are low in calories and macronutrients.

Also, the reluctance to eat novel foods, called food neophobia, is associated with a lower vegetable liking and intake and with an overall less healthy diet (Cooke, Wardle, & Gibson, 2003; Falciglia, Couch, Gribble, Pabst, & Frank, 2000; Russell & Worsley, 2013). Children tend to prefer sweeter food and beverages, and when it comes to vegetables, they choose those high in sugar and free glutamate and, thus, taste sweet and savory (Breslin, 2013).

We are born with a preference for sweet and salty foods and show an inherent preference for snacks low in nutritional value (Desor, Maller, & Turner, 1973; Harris, Thomas, & Booth, 1990). Excessive sugar consumption has been identified as the major cause of excessive caloric intake and the main dietary determinant of obesity among children and adolescents (Ambrosini, Johns, Northstone, Emmett, & Jebb, 2016; Te Morenga, Mallard, & Mann, 2012). Obesity is connected to a heightened intake of food high in salt, fat, and sugar, as well as a decline in physical activity (Robinson, 1999). SSBs, bread and cereals, confectionary, dairy products, and fruit products have been identified as the main sources of sugar intake among children and adolescents (Louie, Moshtaghan, Rangan, Flood, & Gill, 2016; Pawellek et al., 2017). Many parents desire reduced-sugar products for their children, and current studies emphasize the importance of developing healthy eating habits at a young age (Byrd-Bredbenner, McKinley, Martin-Biggers, & Gager, 2016; Chan, Prendergast, Grønhoj, & Bech-Larsen, 2011). As discussed in detail in Chapter 2, Nutritional optimization-reduced sugar products and challenges, high intakes of sugar are observed for dairy products and beverages, in Europe, more in children than adults (Azaïs-Braesco, Sluik, Maillot, Kok, & Moreno, 2017). Also, SSBs, including soda, fruit-flavored drinks, and sports drinks, are one of the main sources of sugars in children's diets (Malik, Pan, Willett, & Hu, 2013).

Dairy products are generally seen as a good source of essential nutrients vitamin A and calcium for children. Flavored milk has a pleasurable taste and provides essential nutrients equivalent to that of plain milk (Murphy, Douglass, Johnson, & Spence, 2008) and is popular amongst children and adults (Kim, Lopetcharat, & Drake, 2013). However, modifications and decreased levels of sugar are easier to perceive than a reduction in fat or salt content, making formulation of reduced-sugar dairy products a challenge (Biguzzi, Schlich, & Lange, 2014). Reformulation of flavored milk has been extensively discussed in Chapter 2, Nutritional optimization-reduced sugar products and challenges. Also as discussed in Chapter 2,

fruit juices contain important vitamins and minerals but can have very high sugar content. Fruit juice products often contain high sugar and calorie levels and combined with high consumption frequencies these facts negate any potential health benefits by a huge margin. Most nutrition researchers agree that whole fruit is nutritionally superior to juice because it contains more fiber and is less energy dense (Herrick, Rossen, Nielsen, Branum, & Ogden, 2015; Heyman & Abrams, 2017). On the contrary, consumption of fruit juice can help children achieve fruit intake recommendations and warn that limiting it will reduce vitamin C, folate, and potassium intake (Byrd-Bredbenner et al., 2017). Lima, Ares, and Deliza (2019) proposed a stepwise sugar reduction strategy based on larger reduction steps, but this strategy could lead to larger changes in consumers' sensory and hedonic product perception. Thus these authors explored a gradual and stepwise sugar reduction strategy on the hedonic perception of grape nectars by children. They found that differences between the sugar reduction strategies were small; the gradual reduction strategy seems to be recommended over the step-wise strategy.

Again, the health benefits of products cannot outweigh its sensory properties, and its acceptance depends on the degree of satisfaction given to the consumers (Bayarri, Taylor, & Hort, 2006). Even more so than adults, if children do not like what they are consuming then that product will be rejected. However, studies with children have shown that it is possible to increase liking for novel foods over repeated exposures. In general, a significant increase of liking can be seen after 5–10 exposures of the novel food, which corresponds to the acquisition of preference (Birch, 1987). Also, children have a clear understanding of product healthiness. Children as young as 4 years can categorize foods as healthy and unhealthy, which improves with age (Holub & Musher-Eizenman, 2010). Children learn about food through explicit instruction from family members, friends, media, and teachers (Nguyen, 2012; Nguyen, Gordon, Chevalier, & Girgis, 2016; VanderBorghet & Jaswal, 2009). Yoo et al. (2017) showed that children and adolescents had a positive attitude toward sugar reduction in dairy products (yogurt, chocolate-flavored milk, and vanilla milk dessert) and that the inclusion of a traffic-lights system on labels increased their unhealthfulness perception of products with high sugar content and could discourage their consumption of these products. However, food advertising is a very effective method of influencing children's food choices (Boyland et al., 2016; Folkvord, Anschutz, Boyland, Kelly, & Buijzen, 2016). Such advertising also almost entirely

promotes high-fat, -sugar, and salty foods (Boyland et al., 2016; Kelly et al., 2010; Powell, Schermebeck, Szczypka, Chaloupka, & Braunschweig, 2011). Food marketers have even adapted to newer advertising techniques to advertise their brands and products to capitalize on children's use of the internet (Folkvord & Riet, 2018). If foods are to be made healthier for children reformulation through the reduction of salt, fat, and sugar, as discussed in the various chapters of this book, can only improve the nutritional status of this group. However, to be truly effective, this must be combined with healthy eating education, both in the home and school, and by restricting access to more unhealthy products, including through media resources and advertising. In this fashion, producers will be forced to an even greater extent to provide healthier food for children.

Foods for the elderly

According to the [World Health Organization \(WHO\) \(2013\)](#), most globally developed countries have acknowledged 65 years of age as a definition of "the elderly" or older adult. However, the elderly population has been classified by some authors according to physiological changes that occur at specific ages. From 65 to 74 years old, elderly are called "young old," those from 75 to 84 years old are called "old old" and elderly who are 85 and more are called "oldest old" ([Hetherington, 1998](#)). [Given and Given \(1989\)](#) suggested that chronological age may be subdivided into younger old (65–74), old/mid-old (75–84), and oldest old (85+). However, [Field and Minkler \(1988\)](#) defined the elderly as young old (60–74), old (75–84), and very old (85+). Advances in medicine, improved nutrition, living conditions, healthcare, and monitoring of the elderly have led to a dramatic increase in the elderly segment of the population in the western world. Over the next 20 years the number of people over 60 years will exceed 1 billion ([Cichero, 2016](#)).

Those aged 65 years or over will account for 29.1% of the EU-28's population by 2080, compared with 19.2% in 2016. The amount of those aged 80 years or over in the EU-28's population is projected to be more than double between 2016 and 2080, from 5.4% to 12.7% ([Eurostat, 2015](#)). Mortality rates are assumed to decrease, which will result in gains in life expectancy at birth from 77.9 years in 2010 to 85.1 years in 2046 for males and 82.7 years in 2010 to 88.5 years in 2046 for females ([Eurostat—European Commission, 2009](#); [Eurostat, 2015](#)). Moreover, living longer in parallel with quality of life is a fundamental consideration

for the ageing population. Disability-free life expectancy examines mortality and disability together, positioning fatal and nonfatal outcomes on a common metric. Such population health indicators have been instrumental in exploring whether the extra years lived have been spent in good or poor health (Robine & Michel, 2004). Age-related diseases increase in frequency in the elderly population with increasing age and include rheumatism, arthritis, stroke, cancer, coronary heart disease, and dementia. Many of these diseases have either a dietary cause or can be at least partly alleviated by dietary change (WHO, 2013).

Physiological changes that inevitably result from aging such as reduction in muscle strength, deterioration in dentition and salivary flow, and alterations in sensory experiences such as aroma and taste come to effect the type of food elderly people choose to consume which can affect nutrient density and predispose them to malnutrition (Achem & deVault, 2005; Charlton et al., 2010). Aging is also often associated with inadequate intake of proteins (Hébel, 2013) and micronutrients (De Groot, Van Den Broek, & Van Staveren, 1999), which can lead to sarcopenia (Cruz-Jentoft et al., 2010), frailty, and dependency (Wells & Dumbrell, 2006). Sarcopenia is the loss of skeletal muscle mass and physical function (muscle strength or physical performance) that occurs with advancing age (Shaw et al., 2017). High-protein intakes have been related to the preservation of skeletal muscle mass and a reduction in this condition (Chernoff, 2004; Millward et al., 2008). The increasing recognition of sarcopenia, the age-related loss of skeletal muscle mass and function (muscle strength and physical performance), as a determinant of poor health in older age, is driving the development of better strategies both for preventing and treating this condition (Bloom et al., 2018). There is an important correlation between inactivity and loss of muscle mass and strength, and this suggests that physical activity should not only be a protective factor for prevention but also the management of sarcopenia (Santilli, Bernetti, Mangone, & Paoloni, 2014). Modifiable behavioral factors such as diet could influence the development of sarcopenia and improving diet and nutrition may be effective for both prevention and treatment of this condition, and promoting health in later life (Bloom et al., 2018; Robinson et al., 2012). The RDA (recommended daily allowance) for protein (0.8 g protein/kg of body weight/day) is the same for all adults, regardless of age or gender. Houston et al. (2008) showed that for both sexes with sarcopenia aged from 70 to 79, those with the highest protein intake lost the least amount of lean muscle mass over a 3-year period. However, recent studies found

that adults aged 65 and older require protein intakes greater than the current RDA for achieving optimal health (Rafii et al., 2014; Tang et al., 2014; Volkert, Saeglit, Gueldenzoph, Sieber, & Stehle, 2010; Volpi et al., 2012). According to the National Health and Nutrition Examination Survey (NHANES), about 6% of men at the age of 71 and over and about 4%–6% of women over the age of 50 are not meeting the recommended protein intake levels (Berner, Becker, Wise, & Doi, 2013).

In general, the food industry has not capitalized on the development of bespoke foods designed for the elderly population in order to meet their nutritional needs and sensory expectations. In the past the elderly consumer voice was often ignored in primary consumer research as their views did not match marketing targets (Popper & Kroll, 2003). There is a significant interest in the role of dietary patterns and the effects of whole diets in predicting health. Better diet quality in older adults is certainly linked with various health outcomes, including a reduced risk of common age-related diseases and to greater longevity (Bloom et al., 2018). Thus it is clear that the foods that the elderly consume have a direct bearing on health, quality of life, and longevity. For this reason as well as for the increasing economic power, of the over 65 demographic, food producers must understand the age-related physiological changes, food behaviors, sensory preferences, and nutritional requirements of the ageing population to improve quality of life but also as a lucrative source of revenue.

The human aging process is generally accompanied by a decrease in sensory functioning because sensory receptors, age, and their neural efficiency, drop (Corso, 1981). Ageing is associated with many physiological changes, amongst them are the ones related to food perception. It is well established that the sense of taste, smell, and texture are impaired in the elderly population. The sense of smell and taste are defined as “chemical senses” as they both are stimulated by different molecules that contact receptors located in various parts of the mouth and nasal cavity (Schiffman, 1994). Losses of taste perception can be caused by different factors, including age, medication, certain diseases (such as cancer), surgical interventions, malnutrition, environmental exposures, and dental problems (Schiffman & Gatlin, 1993; Schiffman & Graham, 2000). As we age, our senses become dulled. The sense of smell is described to be more prone to losses than the sense of taste (Stevens, Barthoshuk, & Cain, 1984). Mojet (2003) found that taste intensity rating decreased with age (19–75 years, $n = 42$) for all investigated tastants [NaCl, KCl, sucrose, aspartame,

acetic acid, citric acid, caffeine, quinine, hydrochloric acid (HCl), monosodium glutamate (MSG), and inosine 5' monophosphate] when dissolved in water and food products. However, only the salty and sweet tastants decreased in perception with age in products. Also, it has been suggested that age is the strongest predictor of reactions to off-flavors, where older respondents demonstrate a reduced aversion to off-flavors (i.e., bitter), compared to younger respondents (Drenowski, Henderson, & Barratt-Fornell, 2001).

The loss in chewing ability in elderly prevents the detection of flavors from food (Doty, 1989). The decreased chewing ability associated with dentures may weaken olfaction and influence food preferences (Duffy, Cain, & Ferris, 1999; Ship, 1999). Also, dentures that cover the palate potentially decrease the flow of air between the oral and the nasal cavity and thus weaken retronasal perception (Ship, 1999). In addition, denture wearers usually choose soft food to eat and swallow, but this food is usually nutritionally compromised (Nagao, 1992). Thus some elderly denture wearers avoid foods that are difficult to chew such as whole fresh meat cuts and by default are eliminating a rich protein and iron source in their diets making them even more susceptible to diseases such as sarcopenia. Conroy, O'Sullivan, Hamill, and Kerry (2017), in a study that assessed the capability of various Irish assessor age cohorts (18–85) to identify beef steaks of varying texture, found that attribute blindness was observed in subjects aged from 71 years old. Also, the over 75 age categories (late elderly) failed to recognize textural differences between tender and tough samples or any eating quality difference between steak treatments. One can postulate that perhaps the reason for this was a loss of sensory acuity regarding oral texture perception in the elderly due to a reduced level of experience or increased unfamiliarity due to meat avoidance. In addition, the avoidance of certain food textures (hard, dry, fibrous, sticky, and adhesive foods) by the elderly affects the ability to consume iron-rich protein (meat, poultry, fish, nuts, seeds, etc.), foods containing vitamins and minerals (raw fruits and vegetables), and foods containing dietary fiber (fruits and vegetables). Healthy elders will typically choose soft-textured food by preference (Cichero, 2016). In another study examining the various textural preferences for carrots, it was determined that the young adults liked difficult textures such as rough, crispy, crunchy, and hard to a far greater degree than the elderly respondents, but interestingly, the softer textures were not liked by either age group (Roininen, Fillion, Laurence Kilcast, & Lahteenmaki, 2003). Foods that are fibrous, hard, or dry may

prove difficult to consume for the elderly as they may have problems in safely reducing particle size for the creation of the bolus prior to swallowing. Foods that are sticky and adhesive are also problematic and increase risk for both choking and residue. Soft, moist foods that can be reduced easily with minimal chewing effort are perhaps the most suitable for the elderly (Cichero, 2016). However, the chewing process releases flavor volatiles in the mouth as particles mix with saliva throughout the oral phase, whereas foods that require little or no chewing result in retronasal flavor appreciation that occurs after the swallow (Foster et al., 2011). The sensory experience in the elderly could be enhanced by boosting perceived flavor and aroma in foods (Popper & Kroll, 2003).

Sensory losses influence food liking, and it is thought that the elderly perceive sensory properties of food to a lower extent due to a decreased sensitivity, but it is difficult to correlate this with a loss of enjoyment of foods (Murphy & Gilmore, 1990; Schiffman, 1993; Schiffman & Gatlin, 1993). Medications complicate perception in this cohort; even further around 250 drugs been reported to affect taste perception (Finkelstein & Schiffman, 1999; Schiffman & Warwick, 1991). Medicines are assumed to block channels and receptors, disrupt second-messenger systems, interfere with cell replacement, or hinder neural signal propagation, but these effects are drug dependent and vary from one medication to another (Schiffman, 1993).

Olfaction is one of the most important age-related impairment concerns which results in a decreased perception of the complexity of foods (especially the flavor of foods) and may cause a lower enjoyment of foods in the elderly population (Murphy & Gilmore, 1990; Wysocki & Pelchat, 1993). Ageing causes some odorants to be less perceived, which causes a concurrent loss in overall flavor perception and can result in decreased enjoyment of foods (Murphy, 1993). However olfactory impaired elderly still report enjoying the food they eat, which might be explained by the fact that olfactory losses happen gradually and over time often get unnoticed by elderly (Wysocki & Pelchat, 1993). Flavor enhancement might be an approach to improve the sensory quality of foods and beverages for the elderly suffering from chemosensory losses (Finkelstein & Schiffman, 1999). Drewnowski, Coldwell, and Rolls (2002) suggested that flavor enhancement would be more beneficial than flavor addition to increase the liking of elderly individuals. Spices might be an option, but not for a significant elderly cohort who possess fragile digestive systems (Madeira & Goldman, 1988; Schiffman, 1997). Some research has demonstrated that adding either basic tastants, such as sucrose (De Jong, de Graaf, & Van Staveren, 1996) or MSG (Schiffman, 2000) or flavor and spices (Griep,

Mets, & Massard, 1996) would increase liking for foods by the elderly. However, adding an extra flavor did not always successfully increase liking with this group (Koskinen, Kalviainen, & Tuorila, 2003). Laureati, Pagliarini, Calcinoni, and Bidoglio (2006) reported that the elderly prefer traditional food preparations from their own culture. This phenomenon was the basis for the case studies presented later in the present chapter where a traditional food formulation, breakfast sausages, was optimized from a nutritional and sensory perspective for the older consumer.

Case study 1: Impact on the physical and sensory properties of salt- and fat-reduced traditional Irish breakfast sausages on various age cohorts acceptance.

Sausages were produced with fat levels of 30%, 20%, and 15% with fat replaced with pea extract and salt levels of 2.5%, 1.1%, and 0.0%. A reduced sodium salt which contains 45% less sodium than standard salt was used to assist in reducing overall sodium levels in the final product. Sensory hedonic analysis was conducted on consumers ($n = 228$) with the age ranges 18–40, 41–64, and 65–85 years. The 18–40 year olds preferred sausages containing 20% fat, the 41–64 year olds preferred sausages with 15% fat, and the 65+ age group preferred sausages containing 30% fat. However, the 18–40 year olds preferred lower salt samples, 41–64 year olds displayed no salt preference, while the 65+ age group preferred high salt sausages. There is thus a need to understand how meat products might be reformulated for different age palates (Conroy, O'Sullivan, Hamill, & Kerry, 2018a). Texture attributes influenced the younger age categories choice in sausage formulation, flavor, and its associated attributes influenced the 41–64 year olds choice of sausage formulation, whereas visual aspects such as color were the main driving force influencing the >65 year olds' choice (Fig. 5.1). All age groups, with the exception of 65+ panelists, accepted samples with salt levels below, or equal to, that of the FSAI (Food Safety Authority of Ireland) and FSA (Food Safety Authority, United Kingdom) 2017 salt targets. This study provides evidence that salt concentrations in sausages, and possibly other processed meats, may be reduced without having an impact on the sensory aspects perceived by consumers of certain age cohorts. This research also provides evidence that age-related sensory differences in preferred fat concentrations exist. The 65+ age cohort demonstrated neophobic characteristics when novel sausage formulations were introduced. Reducing the levels of fat by adding pea extract caused varying results between all three age cohorts, especially with respect to product flavor and texture. Pea extract increased protein content. This is a valuable asset to food products tailor



Figure 5.1 A selection of gluten-free bread products. Better quality and more varied products have become available in recent years to service demand amongst celiac and gluten avoiding consumers.

made for consumers, especially those with depleted muscle mass such as the elderly consumers. Pea extract may be used in further reformulations of food products to increase protein content. The elderly did not accept the reduced sodium salt as a salt replacer or the pea extract as a fat replacer, whereas the other two age cohorts did. The reduced sodium salt and the pea extract were widely accepted among the 41–64-year-old age group. This is important considering that this age group is our “future elderly” (Conroy et al., 2018a). This research suggests that those aged 41–64 are more accepting of novel formulations. This information can be used to develop tailor-made food products with our “future” elderly consumers in mind. This research demonstrates different preferences and dislikes for various attributes presented by the reformulation of a traditional meat product based on the age of panelists consuming them. While selective targeted formulation of such products could be implemented, this study clearly shows that a considerable amount of research is needed to formulate processed meat products which will meet the sensory needs of the growing the elderly market, but which will allow the necessary reformulation to take place in order to improve the nutritional composition of such products for specific consumer groupings (Conroy et al., 2018a) (Fig. 5.2).

References

- Achem, S. R., & deVault, K. R. (2005). Dysphagia in aging. *Journal of Clinical Gastroenterology*, 39, 357–371.
- Agnoli, C., Baroni, L., Bertini, I., Ciappellano, S., Fabbri, A., Papa, M., et al. (2017). Position paper on vegetarian diets from the working group of the Italian Society of Human Nutrition. *Nutrition, Metabolism, and Cardiovascular Diseases*, 27, 1037–1052.
- Alvarez-Jubete, L., Auty, M., Arendt, E. K., & Gallagher, E. (2010). Baking properties and microstructure of pseudocereal flours in gluten-free bread formulations. *European Food Research and Technology*, 230, 437–445.
- Ambrosini, G. L., Johns, D. J., Northstone, K., Emmett, P. M., & Jebb, S. A. (2016). Free sugars and total fat are important characteristics of a dietary pattern associated with adiposity across childhood and adolescence. *Journal of Nutrition*, 146, 779–784.
- Anton, A. A., & Artfield, S. D. (2008). Hydrocolloids in gluten-free breads: A review. *International Journal of Food Sciences and Nutrition*, 59, 11–23.
- Arendt, E. K., Morrissey, A., Moore, M. M., & Dal Bello, F. (2008). Application of dairy ingredients in gluten-free food. In E. K. Arendt, & F. Dal Bello (Eds.), *Gluten-free cereal products and beverages* (pp. 228–231). San Diego, CA: Academic Press.
- Arendt, E. K., Ryan, L. A. M., & Dal Bello, F. (2007). Impact of sourdough on the texture of bread. *Food Microbiology*, 24, 165–174.
- Azaïs-Braesco, V., Sluik, D., Maillot, M., Kok, F., & Moreno, L. A. (2017). A review of total & added sugar intakes and dietary sources in Europe. *Nutrition Journal*, 16, 6–21.
- Bath, S. C., Steer, C. D., Golding, J., Emmett, P., & Rayman, M. P. (2013). Effect of inadequate iodine status in UK pregnant women on cognitive outcomes in their children: Results from the Avon Longitudinal Study of Parents and Children (ALSPAC). *Lancet*, 382, 331–337.
- Bayarri, S., Taylor, A. J., & Hort, J. (2006). The role of fat in flavor perception: Effect of partition and viscosity in model emulsions. *Journal of Agriculture and Food Chemistry*, 54, 8862–8868.
- Bayley, T. M., Dye, L., Jones, S., DeBono, M., & Hill, A. J. (2002). Food cravings and aversions during pregnancy: Relationships with nausea and vomiting. *Appetite*, 38, 45–51.
- Belzer, L. M., Smulian, J. C., Lu, S. E., & Tepper, B. J. (2010). Food cravings and intake of sweet foods in healthy pregnancy and mild gestational diabetes mellitus. A prospective study. *Appetite*, 55(3), 609–615.
- Berner, L. A., Becker, G., Wise, M., & Doi, J. (2013). Characterization of dietary protein among older adults in the United States: Amount, animal sources, and meal patterns. *Journal of the Academy of Nutrition and Dietetics*, 113(6), 809–815.
- Biagi, F., Klersy, C., Balducci, D., & Corazza, G. R. (2010). Are we not over-estimating the prevalence of celiac disease in the general population? *Annals of Medicine*, 42, 557–561.
- Biguzzi, C., Schlich, P., & Lange, C. (2014). The impact of sugar and fat reduction on perception and liking of biscuits. *Food Quality Preference*, 35, 41–47.
- Birch, L. L. (1987). Effects of experience on the modification of food acceptance patterns. *Annals New York Academy of Sciences*, 561, 209–216.
- Bloom, I., Shand, C., Cooper, C., Robinson, S., & Baird, J. (2018). Diet quality and sarcopenia in older adults: A systematic review. *Nutrients*, 10, 308.
- Bowen, D. J. (1992). Taste and food preference changes across the course of pregnancy. *Appetite*, 19, 233–242.
- Boylund, E. J., Nolan, S., Kelly, B., Tudur-Smith, C., Jones, A., Halford, J. C., et al. (2016). Advertising as a cue to consume: A systematic review and meta-analysis of the effects of acute exposure to unhealthy food and nonalcoholic beverage advertising on intake in children and adults. *The American Journal of Clinical Nutrition*, AJCN, 103, 519–533.

- Breslin, P. A. S. (2013). An evolutionary perspective on food review and human taste. *Current Biology*, 23, R409–R418. Available from <https://doi.org/10.1016/j.cub.2013.04.010>.
- Brouns, F., van Buul, V., & Shewry, P. (2013). Does wheat make us fat and sick? *Journal of Cereal Science*, 58, 209–215.
- Brown, J. E., & Toma, R. B. (1986). Taste changes during pregnancy. *American Journal of Clinical Nutrition*, 43, 414–418.
- Bunyavanich, S., Rifas-Shiman, S. L., Platts-Mills, T., Workman, L., Sordillo, J., Gillman, M., et al. (2014). Peanut allergy prevalence among school-age children in a US cohort not selected for any disease. *Journal of Allergy and Clinical Immunology*, 134(4), 735–755.
- Byrd-Bredbenner, C., Ferruzzi, M. G., Fulgoni, V. L., Murray, R., Pivonka, E., & Wallace, T. C. (2017). Satisfying America's fruit gap: Summary of an expert roundtable on the role of 100% fruit juice. *Journal of Food Science*, 82, 1523–1534.
- Byrd-Bredbenner, C., McKinley, J., Martin-Biggers, J., & Gager, E. (2016). Encouraging reductions in sugar-sweetened beverage consumption: HomeStyles best drinks for families guide. *Journal of Nutrition Education and Behavior*, 48, S11–S12.
- Campo, E., del Arco, L., Urtasun, L., Oria, R., & Ferrer-Mairal, A. (2016). Impact of sourdough on sensory properties and consumers' preference of gluten-free breads enriched with teff flour. *Journal of Cereal Science*, 67, 75–82.
- Capriles, V. D., & Arêas, J. A. G. (2013). Effects of prebiotic inulin-type fructans on structure, quality, sensory acceptance and glycemic response of gluten-free breads. *Food and Function*, 4, 104–110.
- Capriles, V. D., dos Santos, F. G., & Arêas, J. A. G. (2016). Gluten-free breadmaking: improving nutritional and bioactive compounds. *Journal of Cereal Science*, 67, 83–91.
- Chan, K., Prendergast, G., Grønhoj, A., & Bech-Larsen, T. (2011). Danish and Chinese adolescents' perceptions of healthy eating and attitudes toward regulatory measures. *Young Consumers*, 12, 216–228.
- Capriles, V. D., dos Santos, F. G., & Arêas, J. A. G. (2016). Gluten-free breadmaking: improving nutritional and bioactive compounds. *Journal of Cereal Science*, 67, 83e91.
- Charlton, K. E., Nichols, C., Bowden, S., Lambert, L., Barone, L., Mason, M., & Milosavljevic, M. (2010). Older rehabilitation patients are at high risk of malnutrition: Evidence from a large Australian database. *The Journal of Nutrition, Health and Aging*, 14, 622–628.
- Chernoff, R. (2004). Protein and older adults. *Journal of the American College of Nutrition*, 23, 627S–630S.
- Christoph, M. J., Larson, N., Hootman, K. C., Miller, J. M., & Neumark-Sztainer, D. (2018). Who values gluten-free? Dietary intake, behaviors, and sociodemographic characteristics of young adults who value gluten-free food. *Journal the Academy of Nutrition and Dietetics*, 118, 1389–1398.
- Cichero, J. A. Y. (2016). Adjustment of food textural properties for elderly patients. *Journal of Texture Studies*, 47, 277–283.
- Coeliac Society of Ireland (2016). *Symptoms*. < <https://www.coeliac-ireland.com/coeliac-disease/symptoms/> > .
- Cooke, L., Wardle, J., & Gibson, E. L. (2003). Relationship between parental report of food neophobia and everyday food consumption in 2–6-year-old children. *Appetite*, 41(2), 205–206.
- Comino, I., Moreno, M. D., Real, A., Rodriguez-Herrera, A., Barro, F., & Sousa, C. (2013). The gluten-free diet: Testing alternative cereals tolerated by celiac patients. *Nutrients*, 5, 4250–4268.
- Conroy, P., O'Sullivan, M. G., Hamill, R. H., & Kerry, J. P. (2017). Sensory capabilities of young, middle aged and elderly Irish assessors to identify beef steaks of varying texture. *Meat Science*, 132, 125–130.

- Conroy, P. M., O'Sullivan, M. G., Hamill, R. H., & Kerry, J. P. (2018a). Impact on the physicochemical and sensory properties of salt- and fat-reduced traditional Irish breakfast sausages on various age cohorts acceptance. *Meat Science*, 143, 190–198.
- Corso, J. F. (1981). *Aging sensory systems and perception*. New York: Praeger.
- Costa-Rodrigues, J., Sá-Azevedo, R., Balinha, J., & Ferro, G. (2018). Vegetarianism during pregnancy: Risks and benefits. *Trends in Food Science and Technology*, 79, 28–34.
- Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., & Schneider, S. M. (2010). Sarcopenia: European consensus on definition and diagnosis. Report of the European Working Group on Sarcopenia in Older People. *Age and Ageing*, 39(4), 412–423.
- Crystal, S. R., Bowen, D. J., & Bernstein, I. L. (1999). Morning sickness and salt intake, food cravings, and food aversions. *Physiology & Behavior*, 67(2), 181–187.
- De Groot, C. P. G. M., Van Den Broek, T., & Van Staveren, W. (1999). Energy intake and micronutrient intake in the elderly Europeans: Seeking the minimum requirement in the SENECA study. *Age and Ageing*, 28(5), 469–474.
- De Jong, N., de Graaf, C., & Van Staveren, A. (1996). Effect of sucrose in breakfast items in pleasantness and food intake in the elderly. *Physiology and Behavior*, 60(6), 1453–1462.
- De-Regil, L. M., Fernandez-Gaxiola, A. C., Dowswell, T., & Pena-Rosas, J. P. (2010). Effects and safety of periconceptional folate supplementation for preventing birth defects. *Cochrane Database of Systematic Reviews*, 2010, CD007950. Available from <https://doi.org/10.1002/14651858.CD007950.pub2>.
- De Silva, D., Geromi, M., Halken, S., Host, A., Panesar, S. S., Muraro, A., et al. (2014). Primary prevention of food allergy in children and adults: Systematic review. *Allergy*, 2014(69), 581–589.
- Desor, J. A., Maller, O., & Turner, R. E. (1973). Taste in acceptance of sugars by human infants. *Journal of Comparative and Physiological Psychology*, 84(3), 496–501. Available from <https://doi.org/10.1037/h0034906>.
- De Vuyst, L., & Neysens, P. (2005). The sourdough microflora: Biodiversity and metabolic interactions. *Trends in Food Science and Technology*, 16, 43–56.
- Di Cairano, M., Galgano, F., Tolve, R., Caruso, M. C., & Condelli, N. (2018). Focus on gluten free biscuits: Ingredients and issues. *Trends in Food Science & Technology*, 81, 203–212.
- Dodd, J. M., Grivell, R. M., Nguyen, A. M., Chan, A., & Robinson, J. S. (2011). Maternal and perinatal health outcomes by body mass index. *Australian and New Zealand Journal of Obstetrics and Gynaecology*, 51(2), 136–140.
- Doty, R. L. (1989). Influence of age and age-related diseases on olfactory function. *Annals of the New York Academy of Sciences*, 561(1), 76–86.
- Duffy, V. B., Cain, W. S., & Ferris, A. M. (1999). Measurement of sensitivity to olfactory flavor: Application in a study of aging and dentures. *Chemical Senses*, 24(6), 671.
- Drenowski, A., Henderson, S. A., & Barratt-Fornell, A. (2001). Genetic taste markers and food preferences. *Drug Metabolism and Disposition*, 29, 535–538.
- Drewnowski, A., Coldwell, S. E., & Rolls, B. J. (2002). Taste and smell. In D. J. Ekerdt (Ed.), *Encyclopedia of Aging*. New York: Macmillan Reference USA.
- Eurostat. (2015). *Demographic statistics. A review of definitions and methods of collection in 44 European countries*.
- Eurostat—European Commission. (2009). *Health statistics—Atlas on mortality in the European Union*.
- Falciglia, G. A., Couch, S. C., Gribble, L. S., Pabst, S. M., & Frank, R. (2000). Food neophobia in childhood affects dietary variety. *Journal of the American Dietetic Association*, 100(12), 1474–1481.

- Fasano, A., & Catassi, C. (2012). Celiac disease. *The New England Journal of Medicine*, 367, 2419–2426.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding sausages. *Meat Science*, 103, 75–82.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016a). Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings. *European Food Research and Technology*, 242, 2105–2118.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016b). Impact of using replacers on the physicochemical properties and sensory quality of reduced salt and fat black pudding. *Meat Science*, 113, 17–25.
- Field, D., & Minkler, M. (1988). Continuity and change in social support between young old and old-old or very-old age. *Journal of Gerontology*, 43(4), P100–P106.
- Financial Times. *Healthy appetites drive jump in sales of gluten-free foods*. (2017). <<https://www.ft.com/content/4ec0f2f2-2c0a-11e7-9ec8-168383da43b7>>.
- Finkelstein, J. A., & Schiffman, S. S. (1999). Workshop on taste and smell in the elderly: An overview. *Physiology and Behavior*, 66, 173–176.
- Folkvord, F., & Riet, J. V. (2018). The persuasive effect of advergames promoting unhealthy foods among children: A meta-analysis. *Appetite*, 129, 245–251.
- Folkvord, F., Anschutz, D. J., Boyland, E., Kelly, B., & Buijzen, M. (2016). Food advertising and eating behavior in children. *Current Opinion in Behavioral Sciences*, 9, 26–31.
- Foster, K. D., Grigor, J. M. V., Cheong, N. E., Yoo, M. J., Bronlund, J. E., & Morgenstern, M. P. (2011). The role of oral processing in dynamic sensory perception. *Journal of Food Science*, 76, R49–R61.
- Galtier-Dereure, F., Boegner, C., & Bringer, J. (2000). Obesity and pregnancy: Complications and cost. *American Journal of Clinical Nutrition*, 71, 1242S–1248S.
- Gante, I., Amaral, N., Dores, J., & Almeida, M. C. (2015). Impact of gestational weight gain on obstetric and neonatal outcomes in obese diabetic women. *BMC Pregnancy and Childbirth*, 15, 249. Available from <https://doi.org/10.1186/s12884-015-0692-z>.
- Given, B., & Given, C. W. (1989). Cancer nursing for the elderly. A target for research. *Cancer Nursing*, 12(2), 71–77.
- Gobbetti, M., Pontonio, E., Filannino, P., Rizzello, C. G., De Angelis, M., & Di Cagno, R. (2018). How to improve the gluten-free diet: The state of the art from a food science perspective. *Food Research International*, 110, 22–32.
- Goodrich, K., Cregger, M., Wilcox, S., & Liu, J. (2013). A qualitative study of factors affecting pregnancy weight gain in African American women. *Maternal and Child Health Journal*, 17(3), 432–440.
- Griep, M. I., Mets, T. F., & Massard, D. L. (1996). Different effects of flavour amplification of nutrient dense foods on preference and consumption in young and elderly subjects. *Food Quality and Preference*, 8(2), 151–156.
- Hammes, W. P., & Ganzel, M. G. (1998). Sourdough breads and related products. In B. J. B. Woods (Ed.), *Microbiology of fermented foods* (pp. 199–216). Blackie Academic Professional.
- Harris, G., Thomas, A., & Booth, D. A. (1990). Development of salt taste in infancy. *Developmental Psychology*, 26(4), 534–538. Available from <https://doi.org/10.1037/0012-1649.26.4.534>.
- Hébel, P. (2013). *Evolution de la consommation de viande en France: les nouvelles données de l'enquête CCAF 2010*.
- Herrick, K. A., Rossen, L. M., Nielsen, S. J., Branum, A. M., & Ogden, C. L. (2015). Fruit consumption by youth in the United States. *Pediatrics*, 136, 664–671.
- Hetherington, M. (1998). Taste and appetite regulation in the elderly. *Proceedings of the Nutrition Society*, 57, 625–631.

- Heyman, M. B., Abrams, S. A., & American Academy of Pediatrics (AAP) Section on Gastroenterology, Hepatology, and Nutrition, AAP Committee on Nutrition. (2017). Fruit juice in infants, children, and adolescents: Current recommendations. *Pediatrics*, 139, e20170967.
- Hillesund, E. R., Bere, E., Haugen, M., & Øverby, N. C. (2014). Development of the New Nordic Diet score and its association with gestational weight gain and fetal growth – A study performed in the Norwegian Mother and Child Cohort Study. *Public Health Nutrition*, 17, 1909–1918.
- Holub, S. C., & Musher-Eizenman, D. R. (2010). Examining preschoolers' nutrition knowledge using a creation and food group classification task: Age and gender differences. *Early Child Development and Care*, 180(6), 787–798. Available from <https://doi.org/10.1080/03004430802396027>.
- Hook, E. B. (1978). Dietary cravings and aversions during pregnancy. *American Journal of Clinical Nutrition*, 31, 1355–1362.
- Houben, A., Hochstotter, A., & Becker, T. (2012). Possibilities to increase the quality in gluten free bread production: An overview. *European Food Research and Technology*, 235, 195–208.
- Houston, D. K., Nicklas, B. J., Ding, J., Harris, T. B., Tyllavsky, F. A., Newman, A. B., ... Kritchevsky, S. B. (2008). Dietary protein intake is associated with lean mass change in older, community-dwelling adults: The Health, Aging, and Body Composition (Health ABC) study. *The American Journal of Clinical Nutrition*, 87, 150–155.
- Huttner, E. K., & Arendt, E. K. (2010). Recent advances in gluten-free baking and the current status of oats. *Trends in Food Science & Technology*, 21, 303–312.
- Jnawali, P., Kumar, V., & Tanwar, B. (2016). Celiac disease: Overview and considerations for development of gluten-free foods. *Food Science and Human Wellness*, 5(4), 169–176. Available from <https://doi.org/10.1016/j.fshw.2016.09.003>.
- Kelly, B., Halford, J. C., Boyland, E. J., Chapman, K., Bautista-Castaño, I., Berg, C., & Grammatikaki, E. (2010). Television food advertising to children: A global perspective. *American Journal of Public Health*, 100(9), 1730–1736.
- Kim, M. K., Lopetcharat, K., & Drake, M. A. (2013). Influence of packaging information on consumer liking of chocolate milk. *Journal of Dairy Science*, 96, 4843–4856.
- Kölbe, N., Hummel, T., von Mering, R., Huch, A., & Huch, R. (2001). Gustatory and olfactory function in the first trimester of pregnancy. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 99, 179–183.
- Kong, K. L., Epstein, L. H., Phillips, J. K., Carr, K. A., Paluch, R. A., & Gerard, K. S. (2018). Food and non-food reinforcement among pregnant women. *Appetite*, 131, 155–159.
- Koskinen, S., Kalviainen, N., & Tuorila, H. (2003). Flavor enhancement as a tool for increasing pleasantness and intake of a snack product among the elderly – Research report. *Appetite*, 41, 87–96.
- Laureati, M., Pagliarini, E., Calcinoni, O., & Bidoglio, M. (2006). Sensory acceptability of traditional food preparations by elderly people. *Food Quality and Preference*, 17, 43–52.
- Lima, M., Ares, G., & Deliza, R. (2019). Comparison of two sugar reduction strategies with children: Case study with grape nectars. *Food Quality and Preference*, 71, 163–167.
- Lionetti, E., Gatti, S., Pulvirenti, A., & Catassi, C. (2015). Celiac disease from a global perspective. *Best Practice & Research Clinical Gastroenterology*, 29, 365–379.
- Louie, J. C. Y., Moshtaghlani, H., Rangan, A. R., Flood, V. M., & Gill, T. P. (2016). Intake and sources of added sugars among Australian children and adolescents. *European Journal of Nutrition*, 55, 2347–2355.

- Malik, V. S., Pan, A., Willett, W. C., & Hu, F. B. (2013). Sugar-sweetened beverages and weight gain in children and adults: A systematic review and meta-analysis. *American Journal of Clinical Nutrition*, 98(4), 1084–1102.
- Madeira, K. M., & Goldman, A. (1988). Some aspects of sensory properties of food that relate to food habits and associated problems of elderly consumers. *Journal of Nutrition for the Elderly*, 8, 3–24.
- Masure, H. G., Fierens, E., & Delcour, J. A. (2016). Current and forward looking experimental approaches in gluten-free bread making research. *Journal of Cereal Science*, 67, 92–111.
- Matos, M. E., & Rosell, C. M. (2013). Quality indicators of rice-based gluten-free bread-like products: Relationships between dough rheology and quality characteristics. *Food Bioprocess Technol*, 6, 2331–2341.
- Melina, V., Craig, W., & Levin, S. (2016). Position of the academy of nutrition and dietetics: Vegetarian diets. *Journal of the Academy of Nutrition and Dietetics*, 116, 1970–1980.
- Millward, D. J., Layman, D. K., Tomé, D., & Schaafsma, G. (2008). Protein quality assessment: Impact of expanding understanding of protein and amino acid needs for optimal health. *American Journal of Clinical Nutrition*, 87, 1576S–1581S.
- Mojet, J. (2003). Taste perception with age: Generic or specific losses in supra-threshold intensities of five taste qualities? *Chemical Senses*, 28(5), 397–413.
- Murphy, C. (1993). Nutrition and chemosensory perception in the elderly. *Critical Reviews in Food Science and Nutrition*, 33(1), 3–15.
- Murphy, C., & Gilmore, M. M. (1990). Effect of aging on sensory functioning: Implications for the dietary selection. In R. L. McBride, & H. J. H. Mac Fie (Eds.), *Psychophysical basis of sensory evaluation book* (pp. 19–39). Elsevier Applied Science.
- Murphy, M. M., Douglass, J. S., Johnson, R. K., & Spence, L. A. (2008). Drinking flavored or plain milk is positively associated with nutrient intake and is not associated with adverse effects on weight status in US children and adolescents. *Journal of the American Dietetic Association*, 108, 631–639.
- Nagao, M. (1992). The effects of aging on mastication. *Nutrition Reviews*, 50(12), 434–437.
- Naqash, F., Gani, A., Gani, A., & Masoodi, F. A. (2017). Gluten-free baking: Combating the challenges – A review. *Trends in Food Science & Technology*, 66, 98–107. Available from <https://doi.org/10.1016/j.tifs.2017.06.004>.
- Nenna, R., Petrarca, L., Verdecchia, P., Florio, M., Pietropaoli, N., Mastrogiorgio, G., ... Cucchiara, S. (2016). Celiac disease in a large cohort of children and adolescents with recurrent headache: A retrospective study. *Digestive and Liver Disease*, 48, 495–498.
- Nguyen, S. P. (2012). The role of external sources of information in children's evaluative food categories. *Infant and Child Development*, 21(2), 216–235. Available from <https://doi.org/10.1002/icd.745>.
- Nguyen, S. P., Gordon, C. L., Chevalier, T. N., & Girgis, H. (2016). Trust and doubt, an examination of children's decision to believe what they are told about food. *Journal of Experimental Child Psychology*, 144, 66–83. Available from <https://doi.org/10.1016/j.jecp.2015.10.015>.
- Nordin, S., Broman, D. A., Olofsson, J. K., & Wulff, M. (2004). A longitudinal descriptive study of self-reported abnormal smell and taste perception in pregnant women. *Chemical Senses*, 29, 391–402.
- Norelle, R., & Reilly, M. D. (2016). The gluten-free diet: Recognizing fact, fiction, and fad. *The Journal of Pediatrics*, 175, 206–210.

- Nyaradi, A., Li, J., Hickling, S., Foster, J., & Oddy, W. H. (2013). The role of nutrition in children's neurocognitive development, from pregnancy through childhood. *Frontiers in Human Neuroscience*, 7, 97.
- Orloff, N. C., Flammer, A., Hartnett, J., Liquorman, S., Samelson, R., & Holmes, J. M. (2016). Food cravings in pregnancy: Preliminary evidence for a role in excess gestational weight gain. *Appetite*, 105(1), 259–265.
- O'Sullivan, M. G. (2017). CH14. *Sensory properties of bakery and confectionary products. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 305–324). London, United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017b). CH2. *descriptive methods. A handbook for sensory and consumer driven new product development: innovative technologies for the food and beverage industry* (pp. 13–37). United Kingdom: Woodhead Publishing Ltd.
- Paciulli, M., Rinaldi, M., Cirilini, M., Scazzina, F., & Chiavaro, E. (2016). Chestnut flour addition in commercial gluten-free bread: A shelf-life study. *LWT—Food Science and Technology*, 70, 88–95.
- Pahlavan, A., Sharma, G. M., Pereira, M., & Williams, K. M. (2016). Effects of grain species and cultivar, thermal processing, and enzymatic hydrolysis on gluten quantitation. *Food Chemistry*, 208, 264–271.
- Painter, R. C., Roseboom, T. J., & Bleker, O. P. (2005). Prenatal exposure to the Dutch famine and disease in later life: An overview. *Reproductive Toxicology*, 20, 345–352.
- Pawellek, I., Grote, V., Theurich, M., Closa-Monasterolo, R., Stolarczyk, A., Verduci, E., et al. (2017). Factors associated with sugar intake and sugar sources in European children from 1 to 8 years of age. *European Journal of Clinical Nutrition*, 71, 25–32.
- Pope, J. F., Skinner, J. D., & Carruth, B. R. (1992). Cravings and aversions of pregnancy adolescents. *Journal of the American Dietetic Association*, 92, 1479–1482.
- Popper, R., & Kroll, B. J. (2003). Food preference and consumption among the elderly. *Food Technology*, 57, 32–40.
- Powell, L. M., Schermbek, R. M., Szczypka, G., Chaloupka, F. J., & Braunschweig, C. L. (2011). Trends in the nutritional content of television food advertisements seen by children in the United States: Analyses by age, food categories, and companies. *Archives of Pediatrics and Adolescent Medicine*, 165(12), 1078–1086.
- Pszczola, D. (2012). The rise of gluten-free. *Food Technology*, 66, 55–66.
- Rafii, M., Chapman, K., Owens, J., Elango, R., Campbell, W. W., Ball, R. O., & Courtney-Martin, G. (2014). Dietary protein requirement of female adults >65 years determined by the indicator amino acid oxidation technique is higher than current recommendations. *The Journal of Nutrition*, 145(1), 18–24.
- Reynolds, C. M., Vickers, M. H., Harrison, C. J., Segovia, S. A., & Gray, C. (2014). High fat and/or high salt intake during pregnancy alters maternal meta-inflammation and offspring growth and metabolic profiles. *Physiological Reports*, 2(8), e12110. Available from <https://doi.org/10.14814/phy2.12110>.
- Rifas-Shiman, S. L., Rich-Edwards, J. W., Kleinman, K. P., Oken, E., & Gillman, M. W. (2009). Dietary quality during pregnancy varies by maternal characteristics in Project Viva: A US cohort. *Journal of the American Dietetic Association*, 109, 1004–1011.
- Robine, J.-M., & Michel, J.-P. (2004). Looking forward to a general theory on population aging. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 59(6), M590–M597.
- Robinson, S., Cooper, C., & Aihie Sayer, A. (2012). Nutrition and sarcopenia: A review of the evidence and implications for preventive strategies. *Journal of Aging Research*, 2012, 510801.
- Robinson, T. N. (1999). Reducing children's television viewing to prevent obesity: A randomized controlled trial. *Journal of the American Medical Association*, 282(16). Available from <https://doi.org/10.1001/jama.282.16.1561>, 1561e1567.

- Roininen, K., Fillion, Laurence Kilcast, D., & Lahteenmaki, L. (2003). Perceived eating difficulties and preferences for various textures of raw and cooked carrots in young and elderly subjects. *Journal of Sensory Studies*, 18(6), 437–451.
- Roseboom, T. J., van der Meulen, J. H., Osmond, C., et al. (2000). Coronary heart disease after prenatal exposure to the Dutch famine, 1944–45. *Heart*, 84, 595–598.
- Rothman, K. J., Moore, L. L., Singer, M. R., Nguyen, U. S., Mannino, S., & Milunsky, A. (1995). Teratogenicity of high vitamin A intake. *New England Journal of Medicine*, 333, 1369–1373.
- Russell, C. G., & Worsley, A. (2013). Why don't they like that? And can I do anything about it? The nature and correlates of parents' attributions and self-efficacy beliefs about preschool children's food preferences. *Appetite*, 66, 34–43.
- Santilli, V., Bernetti, A., Mangone, M., & Paoloni, M. (2014). Clinical definition of sarcopenia. *Clinical Cases in Mineral and Bone Metabolism*, 11(3), 177.
- Schiffman, S. S. (1993). Perception of taste and smell in the elderly persons. *Critical reviews in Food Science and Nutrition*, 33(1), 17–26.
- Schiffman, S. S. (1994). Changes in taste and smell: Drug interactions and food preferences. *Nutrition reviews*, 52(8), S1–S14.
- Schiffman, S. S. (1997). Taste and smell losses in normal aging and disease. *JAMA*, 278 (16), 1357–1362.
- Schiffman, S. S. (2000). Intensification of sensory properties of foods for the elderly. *Journal of Nutrition, Supplement*, 927–930.
- Schiffman, S. S., & Gatlin, C. A. (1993). Clinical physiology of taste and smell. *Annual Review of Nutrition*, 13, 405–436.
- Schiffman, S. S., & Graham, B. G. (2000). Taste and smell perception affect appetite and immunity in the elderly. *European Journal of Clinical Nutrition*, 54(Suppl. 3), S54–63.
- Schiffman, S. S., & Warwick, Z. S. (1991). Changes in taste and smell over the lifespan: Effects on appetite and nutrition in the elderly. In M. I. Friedman, M. G. Tordoff, & M. R. Kare (Eds.), *Chemical senses, appetite and nutrition* (Vol. 4, pp. 341–365). New York: Marcel Dekker.
- Shaw, S. C., Dennison, E. M., & Cooper, C. (2017). Epidemiology of sarcopenia: Determinants throughout the life course. *Calcified Tissue International*, 101, 229–247.
- Shevkani, K., Kaur, A., Kumar, S., & Singh, N. (2015). Cowpea protein isolates: Functional properties and application in gluten-free rice muffins. *LWT—Food Science and Technology*, 63, 927–933.
- Ship, J. A. (1999). The influence of aging on oral health and consequences for taste and smell. *Physiology & Behavior*, 66(2), 209–215.
- Sipiora, M. L., Murtaugh, M. A., Gregoire, M. B., & Duffy, V. B. (2000). Bitter taste perception and severe vomiting in pregnancy. *Physiology and Behaviour*, 69, 259–267.
- Skinner, J. D., Pope, J. F., & Carruth, B. R. (1998). Alterations in adolescents' sensory taste preferences during and after pregnancy. *Journal of Adolescent Health*, 22(1), 43–49.
- Stevens, J. C., Barthoshuk, L. M., & Cain, W. S. (1984). Chemical senses and aging: Taste versus smell. *Chemical Senses*, 9, 167–179.
- Stotland, N. E., Hopkins, L. M., & Caughey, A. B. (2004). Gestational weight gain, macrosomia, and risk of cesarean birth in nondiabetic nuliparas. *Obstetrics & Gynecology*, 104(4), 671–677.
- Tang, M., McCabe, G. P., Elango, R., Pencharz, P. B., Ball, R. O., & Campbell, W. W. (2014). Assessment of protein requirement in octogenarian women with use of the indicator amino acid oxidation technique. *The American Journal of Clinical Nutrition*, 99 (4), 891–898.
- Te Morenga, L., Mallard, S., & Mann, J. (2012). Dietary sugars and body weight: Systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ*, 346, 7492.

- Thrift, A. P., & Callaway, L. K. (2014). The effect of obesity on pregnancy outcomes among Australian Indigenous and non-Indigenous women. *Medical Journal of Australia*, 201(10), 592–595.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, 93, 145–152.
- Turkut, G. M., Cakmak, H., Kumcuoglu, S., & Tavman, S. (2016). Effect of quinoa flour on gluten-free bread batter rheology and bread quality. *Journal of Cereal Science*, 69, 174–181.
- VanderBorghet, M., & Jaswal, V. K. (2009). Who knows best? Preschoolers sometimes prefer child informants over adult informants, 2018 child informants over adult informants. *Infant and Child Development*, 18, 61–71. Available from <https://doi.org/10/1002/icd.591>.
- Vici, G., Belli, L., Biondi, M., & Polzonetti, V. (2016). Gluten free diet and nutrient deficiencies: A review. *Clinical Nutrition*, 35(6), 1236–1241. Available from <https://doi.org/10.1016/j.clnu.2016.05.002>.
- Volkert, D., Saeglit, C., Gueldenzoph, H., Sieber, C. C., & Stehle, P. (2010). Undiagnosed malnutrition and nutrition-related problems in geriatric patients. *The Journal of Nutrition, Health & Aging*, 14(5), 387–392.
- Volpi, E., Campbell, W. W., Dwyer, J. T., Johnson, M. A., Jensen, G. L., Morley, J. E., & Wolfe, R. R. (2012). Is the optimal level of protein intake for older adults greater than the recommended dietary allowance? *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 68(6), 677–681.
- Wells, J. L., & Dumbrell, A. C. (2006). Nutrition and aging: Assessment and treatment of compromised nutritional status in frail the elderly patients. *Clinical Interventions in Aging*, 1(1), 67.
- Wennberg, A. L., Isaksson, U., Sandström, H., Lundqvist, A., Hörnell, A., & Hamberg, K. (2016). Swedish women's food habits during pregnancy up to six months post-partum: A longitudinal study. *Sexual & Reproductive Healthcare*, 8(2016), 31–36.
- World Health Organization (WHO). (2013). *Proposed working definition of an older person in Africa for the MDS Project: Definition of an older or the elderly person*.
- Wysocki, C. J., & Pelchat, M. L. (1993). The effects of aging on the human sense of smell and its relationship to food choice. *Critical Reviews in Food Science & Nutrition*, 33(1), 63–82.
- Yeon, J. Y., & Lee, S. K. (2016). Perception of sugar reduction, nutrition education, and frequency of snacking in children by the self-perceived sweet dietary habits of mothers in Busan. *Nutrition Research and Practice*, 10, 546–554.
- Yoo, H. J., Machín, L., Arrúa, A., Antúnez, L., Vidal, L., Giménez, A., ... Ares, G. (2017). Children and adolescents' attitudes towards sugar reduction in dairy products. *Food Research International*, 94, 108–114.

Further reading

- Conroy, P. M., O'Sullivan, M. G., Hamill, R. H. & Kerry, J. P. (2018b). Sensory analysis of MSG flavour enhanced traditional breakfast sausages: A consumer age profile. *Meat Science* (Submitted).
- Kremer, S., Mojet, J. O. S., & Kroeze, J. H. A. (2005). Perception of texture and flavor in soups by the elderly and young subjects. *Journal of Texture Studies*, 36(3), 255–272.
- Menrad, K. (2002). Market and marketing of functional food in Europe. *Journal of Food Engineering*, 56, 181–188.

- Michon, C., O'Sullivan, M. G., Delahunty, C. M., & Kerry, J. P. (2010a). Study on the influence of age, gender and familiarity with the product on the acceptance of vegetable soups. *Food Quality and Preference*, 21, 478–488.
- Michon, C., O'Sullivan, M. G., Delahunty, C. M., & Kerry, J. P. (2010b). The investigation of gender related sensitivity differences in food perception. *Journal of Sensory Studies*, 24, 922–937.
- Michon, C., O'Sullivan, M. G., Sheehan, E., Delahunty, C. M., & Kerry, J. P. (2010). Investigation of the influence of age, gender and consumption habits on the liking for jam-filled cakes. *Food Quality and Preference*, 21, 553–561.



Descriptive methods for reformulation

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Introduction

Sensory methods can be broadly segmented into three different areas—difference methods, affective methods, and descriptive methods. Difference methods simply discriminate between two (paired comparison), three (duo-trio and triangle), or four products (tetrad) and are the most basic test used for reformulation purposes and are useful to determine how close new variants are to standardized products. Results can easily be determined by referencing published significance tables based on the binomial distribution (Lawless & Heymann, 2010). Affective tests use untrained assessors to determine hedonics, the degree of acceptability, liking or preference of products and where description is never the remit of these tests. Finally, descriptive tests use trained panelists to define the sensory profile or character of products in an absolute fashion in terms of appearance, aroma, flavor, taste, and aftertaste.

Sensory profiling methods first evolved from in the 1950s from expert-based industry methods used by winemakers, perfumers, and brewmasters

(Muñoz, Civile, & Carr, 1992). These simple sensory methods only detected problems and defects, which was only really effective for commodity type products (Lawless & Heymann, 1998). Sensory methods using trained panels evolved from these simple methods in the 1950s and 1960s (Muñoz, 2002). One of the most well-known contributions of this era was “the 9-point hedonic scale” or the “degree of liking scale” in the 1940s invented by the US Army Corps of Engineers (US Army Quartermaster Food and Container Institute, Chicago, Illinois) in the 1940s (Peryam & Pilgrim, 1957).

Sensory perception is a very variable response in humans and is affected by age, gender (Michon, O’Sullivan, Delahunty, & Kerry, 2010a, 2010b; Michon, O’Sullivan, Sheehan, Delahunty, & Kerry, 2010), cultural influences (Yusop, O’Sullivan, Kerry, & Kerry, 2009a, 2009b), as well as many other factors. However, descriptive methods involve the training of panelists to quantitatively determine the sensory attributes, typically in a selection of samples and to an extent calibrate humans to produce a more standardized sensory response (O’Sullivan, 2017). This statement is truer for the spectrum method of sensory profiling than quantitative descriptive analysis (QDA) as it employs a series of strictly defined terms and sensory references to obtain absolute sensory/taste values by panelists, which are standardized across countries (Teo et al., 2018). However, for both methods, assessors are trained to measure the attributes associated with the relevant sensory modalities of appearance, aroma, flavor, texture, taste, and aftertaste. Evaluations are descriptive and not in any way hedonic or involve the measurement of subjective or affective responses (O’Sullivan, 2017). A screened sensory panel is selected based on performance through the use of various acuity tests (e.g., triangle threshold detection and JAR or ranked scaling) with those scoring above a set threshold, usually 60%, making the grade for panel inclusion. The profiling procedure then involves the use of sensory terms that are produced in collaboration with the panelists and the panel leader. With QDA the panelists are trained, using a subset of the samples to be profiled, which reflects the main sensory variation in the whole set of samples and their performance monitored using statistical methods. A reference is provided for each sensory attribute to assist the panelist in quantifying that particular attribute. When training is complete, these references are removed and profiling takes place on the full sample set (O’Sullivan, 2017). The method is quantitative and can be used to describe differences between products and the main sensory drivers, be they positive or negative, identified within products or especially when combined with objective consumer

testing and objective multivariate data analysis (O'Sullivan, 2017; O'Sullivan, Kerry, & Byrne, 2011). Descriptive profiling methods are one of the most powerful sensory evaluation approaches and can minutely characterize the sensory descriptive profile of products. However, the method can be expensive and time-consuming because of the necessity to train and profile individual panelists over extended periods of time, days or even weeks. It is also not a method that can be readily used for routine analysis. For product-development systems, these methods can sometimes be limiting and slow. Also, line extensions, such as a new flavor variant of a product, require a new descriptive profile to be undertaken (O'Sullivan, 2017; O'Sullivan et al., 2011). Also, a single stimulus can be perceived as quantitatively and qualitatively different from one subject to the other, especially when chemical senses are involved (Lawless, 1999).

Other descriptive profiling methods also include the flavor profile method, free-choice profiling (FCP), and texture profile method (TPM). Only some of these methods (QDA, spectrum) are now widely used for reformulation purposes, while the rest have become historical or academic curiosities.

The TPM evolved from FPM, a very basic profiling technique no longer used, and was developed in the 1960s by General Foods. The technique aims to allow the description of only texture attributes from the first bite through complete mastication and also accounts for the temporal aspect of attributes (Murray, Delahunty, & Baxter, 2001). Sensory scales are anchored using sensory references for texture, but these references can now be quite hard to define either due to unavailability or reformulation. It is no surprise that this method has lost favor with sensory scientists.

FCP can also be used, and this involves panelists developing their own descriptive terms (Delahunty, McCord, O'Neill, & Morrissey, 1997; Williams & Arnold, 1985). The problem with this method is the subjective correlation of terms derived by different assessors that may not, in reality, be related, and for this reason, it has not been widely adopted.

As only the spectrum and QDA are the descriptive profiling method most commonly used, these techniques will be discussed in greater detail later as well as practical factors associated with profiling. These include the provision of a standardized testing environment, the screening and inclusion of panelists, and randomization and sample presentation protocols.

Affective methods use hedonics or ask untrained assessors their opinion of a product or products, such as liking of appearance, aroma, flavor, texture, and overall acceptability or preference. They do not describe the

product. Commonly used affective methods include the “Sensory Acceptance Test” and the “Consumer Test.” Combining descriptive data and hedonic is a powerful reformulation tool as hedonic qualities can be directly related to the descriptive profile. Thus positive hedonic drivers may be identified and subsequently increased and negative drivers decreased. Such data is typically analyzed using data analytical tools that involve predominantly chemometrics in a method called preference mapping. Thus it is important to note that by combining hedonic and descriptive data statistically valid correlations could be determined from the data set so that sensory scientists could understand how their modifications were affecting the sensory profile of the product with respect to the modalities, appearance, aroma, flavor, texture, taste, and aftertaste, as well as consumer opinion (O’Sullivan, 2017). This presents a very powerful sensory tool for reformulation scientists.



Environment and panel conditions

ISO (2007) describes the requirements to set up a test room comprising a testing area, a preparation area, and an office, specifying those that are essential or those that are merely desirable. The ASTM (2008) manual provides the latest guidelines for sensory evaluation professionals who undertake the development of a new facility or remodeling of an existing sensory laboratory. Sensory testing rooms should be separated from preparation areas to eliminate odor transfer. The test room must be divided into separate booths with adequate lighting, and the area must have a suitable controlled atmosphere ISO (2007).

For successful descriptive sensory evaluation the environment where the sensory analysis is conducted is critical. It is crucial to remove as many negative extrinsic environmental factors as possible from the testing area so that the space does not interfere with the actual task of sensory judgment. This ensures that the panelist is not distracted or biased by their surroundings and that their assessment is purely on the product they are testing without any other external factors to influence them (O’Sullivan, 2017). This is achieved through compliance with the international standards and guidelines for the design of sensory testing facilities as described earlier.

Ventilation requirements are crucial to sensory testing design as it is important that air turnover in the booths should occur every 30 second as

a minimum. This is so that product odors, heat, and exhaled gasses are removed, which could affect evaluations. Maximum capacity needs to be factored into this so that the ventilation system is adequate to accommodate fully occupied booths, with the maximum number of people in the preparation areas, the presence of heating equipment (ovens) over an extended periods of time (e.g., 8 hours). It is most beneficial if testing booths have a slight positive pressure (Stone & Sidel, 2004).

Lighting in the booth area should be fluorescent, except in the booths themselves, where incandescent lighting is recommended. This lighting should be sufficient to provide 100–110 ft-candles (or their equivalent) of shadow-free light at the counter surface. The use of colored lights (e.g., red, yellow, and blue) intended to mask color differences between products (e.g., standard and red cheddar) is not recommended. Colored lighting increases subject variance as color differences may not be masked but only altered (Stone & Sidel, 2004).



Panelist selection

The sensory panelist is the most important component of sensory testing and must be in optimal physiological condition when undertaking testing. Also the panelist must be available, have completed and passed screening tests but must be a user or potential user of the product or of the product class to be evaluated. As a product user, the individual will have repeated exposure to the product, and those individuals who do not like or would never use the product tend to be less sensitive and more variable to product differences (Stone & Sidel, 2004; Lawless and Heymann, 1998). Panelists must not consume food for a minimum of 1 hour before undertaking an oral sensory evaluation. Muñoz, Civille, and Carr (1992) outline practical guidelines for participation in sensory evaluations. These guidelines include the following: be in good mental and physical condition, know the scorecard, relevant defects, and intensities; evaluate the aroma first (for the relevant products, what is important); taste a sufficient amount or volume of the product, pay attention to the flavor sequence; rinse occasionally, concentrate; do not be too critical; it is essential to obtain feedback and review punctuation; be honest while practicing and be professional; panelists should not eat, drink, or smoke for at least 30 minutes before participation, should not use perfume,

cologne or aftershave lotion, or any other perfumed products (Nelson & Trout, 1964).

Panelists included in descriptive panels are screened to ensure they have a relatively normal sensory response and also be able to demonstrate that they are capable of discriminating between samples. Initially, a large volume of individuals should be screened as not all will meet the selection criteria and those that do are not always available to participate in panels for various reasons (O'Sullivan, 2017). Selection of panelists should be also assessed using a questionnaire targeting certain criteria, including availability, health, motivation, and suitable character and dislikes (foods). Other qualifications include the ability to verbalize and to work as a group, both are important to the success of the language development process, and finally the ability to perform during actual testing (Stone & Sidel, 2004; Lawless & Heymann, 2010). Selected panelists in effect should be punctual, in good health, have an interest in participating, and be able to communicate their responses without being too dominant or weak in character as these individuals may introduce bias into the panel. Also, it is important to produce a file for each panelist of the products they may wish to avoid for health reasons that might manifest allergic responses or if they particularly dislike a food or beverage. One should be especially careful when selecting individuals that they are at risk due to nut allergies or allergies to antibiotics. The former should generally be excluded as a precaution whereas for the latter, antibiotics could be present in mold-ripened cheeses and thus present a serious health risk to those susceptible assessors. It is not recommended to include females who may be pregnant as their dietary needs can exclude them from being able to assess some products for dietary and safety reasons and also their sensory response may also be skewed (Lawless & Heymann, 2010; O'Sullivan, 2017).

Panel candidates are required to go through a screening procedure to ensure that they have a suitable sensory response, should have normal color vision, and be screened for ageusia that is the inability to taste and anosmia, the inability to detect odors (ISO, 1991). Screening tests could include difference testing, sensory threshold testing, or ranking tests that are described in detail in ISO (1993). In addition triangle, duo-trio, basic taste testing, taste intensity, and odor recognition testing are undertaken (Conroy, O'Sullivan, Hamill, & Kerry, 2018a,b). Examples of screening tests are outlined in the case study presented at the end of this chapter. Those that do not pass the selection criteria should be excluded from

participation, but borderline candidates who may have potential as their level of acuity will increase with practice should be retested. It is really up to the discretion of the panel screening leader to decide on this. To be included in the descriptive panel, the panelist must pass an arbitrary percentage of the screening tests, and this level is usually set at 65% but this is at the discretion of the panel leader (Stone & Sidel, 2004; Lawless & Heymann, 2010).

Selecting a panel can come from internal (within organization) or external (outside organization). Internal panels have the advantages of not having to additionally be paid and they are easily contactable, but they must leave their official duties to participate. However, external panels are impartial and do not suffer from these problems, but they need to be paid and getting their participation can be logistically more complicated. It is estimated to screen 2–3 times more individuals than are required to account for those not making the grade and unplanned for attrition (Murray et al., 2001).



Sampling and sample presentation

All methods of sample preparation must be standardized to ensure minimal influences on the sensory properties of the samples being tested. In order to ensure that the true sensory response is obtained during sensory assessment, it is important that samples are prepared and presented appropriately so that potential sources of error are reduced (O'Sullivan, 2017). The most important factor is sample presentation order, which must be unbiased with samples presented in a randomized order to prevent first-order and carry-over effects (MacFie, Bratchell, Greenhoff, & Vallis, 1989). This is to ensure that the aftereffects of evaluating a sample do not carry over, thus influence the subsequent sample being tested. An example of this might be where one sample has a strong persistent flavor (chili heat, spice, herb, off-flavor, etc.) that could influence the subsequent sample. By presenting a different sampling order for each panelist, this error is averaged out and minimized. In addition, sampling of a product must be representative of the sample to be tested. This is relatively easy with liquid products, where samples served at the same temperature (e.g., ambient) but can be more challenging for more complex products. This complexity is clearly demonstrated when working with fresh meat

products. Animal carcasses contain over 300 separate muscles, differing in the ratio of red and white muscle fiber types. Scientists often standardize their sampling so that a standard thickness (~ 1 in., 2.54 cm) from the same parts of the muscle is compared across different treatment muscles from other test animals. As one of the more homogeneous muscles the *musculus longissimus dorsi* is often chosen for standardized sensory experiments. In addition, it is imperative that these standardized samples are then cooked in an identical fashion and then served to assessors at a standardized temperature (O'Sullivan, 2017). Quite of ten it is important that samples are presented to panelists at ambient temperature even if sometimes the product itself is served chilled. The flavor volatiles of cheese, chocolate, beer, or white wine are easier to evaluate at $\sim 20^{\circ}\text{C}$ than at chilled temperatures.

Sensory testing should be undertaken “blind” with samples presented with random 3-digit codes in order to liberate the assessor from personal views or biases such as brand, packaging, or product configuration. Assessors are given minimal information prior to a sensory test because this too can influence their evaluation. If assessors were told they were assessing samples in order to determine if off-flavors exist in the product or not, a bias would be introduced with the assessor; then focusing on this attribute which may have an influential effect (O'Sullivan, 2017). Branding can also affect evaluation either introducing positive or negative bias. A product perceived on a supermarket shelf may have different attributes affecting perception when compared to the same product seen on blind on a plate (Hutchings, 1977). Moskowitz (1981) studied the “Relative importance of perceptual factors to consumer Acceptance” and found that branding can encourage a product's acceptability. Similarly, Martin (1990) found that a beer tasted blind was rated higher than when the test was repeated and the brand identified.



Spectrum

The Spectrum method was developed in the 1970s (Civille & Szczesniak, 1973) and uses a strict technical sensory vocabulary using reference materials to train panelists. It is a QDA method in which a series of defined references is used to obtain absolute sensory/taste values. Different references might describe different intensities of a specific attribute. These references are solutions to simple tastants that are standardized

across countries (Teo et al., 2018). To evaluate a range of products the trained panel goes through a language development process similar to that described for QDA, but with considerable attention given to the identification and use of specific references to represent the various attributes (Stone & Sidel, 2004). Standard attribute names (lexicons) are used in Spectrum, each with a set of standards that define the intensity scale (Meilgaard, Civille, & Carr, 1999; Muñoz & Civille, 1992). The objective is that the resulting profiles are commonly understood. The panelists develop a list of attributes when evaluating a wide range of products in this category (Murray et al., 2001). One of the disadvantages is that intensive panelist training is required when using the Spectrum method. The training process for the Spectrum method is very lengthy, requiring 3–4 hours/week, for a period of 14 weeks. This is necessary to enable the panel to be universal and to be able to evaluate all types of products (Stone & Sidel, 2004). Also, some reference materials are not available outside of America. The cultural differences of the panels and the difficulty in quantifying the attribute in a number of different products are other problems of this method mentioned in the literature (Murray et al., 2001). Sensory lexicons similar to those outlined later for QDA are also available for the spectrum methods.



Quantitative descriptive analysis

The QDA methodology provides a complete word description for all of a product's sensory properties and can be a valuable in understanding how reformulation affects the flavor profile of foods and beverages. Samples can be an existing product (currently in the marketplace), an ingredient, an idea, or it can be an entirely new product for which there is no existing competition (Stone & Sidel, 2004). Descriptive analysis is a method where defined sensory terms are quantified by sensory panelists. Detailed descriptions of sensory terminology and procedural guidelines for the identification and selection of descriptors for establishing a sensory profile by a multidimensional approach have been described in ISO (1992) and ISO (1994).

The QDA method was first proposed by Stone, Sidel, Oliver, Woolsey, and Singleton (1974) and relies heavily on statistical analysis to determine the appropriate terms, procedures, and panelists to be used for the analysis of a specific selection of product. Statistical analysis is initially used in the

sensory term reduction process during training and requires the use of product references to stimulate the generation of terminology. These references help the panelist define and quantify the attribute they are assessing and greatly assist in the training process. The panel leader acts as moderator and facilitator, without directly influencing the group (Stone et al., 1974).

With the QDA method, experts with product knowledge can evaluate a sample set of the products to be profiled in the laboratory and suggest descriptive terms that specifically describe the product to be tested and the sensory dimension to be examined to produce an initial or “meta” sensory term list. The vocabulary is based on terms suggested by the panelists themselves in discussions under supervision of the panel leader. Sensory lexicons can also be provided, which consist of lists of sensory terms describing appearance, aroma, flavor, texture, taste, and aftertaste attributes (O’Sullivan, 2017). References must then be produced or found that reflect these sensory terms. A list of descriptive terms, determined initially and referred to as a lexicon or descriptive vocabulary, describes the specific sensory attributes in the food or beverage sample and can be used to evaluate the changes in these attributes (O’Sullivan, 2017). These descriptive terms, determined from such lexicons of descriptive terms, have been developed and employed by a number of authors for the sensory evaluation of different products: Johnson and Civille (1986) for beef; Lyon (1987) and Byrne, Bredie, and Martens (1999) for chicken; Byrne, Bak, Bredie, Bertelsen, and Martens (1999) and Byrne, O’Sullivan, Dijksterhuis, Bredie, and Martens (2001) for pork; Johnsen, Civille, Vercellotti, Sanders, and Dus (1998) for peanut flavor; Desai, Shepard, and Drake (2013) for Greek yoghurt; and Van Hekken, Drake, Corral, Prieto, and Gardea (2006) for Mexican cheese. Lexicons are also available for other foods and beverage products; Cheddar cheese (Drake et al., 2005) and French cheese (Rétiveau, Chambers, & Esteve, 2005). Panelists cannot discuss data, terminology, or samples after each taste session but must rely on the discretion of the panel leader for any information on their performance. Feedback is provided by the facilitator based on the statistical analysis of the taste session data (Lawless & Heymann, 1998; Meilgaard et al., 1999). For each descriptive term a sensory reference is provided in order to assist the panelist in understanding and then in turn quantifying the attribute in the training samples and ultimately the full set of profiling samples. Examples of references corresponding to sensory terms are described in the case study presented at the end of the chapter. Once an initial list of terms and references is decided upon, the next step is to reduce these terms through the training and term reduction process.

In order for a term to be included during subsequent profiling, it must fit four criteria: (1) the sensory terms selected must be relevant to the samples, (2) discriminate between the samples, (3) have cognitive clarity, and (4) be nonredundant (Byrne, Bak, et al., 1999; Byrne, Bredie, et al., 1999; Byrne et al., 2001; O'Sullivan, Byrne, & Martens, 2002). Various means can be employed in this term reduction process and have included principal component analysis (PCA) in conjunction with assessor suggestions (Byrne, Bak, et al., 1999; Byrne, Bredie, et al., 1999; Byrne et al., 2001; O'Sullivan et al., 2002). FCP can also be used and involves panelists coming up with their own descriptive terms (Delahunty et al., 1997). The problem with this method is the subjective correlation of terms derived by different assessors. Generalized Procrustes analysis (GPA) has also been used in terms of reduction (Byrne et al., 2001). At the end of each session (day) in the training period, redundant or unreliable sensory terms are eliminated or merged in order to select a reduced list of terms for use in the next session. The goal is to obtain, at the end of the training period, a reduced descriptor list where each remaining term was relevant to the product, nonredundant, sample discriminating, and cognitively clear to the assessors (Byrne, Bak, et al., 1999; Byrne, Bredie, et al., 1999; Byrne et al., 2001; O'Sullivan et al., 2002). The profile reduction on each day can be carried out on the basis of panel discussions, term grouping sheet recommendations, and interpretation of PCA performed on the data from that day of training (based on mean centered, unweighted variables, assessed by full cross-validation). Once training is complete and the panel is stable, the sensory profiling of the full set of samples can commence. Training, sensory term reduction followed by sensory profiling, is described in detail in the case study section below with an example of reformulation of a processed meat product in order to optimize salt and fat reduction from a sensory perspective.



Case study. Quantitative descriptive analysis of salt- and fat-reduced traditional breakfast sausages containing monosodium glutamate

QDA was used to explore the sensory variation of ten sausage samples that included salt (0%–2.5%)— and fat (15%–30%)—reduced sausage and MSG (monosodium glutamate) (0%–3.0%) flavor enhanced sausages (Conroy, O'Sullivan, Hamill, & Kerry, 2020).

Screening, training and profiling

Panelists were initially screened using an online structured questionnaire. Of the 730 respondents, 103 were identified as eligible to attend the sensory screening component. These individuals then performed scaling tests, matching tests of taste and aroma, and ranking tests. In addition triangle, duo-trio, basic taste testing, taste intensity, and odor recognition testing were conducted on the panelists. Sensory training then took place which featured screening of terms and grouping terms by consensus whereby 36 attributes were generated in a sample set of sausage samples which reflected the main sensory variation in the profiling set with variations in salt, fat and MSG. The term generation was monitored using a PCA. The third session involved a scaling exercise with the participants. The fourth session involved training the panel on the scaling method. The references generated by the expert panel were introduced. The panelists familiarized themselves with the terms they generated and the references. The panel completed some line scaling exercises. Anchors were used to aid the panelist's decision and to reinforce the perceived intensity of the attributes to the panelists. The fifth session involved using a 15-cm scale. The anchors and the corresponding lexicons were used as previously developed by the expert panel. A representative sample set was tasted and a panel discussion followed. The list was again modified. The panelists discussed the anchors and developed new ones they felt explained the attribute with greater clarity (Conroy et al., 2020).

During the sixth session the panelists were asked to identify any references or terms they were not completely satisfied with or had difficulty with understanding. Umami, traditional sausage, and pork identity proved challenging for one panelist, but this issue was resolved by the panel leader and through group discussion. The new references developed by the panelists were also used to help clarify the differences between attributes to the panelist. In the seventh session the final attribute and lexicon list were presented to the panelists (Table 6.1). The panelists were asked to again familiarize themselves with the attributes and lexicons and indicate any difficulty they had in understanding the list. PCA was again carried out to interpret the data.

Source: From Conroy, P. M., O'Sullivan, M. G., Hamill R. H., & Kerry J. P. (2020). *Quantitative descriptive analysis (QDA) of salt-and fat-reduced traditional breakfast sausages containing monosodium glutamate (MSG): Development of a flavour wheel*. Following the above protocol eight panelists

Table 6.1 List of descriptors and definitions ($n = 35$).

Descriptor	Definition
Warmed over	Dried out reheated meat smell, unpleasant chemical flavor
Sulfur	Rotten eggs/striking a match smell, unpleasant chemical flavor
Rubber	Overheated tire, the smell of an eraser, unpleasant chemical flavor
Green	Earthy, herby taste, for example, spinach, cabbage taste, unpleasant chemical flavor
Rancid	Gone off fat or a dairy product. More bitter than putrid, unpleasant chemical flavor
Fishy	Distinct oily fish smell and taste, pungent negative flavor
Astringent	A drying pinching on the tongue—with a slight metallic taste, negative mouthfeel, and flavor
Boar taint	An unpleasant smell associated with mothballs, chemical flavor
Bloody/serumy	Metallic, slightly sweet, blood-like smell, warming, negative flavor
Brown/roasted	Pork scratching, cooked fatty smell, cooked animal skin, negative, warming
Burnt	Overcooked caramel/blackened toast, warming, negative flavor
Cardboardy	Faint woody smell—such as, smelling a cardboard box—negative, warming flavor
Nutty	Woody/toasted/earthy/roasted aftertaste with a fatty/oily texture, negative, warming flavor
Pork identity	Sweet organ smell, like a cooked pork chop. More dry/stringy/bland than other meats, traditional positive flavor
Refrigerator stale	Undesirable rubbish bin smell. A moldy, musty, sweet smell like silage. The loss of own taste absorbance of smells from the fridge, negative, traditional flavor
Soapy	Chemical smell, sweet, clean, nonedible: the smell of clean hands after washing them in soap, pungent negative flavor
Chemical	An unpleasant metallic bitter off-taste, a warning signal, smells like petroleum-based products, pungent negative flavor
Floral	Fresh summer burst: a rose-like sweet smell, pungent negative flavor
Heated oil	Fast-food shop smell, greasy, ready salted crisps smell and taste, warming, positive flavor
Metallic	Astringent, tropical, tinned foods. Old penny in your mouth sensation, chemical, negative flavor
Sour	Lemon-like taste, gone off milk. A pinch/tingle in your jaw, basic negative flavor

(Continued)

Table 6.1 (Continued)

Descriptor	Definition
Spoiled/putrid	Vomit, repulsive, foul smell. Similar to potato decay smell, pungent negative flavor
Sweet	Feeling perceived on the front of the tongue—a sugar, syrup, hard-boiled sweet flavor, basic positive flavor
Umami	Aromat, breathy, soup like, stock cube artificial smell and taste, basic positive flavor
Vinegary	Chips, salt, and vinegar crisps. Both the smell and taste associated with vinegar, chemical, negative flavor
Tinny	Metallic, tin can smell, negative flavor
Traditional breakfast sausage taste	Peppery, fleshy taste, pork identity, savory, greasy taste, that is grainy, traditional positive flavor
Salty	Taste and aftertaste of salt water (NaCl), basic positive flavor
Grainy	Consistency not uniform—texture is like white/black pudding/oaty texture, positive mouthfeel
Chewy	A product that takes a long time to chew—hard to break down, positive mouthfeel and texture
Oily	Oil on your fingers, greasy, moist on your lips, positive mouthfeel and texture
Bitter	An unpleasant, dry taste, and aftertaste such as tonic water, negative basic flavor
Meaty (pork)	Strongly flavored meat taste. Like pork chop smell, traditional, positive
Livery	Organ, haggis, metallic-like negative flavor and smell
Crispy	On first bite—crunch (in teeth) and a puncture to the sausage skin

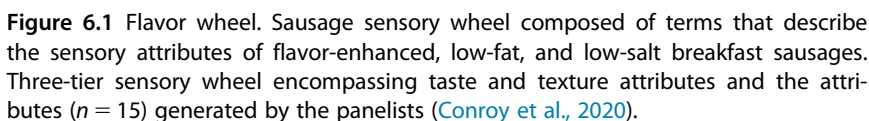
were trained according to the QDA method (O'Sullivan et al., 2002) as described above. Panelists were trained for a total of seven sessions (a total of 21 hours). The panelists were trained in attribute generation, lexicon generation, and anchor generation according to ISO 8586 (1993). Panelist performance was measured throughout the study using PCA in accordance with ISO 11132 (2012). Panelists were considered trained when they could distinguish the replicate samples and their results agreed with the other panelists. Nine samples were used for evaluation, along with one commercial sample. The panels were presented with various types of breakfast sausages. They included reduced salt, reduced fat, and flavored and commercial sausages. They were encouraged to describe the various attributes they felt were present in the samples.

Sensory evaluation took place in the sensory booths in University College Cork. The booths conform to the ISO standards (ISO 8589, 1993). The samples were cooked to an internal temperature of 73°C and served as 30 g portions, coded in randomized order and presented simultaneously to assessors (Stone, Bleibaum, & Thomas, 2012) with separate sessions undertaken for duplicates. The samples were presented to the panel on white polystyrene plates. The panelists were asked to rinse their mouths with water or have some unsalted cracker (Carr's table water biscuits) in-between each sample in accordance with the methods of Tobin et al. (2012a). Judges recorded their responses for each of the sensory terms presented in Table 6.1 on a 15-cm intensity line scale. Standards were available for comparison to samples. For aroma evaluation, judges smelled the samples in two short sniffs. Judges were instructed to swallow the samples and rinse their mouths with water in-between samples (Conroy et al., 2020).

An analysis of variance was performed for each assessor separately and for each of the descriptors in order to check whether there was a product effect or not, to verify for each assessor if they were able to distinguish the products using the available descriptors. This was used to monitor panel performance. Atypical assessors were identified using the measure for each product of the Euclidean distance of each assessor to an average for all the descriptors. To check if there was a session effect, a Wilcoxon signed ranked-test was carried out on all product descriptors by descriptor. The assessors were then classified using a GPA (Conroy et al., 2020).

The standardized lexicon generated in this study provides industry and research with a reference for evaluating the main sensory variation in reduced-fat and -salt breakfast sausages.

A low-fat and low-salt pork breakfast sausage lexicon was successfully developed and validated by the trained panelists. Differences in attributes were established and were found between treatments. The flavor wheel proved to be a useful tool in organizing attributes in a visually appealing way. The wheel served as a thought-provoking device when trying to characterize attribute differences. The following sausage attributes were deemed the most distinguishing features between low-fat and low-salt sausages; bitter, bland, chewy, crispy, drying, fatty, grainy, metallic, peppery, pork identity, salty, spicy, traditional sausage flavor, umami, and warmed over. The product attributes of spicy and salty were the most distinguishing defining low-fat and low-salt sausages from control samples. Sausages containing NaCl and 0.2% MSG were deemed to be the optimal



References

AMSA, Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat, 1995, American Meat Science Association, Chicago, IL.

- ASTM. (2008). *Guidelines for the sensory evaluation professionals who undertake the development of a new facility or remodelling of an existing sensory laboratory*. ISBN-13: 978-0-8031-5893-1.
- Byrne, D. V., Bak, L. S., Bredie, W. L. P., Bertelsen, G., & Martens, M. (1999). Development of a sensory vocabulary for warmed-over flavour 1: In porcine meat. *Journal of Sensory Studies*, 14, 47–65.
- Byrne, D. V., Bredie, W. L. P., & Martens, M. (1999). Development of a sensory vocabulary for warmed-over flavour: Part II. In chicken meat. *Journal of Sensory Studies*, 14, 67–78.
- Byrne, D. V., O'Sullivan, M. G., Dijksterhuis, G. B., Bredie, W. L. P., & Martens, M. (2001). Sensory panel consistency during development of a vocabulary for warmed-over flavour. *Food Quality Preference*, 12, 171–187.
- Civille, G. V., & Szczesniak, A. S. (1973). Guidelines to training a texture profile panel. *Journal of Texture Studies*, 4, 204–223.
- Conroy, P. M., O'Sullivan, M. G., Hamill, R. H., & Kerry, J. P. (2018a). Impact on the physicochemical and sensory properties of salt- and fat-reduced traditional Irish breakfast sausages on various age cohorts acceptance. *Meat Science*, 143, 190–198.
- Conroy, P. M., O'Sullivan, M. G., Hamill, R. H., & Kerry, J. P. (2018b). Sensory optimisation of salt reduced corned beef for different consumer segments. *Meat Science*, 154, 1–10.
- Conroy, P. M., O'Sullivan, M. G., Hamill, R. H., & Kerry, J. P. (2020). *Quantitative Descriptive Analysis (QDA) of salt-and fat-reduced traditional breakfast sausages containing monosodium glutamate (MSG): Development of a flavour wheel*.
- Delahunty, C. M., McCord, A., O'Neill, E. E., & Morrissey, P. A. (1997). Sensory characterisation of cooked hams by untrained consumers using free-choice profiling. *Food Quality and Preference*, 8, 381–388.
- Desai, N. T., Shepard, L., & Drake, M. A. (2013). Sensory properties and drivers of liking for Greek yogurts. *Journal of Dairy Science*, 96(12), 7454–7466. Available from <https://doi.org/10.3168/jds.2013-6973>.
- Drake, M. A., Yates, M. D., Gerard, P. D., Delahunty, C. M., Sheehan, E. M., Turnbull, R. P., & Dodds, T. M. (2005). Comparison of differences between lexicons for descriptive analysis of Cheddar cheese flavour in Ireland, New Zealand, and the United States of America. *International Dairy Journal*, 15(5), 473–483. Available from <https://doi.org/10.1016/j.idairyj.2004.09.006>.
- Hutchings, J. B. (1977). The importance of visual appearance of foods to the food processor and the consumer. *Journal of Food Quality*, 1, 267–278.
- ISO. (1991). *International Standard 3972. Sensory Analysis Methodology. Method of investigating sensitivity of taste. Ref. No. ISO 3972:1991 (E)*. Genève, Switzerland: International Organization for Standardization.
- ISO. (1992). *International standard 5496. Sensory analysis methodology. Initiation and training of assessors in the detection and recognition of odours. Ref. No. ISO 5496:1992 (E)*, International Organization for Standardization, Genève, Switzerland.
- ISO. (1993). *International Standard 8586-1. Sensory Analysis Methodology. General guidance for the selection, training and monitoring of assessors. Ref. No. ISO 8586-1:1993 (E)*. Genève: International Organization for Standardization.
- ISO. (1994). *International Standard. 11035. Sensory analysis-identification and selection of descriptors establishing a sensory profile by a multidimensional approach. Ref. no. ISO 11035:1994 (E)*. Genève: International Organization for Standardization.
- ISO. (2007). *International Standard 8589. Sensory analysis—General guidance for the design of test rooms*. International Organization for Standardization.
- ISO 11132. (2012). *Sensory analysis—Methodology—Guidelines for monitoring the performance of a quantitative sensory panel*.

- ISO 8586. (1993). *ISO 8586-1:1993 Sensory analysis — General guidance for the selection, training and monitoring of assessors — Part 1: Selected assessors*.
- Johnson, P. B., & Civille, G. V. (1986). A standardized lexicon of meat WOF descriptors. *Journal of Sensory Studies*, 1, 99–104.
- Johnsen, P. B., Civille, G. V., Vercellotti, J. R., Sanders, T. H., & Dus, C. A. (1998). Development of a lexicon for the description of peanut flavour. *Journal of Sensory Studies*, 3, 9–17.
- Lawless, H. T., & Heymann, H. (1998). Sensory evaluation in quality control. In H. T. Lawless, & H. Heymann (Eds.), *Sensory evaluation of food, principles and practices* (pp. 548–584). New York: Chapman and Hall.
- Lawless, H. T. (1999). Descriptive analysis of complex odors: reality, model or illusion? *Food quality and preference*, 10, 325–332.
- Lawless, H. T., & Heymann, H. (2010). Pages 79–100 and 227–257 in *Sensory evaluation of food: Principles and practices* (2nd ed.). New York: Chapman and Hall.
- Lyon, B. G. (1987). Development of chicken flavour descriptive attribute terms aided by multivariate statistical procedures. *Journal of Sensory Studies*, 2, 55–67.
- MacFie, H. J., Bratchell, N., Greenhoff, K., & Vallis, L. V. (1989). Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests. *Journal of Sensory Studies*, 4, 129–148.
- Martin, D. (1990). The impact of branding and marketing on perception of sensory qualities. *Food Science and Technology*, 4, 44–49.
- Meilgaard, M. C., Civille, G. V., & Carr, B. T. (1999). *Sensory evaluation techniques* (3rd ed., pp. 54–55). FL: Academic Press, Chapter 5.
- Michon, C., O'Sullivan, M. G., Delahunty, C. M., & Kerry, J. P. (2010). Study on the influence of age, gender and familiarity with the product on the acceptance of vegetable soups. *Food Quality and Preference*, 21, 478–488.
- Michon, C., O'Sullivan, M. G., Delahunty, C. M., & Kerry, J. P. (2010). The investigation of gender related sensitivity differences in food perception. *Journal of Sensory Studies*, 24, 922–937.
- Michon, C., O'Sullivan, M. G., Sheehan, E., Delahunty, C. M., & Kerry, J. P. (2010). Investigation of the influence of age, gender and consumption habits on the liking for jam-filled cakes. *Food Quality and Preference*, 21, 553–561.
- Moskowitz, H. R. (1981). Relative importance of perceptual factors to consumer acceptance: Linear versus quadratic analysis. *Journal of Food Science*, 46, 244–248.
- Muñoz, A. M. (2002). Sensory evaluation in quality control: An overview, new developments and future opportunities. *Food Quality and Preference*, 13, 329–339.
- Muñoz, A. M., & Civille, G. V. (1992). The spectrum descriptive analysis method. In R. C. Hootman (Ed.), *ASTM manual on descriptive analysis*. PA: American Society for Testing and Materials.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992). *Comprehensive descriptive method. Sensory evaluation in quality control* (pp. 55–82). New York: Van Nostrand Reinhold.
- Murray, J., Delahunty, C., & Baxter, I. (2001). Descriptive sensory analysis: Past, present and future. *Food Research International*, 34(6), 461–471.
- Nelson, J. A., & Trout, G. M. (1964). *Judging dairy products*. Milwaukee, WI: The Olson Publishing Co.
- O'Sullivan, M. G. (2017). CH2. Descriptive methods. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 13–37). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G., Byrne, D. V., & Martens, M. (2002). Data analytical methodologies in the development of a vocabulary for evaluation of meat quality. *Journal of Sensory Studies*, 17, 539–558.

- O'Sullivan, M. G., Kerry, J. P., & Byrne, D. V. (2011). Use of sensory science as a practical commercial tool in the development of consumer-led processed meat products. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats*. United Kingdom: Woodhead Publishing Ltd.
- Peryam, D. R., & Pilgrim, F. J. (1957). Hedonic scale method of measuring food preferences. *Food Technology*, 11(9), 9–14.
- Rétiveau, A., Chambers, D. H., & Esteve, E. (2005). Developing a lexicon for the flavor description of French cheeses. *Food Quality and Preference*, 16(6), 517–527. Available from <https://doi.org/10.1016/j.foodqual.2004.11.001>.
- Stone, H., & Sidel, J. (2004). *Sensory evaluation practices*. (3rd ed.). Elsevier Academic Press.
- Stone, H., Bleibaum, R., & Thomas, H. (2012). *Sensory evaluation practices* (4, pp. 117–157). Elsevier Academic Press.
- Stone, H., Sidel, J., Oliver, S., Woolsey, A., & Singleton, R. C. (1974). Sensory evaluation by quantitative descriptive analysis. *Food Technology*, 28, 24–34.
- Teo, P. S. B., van Langeveld, A. W. B., Pol, K., Siebelink, E., de Graaf, C., Martin, C., ... Mars, M. (2018). Training of a Dutch and Malaysian sensory panel to assess intensities of basic tastes and fat sensation of commonly consumed foods. *Food Quality and Preference*, 65, 49–59.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, 4, 460–465.
- Van Hekken, D. L., Drake, M. A., Corral, F. J. M., Prieto, V. M. G., & Gardea, A. A. (2006). Mexican chihuahua cheese: Sensory profiles of young cheese. *Journal of Dairy Science*, 89(10), 3729–3738. Available from [https://doi.org/10.3168/jds.S0022-0302\(06\)72414-6](https://doi.org/10.3168/jds.S0022-0302(06)72414-6).
- Williams, A. A., & Arnold, G. M. (1985). A comparison of the aroma of six coffees characterised by conventional profiling, free-choice profiling and similarity scaling methods. *Journal of the Science of Food and Agriculture*, 36, 204–214.
- Yusop, S. M., O'Sullivan, M. G., Kerry, J. F., & Kerry, J. P. (2009a). Sensory evaluation of Indian-style marinated chicken by Malaysian and European naïve assessors. *Journal of Sensory Studies*, 24, 269–289.
- Yusop, S. M., O'Sullivan, M. G., Kerry, J. F., & Kerry, J. P. (2009b). Sensory evaluation of Chinese-style marinated chicken by Chinese and European naïve assessors. *Journal of Sensory Studies*, 24, 512–533.

Further reading

- ISO. (1988). *Sensory analysis. Ref. no. General guidance for the design of test rooms*. Genève, Switzerland: International Organization for Standardization (ISO 8589).
- Piggott, J. R., Simpson, S. J., & Williams, S. A. R. (1998). Sensory analysis. *International Journal of Food Science & Technology*, 33(1), 7–12.



Quantitative and qualitative affective methods for reformulation

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Introduction

Traditional descriptive analysis employs a training regime to calibrate a suitably screened panel to evaluate food or beverage products so that they evaluate with a standardized response. These individuals, or panelists, quantify sensory descriptors such as appearance, aroma, flavor, taste, texture, and aftertaste often benchmarked against clear instructions provided by the panel leader [ranking descriptive analysis (RDA)] and often using defined sensory reference materials [quantitative descriptive analysis (QDA) and spectrum]. These assessors are never asked to rate their emotional responses to products; only the descriptors then have been trained to evaluate. The reason being that through training, their subjective responses become biased. Consumers can be clear about which products they like and which they do not, but they cannot always describe any specific reason for that (Van Kleef, Van Trijp, & Luning, 2006). Therefore affective sensory testing methods can be considered the

opposite of these descriptive techniques, where hedonics are used to capture the affective sensory response of naïve evaluators who may be consumers or analogous evaluators to the consumer. They are judged by their preferences or for their personal liking of things such as appearance, taste or texture, and, ultimately, their general impression of a product or its “general acceptance” (O’Sullivan, 2017a). They form part of a critical battery of tests that must be employed in order to determine if a reformulation protocol has been successful. Reformulation of food or beverage products can be undertaken to maintain or improve the liking of that product with respect to consumer sensory quality. Situations where it is required to maintain quality rather than improve quality for reformulation include an ingredient substitution, nutritional optimization strategy, or perhaps as part of a least cost formulation (LCF) process. Typically, reformulation is employed for reasons of nutritional optimization by replacing an ingredient with a healthier ingredient. Hedonic evaluations can be thus used to determine if formulation modifications to the product are necessary and cost-effective. Forced preference can be used to determine if one product is significantly preferred over others. For two or more samples a ranking test can be used to determine preference (O’Sullivan, 2017a). Quite often an ingredient such as fat, salt, or sugar is replaced in a product and must be determined if the new “nutritionally optimized” variant meets sensory hedonic criteria. As seen in previous chapters, fat, salt, and sugar are more than antinutritional scapegoats to be reduced or removed but act in multimodal roles. Sugar is a functional ingredient in cake making by facilitating creaming with the fat and incorporating air in to the product through friction. In addition, sugar is an important tastant masking bitterness, a flavor enhancer (fruit), a preservative, a bulking agent, and facilitates caramelization. Similarly, salt in meat products acts as a preservative, an important tastant, flavor enhancer (meats), promoter of water holding, and because of the latter improves texture. Fat is important in confectionary and meat products for texture, flavor, and also satiety. Quite often the new product, if optimized from a standardized formulation, has a slightly diminished hedonic sensory profile and it must be determined if this profile is of sufficient quality to justify commercial sale and meet sufficiently consumer expectations.

Sensory acceptance testing (SAT) usually requires between 25 and 75 naïve individuals, who are typically users of the product to be tested. They evaluate the new or reformulated product, for the attributes liking of appearance, aroma, texture, taste, flavor, aftertaste and overall

acceptability. Better and more statistically valid results are obtained if samples are presented in duplicate. Consumer testing requires 100 or more naïve assessors using the same hedonic attributes as SAT, but usually samples are presented only once and thus this data, a benchmark for market consumer assessment, can be a little noisier than SAT (O'Sullivan, 2017a).

Quantitative affective sensory methods such as sensory acceptance testing, consumer, or preference testing are used to specifically determine the level of liking or preference in products, respectively. The types of qualitative and quantitative affective tests are usually located at opposite ends of the research and development spectrum. The hedonic measurements process must use the consumers of the product in question, who know better the subjective modality of affective testing for these products instead of using consumers in a random or an ad hoc manner. The greater the number of consumers they use, the more reliable the data will be. Sensory acceptance tests are very useful for the detection of experimental prototypes, but they are not a substitute for more expensive large-scale affective tests, which use specific consumers (O'Sullivan, 2017a). Acceptance and preference tests can be used to qualitatively and quantitatively determine if consumers like the modified product as well as account for differences due to age and gender as well as cultural influences (Michon, O'Sullivan, Delahunty, & Kerry, 2010a, 2010b; Michon, O'Sullivan, Sheehan, Delahunty, & Kerry, 2010; Yusop, O'Sullivan, Kerry, & Kerry, 2009a, 2009b). Qualitative methods are much less specific and are usually used to test product ideas, packaging, concepts, or even marketing by determining the opinions of specifically selected groups of people deemed to have a relevant input due to their demographic status. These qualitative methods fit very much in the realm of ideation and new product development (NPD) and are discussed in great detail by O'Sullivan (2017a, 2017b) in his *Handbook for Sensory and Consumer Driven Product Development*. Developing products is easy, developing products that appeal to consumers is less so, and developing products that appeal to sufficient numbers of consumers and also achieve commercial success is very difficult (Stone & Sidel, 2007). If the objective of reformulation is to modify a standard recipe of a food or beverage, quite often to make them healthier from a nutritional perspective, then the sensory outcome should not be a dramatic deviation from the original or existing sensory profile and should be a less risky endeavor compared to a new product being developed. It is well documented that more than 90% of all NPD in the food and beverage industry fail. Some say that the number is actually closer to 98%. The

successful 2% makes billions of pounds, dollars, yen, and euros everyday, which raises the question: is risk a reasonable risk? (Business Insights, 2004). If a reformulation protocol has been successful, the sensory signature of a product should be intact and to a certain extent the current consumer information regarding that product and sales information can be reassuring regarding the introduction of the reformulated product. However, matching perfectly a standard recipe's sensory profile with that of a reformulated product where ingredients such as fat, sugar, or salt have been reduced is a gigantic challenge and sensory outcomes are often compromises. Due to this, qualitative affective techniques play an important role and are very useful to determine feedback from focus groups regarding reformulated products. Focus groups generally use relatively small numbers of suitable screened individuals (5–20) and are good for testing product and packaging concepts, ideas and are not that expensive. This feedback can give a general indication to the reformulation team to determine if the reformulated product will be even detected by the group if stealth is the approach. Also, in the case where a reformulation and recipe change is clearly revealed to the focus group, the reaction can be noted. This may not always be positive. Modification of traditional food formulations, for example, can be sometimes off-limits in the consumer mind. [Stolzenbach, Bredie, and Byrne \(2013\)](#) presented that recipe modifications in traditional foods without a clear understanding of the impact on consumers' perception and acceptance can potentially be more harmful than beneficial. Thus qualitative affective testing of ideas and concepts is a critical first step as even the idea that a recipe has been “messed with” could potentially be anathema to the ultimate consumer. However, the traditional food sector faces additional challenges of a potential discrepancy between the concept of traditional food and innovation ([Guerrero et al., 2009](#); [Stolzenbach et al., 2013](#)) which show an insufficient adoption of optimization strategies, possibly due the resistance to reformulate because of conservatism ([Jordana, 2000](#)). Some populations are more conservative than others. Anecdotally, the Irish are more open to reformulated traditional foods than perhaps the Greeks who are very conservative. Therefore insights in consumer requirements and expectations are imperative for a successful market launching of product innovations ([Grunert, Verbeke, Kügler, Saeed, & Scholderer, 2011](#)). However, on the other hand, some groups may be open to innovation or reformulation of traditional products. [Fellendorf, Kerry, and O'Sullivan \(2018\)](#) and [Fellendorf, Kerry, Hamill, and O'Sullivan \(2018\)](#), from their consumer survey, found that that there was also no conflict for traditional foods reduced in salt

and fat content when intrinsic character is kept. It has even been suggested that traditional food reformulation in the future may suffer from a less favorable attitude regarding health and nutritional aspects. The greatest threat for the future is seen in an insufficient adaptation to new requirements demanded by consumers (Jordana, 2000).

Affective methods are used to measure the hedonic (liking) qualities of foods, beverages, and objects (packaging), which includes acceptability or preference, but these approaches do not describe the product, whereas descriptive analysis is used to determine the sensory profile of products using trained panelists and are not measuring hedonics. How do we mesh these diametrically opposed types of data, the subjective and emotive to the objective and descriptive. Data analysis is the key to unlocking the valuable information we gather as sensory and consumer scientists and is the essence of product development and optimization. However, this process presents some challenges as depending on your perspective we are quite often trying to compare apples and oranges (O'Sullivan, 2017b). Preference analyses techniques are able to relate external information about perceived product characteristics to consumer preference ratings in order to understand what attributes of a product are driving preferences (Van Kleef, Van Trijp, & Luning, 2005).



Preference tests

Paired comparison tests, where assessors are asked to determine if one sample is different from another, can also be categorized as an affective test when used to measure preference. Simply, assessors are asked which product they prefer over another. They can also rank products for preference on a category hedonic scale (e.g., 7 or 9 point) or using a continuous rating scale anchored from dislike extremely to like extremely.



Sensory acceptance and consumer testing

Hedonic or affective analysis is the subjective measurement by untrained assessors of their emotive responses to products. Typically, these tests measure preference (Preference Test), or liking and acceptability as in the case of the sensory acceptance test (SAT) and Consumer Tests. SAT is

a small-panel guidance test that usually involves 25–75 participants who are regular consumers of the product to be tested. Consumer testing can be considered a larger scale sensory acceptance test ($n \geq 100$). The logistics of organizing these are much more complicated, but the number of samples presented is usually reduced (O'Sullivan, 2017b). This clear demarcation has been etched in stone by those working in hedonic studies and involves what Stone and Sidel (2004) describes as “The curse of N.” The larger the number of respondents ($n \geq 100$), as in a consumer test, the greater the reliability of the data obtained (O'Sullivan, 2017b). Sensory acceptance tests are much cheaper to conduct compared to larger scale consumer tests. However, the value of these tests is in assisting the product developer in filtering their experimental prototypes in a standardized and scientific manner using hedonics. Sensory acceptance tests are not a substitute for the more costly large-scale consumer tests, so ultimately the final variants produced through product development and optimization should be validated by appropriately conducted larger scale consumer testing. Here again the sensory aspects of the product are measured (O'Sullivan, 2017b). Stone and Sidel (2004) argue that the notion of validity, due to larger numbers of assessors, is mistaken. Management often is more comfortable making business investment decisions when the information is based on large numbers of responses (usually from several regions of a country). They state that having the largest number of consumers in a test enhances the likelihood of finding product differences, and of determining which product is preferred (Stone & Sidel, 2004). The costs and logistics of organizing consumer tests are much more complicated but not every consumer can be tested (O'Sullivan, 2017b; Stone & Sidel, 2004). However, the application of statistical sampling techniques that permit the use of a subset of the population allows one to generalize the results (Stone & Sidel, 2004).

With SAT, only hedonic (liking) descriptors are measured by assessors such as liking of; Appearance, Aroma, Flavor, Texture and Overall Acceptability or they can assess only preference or the attributes that determine preference using the 9-point hedonic scale. It is a proven scale that is reliable and easy to use by naïve or untrained assessors. This scale has been used widely for this sensory assessment since its development by Peryam and Pilgrim (1957). Continuous line scaling can also be used when testers place their scores (usually a vertical line) on a scale of 10 or 15 cm anchored left by the term none and right by the extreme term. This is not a problem with electronically collected data (Fizz,

Compusense, or Redjade), but when using paper ballots, this scale is more difficult. Evaluations must be measured with a ruler and then entered manually into computer software, such as Excel. Magnitude scaling is also discussed in the literature, but is not widely used (O'Sullivan, 2017b); however, in the context of calibration of instrumental devices using sensory derived benchmarks, it is discussed extensively in Chapter 12, Magnitude estimation—alignment of sensory and instrumental analysis.

A large numbers of experimental reformulation variants can be initially screened using SAT, but it is recommended that selected products be validated before market launch with further affective sensory testing using conventional consumer preference studies using consumers ($n \geq 100$).

SATs can be undertaken in a sensory laboratory, a central location, or in the home. The presentation situation is standardized for assessors, in the lab setting, for product presentation order, lighting, temperature, and surroundings (standard sensory booth with serving hatch). For this reason it is possible to use between 25 and 50 assessors up to 75, but 40 is recommended (Stone, Bleibaum, & Thomas, 2012). A laboratory acceptance test could be conducted with as little as 24 assessors if all the assessors evaluate all the products (balanced block design) (Stone et al., 2012). However, the data obtained becomes statistically stronger the greater the number of assessors used. The greater the number of subjects used in a test, the less the likelihood of Type I and Type II errors occurring. Type I error occurs when differences are found between samples when really there are not any. The opposite can also occur, by not rejecting the null hypothesis and is called Beta risk, or Type II error. Here no differences are found between samples where differences really exist. Alpha and Beta risk can be reduced by increasing the number of observations or the amount of data needed to make a decision (O'Sullivan, 2017b).

For home testing usually one or two products are evaluated with between 50 and 100 members of the public. Acceptance or preference attributes are determined but also attribute intensity and marketing information can be obtained. Home testing, although expensive, is highly effective as products can be tested under a real world setting as well as information determined on the entire households opinion, pricing, frequency of use, etc. (Stone et al., 2012).

Central location testing should use +100 members and are considered consumer tests and use the general public, not employees, who are users of the product to be tested. Again no more than five or six products

should be tested and acceptance or preference should only be measured. The numbers of assessors used in the aforementioned tests are recommendations and as such should not be considered a go or no go scenario if target numbers cannot be met.

Assessors for hedonic analysis should be carefully screened and represent the target audience of the product or concept. Thus a particular demographic group is recruited based on the company's own knowledge of their products consumers. This information can come from market research sources, which also sometimes undertake research tests, which are broader in their design also capturing information perhaps on pricing, purchase intent or use of the product. In this fashion the product developer can then examine the data and decide if the product is good enough to go to market or not. The demographic group can be organized on a very large number of potential factors, but gender, age, employment situation, and income group are usually important factors. In addition, where the consumers live, for example, rural or urban could also be considered. Acceptance testing data can be combined with more descriptive data and analyzed using chemometrics, which will be discussed in relation to preference mapping.



Conjoint analysis

Conjoint analysis is a statistical technique used to identify the value placed by individuals on different product attributes. Specific products or concepts are presented to consumers and the manner in which they make preferences can be analyzed by modeling to determine information such as profitability and market share. This method also determines what combination of attributes influences consumer choice and decision-making and is used frequently in market research to study the effects of controlled stimuli or information on a particular consumer response (O'Sullivan, 2017b). Statistical experimental design, analysis of variance, and cluster analysis enable the response of each consumer to be analyzed for the relative importance of each factor, and, similarly performing subjects can be clustered. It is a method used for understanding how consumers trade-off product features (Green & Rao, 1971). The process measures a mapping from more detailed descriptors of a product or service onto an overall measure of the customer's evaluation of that product (Hauser & Rao, 2004).



Ranking preference tests

For ranking preference tests naïve assessors or consumers receive simultaneously coded randomized samples (4–6) and are asked to rank them in order of descending or ascending preference. The mean highest scoring samples for preference are the most preferred. Where fatigue is less likely more samples may be used. A modification of this approach is used with RDA where descriptive attributes instead of preference are ranked. RDA can use trained, semitrained or naïve assessors and is presented in detail in Chapter 9, Discrimination testing for reformulated products.



Preference mapping

Preference mapping combines descriptive data and hedonic data using data analytical tools such as multivariate data analysis. Statistical correlations between products, descriptive and hedonic data, can be extracted in order to observe the effects of modifications, due reformulation, on the sensory profile of the product with respect to appearance, aroma, flavor, texture, taste and aftertaste, as well as consumer opinion. Preference mapping techniques involve statistically relating external information about perceived product characteristics to consumer preference or acceptance ratings in order to determine a product's characteristics and obtain a better understanding of what attributes of a product are driving preferences (Meilgaard, Civille, & Carr, 2007; Van Kleef, Van Trijp, & Luning, 2005).

For partial least squares (PLS) preference mapping the *Y*-matrix might include consumer segment's preferences for a product and the *X*-matrix the sensory descriptive profile for the same products (Martens & Martens, 2007). PLS is commonly used to correlate consumer and descriptive data to determine the sensory characteristics that are most important for consumer preference or acceptance (Meilgaard et al., 2007). Today, multivariate data analytical software packages are very easy to use with training courses and webinars provided by the software providers making the technique widely accessible to NPD and reformulation scientists as a product optimization tool. Different modes of data can be modeled and can

include hedonic consumer evaluations as well as their demographic (age, gender, and habitation), sensory profiling data (e.g., QDA), and physico-chemical analysis [rheological, compositional, volatile flavor (GCMS), etc.] or LCF information. The plots produced through software programs such as Senstools, XLSTAT, or Unscrambler (Camo, Norway) can provide graphical correlations of these data (PCA plots) as well as the underlying statistics (O'Sullivan, 2017b). As consumers do not provide objective descriptive information, preference mapping using multivariate data analysis allows for the correlation of this data to the aforementioned objective measurements. A typical reformulation scenario where preference mapping could be applied might be for the nutritional optimization of a formulation with regard to salt, sugar or fat reduction. The samples selected for analysis must representatively reflect the product consumer space and include competitor samples in the market place as well as the reformulated prototypes. Consumer preference data can be mapped on to sensory descriptive and physicochemical data to determine which products are the most accepted or, more often, which products offer the best possible compromise with respect to consumer sensory quality, functionality, shelf life, and even cost (O'Sullivan, 2017b).

For preference analysis, there are two main types, internal and external. Internal preference analysis gives precedence to consumer preferences and uses perceptual information as a complementary source of information (Van Kleef, Van Trijp, & Luning, 2006). The consumer data is central to the space, and this data forms the core on to which the other information is projected. The opposite is the case for external analysis where the sensory space is set by descriptive sensory data or instrumental data, and consumer preference information is subsequently overlaid onto this sensory space. It is based on attribute ratings and only fits consumer preferences at a later stage (Van Kleef, Van Trijp, & Luning, 2005). Hybrid preference mapping is a third approach based on the integration of consumer and sensory data.



Adaptation methods and masking

New product ideas and concepts are sometimes not immediately accepted by consumers. However, as humans we can adapt to new sensations over time. We can all draw examples of these from our own life

experiences. Foods or beverages we hated as children are learned and adapted to appreciate over time through repeated exposure. Polarizing flavors or textures like those of cucumber, mushroom, beer, avocado, anchovies, or chili can be learned to be appreciated. Consumer attitudes and preferences for foods can change with repeated exposure (Porcherot & Issanchou, 1998; Rolls & DeWaal, 1985; Schutz & Pilgrim, 1958; Siegel & Pilgrim, 1958; Vickers & Holton, 1998). Therefore with new products, standard consumer testing is not always completely appropriate and exposure or adaptation studies may give more insight into consumer behavior. The repeated exposure to new aromas and flavors of uniquely flavored products might improve consumer “liking” ratings of these products over time due to an increase in consumer familiarity with their novel flavor (Luckow, Sheehan, Delahunty, & Fitzgerald, 2005). Consumer preferences for novel foods (e.g., containing unique ingredients) increase with exposure, due to a reduction in neophobia and an increase in familiarity (Pliner, 1982).

Probiotic cultures are usually added to dairy based products and consumers are accustomed to the presence of microorganisms in this type of product (Pimentel, Madrona, Garcia, & Prudencio, 2015). Probiotics are “friendly” microorganisms that contribute to the health and to the balance of the intestinal tract (Fuller, 1989). However, other food matrices need to be evaluated as carriers of probiotics to provide other options to the market, especially to consumers who do not appreciate or cannot consume milk derivatives, including people who are lactose intolerant, allergic to milk proteins, hypercholesterolemic, or strictly vegetarian (Granato, Branco, Nazzaro, Cruz, & Faria, 2010). The introduction of probiotic ingredients into nondairy systems has provided numerous technical challenges (Mattila-Sandholm et al., 2002) and has been shown to create sensory barriers (Luckow & Delahunty, 2004a). Probiotics are live microbial food supplements, which have been shown to exert numerous health benefits. Research has identified that probiotics cause perceptible off-flavors that often contribute to consumer dissatisfaction. Preliminary sensory studies (Luckow & Delahunty, 2004a, 2004b) have shown that probiotic cultures possess “dairy” and “medicinal” flavors when introduced into fruit juice drinks. Also perceptible off-flavors (e.g., dairy, medicinal, and savory) have been associated with probiotic orange juices (Luckow et al., 2005). These uncharacteristic flavors were the cause of consumer rejection of fruit juices containing probiotic ingredients (Luckow & Delahunty, 2004a, 2004b). Luckow et al. (2005) showed that

exposure to and familiarity with probiotic drinks and their characteristic medicinal flavor helps to improve consumer acceptance and liking for the sensory characteristics of probiotic juices over time. Therefore it is important that sensory consumer exposure testing is undertaken to identify the potential adaptation effects of new products over time. It is also important to understand how consumers will compromise sensory quality in order to receive nutritional benefit from a product. A good example is the advent of gluten-free products as a replacement for wheat-containing products with individual diagnosed with gluten intolerance or celiac disease. The sensory quality of the gluten-free product is seldom up to par with the wheat-containing version of the product, but the consumer has no option but to compromise in order to manage the negative symptoms of the disease.



Focus groups

Focus groups are qualitative affective sensory approaches, which use small groups (6–10) of targeted paid individuals to determine their opinion on various topics. This group should be carefully selected and reflect the demographic or projected target market of the product, concept, or package to be assessed. Consumers are better at articulating opinion on familiar categories of products than new category or mold breaking ones (van Kleef & van Trijp, 2007). Focus groups are thus ideal for determining the impact of reformulation processes. They can also initially determine strategies for launching reformulated products—should a healthier version of a standard product be blatantly presented by packaging, for example, or should the new formulation be introduced through stealth. The concept, and even an early prototype, with also potentially including packaging (mock up) can be evaluated by the appropriately selected focus group. Focus groups can be used to build an understanding of a product category from the consumer viewpoint, inspiring idea generation, but can also be used to evaluate new product concepts and even samples (Edmunds, 1999). The focus group leader acts as a moderator, working from a predetermined script to encourage informal free flowing discourse on selected topics that are introduced in the session. The moderator should be a trained individual in order for consumer insights and behavior to be determined rather than just superficial responses by the group. The

test is subjective in that members of the group are asked about their feelings towards a product. The aim is to determine eating habits, preferences, and opinions of the panel for the particular product in question (Bryhni et al., 2002). This method is particularly useful in determining insights into consumer thoughts and behavior regarding a particular product concept. The location is also usually very informal in order to put the group at ease. Bespoke focus rooms are used in large companies and consumer insight organizations where the proceedings are recorded by video through a two way mirror, in an adjoining room. Also, the discussion can be observed by technical staff in this room who may take notes on the reaction of the group to the topics and elements discussed. Opinions, behaviors, body language and facial expressions of the group can be analyzed, along with the video for later dissection. The researcher's interest provides the focus, whereas group interaction produces the data. This can be achieved through direct questioning, role-playing, or other projective techniques. Typically sessions can last up to 2 hours.

Focus groups typically pay members, so the moderator must clearly determine the suitability and motives of candidates for participation. If their main motivation is payment, their insights may be misleading. Such individuals can be classed as "cheaters," "repeaters," or "cheater/repeaters." Cheaters lie about their situation in order to qualify for the focus group, whereas repeaters lie about the length of time since they last participated in a group, which should be not less than 6 months. Obviously the "cheater/repeater" practices both of these untruthful tactics and can even do this on a professional or semiprofessional basis (O'Sullivan, 2017a, 2017b). The "cheater/repeater" phenomenon is a particular pitfall of focus groups and can be extremely difficult to prevent. Thus recruited individuals must provide reliable identification or be paid directly to a bank account, which eliminates false identities and allows for records to be kept to monitor future participation. Screening questionnaires should also be used to identify such unsuitable individuals along with an informal interview by the moderator. A lack of knowledge of the product to be tested or an ambiguous demographic situation is the ground for noninclusion. In the United States and Canada, focus group tracking service can be used to help identify "cheater/repeaters." Their details and contact number are searched through a database of focus group participants to identify and then exclude these individuals (O'Sullivan, 2017a, 2017b).

Focus groups are critical in order to generate concepts for an area when previous knowledge about the area to be investigated quantitatively

is limited Powell and Single (1996). However, focus groups can mislead if members are not recruited appropriately and lead the researcher down a rabbit hole of artefactual concepts, which could prove very expensive to an organization. One way to avoid this is to use two or more focus groups as validators. Obtaining similar results is an indication of consensus, and the moderator can be sure that the data received is correct. Focus participants should not be too docile or daring. Persons who do not voice their opinions are of little use and as useless as the most extroverted of persons who can take over the discussion and perhaps be biased (O'Sullivan, 2017a, 2017b).

References

- Bryhni, E. A., Byrne, D. V., Claudi-Magnussen, C., Agerhem, H., Johansson, M., Lea, P., ... Martens, M. (2002). Consumer perceptions of pork in Denmark, Norway and Sweden. *Food Quality and Preference*, 13, 257–266.
- Business Insights, Future Innovations in Food and Drinks to 2006: Forward-Focused NPD and Consumer Trends.
- Edmunds, H. (1999). *The focus group handbook*. Chicago, IL: NTC Contemporary Publishing Group.
- Fellendorf, S., Kerry, J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Science and Technology*, 92, 584–592.
- Fellendorf, S., Kerry, J. P., & O'Sullivan, M. G. (2018). Consumer attitudes on salt and fat reduced foods in the Republic of Ireland. *Food and Nutrition Sciences*, 9, 880–898. Available from <https://doi.org/10.4236/fns.2018.97066>.
- Fuller, R. (1989). Probiotics in man and animals. *Journal of Applied Bacteriology*, 66, 65–72.
- Granato, D., Branco, G. F., Nazzaro, F., Cruz, A. G., & Faria, J. A. F. (2010). Functional foods and nondairy probiotic food development: Trends, concepts and products. *Comprehensive Reviews in Food Science and Food Safety*, 9, 292–302.
- Green, P. E., & Rao, V. R. (1971). Conjoint measurement for quantifying judgmental data. *Journal of Marketing Research*, 8, 355–363.
- Grunert, K. G., Verbeke, W., K  gler, J. O., Saeed, F., & Scholderer, J. (2011). Use of consumer insight in the new product development process in the meat sector. *Meat Science*, 89, 251–258.
- Guerrero, L., Gu  rdia, M. D., Xicola, J., Verbeke, W., Vanhonacker, F., Zakowska-Biemans, S., & Hersleth, M. (2009). Consumer-driven definition of traditional food products and innovation in traditional foods. A qualitative cross-cultural study. *Appetite*, 52(2), 345–354.
- Hauser, J. R., & Rao, V. (2004). Conjoint analysis, related modeling, and applications. In P. E. Green, & Y. Wind (Eds.), *Advances in marketing research: Progress and prospects* (2004, pp. 141–168). Springer Science & Business Media.
- Jordana, J. (2000). Traditional foods: Challenges facing the European food industry. *Food Research International*, 33(3–4), 147–152.
- van Kleef, E., & van Trijp, H. C. M. (2007). CH14. Opportunity identification in new product development and innovation in food product development. In H. Macfie (Ed.), *Consumer-led food product development* (pp. 321–338). Cambridge, United Kingdom: Woodhead.

- van Kleef, E., Van Trijp, H. C. M., & Luning, P. (2006). Internal versus external preference analysis: an exploratory study on end-user evaluation. *Food Quality and Preference*, 17, 387–399.
- van Kleef, E., van Trijp, H. C. M., & Luning, P. (2005). Consumer research in the early stages of new product development: a critical review of methods and techniques. *Food Quality and Preference*, 16, 181–201.
- Luckow, T., & Delahunty, C. (2004a). Which juice is 'healthier'? A consumer study of probiotic non-dairy juice drinks. *Food Quality and Preference*, 15, 751–759.
- Luckow, T., & Delahunty, C. (2004b). Consumer acceptance of orange juice containing functional ingredients. *Food Research International*, 37, 805–814.
- Luckow, T., Sheehan, V., Delahunty, C., & Fitzgerald, G. (2005). Determining the odor and flavor characteristics of probiotic, health-promoting ingredients and the effects of repeated exposure on consumer acceptance. *Journal of Food Science*, 70(1), S53–S59.
- Martens, H., & Martens, M. (2007). Chapter 21. The use of partial least squares methods in new food product development. In H. Macfie (Ed.), *Consumer-led food product development* (pp. 492–523). Cambridge, United Kingdom: Woodhead.
- Mattila-Sandholm, T., Myllärinen, P., Crittenden, R., Mogensen, G., Fondén, R., & Saarela, M. (2002). Technological challenges for future probiotic foods. *International Dairy Journal*, 12, 173–182.
- Meilgaard, M. C., Civille, G. V., & Carr, B. T. (2007). *Sensory Evaluation Techniques*. Boca Raton, FL: CRC Press.
- Michon, C., O'Sullivan, M. G., Delahunty, C. M., & Kerry, J. P. (2010a). Study on the influence of age, gender and familiarity with the product on the acceptance of vegetable soups. *Food Quality and Preference*, 21, 478–488.
- Michon, C., O'Sullivan, M. G., Delahunty, C. M., & Kerry, J. P. (2010b). The investigation of gender related sensitivity differences in food perception. *Journal of Sensory Studies*, 24, 922–937.
- Michon, C., O'Sullivan, M. G., Sheehan, E., Delahunty, C. M., & Kerry, J. P. (2010). Investigation of the influence of age, gender and consumption habits on the liking for jam-filled cakes. *Food Quality and Preference*, 21, 553–561.
- O'Sullivan, M. G. (2017a). CH10. *Sensory and consumer led innovative product development—from Inception to the shelf (current and future methodologies). A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 197–222). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017b). CH3. *Sensory affective (hedonic) testing. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 39–57). United Kingdom: Woodhead Publishing Ltd.
- Peryam, D. R., & Pilgrim, F. J. (1957). Hedonic scale method of measuring food preferences. *Food Technology*, 11(9), 9–14.
- Pimentel, T. C., Madrona, G. S., Garcia, S., & Prudencio, S. H. (2015). Probiotic viability, physicochemical characteristics and acceptability during refrigerated storage of clarified apple juice supplemented with *Lactobacillus paracasei* ssp. *paracasei* and oligofructose in different package type. *LWT—Food Science and Technology*, 63, 415–422.
- Pliner, P. (1982). The effects of mere exposure on liking for edible substances. *Appetite*, 3, 283–290.
- Porcherot, C., & Issanchou, S. (1998). Dynamics of liking for flavoured crackers: Test of predictive value of a boredom test. *Food Quality and Preference*, 9, 21–29.
- Powell, R. A., & Single, H. M. (1996). Focus groups. *International Journal for Quality in Health Care*, 8, 499–504.
- Rolls, E. T., & De Waal, A. W. L. (1985). Long-term sensory-specific satiety: Evidence from an Ethiopian refugee camp. *Physiology and Behaviour*, 34, 1017–1020.

- Schutz, H. G., & Pilgrim, F. J. (1958). A field study of food monotony. *Psychological Reports*, 4, 559–565.
- Siegel, P. S., & Pilgrim, F. J. (1958). The effect of monotony on the acceptance of food. *American Journal of Psychology*, 71, 756–759.
- Stolzenbach, S., Bredie, W. L. P., & Byrne, D. V. (2013). Consumer concepts in new product development of local foods: Traditional versus novel honeys. *Food Research International*, 52(1), 144–152.
- Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012). Affective testing. In H. Stone, R. N. Bleibaum, & H. A. Thomas (Eds.), *Sensory evaluation practices* (4th ed., pp. 306–309). Elsevier Academic Press.
- Stone, H., & Sidel, J. L. (2004). Affective testing. In H. Stone, & J. L. Sidel (Eds.), *Sensory evaluation practices. Food science and technology, international series* (3rd ed., pp. 247–277). USA: Academic Press/Elsevier.
- Stone, H., & Sidel, J. L. (2007). CH13. Sensory research and consumer-led food product development. In H. Macfie (Ed.), *Consumer-led food product development* (pp. 307–320). Cambridge, United Kingdom: Woodhead.
- Vickers, Z., & Holton, E. (1998). A comparison of taste test ratings, repeated consumption, and postconsumption ratings of different strengths of iced tea. *Journal of Sensory Studies*, 13, 199–212.
- Yusop, S. M., O'Sullivan, M. G., Kerry, J. F., & Kerry, J. P. (2009a). Sensory evaluation of Indian-style marinated chicken by Malaysian and European naïve assessors. *Journal of Sensory Studies*, 24, 269–289.
- Yusop, S. M., O'Sullivan, M. G., Kerry, J. F., & Kerry, J. P. (2009b). Sensory evaluation of Chinese-style marinated chicken by Chinese and European naïve assessors. *Journal of Sensory Studies*, 24, 512–533.

Further reading

- de Barcellos, M. D., Grunert, K. G., & Scholderer, J. (2011). Processed meat products: Consumer trends and emerging markets. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats. Improving safety, nutrition and quality* (pp. 30–53). Oxford, Cambridge, Philadelphia, New Delhi: Woodhead Publishing Ltd.
- Krystallis, A. (2007). In H. Macfie (Ed.), CH8. *Using means-end chains to understand consumer's knowledge structures* (pp. 158–196). Cambridge, United Kingdom: Woodhead.
- Worch, T., Crine, A., Gruel, A., & Lê, S. (2014). Analysis and validation of the ideal profile method: Application to a skin cream study. *Food Quality and Preference*, 32, 132–144.
- Worch, T., & Ennis, J. M. (2013). Investigating the single ideal assumption using Ideal Profile Method. *Food Quality and Preference*, 29, 40–47.

Rapid sensory methods for reformulation

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Introduction—the need for new methods

The drive by the food and beverage industry to reformulate has never been stronger. On April 6, and May 1, 2018, respectively, the United Kingdom and Ireland introduced a sugar tax on soft drinks. The introduction was coordinated between the two states so that sugar tax strategies were aligned to negate any discrepancies that would develop and undermine the tax at the border between Northern Ireland and the Republic of Ireland. For both taxes, products containing between 5 and 8 g/100 mL sugar were levied at 20 c/L in Ireland 18 p/L in the United Kingdom. For beverages over 8 g/100 mL the levies were 30 c/L in Ireland and 24 p/L in the United Kingdom. Immediately, this resulted in

dramatic increase in reformulation projects by the beverage sector in order for their business strategies to best fit with the new regulation ([Lancet, 2017](#)).

However, Ireland and the United Kingdom countries are not the first to implement such taxes. Mexico (2014), France (2012), Hungary (2012), and Finland (2016) have taxes on sugar-containing beverages drinks, and South Africa, the Philippines, Indonesia, and India are considering doing so. In addition, Hungary and Finland have also taxed some unhealthy foods ([Briggs, 2016](#)). One of the most comprehensive and wide-ranging ingredient tax initiatives was implemented by Hungary in 2011 targeting foods with high fat, sugar, salt, caffeine content, and alcohol. The added levy on sugar-sweetened soft drinks was 16 c/L, 33 p/kg for prepackaged sweetened products, 67 p/kg for salty snacks, and 84 p/L for energy drinks. These taxes were implemented by the Hungarian government to attempt to address a health crisis in its population. 19.5% of adult Hungarians self-reported as being obese in 2009 ([Villanueva, 2011](#)). The overnight implementation of the tax came as a shock to the food industry in Hungary and forced them to implement reformulation strategies with immediate effect. Thus as a result, of this tax, 40% of manufacturers reformulated their products by reducing or ridding them of sugar and other unhealthy ingredients such as caffeine and salt ([Lancet, 2017](#)). In order to meet this urgency to reformulate, the food and beverage sector requires the tools and methodologies to achieve objectives successfully. They must first comply with the law and meet regulatory threshold levels for the ingredient in question. They must achieve this in the most commercially viable fashion and align with their own least-cost formulation policies. Lastly, but most importantly, they must achieve the aforementioned objectives while also maintaining sensory quality and meeting optimum consumer expectations.

Affective methods (Chapter 7: Quantitative and qualitative affective methods for reformulation) are restricted to only measure hedonics, which includes acceptability or preference, but do not describe the product. The “intensive” use of consumers for sensory tests is not accepted by everybody in the sensory community ([Worch, Crine, Gruel, & Lê, 2014](#)). Consumers can only tell you what they like or dislike ([Lawless, 1999](#)). Some sensory scientists consider that using consumers for sensory descriptive tasks is not appropriate as consumers lack consensus, repeatability and comprehension of the meaning of the sensory attributes ([Lawless & Heymann, 1999](#); [Stone & Sidel, 1993](#)). In contrast, other sensory scientists

have shown through different studies that consumers can describe the sensory characteristics of products with a precision comparable to those obtained by experts (Worch et al., 2014). However, only “simple” sensory attributes can be used (cannot use technical or chemical terms) (Worch et al., 2014; Worch, Lê, & Punter, 2010), and larger numbers of consumers are required to make up for a lack of appropriate training.

The different methods for descriptive profiling (Chapter 6: Descriptive methods for reformulation) are the most powerful, sophisticated, and most extensively used tools in sensory science, which provide a complete description of the sensory characteristics of food products (Varela & Ares, 2012). Traditionally, by combining descriptive data and hedonic data using data analytical tools involving predominantly chemometrics in a method called preference mapping statistically, valid correlations could be determined from the data. This approach is not one undertaken routinely by industry as it is very expensive, costing upwards of €100,000 to benchmark a small selection of products against competitors. However, for many years, it allowed product development scientists to understand how their modifications were affecting the sensory profile of the product with respect to the modalities, appearance, aroma, flavor, texture, taste, and aftertaste as well as consumer opinion (O’Sullivan, 2017). Descriptive profiling alone can be expensive and time-consuming because of the necessity to train and profile individual panelists over extended periods of time, days or even weeks. It is also not a method that can be readily used for routine analysis (O’Sullivan, Kerry, & Byrne, 2011). Reformulated products and line extension variants of a product with perhaps a new flavor profile make it necessary to undertake completely new descriptive profiles. In a dynamic product development environment where it can be necessary to get the product to market with all due speed, especially considering the fickleness of the consumer, descriptive profiling does not always fit well (O’Sullivan, 2017). In this chapter, new sensory methods will be presented that deliver rapid and more cost-effective solutions to these problems, and to a certain extent, narrow the divide between the rigid rules of classic descriptive profiling and the emotional responses involved with affective sensory methods. One of the primary considerations in selecting a sensory methodology is whether the method is appropriate for the type and number of samples, the cost, and time involved. Researchers must take into account the value and detail of information gained versus the costs of gaining such knowledge (Wilson, Brand, du Toit, & Buica, 2018).

Rapid sensory evaluation methods are more flexible than classical approaches and can be used with semitrained assessors and even naïve assessors, providing sensory maps very close to a classic descriptive analysis with highly trained panels (Varela & Ares, 2012). These methods can provide the industry with quick results with respect to the end user and a reduction in resources needed to complete them. A number of different techniques have been published over the years on such rapid methods, including projective mapping (Risvik, McEwan, Colwill, Rogers, & Lyon, 1994), polarized sensory positioning (PSP) (Teillet, Schlich, Urbano, Cordelle, & Guichard, 2010), ranking test (Rodrigue, Guillet, Fortin, & Martin, 2000), flash profiling (Dairou & Sieffermann, 2002; Delarue & Sieffermann, 2004; Loescher, Sieffermann, Pinguet, Kesteloot, & Cuvlier, 2001), ultraflash profiling (Pagès, 2003), napping (Pagès, 2003, 2005), free sorting (Lawless, Sheng, & Knoop, 1995; Rosenberg, Nelson, & Vivekana, 1968), optimized descriptive profiling (ODP) (Silva et al., 2012, 2013; Silva, Minim, Silva, Peternelli, & Minim, 2014), check-all-that-apply (CATA) methods (Adams, Williams, Lancaster, & Foley, 2007; Ares, Barreiro, Deliza, Giménez, & Gámbaro, 2010; Ares, Giménez, Barreiro, & Gámbaro, 2010), temporal dominance of sensations (TDS) (Pineau et al., 2009), and the ideal profile method (IPM) (Worch et al., 2014; Worch & Ennis, 2013).



Ranking test

Rodrigue et al. (2000) performed two experiments to compare the quality of results obtained by conventional profiling and a new alternative solution, the ranking test. The first panel received suitable training to perform a descriptive profile whereas the second, with limited training, was asked to rank the products according to the same attributes as the first panel. They used a panel of 8 assessors to evaluate 10 attributes of sweet corn as well as untrained ($n = 20$) assessors evaluating the same products and attributes using the ranking procedure. They found that 10 attributes were thus common to both groups. The trained group rated the intensity of each attribute monadically, on an unstructured 10-point scale, whereas the untrained subjects were presented with all the products simultaneously and asked to rank them for each attribute. Ties between products were not allowed. The results from both methods were similar in terms of

overall product discrimination. These experiments also showed that methods used to measure consensus for profile data such as generalized Procrustes analysis can be applied to ranking data (Rodrigue et al., 2000). Rodrigue et al. (2000) concluded that whenever one has not enough time to train a descriptive panel, one could consider using an untrained panel and conduct a ranking test. The cost of the ranking test was less than a third of the cost involved for the traditional profile. This recommendation may still hold even if the number of products to compare is large, as a ranking test using a balanced incomplete block design could be used. The great advantage here was that only one familiarization or training session was required for the ranking test compared to the much more elaborate procedure followed for descriptive profiling (Rodrigue et al., 2000).

Pecore, Kamerud, and Holschuh (2015) utilized a method called ranked-scaling that involves the initial tasting by a previously trained panel of a set of specific spectrum intensity references, then the side-by-side presentation of all samples. The samples are tasted for the presence of the first attribute and ranked in order of intensity for that attribute. The panelists then assign an intensity rating for that attribute for each sample and then progress through the rest of the attributes. The method is useful when studying subtle product differences and when striving for accuracy in correlating to instrumental measurements. However, it is potentially fatiguing thus Pecore et al. (2015) suggest the method be limited to six or fewer attributes, and for five or fewer samples.



Flash profiling

Rapid sensory methods have gained considerable interests as alternatives to conventional descriptive profiling, due to their speed and cost-effectiveness (Liu, Schou Grønbecka, Di Monaco, Giacalone, & Bredie, 2016). In 2000 Sieffermann suggested combining free-choice profiling (FCP) with a comparative evaluation of the product set in a technique named flash profiling (Sieffermann, 2000). This method was one of the first new generation of rapid descriptive sensory methods developed. The (FCP) component was the novel aspect of the technique that involved panelists developing their own descriptive terms (Delahunty, McCord, O'Neill, & Morrissey, 1997; Williams & Langron,

1984), and then products are evaluated not in a monadic fashion as in traditional descriptive profiling but simultaneously. In flash profiling, because assessors choose their own words to evaluate the whole product set comparatively (Dairou & Sieffermann, 2002), the profiling is thus a very rapid sensory profiling technique. Also as a consequence of removing the need to agree vocabularies, FCP requires little training, only instruction in the use of the chosen scale (Kilcast, 2000). Assessors are asked to list the sensory characteristics that best describe the differences among the samples and then rank all the samples for each of their individual attribute lists (Dairou & Sieffermann, 2002). The method is based on the assumption that panelists do not differ in their perceptions but only in the manner they describe them (Murray, Delahunty, & Baxter, 2001). After an instructional presentation, assessors produce their own vocabulary free-of-choice, based on their perception of the variations in the samples. They are then allowed to see the other assessors' lists of terms and to add or substitute attributes in their own list as they wish (O'Sullivan, 2017). For each attribute, samples are ranked according to their intensity on an ordinal scale anchored from "lower" to "higher." Unlike the ranking test proposed by Rodrigue et al. (2000) where ties are not allowed, flash profiling allows the assessors to apply the same rank to two or more samples if no difference was perceived (Dehlholm, Brockhoff, Meinert, Aaslyng, & Bredie, 2012). Flash profiling offers a compromise to conventional descriptive methods and has been compared to them in a number of research papers (Dairou & Sieffermann, 2002; Delarue & Sieffermann, 2004; Loescher et al., 2001). Flash profiling can be carried out using semitrained or trained assessors (Dairou & Sieffermann, 2002; Delarue & Sieffermann, 2004) or with consumers (Lassoued, Delarue, Launay, & Michon, 2008; Moussaoui & Varela, 2010; Veinand, Godefroy, Adam, & Delarue, 2011).

The principal advantage of flash profiling is that the method is less time-consuming compared to traditional profiling because extensive training is not undertaken. This is because absolute consensus is not required between subjects for the definition of descriptive sensory term development as attributes are generated individually by free choice. Disadvantages of flash profiling include that the number of samples that can be profiled can be limited as large sample sets could possibly cause confusion with assessors. Tarea, Cuvelier, and Sieffermann (2007) demonstrated that up to 49 samples could be assessed in a flash profile of pear puree in one session (2–5 hours). A significant contributing factor to this was the fact that

the assessors were highly motivated, experienced, and also trained and could take breaks during the profiling session. As a common vocabulary is not imposed on semantic interpretation, the results can be complex. Also, if assessors generate a large amount of attributes, the difficulty of ranking samples would increase significantly. Thus the lexicon generation step in flash profiling is a critical step and has a major bearing on the quality of the results obtained (Liu et al., 2016).

This method of sensory profiling may have useful applications in the sensory evaluation of foods and beverages as it is a convenient methodology to employ compared to the more conservative methods and the necessity to minimize costs within the very competitive processed food sector (O'Sullivan et al., 2011). Traditional descriptive profiling is more appropriate when there is a need to compare samples in different moments in time or when comparing different sample sets with a few samples in common, or when a very detailed sensory description is required (Varela & Ares, 2012). The semantic consensus obtained in the conventional profile (CP) allows for a far more accurate description of the products (Dairou & Sieffermann, 2002). The flash profiling technique is also not recommended for studies of stability and quality control, since it does not indicate the magnitude of the difference between the products. Rapid sensory methods such as flash profiling have been demonstrated for a diverse selection of products, including pear/apple puree and fresh cheese (Loescher et al., 2001) yoghurt, (Delarue & Sieffermann, 2004), jams (Dairou & Sieffermann, 2002), beer (Hempel, O'Sullivan, Papkovsky, & Kerry, 2013a), bakery products (Hempel, O'Sullivan, Papkovsky, & Kerry, 2013d; Lassoued et al., 2008), Gouda cheese (Cavanagh, Kilcawley, O'Sullivan, Fitzgerald, & McAuliffe, 2014; Yarlagadda, Wilkinson, O'Sullivan, & Kilcawley, 2014), cheddar cheese (Yarlagadda, Wilkinson, Ryan, et al., 2014), French dry sausages (Rason, Lebecque, leger, & Dufour, 2003), beef patties (Tobin, O'Sullivan, Hamill, & Kerry, 2012a), frankfurters (Tobin, O'Sullivan, Hamill, & Kerry, 2012b), breakfast sausages (Tobin, O'Sullivan, Hamill, & Kerry, 2013a, 2013b), and ready-to-eat mixed salad products (Hempel, O'Sullivan, Papkovsky, & Kerry, 2013b, 2013c). Several researchers have found flash profiling was repeatable and is usually performed in two or three replicates (Dairou & Sieffermann, 2002; Moussaoui & Varela, 2010; Price et al., 2014; Veinand et al., 2011).



Ranking descriptive analysis

One of the most promising rapid methods developed to date is ranking descriptive analysis (RDA). This profiling technique is a modification of flash profiling developed by Richter, Almeida, Prudencio, and Benassi (2010), but where the lexicon is not developed in a free-choice fashion, but through consensus such as the traditional method. Thus there is no issue with differences in semantic consensus as described earlier for flash profiling. This method allowed the discrimination of the samples with efficiency similar to that displayed by the descriptive methods of the QDA (quantitative descriptive analysis) and FCP. Richter et al. (2010) also suggest that when time is insufficient to train a panel, the use of an untrained panel and a ranking test should be considered. Although larger numbers of assessors (21 assessors for Richter et al., 2010) were required for RDA, it could be conducted with minor costs compared to QDA and with smaller amounts of product and sessions. However, it is optimal to train a panel in order to obtain good descriptor conceptualization and greater panel consensus (Richter et al., 2010).

RDA has been successfully demonstrated for a number of other products, including chocolate pudding (Richter et al., 2010), white pudding (Fellendorf, O'Sullivan, & Kerry, 2015, 2016b), black pudding (Fellendorf, Kerry, Hamill, & O'Sullivan, 2018; Fellendorf, Kerry, & O'Sullivan, 2018; Fellendorf et al., 2016b), corned beef (Fellendorf, Kerry, Hamill et al., 2018), coffee (Stokes, O'Sullivan, & Kerry, 2017), butter (O'Callaghan et al., 2016), and mozzarella cheese (Henneberry et al., 2016). Fig. 8.1 depicts an RDA performed for corned beef (Fellendorf, Kerry, Hamill, et al., 2018; Fellendorf, Kerry, & O'Sullivan, 2018).

RDA is one of the most effective of the rapid methods for product reformulation purposes. Quite often it has been combined with a hedonic technique such as SAT (sensory acceptance testing) with multivariate data analysis used to link correlations between the ranking and hedonic data. In fact, this can be considered almost like a mini preference map—type protocol. This approach was applied to a wide range of products yielding correlations between descriptive and hedonic data. RDA as well as SAT was used to investigate 25 white pudding formulations simultaneously, produced with varying fat contents (2.5%–20%) and varying sodium contents (0.2%–1.0%) (Fellendorf et al., 2015). The SAT was conducted

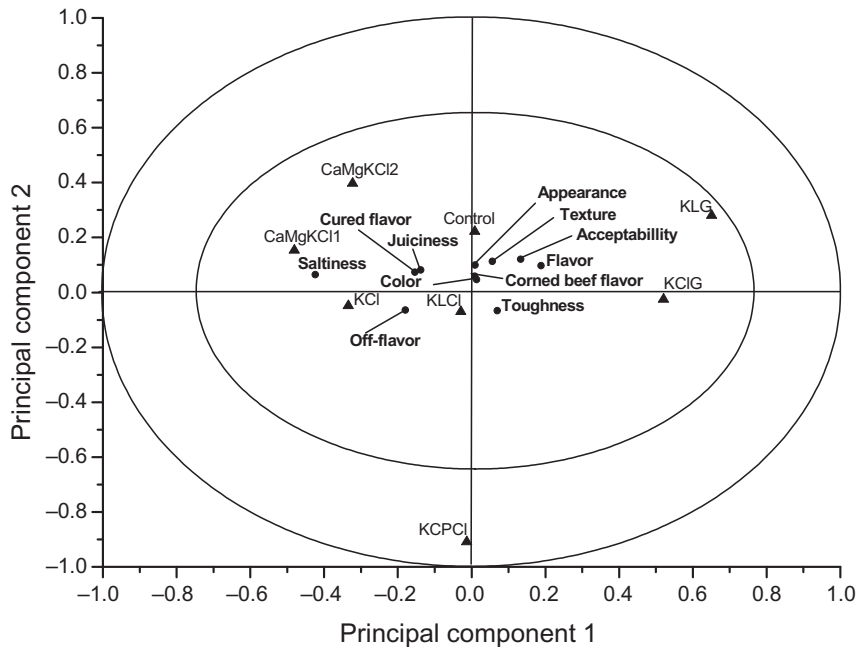


Figure 8.1 APLSR for the corned beef formulations. ▲, Samples [code: control = corned beef (0.4 g/100 g sodium)]; ●, sensory attributes; APLSR, ANOVA-partial least squares regression; CaMgKCl₂, mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/25); KCl, potassium chloride; KClG, mixture of potassium chloride and glycine; KCPCl, mixture of potassium chloride, potassium phosphate, potassium chloride, CaMgKCl₁, mixture of calcium chloride, magnesium chloride, potassium chloride (15/5/45); KLCI, mixture of potassium lactate and potassium chloride; KLG, mixture of potassium lactate and glycine. From Fellendorf, S., Kerry J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). *Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers*. *LWT-Food Science and Technology*, 92, 584–592; Fellendorf, S., Kerry J. P., & O'Sullivan, M. G. (2018). *Consumer Attitudes on salt and fat reduced foods in the Republic of Ireland*. *Food and Nutrition Sciences* 9, 880–898. doi: 10.4236/fns.2018.97066.

using untrained assessors ($n = 25–30$) (Stone, Bleibaum, & Thomas, 2012a; Stone & Sidel, 2004). The assessors then participated in the RDA using a consensus list of sensory descriptors. These authors found that the pudding sample containing 15% fat and 0.6% sodium was highly accepted ($P < .05$), thereby satisfying the sodium target (0.6%) set by the Food Safety Authority of Ireland (FSAI) (2011, 2014). In this case, Fellendorf et al. (2015) assessed a large number of samples ($n = 25$) using RDA but had a relatively short attribute list ($n = 7$). Samples were also presented in

a duplicate separate session with good reproducibility. A similar approach was used, combining RDA and SAT, for other projects. A reformulation study on black pudding samples (Fellendorf, O'Sullivan, & Kerry, 2017) found that product containing 0.6% sodium and 10% fat displayed a positive ($P < .05$) correlation to liking of flavor and overall acceptability. This reached the sodium target level set by FSAI (2011). The correlation of SAT and RDA with the application of salt and fat replacers were investigated as a means of further reducing salt and fat levels in black pudding (Fellendorf et al., 2016b). Fellendorf, Kerry, Hamill, et al. (2018) using the SAT and RDA combined sensory approaches observed that corned beef samples low in sodium (0.2%, 0.4%) showed reduced ($P < .05$) saltiness perception but were positively correlated ($P > .05$) to liking of flavor and overall acceptability. As well as salt reduction without replacement samples formulated with the salt replacers were also investigated to determine if further reduction could be achieved (Fellendorf, Kerry, Hamill, et al., 2018; Fellendorf, Kerry, & O'Sullivan, 2018) (Fig. 8.1). A sodium reduction of 60% in corned beef was determined to be achievable as assessors liked ($P < .05$) the flavor of the sodium-reduced corned beef containing 0.4% sodium and formulated with potassium lactate and glycine (KLG), even with the noticeable lower salty taste. Sodium reduction in corned beef (packaged under modified atmosphere) did not negatively impact on the microbiological shelf life. The application of SAT combined with RDA in these studies demonstrate that sensory quality can be optimally achieved while also meeting if not surpassing reduced salt targets set by regulators.



Free sorting

The “sorting” method has its origins in the late 1960s in the social sciences. Rosenberg et al. (1968) employed a multidimensional approach to the structure of personality impressions. For “sorting,” subjects, either trained or untrained, are presented with a set of samples and instructed to sort them in as many groups (must contain a least two samples) as possible, in a single session. It is based on the pretext that the stimuli are assumed to be similar to each other within each group and differ from the stimuli that are sorted in other groups (Cariou & Qannari, 2018; Heymann, 1994; Lawless et al., 1995). Once complete, the assessors describe the

groups using their own descriptive terms (Lawless et al., 1995; Popper & Heymann, 1996). Larger numbers of assessors are generally used for untrained assessors ($n = 20\text{--}50$) compared to trained panels ($n = 9\text{--}15$) (Cartier et al., 2006). It is also described as being an easy and enjoyable task for participants (Coxon, 1999). Trained assessors will find this component of sorting easier than untrained panelists, and for this reason, it is recommended that naïve assessors receive a list of predefined sensory characteristics from which they choose to describe the sample groups (Lelièvre, Chollet, Abdi, & Valentin, 2008). Sorting procedures have been applied to a large selection of different food and beverage products, including cheese (Lawless et al., 1995), yogurts (Saint Eve, Paci-Kora, & Martin, 2004), jellies (Tang & Heymann, 1999), breakfast cereals (Cartier et al., 2006), olive oil (Santosa, Abdi, & Guinard, 2010), red wine (Gawel, Iland, & Francis, 2001), drinking waters (Falahee & MacRae, 1997), beers (Chollet & Valentin, 2001), coffee (Moussaoui & Varela, 2010), and orange-flavored powdered drinks (Ares, Varela, Rado, & Gimenez, 2011).

Sorting has advantages over traditional descriptive methods, since it is easy to perform with minimal training, does not require a quantitative evaluation system, does not impose compliance (forced agreement) of the participants, is less tedious, and can process a large number of samples (O'Sullivan, 2017). However, for more complex products, due to the possible fatigue of the tester, a smaller number of samples should be evaluated, and it is a simpler technique for trained examiners than for inexperienced ones (Bijmolt & Wedel, 1995; Cartier et al., 2006; Varela & Ares, 2012). Although sorting tasks can be applied to a large sample set, it should be noted that all samples must be presented simultaneously in one session (Varela & Ares, 2012). Also, sorting is a stand-alone technique because it has to be combined with other sensory or instrumental data for the effective interpretation of the data (Pagès, 2005).

The data collected from sorting can be analyzed by either multidimensional scaling (MDS) (Lawless et al., 1995; Varela & Ares, 2012) or a method called DISTATIS. With MDS a similarity matrix is created by counting the number of times that each pair of samples is sorted within the same group (Varela & Ares, 2012). It is calculated for the entire group of assessors and not individually. On the other hand, DISTATIS uses three-way distance tables and does take into account the sample grouping provided by each assessor (Abdi et al., 2007). Lawless et al. (1995) employed MDS of sorting data for a range of 16 different cheese samples,

presented together in a blind (coded) randomized fashion to two different groups of assessors, consumer, or semitrained. The consumer group produced results that were similar in the perceptual maps of the experienced group.

Dehlholm et al. (2012) presented nine liver pâté samples to two panels ($n = 13$ and 10) who were asked to sort the same set of samples multiple times until they had exhausted their own individual permutations. In each sorting, they could generate between two and eight groups containing one-to-eight samples. Free multiple sorting (FMS) as described by Dehlholm et al. (2012) appears to be an elaboration of the sorting technique. They state that the difference between “sorting” and “FMS” is that with sorting, assessors group the samples only once whereas with FMS multiple groupings can be made (O’Sullivan, 2017). FMS appears to be a development of the free sorting method described by Steinberg (1967) and Dehlholm et al. (2012).



Projective mapping: napping, partial napping, sorted napping, and ultraflash profiling

The term napping originates from the French word *nappe* that means tablecloth, that is, grouping samples on a bidimensional space like a tablecloth (Varela & Ares, 2012). Projective mapping or napping is a technique with its origins in market research (Pagès, 2005; Risvik et al., 1994) where presented samples are grouped by subjects on typically an A3, A4, or 60 cm² sheets (Kennedy & Heymann, 2009; King, Cliff, & Hall, 1998; Nestrud & Lawless, 2010). During one session the assessors are tasked with evaluating the products (appearance, aroma, flavor, etc.), and they then must orientate the samples into groups on the paper sheet provided according to similarity. A control sample may also be used. Samples that are close are similar and those that are far apart are the opposite. Assessors can be trained ($n = 9–15$) (Perrin et al., 2008; Risvik, McEwan, & Rodbotten, 1997; Varela & Ares, 2012) or untrained ($n = 15–50$) (Albert, Varela, Salvador, Hough, & Fiszman, 2011; Ares, Deliza, Barreiro, Giménez, & Gámbaro, 2010; Kennedy & Heymann, 2009; Nestrud & Lawless, 2010; Varela & Ares, 2012). The coordinates of sample positions for the individual assessor groupings are marked on the sheets (A3) and then recorded as position coordinates (x and y) that can then

entered into statistical software (Perrin et al., 2008). Napping is a very user rapid user-friendly technique (Risvik et al., 1994), is easy to perform using minimum training, and like sorting does not require any quantitative rating systems, and there is no forced agreement among panelists. Disadvantages of napping can include a limitation in the maximum number of samples assessed due to adaptation or fatigue, 10–20 (Schifferstein, 1996). Also, napping does not stand alone as a technique as in order to interpret the data effectively, it must be combined with other sensory or instrumental data (Pagès, 2005) or with a verbalization task to better understand the perceptual dimensions (Moussaoui & Varela, 2010). Napping data can often have quite a high noise-to-signal ratio as assessors make their evaluations in a very personal fashion and variability between assessors can be high even though relative associations between products can still be determined (O'Sullivan, 2017). Differences between less complex products are thus easier to observe than products that are more complex. Often in sensory experiments, it is a requirement that the food or beverage to be tested is served at the temperature that it is normally consumed. Thus monadic presentation of samples to panelists ensures that this critical aspect is factored into sensory testing in descriptive tests such as spectrum or QDA. However, the napping method may be restricted to products that can be served at a relatively easy to maintain constant temperature (e.g., ambient). Pramudya and Seo (2018) state that due to the limited number of sensory attributes used in the scoring-based traditional methods, a “rapid sensory profiling technique” seems to be more suitable for capturing dynamics of temperature-dependent sensory attributes in hot or cold foods and beverages. However, the napping method seems inapplicable to sensory studies aiming at characterizing variations in sensory attributes of hot food when there are many samples to be evaluated and thus variations in the temperature of evaluation of products relative to the other assessors is unavoidable (Pramudya & Seo, 2018). The temperature of the tongue has a critical role in modulating the associations between sample temperature and sensory perception (Green & Frankmann, 1987; Mony et al., 2013). This is a limitation of the method that should not be ignored as noise can easily be introduced into the obtained data due to temperature variability.

Napping has been applied to various food products and beverages such as brandy (Louw et al., 2015), beer (Reinbach, Giacalone, Machado Ribeiro, Bredie, & Michael Bom Frøst, 2014) wines (Perrin & Pagès, 2009), coffee (Moussaoui & Varela, 2010) chocolate, (Risvik et al., 1994),

chocolate dairy desserts (Ares, Giménez, et al., 2010), soups (Risvik et al., 1997), snack bars (King et al., 1998), citrus juices (Nestrud & Lawless, 2010), fish nuggets (Albert et al., 2011), and powdered drinks (Ares et al., 2011).

“Ultraflash profiling” is a development of napping, which adds a descriptive component to the mapping process by association sensory terms with groupings (Dehlholm et al., 2012; Varela & Ares, 2012). Similar to this method, “sorted napping” involved the assessors basically categorizing their product maps by circling groupings on their mapping sheets and associating words with these groups (Pagès, Cadoret, & Lê, 2010). Partial napping is a simplified version of napping where assessors perform the napping procedure on one or specific sensory modalities instead of the intuitive association of conventional projective mapping (Dehlholm et al., 2012; Grygorczyk, Lesschaeve, Corredig, & Duizer, 2013; Pfeiffer & Gilbert, 2008).



Rapid profiling using references: polarized sensory positioning, the optimized sensory profile method, off-flavor quantification, and polarized projective mapping

PSP is a novel methodology for sensory characterization, which is based on the comparison among samples and a set of reference products, called poles (de Saldamando, Delgado, Herencia, Giménez, & Ares, 2013). In PSP, samples are assessed by either trained or untrained assessors through the comparison of a sample (or set) to provided reference products. The method is convenient and rapid, and because references are used samples analysis does not have to be completed in a single session (O'Sullivan, 2017). First proposed by Teillet et al. (2010) to explore the sensory aspects of mineral water (Evian, Volvic, and Vittel), assessors ($n = 15$) were asked to compare the similarity of samples to reference water samples on unstructured line scales anchored on one end with the term “same taste” and the other with “totally different taste.” Thus how similar the samples were to each of the three references was determined with a line marked on these three different similarity scales. The technique's main advantage is that results from different sessions can be compared, which is useful when working with samples with persistent flavors,

when evaluating a large number of samples over a long period of time or during quality control (de Saldamando et al., 2013). Multivariate data analysis can then be used to analyze the raw data collected, and the samples can be correlated directly to their similarity to the reference products. Teillet et al. (2010) state that references can also be considered as “global” descriptors where the data is analyzed by calculating average scores, and sample representation is obtained by principal component analysis (Teillet et al., 2010; Varela & Ares, 2012). A description phase should also be performed in order to gather information about the sensory characteristics responsible for the similarities and differences between products (Varela & Ares, 2012). Ares, Antúñez, et al. (2015) and Ares, Jaeger, et al. (2015) undertook three consumer studies on three product categories: chocolate-flavored milk, vanilla milk desserts, and orange-flavored powdered drinks. They found that consumers tended to evaluate the degree of difference between the samples and each of the poles by evaluating the intensity of only one or two main sensory characteristics. They demonstrated that it was possible to unfold a multidimensional sensory space with the use of just two well-selected poles.

O’Sullivan, Cruz, and Kerry (2011) used a similar method to PSP for off-flavor quantification of gas initiated flavor taints in modified atmosphere packed beef steaks. The CO₂ flavor taint reference sample was presented as a steak packed in 100 mL CO₂/100 mL pack gas and cooked immediately on pack opening and served on each test day to the panelists. It had a distinctively sour and acidic taste. One set of test samples was cooked immediately on pack opening and the other set cooked after 30 mins to facilitate the dissipation of the CO₂ flavor from the meat (O’Sullivan, Cruz-Romero, & Kerry, 2010; O’Sullivan et al., 2011). In effect the references provided on the given test day represented the maximum loading of the off-flavor in the same sample test samples. In this fashion, off-flavor development could be tracked over the course of the shelf life to an end point determined by the maximum safe microbiological threshold (O’Sullivan, 2017; O’Sullivan et al., 2010, 2011).

The “optimized descriptive profile” has been proposed by Navarro da Silva et al. (2012). Reference materials are presented during evaluation of the products for all the attributes and anchored with “weak and strong” references. The judges could compare samples with the reference materials, facilitating the allocation of attribute intensity on the unstructured scale. The description obtained by the ODP was compared with the CP (Navarro da Silva et al., 2012).

Polarized projective mapping (PPM) is a form of projective mapping that integrates the concept of reference samples, termed “poles,” from PSP. It is a hybrid method combining of projective mapping and PSP where assessors are asked to locate a set of samples on a sheet of paper in which three reference samples have been previously located (Ares et al., 2013). These poles have a fixed, predetermined location on the panelists’ map who in turn are presented with test products to arrange around these poles to create a two-dimensional product map. Ares et al. (2013) state that the method enables the results from different sessions to be compared as well as obtaining verbal descriptive information about the sensory characteristics of the products tested and not a just descriptive comparison between the samples and the reference products. This use of poles, which serve as references, allows direct comparison of data from multiple sessions where new test samples can be introduced. This allows PPM the ability to analyze large sample sets (Wilson et al., 2018). Assessors taste the references and samples and then place each of the samples on the sheet according to the perceived similarities and differences between the sample and each of the references or poles. Again, like projective mapping the samples that are placed close to each other are similar and those that are far apart are not similar. Then the assessors are asked to describe their groupings which they have made in a fashion very similar to ultraflash profiling (O’Sullivan, 2017).



Check-all-that-apply

CATA questions are an increasingly popular technique for fast sensory profiling of food products (Adams et al., 2007). CATA questions consist of a list of sensory attributes (in the form of words or phrases) from which trained or untrained panelists can select all the attributes that they consider appropriate to characterize each sample (Valentin, Chollet, Lelièvre, & Abdi, 2012). Generally, large numbers of consumers are required, between 50 and 100, with samples presented monadically in the standard randomized fashion (Adams et al., 2007; Ares, Barreiro, Deliza, et al., 2010; Dooley, Lee, & Meullenet, 2010; Lado, Vicente, Manzoni, & Ares, 2010; Varela & Ares, 2012). The method is quick but only provides qualitative data, and the technique is only as good as the questions provided (Varela & Ares, 2012). The method is used to gather consumer

information by means of assessors answering multiple-choice questions on a survey-type questionnaire. Quite simply it involves a product presented to the assessor, usually the consumer, and they are asked to either answer questions relating to the product (packaging, usage, hedonics, situation, etc.) or on the sensory attributes of the product (O'Sullivan, 2017). They answer the questions provided by ticking the box (or boxes) from a list of multiple terms provided which they decide are pertinent or fit the product. The method has applications in sensory science, particularly with consumer studies and has its origins in the market research realm (Rasinski, Mingay, & Bradburn, 1994). Rotation of terms within a CATA question is important as consumers sometimes select terms based solely on their position on the list, biased to those at the top, therefore an unchecked term could still actually apply to the product (Castura, 2009; Krosnick, 1999; Sudman & Bradburn, 1982). CATA questions are considered consumer friendly, easy to understand, and highly reproducible, making this methodology applicable to a large number of consumer panels (Jaeger et al., 2013). CATA yields data that is binary, that is, checked or unchecked, but it is claimed the use of CATA questions with naïve consumer panelists has been found to demonstrate high discriminative capability among test samples and produce results similar to those obtained from descriptive sensory analysis (Ares, Barreiro, et al., 2010; Bruzzone, Ares, & Giménez, 2012; Cadena, Caimi, et al., 2014). If very similar products are tested, differentiation may not be achieved as the CATA questions may not provide suitable levels of separation (Dooley et al., 2010; Varela & Ares, 2012).



Temporal dominance of sensations

TDS is a relatively new dynamic sensory methodology that consists of presenting a list of attributes to the assessors who are asked to continuously select the attribute that is perceived as dominant at each time of the evaluation (Pineau et al., 2009). It is a method that measures the specific dynamic sensory sensation of food or beverage products while they are being perceived in the mouth during a specific time period (O'Sullivan, 2017). Food and beverage products are not unidimensional in that they do not only have one sensory dimension but also are composed of many which change over the course of product consumption. TDS judges do

not require lengthy training, and several attributes can be evaluated over the evaluation period. TDS studies the sequence of dominant sensations of a product during a certain time period (Pineau et al., 2009). The method is focused on dominant attributes instead of quantifying attribute intensity, and thus results from this technique may better explain consumer perception and more accurately identify the sensations that determine their hedonic perception (Cadena, Vidal, Ares, & Varela, 2014).

TDS involves assessors identifying and also sometimes rating the intensity of sensations perceived as dominant until the perception fades and then they must select the next dominant attribute until all have been identified (Di Monaco, Su, Masi, & Cavella, 2014). Judges start the evaluation while putting samples into their mouths, then also start the chronometer. The evaluation ends when judges can no longer perceive sensations and stop the chronometer (Meillon, Urbano, & Schlich, 2009). The statistical analysis of TDS data can be difficult and is restricted to the description of TDS curves (Lawless and Heymann). The TDS sequences are unfolded to data matrices with a single nonzero entry per time point (column). The sum of the Euclidean distances between these matrices is determined and serves as a test statistic for the global test (Meyners & Pineau, 2010). TimeSens, a web-based software, dedicated to both TDS data acquisition, and analysis has been developed and runs as a plug-in web browser, requiring only an Internet access and allowing data acquisition anywhere, even allowing interfacing with personal mobile phones (Visalli, Monterymard, Duployer, & Schlich, 2011). One of the drawbacks of TDS is how to modify products once areas of optimization have been identified. By attempting to subtly change a sensory dimension in the TDS spectrum the flavor profile of the product might be knocked out of kilter. An identified sensory dimension might have a synergistic or antagonistic effect on other sensory dimensions making modification more difficult (O'Sullivan, 2011, 2017). Also, with TDS the evaluation is performed during the first sip/bite, but in real-life products are consumed in rapid repeated ingestions that can cause changes in how products are perceived due to sensory adaptation (Köster, 2003). For this reason the first sip/bite may not be enough to fully perceive all the sensory characteristics of the products, particularly when dealing with complex products (Zorn, Alcaire, Vidal, Giménez, & Ares, 2014). Multiple bite or sip TDS is a proposed method that may counter this drawback (Vandeputte, Romans, Pineau, & Lenfant, 2011; Zorn et al., 2014). Zorn et al. (2014) explored multiple sips for the identification of changes in the temporal

profile of sweetened orange juices (sucrose, sucralose, thaumatin, and stevia) with repeated rapid ingestions. The results suggest that multiple sip TDS identified differences between sweeteners that would not be detected using classic static sensory measurements. (Zorn et al., 2014). Thomas, Visalli, Cordelle, and Schlich (2015) presented a method for the assessment of the “temporal drivers of liking” to identify sensory attributes inducing a positive or negative trend of liking when they become dominant. The inclusion of hedonics is novel, but it is yet to be seen how useful this test really is, as again by modifying a particular sensory dimension from identified trends of liking might result in unknown synergistic or antagonistic effects on other liking dimensions (O’Sullivan, 2011, 2017).

TDS has been used to study a wide range of products, including orange juice (Zorn et al., 2014), wine (Frost, Blackman, Ebeler, & Heymann, 2018; Meillon et al., 2009; Pineau et al., 2009; Sokolowsky & Fischer, 2012), coffee (Dinnella, Masi, Naes, & Monteleone, 2013), olive oil (Dinnella, Masi, Zoboli, & Monteleone, 2012), fish (Albert, Salvador, Schlich, & Fiszman, 2012), cheese (Meyners, 2016; Thomas et al., 2017), and yogurt (Bruzzzone, Ares, & Giménez, 2013).



Temporal check-all-that-apply

Temporal CATA (TCATA) is a CATA-based technique for temporal sensory product characterization, which used a similar format to the question format of CATA except, assessors also select all the terms they consider applicable for describing the sensations they perceive at each moment of the evaluation process. Ares, Antúnez, et al. (2015) and Ares, Jaeger, et al. (2015) investigated the approach for yogurt, salami, cheese, orange juice, French bread, and marinated mussels using consumers and trained panelists as assessors. They concluded that TCATA may provide a more detailed description of the dynamics of the sensory characteristics of products. Esmerino et al. (2017) investigated the dynamic profiling of different ready-to-drink fermented dairy products using TCATA, TDS, and progressive profile (PP). TCATA was shown to be the most sensitive method in detecting textural changes in products. McMahon, Culver, Castura, and Ross (2017) investigated the perception of carbonation in sparkling wines using descriptive analysis and TCATA and found both methods were similar in their ability to distinguish between carbonated

wine treatments. [Nguyen, Næs, and Varela \(2018\)](#) investigated TDS, TCATA, and a variant of TDS, performed by modality (M-TDS) in the outcome of the dynamic sensory description for semisolid foods. They found that TCATA was more discriminative and panelists were more in agreement. TCATA also described samples in more detail in terms of number of discriminating attributes as compared with TDS.



Just-about-right scales

The most common sensory-hedonic methods used with consumer panels are optimization methods such just-about-right (JAR) scaling and the IPM ([Ruark, Vingerhoeds, Kremer, Nijenhuis-de Vriesa, & Piqueras-Fizman, 2016](#)). Only attributes that have an optimum can be used (attributes where more or less is always better are not suitable) and the attribute must not have a negative association ([Lawless & Heymann, 2010](#)). These bipolar scales 5- or 7-point category scales is labeled “JAR” in the center with the opposing anchor points labeled “much too little” and “much too much” ([Lawless & Heymann, 2010](#)). Unstructured line scaling can also be employed where the scales are anchored at 1 point with “not nearly enough” at one end, “much too much at the other” and “JAR” in the center ([Anon, 2015](#)). JAR scales are used by sensory scientists and market researchers to measure the optimum level of a specific attribute (or attributes), by allowing the assessor to determine if an attribute is “just-about-right.” They are often used in conjunction with liking (hedonic) and sensory intensity scales ([Gacula, Rutenbeck, Pollack, Resurreccion, & Moskowitz, 2007](#); [López Osorino & Hough, 2010](#)). In consumer research and sensory sciences, the relationship between the JAR variable and the hedonic score is used for either optimization or further development of products ([Gere, Sipos, & Héberger, 2015](#)). [Jeon, Lee, and Kim \(2014\)](#) evaluated the level of saltiness in two soup types, soybean-sprout soup and chicken soup, with six different levels of salt in each. JAR scales were used to measure salt perception in soup samples using either a beaker-tasting protocol (BTP) or a spoon-tasting protocol (STP). The optimum NaCl concentrations as determined by BTP were 0.59% for soybean-sprout soup and 0.48% for chicken soup that were lower than those determined by STP (0.66% for soybean-sprout soup and 0.52% for chicken soup) ([Jeon et al., 2014](#)). This signals the importance of

presentation protocol for reformulation studies. In addition, JAR scales have been used to optimize cooked steaks (Chan, Moss, Farmer, Gordon, & Cuskelly, 2013) and Korean traditional barbecued beef (Hong et al., 2011).

A criticism of JAR scales is that tasks that force consumers to focus their attention on specific sensory characteristics can induce an analytical mind-set that can inhibit representation of synthetic characteristics, such as overall liking (Prescott, Lee, & Kim, 2011).

Also, there is a risk that the subject might misinterpret an attribute, or that the test is a too analytical evaluation of the food or beverage than the consumer can handle. It can be ambiguous whether the JAR level refers to the acceptance of the product or to a preference (Gacula et al., 2007). The inclusion of JAR questions present in the questionnaire has an effect on overall liking thus introduce bias (Earthy, Macfie, & Hedderley, 1997; Popper, Rosenstock, Schraidt, & Kroll, 2004). The Stuart–Maxwell frequency test and the McNemar test for JAR data are suitable statistical methods that can be used to test difference between products (Anon, 2015; Lawless & Heymann, 2010). The generalized pairwise correlation method (GPCM) is a nonparametric technique and is useful to rank JAR variables according to their impact on liking. This is done using the McNemar's, the Chi-square, the conditional Fisher's, and the Williams' *t*-test (Gere et al., 2015). Also, data penalty analysis can be used for data interpretation (Lawless & Heymann, 2010).



The ideal profile method

Ideal scaling measures the perceived intensity of an attribute and the intensity of a hypothetical ideal separately (Gilbert, Young, Ball, & Murray, 1996; Rothman & Parker, 2009; van Trijp, Punter, Mickartz, & Kruithof, 2007; Worch, Lê, Punter, & Pagès, 2012). As discussed previously, JAR scales can be used to determine the optimum level of an attribute intensity of a food or beverage product. A step forward from this is the IPM (O'Sullivan, 2017). Each consumer provides a sensory profile of the products, their hedonic ratings, and their ideal profile. Consumers are asked to rate products on both their “perceived” and “ideal” intensities from a list of attributes. In addition, overall liking is asked (Worch et al., 2014; Worch & Ennis, 2013). The ideal profiles are directly actionable to

guide for products' improvement, but the obtained information should be carefully managed since it is obtained from consumers, and it describes virtual products. In theory the method could be used to create ideal products for consumers, but the reliability of the data can be fragile (Worch & Ennis, 2013).



Pivot profile

Thuillier, Valentin, Marchal, and Dacremont (2015) proposed a rapid descriptive technique known as the Pivot Profile (PP). These authors evaluated champagne beverages by comparing each product to a stable reference termed the “pivot.” Assessors are asked to observe, smell, and taste the sample and compare it to the pivot and to write down each attribute that the product has in smaller or larger amount than the pivot product (e.g., less sweet, more astringent). Data analysis is undertaken by regrouping synonyms and terms by categories and collating negative and positive frequencies for each term and each product, with the negative frequency subtracted from the positive frequency. The final matrix is submitted to correspondence analysis to obtain a sensory map of the products (Lelièvre-Desmas, Valentin, & Chollet, 2015; Thuillier et al., 2015). Fonseca et al. (2016) determined the sensory profile of different commercial samples of chocolate ice cream (conventional and light or diet), using the “comment analysis” and “PP” methods using consumers. They found that the PP method showed high analytical and discriminative power even using consumers, proving to be a promising technique for routine applications. Deneulin, Reverdy, Rébénague, Danthe, and Mulhauser (2018) used the PP to characterize a large variety of honeys ($n = 50$) from around the world. The method provided three perfectly interpretable maps where one was ranked, based on their light/yellow to dark/brown color and their crystallization.

References

- Abdi, H., Valentin, D., Chollet, S., Chrea, C., Abdi, H., Valentin, D., et al. (2007). Analyzing assessors and products in sorting tasks: DISTATIS, theory and applications. *Food Quality and Preference*, 18, 627–640.
- Adams, J., Williams, A., Lancaster, B., & Foley, M. (2007). Advantages and uses of check-all-that-apply response compared to traditional scaling of attributes for salty snacks. In *7th Pangborn sensory science symposium*. Minneapolis, MN, August 12–16, 2007.

- Albert, A., Salvador, A., Schlich, P., & Fiszman, S. (2012). Comparison between temporal dominance of sensations (TDS) and key-attribute sensory profiling for evaluating solid food with contrasting textural layers: Fish sticks. *Food Quality and Preference*, 24, 111–118.
- Albert, A., Varela, P., Salvador, A., Hough, G., & Fiszman, S. (2011). Overcoming the issues in the sensory description of hot served food with a complex texture. Application of QDA®, flash profiling and projective mapping using panels with different degrees of training. *Food Quality and Preference*, 22, 463–473.
- Anon. (2015). *Just about right scales*. Society of Sensory Professionals. <<http://www.sensorysociety.org/knowledge/sspwiki/Pages/Just%20About%20Right%20Scales.aspx>>.
- Ares, G., Antúnez, L., Oliveira, D., Alcaire, F., Giménez, A., Berget, I., ... Varela, P. (2015). Pole selection in polarized sensory positioning: Insights from the cognitive aspects behind the task. *Food Quality and Preference*, 46, 48–57.
- Ares, G., Barreiro, C., Deliza, R., Giménez, A., & Gámbaro, A. (2010). Application of a check-all-that-apply question to the development of chocolate milk desserts. *Journal of Sensory Studies*, 25, 67–86.
- Ares, G., Barreiro, C., Deliza, R., Giménez, A., & Gámbaro, A. (2010a). Application of a check-all that-apply question to the development of chocolate milk desserts. *Journal of Sensory Studies*, 25, 67–86.
- Ares, G., de Saldamando, L., Vidal, L., Antúnez, L., Giménez, A., & Varela, P. (2013). Polarized projective mapping: Comparison with polarized sensory positioning approaches. *Food Quality and Preference*, 28, 510–518.
- Ares, G., Giménez, A., Barreiro, C., & Gámbaro, A. (2010). Use of an open-ended question to identify drivers of liking of milk desserts. Comparison with preference mapping techniques. *Food Quality and Preference*, 21, 286–294.
- Ares, G., Jaeger, S. R., Antúnez, L., Vidal, L., Giménez, A., Coste, B., ... Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International*, 78, 148–158.
- Ares, G., Varela, P., Rado, G., & Gimenez, A. (2011). Are consumer profiling techniques equivalent for some product categories? The case of orange-flavoured powdered drinks. *International Journal of Food Science and Technology*, 46, 1600–1608.
- Bijmolt, T., & Wedel, M. (1995). The effects of alternative methods of collecting similarity data for multidimensional scaling. *International Journal of Research in Marketing*, 12, 363–371.
- Briggs, A. (2016). Sugar tax could sweeten a market failure. *Nature*, 531. Online. <https://www.nature.com/news/polopoly_fs/1.19646!/menu/main/topColumns/topLeftColumn/pdf/531551a.pdf>.
- Bruzzzone, F., Ares, G., & Giménez, A. (2012). Consumers' texture perception of milk desserts II – Comparison with trained assessors' data. *Journal of Texture Studies*, 43, 214–226.
- Bruzzzone, F., Ares, G., & Giménez, A. (2013). Temporal aspects of yoghurt texture perception. *International Dairy Journal*, 29, 124–134.
- Cadena, R. S., Caimi, D., Jaunarena, I., Lorenzo, I., Vidal, L., Ares, G., et al. (2014). Comparison of rapid sensory characterization methodologies for the development of functional yogurts. *Food Research International*, 64, 446–455.
- Cadena, R. S., Vidal, L., Ares, G., & Varela, P. (2014). Dynamic sensory descriptive methodologies time–intensity and temporal dominance of sensations. In P. Varela, & G. Ares (Eds.), *Novel techniques in sensory characterization and consumer profiling* (pp. 333–364). Boca Raton, FL: CRC Press.
- Cariou, V., & Qannari, E. M. (2018). Statistical treatment of free sorting data by means of correspondence and cluster analyses. *Food Quality and Preference*, 68, 1–11.

- Cartier, R., Rytz, A., Lecomte, A., Poblete, F., Krystlik, J., Belin, E., & Martin, N. (2006). Sorting procedure as an alternative to quantitative descriptive analysis to obtain a product sensory map. *Food Quality and Preference*, 17, 562–571.
- Castura, J. C. (2009). Do panellists donkey vote in sensory choose-all-that-apply questions? In *8th Pangborn sensory science symposium*, July 26–30, Florence.
- Cavanagh, D., Kilcawley, K. N., O'Sullivan, M. G., Fitzgerald, G. F., & McAuliffe, O. (2014). Assessment of wild non-dairy lactococcal strains for flavour diversification in a mini Gouda type cheese model. *Food Research International*, 62, 432–440.
- Chan, S. H., Moss, B. W., Farmer, L. J., Gordon, A., & Cuskelly, G. J. (2013). Comparison of consumer perception and acceptability for steaks cooked to different endpoints: Validation of photographic approach. *Food Chemistry*, 136(3–4), 1597–1602.
- Chollet, S., & Valentin, D. (2001). Impact of training on beer flavour perception and description: Are trained and untrained panelists really different? *Journal of Sensory Studies*, 16, 601–618.
- Coxon, A. P. M. (1999). *Sorting data: Collection and analysis. Series: Quantitative Applications in the Social Sciences*. New York: Sage Publications Inc.
- Dairou, V., & Sieffermann, J. M. (2002). A comparison of 14 jams characterized by conventional profile and a quick original method, the Flash profile. *Journal of Food Science*, 67(2), 826–834.
- Delahunty, C. M., McCord, A., O'Neill, E. E., & Morrissey, P. A. (1997). Sensory characterisation of cooked hams by untrained consumers using free-choice profiling. *Food Quality and Preference*, 8, 381–388.
- Delarue, J., & Sieffermann, J. M. (2004). Sensory mapping using Flash profile. Comparison with a conventional descriptive method for the evaluation of the flavour of fruit dairy products. *Food Quality and Preference*, 15, 383–392.
- Dehlholm, C., Brockhoff, P. B., Meinert, L., Aaslyng, M. D., & Bredie, W. L. P. (2012). Rapid descriptive sensory methods – Comparison of free multiple sorting, partial napping, napping, flash profiling and conventional profiling. *Food Quality and Preference*, 26, 267–277.
- Deneulin, P., Reverdy, C., Rébénague, P., Danthe, E., & Mulhauser, B. (2018). Evaluation of the Pivot Profile©, a new method to characterize a large variety of a single product: Case study on honeys from around the world. *Food Research International*, 106, 29–37.
- Di Monaco, R., Su, C., Masi, P., & Cavella, S. (2014). Temporal dominance of sensations: A review. *Trends in Food Science & Technology*, 38, 104–112.
- Dinnella, C., Masi, C., Naes, T., & Monteleone, E. (2013). A new approach in TDS data analysis: A case study on sweetened coffee. *Food Quality and Preference*, 30(1), 33–46.
- Dinnella, C., Masi, C., Zoboli, G., & Monteleone, E. (2012). Sensory functionality of extra-virgin olive oil in vegetable foods assessed by temporal dominance of sensations and descriptive analysis. *Food Quality and Preference*, 26, 141–150.
- Dooley, L., Lee, Y.-S., & Meullenet, J.-F. (2010). The application of check-all-that-apply (CATA) consumer profiling to preference mapping of vanilla ice cream and its comparison to classical external preference mapping. *Food Quality and Preference*, 21, 394–401.
- Earthy, P. J., Macfie, H. J. H., & Hedderley, D. (1997). Effect of question order on sensory perception and preference in central location trials. *Journal of Sensory Studies*, 12, 215–237.
- Esmerino, E. A., Castura, J. C., Ferraz, J. P., Tavares Filho, E. R., Silva, R., Cruz, A. G., ... Bolini, H. M. A. (2017). Dynamic profiling of different ready-to-drink fermented dairy products: A comparative study using temporal check-all-that-apply (TCATA),

- temporal dominance of sensations (TDS) and progressive profile (PP). *Food Research International*, 101, 249–258.
- Falahee, M., & MacRae, A. (1997). Perceptual variation among drinking waters: The reliability of sorting and ranking data for multidimensional scaling. *Food Quality and Preference*, 8, 389–394.
- Fellendorf, S., Kerry, J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Science and Technology*, 92, 584–592.
- Fellendorf, S., Kerry, J. P., & O'Sullivan, M. G. (2018). Consumer attitudes on salt and fat reduced foods in the Republic of Ireland. *Food and Nutrition Sciences*, 9, 880–898. Available from <https://doi.org/10.4236/fns.2018.97066>.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding sausages. *Meat Science*, 103, 75–82.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016a). Effect of using replacers on the physicochemical properties and sensory quality of low salt and low fat white puddings. *European Food Research and Technology*, 242, 2105–2118.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016b). Impact of using replacers on the physicochemical properties and sensory quality of reduced salt and fat black pudding. *Meat Science*, 113, 17–25.
- Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2017). Effect of different salt and fat levels on the physicochemical properties and sensory quality of black pudding. *Food Science & Nutrition*, 5(2), 273–284.
- Fonseca, F. G. A., Esmerino, E. A., Filho, E. R. T., Ferraz, J. P., da Cruz, A. G., & Bolini, H. M. A. (2016). Novel and successful free comments method for sensory characterization of chocolate ice cream: A comparative study between pivot profile and comment analysis. *Journal of Dairy Science*, 99, 3408–3420.
- Frost, S. C., Blackman, J. W., Ebeler, S. E., & Heymann, H. (2018). Analysis of temporal dominance of sensation data using correspondence analysis on Merlot wine with differing maceration and cap management regimes. *Food Quality and Preference*, 64, 245–252.
- Food Safety Authority of Ireland (FSAI). (2011). *Salt reduction programme (SRP)—2011 to 2012* (p. 85).
- Food Safety Authority of Ireland (FSAI). (2014). *Monitoring of sodium and potassium in processed foods period: September 2003 to July 2014* (p. 44).
- Gacula, M., Rutenbeck, S., Pollack, L., Resurreccion, A. V. A., & Moskowitz, H. R. (2007). The just about right intensity scale: Functional analyses and relation to hedonics. *Journal of Sensory Studies*, 22, 194–211.
- Gawel, R., Iland, P. G., & Francis, I. L. (2001). Characterizing the astringency of red wine: A case study. *Food Quality of Preference*, 12, 83–94.
- Gere, A., Sipos, L., & Héberger, K. (2015). Generalized pairwise correlation and method comparison: Impact assessment for JAR attributes on overall liking. *Food Quality and Preference*, 43, 88–96.
- Gilbert, J. M., Young, H., Ball, R. D., & Murray, S. H. (1996). Volatile flavor compounds affecting consumer acceptability of kiwifruit. *Journal of Sensory Studies*, 11(3), 247–259.
- Green, B. G., & Frankmann, S. P. (1987). The effect of cooling the tongue on the perceived intensity of taste. *Chemical Senses*, 12, 609–619.
- Grygorczyk, A., Lesschaeve, I., Corredig, M., & Duizer, L. (2013). Impact of structure modification on texture of a soymilk and cow's milk gel assessed using the napping procedure. *Journal of Texture Studies*, 44, 236–246.

- Hempel, A., O'Sullivan, M. G., Papkovsky, D., & Kerry, J. P. (2013a). Use of optical oxygen sensors to monitor residual oxygen in pre- and post-pasteurised bottled beer and its effect on sensory attributes and product acceptability during simulated commercial storage. *LWT-Food Science and Technology*, 50, 226–231.
- Hempel, A., O'Sullivan, M. G., Papkovsky, D., & Kerry, J. P. (2013b). Non-destructive and continuous monitoring of oxygen levels in modified atmosphere packaged ready-to-eat mixed salad products using optical oxygen sensors. *Journal of Food Science*, 78, S1057–S1062.
- Hempel, A., O'Sullivan, M. G., Papkovsky, D., & Kerry, J. P. (2013c). Assessment and use of optical oxygen sensors as tools to assist in optimal product component selection for the development of packs of ready-to-eat mixed salads and for the non-destructive monitoring of in-pack oxygen levels using chilled storage. *Foods*, 2, 213–224.
- Hempel, A., O'Sullivan, M. G., Papkovsky, D., & Kerry, J. P. (2013d). Use of smart packaging technologies for monitoring and extending the shelf-life quality of modified atmosphere packaged (MAP) bread: Application of intelligent oxygen sensors and active ethanol emitters. *European Food Research and Technology*, 237, 117–124.
- Henneberry, S., O'Sullivan, M. G., Kilcawley, K. N., Kelly, P. M., Wilkinson, M. G., & Guinee, T. P. (2016). Sensory quality of unheated and heated Mozzarella-style cheeses with different fat, salt and calcium levels. *International Journal of Dairy Science*, 69, 38–50.
- Heymann, H. (1994). A comparison of free choice profiling and multidimensional scaling of vanilla samples. *Journal of Sensory Studies*, 9, 445–453.
- Hong, J. H., Yoon, E. K., Chung, S. J., Chung, L., Cha, S. M., & O'Mahony, M. (2011). Sensory characteristics and cross-cultural consumer acceptability of Bulgogi (Korean Traditional Barbecued Beef). *Journal of Food Science*, 76(5), S306–S313.
- Jaeger, S. R., Chheang, S. L., Yin, J., Bava, C. M., Gimenez, A., Vidal, L., et al. (2013). Check-all-that-apply (CATA) responses elicited by consumers: Within-assessor reproducibility and stability of sensory product characterizations. *Food Quality and Preference*, 30, 56–67.
- Jeon, S. Y., Lee, E. K., & Kim, K. O. (2014). The perceived saltiness of soup affected by tasting protocols. *Food Quality and Preference*, 35, 98–103.
- Kennedy, J., & Heymann, H. (2009). Projective mapping and descriptive analysis of milk and dark chocolates. *Journal of Sensory Studies*, 24, 220–233.
- Kilcast, D. (2000). Sensory evaluation methods for shelf-life assessment. In D. Kilcast, & P. Subramaniam (Eds.), *The stability and shelf-life of food* (pp. 79–103). Cambridge: Woodhead Publishing Limited. (Chapter 4).
- King, M. C., Cliff, M. A., & Hall, J. W. (1998). Comparison of projective mapping and sorting data collection and multivariate methodologies for identification of similarity-of-use of snack bars. *Journal of Sensory Studies*, 13, 347–358.
- Köster, E. P. (2003). The psychology of food choice: Some often encountered fallacies. *Food Quality and Preference*, 14, 359–373.
- Krosnick, J. A. (1999). Survey research. *Annual Review of Psychology*, 50, 537–567.
- Lado, J., Vicente, E., Manzoni, A., & Ares, G. (2010). Application of a check-all-that-apply question for the evaluation of strawberry cultivars from a breeding program. *Journal of the Science of Food and Agriculture*, 90, 2268–2275.
- Lancet. (2017). Sweet success: Will sugar taxes improve health? *The Lancet Diabetes & Endocrinology*, 5(4), 235.
- Lassoued, N., Delarue, J., Launay, B., & Michon, C. (2008). Baked product texture: Correlations between instrumental and sensory characterization using flash profile. *Journal of Cereal Science*, 48, 133–143.
- Lawless, H. T. (1999). Descriptive analysis of complex odors: Reality, model or illusion? *Food Quality and Preference*, 10, 325–332.

- Lawless, H. T., & Heymann, H. (1999). *Sensory evaluation of food: principles and practices*. New York: Kluwer Academic/Plenum Publishers.
- Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food – Principles and practices* (2nd ed.). New York Dordrecht Heidelberg, London: Springer.
- Lawless, H. T., Sheng, N., & Knoops, S. S. C. P. (1995). Multidimensional-scaling of sorting data applied to cheese perception. *Food Quality and Preference*, 6, 91–98.
- Lelièvre, M., Chollet, S., Abdi, H., & Valentin, D. (2008). What is the validity of the sorting task for describing beers? A study using trained and untrained assessors. *Food Quality and Preference*, 19, 697–703.
- Lelièvre-Desmas, M., Valentin, D., & Chollet, S. (2015). Pivot profile method: What is the influence of the pivot and product space? *Food Quality and Preference*, 61, 6–14.
- Loescher, E., Sieffermann, J. M., Pinguet, C., Kesteloot, R., & Cuvier, G. (2001). Development of a list of textural attributes on pear/apple puree and fresh cheese: Adaptation of the quantitative descriptive analysis method and use of Flash profiling. In *4th Pangborn*, Dijon, France.
- López Osorino, M. M., & Hough, G. (2010). Comparing 3-point versus 9-point just-about-right-scales for determining the optimum concentration of sweetness in a beverage. *Journal of Science*, 25(Suppl. s1), 1–17.
- Louw, L., Oelofse, S., Naes, T., Lambrechts, M., van Rensburg, P., & Nieuwoudt, H. (2015). Optimisation of the partial napping approach for the successful capturing of mouthfeel differentiation between brandy products. *Food Quality and Preference*, 41, 245–253.
- Liu, J., Schou Grønbecka, M., Di Monaco, R., Giacalone, D., & Bredie, W. L. P. (2016). Performance of Flash Profile and Napping with and without training for describing small sensory differences in a model wine. *Food Quality and Preference*, 48, 41–49.
- McMahon, K. M., Culver, C., Castura, J. C., & Ross, C. F. (2017). Perception of carbonation in sparkling wines using descriptive analysis (DA) and temporal check-all-that-apply (TCATA). *Food Quality and Preference*, 59, 14–26.
- Meillon, S., Urbano, C., & Schlich, P. (2009). Contribution of the temporal dominance of sensations (TDS) method to the sensory description of subtle differences in partially dealcoholized red wines. *Food Quality and Preference*, 20, 490–499.
- Meyners, M. (2016). Temporal liking and CATA analysis of TDS data on flavoured fresh cheese. *Food Quality and Preference*, 47, 101–108.
- Meyners, M., & Pineau, N. (2010). Statistical inference for temporal dominance of sensations data using randomization tests. *Food Quality and Preference*, 21, 805–814.
- Mony, P., Tokar, T., Pang, P., Fiegel, A., Meullenet, J.-F., & Seo, H.-S. (2013). Temperature of served water can modulate sensory perception and acceptance of food. *Food Quality and Preference*, 28, 449–455.
- Moussaoui, K. A., & Varela, P. (2010). Exploring consumer product profiling techniques and their linkage to a quantitative descriptive analysis. *Food Quality and Preference*, 21, 1088–1099.
- Murray, J. M., Delahunty, C. M., & Baxter, I. A. (2001). Descriptive sensory analysis: Past, present and future. *Food Research International*, 34, 461–471.
- Navarro da Silva, R. C. S., Rodrigues Minim, V. O., Simiqueli, A. A., da Silva Moraes, L. E., Aline Iamin Gomide, L. E., & Minim, L. A. (2012). Optimized descriptive profile: A rapid methodology for sensory description. *Food Quality and Preference*, 24, 190–200.
- Nestrud, M. A., & Lawless, H. T. (2010). Perceptual mapping of apples and cheeses using projective mapping and sorting. *Journal of Sensory Studies*, 25, 390–405.
- Nguyen, Q. C., Nes, T., & Varela, P. (2018). When the choice of the temporal method does make a difference: TCATA, TDS and TDS by modality for characterizing semi-solid foods. *Food Quality and Preference*, 66, 95–106.

- O'Callaghan, T., Faulkner, H., McAuliffe, S., O'Sullivan, M. G., Hennessy, D., Dillon, P., Kilcawley, K. N., Stanton, C., & Ross, P. (2016). Quality characteristics, chemical composition, and sensory properties of butter from cows on pasture versus indoor feeding systems. *Journal of Dairy Science*, 99, 9441–9460.
- O'Sullivan, M. G. (2011). CH 4, Sensory shelf-life evaluation. In J. R. Piggott (Ed.), *Alcoholic beverages: Sensory evaluation and consumer research*. Cambridge: Woodhead Publishing Limited.
- O'Sullivan, M. G. (2017). CH4. *Rapid sensory profiling methods. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 59–82). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G., Cruz, M., & Kerry, J. P. (2011). Evaluation of carbon dioxide flavour taint in modified atmosphere packed beef steaks. *LWT-Food Science and Technology*, 44, 2193–2198.
- O'Sullivan, M. G., Cruz-Romero, M., & Kerry, J. P. (2010). Carbon dioxide flavour taint in modified atmosphere packed lean beef. In *Fourth European conference on sensory and consumer research: A sense of quality*, 5–8 Sept, Palacio Europa, Vitoria-Gasteiz, Spain.
- O'Sullivan, M. G., Kerry, J. P., & Byrne, D. V. (2011). Use of sensory science as a practical commercial tool in the development of consumer-led processed meat products. In J. P. Kerry, & J. F. Kerry (Eds.), *Processed meats*. United Kingdom: Woodhead Publishing Ltd.
- Pagès, J. (2003). Direct collection of sensory distances: Application to the evaluation of ten white wines of the Loire Valley. *Sciences des Aliments*, 23, 679–688.
- Pagès, J. (2005). Collection and analysis of perceived product inter-distances using multiple factor analysis: Application to the study of 10 white wines from the Loire Valley. *Food Quality and Preference*, 16, 642–649.
- Pagès, J., Cadoret, M., & Lê, S. (2010). The sorted napping: A new holistic approach in sensory evaluation. *Journal of Sensory Studies*, 25, 637–658.
- Pecore, S., Kamerud, J., & Holschuh, N. (2015). Ranked-scaling: A new descriptive panel approach for rating small differences when using anchored intensity scales. *Food Quality and Preference*, 40(2015), 376–380.
- Perrin, L., Symoneaux, R., Maître, I., Asselin, C., Jourjon, F., & Pagès, J. (2008). Comparison of three sensory methods for use with the Napping procedure: Case of ten wines from Loire Valley. *Food Quality and Preference*, 19, 1–11.
- Perrin, L., & Pagès, J. (2009). Construction of a product space from the ultra-flash profiling method: application to 10 red wines from the Loire Valley. *Journal of sensory Studies*, 24, 372–395.
- Pfeiffer, J. C., & Gilbert, C. C. (2008). Napping by modality: A happy medium between analytical and holistic approaches. In *Proceedings of sensometrics conference 2008*, Canada.
- Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., et al. (2009). Temporal dominance of sensations: Construction of the TDS curves and comparison with time–intensity. *Food Quality and Preference*, 20, 450–455.
- Popper, P., & Heymann, H. (1996). Analyzing differences among products and panelists by multidimensional scaling. In T. Naes, & E. Risvik (Eds.), *Multivariate analysis of data in sensory science* (pp. 159–184). Amsterdam: Elsevier.
- Popper, R., Rosenstock, W., Schraidt, M., & Kroll, B. J. (2004). The effect of attribute questions on overall liking ratings. *Food Quality and Prefer*, 15, 853–858.
- Pramudya, R. C., & Seo, H. S. (2018). Using check-all-that-apply (CATA) method for determining product temperature-dependent sensory-attribute variations: A case study of cooked rice. *Food Research International*, 105, 724–732.
- Prescott, J., Lee, S. M., & Kim, K. (2011). Analytic approaches to evaluation modify hedonic responses. *Food Quality and Preference*, 22, 391–393.

- Price, E. J., Linforth, R. S., Dodd, C. E., Phillips, C. A., Hewson, L., Hort, J., et al. (2014). Study of the influence of yeast inoculum concentration (*Yarrowia lipolytica* and *Kluyveromyces lactis*) on blue cheese aroma development using microbiological models. *Food Chemistry*, 145, 464–472.
- Rasinski, K. A., Mingay, D., & Bradburn, N. M. (1994). Do respondents really mark all that apply on self-administered questions? *Public Opinion Quarterly*, 58, 400–408.
- Rason, J., Lebecque, A., Ieger, L., & Dufour, E. (2003). Delineation of the sensory characteristics of traditional dry sausage. I – Typology of the traditional workshops in Massif Central. In *The 5th Pangborn sensory science symposium*, July 21–24, Boston, MA.
- Reinbach, H. C., Giacalone, D., Machado Ribeiro, L., Bredie, W. L. P., & Michael Bom Frøst. (2014). Comparison of three sensory profiling methods based on consumer perception: CATA, CATA with intensity and Napping®. *Food Quality and Preference*, 32, 160–166.
- Richter, V., Almeida, T., Prudencio, S., & Benassi, M. (2010). Proposing a ranking descriptive sensory method. *Food Quality and Preference*, 21(6), 611–620. Available from <https://doi.org/10.1016/j.foodqual.2010.03.011>.
- Risvik, E., McEwan, J. A., Colwill, J. S., Rogers, R., & Lyon, D. H. (1994). Projective mapping: A tool for sensory analysis and consumer research. *Food Quality and Preference*, 5, 263–269.
- Risvik, E., McEwan, J. A., & Rodbotten, M. (1997). Evaluation of sensory profiling and projective mapping data. *Food Quality and Preference*, 8, 63–71.
- Rodrigue, N., Guillet, M., Fortin, J., & Martin, J. F. (2000). Comparing information obtained from ranking and descriptive tests of four sweet corn products. *Food Quality and Preference*, 11, 47–54.
- Rosenberg, S., Nelson, C., & Vivekana, P. S. (1968). A multidimensional approach to structure of personality impressions. *Journal of Personality and Social Psychology*, 9, 283.
- Rothman, L., & Parker, M. J. (2009). *Just-about-right (JAR) scales: Design, usage, benefits and risks*. West Conshohocken, PA: ASTM International.
- Ruark, A., Vingerhods, M. H., Kremer, S., Nijenhuis-de Vries, M. A., & Piqueras-Fizman, B. (2016). Insights on older adults' perception of at-home sensory-hedonic methods: A case of Ideal Profile Method and CATA with ideal. *Food Quality and Preference*, 53, 29–38.
- Saint Eve, A., Paci-Kora, E., & Martin, N. (2004). Impact of the olfactory quality and chemical complexity of the flavouring agent on the texture of low fat stirred yogurts assessed by three different sensory methodologies. *Food Quality and Preference*, 15, 655–668.
- de Saldamando, L., Delgado, J., Herencia, P., Giménez, A., & Ares, G. (2013). Polarized sensory positioning: Do conclusions depend on the poles? *Food Quality and Preference*, 29, 25–32.
- Santosa, M., Abdi, H., & Guinard, J. X. (2010). A modified sorting task to investigate consumer perceptions of extra virgin olive oils. *Food Quality and Preference*, 21, 881–892.
- Schiffstein, H. N. J. (1996). Cognitive factors affecting taste intensity judgments. *Food Quality and Preference*, 7(3–4), 167–175, Second Rose-Marie Pangborn Memorial Symposium.
- Sieffermann, J. M. (2000). *Le profil flash: un outil rapide et innovant d'évaluation sensoriel descriptive, Agoral 2000, 12ème rencontres, L'innovation: de l'idée au succès* (pp. 335–340).
- Silva, R. C. S. N., Minim, V. P. R., Carneiro, J. D. S., Nascimento, M., Della Lucia, S. M., & Minim, L. A. (2013). Quantitative sensory description using the optimized descriptive profile: Comparison with conventional and alternative methods for evaluation of chocolate. *Food Quality and Preference*, 30, 169–179.

- Silva, R. C. S. N., Minim, V. P. R., Silva, A. N., Peternelli, L. A., & Minim, L. A. (2014). Optimized descriptive profile: How many judges are necessary? *Food Quality and Preference*, 36, 3–11.
- Silva, R. C. S. N., Minim, V. P. R., Simiqueli, A. A., Moraes, L. E. S., Gomide, A. I., & Minim, L. A. (2012). Optimized descriptive profile: A rapid methodology for sensory description. *Food Quality and Preference*, 24, 190–200.
- Sokolowsky, M., & Fischer, U. (2012). Evaluation of bitterness in white wine applying descriptive analysis, time-intensity analysis, and temporal dominance of sensations analysis. *Analytica Chimica Acta*, 732, 46–52.
- Sudman, S., & Bradburn, M. B. (1982). *Asking questions*. San Francisco, CA: Jossey-Bass.
- Steinberg, D. D. (1967). The Word Sort: An instrument for semantic analysis. *Psychonomic Science*, 8, 541–542.
- Stokes, C., O'Sullivan, M. G., & Kerry, J. P. (2017). Ranking acceptance analysis and the investigation of simultaneous or monadic sample presentation with affective and descriptive sensory evaluation methods. *Journal of Sensory Studies*. (Submitted).
- Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Affective testing. In H. Stone, R. N. Bleibaum, & H. Thomas (Eds.), *Sensory evaluation practices* (4th ed., pp. 291–325). Elsevier Academic Press.
- Stone, H., & Sidel, J. (1993). *Sensory evaluation practices*. California: Academic Press.
- Stone, H., & Sidel, J. L. (2004). Affective testing. In H. Stone, & J. L. Sidel (Eds.), *Sensory evaluation practices. Food science and technology, international series* (3rd ed., pp. 247–277). Academic Press/Elsevier.
- Tang, C., & Heymann, H. (1999). Multidimensional sorting, similarity scaling and free-choice profiling of grape jellies. *Journal of Sensory Studies*, 17, 493–509.
- Tarea, S., Cuvelier, G., & Sieffermann, J.-M. (2007). Sensory evaluation of the texture of 49 commercial apple and pear purees. *Journal of Food Quality*, 30, 1121–1131.
- Teillet, E., Schlich, P., Urbano, C., Cordelle, S., & Guichard, E. (2010). Sensory methodologies and the taste of water. *Food Quality and Preference*, 21, 967–976.
- Thomas, A., Chambault, M., Dreyfuss, L., Gilbert, C. C., Hegyi, A., Henneberg, S., ... Schlich, P. (2017). Measuring temporal liking simultaneously to temporal dominance of sensations in several intakes. An application to Gouda cheeses in 6 Europeans countries. *Food Research International*, 99(Part 1), 426–434.
- Thomas, A., Visalli, M., Cordelle, S., & Schlich, P. (2015). Temporal drivers of liking. *Food Quality and Preference*, 40, 365–375.
- Thuillier, B., Valentin, D., Marchal, R., & Dacremont, C. (2015). Pivot profile: A new descriptive method based on free description. *Food Quality and Preference*, 42, 66–77.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012a). Effect of varying salt and fat levels on the sensory quality of beef patties. *Meat Science*, 4, 460–465.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012b). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, 92, 659–666.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013a). The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Science*, 93, 145–152.
- Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2013b). European consumer attitudes on the associated health benefits of nutraceutical-containing processed meats using co-enzyme Q10 as a sample functional ingredient. *Meat Science*, 97, 207–213.
- Valentin, D., Chollet, S., Lelièvre, M., & Abdi, H. (2012). Quick and dirty but still pretty good: A review of new descriptive methods in food science. *International Journal of Food Science and Technology*, 47, 1563–1578.

- van Trijp, H. C. M., Punter, P. H., Mickartz, F., & Kruithof, L. (2007). The quest for the ideal product: Comparing different methods and approaches. *Food Quality and Preference*, 18(5), 729–740.
- Vandeputte, A., Romans, J., Pineau, N., & Lenfant, F. (2011). Innovative methods to assess the evolution of the sensory characteristics during the tasting of a full product portion (several bites). In *9th Pangborn sensory science symposium*, 4–8th September 2011, Toronto, Canada.
- Varela, P., & Ares, G. (2012). Sensory profiling, the blurred line between sensory and consumer science. A review of novel methods for product characterization. *Food Research International*, 48, 893–908.
- Veinand, B., Godefroy, C., Adam, C., & Delarue, J. (2011). Highlight of important product characteristics for consumers. Comparison of three sensory descriptive methods performed by consumers. *Food Quality and Preference*, 22, 474–485.
- Villanueva, T. (2011). European nations launch tax attack on unhealthy foods. *CMAJ, Canadian Medical Association Journal*, 183(17), E1229–E1230. Available from <https://doi.org/10.1503/cmaj.109-4031>, November 22, 2011.
- Visalli, M., Montereymard, C., Duployer, G., & Schlich, P. (2011). TimeSens, a Web-based sensory software for Temporal Dominance of Sensations. In *Pangborn symposium*, 4–8 September 2011, Toronto, Canada.
- Williams, A. A., & Langron, S. P. (1984). The use of free-choice profiling for the evaluation of commercial ports. *Journal of the Science of Food and Agriculture*, 35, 558–568.
- Wilson, C., Brand, J., du Toit, W., & Buica, A. (2018). Polarized projective mapping as a rapid sensory analysis method applied to South African Chenin Blanc wines. *LWT-Food Science and Technology*, 92, 140–146.
- Worch, T., Crine, A., Gruel, A., & Lê, S. (2014). Analysis and validation of the ideal profile method: Application to a skin cream study. *Food Quality and Preference*, 32, 132–144.
- Worch, T., & Ennis, J. M. (2013). Investigating the single ideal assumption using ideal profile method. *Food Quality and Preference*, 29, 40–47.
- Worch, T., Lê, S., & Punter, P. (2010). How reliable are the consumers? Comparison of sensory profiles from consumers and experts. *Food Quality and Preference*, 21, 309–318.
- Worch, T., Lê, S., Punter, P., & Pagès, J. (2012). Assessment of the consistency of ideal profiles according to non-ideal data for IPM. *Food Quality and Preference*, 24, 99–110.
- Yarlagadda, A., Wilkinson, M. G., O'Sullivan, M. G., & Kilcawley, K. N. (2014). Utilisation of microfluidisation to enhance enzymatic and metabolic potential of lactococcal strains as adjuncts in Gouda type cheese. *International Dairy Journal*, 38, 124–132.
- Yarlagadda, A., Wilkinson, M. G., Ryan, S., Doolan, A. I., O'Sullivan, M. G., & Kilcawley, K. N. (2014). Utilisation of a cell free extract of lactic acid bacteria entrapped in yeast to enhance flavour development in Cheddar cheese. *International Journal of Dairy Science Technology*, 67, 21–30.
- Zorn, S., Alcaire, F., Vidal, L., Giménez, A., & Ares, G. (2014). Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners. *Food Quality and Preference*, 36, 135–143.

Further reading

- Bayarri, S., Taylor, A. J., & Hort, J. (2006). The role of fat in flavor perception: Effect of partition and viscosity in model emulsions. *Journal of Agriculture and Food Chemistry*, 54, 8862–8868.

- Stone, H., Bleibaum, R., & Thomas, H. (2012b). Test strategy and design of experiments. In H. Stone, R. N. Bleibaum, & H. A. Thomas (Eds.), *Sensory evaluation practices* (4th ed., pp. 117–157). USA: Elsevier Academic Press.
- Worch, T., Lê, S., Punter, P., & Pagès, J. (2013). Ideal profile method (IPM): The ins and outs. *Food Quality and Preference*, 28, 45–59.



Discrimination testing for reformulated products

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Introduction

Virtually, every food or beverage manufacturing company will be involved in reformulation strategies as part of their day-to-day business. Sensory difference tests are useful to determine the degree of sensory difference between the samples generated from reformulation strategies. These measurements are important for various business decisions such as quality control, determining the effects of changing ingredients, equipment, processing changes, or changes in packaging (Kim & Lee, 2012). In addition, difference tests could also be used to monitor the reformulated product sensory shelf life when compared to standard products to determine end points. With reformulation projects, often a difference between products is also not the desired outcome. Developers may not wish the consumer to detect a discernible difference. Discrimination testing can be used to determine if the final product has been noticeably effected. The type of discrimination test used may depend on the complexity of the product, test sensitivity, and panelists to be used (Burns, Penfield, Saxton, & Luckett, 2018).

Difference methods are the most basic form of sensory test and are relatively simple procedures whereby samples are compared directly to other samples and assessors are asked to determine if they are the same or different (O'Sullivan, 2017). In sensory evaluation, difference tests are generally used for determining the degree of difference between food samples that are similar enough to be regarded as confusable. Reformulated products certainly fit this category. Thus these approaches can be applied to studies of the effects of ingredient change, quality assurance, ingredient specification, product development, storage studies, and changes in processing or packaging (Xia et al., 2015). Assessors may also be asked to assign a score or grade to the sample or also even comment on why they think they are different. Generally, difference testing involves determining the difference between two (paired comparison), three (triangle), or four (tetrad) products (O'Sullivan, 2017). The most common difference tests are the duo-trio test, the triangle test, the simple same-difference test, and the "A"—"not A" test (Lawless & Heymann, 1998a, 1998b; Piggott, Simpson, & Williams, 1998).

In addition, difference tests can be categorized into overall difference tests and attribute-specific directional difference tests, depending on the evaluation criteria. Difference tests determine if there is a detectable sensory difference between samples, perhaps without defining specifics, whereas attribute difference tests determine if there is a specific perceived attribute difference between samples. An example of these would include if assessors were asked to determine if two lemonades were the same or different. No criteria is offered, thus this is the classical difference method. However, if we ask if one product is sweeter than the other, then the test becomes an attribute-specific directional difference test. These tests are also known as alternate forced choice (AFC) tests and are more sensitive in the detection of sensory differences between samples. For the triangle test, three samples are given to the assessor, which then becomes a 3-AFC test if for example, if the assessor is asked to pick out the saltiest sample of the three presented. Similarly, a paired comparison test becomes a 2-AFC test when assessors are given a criterion to differentiate between samples, for example, sweetness or bitterness. The panelist has to choose a sample in an AFC test even if they cannot differentiate between the samples. The tetrad test is more powerful than the triangle test, but the AFC tests are more powerful than either of these methods (Xia et al., 2015). Attribute difference tests also include the simple ranking test. However, AFC tests are not practical for some complex products such as meat and some cheese studies because they require that only one sensory attribute varies independently of the other

sensory properties. This is more difficult in these complex foods as typically there is an interaction between the sensory variables such as appearance, aroma, flavor, texture, taste, and aftertaste (Byrne & Bredie, 2002).

Difference tests are also used in storage and product-development studies involving product imitation (benchmarking). The test performances of different difference test protocols need to be understood for such measurements in which it is to be used accurately and efficiently (Kim & Lee, 2012). Depending on the goals of the study, difference tests can be used as an analytical tool with highly trained panelists or they can be used to measure consumer discrimination (Xia et al., 2015).



The A–Not A method

The A–Not A method, also called the single stimulus method, was first introduced to food science by Pfaffmann, Schlosberg, and Cornsweet (1954). This method is the simplest of difference methods where the panelists are presented with a series of coded samples, a minimum of two, which consist of sample “A,” the test sample, while other samples are then presented differently from sample “A.” The assessors are then asked whether or not the sample they are evaluating is identical to “A” or not. The assessors evaluate sample A and become familiar with it prior to the commencement of the test (Lawless & Heymann, 1998a, 1998b; O’Sullivan, 2017; Piggott et al., 1998). For familiarization a standard product (A) is presented to the assessors several times at the start of an experimental session, and then, a series of two products, “A” and a slightly different product to be discriminated from “A” (Not A), is presented in randomized order. The assessor has to respond by stating which products are “A” and which are “Not A.” As a reminder the reference A is presented and identified to the assessor as a reminder (Lee, van Hout, & O’Mahony, 2007).



The paired comparison test and the 2 alternative forced choice test

The method of paired comparisons consists of presenting pairs of stimuli to subjects who have to choose which one is greater with respect

to one attribute. Generally used in order to study consumers' preferences, this technique is known to be natural and easy for the subject, and it appears to be sensitive to differences between stimuli (Séménou, Courcoux, Kuusinen, & Lokki, 2017). The paired comparison is generally used to differentiate between two samples based on assessor preference. However, the test can also be undertaken where assessors are presented with two-coded products and are asked to differentiate them based on attribute differences such as saltiness, bitterness, sweetness, etc. In this instance the paired comparison test becomes a 2-AFC test (O'Sullivan, 2017). This an easy and quick test used when the attribute that will change is identified, and it is thus often used to determine whether reformulation changes to a product are detectable. Again, it is more suitable where sensory differences are not so complex. This test is also not statically powerful as there is a 50% chance of being right by simply guessing the answer. The coded samples should be presented twice in reverse order to assessors and should be randomized for presentation to larger assessor groups ($n > 30$) in order to obtain more reliable data (Ennis & Jesionka, 2011). For consumer tests, multivariate paired comparison between products may be conducted on descriptive attributes and not only on preference items (Wichchukit & O'Mahony, 2010). Wichchukit and O'Mahony (2010) used this method to compare the results of paired comparisons between potato chips for the different attributes liking, buying, and takeaway preferences. They state that this may be an interesting alternative to the conventional profile for the sensory description of products because the comparison between the two stimuli does not require any rating scale. Thus untrained subjects or young children can easily perform the task and give a comparison of the intensity of descriptive attributes on a set of products (Séménou et al., 2017). The paired comparison test is often used to detect differences in samples for quality-control purposes, batch-to-batch variation, reformulation ingredient substitution trials, process changes, etc. It is also used in the screening of panelists for descriptive panels (O'Sullivan, 2017).



The duo-trio test

The duo-trio test is frequently used in the sensory evaluation to measure sensitivity to differences in the overall sensory properties of food

(Kim, Lee, & Lee, 2010). The duo-trio (ISO, 2004) test is a quick difference method where assessors are given three coded products with one of the samples identified to assessors as the control. Assessors are thus asked which of the products is the closest to the control. Assessors are not asked about any specific attribute differences (O'Sullivan, 2017). The duo-trio test is not a very statistically powerful test as the probability of an assessor guessing the correct answer is 50%. For this reason, large assessor groups ($n > 32$) (Ennis & Jesionka, 2011) need to be used to increase confidence in the data. When undertaking the test, the sample order should be randomized (O'Sullivan, 2017). The duo-trio test is easier to perform than the triangle test but has lower statistical power (Meilgaard, Civille, & Carr, 2006), but when samples are complex and hard to evaluate, the duo-trio may be more useful. Also, like the triangle test which will be discussed in the next section, the duo-trio is a commonly used nonattribute specified difference test, which is sometimes called the nondirectional difference test or overall difference test (Kim & Lee, 2012). The duo-trio test, unlike the triangle test, has a number of different presentation formats depending on which stimulus is used as the reference (see Fig. 9.1). Two different formats of duo-trio tests have been used in food science depending on the situation or objectives of the sensory evaluation at hand: constant-reference mode and balanced-reference mode (Lawless & Heymann, 1998a; Meilgaard, Civille, & Carr, 1991). In the constant-reference format the reference stimulus is kept constant throughout the tests, whereas in the balanced-reference format, both stimuli being compared are used at random as the reference stimulus (Kim & Lee, 2012; Lawless & Heymann, 2010; Meilgaard et al., 2006). These different reference schemes for each test presentation order can potentially produce differences in cognitive-information processing which in turn can lead to different physiological and cognitive-perceptual bias such as carry-over effects and fatigue effects. These factors can affect the operational power of the sensory difference test (Bi & O'Mahony, 2013; Kim & Lee, 2012; Lee, Chae, & Lee, 2009). Kim and Lee (2012) investigated reference presentation order and effects on operational power. "DTF" (the traditional version, duo-trio with the reference presented first), "DTM" (duo-trio with the reference presented in the middle of the alternative stimuli), "DTFR" (duo-trio with the reference presented twice, first, and last as a reminder), and "DTFM" (duo-trio with the reference presented twice, first and middle) (Kim & Lee, 2012). These authors found that in general, the DTF or DTFM formats using the stronger (saltier) product stimulus as a constant-reference is recommended as an operationally more powerful

TRIANGULAR TEST WITH SCORING

Name: _____ Samples: _____ Date: _____

Instruction:

- 1. Taste these samples and determine if there is any notable difference between them.
- 2. Score and comment on findings/observations.
- 3. If **‘no difference’** is detected, please tick the appropriate box, and record a score and comment for all three.

	<i>Symbol</i>	<i>Score</i>	<i>Comment</i>
Odd sample	☐	☐	_____
Paired sample	☐ ☐	☐	_____
No difference	☐	☐	_____

SCORING SCALE

10 = Perfect. 9 = Very good. 8 = Good. 7 = Borderline, 6 = Reject

Duo Trio TEST WITH SCORING

Name: _____ Samples: _____ Date: _____

Instruction:

- 1. Taste these samples and determine if there is any notable difference between them.
- 2. Score and comment on findings/observations.
- 3. If **‘no difference’** is detected, please tick the appropriate box, and record a score and comment for all three.

	<i>Symbol</i>	<i>Score</i>	<i>Comment</i>
Control sample	☐	☐	_____
Odd sample	☐	☐	_____
No difference	☐	☐	_____

SCORING SCALE

10 = Perfect. 9 = Very good. 8 = Good. 7 = Borderline, 6 = Reject

Figure 9.1 Examples of triangle and duo-trio test scoring sheets. *From O’Sullivan, M. G. (2017). CH1. Difference methods. In: A handbook for sensory and consumer driven new product development: innovative technologies for the food and beverage industry (pp. 3–12). United Kingdom: Woodhead Publishing Ltd.*

protocol to discriminate products having high sodium contents (Kim & Lee, 2012).

The duo-trio test also is used to detect differences in samples for quality-control purposes and used in the screening of panelists for descriptive panels (O'Sullivan, 2017).



The triangle test and the 3 alternative forced choice test

Joseph E. Seagram and Sons were the first to employ the triangle test (ASTM, 2004; ISO, 2004) in 1941 and since then it has been used in a variety of applications including product discrimination testing and panelist selection (Ennis & Rousseau, 2012). In the triangle test, subjects are presented with three stimuli, two of which are alike, and then asked to choose the “odd” item, which may be any one of the three (Kim et al., 2010) (see Fig. 9.1). Sample presentation order to assessors should be blind and equally randomized (across the three samples), and in order to acquire reliable data, a relatively large assessor group should be employed ($n > 30$) (Ennis & Jesionka, 2011). An advantage of the triangle test is that it does not require specification of the nature of the difference. Yet, the triangle test does require large sample sizes to be effective (Ennis, 1993). Assessors are instructed that two samples are the same but are not told which two. They must determine which sample is the different one but are not asked any attribute specific differences. The triangle test is again a quick method and a little more statistically powerful than the duo-trio and paired comparison test as there now is only a 33% chance of an assessor guessing the correct answer. There has been much positive feedback from a relatively recent test “the tetrad” (discussed in the section Tetrad test). This method has been described as a more sensitive testing method than the triangle test with the principal advantage being that it could save companies money by reducing the number of panelists and number of samples required because of its increased test power (Ennis, 1993, 2012). However, the triangle test still very much has a place in difference testing and can have advantages over the tetrad method especially for products that have a more complex sensory profile. Ishii, O'Mahony, and Rousseau (2014) state that while exploring differences in fruit juices, they found the tetrad to be a more powerful test than the triangle test,

but more “fatiguing” products may prove more challenging. The inclusion of a fourth sample in the tetrad could lead to panelist fatigue and a reduction in sensitivity to the stimulus. Also, products with strong flavors containing intense seasonings, spice heat, or lingering flavors may overpower panelist memory and have too much carryover between samples to make the tetrad method effective (Bi & O’Mahony, 2013; Ennis, 2012).

The triangle test becomes a 3-AFC test when assessors are presented with three coded products and are asked to differentiate them based on intensity or specific attribute differences (e.g., saltiness, bitterness, and sweetness). With the 3-AFC test, assessors choose the correct samples more often when compared to the triangle method even though the probability of guessing the right answer is the same, with a one in three for both tests. Thurstonian modeling of both methods shows that the 3-AFC test is more powerful than the triangle or duo-trio test (O’Mahony & Rousseau, 2003). As this method is more powerful also fewer people are required, compared to a triangle test, to have the same degree of confidence in the data. This is a major saving in time, effort and money, but, for the 3-AFC test to be truly effective, we need to know the sensory difference that is important before we undertake this test. This is often not the case as it can be hard to predict the effects of a change in formulation or process change and the subsequent consumer response (Ennis & Jesionka, 2011; Xia et al., 2015). If the nature of the difference is not specified by the experimenter, the more powerful forced-choice methods such as the 2-AFC and 3-AFC are not appropriate. This leaves the triangle and duo-trio methods as the commonly chosen forced-choice alternatives that do not involve the experimenter’s specification. These are considerably less powerful for a given sensory difference and require much larger sample sizes to attain significance (Ennis, 1993; Ennis & Jesionka, 2011) with a resulting increase in cost (Xia et al., 2015).



The ranking test

In the ranking test, assessors are asked to order a selection of coded samples (4–6) in increasing or decreasing intensity of a specific perceived sensory attribute. Samples are randomized across the assessors (O’Sullivan, 2017). For simple tests where fatigue is less likely more samples may be

used. It is often used in panel training or for screening samples prior to using other tests. Using a simple ranking method, assessors rank the products in terms of their similarity to “A” which is designated as the “noise,” the degree of difference between “A” and the various test products (signals) could be computed using an *R*-index analysis (Brown, 1974; O’Mahony, 1992).



The tetrad test

With the tetrad method, four samples are presented simultaneously with two from one group and two from another. Instead of choosing one sample, panelists are asked to sort or group the samples into two based on similarity (Ennis, 2012). These instructions are very different from asking the subjects to identify the two most similar samples (Ennis & Rousseau, 2012). The probability of guessing the right answer is similar to the triangle test (33%). The tetrad test has been reported to have greater power even without specification of an attribute which means that for the same sample size, an existing difference is less likely to be missed (Ennis & Jesionka, 2011; Ennis & Rousseau, 2012). The tetrad method can thus reduce the likelihood of “Alpha” and “Beta” Risk sensory testing errors. Alpha risk is the risk of making a wrong decision, also called Type I error, and occurs when differences are found between samples when none are present. The opposite can also occur and is called Beta risk, or Type II error. Here, no differences are found between samples where differences really exist. Alpha and Beta risk can be reduced by increasing the number of observations or the amount of data needed to make a decision (Bi & O’Mahony, 2013).

The tetrad method has been lauded as being a more sensitive testing method than the traditional triangle and thus could save companies money by reducing the number of panelists and number of samples required because of its increased test power (ASTM, 2015; Ennis, 2012). Ennis and Jesionka (2011) reported that 87 assessors would be required to achieve a significant ($P < .05$, 90% power, $d' = 1.5$) difference between samples for a duo-trio test, 78 for a triangle but only 25 for a tetrad panel. Thus smaller panel sizes can be used to achieve the same performance as the triangle test with potentially only one-third of that required by the triangle test (Ennis & Jesionka, 2011; Ennis & Rousseau, 2012). This could be of great commercial

benefit in the saving of time, money, and resources. Also, this reduction in required resources may allow companies to test products in-house and receive results immediately, saving both time and money involved in outsourcing tests (Bi & O'Mahony, 2013). However, the sensory scientist must determine through comparison which of the triangle or the tetrad method best suits their products and processes (O'Sullivan, 2017).



Rating, weighting, and in/out tests

Other difference tests that can be used, particularly in the realm of quality assurance, are briefly described below and include the methods “ratings for degree of difference from a standard,” “weighting of differences from control,” and the “in/out” method (Lawless & Heymann, 1998a, 1998b; Muñoz, Civile, & Carr, 1992a, 1992b).

For “ratings for degree of difference from a standard” method the relative sensory deviation from a standard product is used in order to detect differences in production batches. It could also be used in comparison of reformulated products compared to a standard. This method is limited; in that, it does not provide any information regarding the source of differences compared to a control (Muñoz, Civile, & Carr, 1992c). The degree of difference from a control or standard test is also quite often used in house for routine sensory testing, again using trained panelists (often external), particularly for monitoring of off-flavor defects and is widely used in the soft drink industry, particularly by the largest cola producers. Sources of defects could be flavor-fading issues but more often involve off-flavor development from cross-contamination issues due to inadequately cleaning-in-place processes where residues in plant (pipework, containment vessels, balance tanks, etc.) from a previous production run contaminate the following run of a different product (O'Sullivan, 2017). The method could have reformulation applications.

The “weighting of differences from control (individual experts)” method is similar to the degree of difference from a standard method but involves an even more complex judgment procedure on the part of panelists. This is because it is not only the differences that matter but also how they are weighted in determining product quality (Lawless & Heymann, 1998a; Muñoz et al., 1992b). This method is routinely used by the large

restaurant chains to determine the quality of the ingredients, particularly beef burgers used in its restaurants. Third-party manufactures of products for the parent company must also utilize this test to ensure quality. The organization's standardized cooking equipment is typically outfitted in the manufacturing premises so that restaurant cooking conditions can be perfectly simulated. Company personnel are expertly trained to use the test by the restaurant chain's liaison team. In this fashion consistency across manufacturing facilities globally can be carefully aligned and coordinated, thus ensuring product consistency and quality within a very tight specification. Presumably, reformulated products could also be tested in this fashion to align with current standard operating procedures.

For the "in/out" *method*, production batches can be evaluated by a trained panel as being either within or outside sensory specifications. The method can be limited though as it does not provide any descriptive information that can be used to amend problems (Muñoz et al., 1992b).

References

- ASTM, *Standard Test Method E1885-04 in Standard Test Method for Sensory Analysis—Triangle Test*, 2004, ASTM International, West Conshohocken, PA.
- ASTM E3009-15, *Standard Test Method for Sensory Analysis—Tetrad Test*, 2015, ASTM International, West Conshohocken, PA. www.astm.org.
- Bi, J., & O'Mahony, M. (2013). Variance of d' for the tetrad test and comparisons with other forced-choice methods. *Journal of Sensory Studies*, 28(2), 91–101.
- Brown, J. (1974). Recognition assessed by rating and ranking. *British Journal of Psychology*, 65, 13–22.
- Burns, S. L., Penfield, M. P., Saxton, A. M., & Luckett, C. R. (2018). Comparison of triangle and tetrad discrimination methodology in an applied manner. *Food Quality and Preference*, 68, 105–112.
- Byrne, D. V., & Bredie, W. L. P. (2002). Sensory meat quality and warmed-over flavour: A Review. In F. Toldrá (Ed.), *Research advances in the quality of meat and meat products. Volume within Agriculture & food chemistry* (pp. 95–212). Research Signpost.
- Ennis, D. M. (1993). The power of sensory discrimination methods. *Journal of Sensory Studies*, 8(4), 353–370.
- Ennis, J. M. (2012). Guiding the switch from triangle testing to tetrad testing. *Journal of Sensory Studies*, 27, 223–231.
- Ennis, J. M., & Jesionka, V. (2011). The power of sensory discrimination methods revisited. *Journal of Sensory Studies*, 26(5), 371–382. Available from <https://doi.org/10.1111/j.1745-459X.2011.00353.x>.
- Ennis, J. M., & Rousseau, B. (2012). Reducing costs with tetrad. *Testing*, 15, 3–4.
- Ishii, R., O'Mahony, M., & Rousseau, B. (2014). Triangle and tetrad protocols: Small sensory differences, resampling, and consumer relevance. *Food Quality and Preference*, 31, 49–55.
- ISO. (2004). *Sensory analysis—methodology—Duo trio test*. International Organization for Standardization, International standard 10399.
- Kim, M. A., & Lee, H. S. (2012). Investigation of operationally more powerful duo-trio test protocols: Effects of different reference schemes. *Food Quality and Preference*, 25, 183–191.

- Kim, M. A., Lee, Y. M., & Lee, H. S. (2010). Comparison of d0 estimates produced by three versions of a duo-trio test for discriminating tomato juices with varying salt concentrations: The effects of the number and position of the reference stimulus. *Food Quality and Preference*, 21, 504–511.
- Lawless, H. T., & Heymann, H. (1998a). Sensory evaluation in quality control. In H. T. Lawless, & H. Heymann (Eds.), *Sensory evaluation of food, principles and practices* (pp. 548–584). New York: Chapman and Hall.
- Lawless, H. T., & Heymann, H. (1998b). Descriptive analysis. In H. T. Lawless, & H. Heymann (Eds.), *Sensory evaluation of food, principles and practices* (pp. 117–138). New York: Chapman and Hall, pp. 341–378.
- Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (2nd ed.). New York: Springer.
- Lee, H. S., van Hout, D., & O'Mahony, M. (2007). Sensory difference tests for margarine: A comparison of *R*-indices derived from ranking and A-Not A methods considering response bias and cognitive strategies. *Food Quality and Preference*, 18, 675–680.
- Lee, Y.-M., Chae, J.-E., & Lee, H.-S. (2009). Effects of order of tasting in sensory difference tests using apple juice stimuli: Development of a new model. *Journal of Food Science*, 74, S268–S275.
- Meilgaard, M., Civille, G. V., & Carr, B. T. (1991). *Sensory evaluation techniques* (2nd ed.). Boca Raton, FL: CRC Press.
- Meilgaard, M., Civille, G. V., & Carr, B. T. (2006). *Sensory evaluation techniques* (4th ed.). Boca Raton, FL: CRC Press.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992a). *Comprehensive descriptive method. Sensory evaluation in quality control* (pp. 55–82). New York: Van Nostrand Reinhold.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992b). *"In/our" method. Sensory evaluation in quality control* (pp. 140–167). New York: Van Nostrand Reinhold.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992c). *Difference-from-control method (degree of difference). Sensory evaluation in quality control* (pp. 168–205). New York: Van Nostrand Reinhold.
- O'Mahony, M. (1992). Understanding discrimination tests: A user-friendly treatment of response bias, rating and ranking *R*-index tests and their relationship to signal detection. *Journal of Sensory Studies*, 7, 1–47.
- O'Mahony, M., & Rousseau, B. (2003). Discrimination testing: A few ideas old and new. *Food Quality & Preference*, 14, 157–164.
- O'Sullivan, M. G. (2017). CH1. *Difference methods. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 3–12). London, United Kingdom: Woodhead Publishing Ltd.
- Pfaffmann, C., Schlosberg, H., & Cornsweet, J. (1954). Variables affecting difference tests. In D. R. Peryam, F. J. Pilgrim, & M. S. Peterson (Eds.), *Food acceptance testing methodology* (pp. 4–20). Chicago, IL: Quartermaster Food and Container Institute.
- Piggott, J. R., Simpson, S. J., & Williams, S. A. R. (1998). Sensory analysis. *International Journal of Food Science & Technology*, 33(1), 7–12.
- Séménou, M., Courcoux, P., Kuusinen, A., & Lokki, T. (2017). Segmentation of subjects in multivariate paired comparisons. Application to the preference for concert halls acoustics. *Food Quality and Preference*, 62, 120–127.
- Wichchukit, S., & O'Mahony, M. (2010). A transfer of technology from engineering: Use of ROC curves from signal detection theory to investigate information processing in the brain during sensory difference testing. *Journal of Food Science*, 75, R183–R193.
- Xia, Y., Zhang, J., Zhang, X., Ishii, R., Zhong, F., & O'Mahony, M. (2015). Tetrads, triads and pairs: Experiments in self-specification. *Food Quality and Preference*, 40, 97–105. Available from <https://doi.org/10.1016/j.foodqual.2014.09.005>.



Validation and safety of reformulated products (shelf-life testing)

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Introduction

As stated in Chapter 1, Understanding the requirement to reformulate science, health, consumer demand, regulation and capability, food safety is a default for any reformulation protocol. Safety is the principal concern with producers, followed only then by sensory quality. Maintaining the appropriate level of hygiene pre- and postproduction is essential to ensure the absence of pathogenic microorganisms and keeping the microbial loading within regulatory tolerance limits. All products must be safe for human consumption across the specification of their use criteria. Once manufactured, products must then be stored within specifications to obtain the desired shelf life. For reformulated products the determination of product shelf life usually starts at the product-development stage. However, irrespective of the stage a food product is at in its development, it is important to ensure that shelf life is considered at each stage and determined accurately using all available data [Food Safety Authority of

Ireland (FSAI), 2014a]. The *Codex Alimentarius* defines shelf life as the period during which a food product maintains its microbiological safety and suitability at a specified storage temperature and where appropriate, under specified storage and handling conditions. Also, The UK Institute of Food Science and Technology (IFST) (1993) defines shelf life as “the period of time during which the food product will remain safe, retain its desired sensory, chemical and microbiological characteristics, and comply with any label declaration of nutrition data”. Shelf life is defined in European legislation as the “date of minimum durability” (FSAI, 2014a).

In the case of fresh meats and poultry, this is generally undertaken using refrigerated storage and in protective packaging such as modified atmosphere packaging (MAP), which will be discussed in the next section on packaging. On the other hand for bread products, ambient temperatures are used and products monitored until the presence of the maximum level of yeasts and molds is determined. However, sensory quality may be the more limiting factor in this case as the product may stale before yeast and mold reach threshold rejection levels. The storage conditions will bring in to play various sensory factors that will affect the stability and shelf life of the product. Prior to determining the shelf life of a food, it is essential to determine which factor(s) limit the shelf life, and may cause physical, chemical, or biological changes that result in a sensory change in the food (Walker, 1994). In order to determine shelf life, the product is stored at the recommended storage temperature and conditions until the maximum legally allowable limit for numbers of defined microflora are reached and then manufactures subtract a further period of time to allow an additional safety margin, or buffer, by which time the product can be consumed. Microbiological safety can be determined by manufacturers by appropriate testing sufficient quantities of the product held at its normal storage temperature. Samples tested should reflect the normal batch to batch variation of the product. This variation should include variation to component ingredients, within specification fluctuations in the manufacturing process and the sample should be contained in its specified packaging. The microflora tested should be broad spectrum and reflect the organisms usually associated with that type of product and related pathogens. When a product comes to the end of its shelf life undesirable characteristics may develop which can be microbiological, chemical, or physical (O’Sullivan, 2017a).

This margin of safety should be determined and applied by the manufacturer after examining all reasonably foreseeable conditions of processing

and use (FSAI, 2014a). With microbial growth, it is often useful to consider safety and spoilage separately although the controlling factors for both may be identical (Walker, 1994). The safety of foodstuffs is mainly ensured by a preventive approach, such as implementation of good hygiene practice and application of procedures based on hazard analysis and critical control point (HACCP) principles (EC 2073/2005). Such practices ensure the absence of pathogenic microorganisms during production and minimize the microbial load within the regulatory guidelines (O'Sullivan, 2017a). Inadequate shelf life determination will lead to consumer dissatisfaction or complaints which will eventually affect the acceptance and sales of brand name products and at worst can lead to malnutrition or illness. For these reasons, food processors pay great attention to adequate storage stability and shelf life (Freitas & Costa, 2006).

Sensory analysis should be performed in parallel with microbiological shelf life analysis in order to monitor the sensory changes in the product over time. It is also important to note that the sensory analysis is only conducted on the product if it is deemed safe for human consumption by reference to the latent and appropriate available microbiological data (O'Sullivan, 2017a). The product can be assessed through affective and descriptive sensory testing and also utilizing preference mapping to explore the sensory dimensions effecting quality. For all microbiologically stable foods with no health specific claim, sensory evaluation is the key factor for determining the acceptance limit, and hence shelf life (Manzocco & Lagazio, 2009). This is the case for many shelf-stable products such as alcoholic beverages due to the antimicrobial properties of ethanol where spoilage or pathogen growth is prevented. Also, foods with low water content (or activity AW), such as biscuits and crackers, will have shelf lives defined by sensory changes as microbiology tends not to be the limiting factor. Typically, in this case, shelf life is limited by textural changes such as softening or even hardening and will also be dependent on packaging type and permeability (moisture/air), exposure to temperature, atmospheric gasses, and humidity (O'Sullivan, 2017a, 2017b). However, shelf life can be prolonged through packaging optimization or by incorporating "hurdle" strategies. This might include an antimicrobial process such as a heat treatment such as retorting or high-pressure processing (both discussed in Chapter 12: Magnitude estimation—alignment of sensory and instrumental analysis) in combination with an organic acid to synergistically retard microbial growth (Rodríguez-Calleja, Cruz-Romero, O'Sullivan, & Kerry, 2012).

Color is often the first sensory modality the consumer encounters and may be relatively stable for most products, but where changes occur over shelf life, they can be limiting factors for consumer acceptance. Color may also be an index of shelf life, especially for meat products as pigments can oxidize over time. One of the primary purchase criteria of fresh meat is meat color. In red meats, consumers relate the bright-red color to freshness, while discriminating against meat that has turned brown in color (Hood & Riordan, 1973; Morrissey, Buckley, Sheehy, & Monaghan, 1994). This is more an issue with red meat due to the greater concentration of myoglobin present in the muscle compared to white meats such as chicken. Color is also a primary factor for dairy-based powders or butters and margarines as they can darken or become more yellow if oxidation occurs. Color can also fade in some beverage products such as soft drinks. Color is easily monitored during shelf life testing using either simple sensory hedonic or descriptive tests for color or by using portable measurement instruments such as the Minolta colorimeter which can measure the CIE or Hunter Lab color measurement indices (O'Sullivan, 2017a).

Rheological changes can occur in foods and beverages as a result of reformulation processes and thus will require monitoring so as to determine the influence on shelf life. For example, a limitation to cream liqueur shelf life can be increases in viscosity, phase separation and plugging of the neck of product bottles. Thus viscosity is also an index of shelf life and can be relatively easily measured by sensory and instrumental means. This parameter is commonly influenced by reformulation and ingredient substitution protocols; thus it is essential to monitor products in real time and also during accelerated shelf life stability studies, discussed at the end of this chapter. Sensory hedonic and descriptive analysis as well as instrumental devices such as rotational or oscillatory rheometers can all be used to establish rheological influences and changes over time to product quality and assist in determining physical quality end points. The Brookfield (rotational) rheometer is commonly used for measuring the viscosity of liquids such as random coil polysaccharide solutions, which have good correlations to sensory perceived texture. However, products such as sauces containing shear-thinning polysaccharides such as Xanthan gum require oscillatory rheometry for correlation to sensory texture indices as rotational devices tend to underestimate actual viscosity. This is discussed in detail in the texture section of this chapter.

Texture profile analysis (TPA) is appropriate for determining the texture of meat, bread, crackers, chocolate or solid, or semisolid-type food

products. The texture of bread, confectionary, crackers, and biscuits may become either softer or harder depending on composition, packaging, and storage humidity and temperature (O'Sullivan, 2017a).

Aroma and flavor will change over the shelf life of foods and beverages. Beer ages with a loss in fresh notes and an increase in oxidation products which lead to off flavor. Similarly, any product containing polyunsaturated fat will oxidize over time proportionally to shelf life. Many off-flavors develop in foods and beverages as a result of oxidation. Cream liqueurs age with an increase in fruity notes as fatty acids are esterified over time to ethyl esters. Thus the flavor chemistry of products can be used to determine sensory thresholds for shelf life where microbiological issues are not limiting factors.

Comprehensive shelf life analysis essentially consists of storing a single large batch of product under normal conditions and to test, using suitable methods at various storage times (Lawless & Heymann, 2010).

Microbial loading and hygiene

The safety of foodstuffs is ensured mainly by a preventive approach, such as implementation of good hygiene practice and application of procedures based on HACCP principles (EC 2073/2005). Such practices ensure the absence of pathogenic microorganisms during production and minimize the microbial load within the regulatory guidelines. Food spoilage organisms can be readily identifiable by a change in appearance, off-odor development, or perhaps changes in texture. The principal danger of pathogenic species of microorganism, such as *Salmonella* or *Listeria*, is the lack of sensory changes to the product after growth of these bacteria. Appearance, odor, flavor, or texture sensory cues may be absent and thus do not indicate to the individual consuming the product that growth has occurred which presents a health risk. The greatest risk of contamination occurs in foods of animal origin and uncooked vegetables products (O'Sullivan, 2017a, 2017b). The major issue with reformulation projects is that modifications, particularly where preservation integrity may have been diminished, can change the shelf life and safety profile of the product. Thus it is necessary to track it like a new product where due diligence is used to analyze and assess the product from first principles. In order to achieve this, the product is stored at the specification storage temperature and conditions until maximum microbial threshold is reached. This is the legally allowable limit for numbers of defined

microorganisms and determines absolute shelf life. For retail shelf life a further period of time, so as to allow an additional safety margin or buffer, is typically subtracted from this period and defines “use-by” or “best-before” dates. Shelf life is defined in the European legislation as the “date of minimum durability.” The date of minimum durability of a foodstuff is defined in Council Directive 2000/13/EC on the labeling, presentation, and advertising of foodstuffs as the date until which a foodstuff retains its specific properties when properly stored. All prepackaged foods must be date-marked (unless exempt in the legislation) (FSAI, 2005). The date mark in European countries itself can be a “best-before” or “use-by” date. The “best-before” date will reflect the quality, for example, taste, aroma, appearance, rather than safety of a food product. A food which is past its “best-before” date may not necessarily be unsafe to consume but it may no longer be of optimum quality. Typically, a “best-before” date is required on products such as canned, dried, and frozen foods (FSAI, 2005). Food products which, from a microbiological point of view, are highly perishable and are therefore likely, after a short period of time, to constitute a danger to human health must have a “use-by” date (EC No. 2000/13/EC). The “use-by” date will indicate the date up until which the product can be safely consumed. Therefore unlike the “best before” date, the accurate determination of the “use-by” date to ensure product safety is critical (EC No. 2073/2005). Challenge testing can be used to determine the likelihood of the growth of particular microorganisms, such as those causing food poisoning. In this case, selected microorganisms are inoculated into products and the growth of these is monitored through a storage test. Selected resistant spoilage organisms that may contaminate the food from the factory or production environment may also be inoculated (Kilcast & Subramaniam, 2004).

The margin of safety built into shelf life by producers should be determined and applied by the manufacturer after examining all reasonably foreseeable conditions of processing and use guidelines (FSAI, 2014a). With microbial growth it is often useful to consider safety and spoilage separately from pathogenesis, although the controlling factors for both may be identical (Walker, 1994). However, safety of foodstuffs is mainly ensured by preventive approaches, such as implementation of good hygiene practice and application of procedures based on HACCP principles (EC 2073/2005). Such practices ensure the absence of pathogenic microorganisms during production and minimize the microbial load within the regulatory guidelines (O’Sullivan, 2017a). The growth of

microorganisms (spoilage or pathogenic) depends on a number of factors which include hygiene (microbial loading), composition (e.g., water content, ethanol concentration, salt content), pH, the heat treatment used in manufacture (pasteurization and UHT), the packaging materials used, and finally storage temperatures and conditions. The species and population of microorganisms on meat are influenced by animal species; animal health, handling of live animals, slaughter practices; plant and personnel sanitation, and carcass chilling; and fabrication sanitation, type of packaging, storage time, and storage temperature (Grau, 1986; McMillin, 2008; Nottingham, 1982). The European regulatory guidelines, EC 2073/2005, present comprehensive and specific tolerance limits for microbial loading by which meat and poultry production must comply. Also the regulation defines the sampling criteria for each specific meat and poultry product (EU, 2005). In many cases the regulation specified the complete absence of pathogenic microorganisms in a known weight of product, for example, minced meat products and meat preparations made from poultry meat placed on the market during their shelf life and intended to be eaten cooked should be completely absent for *Salmonella* in 25 g of product (EC No. 2073/2005). The microbiological guideline for cooked meat, including cured products, by the International Commission on Microbiological Specifications for Foods (ICMSF) (2011) sets the acceptable limit as $<10^5$ cfu/g of sample.

The microorganisms that are principally found on the surface of animal carcasses are Gram-negative bacteria, such as *Acinetobacter*, *Aeromonas*, *Pseudomonas*, *Moraxella*, *Enterobacter*, and *Escherichia*. Gram-positive organisms such as *Bronchotrix*, other lactic acid bacteria and *Micrococcaceae*, can also be found. The microorganisms quantified, in order to set shelf life limits, will depend very much on the product. Each specific meat product will have its own defined set of microbiological tests that must be used to quantify shelf life (O'Sullivan, 2011b, 2017d).

Microbiological criteria have been set in legislation for ready-to-eat foods (FSAI, 2014b). Commission Regulation (EC) No 2073/2005 (EU, 2005) sets guideline limits on various microorganisms at point of sale (EU, 2005). Cheeses made from milk or whey that has undergone heat treatment should have a limit for *Escherichia coli* of <100 cfu/g (O'Sullivan, 2011b, 2017d). Precut fruit and vegetables (ready-to-eat) should have a limit for *E. coli* of $100-10^3$ cfu/g and unpasteurized fruit and vegetable juices (ready-to-eat) should have cutoff level set for *E. coli* bacteria of $>10^3$ cfu/g. Similarly limits for coagulase-positive staphylococci

at point of sale for shelled and shucked products of cooked crustaceans, and molluscan shellfish should be set at $>10^4$ cfu/g. Samples are analyzed at specific regular time points for counts of suitable related spoilage bacteria, at specific incubation temperatures, and when a maximum is reached, a shelf life period may be determined. As stated earlier a safe margin of time should also be built into the shelf life to ensure that the microbial count limits are not reached during the normal shelf life of the product (O'Sullivan, 2017a).

Reformulation can negatively affect the shelf life of foods. Salt acts as a food preservative by reducing the water activity of food and therefore reducing the number of groups of microorganisms that are able to grow (Fellendorf, Kerry, Hamill, & O'Sullivan, 2018). By reducing salt to improve the nutritional profile producers must also diligently determine shelf life to ensure that safety is not compromised. In addition, processed meat products may also contain nitrites and include bacon, bologna, corned beef, frankfurters, luncheon meats, ham, fermented sausages, shelf-stable canned meats, cured meats, perishable canned meats, cured meat (e.g., ham), and a variety of fish and poultry products (Pennington, 1998). The shelf life of meats can be extended significantly by curing as the nitrate/nitrite which has a strong antibacterial effect, particularly to the growth of *Clostridium botulinum*. Nitrite combined with salt is strongly inhibitory to anaerobic bacteria, most importantly *C. botulinum* and contributes to control of other microorganisms such as *Listeria monocytogenes* (Sebranek & Bacus, 2007). However, nitrite can cause the formation of carcinogenic N-nitrosamines in cured products due to its reaction with secondary amines and amino acids in muscle proteins. Furthermore, residual nitrite in cured meats may form nitrosamines in the gastrointestinal tract (Shahidi & Pegg, 1991). There is no conclusive evidence that nitrite is directly carcinogenic (Cantor, 1997); however, in high doses it has been implicated as a cocarcinogen (Schweinsberg & Burkle, 1985). Thus reformulation for the reduction or replacement of nitrate/nitrite is not really recommended because of its anticlostridium properties. Nitrate/nitrite removal strategies for reformulated products are thus problematic as there is no equivalent anticlostridium preservative as effective as nitrate/nitrites, and also these compounds are important for developing cured meat color which is hard to reproduce. It is hoped that the developers of commercial "nitrate-free" bacon, which use alternative ingredients composed of fruit extracts and spices, have undertaken their due diligence with respect to the replacement of this ingredient and its powerful preservative properties.



Sensory shelf life testing. Experimental design and sample handling

Once microbial safety has been established over shelf life and time targets set the next step is to assess the sensory shelf life of a product. As stated earlier, there are legal obligations by food business operators to sell products that are safe to consume. However, there are no defined set sensory limits for negative sensory parameters by which food and beverage should be sold; in any case, these would be very difficult if not almost impossible to set. It is in the commercial interest of producers to sell their products with optimum sensory quality. Shelf life analysis essentially consists of storing a single large batch of product under normal conditions and to test, using suitable methods at various storage times (Lawless & Heymann, 2010). The sensory analysis involves testing the product at specific time points and can include hedonic or descriptive testing. However, the panel (trained or naïve) may become aware that they are participating in a sensory shelf life test and expect that samples to become more deteriorated as time passes by, which could lead to biased results (Lawless & Heymann, 2010; López Osorino & Hough, 2010). A more sophisticated approach, to prevent assessor bias, is to incorporate reverse storage design. Reversed storage design can be performed by staggering product times, so that all products with different storage times are evaluated on the same day (Lawless & Heymann, 2010). However, one of the drawbacks with reverse block design is that the sensory end points should be defined and known beforehand. Another way of avoiding potential bias by real time analysis is to freeze samples once certain time points have been reached. This is a routine procedure for butter, cheese samples, or other fermented food products such as salami, as the freezing process stops ageing or maturation at the required time point (O'Sullivan, 2016, 2017a). Samples are frozen very rapidly with blast freezing to temperatures below -35°C which in turn freezes the water in samples producing very small ice crystals that minimally effect the texture of samples once thawed. After blast freezing, samples can be stored in a normal freezer at -20°C . Blast freezing and then subsequent storage at -20°C can also be used to store “fresh” control samples used for comparison with subsequent aged samples for testing during sensory shelf life analysis. Specific directional difference tests which ask whether a specified attribute is perceived as different between samples can be used to monitor sensory changes over time.

Difference tests include the triangle test, duo-trio test, simple same-difference test, and “A”—“not A” test (Lawless & Heymann, 1998a; Piggott, Simpson, & Williams, 1998).



Sensory shelf life determination; difference, affective, and descriptive approaches

The difference methods discussed in Chapter 9, Discrimination testing for reformulated products, of this book could all be potentially used as part of sensory shelf life testing. Sensory shelf life is defined as the length of time during which the product does not significantly change its sensory characteristics and still corresponds to a product of high quality, or at least sufficient sensory quality. In each case the control sample could consist of the fresh product and the test sample(s), the product at various stages of shelf life. For reformulated products the control sample could consist of the standard product at a specific point of shelf life compared against reformulated products at the same point. Ultimately the level at which sensory quality deteriorates to the extent that the sensory shelf life end point is reached must be set and known as part of the experimental design. In addition, some of the other difference tests, as discussed in the previous chapter, could be used including the methods “In/Out,” “Ratings for degree of difference from a standard,” and “Weighting of differences from control” (Lawless & Heymann, 1998a, 1998b; Muñoz, Civile, & Carr, 1992a, 1992b, 1992c).

The quality index method (QIM) is a method that defines quality standards and the selection of criteria to evaluate if products comply with the requirements of quality standards (Costell, 2002). The quality of products is evaluated using a highly trained assessor panel using a scale in which points are defined in terms of the sensory characteristics that characterize the quality of each grade. QIM involves the evaluation of the key objective sensory attributes of fish species using a scoring system that ranges from 0 to 3 with the lower the score denoting freshness (Costell, 2002). Assessors must be able to recall the sensory characteristics of the ideal product, interpret descriptions corresponding to each point of the scale, and quantify the common sensory defects that appear as a result of shelf life storage (Lawless & Heymann, 2010).

Quantitative descriptive analysis (QDA) is a method that involves the training of panelists to quantify specific sensory attributes for appearance,

flavor, texture, and aftertaste and is extensively covered in Chapter 6, Descriptive methods for reformulation. QDA can be used to determine the changes in the flavor profile of food and beverages over the course of shelf life. Assessors are provided with a set of samples which reflect the main sources of sensory variation at the different storage times to the limit of shelf life and generate the descriptors needed to describe differences amongst samples. A consensus lexicon through open discussion with the panel leader is then defined (Lawless & Heymann, 2010). Attributes that are determined to be critical to shelf life limitations are certainly included, for example, rancid flavor or aroma with respect to oxidative deterioration. The sensory profile is then generated as described in Chapter 6, Descriptive methods for reformulation.

The final sensory profile will display quantifiable sensory changes in products over the course of shelf life, but this does not reflect consumer sentiment or acceptance of these products. Consumer sensory assessment employing untrained or naive assessors using simplified attribute lists can be used to measure consumer product acceptance or preference (O'Sullivan, 2011a, 2011b, 2017d). Zakrys, Hogan, O'Sullivan, Allen, and Kerry (2008) used 134 consumers to evaluate MAP beef steaks (40%, 50%, 60%, 70%, and 80% O₂) that were stored at 4°C for 12 days. The consumers indicated a directional preference for steaks (which were cooked prior to evaluation) stored in packs containing 40% and 80% O₂ and that higher O₂ levels, greater than 40%, imparted greater meat toughness as determined by these consumers.

Affective sensory analysis using sensory acceptance tests is possibly the closest type of analysis to the consumer where hedonics for appearance, aroma, flavor, texture, and overall acceptability are determined. Subjective liking can be determined for each sensory modality until the appropriate sensory cutoff level which is correlated to the set limits for the previously mentioned descriptive and difference tests. Ultimately, large-scale consumer tests can be used to establish hedonic cutoffs, the point at which sensory quality is deemed unacceptable to consumers (usually >50% rejection by the group) and the end point for shelf life is reached. Such testing is, however, time consuming, cumbersome, expensive, requires large sample sizes, a large number of consumers, as well as the application of appropriate statistical techniques (Manzocco, Calligaris, & Nicoli, 2011). Therefore once validated, the smaller scale affective sensory analysis can be utilized as part of routine shelf life analysis as the end points have been determined from the large-scale consumer testing (O'Sullivan, 2017a).

Preference mapping techniques involve correlating consumer preference or acceptance ratings to descriptive profile attributes typically using multivariate data analytical processes. This is undertaken in order to define a product's characteristics and obtain a better understanding of what attributes of a product are driving preferences (Meilgaard, Civille, & Carr, 2007; Van Kleef, Van Trijp, & Luning, 2006). This process can also be used incorporating the samples from shelf life time points, including the most accepted samples as well as those that are rejected. Physicochemical analysis [rheological, compositional, volatile flavor (GCMS), etc.] data can also add into such preference mapping models. In most shelf life studies a medium risk level (50% consumer rejection) is chosen as a reasonable acceptability shelf life limit but it has been suggested that lower percentages of consumer rejection could be much more reliable (Manzocco et al., 2011).



Color and sensory shelf life prediction

Color has a close association with quality factors such as freshness, ripeness and desirability, and food safety. Its prominent role is unquestionable for the consumer acceptability of food products (Wu & Sun, 2013). The measurement of color also allows the detection of certain anomalies or defects that food items may present (Leon, Mery, Pedreschi, & Leon, 2006). For some food products, color will be one of the principal sensory factors that will define shelf life, thus food manufacturers need to ensure that the appearance of the product will be stable over its required shelf life as consumers will perceive color loss as a sign of quality deterioration (Sutherland, Varnum, & Evans, 1986). Fruits such as bananas have their shelf life dictated by color as they change from green to yellow and eventually to black. During this time ethylene is produced, pectin breaks down and starches are converted to sugar softening the fruit in texture. Color fading can occur in soft drinks, and thus stable colors must be able to retain suitable consumer sensory color quality for many months. Such colors can become oxidized by light and deteriorate over time. Similarly oxidation can result in negative sensory color changes. For beverages packaging in bottles with UV barrier protection or the inclusion of antioxidants such as ascorbic acid or tocopherols during manufacture can help retard color fade effects due to light oxidation (O'Sullivan, 2017a).

At the point of sale, color and color stability are the most important attributes of meat quality and various approaches have been used to meet consumer expectations that an attractive, bright-red color indicates a long shelf life and good eating quality (Hood & Mead, 1993). Carpenter, Cornforth, and Whittier (2001) observed a strong association between color preference and purchasing intent with consumers discriminating against beef that is not red (i.e., beef that is purple or brown). The muscle protein myoglobin is primarily responsible for beef color, but also lamb and pork color, but to a lesser extent, due to the proportionate lower levels of the myoglobin pigment in these respective muscles. The myoglobin pigment can exist in three forms: deoxymyoglobin (purple) is rapidly oxygenated to oxymyoglobin (cherry red) on exposure to air. As meat ages, myoglobin oxidizes to metmyoglobin (brown) and this is associated with a lack of product freshness (Kropf, 1993). The degree of meat redness depends on the state of myoglobin oxygenation or oxidation. High-oxygen atmospheres (80% O₂), which are typically used to package beef cuts in MAP promote pigment oxygenation, which prolongs the period of time before metmyoglobin is visible on the muscle surface. Retail fresh meats, whole cuts or MAP, are usually presented to consumers in refrigerated retail display cabinets. The lighting of these cabinets will also affect color shelf life and stability. When conducting pilot shelf life experiments using meat, it is important to measure the lighting using a light intensity meter in the case of retail display cabinets and to also log temperature fluctuations using a data logger to ensure that readings are within required limits in order to acquire consistently reproducible data. Finally, Carpenter et al. (2001) showed that once a decision to purchase beef is made in the market by the consumer, whether the beef is cherry red fresh-bloomed beef, the brown of discounted beef, or the purple of vacuum-packaged beef, eating satisfaction at home will depend only on the beef quality attributes of tenderness, juiciness, and flavor (Carpenter et al., 2001).



Texture changes effecting shelf life

After color, texture is one of the primary sensory modalities by which consumers determine sensory quality and shelf life of food products

in particular. When buying bread, the consumer pinches the loaf to determine freshness. The softness of avocados determines ripeness, the firmness of an apple, the springiness of the orange skin, or the loss of turgor of plant cells causes the wilting of lettuce or spinach. For meats texture is defined by tenderness and cannot be determined from the fresh product but only once consumed after cooking. In addition, tenderness has often been described as the most important factor in terms of high eating quality, especially in beef and is principally an issue with red meats, more so than poultry. It has been shown that a certain level of tenderness is crucial in order that meat quality can be acceptable (Huffman et al., 1996) and that tenderness of beef is such an important quality attribute to consumers that they are willing to pay more for this tenderness (Boleman et al., 1997). It is well established that stretching of the muscle by certain hanging methods (H-bone suspension) improves tenderness of meat. Stretched muscle has greater sarcomere lengths resulting in increased tenderness (Fisher, Poulos, Wood, Young-Boong, & Sheard, 2000). Rowe, Maddock, Lonergan, and Huff-Lonergan (2004) reported that increased protein oxidation during the first 24 hours post-mortem can substantially decrease beef tenderness even in steaks aged 14 days. Zakrys et al. (2008) evaluated the sensory scores of MAP beef *musculus longissimus dorsi* muscle stored under a range of atmospheres (0%, 10%, 20%, 50%, and 80% O₂), samples packed with 50% and 80% O₂ were tougher than low O₂ treated samples. Lund, Lametsch, Hviid, Jensen, and Skibsted (2007) investigated the effect of MAP (70% O₂/30% CO₂) and skin packaging (no O₂) on protein oxidation and texture of pork *M. longissimus dorsi* muscle during storage for 14 days at 4°C and found that the high O₂ atmosphere resulted in reduced tenderness and juiciness of the experimental meat samples. High O₂ MAP has been shown to be detrimental to beef tenderness (Seyfert et al., 2007; Zakrys-Waliwander, O'Sullivan, Allen, O'Neill, & Kerry, 2010; Zakrys-Waliwander, O'Sullivan, O'Neill, & Kerry, 2012; Zakrys-Waliwander, O'Sullivan, Walshe, Allen, & Kerry, 2011) and pork due to protein cross-linking caused by oxidative processes (Lund et al., 2007; McMillin, 2008). Zakrys et al. (2008) showed that protein oxidation increased cooked meat toughness due to storage in higher MAP oxygen atmospheres. Tenderness of meat is affected by aging, type of rigor, chilling, freezing, and storage (Pearson, 1987).

Texture changes for many products over the course of shelf life. Fruits become soft, vegetables wilt, bread surface softens and becomes leathery as moisture evaporates, biscuits soften due to moisture uptake, and cream

liqueurs become viscous due to ethyl ester esterification resulting in reduced sensory consumer liking. As described above these changes can be quantified by sensory descriptive (trained panels) or by subjective affective methods (sensory acceptance testing or consumer panel). However, sensory tests are expensive, difficult to organize and time consuming (Platter et al., 2003). Thus there have been many attempts to devise alternative, reproducible, and less expensive instrumental methods to routinely determine texture of foods and beverages. These instruments can quantify indices of texture, which include force shearing, penetrating, biting, mincing, compressing, and stretching of foods whose results are a prediction of tenderness ratings obtained by taste panels (Lawrie & Ledward, 2006).

The texture profile analyzer (TPA) is appropriate for determining the texture of meat, bread, cakes, crackers, cookies, chocolate, or any solid or semisolid-type food products. The texture of these products may become either softer or harder depending on composition, packaging, and storage humidity and temperature. Shear tests measure the force to cut through fibers of cooked meat samples. They are the simplest and most common tests used to document food texture (O'Sullivan, 2017a).

Viscosity of sauces and cream liqueurs may increase over time and as such viscosity can be used as an index of shelf life. The viscosity of these fluid emulsions is an important characteristic because it influences the rate of creaming, the physical shelf life of the product and the organoleptic properties of the product (McClements, 1999). However, reformulation scientists must have a comprehensive understanding of the ingredients they are using in products so as to apply the most appropriate instrumental texture measuring devices if they are not undertaking sensory tests. As stated in the introduction products such as sauces containing shear-thinning polysaccharides such as Xanthan gum require oscillatory rheometry for correlation to sensory texture indices, as rotational devices tend to underestimate actual viscosity. Xanthan gum has high viscosity at low shear. This property confers viscosity on Xanthan containing tomato ketchups and salad dressings, which are thick and viscous in the bottle but allow flow once force or shear is applied facilitating easy pouring from the bottle. Once force is removed, thickness returns and the sauce or dressing sticks to food. Rotational devices work well for cream liqueurs but will underestimate viscosity of sauces containing shear-thinning thickening ingredients such as Xanthan gum. During sensory perception in the mouth, we perceive the weak gel-like structure as thickness or mouth feel which contributes to the thickness values before it is broken down in

mouth. In contrast, during evaluation with a rotational viscometer, such as the Brookfield, this weak gel network formed by xanthan gum is broken down by the actual disruption caused by the measurement of the viscometer and hence does not contribute to viscosity values. Thus also knowledge of the instrumental rheological properties of ingredients such as Xanthan gum is important for reformulation processes in order to accurately predict sensory quality and shelf life. Mechanical spectra generated by oscillatory rheometers will more accurately correlate to in mouth sensory perception for these types of shear-thinning ingredients. A further relatively recent innovative tribology (discussed in detail Chapter 12: Magnitude estimation—alignment of sensory and instrumental analysis) is the study of friction and lubrication between interacting surfaces in relative motion and can be applied to the interacting surfaces in the mouth during food consumption (Stokes, Boehm, & Baier, 2013). Tribology may present even better correlation to sensory-derived texture indices than even oscillatory rheometry for some products. Texture analysis will be covered in detail in Chapter 12, Magnitude estimation—alignment of sensory and instrumental analysis, of this book on instrumentation.



Shelf life of bread

The most common cause of spoilage in bread is due to mold growth that can dramatically limit shelf life. *Penicillium* spp., *Aspergillus* spp., and *Fusarium* spp. are the most dominant species (Gerez, Torino, Rollán, & Font de Valdez, 2009; Legan, 1993). These organisms produce discoloration due to colony growth as well as the development of off-flavors and potentially also produce mycotoxins. They contaminate bread typically during slicing and packaging and not in baking processes because the baking temperatures are enough to kill these microorganisms and their spores (Alhendi & Choudhary, 2013).

The spoilage of bakery products can result from microbial action, unacceptable sensory texture changes due to staling, softening or off flavor development due to oxidative rancidity. The lower sugar content and high water activity as well as the inherent starch structure reduce shelf life considerably in comparison to cakes and other confectionary products and long before oxidation issues can manifest (O'Sullivan, 2017c). One of the

major differences of bread products compared to cakes and sponges is the much shorter shelf life caused due to spoilage, but more commonly staling or moisture migration. Staling and antistaling strategies are covered extensively in the next chapter on packaging. When all baked products leave the oven, their surfaces are sterile and so it is microbial contamination (handling and slicing) of the surface during cooling that leads to product spoilage (Cauvain, 2011). Spoilage is generally due to mold as the water activity of breads supports their growth but yeasts and bacteria may also occur if conditions are right. Spoilage of bread can also be caused by chalk yeasts (cf. chalk molds) which are spoilage yeasts that cause chalk mold defects (dust-type spots) on bread (Deschuyffeleer et al., 2011). In addition, *Bacillus subtilis* produces heat resistant spores, which can contaminate baker's flour, survive the baking process, and then germinate in the bread as it cools producing an unacceptable fruity odor and ropery crumb texture. As *Bacillus* is a soil bacterium, it is more likely to contaminate whole-meal or multigrain flours than refined white flours because it exists on the surface of the grains (O'Sullivan, 2017c).



Flavor profile changes effecting shelf life

Once a product is manufactured, its inherent flavor profile will start to change. Reformulated products will also change in comparison to the benchmark or standard variant. Chemical reactions in the product result in the destruction of fresh fruity notes in beer and inversely the formation of fruity notes in cream liqueurs due to ethylation. Commonly, different chemicals are formed during oxidation reactions in products. E-2-nonenal is produced from the oxidation of riboflavin in beer resulting in the very characteristic objectionable off-note of aged beer. Lipid oxidation is also the primary cause of rancidity during the storage of foods that contain polyunsaturated fats such as dairy products, ready meals, sauces, soups or fresh and processed meat products. Lipid oxidation reactions are free radical generating chain mechanisms that occur in polyunsaturated fat-containing foods which can result in off-flavor development (Lillard, 1987) through a complex process whereby unsaturated fatty acids react with molecular O₂ via free radical mechanisms to form fatty acyl hydroperoxides or peroxides (Gray, 1978). Factors influencing lipid oxidation

include fatty acid composition, prooxidants, enzymes, and heat (Lillard, 1987). The oxidation of polyunsaturated fatty acids in meat as well as causing the rapid development of meat rancidity also affects color quality, nutritional quality, and meat texture (Kanner, 1994; Zakrys, O'Sullivan, Allen, & Kerry, 2009). In general, muscle foods are susceptible to oxidative activity of their lipid, protein, pigment, vitamin, and carbohydrate composition (Kanner, 1994). For meats the concentration of polyunsaturated fat varies with species and is higher in poultry meat followed by pork, lamb, and beef. Thus meats such as chicken are particularly susceptible to lipid oxidation. Duck meat has higher lipid content than chicken and turkey meat and is more susceptible to oxidation as it contains high levels of unsaturated fatty acids (around 60% of total fatty acids) and also high levels of hemoglobin and myoglobin (Baéza, Dessay, Wacrenier, Marché, & Listrat, 2002). Oxidation is more an issue with cooked meat and poultry products. Generally the product will be spoiled due to microbial action before oxidation becomes an issue.

The proportion of polyunsaturated fat in muscle can also be altered by feed intervention. Feeding a more unsaturated diet will result in greater concentrations of polyunsaturated fat within the muscle tissue which in turn affects meat flavor and reduces oxidative stability. Lipid oxidation is a reaction that occurs in all MAP meats and its development depends on the level of oxygen that comes into contact with the polyunsaturated lipid fraction in meat, especially while contained within the primary pack. These off-flavors increase over the storage time of meats packed in O₂ environments such as in MAP and impact negatively on the oxidative stability of muscle lipids and lead to development of undesirable flavors (Estevez & Cava, 2004; Rhee & Ziprin, 1987).

Oxidative reactions also occur in coffee products, resulting in the loss of pleasant aroma and the formation of off-flavors which lead to a reduction in the quality of instant coffee, coffee concentrates, and drinks (Nicoli & Savonitto, 2005). Roasted coffees are very susceptible to oxidation reactions due to high concentrations of very active volatile and non-volatile compounds that easily react with oxygen (Manzocco et al., 2011).

Off flavor (cardboard-flavor) development also occurs in beer during storage, again as a result of oxidation resulting in the formation of (*E*)-2-nonenal (*trans*-2-nonenal) along with other stale compounds (Vanderhaegen, Neven, Verachtert, & Derdelinckx, 2006). Beer shelf life is determined by development of these stale, oxidized flavors such as *E*-2-nonenal, increases in the compound furfural, with a parallel reduction in

fresh fruity or hop notes with beer aging. In beers and wines, ethyl esters contribute to positive sensory attributes, for beer they denote freshness, and decrease during aging. These positive flavor attributes of beer, such as fruitiness/estery and floral aroma compounds, tend to decrease in intensity during aging (O'Sullivan, 2011a). However, ethyl esters contribute to the overall flavor balance of cream liqueurs, but at high concentrations, they can develop a very fruity flavor which can become the dominant flavor in the liqueur and increase in concentration as cream liqueurs age. Ethyl esters form due to the reaction of the alcohol and fatty acids and can result in the formation of excessive levels of short-chain fatty acids such as ethyl acetate, ethyl butanoate, and ethyl hexanoate, which are the principal causes of this fruity defect. Sensory descriptors for fruity flavors may include "pear-like, banana-like, pineapple-like, apple-like, strawberry-like, ester-like, ethereal, or just fruity." The level of fruitiness may become a limiting factor to consumer acceptance in aged liqueurs (O'Sullivan, 2011a).

Antioxidants are compounds that inhibit or retard the free radical generating chain mechanism of lipid oxidation (O'Sullivan, Kerry, Buckley, Lynch, & Morrissey, 1998). Many studies have been conducted on the basis that incorporation of α -tocopherol into the cell membrane will stabilize the membrane lipids and consequently enhance the quality of meat during storage. Typically this is achieved through animal feeding studies by dietary supplementation with α -tocopherol acetate. Oxidation studies with chicken (Jensen, Skibsted, Jakobsen, & Bertelsen, 1995), turkeys (Marusich et al., 1975), pigs (O'Sullivan et al., 1998; O'Sullivan, Kerry, Buckley, Lynch, & Morrissey, 1997), cattle (Faustman et al., 1989), veal (Shorland et al., 1981), and fish (Frigg, Prabucki, & Ruhdel, 1990) have all demonstrated reduced lipid oxidation in muscles and adipose tissue from animals supplemented with dietary α -tocopherol compared to the same muscles from nonsupplemented animals. In addition, antioxidant consumed in feed by dairy cows will also accumulate in milk and products made from that milk transferring the antioxidant capacity.



Chemical determination of shelf life indices

It is usual to monitor the oxidative stability of fat-containing foods over the course of the shelf life of the product under defined storage

temperature and conditions. The typical design of a shelf life study involves placing the product in a commercial retail display cabinet (Fig. 10.1) ($4^{\circ}\text{C} \pm 1^{\circ}\text{C}$, fluorescent light 1000 lx) and tracking MDA (Malonaldehyde) formation periodically over time by the method of Tarladgis, Watts, Younathan, and Dugan (1960). MDA is a carbonyl formed from the decomposition products of autoxidized, polyunsaturated lipid materials (Crawford, Yu, & Sinnhuber, 1966). In the reaction, one molecule of malonaldehyde reacts with two molecules of 2-thiobarbituric acid (TBA) to form a malonaldehyde-TBA complex, which allows the



Figure 10.1 Retail display cabinet used to simulate commercial retail display conditions. It is important when using such equipment that the light intensity (LUX) is recorded as well as operating temperature fluctuations using a data logger.

resultant pink pigment to be quantitated spectrophotometrically (O'Sullivan, Byrne, & Martens, 2003). These TBARS (TBA reactive substances) have been correlated to sensory determined rancidity (Greene & Cumuze, 1982), but there are no legal limits of the concentration of these compounds to be found in foods. It is reported that a TBARS value of 2.28 could be considered as the limiting threshold for acceptability of oxidation in beef. This value indicates the point where the perception of rancidity overpowers beef flavor (Campo et al., 2006). Tarladgis et al. (1960) observed that threshold TBARS values of 0.5–1.0 for fresh ground pork were highly correlated (0.89) to intensity of rancid odor by trained sensory panelists (Tarladgis et al., 1960). However, Jayasingh and Cornforth (2004) showed that consumers preferred cooked pork patties with TBARS of less than 0.5 compared with patties that had TBARS numbers greater than 1.4.

Accelerated storage tests

Reformulated products will have different compositional properties compared to standard products, and if the levels of salt or sugar have been reduced will have a loss of preservative effect if not compensated for through the use of alternative ingredients, processes, or packaging. Perhaps standard packaging protocols will suffice for reformulated products (See Fig. 10.2); however, it is likely that shelf life will be very



Figure 10.2 A selection of low fat and low sugar products with packaging to obtain suitable shelf life. In the examples presented standard packaging is appropriate for reduced ingredient variants, which is quite often the case.

different and thus appropriate studies, as outlined above, must be implemented. However, for long shelf life, products real time shelf life studies have the potential of taking a very long time. Accelerated aging studies have the potential to predict shelf life of such products much more quickly. Accelerated storage tests reduce shelf life testing time by accelerating deteriorative changes by storing products typically at high temperatures in specialist storage cabinets (binder), where temperature, humidity, and light parameters can be accurately and carefully controlled (O'Sullivan, 2011b, 2016, 2017a). This process involves estimating the reaction rate at different temperatures and then extrapolating to the desired temperature (Waterman & Adami, 2005). Temperature is the most frequently used acceleration factor in the Arrhenius equation. Thus tests typically only employ temperature as a test condition where certain arbitrary assumptions are made. So, for example, if a product lasts 1 month at 40°C, it is assumed that it will last 4 months at ambient temperature, 20°C and the accelerating factor from 20°C to 40°C is equal to 4. Such assumptions could originate from company tradition or estimated from real data on a previous similar product (Nelson, 1990). Guerra, Lagazio, Manzocco, Barnaba, and Cappuccio (2008) also state that given the number of arbitrary choices, the shelf life concept for microbiologically stable food products is more company or researcher driven than product or consumer dependent (Guerra et al., 2008). For nonhermetically sealed coffee products, storage temperature is critical for volatile release and the temperature dependence of volatile release can be well described by the Arrhenius equation from 4°C to 40°C (Nicoli & Savonitto, 2005). Mathematical modeling adjust for differences, linear or nonlinear between real time shelf life and accelerated tests and can be applied to any deterioration process that has a valid kinetic model, which could be chemical, physical, biochemical, or microbial (O'Sullivan, 2011b, 2016; O'Sullivan, 2017a). This kinetic model approach is the most commonly used and has been extensively described by Mizrahi (2000). However, this kinetic model approach does offer some obstacles as finding an attribute that accurately maps the mathematical relation between real and accelerated aging may not be obvious (Guerra et al., 2008) or even exist at all. In addition, for complex foods there may be multifactor parameters that need to be measured overcomplicating the model (Mizrahi, 2000). Deteriorative mechanisms may also occur in the accelerative test that would not normally occur in the real time shelf life environment. Peleg (2006) says there is no evidence, nor theoretical reason for the effects of

different parameters, such as temperature, pH, aW, or any other factor to be additive or multiplicative in accelerated shelf life models.

References

- Alhendi, A., & Choudhary, R. (2013). Current practices in bread packaging and possibility of improving bread shelf life by nanotechnology. *International Journal of Food Science and Nutrition Engineering*, 3, 55–60.
- Baéza, E., Dessay, C., Wacrenier, N., Marché, G., & Lustrat, A. (2002). Effect of selection for improved body weight and composition on muscle and meat characteristics in Muscovy duck. *British Poultry Science*, 43, 560–568.
- Boleman, S. J., Boleman, S. L., Miller, R. K., Taylor, J. F., Cross, H. R., Wheeler, T. L., ... Savell, J. W. (1997). Consumer evaluation of beef of known categories of tenderness. *Journal of Animal Science*, 75, 1521–1524.
- Campo, M. M., Nute, G. R., Hughes, S. I., Enser, M., Wood, J. D., & Richardson, R. I. (2006). Flavour perception of oxidation in beef. *Meat Science*, 72, 303–311.
- Cantor, K. P. (1997). Drinking water and cancer. *Cancer Causes & Control*, 8, 292–308.
- Carpenter, C. H. E., Cornforth, D. P., & Whittier, D. (2001). Consumer preferences for beef colour and packaging did not affect eating satisfaction. *Meat Science*, 57, 359–363.
- Cauvain, S. P. (2011). Chapter 23: The stability and shelf life of bread and other bakery products. In Kilcast (Ed.), *Food and beverage stability and shelf life* (pp. 657–682). Woodhead Publishing Limited.
- Costell, E. (2002). A comparison of sensory methods in quality control. *Food Quality and Preference*, 13, 34–353.
- Crawford, D. L., Yu, T. C., & Sinnhuber, R. O. (1966). Reaction mechanism, reaction of malonaldehyde with glycine. *Journal of Agriculture and Food Chemistry*, 14, 184.
- Deschuyffeleer, N., Audenaert, K., Samapundo, S., Ameye, S., Eeckhout, M., & Devlieghere, F. (2011). Identification and characterization of yeasts causing chalk mould defects on par-baked bread. *Food Microbiology*, 28(5), 1019–1027.
- Estevez, M., & Cava, R. (2004). Lipid and protein oxidation, release of iron from heme molecule and colour deterioration during refrigerated storage of liver pate. *Meat Science*, 68, 551–558.
- EU(2005). EC 2073/2005. *On microbiological criteria for foodstuffs. COMMISSION REGULATION (EC) No 2073/2005. Microbiological criteria for foodstuffs.* <https://www.fsai.ie/uploadedFiles/Consol_Reg2073_2005.pdf>.
- Faustman, C., Cassens, R. G., Schaefer, D. M., Buege, D. R., Williams, S. N., & Scheller, K. K. (1989). Improvement of pigment and lipid stability in Holstein steer beef by dietary supplementation with vitamin E. *Journal of Food Science*, 54, 858–862.
- Fellendorf, S., Kerry, J. P., Hamill, R. H., & O'Sullivan, M. G. (2018). Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Science and Technology*, 92, 584–592.
- Fisher, A. V., Pouro, A., Wood, J. D., Young-Boong, K., & Sheard, P. R. (2000). Effect of pelvic suspension on three major leg muscles in the pig carcass and implications for ham manufacture. *Meat Science*, 56, 127–132.
- Freitas, M. A., & Costa, J. C. (2006). Shelf life determination using sensory evaluation scores: a general Weibull modeling approach. *Computers & Industrial Engineering*, 51, 652–670.
- Frigg, M., Prabucki, A. L., & Ruhdel, E. U. (1990). Effect of dietary vitamin E levels on oxidative stability of trout fillets. *Aquaculture*, 84, 145–158.
- Food Safety Authority of Ireland (FSAI). (2005). *Guidance note no. 18 determination of product shelf-life.* <www.fsai.ie>.

- Food Safety Authority of Ireland (FSAI). (2014a). *Guidance note no. 18 validation of product shelf-life (revision 2)*. ISBN 1-904465-33-1.
- Food Safety Authority of Ireland (FSAI). (2014b). *Guidance note no. 3 guidelines for the interpretation of results of microbiological testing of ready-to-eat foods placed on the market (revision 1)*. ISBN 0-9539183-5-1.
- Gerez, C. L., Torino, M. I., Rollán, G., & Font de Valdez, G. (2009). Prevention of bread mould spoilage by using lactic acid bacteria with antifungal properties. *Food Control*, 20(2), 144–148.
- Grau, F. H. (1986). Microbial ecology of meat and poultry. In A. M. Pearson, & T. R. Dutson (Eds.), *Advances in meat research* (Vol. 2, pp. 1–47). Westport.
- Gray, J. I. (1978). Measurement of lipid oxidation: a review. *Journal of the American Oil Chemists Society*, 55, 539–546.
- Greene, B. E., & Cumuze, T. H. (1982). Relationship between TBA numbers and inexperienced panellists' assessments of oxidized flavour in cooked beef. *Journal of Food Science*, 47, 52–54.
- Guerra, S., Lagazio, C., Manzocco, L., Barnaba, M., & Cappuccio, R. (2008). Risks and pitfalls of sensory data analysis for shelf life prediction: Data simulation applied to the case of coffee. *LWT-Food Science and Technology*, 41, 2070–2078.
- Hood, D. E., & Mead, G. C. (1993). Modified atmosphere storage of fresh meat and poultry. In R. T. Parry (Ed.), *Principles and applications of modified atmosphere packing of food* (pp. 269–298). London: Blackie Academic and Professional.
- Hood, D. E., & Riordan, E. B. (1973). Discoloration in pre-packed beef. *Journal of Food Technology*, 8, 333–348.
- Huffman, K. L., Miller, M. F., Hoover, L. C., Wu, C. K., Brittin, H. C., & Ramsey, C. B. (1996). Effects of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *Journal of Animal Science*, 74, 91–97.
- ICMSF. (2011). In K. M. J. Swanson (Ed.), *Microorganisms in foods 8. use of data for assessing process control and product acceptance* (1st ed., p. 400). Springer. Available from <http://doi.org/10.1007/978-1-4419-9374-8>.
- Institute of Food Science and Technology (IFST). (1993). *Shelf life of foods – Guidelines for its determination and prediction*. London: Institute of Food Science and Technology.
- Jayasingh, P., & Cornforth, D. P. (2004). Comparison of antioxidant effects of milk mineral, butylated hydroxytoluene and sodium tripolyphosphate in raw and cooked ground pork. *Meat Science*, 66(1), 83–89.
- Jensen, C., Skibsted, L. H., Jakobsen, K., & Bertelsen, G. (1995). Supplementation of broiler diets with all-rac- α - or a mixture of natural source RRR- α -1-8-tocopheryl acetate. 2. Effect of oxidative stability of raw and pre-cooked broiler meat products. *Poultry Science*, 74, 2048–2056.
- Kanner, J. (1994). Oxidative processes in meat and meat products: quality implications. *Meat Science*, 36, 169–189.
- Kilcast, D., & Subramaniam, P. (2004). Introduction. In D. Kilcast, & P. Subramaniam (Eds.), *The stability and shelf-life of food* (pp. 1–22). Cambridge: Woodhead Publishing Limited.
- Kropf, D. H. (1993). Colour stability: Factors affecting the colour of fresh meat. *Meat Focus International*, 1, 269–275.
- Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food. Principles and practices* (2nd ed.). New York: Springer.
- Lawless, H. T., & Heymann, H. (1998a). Sensory evaluation in quality control. In H. T. Lawless, & H. Heymann (Eds.), *Sensory evaluation of food, principles and practices* (pp. 548–584). New York: Chapman and Hall.
- Lawless, H. T., & Heymann, H. (1998b). Descriptive analysis. In H. T. Lawless, & H. Heymann (Eds.), *Sensory evaluation of food, principles and practices*. New York: Chapman and Hall, pp. 117–138, pp 341–378.

- Lawrie, R. A., & Ledward, D. A. (2006). *Lawrie's meat science*. Cambridge, England: Woodhead Publishing Ltd.
- Legan, J. D. (1993). Mould spoilage of bread; the problem and some solutions. *International Biodeterioration & Biodegradation*, 32(1–3), 33–53.
- Leon, K., Mery, D., Pedreschi, F., & Leon, J. (2006). Color measurement in L*a*b* units from RGB digital images. *Food Research International*, 39(10), 1084–1091.
- Lillard, D. A. (1987). Oxidative deterioration in meat, poultry, and fish. In A. J. St. Angelo, & M. E. Bailey (Eds.), *Warmed-over flavor of meat* (pp. 41–67). Orlando, FL: Academic Press.
- López Osorino, M. M., & Hough, G. (2010). Comparing 3-point versus 9-point just-about-right-scales for determining the optimum concentration of sweetness in a beverage. *Journal of Science*, 25(Suppl. s1), 1–17.
- Lund, M. N., Lametsch, R., Hviid, M. S., Jensen, O. N., & Skibsted, L. H. (2007). High oxygen packaging atmosphere influences protein oxidation and tenderness of porcine longissimus dorsi during chill storage. *Meat Science*, 77, 295–303.
- Manzocco, L., Calligaris, S., & Nicoli, M. C. (2011). The stability and shelf life of coffee products. In D. Kilcast, & P. Subramaniam (Eds.), *Food and beverage shelf-life and stability*. Cambridge: Woodhead Publishing Limited.
- Manzocco, L., & Lagazio, C. (2009). Coffee brew shelf life modelling by integration of acceptability and quality data. *Food Quality and Preference*, 20, 24–29.
- Marusich, W. L., De Ritter, E., Ogrinz, E. F., Keating, J., Mitrovic, M., & Bunnell, R. H. (1975). Effect of supplemental vitamin E in control of rancidity in poultry meat. *Poultry Science*, 54, 831–844.
- McClements, D. J. (1999). *Food emulsions: Principles. Practices and techniques*. Boca Raton, FL: CRC Press.
- McMillin, K. W. (2008). Where is MAP going? A review and future potential of modified atmosphere packaging for meat. *Meat Science*, 80, 43–65.
- Meilgaard, M. C., Civille, G. V., & Carr, B. T. (2007). *Sensory evaluation techniques*. Boca Raton, FL: CRC Press.
- Mizrahi, S. (2000). CH5, Accelerated shelf-life tests. In D. Kilcast, & P. Subramaniam (Eds.), *The stability and shelf-life of food*. Cambridge: Woodhead Publishing Limited.
- Morrissey, P. A., Buckley, D. J., Sheehy, P. J. A., & Monaghan, F. J. (1994). Vitamin E and meat quality. *Proceedings of the Nutrition Society*, 53, 289–295.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992a). *Comprehensive descriptive method. Sensory evaluation in quality control* (pp. 55–82). New York: Van Nostrand Reinhold.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992b). “In/Out” method. *Sensory evaluation in quality control* (pp. 140–167). New York: Van Nostrand Reinhold.
- Muñoz, A. M., Civille, G. V., & Carr, B. T. (1992c). *Difference-from-control method (degree of difference). Sensory evaluation in quality control* (pp. 168–205). New York: Van Nostrand Reinhold.
- Nelson, W. (1990). *Accelerated testing. Statistical models, test plans and data analyses*. New York: John Wiley & Sons.
- Nicoli, M. C., & Savonitto, O. (2005). Physical and chemical changes of roasted coffee during storage. In R. Viani, & A. Illy (Eds.), *Espresso coffee: the science of quality* (2nd ed., pp. 230–245). San Diego, CA: Elsevier Academic Press.
- Nottingham, P. M. (1982). Microbiology of carcass meats. In M. H. Brown (Ed.), *Meat microbiology* (pp. 13–65). London: Applied Science Publishers.
- O’Sullivan, M. G., Kerry, J. P., Buckley, D. J., Lynch, P. B., & Morrissey, P. A. (1997). The distribution of dietary vitamin E in the muscle of the porcine carcass. *Meat Science*, 45, 297–305.
- O’Sullivan, M. G., Kerry, J. P., Buckley, D. J., Lynch, P. B., & Morrissey, P. A. (1998). The effect of dietary vitamin E supplementation on quality aspects of porcine muscles. *Irish Journal of Agriculture and Food Research*, 37, 227–235.

- O'Sullivan, M. G. (2016). CH18. The stability and shelf life of meat and poultry. In Subramaniam (Ed.), *The stability and shelf life of food*. Oxford: Elsevier Academic Press.
- O'Sullivan, M. G. (2017a). CH6. Shelf life and sensory quality of foods and beverages. *A Handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 103–123). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017b). CH7. Packaging technologies for maintaining sensory quality. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 125–149). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017c). CH14. Sensory properties of bakery and confectionary products. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 305–324). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017d). CH18. The stability and shelf life of meat and poultry. In Subramaniam (Ed.), *The stability and shelf life of food* (pp. 521–537). Oxford: Elsevier Academic Press.
- O'Sullivan, M. G., Byrne, D. V., & Martens, M. (2003). Evaluation of pork colour: Sensory colour assessment using trained and untrained sensory panellists. *Meat Science*, 63, 119–129.
- O'Sullivan, M. G. (2011a). CH 4, Sensory shelf-life evaluation. In J. R. Piggott (Ed.), *Alcoholic beverages: Sensory evaluation and consumer research*. Cambridge: Woodhead Publishing Limited.
- O'Sullivan, M. G. (2011b). CH 25, Case studies: Meat and poultry. In D. Kilcast, & P. Subramaniam (Eds.), *Food and beverage shelf-life and stability*. Cambridge: Woodhead Publishing Limited.
- Pearson, A. M. (1987). Muscle function and post-mortem changes. Ch. 4. In J. F. P. Third, & B. S. Schweigert (Eds.), *The science of meat and meat products* (pp. 307–327). Westport, CT: Food and Nutrition Press, Inc.
- Peleg, M. (2006). *Advanced quantitative microbiology for food and biosystems: Models for predicting growth and inactivation*. Boca Raton, FL: CRC Press.
- Pennington, J. A. T. (1998). Dietary exposure models for nitrates and nitrites. *Food Control*, 9, 385–395.
- Piggott, J. R., Simpson, S. J., & Williams, S. A. R. (1998). Sensory analysis. *International Journal of Food Science & Technology*, 33(1), 7–12.
- Platter, W. J., Tatum, J. D., Belk, K. E., Chapman, P. L., Scanga, J. A., & Smith, G. C. (2003). Relationship of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science*, 81, 2741–2750.
- Rhee, K. I., & Ziprin, Y. A. (1987). Lipid oxidation in retail beef, pork and chicken muscles as affected by concentrations of heme pigments and nonheme iron and microsomal enzymic lipid peroxidation activity. *Journal of Food Biochemistry*, 11, 1–15.
- Rodríguez-Calleja, J. M., Cruz-Romero, M. C., O'Sullivan, M. G., & Kerry, J. P. (2012). High-pressure-based hurdle strategy to extend the shelf-life of fresh chicken breast fillets. *Food Control*, 25, 516–524.
- Rowe, L. J., Maddock, K. R., Lonergan, S. M., & Huff-Lonergan, E. (2004). Influence of early post-mortem protein oxidation on beef quality. *Journal of Animal Science*, 82, 785–793.
- Schweinsberg, F., & Burkle, V. (1985). Nitrite: A co-carcinogen? *Journal of Cancer Research and Clinical Oncology*, 109, 200–202.
- Sebranek, J. G., & Bacus, J. N. (2007). Cured meat products without direct addition of nitrate or nitrite: What are the issues? *Meat Science*, 77, 136–147.

- Seyfert, M., Mancini, R. A., Hunt, M. C., Tang, J., & Faustman, C. (2007). Influence of carbon monoxide in package atmospheres containing oxygen on colour, reducing activity, and oxygen consumption of five bovine muscles. *Meat Science*, 75(3), 432–442.
- Shahidi, F., & Pegg, R. B. (1991). Novel synthesis of cooked cured-meat pigment. *Journal of Food Science*, 56, 1205–1208.
- Shorland, F. B., Igene, J. O., Pearson, A. M., Thomas, J. W., McGuffey, R. K., & Aldridge, A. E. (1981). Effects of dietary fat and vitamin E on the lipid composition and stability of veal during frozen storage. *Journal of Agriculture and Food Chemistry*, 29, 863–871.
- Stokes, J. R., Boehm, M. W., & Baier, S. K. (2013). Oral processing, texture and mouth-feel: From rheology to tribology and beyond. *Current Opinion in Colloid & Interface Science*, 18, 349–359.
- Sutherland, J. P., Varnum, A. H., & Evans, M. G. (1986). *A Color atlas of food quality control*. Weert: CRC Press.
- Tarladgis, B. G., Watts, B. M., Younathan, M. T., & Dugan, L. (1960). A distillation method for the quantitative determination of malonaldehyde in foods. *Journal of the American Oil Chemists Society*, 37, 44–49.
- Vanderhaegen, B., Neven, H., Verachttert, H., & Derdelinckx, G. (2006). The chemistry of beer aging – A critical review. *Food Chemistry*, 95, 357–381.
- Van Kleef, E., Van Trijp, H. C. M., & Luning, P. (2006). Internal versus external preference analysis: An exploratory study on end-user evaluation. *Food Quality and Preference*, 17, 387–399.
- Walker, S. J. (1994). The principles and practice of shelf life prediction of microorganisms. In C. M. D. Man, & A. A. Jones (Eds.), *Shelf life evaluation of foods* (pp. 40–51). London: Chapman and Hall.
- Waterman, K. C., & Adami, R. C. (2005). Accelerated aging: Prediction of chemical stability of pharmaceuticals. *International Journal of Pharmaceutics*, 293, 101–125.
- Wu, D., & Sun, D. W. (2013). Food colour measurement using computer vision. *Instrumental Assessment of Food Sensory Quality*, 165–195.
- Zakrys, P. I., Hogan, S. A., O'Sullivan, M. G., Allen, P., & Kerry, J. P. (2008). Effects of oxygen concentration on sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. *Meat Science*, 79, 648–655.
- Zakrys, P. I., O'Sullivan, M. G., Allen, P., & Kerry, J. P. (2009). Consumer acceptability and physiochemical characteristics of modified atmosphere packed beef steaks. *Meat Science*, 81, 720–725.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., Allen, P., O'Neill, E. E., & Kerry, J. P. (2010). Investigation of the effects of commercial carcass suspension (24 and 48 hours) on meat quality in modified atmosphere packed beef steaks during chill storage. *Food Research International*, 43, 277–284.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., O'Neill, E. E., & Kerry, J. P. (2012). The effects of high oxygen modified atmosphere packaging on protein oxidation of bovine *M. longissimus dorsi* muscle during chilled storage. *Food Chemistry*, 2, 527–532.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., Walshe, H., Allen, P., & Kerry, J. P. (2011). Sensory comparison of commercial low and high oxygen modified atmosphere packed sirloin beef steaks. *Meat Science*, 88, 198–202.



Packaging and compensatory processes

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Introduction

The packaging of foods and beverages is necessary to ensure that products reach the consumer in a condition that satisfies the demands of the consumer including nutrition, quality, safety, and convenience, as well as the ability to deliver a product shelf life that will endure the stresses of handling, transportation, storage, sale, and consumer contact (O'Sullivan, 2017a). Each food or beverage product requires specific packaging requirements to maintain safety and shelf life as well as delivering optimal quality to the consumer. Reformulation of products can result in the reduction or replacement of preservative ingredients, including salt and sugar. In this case the current packaging format may not be as effective in maintaining safety, shelf life, or quality and thus must be examined and optimized in parallel. Compensatory elements may also be necessary such as the inclusion of hurdle type processes that make up for loss of preservative potency. This might include an antimicrobial process combined with

a heat treatment such as retorting or high-pressure processing (HPP) in combination with an organic acid to synergistically retard microbial growth (Rodríguez-Calleja, Cruz-Romero, O'Sullivan, & Kerry, 2012). Consumers are concerned about the presence of chemical additives and preservatives in food and are also now demanding their elimination and the provision of more natural and healthy products (Heras-Mozos et al., 2019). Consumer desire and demand for a wide range of fresh and minimally processed foods inspire food researchers to improve food quality, freshness and increase the shelf life of such products through packaging innovations (O'Sullivan, 2017a). Thus the food and beverage processing industries are seeking alternative ways to maintain shelf life, sensory quality, and nutritional quality with the development of active packaging systems. Active packaging has the advantage of maintaining the preservative effects of various compounds (antimicrobial, antifungal, or antioxidant), but without being in direct contact with the food product (O'Sullivan & Kerry, 2012; O'Sullivan, 2017a).

The fundamental aspects of all food packaging materials is that, in an economic manner, they must contain, protect, preserve, inform (throughout the entire distribution process from point of manufacture to points of consumer usage), and provide convenience (at many different levels) while acknowledging the constraints placed upon their usage from both legal and environmental perspectives (O'Sullivan & Kerry, 2011). As these fundamental principles apply to all forms of packaging materials and systems, it follows that irrespective of the specific level at which the packaging is industrially applied (primary-sales packaging, secondary-collation and handling packaging, or tertiary-transport packaging), all must conform to these same principles (Cruz-Romero & Kerry, 2008).

Different foods and beverages present their own bespoke challenges with respect to reformulation and optimized packaging conditions. In order to optimize shelf life, sensory quality, and the packaging system applied must be product specific (Church & Parsons, 1995). Alcoholic beverages such as beer are not prone to microbial spoilage due to the antimicrobial nature of ethanol; thus sensory quality and off-flavor development are the primary means of defining shelf life. Other beverage products such as carbonated flavored drinks may experience flavor fade over the course of sensory shelf life (O'Sullivan, 2017d). The packaging of bread products must retain freshness while retarding moisture migration from the interior to the exterior of the product resulting in staling. On the other hand, fresh and processed meat products present specific

challenges with respect to maintaining sensory quality and food safety throughout shelf life. The three sensory properties by which consumers most readily judge meat quality are appearance, texture, and flavor (Liu, Lanari, & Schaefer, 1995). Meat color is the first sensory modality that consumers encounter when purchasing both fresh and processed meat products. Only when the product has been taken home and cooked do sensory flavor and texture come in to play. For this reason the packaging methods by which meats are presented to the consumer have been optimized to maintain the optimum color of meat and retard the development of unsightly discolorations (O'Sullivan, 2014, 2017a).

The following section will discuss the challenges presented with the packaging of food and beverage products as well as compensatory techniques due to reformulation and recipe modifications.

Meat packaging

Food packaging of fresh muscle foods is carried out to avoid contamination, delay spoilage, permit some enzymatic activity to improve tenderness, reduce weight loss, and, where applicable, to ensure a cherry-red color in red meats at retail or consumer level (Brody, 1997; Zakrys, Hogan, O'Sullivan, Allen, & Kerry, 2008; Zakrys, O'Sullivan, Allen, & Kerry, 2009; Zakrys-Waliwander, O'Sullivan, Allen, O'Neill, & Kerry, 2010; Zakrys-Waliwander, O'Sullivan, Walshe, Allen, and Kerry, 2011; Zakrys-Waliwander, O'Sullivan, O'Neill, & Kerry, 2012). Fresh red meats may simply be placed on trays and over-wrapped with an oxygen-permeable film, or placed within a gaseous-modified atmosphere (MA) or vacuum packaged. Similarly, cooked meats may be sold in a vacuum-packaged format or gas flushed with CO₂ (O'Sullivan, 2017f). Meat producers have endeavored not only to optimize these conditions to maintain food safety but also to maintain optimal sensory quality. However, this is not always easy as optimizing one sensory parameter can have a negative effect on another sensory parameter. The oxidation of polyunsaturated fatty acids not only causes the rapid development of meat rancidity but also affects the color, the nutritional quality, and the texture of beef (Kanner, 1994). The use of modified atmosphere packaging (MAP) for the storage of meat highlights this issue. High O₂ systems with atmospheres of O₂ and carbon dioxide (CO₂) higher than ambient levels facilitate red meat color development and inhibition of spoilage microorganism growth (McMillin, 2008). The high O₂ environment causes the myoglobin in meat to

become oxygenated resulting in a very appealing cherry-red color which the consumer expects to see. However, this high O₂ environment promotes lipid oxidation which can result in off-flavor development in the resulting cooked meat (Estevez & Cava, 2004; Rhee & Ziprin, 1987) as well as decreased tenderness due to protein oxidation (Jayasingh, Cornforth, Brennand, Carpenter, & Whittier, 2002; Tornngren, 2003; Zakrys et al., 2008, 2009). Thus the desired food safety and color sensory effects must be balanced against any negative effects caused by high levels of O₂ and subsequent oxidation issues. Modern meat packaging methods maintain a low microbial load while optimizing the sensory quality of a product (O'Sullivan, 2014).

The packaging environment used for meat or poultry products has a specific effect on the microorganisms that grow in the product over the course of shelf life. Increased levels of CO₂ inhibit microbial growth in refrigerated storage, with 20%–40% CO₂ used in MAP (Clark & Lentz, 1969). Levels of 20%–60% CO₂ are required for effectiveness against aerobic spoilage organisms by penetrating membranes and lowering intracellular pH (Smith, Ramaswamy, & Simpson, 1990). High O₂ MA packaged meat spoils aerobically with the spoilage flora being dominated by *Pseudomonas*. Oxygen also stimulates the growth of aerobic bacteria and inhibits the growth of anaerobes (McMillin, 2008). One major concern in MAP containing CO₂ is the inhibition of normal aerobic spoilage bacteria and the possible growth of psychrotrophic food pathogens, which may result in the food becoming unsafe for consumption before it appears to be organoleptically unacceptable (Devlieghere, Debever, & Gil, 2003).

There are four categories of preservative packaging that are commonly used predominantly for meat (other foods also) products: high oxygen MA packs (high O₂ MAP); low oxygen MA packs (low O₂ MAP); controlled atmosphere packs (CAP) (Gill & Gill, 2005); vacuum packs (VPs) that includes the ubiquitous vacuum skin pack.



High O₂ modified atmosphere packs

MAP is defined as “a form of packaging involving the removal of air from the pack and its replacement with a single gas or mixture of gases” (Parry, 1993). MAP usually contain mixtures of two or three gases: O₂ (to enhance color stability), CO₂ (to inhibit microbiological growth),

and N₂ (to maintain pack shape) (Jakobsen & Bertelsen, 2000; Kerry, O'Grady, & Hogan, 2006; Sørheim, Nissen, & Nesbakken, 1999).

Meat in packages with greater than 21% O₂ may induce oxidative processes, and lipid oxidation can be a problem with meat in high O₂ MAP (Jackson, Acuff, Vanderzant, Sharp, & Savell, 1992). High O₂ concentrations in MAP packs promote the formation of oxymyoglobin (OxyMb) which is the cherry-red form of myoglobin that is so appealing to the consumer and has a large influence on their desire to purchase. Discoloration in retail meats during display conditions may occur as a combined function of muscle pigment oxidation [OxyMb to metmyoglobin (MMb)] and lipid oxidation in membrane phospholipids (Sherbeck et al., 1995).

In European countries such as Ireland, United Kingdom, and France, beef steaks are commonly displayed under 70% O₂ and 30% CO₂ concentrations in MAP, to maintain this meat bloom, whereas the concentrations used in the United States are 80% O₂ and 20% CO₂. An oxygen-rich atmosphere (70%–80%) promotes the OxyMb pigment of myoglobin (Zakrys et al., 2008) and gives a red color in raw meat enjoyed by consumers (Zakrys et al., 2009). On the other hand, cooked meats are typically stored in 70% N₂:30% CO₂ (Smiddy, Papkovskaia, Papkovsky, & Kerry, 2002) and CO₂ functions as an antimicrobial agent, preventing the growth of aerobic microorganisms. Even though MAP improves fresh meat color stability, it can promote premature browning of cooked meat and lipid oxidation which leads to brown pigments (MMb) and undesirable flavor development (Estevez & Cava, 2004; Rhee & Ziprin, 1987) as well as reduced tenderness (Lund, Lametsch, Hviid, Jensen, & Skibsted, 2007; Mancini & Hunt, 2005).

MAP is recognized as one of the most effective methods for shelf-life extension of fresh meat and is widely used by the industry to reduce spoilage of minced meat (Koutsoumanis, Stamatiou, Drosinos, & Nychas, 2008). Beef and lamb are both red meats and share similar properties, but considerable differences in shelf lives are apparent between them due to their relative susceptibility to chemical and microbial spoilage. The pH of beef is lower than that of lamb, thus making it less susceptible to microbial spoilage (Gill, 1989; Kerry, O'Sullivan, Buckley, Lynch, & Morrissey, 2000). This is because the surface of lamb is adipose tissue, which has a pH close to neutrality (Robertson, 2006).

Protein oxidation, caused by high O₂ concentrations in MAP products, can reduce the tenderness of meat (Seyfert, Mancini, Hunt, Tang,

& Faustman, 2007) and decrease eating quality by reducing tenderness and juiciness and enhancing flavor deterioration and discoloration (Xiong, 2000). Zakrys et al. (2009) showed that high O₂ concentrations in MAP stored beef steaks had increased toughness scores after cooking, as determined by 134 consumers.

Some MAP researchers have focused on finding the correct blend of gases that maximizes initial color, color stability, and shelf life, while also minimizing microbial growth, lipid oxidation, and gaseous headspace (Mancini & Hunt, 2005). Jakobsen and Bertelsen (2000) reported that while O₂ levels higher than 20% were necessary to promote meat color, package O₂ contents higher than 55% did not result in additional color stabilizing benefits. Zakrys et al. (2008) showed that packaging beef steaks in MAP with 50% O₂ promoted the overall quality of the product over its shelf life.

With respect to poultry meat, Seydim, Acton, Hall, and Dawson (2006) used high O₂ atmospheres for packaging of ostrich meat and found that this reduced the shelf life to less than 3 days based on the results of lipid oxidation (TBA values and hexanal content) and loss in color (redness). Lipid oxidation was the probable limiting shelf-life factor for this high heme iron-containing meat.

From a microbial loading perspective, Zakrys-Waliwander et al. (2011) showed that microbiological growth of lactic acid bacteria (LAB) was the highest for commercially packaged sirloin steaks (75% O₂, 25% CO₂, 5% N₂) in comparison to noncommercially packaged samples (80% O₂, 70% O₂, and 50% O₂). Thus LAB were dominant in MAP meats, and due to their metabolic activity, the spoilage appeared as off-flavors and off-odors. Consequently, commercially packaged beef steaks were the least acceptable by sensory naïve assessors in comparison to other MA packaged samples. This is an important finding that suggests that slightly better plant hygiene in this case, especially with respect to LAB, could have a beneficial effect on the subsequent consumer quality of the meat packaged under MAP conditions (Zakrys-Waliwander et al., 2011).

MAP is often used for the packaging of cheddar cheese slices. Gasses employed include 100% CO₂ or CO₂/N₂ combinations, which prevent mold growth on the surface. Similar gas mixtures are used for grated cheese, which are a popular convenient product with consumers. However, due to the increased surface area, these products are much more susceptible to lipid oxidation and so transparent ultraviolet (UV)-protected and light resistant films are included in the laminate layers of the pack to retard this process (O'Sullivan, 2017a, 2017b, 2017c) (Fig. 11.2).

Seafood which is very perishable can have shelf life extended threefold using refrigeration and MAP packaging. Formats typically involve a product to gas ratio of 3:1. Fish with high fat contents are usually packaged with a CO₂ atmosphere in combination with N₂ as a filler to prevent pack collapse (40% CO₂/60% N₂). Prawns, lobster, crab, squid, mussels, and cockles are usually packed in mixtures of 40% CO₂/30% N₂/30% O₂ (O'Sullivan, 2017a). White-fish packaging usually incorporated CO₂ which is effective in inhibiting the growth of common aerobic bacteria whereas in combination with O₂ which preserves flesh color but prevents the growth of the anaerobic *Clostridium botulinum* pathogen, with a typical gas mixture of 40% CO₂/30% N₂/30% O₂.



Low O₂ modified atmosphere packs

Cooked meat products that are packed in MAP usually use gas mixtures of 70%–80% nitrogen and 20%–30% CO₂. The CO₂ acts as the antimicrobial and N₂ as the pack shape stabilizer (Sørheim, Aune, & Nesbakken, 1997). This is the packaging format commonly used for cooked chicken, turkey, ham, and even beef (O'Sullivan, Cruz, & Kerry, 2011). Low O₂ packaging systems for fresh meat have been readily available for usage in the United States but are not as widely implemented as their high O₂ counterparts (Eilert, 2005). The absence of O₂ in an O₂-free MAP or CAP systems results in a significant shelf-life extension, as these packaging formats are very hostile environments to obligate aerobic spoilage microorganisms (O'Sullivan et al., 2011). Low O₂ MAPs are generally packed with CO₂ (usually enough to dissolve into the product) and also N₂, while residual O₂ may be present or included during the packing process. However, CO₂ may cause off-flavor or CO₂ taint in the meat, which can be detected upon consumption (Nattress & Jeremiah, 2000). CO₂ is highly soluble in water, most of which is contained in the muscle, and also in fat tissue. This solubility is increased with decreasing temperature. Thus CO₂ absorbs into the meat resulting in carbonic acid being dissociated to bicarbonate and hydrogen ions (Dixon & Kell, 1989). O'Sullivan et al. (2011) explored off-flavor development by CO₂ in commercial MAP CO₂ and packs containing 100% CO₂ using 10 trained panelists. "CO₂ flavor" increased over time for all treatments, and also directionally, the

most CO₂ off-flavors were found in the samples cooked immediately after opening MA packs and also in the meat packed under 100% CO₂.

In the United States, carbon monoxide (CO) may be used as a gas for meat color enhancement as the FDA has approved the use of CO in low O₂ beef packs. However, the practice has been banned in the EU since 2004 as CO is deemed toxic. The declaration of CO for meat as generally recognized as safe in the United States has a legal basis (Boeckman, 2006). Low or residual O₂ can produce gray/brown oxidized MMb in meat packs. Carbon monoxide (CO) has a useful application in that; it has a higher affinity for myoglobin and forms a bright cherry-red color on the surface of beef (Hunt et al., 2004; Jayasingh et al., 2002; Luno, Roncales, Djenane, & Beltran, 2000; Sørheim et al., 1999). Carboxy-myoglobin is more resistant to oxidation than OxyMb, as it binds more strongly to the iron-porphyrin site on the myoglobin molecule (Wolfe, 1980). Thus there are distinct advantages for storage and display life of meat with CO in low O₂ MAP. However, the FDA (2004) noted that while color did not degrade in a package containing CO, offensive odors could still form normally in the product in the presence of CO. Thus consumers have a negative image of CO because of its hazardous nature and the concern that products may appear fresher than they actually are (Cornforth & Hunt, 2008).



Vacuum packaging technologies

Vacuum packaging was one of the earliest forms of MAP methods developed commercially and is still extensively used for products such as primal cuts of fresh red meat and cured meats (Parry, 1993), cheese (Schneider, Kluge, Weiß, & Rohm, 2010), and fish (Kaale, Eikevik, Bardal, & Kjorsvik, 2013; O'Sullivan, 2017a). Vacuum packs comprise evacuated pouches or vacuum skin packs, in which a film of low gas permeability is closely applied to the surface of the product. Preservative effects are achieved by the development of an anaerobic environment within the pack (Gill & Gill, 2005). VP extends the storage life of chilled meats by maintaining an O₂ deficient environment within the pack (Bell, Penny, & Moorhead, 1995). Vacuum packaging involves the evacuation of air from the packs prior to sealing and is used extensively in the meat and poultry industries. The first significant commercial application was for

vacuum packaging of whole turkeys using rubber stretch bags (Purdue, 1997). Respiration of the meat in VPs quickly consume any residual O_2 , replacing it with CO_2 , which eventually increases to 10%–20% within the package (Gill, 1996; Parry, 1993; Taylor, 1985). However, the amount of O_2 in pack must then be very small if the product is to be effectively preserved (Gill & Gill, 2005). Low O_2 permeability of the packaging film causes a change in meat color from red to purple due to the conversion of OxyMb to deoxymyoglobin. From the consumers' perspective, these forms of myoglobin have been considered as unacceptable meat colors (Parry, 1993). Vacuum packaging is extensively used for the packaging of pork products such as pork steak or fillet, bacon rashers, whole hams, and cured or barbecue ribs to mention just a few products (O'Sullivan & Kerry, 2012).

Vacuum packaging also prevents dehydration and evaporative water loss from the surface of the food and can minimize the effects of freezer burning (excessive hydration loss from the product surface) and drip loss on thawing (Fernández, Aspé, & Roeckel, 2010; Pornchai & Chitsiri, 2011). However, prolonged storage of meat in vacuum packs results in the accumulation of drip, which is also unappealing to consumers (Jeremiah, Gill, & Penney, 1992; Parry, 1993; Payne et al., 1997). A solution to this may be vacuum skin packaging, which uses a film that fits very tightly to the meat surface, leaving little space for the accumulation of drip (Hood & Mead, 1993). Skin packing will produce almost no wrinkles in the packaging in which purge loss may collect (Vázquez et al., 2004).

Once the meat is placed in trays, the upper packaging film is placed over the tray and heated which in turn shrinks tightly around the meat and adheres to the trays when vacuum is drawn. The product shelf life can be 15–22 days depending on the cut which is even more so than traditional vacuum packaging probably due to the surface heat treatment during shrinking and the subsequent lower rate of microbial growth. Since the product is displayed in the myoglobin state, there is no loss of color in the display case and oxidation issues are minimized with this type of package (Belcher, 2006; O'Sullivan, 2017a, 2017c). Also, the product can be easily frozen by the consumer if they wish so without having to repack, and due to O_2 exclusion, the product can potentially last in the freezer for several months with minimal loss of quality (O'Sullivan, 2017a).

Vacuum packaging is one of the most common formats for retail packaging of many different varieties of cheese. O_2 evacuation from the pack prolongs the shelf life and inhibits the development of off-flavors resulting

from lipid oxidation. Calcium lactate (CL) crystals can sometimes form on the surface of Cheddar cheese during retail display, resulting in consumer rejection. However, this may be prevented with tight-fitting packaging over a smooth cheese and eliminating available sites for nucleation (Rajbhandari & Kindstedt, 2014). Clearly, vacuum packaging can be an important format in the prevention of CL crystal formation (O'Sullivan, 2017a).

Active packaging

Active packaging is a recent technological development that has the potential of extending the shelf life of food products. Active packaging has the advantage of maintaining the preservative effects of various compounds (antimicrobial, antifungal, or antioxidant), but without being a constituent part of the food product. This is an important development, considering the consumer drive toward clean labeling of food products and the desire to limit the use of food additives (O'Sullivan & Kerry, 2009, 2011). The aim of active packaging is to increase the display life of contained products, while maintaining their quality, safety, and sensory properties, without direct addition of the active agents to the product (Camo, Antonio Beltrán, & Roncalés, 2008). Active packaging has been mostly used to absorb oxygen, carbon dioxide, moisture, ethylene, and odors and to release some materials such as antimicrobial agents, antioxidants, and carbon dioxide (Alhendi & Choudhary, 2013). Rooney (1995) defined an active package as a material that “performs a role other than an inert barrier to the outside environment.” Looking to the consumers' demand for chemical preservative-free foods, food manufacturers are now using naturally occurring antimicrobials to sterilize and/or extend the shelf life of foods (Han, Zhang, & Buffo, 2005). The most prevalent form of active packaging in the meat industry is based on oxygen scavenging. The scavengers are usually made from iron powders that are combined with acids or salts, or both and a humectant to promote oxidation of the iron (Gill & McGinnis, 2003). Antimicrobial packaging materials must contact the surface of the food if they are nonvolatile, so the antimicrobial agents can diffuse to the surface; therefore surface characteristics and diffusion kinetics become crucial (Appendini & Hotchkiss, 2002). Thus antimicrobial packaging are an active packaging method where antimicrobial agents are incorporated into or coated onto food packaging materials to prolong the shelf life of the packed food, usually by extending the lag phase and reducing the growth rate of microorganisms (Floros, Dock, & Han, 1997;

Han, 2000; Suppakul, Miltz, Sonneveld, & Bigger, 2003). Antimicrobial packaging materials are designed to release antimicrobial molecules embedded in the entire packaging wall, referred to as a film, or incorporated into a devoted active layer coated onto a polymeric or paper substrate, referred to as coating or directly coated onto the food as an edible coating (Van Long, Joly, & Dantigny, 2016). The major potential product applications for antimicrobial films include meat, fish, poultry, bread, cheese, fruits, vegetables, and beverages (López-Rubio et al., 2004).

Active packaging has a potentially important role to play in reformulation of foods. Loss of preservative action due to reformulation such as reduction or replacement of salt or nitrite can be compensated for using active packaging technology. Active packaging has the advantage of maintaining the preservative effects of various compounds (antimicrobial, antifungal, or antioxidant), but without being in direct contact with the food product (O'Sullivan & Kerry, 2012). The antimicrobial agent is incorporated into the packaging material by either spraying, coating, physical mixing, or chemical binding (Berry, 2000). Consumers are increasingly demanding foods free from chemical preservatives. Thus food manufacturers are now using naturally occurring antimicrobials to sterilize and/or extend the shelf life of foods (Han, 2005). Packaging films that release organic acids offer potential for reducing the effect of the growth of slime-forming bacteria on meat (Rooney & Han, 2005). Also, chemical preservatives can be employed in antimicrobial-releasing film systems, including organic acids and their salts (sorbates, benzoates, and propionates), parabens, sulfites, nitrites, chlorides, phosphates, epoxides, alcohols, ozone, hydrogen peroxide, diethyl pyrocarbonate, antibiotics, and bacteriocins (Ozdemir & Floros, 2004). Antimicrobial packaging includes systems such as adding a sachet into the package, dispersing bioactive agents in the packaging, coating bioactive agents on the surface of the packaging material or utilizing antimicrobial macromolecules with film-forming properties or edible matrices (Coma, 2008).



Retort technologies and packaging

Retort technologies have had a relatively recent resurgence due to the development of the flexible retort pouches made from plastic and metal laminates (Fig. 11.2). Traditional canning technologies were falling

out of favor, probably due to lower consumer regard, but retort pouches offer reduced production costs with wider consumer appeal. Also, food packaged in a conventional can must be cooked approximately twice as long as food contained in a retort pouch. Retort flexible packaging has been around since the 1970s when the US Army started developing its Meal-Ready-to-Eat packaging, to replace the unpopular canned C-rations (Hirsch, Kramer, & Meiselman, 2005).

Retort packaging is achieved in the following steps: the preformed pouches or cans are filled, sealed, and then placed into the retort chamber for heating, cooling, and drying cycles. The pouch is then packaged in its secondary carton package. Compared to canned retort packaging, retort pouches offer faster cycle time, reduced transportation costs, and improved shelf appeal. In the retort process, temperature (typically $\leq 119^{\circ}\text{C}$) and pressure (approx 13–18 psi depending on type) are combined to destroy pathogenic and spoilage microorganisms in the food or beverage being sterilized and particularly heat resistant spores. Retort systems use steam or superheated water to cook food in its own package, extending shelf life and ensuring food safety. Any remaining spores must be incapable of growth in the food or beverage under existing conditions. Preservation is based on ensuring that the minimum F_0 value is achieved for the safe production of each of the product formulations. The F value being the time, in minutes, at a specified temperature required to destroy a specific number of viable cells having a specific z -value. In products with a high pH, $>\text{pH } 4.6$, there is a potential risk of growth of surviving *C. botulinum* spores which constitutes a very serious food safety risk. In addition, spoilage sporeformers are usually more heat resistant than pathogenic sporeformers so the process must be designed to ensure the elimination of the most heat resistant spores (i.e., commercial sterilization). Foods can be classified on the basis of pH. Foods $>\text{pH } 4.6$ are low acidic, while foods $<\text{pH } 4.6$ are high acidic. It is also important to know that if the A_w of food is <0.85 processing times and temperatures will be lower for acid foods because microorganisms are more easily destroyed in acid environments. *C. botulinum* spores cannot germinate below pH 4.6. To design the process to achieve the required F_0 (which will vary with the matrix) the sterilization parameters will include pH, A_w , composition of food, container size and material, physical state of food material, rate of heat penetration, position of container in retort, etc. For low acid foods the marker microorganism is *C. botulinum* or substitute (*Clostridium sporogenes*) and for high acid foods (*Bacillus thermoacidurans*). The processing time,

which is the time from the end of the come-up time to the commencement of cooling, will also depend on heating cold spots or the most slowly heating part of the product. The F_0 is the sterilization value or sum of lethality rate that will ensure commercial sterilization or equivalent minutes at 250°F to get a 12D kill for low acid foods or 5D kill for acid foods (Teixeira, 2019).

Although canned foods have a long shelf life and low prices, they suffer from a poor consumer perception of healthiness and taste quality (O'Halloran, 2013). Retort pouches, used for dog food, sous vide, ready meals, soups, baby foods, etc., have a thin profile and a high ratio of surface area to volume. Thus heat penetrates the food much more quickly when it only has to reach the inside of a half-inch-thick mass rather than a much larger mass in a round aluminum can. Using modern rotary retorts (see Fig. 11.1) as opposed to static retorts has a major advantage; in that process, times and energy input can be reduced thus improving sensory and nutrient quality without compromising safety. This produces a product that has better sensory properties, as less energy is used that can deleteriously affect appearance, flavor, and texture, a particular problem for baby foods. The resulting product thus tastes better and has a reduced energy footprint. Originally developed as aluminum foil structures, pouches have evolved into sophisticated multilayer, high barrier laminate package. This type of laminate packaging (Fig. 11.2) is replacing aluminum can technology, but one must remember that cans are far more recyclable (O'Sullivan, 2017a). The popularity of the retort pouch was said to be increasing as the appeal for the traditional is stagnating or falling with



Figure 11.1 A commercial Static Steriflow Retort. The cycle used in the machine brought the temperature up to 122°C and was maintained for 5 min (to reach a 12D cycle on *Bacillus stearothermophilus* spores) (Left picture). Surdy Rotary Retort located at the processing facilities University College Cork (Right picture).



Figure 11.2 Laminated retort pouches. Retort technologies have had a relatively recent resurgence due to the development of the flexible retort pouches made from plastic and metal laminates. One laminate may represent a gas barrier, another a gas barrier, while a third may facilitate printability.

some sources predicting that canned desserts and sauces will completely disappear by 2020 (Holter, 2011). However, in relation to recent negative consumer regards for plastic packaging due to environmental unfriendliness, perhaps aluminum cans will now have their resurgence for retorted products as the laminate-based pouches are not recyclable in their current form or perhaps packaging technologists will design such pouches in the future, made from bio-based materials, as discussed later.



High-pressure processing

As discussed in the previous chapter, shelf life can be prolonged through packaging optimization or by incorporating “hurdle” strategies. The reduction of a preservative effect, as a consequence of reformulation (e.g., sugar or salt reduction), can be thus compensated for this might include an antimicrobial process like a heat treatment such as retorting as described above or HPP in combination with an organic acid to synergistically retard microbial growth (Rodríguez-Calleja et al., 2012). HPP usually consists of initial heating of the confined fluid and packaged foods, followed by the application of adiabatic pressure. A temperature increase of about 3°C for every 100 MPa of pressure applied may also result. The quality of

high-pressure sterilized products is generally superior to equivalent conventionally heat sterilized products with respect to appearance (product dependent) texture, flavor, and retention of nutrients (Matser, Krebbers, Van Den Berg, & Bartels, 2004) (see Fig. 11.3). HPP has become a convenient post-packaging technology for food whose quality would be otherwise changed, for instance, by conventional pasteurization processes (Júnior, Cristianini, Padula, & Anjos, 2019). With HPP covalent bonds related to nutritional and sensory properties are not broken down and the resulting freshness of processed fruit or vegetable products is better retained (Medina-Meza, Barnaba, & Barbosa-Cánovas, 2014; Oms-Oliu, Odriozola-Serrano, Soliva-Fortuny, Elez-Martínez, & Martín-Belloso, 2012). Also, with HPP microorganisms and endogenous enzymes are inactivated, thus quality deterioration and spoilage are reduced (Ramos, Miller, Brandão, Teixeira, & Silva, 2013). For cheese, HPP will eliminate cheese-borne pathogenic bacteria and spoilage microorganisms; however, pressure-resistant *Bacillus* and *Clostridium* spore-forming bacteria require very high pressure along with other hurdle strategies (Nuñez, Calzada, & del Olmo, 2019).

Rodríguez-Calleja et al. (2012) investigated the combined effects of high hydrostatic pressure, a commercial liquid antimicrobial edible coating



Figure 11.3 A well-used HPP rig located in the School of Food and Nutritional Sciences, University College Cork, Ireland. HPP, High-pressure processing.

consisting of lactic and acetic acid, sodium diacetate, pectin and water (articoat DPL), and MAP on the shelf life of chicken breast fillets. These authors found that the sensory and microbiological data obtained showed that the combined treatment of mild HPP at 300 MPa and application of the commercial liquid antimicrobial edible coating “articoat DPL™” exhibited a strongly synergetic interaction, extending the shelf life of skinless chicken breast fillets up to 4 weeks. This confirms the potential utility of the hurdle strategy of HPP and organic acids for improving the shelf life of raw poultry meat using an edible antimicrobial agent.



Bread and bakery product packaging

Fresh baked bread is naturally a highly perishable product, with a typical shelf life of less than 7 days when stored under optimum conditions. Bread is typically spoiled by many types of yeasts and molds, of which the *Penicillium* species are by far the most common spoilage fungus (Legan, 1993). The fungus *Aspergillus niger* is also associated with bread spoilage. This degree of perishability in bread-based products is hard to delay without causing negative sensory attributes (Hempel, O’Sullivan, Papkovsky, & Kerry, 2013). One of the priorities of today’s bread-making industry is to find suitable packaging solutions to satisfy the peculiar requirements of bread (Ambrogina Pagani, Lucisano, Mariotti, & Limbo, 2006). Physical methods such as UV light, infrared, microwave heating, and ultra-high-pressure treatments can also be used to destroy postbaking contaminants and prolong shelf life (Smith, Daifas, El-Khoury, Koukoutsis, & El-Khoury, 2004).

Typically and traditionally, fresh bread products are packaged using waxed paper or polyolefin-based plastic packaging. In more recent times, higher value, specialty-type breads have been packaged using laminate constructions and packaged under MAs (Hempel et al., 2013). Packaging is necessary to prevent excessive loss of moisture from bread to the air, while in biscuits, it prevents water ingress and softening of the product. In both instances a moisture barrier layer is required to retard this moisture migration. In addition, MAP can have applications in the shelf-life extension of bread and biscuits (O’Sullivan, 2017a). Guynot, Sanchis, Ramos, and Marin (2003) extended the mold-free shelf life of cake by adding an O₂ absorbent in the packaging to reduce mold growth. Bread packaging with MAP and employing nitrogen and/or carbon dioxide can be

efficacious in the extension of the microbial shelf life of the product. The removal of oxygen from the headspace of packages inhibits the growth of aerobic microorganisms such as bacteria, yeasts, and molds (Smith, Ooraikul, Koersen, Jackson, & Lawrence, 1986). However, it is difficult to reduce O₂ content to a very low level in bakery product packs due to the porous interior of many of these products which tend to trap oxygen in such a way that it does not readily interchange with the gas which is flushed and flowing through the package (Matz, 1989). Hempel et al. (2013) explored the use of ethanol emitters (EE) or ethanol product surface sprays (ES) for bread products combined with MAP. The use of ES, but particularly EE, reduced mycological counts in bread samples with no negative sensory consequences.

The extension of shelf life can be achieved through the use of the preservatives sodium propionate (E-281), sorbic acid (E-200), sodium sorbate (E-201), potassium sorbate (E-202), calcium acetate (E-263), or ascorbic acid (E-300) (Guynot, Ramos, Sanchis, & Marín, 2005). However, as discussed in the previous section on active packaging systems the consumer demand for preservative-free products is driving the industry not only to reformulate standard products but also to seek alternative ways to inhibit mold growth, including the development of active packaging incorporating antimicrobial agents (Heras-Mozos, et al., 2019). The inclusion of antimicrobial agents in the packaging over including such components in the product formulation has the added advantage of slow release of active materials so that they can come in contact with the product surface where they are most needed (Balaguer et al., 2014). The most common and effective antimicrobial materials being researched for active packaging applications for bakery products include; natural plants' extracts and essential oils such as oregano, mustard, anise, cinnamon, cinnamaldehyde, essential oil, and garlic extract have been reported to show lethal or inhibitory activity against various microorganisms in food (Balaguer, Lopez-Carballo, Catala, Gavara, & Hernandez-Munoz, 2013a, 2013b; Giteru, Oey, Ali, Johnson, & Fang, 2017; Higuera, Lopez-Carballo, Hernandez-Munoz, Catala, & Gavara, 2014; Johnson, Olaleye, & Kolawole, 2016; Ju et al., 2018; Matan, Matan, & Ketsa, 2012; Ribeiro-Santos, Andrade, Melo, & Sanches-Silva, 2017; Teixeira et al., 2014).

Apart from microbial spoilage, staling is equal if not even more so the primary limit to shelf life in bread. Staling is characterized by changes in flavor, taste, and aroma, resulting in a loss of perceived sensory freshness as well as changes in firmness, water absorptive capacity, crystallinity,

opacity, and soluble starch content of the crumb. It also results in the development of unacceptable sensory textural properties, such as crumb firming and crust softening, and is independent of microbial spoilage. Staling is responsible for huge economic losses to the baking and retail sectors every year, as well as to the consumer. Moisture migration from the interior to the exterior of the product occurs during staling, resulting in a firming of the crumb and a softening of the crust. From the consumer perspective, crumb firmness during staling is of greater concern than the softening of the crust that results in a typical tough chewy leathery texture (O'Sullivan, 2017e). In biscuits and pastries the moisture contents are so low that moisture may migrate from the atmosphere into the product, rather than from product to atmosphere as with bread and cakes. This is a common mechanism by which cookies and pastries go soft or stale (Cauvain, 2011).

Bakery technologists have also been working on other treatments that allow bread safety and extended shelf life (Melini & Melini, 2018). These innovations include the use of functional ingredients, sourdough, non-wheat flours, and processing technologies.

The antistaling effects of many compounds such as hydrocolloids, modified starches, dextrans, and malto-oligosaccharides and other fibers have been extensively reviewed by Fadda, Sanguinetti, DelCaro, Collar, and Piga (2014). Examples include hydrocolloids such as pectins (HMP), hydroxypropyl methylcellulose, guar gum, konjac gum, xanthan gums, chitosan; modified starches such as chemically modified tapioca starches; dextrans and malto-oligosaccharides, including fructans and exopolysaccharides as well as other fibers and a plethora of other lipid- and enzyme-based ingredients (O'Sullivan, 2017e).

Sourdough has also recently become an established form of food bio-preservation, and the role played by LAB as bioagents and inhibitors to bread spoilage has been scientifically explored and highlighted (Melini & Melini, 2018). De Vuyst and Neysens (2005) found that sourdough breads had improved technological properties (dough machinability), as well as nutritional and sensory properties and longer shelf life compared to traditional yeasted breads. Mixed flour breads using flours other than wheat or deriving from amylose-free wheat flours (waxy) have been suggested in the production of bread so as to improve nutritional properties and shelf life (Fadda, et al., 2014). Vittadini and Vodovotz (2003) replaced wheat flour with 40% soy flour and found a significant decrease in amylopectin recrystallization, increased moisture retention during storage, and decreased

staling (Vittadini and Vodovotz, 2003). Also, the high β -glucan content of barley flour (20% addition) reduces starch crystallization and delays significantly staling rate of bread, but with increased firmness (Gujral, Gaur, & Rosell, 2003). In addition, wheat flours mixed with varying quantities of pregerminated brown rice (Watanabe, Maeda, Tsukahara, Kayahara, & Morita, 2004), flaxseed flour (Mentes, Bakkalbassi, & Ercan, 2008), potato paste (Wu, Sung, & Yang, 2009), cassava flour (Begum, Rakshit, & Mahfuzur Rahman, 2010), oat, rye, and buckwheat (Angioloni & Collar, 2011) have all demonstrated varying degrees of effectiveness in retarding staling in the resulting bread products.

Oxidation can also be a problem in bread aging restricting the shelf life of bakery products and can also result in off-odor and flavor development reducing sensory quality. In addition, oxidation can result in unappealing color changes and nutritional losses. The addition of antioxidants to products is the traditional countermeasure for oxidation, but keeping with the clean label strategy, it is potentially a better solution if these materials are combined with the packaging material used to contain the product (Alhendi & Choudhary, 2013). Tian, Decker, and Goddard (2012) added metal-chelating carboxylic acids to the surface of polyethylene packaging and propose this as a technique for prolonging shelf life by retarding oxidation for food products. Oxidation issues can occur in biscuit products because of the inherently low water activity, high sugar content, and resistance to microbial spoilage. For this reason, they are longer shelf-life products, and thus, off-flavor development due to oxidation of the fats used in their composition can occur over time. The oxidation processes for biscuits and the subsequent development of off-flavors can thus be the limiting factor to shelf life in the absence of microbial spoilage and staling (O'Sullivan, 2017a).



Sustainable packaging

Current controversies surrounding plastic-based packaging materials will further fuel the initiative toward the development of eco-friendly sustainable packaging materials. The great advantage of traditional packaging, such as cardboard in frozen foods, aluminum cans for beverages, paper and foil for chocolate, was better environmental friendliness. Currently, plastics represent the commonest forms of packaging material and allow

foods and beverages to be stored optimally for longer but are certainly more challenging to dispose of. Glass, metals and paper used in bottles, cans, and cartons have given way to a huge variety of different plastic laminates in recent years. Although paper-based cartons such as the tetra pack remain one of the leading formats worldwide for packaging liquid food and beverage products. Such plastic laminated cardboard provides a good barrier to water vapor and gasses (O'Sullivan, 2017a). Scientific evidence of the pollution of the oceans with plastics and microplastics is turning the consumer away from these materials. Consequently, incessant packaging waste has received major attention from policy-makers, environmental lobbyists, consumers, and the packaging industry alike (Steenis, van Herpen, van der Lans, Ligthart, & van Trijp, 2017). However, the popular belief that packaging is responsible for high environmental impacts collides with scientific evidence of packaging benefits in terms of food waste reduction potential (Licciardello, 2017). Consumers with sustainable motivations could thus be misled (by their own beliefs) and end up making (environmentally) ineffective decisions (Steenis et al., 2017). Also, the increased costs of petroleum will also continue to drive the demands for bio-based packaging materials (Cutter, 2006; Marsh & Bugusu, 2007; O'Sullivan & Kerry, 2009, 2012). However, in the same way, consumer opinion has pushed the clean ingredient label agenda; their negative view of plastics must influence the regulators and industry in incentivizing to a greater extent the development of environmentally friendlier packaging materials.

The development of novel bio-based materials, the optimization of packaging use, and the improvement of materials performances allow the manufacture of lighter and thinner packages. Also, packaging innovations have been developed which improve packaged product quality, extending shelf life, and reducing food waste. In particular, the reduction of food waste must be included in LCA (life cycle assessment) (Licciardello, 2017).

Manfredi, Fantin, Vignali, and Gavara (2015) investigated an LCA of antimicrobial packaging for fresh-milk preservation. They found that despite a slight increase in the impact of package life cycle, overall environmental benefits could be achieved thanks to the reduction of milk waste (Manfredi et al., 2015).

Polymers obtained from renewable sources, widely used in the food industry, have been tested as raw materials in the production of a new type of more sustainable packaging with specific functionality, such as the control of moisture content, gases, and the migration of food additives

and/or nutrients (Martins Sousa, Yamashita, & Soares Soares Júnior, 2016). Now, a wide range of biodegradable biopolymers are available, which have found application in food packaging: poly lactic acid, starch, polyhydroxyalkanoates (PHA), cellulose, zein, chitosan, soy protein isolate, whey protein isolate, and gluten (Licciardello, 2017). Proteins can also be used such as casein, whey, collagen, gelatin, corn, soy and wheat, as well as lipids including fats, waxes, and oils (Cutter & Sumner, 2002; Cutter, 2006). Of the polymers from renewable sources, starch, the largest constituent of cereal grains, including polished rice, is used to make biodegradable films (Liu, Kerry, & Kerry, 2005). Other polymers made from renewable resources include polysaccharides such as alginates, carrageenans, chitosan/chitin, pectin, and starch (O'Sullivan & Kerry, 2012). A variety of bio-based materials have been shown to prevent, drip loss, reduce lipid oxidation and improve flavor attributes, as well as enhancing the handling properties, color retention, and microbial stability of foods (Cutter, 2006).

There is, thus, a great potential for edible packaging made from food-based biopolymer materials for application in the food industry. One of the oldest and most widespread examples of this is the use of gelatin in the manufacture of sausage casings (Liu et al., 2005).



Packaging for the elderly

Older people may find it difficult to open and understand packaging for many reasons, which may be because of visual impairments or various physical diseases such as Parkinson's disease, arthritis, rheumatism, or reduced mobility. As we grow older, well-documented physiological changes occur, which may have an effect on the ability to select and properly use food packaging (Boss & Seegmiller, 1981; Conroy, O'Sullivan, Hamill, & Kerry, 2019). Muscle strength has been found to decrease with age (Doherty, 2003; Frontera et al., 2000; Goodpaster et al., 2006; Marcell, Hawkins, & Wiswell, 2014; von Haehling, Morley, & Anker, 2010) and chronic illness (Hughes et al., 2001; Rantanen et al., 2003). As muscle strength declines, older people experience mobility problems and a loss of independence (Goodpaster et al., 2006). There have been many recommendations that the consumer's life cycle should be considered while designing packaging (Wikström, Williams, Verghese, & Clune, 2014). Conventional packaging design

presents difficulties for the elder population in opening containers where they then turn to the use of inappropriate tools and resultant injuries (Galley, Elton, & Haines, 2005). Despite most packaging designers knowing about inclusive design, they had little or no knowledge of how to put it into practice, admitting that older adults were not routinely considered in design processes. The ergonomics research still classifies older adults as “extraordinary” (Carse, Thomson, & Stansfield, 2011). The ability to cook meals is also extremely important for the elder population for their own personal independence and self-worth, but also in maintaining good nutritional status. For many individuals, in particular ageing consumers, utility will be extremely important (Conroy et al., 2019). There is very little research conducted assessing the opinions of ageing consumers in relation to product packaging, given that they may encounter difficulties with packaging as they age (Duizer, Robertson, & Han, 2009).

Duizer et al. (2009) carried out a study in New Zealand examining ($n = 100$) subjects with hand osteoarthritis. Participants were asked to open a meat package currently available in supermarkets and a modified, newly designed version and rate their experiences with a consumer satisfaction index. The later, easier to open, format appealed to a much greater extent to this elderly group. Conroy et al. (2019) surveyed ageing consumer attitudes toward current food packaging materials and formats used in products with which they are familiar. They found that the elderly have clear likes and dislikes around commodity packaging and that when offered packaging materials and systems that provide aspects of convenience, like ease of opening, they will clearly choose such systems. In addition, these authors also studied the effects of muscle strength and health status on the ability of elderly consumers to open experimental ready-meal packaging formats. In this study the two easy to open experimental food packaging systems (Torus Pak and a Cryova Darfresh) were both preferred by the elderly over the control.

References

- Alhendi, A., & Choudhary, R. (2013). Current practices in bread packaging and possibility of improving bread shelf life by nanotechnology. *International Journal of Food Science and Nutrition Engineering*, 3, 55–60.
- Ambrogina Pagani, M., Lucisano, M., Mariotti, M., & Limbo, S. (2006). Influence of packaging material on bread characteristics during ageing. *Packaging Technology and Science*, 19, 295–302.
- Angioloni, A., & Collar, C. (2011). Nutritional and functional added value of oat, KamutR, spelt, rye and buckwheat versus common wheat in bread making. *Journal of the Science of Food and Agriculture*, 91, 1283–1292.

- Appendini, P., & Hotchkiss, J. H. (2002). Review of antimicrobial food packaging. *Innovative Food Science and Emerging Technologies*, 3, 113–126.
- Balaguer, M. P., Cerisuelo, J. P., Gavara, R., & Hernandez-Muñoz, P. (2013b). Mass transport properties of gliadin films: Effect of cross-linking degree, relative humidity, and temperature. *Journal of Membrane Science*, 428, 380–392.
- Balaguer, M. P., Fajardo, P., Gartner, H., Gomez-Estaca, J., Gavara, R., Almenar, E., & Hernandez-Munoz, P. (2014). Functional properties and antifungal activity of films based on gliadins containing cinnamaldehyde and natamycin. *International Journal of Food Microbiology*, 173, 62–71.
- Balaguer, M. P., Lopez-Carballo, G., Catala, R., Gavara, R., & Hernandez-Munoz, P. (2013a). Antifungal properties of gliadin films incorporating cinnamaldehyde and application in active food packaging of bread and cheese spread food stuffs. *International Journal of Food Microbiology*, 166, 369–377.
- Begum, R., Rakshit, S. K., & Mahfuzur Rahman, S. M. (2010). Protein fortification and use of cassava flour for bread formulation. *International Journal of Food Properties*, 14, 185–198.
- Belcher, J. N. (2006). Industrial packaging developments for the global meat market. *Meat Science*, 74, 143–148.
- Bell, R. G., Penny, N., & Moorhead, S. M. (1995). Growth of the psychrotrophic pathogens *Aeromonas hydrophila*, *Listeria monocytogenes* and *Yersinia enterocolitica* in smoked blue cod *Paraperis colias* packed under vacuum or carbon dioxide. *International Journal of Food Science and Technology*, 30, 515–521.
- Berry, D. (2000). *Packaging's role*. Brief article. Dairy Foods.
- Boeckman, A. M. (2006). Regulatory status of carbon monoxide for meat packaging. In: *Proceedings 59th reciprocal meat conference*. Champaign-Urbana, IL.
- Boss, G., & Seegmiller, J. (1981). Age-related physiological changes and their clinical significance. *Western Journal of Medicine*, 135(6), 434.
- Brody, A. L. (1997). In A. L. Brody, & K. S. Marsh (Eds.), *Packaging of food*. UK: Wiley Books.
- Camo, J., Antonio Beltrán, J., & Roncalés, P. (2008). Extension of the display life of lamb with an antioxidant active packaging. *Meat Science*, 80, 1086–1091.
- Carse, B., Thomson, A., & Stansfield, B. (2011). A novel device for evaluating forces during the dynamic jar opening action—Do older and younger adults do things differently? *Medical Engineering & Physics*, 33(4), 521–525.
- Cauvain, S. P. (2011). Chapter 23 The stability and shelf life of bread and other bakery products. In Kilcast (Ed.), *Food and beverage stability and shelf life* (pp. 657–682). Woodhead Publishing Limited.
- Church, I. J., & Parsons, A. L. (1995). Modified atmosphere packaging technology: Review. *Journal of the Science of Food and Agriculture*, 67, 143152.
- Clark, D. S., & Lentz, C. P. (1969). The effect of carbon dioxide on the growth of slime producing bacteria on fresh beef. *Canadian Institute of Food Science and Technology Journal*, 2(2), 72–75.
- Coma, V. (2008). Bioactive packaging technologies for extended shelf life of meat-based products. *Meat Science*, 78, 90–103.
- Conroy, P. M., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2019). The need for food packaging solutions for elderly consumers in Ireland. In preparation.
- Cornforth, D. P., & Hunt, M. C. (2008). Low-oxygen packaging of fresh meat with carbon monoxide: Meat quality, microbiology, and safety. In: *AMSA white paper series*, nr 2.
- Cruz-Romero, M., & Kerry, J. P. (2008). Crop-based biodegradable packaging and its environmental implications. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 3(82), 25.

- Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, 74, 131–142.
- Cutter, C. N., & Sumner, S. S. (2002). Application of edible coatings on muscle foods. In A. Gennadios (Ed.), *Protein-based films and coatings* (pp. 467–484). Boca Raton, FL: CRC Press.
- De Vuyst, L., & Neysens, P. (2005). The sourdough microflora: Biodiversity and metabolic interactions. *Trends in Food Science and Technology*, 16, 43–56.
- Devlieghere, F., Debever, J., & Gil, M. I. (2003). MAP, product safety and nutritional quality. In R. Ahvenainen (Ed.), *Novel food packaging techniques*. Cambridge: Woodhead Publishing Limited.
- Dixon, N. M., & Kell, B. (1989). A review. The inhibition by CO₂, of the growth and metabolism of micro-organisms. *Journal of Applied Bacteriology*, 67(1989), 109–136.
- Doherty, T. J. (2003). Invited review: Aging and sarcopenia. *Journal of Applied Physiology*, 95(4), 1717–1727.
- Duizer, L. M., Robertson, T., & Han, J. (2009). Requirements for packaging from an ageing consumer's perspective. *Packaging Technology and Science*, 22(4), 187–197.
- Eilert, S. J. (2005). New packaging technologies for the 21st century. *Meat Science*, 71, 122–127.
- Estevez, M., & Cava, R. (2004). Lipid and protein oxidation, release of iron from heme molecule and colour deterioration during refrigerated storage of liver pate. *Meat Science*, 68, 551–558.
- Fadda, C., Sanguinetti, A. M., DelCaro, A., Collar, C., & Piga, A. (2014). Bread staling: Updating the view. *Comprehensive Reviews in Food Science and Food Safety*, 13, 473–492.
- FDA. GRAS Notice Number GRN 000143. United States Food and Drug Administration; Washington, DC, USA: 2004.
- Fernández, K., Aspé, E., & Roeckel, M. (2010). Scaling up parameters for shelf-life extension of Atlantic salmon (*Salmo salar*) fillets using superchilling and modified atmosphere packaging. *Food Control*, 21(6), 857–862.
- Floros, J. D., Dock, L. L., & Han, J. H. (1997). Active packaging technologies and applications. *Food, Cosmetics and Drug Packaging*, 20(1), 10–17.
- Frontera, W. R., Hughes, V. A., Fielding, R. A., Fiatarone, M. A., Evans, W. J., & Roubenoff, R. (2000). Aging of skeletal muscle: A 12-yr longitudinal study. *Journal of Applied Physiology*, 88(4), 1321–1326.
- Galley, M., Elton, E., & Haines, V. (2005). *Packaging: A box of delights or a can of worms? The contribution of ergonomics to the usability, safety and semantics of packaging*. Farapack Briefing 2005 (Faraday Packaging Partnership. Online resource. <https://hdl.handle.net/2134/3105>).
- Gill, A. O., & Gill, C. O. (2005). Preservative packaging for fresh meats, poultry and fin fish. In J. H. Han (Ed.), *Innovations in food packaging* (pp. 204–220). London: Elsevier Academic Press.
- Gill, C. O. (1996). Extending the storage life of raw chilled meats. *Meat Science*, 43 (Suppl.), S99–S109.
- Gill, C. O. (1989). Packaging for prolonged chill storage: The Captech process. *British Food Journal*, 91(7), 11–15.
- Gill, C. O., & McGinnis, J. C. (2003). The use of oxygen scavengers to prevent the transient discolouration of ground beef packaged under controlled, oxygen-depleted atmospheres. *Meat Science*, 41, 19–27.
- Giteru, S. G., Oey, I., Ali, M. A., Johnson, S. K., & Fang, Z. (2017). Effect of kafirin-based films incorporating citral and quercetin on storage of fresh chicken fillets. *Food Control*, 80, 37–44.

- Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., & Newman, A. B. (2006). The loss of skeletal muscle strength, mass, and quality in older adults: The health, aging and body composition study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61(10), 1059–1064.
- Gujral, H. S., Gaur, S., & Rosell, C. M. (2003). Note: Effect of barley flour, wet gluten and ascorbic acid on bread crumb texture. *Food Science and Technology International*, 9, 17–25.
- Guynot, M. E., Ramos, A. J., Sanchis, V., & Marín, S. (2005). Study of benzoate, propionate, and sorbate salts as mould spoilage inhibitors on intermediate moisture bakery products of low pH (4.5–5.5). *International Journal of Food Microbiology*, 101(2), 161–168.
- Guynot, M. E., Sanchis, V., Ramos, A. J., & Marin, S. (2003). Mold-free shelf-life extension of bakery products by active packaging. *Journal of Food Microbiology and Safety*, 68, 2547–2552.
- Han, J. H. (2000). Antimicrobial food packaging. *Food Technology*, 54(3), 56–65.
- Han, J. H. (2005). Antimicrobial packaging systems. In J. H. Han (Ed.), *Innovations in food packaging* (pp. 81–107). Amsterdam: Elsevier Academic Press.
- Han, J. H., Zhang, Y., & Buffo, R. (2005). CH4. Surface chemistry of food, packaging and biopolymer materials. In J. H. Han (Ed.), *Innovations in food packaging*. London: Elsevier Academic Press.
- Hempel, A., O'Sullivan, M. G., Papkovsky, D., & Kerry, J. P. (2013). Use of smart packaging technologies for monitoring and extending the shelf-life quality of modified atmosphere packaged (MAP) bread: Application of intelligent oxygen sensors and active ethanol emitters. *European Food Research and Technology*, 237, 117–124.
- Heras-Mozos, R., Muriel-Galet, V., López-Carballo, G., Catalá, R., Hernández-Muñoz, P., & Gavara, R. (2019). Development and optimization of antifungal packaging for sliced pan loaf based on garlic as active agent and bread aroma as aroma corrector. *International Journal of Food Microbiology*, 290, 42–48.
- Higueras, L., Lopez-Carballo, G., Hernandez-Munoz, P., Catala, R., & Gavara, R. (2014). Antimicrobial packaging of chicken fillets based on the release of carvacrol from chitosan/cyclodextrin films. *International Journal of Food Microbiology*, 188, 53–59.
- Hirsch, E. S., Kramer, F. M., & Meiselman, H. I. (2005). Effects of food attributes and feeding environment on acceptance, consumption and body weight: Lessons learned in a twenty two year program of military ration research. US Army research part 2. *Appetite*, 44, 33–45.
- Holter, G. (2011). *The decline and fall of canned food*. <www.foodmanufacture.co.uk>.
- Hood, D. E., & Mead, G. C. (1993). Modified atmosphere storage of fresh meat and poultry. In R. T. Parry (Ed.), *Principles and applications of modified atmosphere packing of food* (pp. 269–298). London: Blackie Academic and Professional.
- Hughes, V. A., Frontera, W. R., Wood, M., Evans, W. J., Dallal, G. E., Roubenoff, R., & Singh, M. A. F. (2001). Longitudinal muscle strength changes in older adults: Influence of muscle mass, physical activity, and health. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 56(5), B209–B217.
- Hunt, M. C., Mancini, R. A., Hachmeister, K. A., Kropf, D. H., Merriman, M., DelDuca, G., et al. (2004). Carbon monoxide in modified atmosphere packaging affects color, shelf life, and microorganisms of beef steaks and ground beef. *Journal of Food Science*, 69(1), C45–C52.
- Jackson, T. C., Acuff, G. R., Vanderzant, C., Sharp, T. R., & Savell, J. W. (1992). Identification and evaluation of the volatile compounds of vacuum and modified atmosphere packaged beef strip loins. *Meat Science*, 31, 175–190.
- Jakobsen, M., & Bertelsen, G. (2000). Colour stability and lipid oxidation of fresh beef. Development of a response surface model for predicting the effects of temperature, storage time, and modified atmosphere composition. *Meat Science*, 54, 49–57.

- Jayasingh, P., Cornforth, D. P., Brennand, C. P., Carpenter, C. E., & Whittier, D. R. (2002). Sensory evaluation of ground beef stored in high-oxygen modified atmosphere packaging. *Journal of Food Science and Technology*, 67, 3493–3496.
- Jeremiah, L. E., Gill, C. O., & Penney, N. (1992). The effect on pork storage life of oxygen contamination in nominally anoxic packagings. *Journal of Muscle Foods*, 3, 263–281.
- Johnson, M., Olaleye, O. N., & Kolawole, O. S. (2016). Antimicrobial and antioxidant properties of aqueous garlic (*Allium sativum*) extract against *Staphylococcus aureus* and *Pseudomonas aeruginosa*. *British Microbiology Research Journal*, 14(1), 1–11.
- Ju, J., Xu, X., Xie, Y., Guo, Y., Cheng, Y., Qian, H., et al. (2018). Inhibitory effects of cinnamon and clove essential oils on mold growth on baked foods. *Food Chemistry*, 240, 850–855.
- Júnior, L. M., Cristianini, M., Padula, M., & Anjos, C. A. R. (2019). Effect of high-pressure processing on characteristics of flexible packaging for foods and beverages. *Food Research International*, 119, 920–930.
- Kaale, L. D., Eikevik, T. M., Bardal, T., & Kjorsvik, E. (2013). A study of the ice crystals in vacuum-packed salmon fillets (*Salmon salar*) during superchilling process and following storage. *Journal of Food Engineering*, 115, 20–25.
- Kanner, J. (1994). Oxidative processes in meat and meat products: Quality implications. *Meat Science*, 36, 169–189.
- Kerry, J. P., O'Grady, M. N., & Hogan, S. A. (2006). Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: A review. *Meat Science*, 74, 113–130.
- Kerry, J. P., O'Sullivan, M. G., Buckley, D. J., Lynch, P. B., & Morrissey, P. A. (2000). The effects of dietary α -tocopheryl acetate supplementation and modified atmosphere packaging (MAP) on the quality of lamb patties. *Meat Science*, 56, 61–66.
- Koutsoumanis, K. P., Stamatiou, A. P., Drosinos, E. H., & Nychas, G. J. E. (2008). Control of spoilage microorganisms in minced pork by a self-developed modified atmosphere induced by the respiratory activity of meat micro flora. *Food Microbiology*, 25(7), 915–921.
- Legan, J. D. (1993). Mould spoilage of bread: The problem and some solutions. *International Biodeterioration and Biodegradation*, 32, 33–53.
- Licciardello, F. (2017). Packaging, blessing in disguise. Review on its diverse contribution to food sustainability. *Trends in Food Science & Technology*, 65, 32–39.
- Liu, L., Kerry, J. F., & Kerry, J. P. (2005). Section of optimum extrusion technology parameters in the manufacture of edible/biodegradable packaging films derived from food-based polymers. *Journal of Food Agriculture Environment*, 3, 51–58.
- Liu, Q., Lanari, M. C., & Schaefer, D. M. (1995). A review of dietary vitamin E supplementation for improvement of beef quality. *Journal of Animal Science*, 73, 3131–3140.
- von Haehling, S., Morley, J. E., & Anker, S. D. (2010). An overview of sarcopenia: Facts and numbers on prevalence and clinical impact. *Journal of Cachexia, Sarcopenia and Muscle*. Available from <https://doi.org/10.1007/s13539-010-0014-2>.
- Van Long, N. N., Joly, C., & Dantigny, P. (2016). Active packaging with antifungal activities. *International Journal of Food Microbiology*, 220, 73–90.
- López-Rubio, A., Almenar, E., Hernandez-Muñoz, P., Lagarón, J. M., Catalá, R., & Gavara, R. (2004). Overview of active polymer-based packaging technologies for food applications. *Food Reviews International*, 20(4), 357–387.
- Lund, M. N., Lametsch, R., Hviid, M. S., Jensen, O. N., & Skibsted, L. H. (2007). High oxygen packaging atmosphere influences protein oxidation and tenderness of porcine longissimus dorsi during chill storage. *Meat Science*, 77, 295–303.
- Luno, M., Roncales, P., Djenane, D., & Beltran, J. A. (2000). Beef shelf life in low O_2 and high CO_2 atmospheres containing different low CO concentrations. *Meat Science*, 55(4), 413–419.

- Mancini, R. A., & Hunt, M. C. (2005). Current research in meat colour. *Meat Science*, 71, 100–121.
- Manfredi, M., Fantin, V., Vignali, G., & Gavara, R. (2015). Environmental assessment of antimicrobial coatings for packaged fresh milk. *Journal of Cleaner Production*, 95, 291e300.
- Marcell, T. J., Hawkins, S. A., & Wiswell, R. A. (2014). Leg strength declines with advancing age despite habitual endurance exercise in active older adults. *The Journal of Strength & Conditioning Research*, 28(2), 504–513.
- Marsh, K., & Bugusu, B. (2007). Food packaging: Roles, materials, and environmental issues. *Food Science*, 72(3), 39–55.
- Martins Sousa, G., Yamashita, F., & Soares Soares Júnior, M. (2016). Application of biodegradable films made from rice flour, poly(butylene adipate-co-terephthalate), glycerol and potassium sorbate in the preservation of fresh food pastas. *LWT—Food Science and Technology*, 65, 39–45.
- Matan, N., Matan, N., & Ketsa, S. (2012). Effect of heat curing on antifungal activities of anise oil and garlic oil against *Aspergillus niger* on rubberwood. *International Biodeterioration & Biodegradation*, 75, 150–157.
- Matser, A. M., Krebbers, B., Van Den Berg, R. W., & Bartels, P. V. (2004). Advantages of high pressure sterilisation on quality of food products. *Trends in Food Science and Technology*, 15(2), 79–85.
- Matz, S. A. (1989). *Modified atmosphere packaging. Bakery technology: Packaging, nutrition, product development and quality assurance* (pp. 150–152). Essex: Elsevier Science Publishers.
- McMillin, K. W. (2008). Where is MAP going? A review and future potential of modified atmosphere packaging for meat. *Meat Science*, 80, 43–65.
- Medina-Meza, I. G., Barnaba, C., & Barbosa-Cánovas, G. V. (2014). Effects of high pressure processing on lipid oxidation: A review. *Innovative Food Science & Emerging Technologies*, 22, 1–10.
- Melini, V., & Melini, F. (2018). Strategies to extend bread and GF bread shelf-life: From sourdough to antimicrobial active packaging and nanotechnology. *Fermentation*, 4, 9. Available from <https://doi.org/10.3390/fermentation4010009>.
- Mentes, O., Bakkalbasi, E., & Ercan, R. (2008). Effect of the use of ground flaxseed on quality and chemical composition of bread. *Food Science and Technology International*, 14, 299–306.
- Nattress, F. M., & Jeremiah, L. E. (2000). Bacterial mediated off-flavours in retail-ready beef after storage in controlled atmospheres. *Food Research International*, 33, 743–748.
- Núñez, M., Calzada, J., & del Olmo, A. (2019). High pressure processing of cheese: Lights, shadows and prospects. *International Dairy Journal* (In Press).
- O'Halloran, S. (2013). US canned foods market declines. *Food Engineering*. <<http://www.foodengineeringmag.com/articles/90980-us-canned-foods-market-declines>>.
- Oms-Oliu, G., Odriozola-Serrano, I., Soliva-Fortuny, R., Elez-Martínez, P., & Martín-Belloso, O. (2012). Stability of health-related compounds in plant foods through the application of non-thermal processes. *Trends in Food Science & Technology*, 23(2), 111–123.
- O'Sullivan, M. G. (2014). CH18. The stability and shelf life of meat and poultry. In Subramaniam (Ed.), *The stability and shelf life of food* (pp. 521–537). Oxford: Elsevier Academic Press.
- O'Sullivan, M. G. (2017a). CH7. *Packaging technologies for maintaining sensory quality. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 125–149). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017b). CH4. *Rapid sensory profiling methods. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 59–82). United Kingdom: Woodhead Publishing Ltd.

- O'Sullivan, M. G. (2017c). CH5. *Multivariate data analysis. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 83–99). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017d). CH13. *Sensory properties of beverage products. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 281–304). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017e). CH14. *Sensory properties of bakery and confectionary products. A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 305–324). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G. (2017f). CH18. The stability and shelf life of meat and poultry. In Subramaniam (Ed.), *The stability and shelf life of food* (pp. 521–537). Oxford: Elsevier Academic Press.
- O'Sullivan, M. G., Cruz, M., & Kerry, J. P. (2011). Evaluation of carbon dioxide flavour taint in modified atmosphere packed beef steaks. *LWT—Food Science and Technology*, 44, 2193–2198.
- O'Sullivan, M. G., & Kerry, J. P. (2009). Chapter 13, Meat packaging. In F. Toldrá (Ed.), (pp. 211–230). Chichester, West Sussex: Handbook of Meat Processing. John Wiley & Sons.
- O'Sullivan, M. G., & Kerry, J. P. (2011). Sensory quality of fresh and processed meats. In J. P. Kerry, & D. A. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh and processed meats* (pp. 585–598). Cambridge: Woodhead Publishing Limited.
- O'Sullivan, M. G., & Kerry, J. P. (2012). Chapter 4, Packaging of (fresh and frozen) pork. In L. M. L. Nollet (Ed.), *Handbook of meat, poultry and seafood quality*. Oxford: Wiley-Blackwell Publishing Ltd.
- Ozdemir, M., & Floros, J. D. (2004). Active food packaging technologies. *Critical Reviews in Food Science and Nutrition*, 44, 185–193.
- Parry, R. T. (1993). Chapter 1. In R. T. Parry (Ed.), *Introduction principles and applications of modified atmosphere packaging of food* (pp. 1–4). Glasgow: Blackie Academic and Professional, an imprint of Chapman and Hall.
- Payne, S. R., Durham, C. J., Scott, S. M., Penney, N., Bell, R. G., Devine, C. E. (1997). The effects of rigor temperature, electrical stimulation, storage duration and packaging systems on drip loss in beef. In: *Proceedings of the 43rd international congress of meat science and technology* (pp. 592–593). Auckland (GI-22).
- Pornchai, R., & Chitsiri, R. (2011). Vacuum packaging. In D.-W. Sun (Ed.), *Handbook of frozen food processing and packaging* (2nd ed., pp. 861–874). New York: CRC Press.
- Purdue, R. (1997). Vacuum packaging. In A. L. Brody, & K. S. Marsh (Eds.), *Encyclopedia of packaging technology* (2nd ed.). New York: John Wiley & Sons.
- Rajbhandari, P., & Kindstedt, P. S. (2014). Surface roughness and packaging tightness affect calcium lactate crystallization on Cheddar cheese. *Journal of Dairy Science*, 97, 1885–1892.
- Ramos, B., Miller, F. A., Brandão, T. R. S., Teixeira, P., & Silva, C. L. M. (2013). Fresh fruits and vegetables—An overview on applied methodologies to improve its quality and safety. *Innovative Food Science & Emerging Technologies*, 20, 1–15.
- Rantanen, T., Volpato, S., Ferrucci, L., Heikkinen, E., Fried, L. P., & Guralnik, J. M. (2003). Handgrip strength and cause-specific and total mortality in older disabled women: Exploring the mechanism. *Journal of the American Geriatrics Society*, 51(5), 636–641.
- Rhee, K. I., & Ziprin, Y. A. (1987). Lipid oxidation in retail beef, pork and chicken muscles as affected by concentrations of heme pigments and nonheme iron and microsomal enzymic lipid peroxidation activity. *Journal of Food Biochemistry*, 11, 1–15.
- Ribeiro-Santos, R., Andrade, M., Melo, N. R., & Sanches-Silva, A. (2017). Use of essential oils in active food packaging: Recent advances and future trends. *Trends in Food Science & Technology*, 61, 132–140.

- Robertson, G. L. (2006). *Food packaging principles and practice* (2nd ed., pp. 286–309). Boca Raton, FL: CRC Press, Taylor and Francis Group.
- Rodríguez-Calleja, J. M., Cruz-Romero, M. C., O'Sullivan, M. G., & Kerry, J. P. (2012). High-pressure-based hurdle strategy to extend the shelf-life of fresh chicken breast filets. *Food Control*, 25, 516–524.
- Rooney, M., & Han, J. H. (2005). Introduction to active food packaging technologies. In J. H. Han (Ed.), *Innovations in food packaging* (pp. 63–69). Amsterdam: Elsevier Academic Press, 81–107.
- Rooney, M. L. (1995). *Active food packaging*. London: Blackie Academic & Professional, Chapman & Hall.
- Schneider, Y., Kluge, C., Weiß, U., & Rohm, H. (2010). CH12, Packaging materials and equipment. In Barry A. Law, & A. Y. Tamime (Eds.), *Technology of cheesemaking* (2nd ed., pp. 413–439). Chichester, West Sussex: Wiley-Blackwell, John Wiley & Sons.
- Seydim, A. C., Acton, J. C., Hall, M. A., & Dawson, P. L. (2006). Effects of packaging atmospheres on shelf-life quality of ground ostrich meat. *Meat Science*, 73, 503–510.
- Seyfert, M., Mancini, R. A., Hunt, M. C., Tang, J., & Faustman, C. (2007). Influence of carbon monoxide in package atmospheres containing oxygen on colour, reducing activity, and oxygen consumption of five bovine muscles. *Meat Science*, 75(3), 432–442.
- Sherbeck, J. A., Wulf, D. M., Morgan, J. B., Tatum, J. D., Smith, G. C., & Williams, S. N. (1995). Dietary supplementation of vitamin E to feedlot cattle affects retail display properties. *Journal of Food Science*, 60, 250–252.
- Smiddy, M., Papkovskaia, N., Papkovsky, D. B., & Kerry, J. P. (2002). Use of oxygen sensors for the non-destructive measurement of the oxygen content in modified atmosphere and vacuum packs of cooked chicken patties: Impact of oxygen content on lipid oxidation. *Food Research International*, 35, 577–584.
- Smith, J. P., Daifas, D. P., El-Khoury, W., Koukoutsis, J., & El-Khoury, A. (2004). Shelf life and safety concerns of bakery products—A review. *Critical Reviews in Food Science and Nutrition*, 44, 19–55.
- Smith, J. P., Ooraikul, B., Koersen, W. J., Jackson, E. D., & Lawrence, R. A. (1986). Novel approach to oxygen control in modified atmosphere packaging of bakery products. *Food Microbiology*, 3, 315–320.
- Smith, J. P., Ramaswamy, H. S., & Simpson, B. K. (1990). Developments in food packaging technology. Part II. Storage aspects. *Trends in Food Science and Technology*, 1(5), 111–118.
- Sørheim, O., Aune, T., & Nesbakken, T. (1997). Technological, hygienic and toxicological aspects of carbon monoxide used in modified-atmosphere packaging of meat. *Trends in Food Science and Technology*, 8(9), 307–312.
- Sørheim, O., Nissen, H., & Nesbakken, T. (1999). The storage life of beef and pork packaged in an atmosphere with low carbon monoxide and high carbon dioxide. *Meat Science*, 52, 157–164.
- Steenis, N. D., van Herpen, E., van der Lans, I. A., Ligthart, T. N., & van Trijp, H. C. M. (2017). Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations. *Journal of Cleaner Production*, 162, 286–298.
- Suppakul, P., Miltz, J., Sonneveld, K., & Bigger, S. W. (2003). Active packaging technologies with an emphasis on antimicrobial packaging and its applications. *Journal of Food Science*, 68(2), 408–420.
- Taylor, A. A. (1985). Packaging fresh meat. In R. A. Lawrie (Ed.), *Developments in Meat Science* (Vol. 3). Essex, England: Elsevier Applied Science Publishers.
- Teixeira, B., Marques, A., Pires, C., Ramos, C., Batista, I., Saraiva, J. A., et al. (2014). Characterization of fish protein films incorporated with essential oils of clove, garlic

- and origanum: Physical, antioxidant and antibacterial properties. *LWT—Food Science and Technology*, 59(1), 533–539.
- Teixeria, A. A. (2019). Chapter 20—Thermal processing for food sterilization and preservation. In M. Kutz (Ed.), *Handbook of farm, dairy and food machinery engineering* (3rd ed.). Academic Press.
- Tian, F., Decker, E. a, & Goddard, J. M. (2012). Development of an iron chelating polyethylene film for active packaging applications. *Journal of Agricultural and Food Chemistry*, 60, 2046–2052.
- Torngren, M. A. (2003). Effect of packaging method on colour and eating quality of beef loin steaks. In: *49th International congress of meat science and technology* (pp. 495–496). Brazil.
- Vázquez, B. I., Carriera, L., Franco, C., Fente, C., Cepeda, A., & Barros-Velázquez, J. (2004). Shelf life extension of beef retail cuts subjected to an advanced vacuum skin packaging system. *European Food Research and Technology*, 218, 118–122.
- Vittadini, E., & Vodovotz, Y. (2003). Changes in the physico-chemical properties of wheat and soy containing breads during storage as studied by thermal analyses. *Journal of Food Science*, 68, 2022–2027.
- Watanabe, M., Maeda, T., Tsukahara, K., Kayahara, H., & Morita, N. (2004). Application of pregerminated brown rice for breadmaking. *Cereal Chemistry*, 81, 450–455.
- Wikström, F., Williams, H., Verghese, K., & Clune, S. (2014). The influence of packaging attributes on consumer behaviour in food-packaging life cycle assessment studies—A neglected topic. *Journal of Cleaner Production*, 73, 100–108.
- Wolfe, S. K. (1980). Use of CO₂- and CO₂ enriched atmospheres for meats, fish, and produce. *Food Technology*, 34(3), 55–63.
- Wu, K. L., Sung, W. C., & Yang, C. H. (2009). Characteristics of dough and bread as affected by the incorporation of sweet potato paste in the formulation. *Journal of Marine Science and Technology*, 17, 13–22.
- Xiong, X. L. (2000). Protein oxidation and implications for muscle food quality. In *Antioxidants in muscle foods* (pp. 85–111) (Chapter 4).
- Zakrys, P. I., Hogan, S. A., O'Sullivan, M. G., Allen, P., & Kerry, J. P. (2008). Effects of oxygen concentration on sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. *Meat Science*, 79, 648–655.
- Zakrys, P. I., O'Sullivan, M. G., Allen, P., & Kerry, J. P. (2009). Consumer acceptability and physiochemical characteristics of modified atmosphere packed beef steaks. *Meat Science*, 81, 720–725.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., Allen, P., O'Neill, E. E., & Kerry, J. P. (2010). Investigation of the effects of commercial carcass suspension (24 and 48 hours) on meat quality in modified atmosphere packed beef steaks during chill storage. *Food Research International*, 43, 277–284.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., O'Neill, E. E., & Kerry, J. P. (2012). The effects of high oxygen modified atmosphere packaging on protein oxidation of bovine *M. longissimus dorsi* muscle during chilled storage. *Food Chemistry*, 2, 527–532.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., Walshe, H., Allen, P., & Kerry, J. P. (2011). Sensory comparison of commercial low and high oxygen modified atmosphere packed sirloin beef steaks. *Meat Science*, 88, 198–202.



Magnitude estimation— alignment of sensory and instrumental analysis

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Introduction

Measurements of sensory indices allow convenient and accurate quantification of responses that otherwise require evaluation by human sensory responses. Sensory measurements will always be the default reference method for evaluation, but instrumental techniques can be cheaper if reliably implemented in the measurement environment. Although sensory evaluation is routinely used in the industry to evaluate the quality of foods, including reformulated products, these approaches can be expensive and time-consuming. However, it must be noted that sensory analysis is still an optimum approach when undertaking such analysis. Alternatively, instrumental techniques are widely used to assess quality attributes and determine changes in quality (Dijksterhuis, 1995; Kong & Singh, 2011) and are invaluable in understanding how reformulation effects product matrices. Color, aroma, taste, flavor, and texture are all important factors affecting food and beverage quality. As these sensory modalities are

assessed by human responses, it is important that reproducible and reliable methods are available to accurately quantify them (O'Sullivan & Kerry, 2008). A considerable amount of research has been undertaken to investigate the suitability of advanced sensor technology to simulate human sensory responses. The development of valid and relevant instrumental methods in concert with dynamic sensory methods has allowed for a more comprehensive analysis of human perception (Ross, 2009). Thus sensory-based instrumental methods are often employed to measure sensory changes that occur in food products. The idea behind such methods is that sensory perceptions have chemical and physical counterparts in the substance under investigation (Dijksterhuis, 1995). Instrumental methods are usually quick and directly correlated to a sensory-based criterion. Instrumental and sensory limits can be assessed using survival analysis results to determine what instrumental limits correspond to the appropriate sensory limit of acceptability (O'Sullivan & Kerry, 2013). Also, these devices are an additional modality that are invaluable in determining the physico-chemical aspects of reformulation on food or beverage products as well as quantifying visual, aroma-flavor chemistry, and structural changes over shelf life. Some instruments are more closely correlated to the human sensory response than others. Color evaluation, for example, can very accurately quantify color of food and beverages, probably better and more consistently than a human sensory panel, either trained or untrained. Chemometrics, which uses multivariate data analysis to interpret sensory-based instrumental data, is an important research area that ultimately will determine the extent to which sensory-based instrumental technology is applied. This chapter will discuss sensory-based instrumental methods for color assessment based on colorimetry and computer vision technology, texture systems (texture and rheology) and odor-based instrumental methods [gas chromatography (GC)/mass spectrometry (MS) (GC-MS) and the electronic nose (EN)], and flavor-based systems [the electronic tongue (ET)]. Near infrared (NIR) and Fourier transform infrared (IR) (FTIR) spectroscopic methods will also be discussed.

Classical magnitude estimation relates rheological measurements (instrumental) to human sensory responses. An example is the instrumental analysis of texture calibrated to that perceived in the mouth using classical rheological devices like the rheometer (e.g., Brookfield) or the more complex dynamic rheometer (oscillatory). Magnitude estimation uses conventional rheological measurements to generate data using mathematical modeling to directly correlate to mouth perception. Limitations have

been observed in using rotational rheometers in which they worked relatively well for random-coil polysaccharides but constantly underestimated viscosity for shear thinning polysaccharides such as Xanthan gum. Dynamic viscosity (Oscillatory) produced mechanical spectra using oscillatory measurements that could account for this discrepancy as the rotating surfaces of the measurement plate more closely mimicked how mouthfeel is perceived in the human mouth. However, texture analysis using a texture profile analyzer, up to now, has not effectively simulated the human perception of texture but new innovations in a field known as tribology appear to be closing this gap. Tribology is the study of friction and lubrication between interacting surfaces in relative motion and can be applied to the interacting surfaces in the mouth such as, teeth—teeth, tongue—palate, tongue—teeth, teeth—food, tongue—food, tongue—bolus, lips, lips—food, bolus—palate, food particles—oral surfaces, during food consumption (Stokes, Boehm, & Baier, 2013). At the early stages of food structural breakdown, the dominant factor is bulk rheology but this gradually shifts to tribology as eating progresses (Wang & Cheng, 2017). The pros and cons of different instrumental techniques for measuring color, aroma/flavor, and texture will thus be discussed with focus on applications for reformulated products.



Color vision systems and color determination

Color of food and agricultural products is influenced by the internal biochemical, microbial, physical, and chemical changes, which often result from growth, ripeness, and postharvest handling and processing stages, thus, color assessment has been utilized for the indirect estimation of internal quality characteristics, such as freshness, maturity, variety, and desirability (Wu & Sun, 2013b; Zhang et al., 2014). The first sensory parameter we encounter as consumers is usually color, either through transparent packaging or immediately on opening secondary or primary packaging. When consumers consider buying fresh products, such as fruits, vegetables, and meat, color is used as a quality parameter (MacDougall & Hutchings, 2002). Colors can fade in products, as with soft drinks, or become oxidized by light over time to develop negative sensory color characteristics. Determination of meat quality parameters has always been essential throughout the production system because consumers are always

demanding superior quality of meat and meat products (Elmasry, Barbin, Sun, & Allen, 2012; McDonald & Sun, 2001; McDonald, Sun, & Kenny, 2001). Consumers perceive this color loss as a sign of quality deterioration for certain foods and beverages where color changes can occur; it will be one of the principal sensory factors that will define quality and shelf life (Sutherland, Varnum, & Evans, 1986). In some cases, color will be the primary purchase criteria such as when we buy fresh meat. The color of meat will, over time, convert from a cherry red color to an unsightly brown color over time due to pigment oxidation. The meat is still safe to eat but a consumer will choose a red product in preference. In fresh meat products the cherry red color of oxymyoglobin will oxidize to the gray-brown pigment of metmyoglobin over time. Oxymyoglobin is a heme protein in which iron exists in the ferrous form (Fe^{2+}), unlike metmyoglobin that possesses the ferric form (Fe^{3+}). The conversion of the ferrous to the ferric form is a result of oxidation (Liu, Lanari, & Schaefer, 1995). Consumers relate this bright-red color to meat that is fresh, while, discriminating against meat that has turned brown in color, which they consider unsightly. At the point of sale, color and color stability are the most important attributes of meat quality and various approaches have been used to meet consumer expectations that an attractive, bright-red color indicates a long shelf life and good eating quality (Hood & Mead, 1993). Thus it is important to quantify the color quality, particular of red meat products such as beef, lamb, and pork (O'Sullivan & Kerry, 2013). Color is also one of the main quality parameters of wines and has an important influence on the overall acceptability by consumers (Martin, Ji, Luo, Hutchings, & Heredia, 2007). For standard beer analysis, EBC (European Brewing Convention) color and bitterness units can be assessed by photometry (Lachenmeier, 2007). Color is a major quality attribute in olive oil that darkens during storage and needs to be evaluated in a robust quality authentication system (Sanaeifar, Jafaria, & Golmakanic, 2018).

Instrumental methods have been developed that can accurately measure the color characteristics of food products and have been used in the food and beverage industries for many years (O'Sullivan, 2017). In image analysis for food products, color is an important attribute and robust descriptor that often simplifies object extraction and detection from an image, and it is the first factor that influences the consumer to choose or reject a foodstuff (Sanaeifar et al., 2018). The Minolta colorimeter (Minolta Camera Co. Ltd., Osaka, Japan) is widely used by both the industry and research institutes to measure meat color quality as well as

color quality of many other products. This small portable handheld device can use different measurement coordinates, but the principal one used for meats are the Commission Internationale d'Eclairage (CIE), L (white to black), a (green to red), and b (blue to yellow) values (O'Sullivan, 2017). The $L^*a^*b^*$, or CIELab, color space is an international standard for color measurements, adopted by the CIE in 1976 (CIE, 1986) and is very close to human perception of color (Wu & Sun, 2013a). O'Sullivan, Byrne, Stagsted, Andersen, and Martens (2002) investigated the color sensory quality of retail displayed pork patties using traditional sensory methods and a Minolta colorimeter. These authors found that the RED sensory term, as quantified by a trained sensory panel, was significantly ($P < .01$) positively correlated to a values determined by the Minolta colorimeter. This demonstrates that instrumental devices can be accurate and be correlated to actual sensory modalities. On the other hand, Huselegge, Engel, Buist, Merkus, and Klont (2001) found significant differences between Minolta CR300 devices when they analyzed 56,000 veal carcasses. They explained that these discrepancies were to the fact that individual Minolta instruments were operated by two different persons, who may not have placed the instrument on the same site. Meat is not a homogenous material and variations in pigment concentration, and therefore development of metmyoglobin occurs on the surface of meat during display in commercial retail conditions (O'Sullivan, 2017; O'Sullivan & Kerry, 2013). Meat color is difficult to assess because of this color variation over a meat cut, even from within the same muscle (AMSA, 1991). Taking a picture of the entire surface of a meat sample can provide a more representative color profile compared to the point-to-point measurements of traditional colorimeters (O'Sullivan, Byrne, Martens, et al., 2003).

Traditionally, quality inspection of agricultural and food products has been performed by human graders. However, in most cases, these manual inspections are time-consuming (Di Rosa, Leone, Cheli, & Chiofalo, 2017). Also, factors affecting fruits and vegetables can be quantified visually, which is laborious, expensive, and is easily effected by physical factors, including inconsistent evaluation and subjective results (Bhargava & Bansal, 2018). Thus to ensure food conformity to consumer expectations, it is critical for the food processing industry to develop effective color-inspection systems to measure the color information of food product during processing operations and storage periods (Wu & Sun, 2013a). Recently, imaging techniques have been applied for visual evaluation of meat and other food quality and for rapidly identifying quality problems

on the processing line by color, shape, size, and surface texture (Du & Sun, 2006; Fathi, Mohebbi, & Razavi, 2009; Yang, Chao, & Kim, 2009; Zheng, Sun, & Zheng, 2006b). Computer vision systems applications are targeted at those food products for which the appearance is the main key quality attribute evaluated by the consumers (Di Rosa et al., 2017). Advantages of computer vision systems are noninvasive, objective, consistent, and rapid estimations of meat palatability (Jackman, Sun, Du, & Allen, 2009). In addition, computer vision systems can be used to classify food products into specific grades, detect defects, and estimate properties such as color, shape, size, surface defects, and contamination (Ma et al., 2016). Shrivastava, Singh, and Hooda (2016) explored computer vision as a method to detect and categorize soybean plant foliar diseases with mixed results. Computer vision is a rapid, objective, and economic inspection technique that could provide a detailed characterization of color uniformity at pixel-based level (Wu & Sun, 2013a). The hardware configuration of a computer vision system consists of an illumination device, a camera, a personal computer, and a high-resolution monitor (Wu & Sun, 2013a).

Sanaeifar et al. (2018) investigated fusion of dielectric spectroscopy and computer vision for the characterization of olive oil quality indices during storage. After data preprocessing, classification and prediction models were developed and compared. These authors found the best result in the classification of olive oils during the storage period was obtained by a Bayesian network technique with 100% accuracy. Papadakis, Abdul-Malek, Emery-Kamdem, and Yam (2000) investigated using a high-resolution digital camera to capture images of different types of microwavable pizza bases and used computer software (Photoshop, Adobe Systems Inc., California, United States) to obtain color parameters from digital images. They found this system to be versatile, affordable, and easy to use and presented the technique as applicable to many other foods besides pizza.

Matiacevich, Silva, Enrione, and Osorio (2011) investigated different quality indicators for different blueberry cultivars hand-harvested in Chile during storage using computer vision. Digital images from each blueberry (both front and back) were captured at each storage time through a computer vision system. These authors found that the method was useful for the objective quality evaluation of fruits such as color, dehydration signs, fungal growth, epicuticular wax presence, with a possible application in online packing control.

O'Sullivan, Byrne, Martens, et al. (2003) investigated the color parameters of various fresh pork meat patties using a high-resolution digital camera correlated to sensory color data with a custom algorithm

(MATLAB, Massachusetts, United States). These authors found that the digital camera-derived “a Values” correlated to a greater extent to the sensory RED term compared to the Minolta colorimeter measurements for both trained and untrained panels. Zapotoczny, Szczypiński, and Daszkiewicz (2016) determined the quality of 16 types of pork (PK) and poultry (PL) cold meats by digital image analysis. They used canonical analysis to determine correlations between the chemical composition and image textures of the cold meats. The developed statistical model discriminated cold meats with 89%–100% accuracy, subject to product type with a relatively high correlation (coefficients of correlation, 0.7–0.92) of chemical composition to image texture parameters. Tomasevic et al. (2019) studied color measurements using a standard colorimeter and computer vision on fresh processed, raw cured, cooked cured, raw-cooked, precooked–cooked meat products, and raw (dry) fermented sausages. They found that computer vision was more accurate and precise for measuring color not only of uniformly colored samples, but especially better for bicolored and nonuniformly colored meat. Jackman, Sun, Allen, Brandon, and White (2010) correlated computer vision methodology to consumer panel palatability data for beef samples. These authors found that it is possible for consumer opinion of beef likeability to be accurately modeled by using image color, marbling, and surface texture features.

Computer vision technology has also been applied to many food products including processed meat (Tomasevic et al., 2019), pork (Lu, Tan, Shatadal, & Gerrard, 2000; O’Sullivan, Byrne, Martens, et al., 2003), beef (Jackman et al., 2010; Zheng, Sun, & Zheng, 2006a), poultry (Zapotoczny et al., 2016), fish (Quevedo, Aguilera, & Pedreschi, 2010), ham (Valous, Mendoza, Sun, & Allen, 2009), fruits (Arakeria & Lakshmana, 2016; Balaban, Aparicio, Zotarelli, & SIMS, 2008; Zou, Zhao, Li, & Holmes, 2010), pizza (Papadakis et al., 2000), cheese (Everard et al., 2007), wheat (Zapotoczny & Majewska, 2010), olive oil (Sanaeifar et al., 2018), and tea (Xu, Wang, & Gu, 2019).



Instrumental methods for measuring texture

Texture can be evaluated by objective methods, instrumental or sensory (trained panels) or by subjective methods (consumer panel). Sensory analysis is the gold standard for determining food texture; however, descriptive sensory panel training and maintenance is

time-consuming and expensive (Lawless & Heymann, 2010; Platter et al., 2003). Due the way in which a food deforms, fractures, flows, and breaks down is a key component of textural sensations, significant effort has been given to determining relationships between food rheological behaviors and sensory texture attributes (Joyner (Melito), 2018). Force (F), deformation (D), and time (t) are three basic variables used in studying the mechanical properties of foods. The external force, measured in Newtons (N) or deformation relationship for most food materials is dependent on time or loading rate (Lu, 2013). Thus there have been many attempts to devise instrumental methods of assessing the force shearing, penetrating, biting, mincing, compressing, and stretching of foods whose results are a prediction of tenderness ratings obtained by taste panels (Lawrie & Ledward, 2006). The most widely used method for measuring meat texture is the single blade shear test of the Warner—Bratzler (WB) type (Culioli, 1995). The WB shear (WBS) test is an indicator of meat sensory hardness (tenderness) and almost the sole methodology used in raw meat (Bratzler, 1932; Culioli, 1995; Warner, 1928). The WBS device (Bratzler, 1932) with its familiar blade (triangular hole in the middle) remains one of the most ubiquitous meat texture measuring devices. Other machines built to measure rheological parameters of foods and materials usually include a version of the WB blade as a basic attachment to the system (Lyon & Lyon, 1998). Destefanis, Brugiapaglia, Barge, and Dal Molin (2008) and McMillin (2008) suggest that WBS values of less than 42.87 N and greater than 52.68 N allow classification of tough and tender beef in a sufficiently reliable way to be highly related to consumer tenderness perception (Destefanis et al., 2008; McMillin, 2008). Shackelford, Wheeler, and Koohmaraie (1997) state that WBS force is an imprecise predictor of beef tenderness characteristics determined by sensory-trained panelists. The results obtained from using this method can be variable and depend on many factors, such as muscle type, sample preparation, cooking method, shear apparatus, measurement procedure, and panel type (Destefanis et al., 2008). In addition, the width of the blades, position of the triangle, the speed of the test, the shape, mass, and orientation of the test sample are important to interpret the results of shear tests. However, this critical information is often omitted from reports on testing protocols (Lyon & Lyon, 1998). Thus it is sometimes difficult to replicate a previous workers study due to this lack of information (O’Sullivan, 2017).

As discussed in Chapter 10, Validation and safety of reformulated products (shelf life testing), texture changes for many products over the

course of shelf life. Fruits become soft, vegetables wilt, bread surface softens and becomes leathery as moisture evaporates, biscuits soften due to moisture uptake, and cream liqueurs become viscous due to ethyl ester esterification resulting in reduced sensory consumer perception. Also, tenderness, which denotes the texture of meats has often been described as the most important factor in terms of high eating quality of meats, especially in beef (O'Sullivan & Kerry, 2013; Zakrys, Hogan, O'Sullivan, Allen, & Kerry, 2008; Zakrys, O'Sullivan, Allen, & Kerry, 2009; Zakrys-Waliwander, O'Sullivan, Allen, O'Neill, & Kerry, 2010; Zakrys-Waliwander, O'Sullivan, O'Neill, & Kerry, 2011; Zakrys-Waliwander, O'Sullivan, Walshe, Allen, & Kerry, 2011).

Also, as described above, texture can be quantified by sensory methods (descriptive or affective). However, these approaches can be expensive, cumbersome, and time-consuming (Platter et al., 2003). Firmness is important for fresh fruits, including apples where it is measured by the standard destructive penetrometric test. This type of test, or puncture test, is often used to measure the force required for a probe to penetrate into a food to a specified depth and involves both compression and shearing of a food sample and is analogous to the biting of a food item in the mouth (Lu, 2013). Thus many less expensive instrumental methods have been developed to routinely determine the texture of foods and beverages (Lawrie & Ledward, 2006).

One of the most common texture measuring devices is the texture profile analyzer (TPA). The TPA can be employed in determining the texture of meat, cheese, vegetables, bread, cakes, crackers, cookies, chocolate, or any solid or semisolid type food products. However, the development of foods with adequate texture also involves the use of multivariate tools, structuring different areas such as culinary arts, food science, materials science, sensory science, and the study of consumer behavior (Saldaña et al., 2015). The texture of these products may become either softer or harder depending on composition, packaging and storage humidity, and temperature. Shear tests are the simplest and most common tests used to document food texture (O'Sullivan, 2017). Texture analysis of meat products involves the uniaxial compression of food samples between two plates and shear tests measure the force to cut through fibers of cooked samples. They are the simplest and most common tests used to document

raw and cooked meat texture (O'Sullivan & Kerry, 2013). One drawback of texture analysis is that information obtained from shearing devices that perform in a similar way may not be interchangeable (Lyon & Lyon, 1998). Instrumental tests can be designed to measure mechanical properties that impact texture attributes and approximate human actions used during texture evaluation, but these tests cannot measure texture attributes directly (Joyner (Melito), 2018). The mechanical process of mastication has been simulated using texture profile analysis. This objective method measures the compression force of a probe and the related textural parameters of a test food during two cycles of deformation (Caine, Aalhus, Best, Dugan, & Jeremiah, 2003). TPA is a two-cycle compression test that mimics the first two bites to a food where TPA parameters are often related to compression sensory terms, such as firmness and adhesiveness (Chen & Stokes, 2012). Variates that can be assessed with this analysis are hardness, springiness, cohesiveness, adhesiveness, resiliency, fracturability, gumminess, chewiness, etc. In meat the variates assessed are hardness, springiness, and cohesiveness; the three altogether permit the calculation of chewiness (Ruiz de Huidobro et al., 2001). However, users of TPA should be careful not to violate TPA assumptions and carefully select parameters for analysis, as not all parameters apply to all samples (e.g., bread is not generally adhesive) (Joyner (Melito), 2018).

Food rheology is the study of deformation and flow of foods under well-defined conditions and has been shown to be closely correlated with food texture (Bourne, 2002). For liquids texture is described as viscosity. A viscometer is an instrument used to measure the viscosity of a fluid. Typically rotational viscometers are used to quantify the viscosity of cream liqueurs, such as the "Cup and bob" type, which measure the torque required to rotate the bob in a fluid at a known speed, where this measured torque is a function of the viscosity of that fluid (O'Sullivan, 2011). Emulsion-based alcoholic beverages such as cream liqueurs become more viscous over time, and this can be a limiting factor with respect to quality and shelf life, thus requiring monitoring using rheological measurement. Some of the measurements that can be used to assess cream liqueur shelf life include droplet size distributions and viscosity (O'Sullivan, 2011). Viscosity of cream liqueurs can be determined using a viscometer such as Carri-med CSL 100 rheometer (Carri-Med Ltd., Dorking, Surrey, United Kingdom) (O'Sullivan, 2011). This is generally performed at a constant shear rate at a specific temperature, 20°C (Lynch & Mulvihill, 1997; Power, 1996). Also, the Brookfield Synchro-Lectric Viscometer utilizes a

series of cylindrical spindles and horizontal disks which are rotated at fixed speeds while the torque required to overcome the viscous drag of the fluid is recorded. Conversion tables are available to convert this into Newtonian viscosity (McKenna & Lyng, 2013). However, sensory viscosity may not be well predicted by rheological measurements. Janhoj, Bom Frøst, and Ipsen (2008) investigated the relationships between rheological and sensory attributes of acidified milk drinks and found that creaminess appeared to be largely determined by sensory viscosity (viscosity as perceived by the consumer), but the science of relating sensory and rheological properties is hampered by poor physical definition of the sensory terms. Traditional rotational viscometry is an appropriate technique for measuring random-coil polysaccharides and can yield data which can be correlated to sensory derived magnitude estimation type experiments which will be discussed below. However, shear thinning polysaccharides, like xanthan gum, do not correlate well to this methodology and viscosity is consistently underestimated using this approach (Wood, 1968). The reason for this is that xanthan gum has high viscosity at low shear rates which falls as force is applied and its sensory rheological properties do not correlate to rotational viscometry as it is a poor reproduction of the physics of oral processing in the mouth. On the other hand, oscillatory rheometry and the collection of mechanical spectra provide good correlation to sensory data for both random-coil polysaccharides and shear thinning polysaccharides.

Magnitude estimation is a technique standardly applied in psychophysics to measure judgments of sensory stimuli (Stevens, 1975). The magnitude estimation procedure requires subjects to estimate the magnitude of physical stimuli by assigning numerical values proportional to the stimulus magnitude they perceive. A sensory value of 100 may be assigned to a particular sensory stimulus and thus 200 to twice the intensity of that reference or 50 to half the intensity of the reference stimulus. In this fashion sensory evaluations can be correlated directly to instrumental observations. Highly reliable judgments can be achieved for a whole range of sensory modalities.



Tribology

As determined by Wood (1968) many years ago the measurement of viscosity at 50 s^{-1} using traditional rheometry was comparable to human sensory responses of viscosity. Wood (1968) pioneered work in

this area. He took samples with different flow behaviors (i.e., that gave different flow curves) and plotted the flow curves obtained using rotational viscometry. He then asked panelists to rank the samples in terms of perceived thickness. Wood looked at the order of the samples in terms of thickness and looked at what shear rate gave viscosity values for the sample that gave the same order. Wood concluded that if one used a shear rate of 50 s^{-1} that the rank order was the same for viscosity values and thickness ratings. Initial thickness perception has been found to reasonably correlate to viscosity measurements made at shear rates around 50 s^{-1} (Wood, 1968). However, Terpstra et al. (2005) and de Wijk, Janssen, and Prinz (2011) conducted a range of experiments on custard and soft food where they compared instrumental sensory and physiological measurements (de Wijk et al., 2011; Terpstra et al., 2005). These authors found that in fact viscosity at 50 s^{-1} does not enable prediction of complex sensory sensations of creaminess, fattiness, smoothness, and stickiness. They found that these properties are dependent on the rheology of the bolus formed and on other “surface-related” properties that can be measured using tribology (Fig. 12.2) (de Wijk, Prinz, & Janssen, 2006).

While tribology is clearly important to oral processing, the challenge is how to interpret and utilize tribological measurement techniques to obtain meaningful insights into oral processing, texture, and mouthfeel (Stokes et al., 2013).

According Stokes et al. (2013) studies into food oral tribology can be split into three categories: imitative, empirical, and fundamental approaches. Imitative approaches using animal tongues (pigs) are currently the only way to effectively study how the specific topology of the tongue surface influences lubrication between the esophagus or glass surface (Dresselhuys, de Hoog, Cohen Stuart, & van Aken, 2008; Dresselhuys et al., 2007).

Empirical approaches are those merely seeking a relationship between some friction coefficient and texture/mouthfeel perception. Purely empirical approaches do not easily lead to insights to actual mechanisms. The use of different configurations such as surfaces and geometries that are not well-defined makes it difficult to determine underlying mechanisms for observed tribological responses. A simple friction coefficient cannot predict a texture or mouthfeel attribute where it can be used for rational design by product developers (Stokes et al., 2013). Despite a growing consensus of the importance of oral tribology on the oral sensation of specific sensory features (e.g., creaminess, smoothness, and astringency), there is still a lack of experimental evidence to support this (Wang & Cheng, 2017).

Fundamental studies contribute to the understanding of oral tribology and food lubrication. The ball-on-disk in a mixed rolling and sliding contact using at least one (preferably two) polydimethylsiloxane substrate which are designed to emulate the tongue surface is the most widely set up for such studies, (Stokes et al., 2013). Some key oral processing conditions such as tongue movement speed, tongue pressure, film thickness, as well as bulk rheological properties of the thin layer of food and saliva between the tongue and palate need to be better understood before oral tribology measurements can be linked directly to sensory measurements (Wang & Cheng, 2017).



Sensory-instrumental methods—gas chromatography/mass spectrometry

GC is a routine method used in the analysis of characteristic food odors by headspace/direct GC–MS (Grigioni, Margaria, Pensel, Sánchez, & Vaudagna, 2000). It is the most useful method for the analysis of volatile compounds where individual volatile compounds are separated by their vapor pressure, interaction (or lack of) with the column stationary phase and usually by a temperature gradient applied to the column (Kilcawley, 2015). Using this method (GC) a sample is injected into an inlet and volatilized in the injector and swept onto a column by a carrier gas (Kilcawley, 2015) and the volatiles are separated in a column as they are forced along by a carrier gas, and the analytes are labeled and quantified by a detector. Utilization of a flame ionization detector or MS are the most often used detectors (Kong & Singh, 2011). GC–MS utilizes a mass spectrometer as a detector after volatile separation, using the column, can yield information on the concentration of volatiles present in a sample. MS detectors operate by using ionization energy (electron or chemical) to fragment molecules exiting a GC column in a gas stream. The fragments are categorized based on their mass to charge ratio (m/z) and detected as ion profiles. These profiles are in turn compared to an online reference mass spectral library that in conjunction with retention indices of standards (standard reference compounds) are used to positively identify the compound (Kilcawley, 2015). These volatiles can be flavor or odor in origin and can be used to quantify the flavor characteristics of foods and beverages or they can be chemicals which denote off-flavor

such as oxidation compounds. GC/MS is routinely used to identify chemical markers that can be used as indices of sensory quality (Kilcawley & O'Sullivan, 2017; O'Sullivan, 2017). The usefulness of GC/MS is obvious, but as a technique, it has certain drawbacks such as high operating costs and methods can be time-consuming (Pryzbylski & Eskin, 1995). Also, GC/MS requires considerable analytical skills, involve a lot of tedious and complex pretreatment of samples, and use many hazardous organic reagents that require high costs for storage and disposal (Huang, Liu, Zhang, & Wu, 2015).

For a standard spirit drink analysis, higher alcohols and other volatile compounds are determined using GC (Lachenmeier, 2007). With respect to food products much work has undertaken in order to identify chemical markers of oxidation that can be directly correlated to human sensory responses. GC is used to monitor volatile lipid oxidation products of food and is commonly used to quantify the secondary oxidation products, including aldehydes, ketones, alcohols, short carboxylic acids, and hydrocarbons (Kong & Singh, 2011) and thus is a useful tool in shelf life analysis. Holm, Schäfer, Skov, Koch, and Petersen (2012) showed that the GC/MS-derived microbial metabolites 2- and 3-methylbutanal, 2- and 3-methylbutanol, acetoin, and diacetyl were closely related to the changes of the sensory attributes meaty and sour and old odor in saveloy, a Danish cooked sliced pork sausage or luncheon meat type product. Thus these aroma compounds could be used as chemical markers for the sensory shelf life of sliced saveloy (Holm et al., 2012). GC/MS is also often used to quantify fatty acid composition fatty acid composition of many different foods including meat and dairy products. The intramuscular fatty acid composition of the monogastric animals and, in particular, the triacylglycerols are a reflection of the dietary fatty acids, while in ruminants the biohydrogenation in the rumen (i.e., saturation of the dietary unsaturated fatty acids) is responsible for the smaller variations in intramuscular fatty acid composition (Raes, De Smet, & Demeyer, 2004).

Ethyl esters form due to the reaction of alcohol and fatty acids and can result in the formation of excessive levels of short-chain fatty acids such as ethyl acetate, ethyl butanoate, and ethyl hexanoate, which are the principal causes of a fruity defect in cream liqueurs. Increases in these compounds correlate to increasing shelf life. Thus the level of fruitiness may become a limiting factor to consumer acceptance in aged liqueurs (O'Sullivan, 2011). Typically the levels of these ethyl esters can be monitored and quantified using GC or GC-MS and liquid extraction of methylated esters or using solid-phase microextraction (O'Sullivan, 2017).



Figure 12.1 Agilent GC–MS with GCO sniffer port. GC–MS, Gas chromatography/mass spectrometry; GCO, GC-olfactometry.

The specific aroma and flavor properties of cheese are designated by characteristic volatile compounds and can be quantified by various GC methods. The metabolism of carbohydrates (lactose and citrate) by LAB (lactic acid bacteria) produce signature aromatic compounds resulting in acetate, diacetyl (2,3-butanedione), acetaldehyde, acetoin (3-hydroxy 2-butanone), ethanol, 2,3-butanediol, propionate, and lactate. In addition, short-chain free fatty acids (butyrate, caproate, caprylate, and caprate) are the product of lipolysis and are both volatile and odor active. Many cheese aroma compounds are also formed from the metabolism of amino acids (leucine, isoleucine, and valine) (Kilcawley, 2015).

GC-olfactometry (GCO) is a method closely aligned with trained sensory panelists. The trained individual qualitatively and quantitatively measures volatiles in parallel to the GC–MS by means of a sniffer port interface. This is a powerful technique where the sensory potency of a compound can be better quantified than GC elution area or peak area (Kilcawley, 2015; Plutowska & Wardencki, 2008) (see Fig. 12.1).



Sensory-instrumental methods—electronic nose

Persaud and Dodd (1982) were some of the first scientists to propose the concept of an artificial nose system. The EN is a technology designed to mimic the olfactory system of humans (Song et al., 2013).

The EN functions very differently compared to either sensory evaluation or quantitative GC–MS. The outputs from the EN typically do not give any information about the compounds causing the investigated aroma; neither the identity of the compounds nor their sensory properties (O'Sullivan & Kerry, 2013). It is essentially an artificial olfactory system based on GC volatile analysis that can detect and recognize a wide spectrum of odor patterns and determine the odor intensity of mixtures of a variety of volatile oil–degradation compounds (Kong & Singh, 2011). Using the EN the aroma is judged by the so-called aroma pattern, which should be characteristic to the investigated substrate (Siegmund & Pfannhauser, 1999). Pattern-detection techniques can analyze the information on the electric resistance variations and use them to detect and classify various smells (Mahmodi, Mostafaei, & Mirzaee-Ghaleh, 2019). The sensor array of an EN has a large information potential and will give a unique overall pattern of the volatiles. In principle, both the electronic and the human nose operate by sensing simultaneously a high number of components giving rise to a specific response pattern (Haugen & Kvaal, 1998). Gardner and Bartlett (1994) defined an EN as an instrument that comprises an array of electronic chemical sensors with partial specificity and an appropriate pattern-recognition system that is capable of recognizing simple or complex odors. E-nose technology has been employed both in research and in the food industry for quality control of raw and manufactured products: process, freshness and maturity monitoring, shelf life investigations, authenticity assessments of premium products and microbial pathogen detection (Di Rosa et al., 2017). Its application in the food industry has been increasing due to its rapidity, cost-effectiveness, objectivity, and simplicity (Kong & Singh, 2011). An EN can function as a rapid and nondestructive tool for online flavor characterization. Thus in food-production plants, there is a growing demand for online/at-line measurement of sensory relevant quality criteria. One promising technology in this capacity is the application of an EN (Hansen, Pedersen, & Byrne, 2005; O'Sullivan, Byrne, Jensen, Andersen, & Vestergaard, 2003). For example, the EN may provide a practical advantage over other methods and may have an application in an online/at-line capacity for the quality determination of meat products with respect to WOF development (O'Sullivan, Byrne, Jensen, et al., 2003).

The EN–detection system is an array of chemical gas sensors with a broad and partly overlapping selectivity for measurement of volatile compounds within the headspace over a sample combined with computerized

multivariate statistical data-processing tools (Gardner & Bartlett, 1994). In order to classify samples an EN combines the response profiles of the various sensors, which react to different types of volatile compounds in the sample gas (Rajamäki et al., 2006). An EN can detect different smells through use of an array of chemical sensors. These can compose metal oxide semiconductor sensors housed in a chamber. Each sensor may have a different level of sensitivity to the chemical compounds it interacts with (Mahmodi et al., 2019). If an EN is to be used in quality assurance and quality control programs for raw materials and/or end-products, there is a need to calibrate it against sensory assessment in order to determine the relevance of the measurements (Hansen et al., 2005). The EN has been assessed in the analysis of a large variety of different food products and has found application in the analysis of meat, poultry, and seafood including: fermented sausage (Eklöv, Johansson, Winquist, & Lundström, 1998), chicken (Ólafsdóttir, Martindóttir, & Jónsson, 1997; Rajamäki et al., 2006; Song et al., 2013), fish (O'Connell, Valdora, Peltzer, & Negri, 2001; Tian, Cai, & Zhang, 2012), meat loaf (Hansen et al., 2005), meat balls (Tikk, Haugen, Andersen, & Aaslyng, 2008), beef (Mohareb, Papadopoulou, Panagou, Nychas, & Bessant, 2016; Panigrahi, Balasubramanian, Gub, Logue, & Marchello, 2006), pork (Li, Wang, Sun, Zhao, & Huang, 2016; Tian et al., 2012), mutton (Tian, Wang, & Cui, 2013), and in the warmed-over flavor analysis of various meat products (e.g., Siegmund & Pfannhauser, 1999—chicken; Grigioni et al., 2000—beef; and O'Sullivan, Byrne, Jensen, et al., 2003—pork). The EN has also been used for eggs (Liu & Tu, 2012), honey (Huang et al., 2015; Cheng, Qin, Guo, Hu, & Wu, 2013), olive oil (Di Rosa et al., 2015), wine (Garcia, Aleixandre, Gutierrez, & Horrillo, 2006), fruits (Infante, Farcuh, & Meneses, 2008), pizza (Vestergaard, Martens, & Turkki, 2007), and dairy products (Ampuero & Bosset, 2003; Bougrini et al., 2014; Cevoli, Cerretani, Gori, Gallina Toschi, & Fabbri, 2011; Limbo, Sinelli, Torri, & Riva, 2009; Lorenzen, Walte, & Bosse, 2013; Marsili, 1999).

Electronic nose technology, although rapid and convenient, does have some drawbacks, and these include the noise of the detected major compounds, which may not be relevant to the aroma in question (Rodriguez-Mendez, Apetrei, & de Saja, 2008); sensor drift (Loutfi, Coradeschi, Mani, Shankar, & Balaguru Rayappan, 2015), and ambiguous qualitative or quantitative information from the responses obtained by each sensor, which provide highly variable data resulting in a sort of “fingerprint” of the sample (Ampuero & Bosset, 2003). O'Sullivan, Byrne, Jensen, et al.

(2003) used level correction, a multivariate data analytical tool, to normalize the data from sample sets analyzed at a 7-month interval prior to subsequent PLSR, and this allowed their direct comparison and to a certain extent accounted for sensor drift. Another potential drawback of the EN is that sensors must be replaced eventually as they have a limited life and new sensors from another batch will differ in performance (Haugen & Kvaal, 1998). One potential method of solving these fundamental problems is to use a reliable data analytical tool to correct for variations over time, possibly using a reference sample and secondly to use an EN in which the sensors do not require replacement (O'Sullivan et al., 2017h). O'Sullivan, Byrne, Jensen, et al. (2003) appear to counteract these issues by employing an EN, in an off-flavor experiment in pork, which used sensor technology (MGD-1, Environics Ltd, Finland), which do not wear out because the molecules measured do not come in direct contact with the sensors. The sensors work on the principle of ion mobility and ionization of gas molecules where the clusters formed through ion-molecule reactions are brought into different electrical fields perpendicular to the sample flow and detected.

Electronic nose devices have both large differences in sensitivity and selectivity from the human nose (Haugen & Kvaal, 1998). Hansen et al. (2005) demonstrated that an E-nose could predict the sensory quality of porcine meat loaf, based on measuring the volatiles in either the raw materials or the meat loaf produced from those raw materials. Also, Tikk et al. (2008) found a significant, positive correlation between the E-nose gas sensor signals, the WOF-associated sensory attributes and the levels of secondary lipid oxidation products for pork meat balls, a very popular Danish dish. O'Sullivan, Byrne, Jensen, et al. (2003) found that the EN device used, in the forementioned off-flavor experiment in pork, could clearly separate samples on the basis of muscle type, treatment, and degree of WOF development.

Electronic tongue

The first ET known as the “taste sensor,” was proposed by Hayashi, Yamanaka, Toko, and Yamafuji (1990). The device was composed of a multichannel electrode with transducers made of lipid membranes immobilized with a polymer, for the intension of mimicking the functions of human gustatory receptors. By mimicking the human tongue ET's can differentiate as well as quantify tastes such as sourness, saltiness, bitterness,

sweetness and umami (Kong & Singh, 2011), as well as astringent and pungent substances (Zou, Wan, Zhang, Ha, & Wang, 2015). The ET is described as “an analytical tool including an array of nonspecific, poorly selective chemical sensors with partial specificity (cross selectivity), coupled with chemometric processing, for recognizing the qualitative and quantitative composition of multispecies solutions” (Ha et al., 2015). The e-tongues do not provide information regarding the nature of the compounds present in the liquid food sample or a solid food transformed into a liquid sample, they generate a digital fingerprint of food material (Ghasemi-Varnamkhasti, Mohtasebi, & Siadat, 2010). ETs consist of an array of electrochemical sensors interfaced with advanced data-processing tools that are able to interpret the complex electrochemical signals developed to detect taste and olfaction in foods (Winquist, Lundström, & Wide, 1999; Kong & Singh, 2011). ET technology employs a large variety of chemical sensors in the design of devices including electrochemical (voltammetric, potentiometric, amperometric, impedimetric, conductimetric, and piezoelectric), optical or enzymatic sensors (biosensors) ion-selective field-effect transistor, with pattern-recognition tools for data processing. The most common systems, however, are based on potentiometric sensors (Ciosek & Wroblewski, 2011; Wardencki, Chmiel, & Dymerski, 2013).

The data-processing algorithms can also include principal component analysis (PCA) which is mostly used in identification/classification for qualitative purpose, partial least squares (PLS) which is mainly used in multidetermination for quantitative purposes, artificial neural networks (formed by algorithms inspired in biological neural systems) which is a powerful parallel computing method, especially suitable for nonlinear sensor signals and extremely related to human pattern recognition (Gil-Sánchez et al., 2015; Ha et al., 2015). Wei and Wang (2013) used voltammetric ET for the authentication of various honeys using PCA, discriminant function analysis, and cluster analysis. The ET combined with data processing allows liquid solutions to be sampled without alteration, and the ET will provide a characteristic fingerprint, similar to the E-nose, for the sample tested with the detection thresholds of sensors similar or better than those of human receptors. The ET employment is easy for liquid food products (milk, eggs, yogurt, and honey), whose preparation is limited to dilution and/or filtration, but laborious for solids (Di Rosa et al., 2017), although some researchers have developed approaches for beef (Apetrei & Apetrei, 2016; Zhang, Zhang, Meng, & Ren, 2015) and ham (Dang, Gao, Ma, & Wu, 2015).

ETs have emerged as rapid and easy-to-use tools, very promising for evaluation of food quality, especially in such situations in which only qualitative or semiquantitative information is required (Escuder-Gilabert & Peris, 2010). The data from the ET can be calibrated against those from a trained sensory panel. The e-tongue can easily “taste” raw substances, semiproductions and also new entities that are not yet allowed for human consumption (Wardencki et al., 2013). The major categories of applications for ETs for foodstuffs are freshness and shelf life evaluation as well as process monitoring, quality control studies, authenticity evaluation, and foodstuff recognition (Escuder-Gilabert & Peris, 2010). Electronic nose and ET technologies are sometimes combined for food flavor detection, simulating the coexistence of the two sensory functions in humans (Kong & Singh, 2011; Li, Wang, & Vigneault, 2006). To date ETs have found application in extra virgin oils (Rodríguez-Mendez et al., 2008), wine (Cetó, Apetrei, del Valle, & Rodríguez-Mendez, 2014; Cetó, Capdevila, Puig-Pujol, & del Valle, 2014), beer (Gutiérrez et al., 2013), fruit drinks and milk (Winqvist, Wide, & Lundstrom, 1997), dairy protein (Newman, Harbourne, O’Riordan, Jacquier, & O’Sullivan, 2014), milk (Dias et al., 2009), olive oil (Apetrei et al., 2010), and tomato (Beullens et al., 2008) products. Finally, ET technologies are still very much in an early stage of development and can be limited by sensor drift that can occur as the sensors age and with surface contamination (Ha et al., 2015).



Near infrared (NIR) and Fourier transform infrared spectroscopy

Reference method analysis of fat (Mojonnier), protein (Kjeldahl), moisture (oven drying), and other methods for salt (Volhard silver nitrate titration) are accurate but very slow for routine analysis (Rodríguez-Otero, Hermida, & Cepeda, 1995). IR spectroscopy techniques are rapid and convenient and very suited to dynamic reformulation projects, especially when several prototype variants are being tested. Near-IR reflectance (NIR) spectroscopy is an advanced and efficient tool for the estimation of quality attributes in food products (O’Sullivan & Kerry, 2013; Prieto, Roehe, Lavín, Batten, & Andrés, 2009). NIR spectroscopy is a sensitive, fast, and nondestructive analytical technique with simplicity in sample preparation allowing a simultaneous assessment of numerous food properties (Osborne, Fearn, & Hindle, 1993; Ripoché & Guillard, 2001).

IR is based on vibrational spectroscopy and explores the relationship between the interaction of light with matter (solids, liquids, or gases) in that part of the electromagnetic spectrum beyond the visible (390–700 nm) between 714 and 1×10^6 nm (Bureau, Cozzolino, & Clark, 2019). Identification of compounds by IR spectroscopy in food applications depends on the property of molecules to absorb IR light and experience a wide variety of vibrational motion characteristic of their composition. When coupled with chemometric data analysis techniques, NIR spectroscopy is a rapid technique that possesses potential selectivity for screening products for qualitative attributes (Kong & Singh, 2011). The IR region is subdivided into three [near-IR, mid-IR (MIR), and far-IR]. The boundaries between them are decided on by detector responses, that is, the near-IR (NIR) ($14,000\text{--}4,000\text{ cm}^{-1}$ or 714–2500 nm), the MIR ($4,000\text{--}400\text{ cm}^{-1}$ or 2500–25,000 nm) and the far-IR region ($400\text{--}10\text{ cm}^{-1}$ or 25,000– 1×10^6 nm) (Larkin, 2018). Near-IR spectroscopy uses a source producing light of known wavelength pattern (usually 800–2500 nm) and that enables it to obtain a complete picture of the organic composition of the analyzed substance/material (Van Kempen, 2001). It is based on the principle that different chemical bonds in organic matter absorb or emit light of different wavelengths when the sample is irradiated (Prevolnik, Čandek-Potokar, & Škorjanc, 2004). NIR and MIR are the regions containing the greatest number of applications pertaining to fruit and vegetable crops and their processed products (Bureau et al., 2019). For these reasons, NIR is considered one of the most promising on/in-line measuring devices for detecting fat, moisture, and protein content in meats, grain and grain products, milk and dairy products, and beverages and other products (Huang, Yu, Xu, & Ying, 2008). It is a technique often used for authentication of food products, such as fats and oils, soluble coffee, green coffee, and fruits (Kong & Singh, 2011). NIR spectroscopy has been successfully applied to the quantitative determination of major constituents (moisture, fat, and protein) in meat and meat products including beef (Alomar, Gallo, Castaneda, & Fuchslocher, 2003; Eichinger & Beck, 1992; Prevolnik et al., 2005; Prieto, Andres, Giraldez, Mantecon, & Lavin, 2006; Tøgersen, Arnesen, Nilsen, & Hildrum, 2003), pork (Brøndum et al., 2000; Ortiz-Somovilla, Espana-Espana, Gaitan-Jurado, Perez-Aparicio, & De Pedro-Sanz, 2007; Tøgersen, Isaksson, Nilsen, Bakker, & Hildrum, 1999), poultry meat (Abeni & Bergoglio, 2001; Berzaghi, Dalla Zotte, Jansson, & Andrighetto, 2005; Cozzolino & Murray, 2002; McDevitt, Gavin, Andres, & Murray, 2005;

Renden, Oates, & Reed, 1986; Valdes & Summers, 1986), and mutton (Viljoen, Hoffman, & Brand, 2007). Also, IR spectroscopy is one of the most relevant and widely used technologies in the dairy industry for raw material, process control, and end product specification analysis (De Marchi, Penasa, Zidi, & Manuelian, 2018). MIR spectroscopy is commonly employed by raw milk processors for standardization purposes before milk transformation, by the dairy industry for milk payment, and by farmers, technicians, and breeding companies (De Marchi, Toffanin, Cassandro, & Penasa, 2014).

FTIR spectroscopy uses an interferometer to generate modulated light and measures all IR wavelengths simultaneously, rather than individual wavelengths of the radiation. The interferogram is then converted into a conventional spectrum using the Fourier transform algorithm (Kong & Singh, 2011). FTIR has also found applications in distilled liquors and wines (Cocciardi, Ismail, & Sedman, 2005; Fernandez & Agosin, 2007; Moreira, Marcos, & Barros, 2002; Villiers, Alberts, Tredoux, & Nieuwoudt, 2012). Lachenmeier (2007) investigated FTIR in combination with PLS regression as an official food control multicomponent screening technique for spirit drinks and beer. He found that the majority of samples were classified as being in conformance with legal and quality requirements and that FTIR spectroscopy is faster and only requires a simple sample preparation compared to conventional methods. FTIR spectroscopy has substantial potential as a quantitative control method in the food industry (Van de Voort, Sedan, Emo, & Ismail, 1992) and has also been used to monitor shelf life of Crescenza cheese (Cattaneo, Giardina, Sinelli, Riva, & Giangiacomo, 2005) and ricotta cheese (Sinelli, Barzaghi, Giardina, & Cattaneo, 2005). FT-MIR has been used for the prediction of quality traits in Cheddar cheese (Margolies & Barbano, 2018), whereas FT-NIR.R (Fourier-transform near-IR spectroscopy in reflectance mode) has been used for Edam (Mlček, Rop, Dohnal, & Šustová, 2011) and Mozzarella (Manuelian et al., 2017). Flåtten, Bryhni, Kohler, Egelanddal, and Isaksson (2005) showed that marine fatty acids and general fatty acid composition in pork fat can be measured with good precision with FT-MIR. FTIR analysis is rapid, noninvasive, requires minimum sample pretreatment or specific consumables or reagents, and in conjunction with attenuated total reflectance (ATR) technology permits users to collect full spectra in a few seconds, allowing simultaneous assessment of numerous food properties (Ammor, Argyri, & Nychas, 2009; Ellis, Broadhurst, & Goodacre, 2004; Ellis, Broadhurst, Kell, Rowland, & Goodacre, 2002; Vlachos et al., 2006).

Interpretation of FTIR spectra is however not an easy task because the high sensitivity of FTIR to chemical environment implies that FTIR spectra are also very sensitive to experimental conditions, such as sample preparation or atmospheric conditions (Petit & Tuskar, 2018). In addition, it is necessary to process captured data from FTIR (also NIR) using an appropriate chemometric or multivariate data analytical method. This involves comparison of spectra, chemometrically, to a database of similar known samples or standards (O'Sullivan, 2017; O'Sullivan & Kerry, 2013). The best fit model that correlates to current results in the database presents the concentration of the known variable of interest. However, it is essential that a suitable database of known compounds in specific samples must be available, either through the instrument vendor or created by the scientists undertaking the work in order to derive any significant data from NIR or FTIR (O'Sullivan, 2017; O'Sullivan & Kerry, 2013). Anjos, Campos, Ruiz, and Antunes (2015) used FTIR-ATR and PLS regression model for the prediction of sugar content in honey samples. For lipid measurement it has the advantage of easy sample preparation, rapid measurements, and there is no use of chemicals in contrast to traditional solvent methods accompanied by chromatographic techniques (Flåtten, Bryhni, et al., 2005). Cheese composition analysis can use PLS calibration models which are typically developed locally in each cheese factory. However, these models require a large number of cheese samples (200–400) of each cheese type to be tested by reference chemistry and the NIR within each cheese factory (Barbano & Lynch, 2006).

FTIR spectroscopy has been used for authentication of many different types of edible oil including extra virgin olive oil, sunflower, corn, soybean, sesame, hazelnut (Gurdeniz & Ozen, 2009; Lerma-Garcia, Ramis-Ramos, Herrero-Martinez, & Simo-Alfonso, 2010; Vlachos et al., 2006), sesame, walnut, and peanut oils (Ozen & Mauer, 2002; Zhang, Liu, et al., 2012; Zhang, Wu, et al., 2012). In addition, Al-Jowder, Defernez, Kemsley, and Wilson (1999) and Al-Jowder, Kemsley, and Wilson (2002), identified and quantified adulteration of beef meat with heart, tripe, kidney, and liver using FTIR-ATR and multivariate analysis. Meza-Márquez, Gallardo-Velázquez, and Osorio-Revilla (2010) used Mid-FTIR-ATR spectroscopy with SIMCA (soft independent modeling class of analogies) to quantify and detect the adulteration of horse meat, textured soy protein, or the addition of fat beef trimmings in minced beef. In addition, the same model could simultaneously determine the composition (water, protein, fat, ashes, and glycogen) of the meat samples (99% confidence limit) (Meza-Márquez et al., 2010).

Package testing

As outlined in Chapter 10, Validation and safety of reformulated products (shelf life testing), when developing compensatory processes due to reformulation or preservative ingredient replacement it is also important to consider packaging, such that it is fit for purpose and will preserve and maintain shelf life as required. Depending on requirements, packages will have a specification for tensile strength, oxygen transmission rate (OTR), and moisture permeability of flexible barrier materials. Testing should thus be carried out as part of the total quality assurance process. Devices such as the TA-HD Plus (stable micro systems) can quantify packaging parameters such as coefficient of friction, puncture test, tear force, tensile strength, resistance to crushing/deformation, 3-point bend test to measure flexural properties, tamper-evident closures strength, torques of child-resistant closures, force of snap-caps and other closures, etc.

Moisture permeability may be quantified using a Mocon Permatran-W Model 3/33 Series (Fig. 12.2). This PERMATRAN-W 3/33 system uses an IR sensor to detect water vapor transmission through packaging material with ppm sensitivity. OTR can be measured using the Mocon Ox-Tran, Model 2/21 (Fig. 12.2). This device uses a coulometric sensor (Coullox) to detect oxygen transmission through both materials with ppb sensitivity even in the presence of water vapor.



Figure 12.2 On left a Mocon Permatran-W Model 3/33 Series for measuring moisture permeability. On right an oxygen permeation rate testing device, the OX-TRAN Model 1/50.

Packaging leak tests can be determined using the TM Electronics BT-1000 Automated Package Tester, which can also determine inflation seal-strength test (Burst test). Inflation seal-strength testing includes burst, creep, and creep-to-failure testing. Inflation tests are applicable to most materials (porous and nonporous) and most package forms such as pouches, lidded trays, and laminated or rolled tubes. The TM Electronics BT-1000 provides graphs of individual tests of products. The pressure at which the package bursts is a variable statistic that can be utilized to document process development and process control through the use of tools such as upper and lower control limits. Inflation package integrity test (leak test) or pressure decay testing is effective in determining leaks in flexible packages that have nonporous material surfaces and seals. The TM Electronics BT-1000, which is capable of performing both seal strength and package leak tests, has a resolution of 0.02 psi.

Gas analysis (MAP packs) in headspace can be undertaken qualitatively and quantitatively using the PBI Dansensor check Mate 9900. A needle is inserted into the pack through a rubber septum, placed on the pack beforehand, drawing the headspace gas mix into the tester. This device will give a reading of percent O₂, CO₂, and N₂ (by difference) in pack headspace.

References

- Abeni, F., & Bergoglio, G. (2001). Characterization of different strains of broiler chicken by carcass measurements, chemical and physical parameters and NIRS on breast muscle. *Meat Science*, 57, 133–137.
- Al-Jowder, O., Defernez, M., Kemsley, E., & Wilson, R. H. (1999). Mid-infrared spectroscopy and chemometrics for the authentication of meat products. *Journal of Agricultural and Food Chemistry*, 47, 3210–3218.
- Al-Jowder, O., Kemsley, E. K., & Wilson, R. H. (2002). Detection of adulteration in cooked meat products by mid-infrared spectroscopy. *Journal of Agricultural and Food Chemistry*, 50, 1325–1329.
- Alomar, D., Gallo, C., Castaneda, M., & Fuchslocher, R. (2003). Chemical and discriminant analysis of bovine meat by near infrared reflectance spectroscopy (NIRS). *Meat Science*, 63, 441–450.
- Ammor, S. A., Argyri, A., & Nychas, G. J. E. (2009). Rapid monitoring of the spoilage of minced beef stored under conventionally and active packaging conditions using Fourier transform infrared spectroscopy in tandem with chemometrics. *Meat Science*, 81, 507–514.
- Ampuero, S., & Bosset, J. O. (2003). The electronic nose applied to dairy products: a review. *Sensors Actuators B*, 94(1), 1–12.
- AMSA. (1991). *American Meat Science Association Committee on guidelines for meat color evaluation. Contribution No. 91-545-A*.
- Anjos, O., Campos, M. C., Ruiz, P. C., & Antunes, P. (2015). Application of FTIR-ATR spectroscopy to the quantification of sugar in honey. *Food Chemistry*, 169, 218–223.

- Apetrei, C., Apetrei, I. M., Villanueva, S., de Saja, J. A., Gutierrez-Rosales, F., & Rodriguez-Mendez, M. L. (2010). Combination of an e-nose, an e-tongue and an e-eye for the characterisation of olive oils with different degree of bitterness. *Analytica Chimica Acta*, 663(1), 91.
- Apetrei, I. M., & Apetrei, C. (2016). Application of voltammetric e-tongue for the detection of ammonia and putrescine in beef products. *Sensors Actuators B*, 234, 371–379.
- Arakeria, M. P., & Lakshmana. (2016). Computer vision based fruit grading system for quality evaluation of tomato in agriculture industry. In *International conference on communication, computing and virtualization* (pp. 426–433).
- Balaban, M. O., Aparicio, J., Zotarelli, M., & SIMS, C. (2008). Quantifying nonhomogeneous colors in agricultural materials. Part II: Comparison of machine vision and sensory panel evaluations. *Journal of Food Science*, 73(9), S438–S442.
- Barbano, D. M., & Lynch, J. M. (2006). Major advances in testing of dairy product: Milk components and dairy product attribute testing. *Journal of Dairy Science*, 89, 1189–1194.
- Bratzler, L. J. (1932). *Measuring the tenderness of meat by means of a mechanical shear* (Master of science thesis). Kansas State College (KA), USA.
- Berzaghi, P., Dalla Zotte, A., Jansson, L. M., & Andrighetto, I. (2005). Near-infrared reflectance spectroscopy as a method to predict chemical composition of breast meat and discriminate between different n-3 feeding sources. *Poultry Science*, 84, 128–136.
- Beullens, K., Mészáro, P., Vermeir, S., Kirsanov, D., Legin, A., Buysens, S., ... Lammertyn, J. (2008). Analysis of tomato taste using two types of electronic tongues. *Sensors and Actuators*, 131, 10–17.
- Bhargava, A., & Bansal, A. (2018). Fruits and vegetables quality evaluation using computer vision: A review. *Journal of King Saud University Computer and Information Sciences*, in press.
- Bougrini, M., Tahri, K., Haddi, Z., El Bari, N., Llobet, E., Jaffrezic-Renault, N., & Bouchikhi, B. (2014). Aging time and brand determination of pasteurized milk using a multisensor e-nose combined with a voltammetric e-tongue. *Materials Science and Engineering C*, 45, 348–358.
- Bourne, M. C. (2002). *Sensory methods of texture and viscosity measurement. Food texture and viscosity* (2nd ed., pp. 257–291). London and New York: Academic Press.
- Brøndum, J., Munck, L., Henckel, P., Karlsson, A., Tornberg, E., & Engelsen, S. B. (2000). Prediction of water-holding capacity and composition of porcine meat by comparative spectroscopy. *Meat Science*, 55, 177–185.
- Bureau, S., Cozzolino, D., & Clark, C. J. (2019). Contributions of Fourier-transform mid infrared (FT-MIR) spectroscopy to the study of fruit and vegetables: A review. *Postharvest Biology and Technology*, 148, 1–14.
- Caine, W. R., Aalhus, J. L., Best, D. R., Dugan, M. E. R., & Jeremiah, L. E. (2003). Relationship of texture profile analysis and Warner–Bratzler shear force with sensory characteristics of beef rib steaks. *Meat Science*, 64, 333–339.
- Cattaneo, T. M. P., Giardina, C., Sinelli, N., Riva, M., & Giangiacomo, R. (2005). Application of FT-NIR and FT-IR spectroscopy to study the shelf-life of Crescenza cheese. *International Dairy Journal*, 15, 693–700.
- Cetó, X., Apetrei, C., del Valle, M., & Rodriguez-Mendez, M. L. (2014). Evaluation of red wines antioxidant capacity by means of a voltammetric e-tongue with an optimized sensor array. *Electrochimica Acta*, 120, 180–186.
- Cetó, X., Capdevila, J., Puig-Pujol, A., & del Valle, M. (2014). Cava wine authentication employing a voltammetric electronic tongue. *Electroanalysis*. Available from <https://doi.org/10.1002/elan.201400057>.
- Cevoli, C., Cerretani, L., Gori, A., Gallina Toschi, T., & Fabbri, A. (2011). Classification of Pecorino cheeses using electronic nose combined with artificial neural network and

- comparison with GCMS analysis of volatile compounds. *Food Chemistry*, 129, 1315–1319.
- Chen, J., & Stokes, J. R. (2012). Rheology and tribology: Two distinctive regimes of food texture sensation. *Trends in Food Science and Technology*, 25, 4–12.
- Cheng, H., Qin, Z. H., Guo, X. F., Hu, X. S., & Wu, J. H. (2013). Geographical origin identification of propolis using GC–MS and electronic nose combined with principal component analysis. *Food Research International*, 51(2), 813–822.
- CIE. (1986) *Colorimetry* (2nd ed.). Kegelgasse 27 A-1030, Wien, Austria: CIE Central Bureau.
- Ciosek, P., & Wroblewski, W. (2011). Potentiometric electronic tongue for foodstuff and biosample recognition – An overview. *Sensors*, 11(5), 4688–4701.
- Cocciardi, R. A., Ismail, A. A., & Sedman, J. (2005). Investigation of the potential utility of single-bounce attenuated total reflectance Fourier transform infrared spectroscopy in the analysis of distilled liquors and wines. *Journal of Agriculture and Food Chemistry*, 53(8), 2803–2809.
- Cozzolino, D., & Murray, I. (2002). Effect of sample presentation and animal muscle species on the analysis of meat by near infrared reflectance spectroscopy. *Journal of Near Infrared Spectroscopy*, 10, 37–44.
- Culioli, J. (1995). Meat tenderness: Mechanical assessment. In A. Ouali, D. I. Demeyer, & F. J. M. Smulders (Eds.), *Expression of tissue proteinases and regulation of protein degradation as related to meat quality* (pp. 239–266). Utrecht: ECCEAMST.
- Dang, Y., Gao, X., Ma, F., & Wu, X. (2015). Comparison of umami taste peptides in water-soluble extractions of Jinhua and Parma hams. *LWT e Food Sci. Technol.*, 60 (2e2), 1179–1186.
- De Marchi, M., Penasa, M., Zidi, A., & Manuelian, C. L. (2018). Invited review: Use of infrared technologies for the assessment of dairy products—Applications and perspectives. *Journal of Dairy Science*, 101, 10589–10604.
- De Marchi, M., Toffanin, V., Cassandro, M., & Penasa, M. (2014). Invited review: Mid-infrared spectroscopy as phenotyping tool for milk traits. *Journal of Dairy Science*, 97, 1171–1186.
- Destefanis, G., Brugiapaglia, A., Barge, M. T., & Dal Molin, E. (2008). Relationship between beef consumer tenderness perception and Warner-Bratzler shear force. *Meat Science*, 78, 153–156.
- de Wijk, R. A., Janssen, A. M., & Prinz, J. F. (2011). Oral movements and the perception of semi-solid foods. *Physiology and Behaviour*, 104, 423–428.
- de Wijk, R. A., Prinz, J., & Janssen, A. M. (2006). Explaining perceived oral texture of starch-based custard desserts from standard and novel instrumental tests. *Food Hydrocolloids*, 20, 24–34.
- Dias, L. A., Peres, A. M., Veloso, A. C. A., Reis, F. S., Vilas-boas, M., & Machado, A. A. S. C. (2009). An electronic tongue taste evaluation: identification of goat milk adulteration with bovine milk. *Sensors and Actuators B*, 136, 209–217.
- Dijksterhuis, G. B. (1995). Multivariate data analysis in sensory and consumer science: an overview of developments. *Trends in Food Science and Technology*, 6, 206–211.
- Di Rosa, A. R., Leone, F., Cheli, F., & Chiofalo, V. (2017). Fusion of electronic nose, electronic tongue and computer vision for animal source food authentication and quality assessment – A review. *Journal of Food Engineering*, 210, 62–75.
- Dresselhuys, D. M., de Hoog, E. H. A., Cohen Stuart, M. A., & van Aken, G. A. (2008). Application of oral tissue in tribological measurements in an emulsion perception context. *Food Hydrocolloids*, 22, 323–335.
- Dresselhuys, D. M., Klok, H. J., Stuart, M. A. C., de Vries, R. J., van Aken, G. A., & de Hoog, E. H. A. (2007). Tribology of o/w emulsions under mouth-like conditions: Determinants of friction. *Food Biophysics*, 2, 158–171.

- Du, C. J., & Sun, D. W. (2006). Learning techniques used in computer vision for food quality evaluation: A review. *Journal of Food Engineering*, 72(1), 39–55.
- Eichinger, H., & Beck, G. (1992). Possibilities for improving breeding value estimation of meat quality in cattle by using the near-infrared measurement technique. *Archiv für Tierzucht*, 35, 41–50.
- Eklöv, T., Johansson, G., Winqvist, F., & Lundström, I. (1998). Monitoring sausage fermentation using an electronic nose. *Journal of Science and Food Agriculture*, 76, 525–532.
- Ellis, D. I., Broadhurst, D., & Goodacre, R. (2004). Rapid and quantitative detection of the microbial spoilage of beef by Fourier transform infrared spectroscopy and machine learning. *Analytica Chimica Acta*, 514, 193–201.
- Ellis, D. I., Broadhurst, D., Kell, D. B., Rowland, J. J., & Goodacre, R. (2002). Rapid and quantitative detection of the microbial spoilage of meat by Fourier transform infrared spectroscopy and machine learning. *Applied and Environmental Microbiology*, 68, 2822–2828.
- Elmasry, G., Barbin, D. F., Sun, D. W., & Allen, P. (2012). Meat quality evaluation by hyperspectral imaging technique: An overview. *Critical Review in Food Science and Nutrition*, 52(8), 689–711.
- Escuder-Gilabert, L., & Peris, M. (2010). Review: highlights in recent applications of electronic tongues in food analysis. *Analytica Chimica Acta*, 665(1), 15–25.
- Everard, C. D., O'Callaghan, D. J., Fagan, C. C., O'Donnell, C. P., Castillo, M., & Payne, F. A. (2007). Computer vision and colour measurement techniques for inline monitoring of cheese curd syneresis. *Journal of Dairy Science*, 90, 3162–3170.
- Fathi, M., Mohebbi, M., & Razavi, S. M. A. (2009). Application of image analysis and artificial neural network to predict mass transfer kinetics and color changes of osmotically dehydrated kiwifruit. *Food and Bioprocess Technology*, 4, 1–10.
- Fernandez, K., & Agosin, E. (2007). Quantitative analysis of red wine tannins using Fourier-transform mid-infrared spectroscopy. *Journal of Agriculture and Food Chemistry*, 55, 7294–7300.
- Flåtten, Bryhni, E. A., Kohler, A., Egelanddal, B., & Isaksson, T. (2005). Determination of C22:5 and C22:6 marine fatty acids in pork fat with Fourier transform mid-infrared spectroscopy. *Meat Science*, 69(2005), 433–440.
- Garcia, M., Aleixandre, M., Gutierrez, J., & Horrillo, M. C. (2006). Electronic nose for wine discrimination. *Sensors and Actuators B: Chemical*, 113(2), 911–916.
- Gardner, J. W., & Bartlett, P. N. (1994). A brief history of electronic noses. *Sensors and Actuators B*, 18, 211–220.
- Ghasemi-Varnamkhasti, M., Mohtasebi, S. S., & Siadat, M. (2010). Biomimetic-based odor and taste sensing systems to food quality and safety characterization: An overview on basic principles and recent achievements. *Journal of Food Engineering*, 100(3), 377–387.
- Gil-Sánchez, L., Garrigues, J., Garcia-Breijo, E., Grau, R., Aliño, M., Baigts, D., & Barat, J. M. (2015). Artificial neural networks (Fuzzy ARTMAP) analysis of the data obtained with an electronic tongue applied to a ham-curing process with different salt formulations. *Applied Soft Computing*, 30, 421–429.
- Grigioni, G. M., Margaria, C. A., Pensel, N. A., Sánchez, G., & Vaudagna, S. R. (2000). Warmed-over flavour in low temperature-long time processed meat by an “electronic nose”. *Meat Science*, 56, 221–228.
- Gurdeniz, G., & Ozen, B. (2009). Detection of adulteration of extra-virgin olive oil by chemometric analysis of mid-infrared spectral data. *Food Chemistry*, 116, 519–525.
- Gutiérrez, J. M., Haddi, Z., Amari, A., Bouchikhi, B., Mimendia, A., Cetó, X., & del Valle, M. (2013). Hybrid electronic tongue based on multisensory data fusion for discrimination of beers. *Sensors and Actuators B*, 177, 989–996.

- Ha, D., Sun, Q., Su, K., Wan, H., Li, H., Xu, N., ... Wang, P. (2015). Recent achievements in electronic tongue and bioelectronic tongue as taste sensors. *Sensors and Actuators B*, 207, 1136–1146.
- Hansen, T., Pedersen, M. A., & Byrne, D. V. (2005). Sensory based quality control utilising an electronic nose and GC-MS analyses to predict end-product quality from raw materials. *Meat Science*, 69, 621–634.
- Haugen, J. E., & Kvaal, K. (1998). Electronic nose and artificial neural network. *Meat Science*, 49, S273–S286.
- Hayashi, K., Yamanaka, M., Toko, K., & Yamafuji, K. (1990). Multichannel taste sensor using lipid membranes. *Sensors Actuators B*, 2(3), 205–213.
- Holm, E. S., Schäfer, A., Skov, T., Koch, A. G., & Petersen, M. A. (2012). Identification of chemical markers for the sensory shelf-life of saveloy. *Meat Science*, 90(2012), 314–322.
- Hood, D. E., & Mead, G. C. (1993). Modified atmosphere storage of fresh meat and poultry. In R. T. Parry (Ed.), *Principles and applications of modified atmosphere packing of food* (pp. 269–298). London: Blackie Academic and Professional.
- Huang, H., Yu, H., Xu, H., & Ying, Y. (2008). Near infrared spectroscopy for on/in-line monitoring of quality in foods and beverages: A review. *Journal of Food Engineering*, 87, 303–313.
- Huang, L., Liu, H., Zhang, B., & Wu, D. (2015). Application of electronic nose with multivariate analysis and sensor selection for botanical identification and quality determination of honey. *Food Bioprocess Technology*, 8(2), 359–370.
- Huselege, B., Engel, B., Buist, W., Merkus, G. S. M., & Klont, R. E. (2001). Instrumental colour classification of veal carcasses. *Meat Science*, 57, 191–195.
- Infante, R., Farcuh, M., & Meneses, C. (2008). Monitoring the sensorial quality and aroma through an electronic nose in peaches during cold storage. *Journal of the Science of Food and Agriculture*, 88, 2073–2078.
- Jackman, P., Sun, D.-W., Du, C.-J., & Allen, P. (2009). Prediction of beef eating qualities from colour, marbling and wavelet surface texture features using homogenous carcass treatment. *Pattern Recognition*, 42(5), 751–763.
- Jackman, P., Sun, D. W., Allen, P., Brandon, K., & White, A. M. (2010). Correlation of consumer assessment of longissimus dorsi beef palatability with image colour, marbling and surface texture features. *Meat Science*, 84, 564–568.
- Janhøj, T., Bom Frøst, M., & Ipsen, R. (2008). Sensory and rheological characterization of acidified milk drinks. *Food Hydrocolloids*, 22, 798–806.
- Joyner (Melito), H. S. (2018). Explaining food texture through rheology. *Current Opinion in Food Science*, 21, 7–14.
- Kilcawley, K. (2015). Cheese flavour. In P. F. Fox., T. P. Guinee, T. M. Cogan, P. I. H. McSweeney (Eds.), *Fundamentals of Cheese Science* (2nd ed.). New York: Springer.
- Kilcawley, K. N., & O'Sullivan, M. G. (2017). Cheese flavour development and sensory characteristics. In P. Papademas, & T. Bintsis (Eds.), *Global cheese making technology: Cheese quality and characteristics*. Chichester: John Wiley & Sons Ltd.
- Kong, F., & Singh, R. P. (2011). Advances in instrumental methods to determine food quality deterioration. In D. Kilcast, & P. Subramaniam (Eds.), *The stability and shelf-life of food*. Cambridge, UK: Woodhead Publishing Limited.
- Lachenmeier, D. W. (2007). Rapid quality control of spirit drinks and beer using multivariate data analysis of Fourier transform infrared spectra. *Food Chemistry*, 101, 825–832.
- Lawless, H. T., & Heymann, H. (2010). *Physiological and psychological foundations of sensory function. Sensory Evaluation of Foods: Principles and Practices* (pp. 19–56). New York: Springer.
- Larkin, P. J. (2018). *Infrared and Raman spectroscopy. Principles and Spectral Interpretation* (2nd ed). Amsterdam, Netherlands: Elsevier.

- Lawrie, R. A., & Ledward, D. A. (2006). *Lawrie's meat science*. Cambridge, England: Woodhead Publishing Ltd.
- Lerma-Garcia, M. J., Ramis-Ramos, G., Herrero-Martinez, J. M., & Simo-Alfonso, E. F. (2010). Authentication of extra virgin olive oils by Fourier transform infrared spectroscopy. *Food Chemistry*, 118, 78–83.
- Li, M., Wang, H., Sun, L., Zhao, G., & Huang, X. (2016). Application of electronic nose for measuring total volatile basic nitrogen and total viable counts in packaged pork during refrigerated storage. *Journal of Food Science*, 81(4), 906–912.
- Li, Z., Wang, N., & Vigneault, C. (2006). Electronic nose and electronic tongue in food production and processing. *Stewart Postharvest Review*, 2, 1–5.
- Limbo, S., Sinelli, N., Torri, L., & Riva, M. (2009). Freshness decay and shelf life predictive modelling of European sea bass (*Dicentrarchus labrax*) applying chemical methods and electronic nose. *LWT, Food Science and Technology*, 42, 977–984.
- Liu, P., & Tu, K. (2012). Prediction of TVB-N content in eggs based on electronic nose. *Food Control*, 23(1), 177–183.
- Liu, Q., Lanari, M. C., & Schaefer, D. M. (1995). A review of dietary vitamin E supplementation for improvement of beef quality. *Journal of Animal Science*, 73, 3131–3140.
- Lorenzen, P. C., Walte, H.-G., & Bosse, B. (2013). Development of a method for butter type differentiation by electronic nose technology. *Sensors Actuators B*, 181, 690–693.
- Loutfi, A., Coradeschi, S., Mani, G. K., Shankar, P., & Balaguru Rayappan, J. B. (2015). Electronic noses for food quality: A review. *Journal of Food Engineering*, 144, 103–111.
- Lu, J., Tan, J., Shatadal, P., & Gerrard, D. E. (2000). Evaluation of pork color by using computer vision. *Meat Science*, 56, 57–60.
- Lu, R. (2013). Principles of solid food texture analysis. *Instrumental Assessment of Food Sensory Quality*, 56, 103–128.
- Lynch, A. G., & Mulvihill, D. M. (1997). Effect of sodium caseinate on the stability of cream liqueurs. *International Journal of Dairy Technology*, 50, 1–7.
- Lyon, B. G., & Lyon, C. E. (1998). Assessment of three devices used in shear tests of cooked breast meat. *Poultry Science*, 77, 1585–1590.
- Ma, J., Sun, D.-W., Qu, J.-H., Liu, D., Pu, H., Gao, W.-H., & Zeng, X.-A. (2016). Applications of computer vision for assessing quality of agri-food products: A review of recent research advances. *Critical Reviews in Food Science and Nutrition*, 56(1), 113–127.
- MacDougall, D., & Hutchings, J. (2002). *Colour in food—Improving quality*. Woodhead Publishing.
- Mahmodi, K., Mostafaei, M., & Mirzaee-Ghaleh, E. (2019). Detection and classification of diesel-biodiesel blends by LDA, QDA and SVM approaches using an electronic nose. *Fuel*, 258, 116114.
- Manuelian, C. L., Currò, S., Visentin, G., Penasa, M., Cassandro, M., Dellea, C., . . . De Marchi, M. (2017). Technical note: At-line prediction of mineral composition of fresh cheeses using near-infrared technologies. *Journal of Dairy Science*, 100, 6084–6089.
- Margolies, B. J., & Barbano, D. M. (2018). Determination of fat, protein, moisture, and salt content of Cheddar cheese using mid-infrared transmittance spectroscopy. *Journal of Dairy Science*, 101, 924–933.
- Marsili, R. T. (1999). SPME-MS-MVA as an electronic nose for the study of off-flavours in milk. *Journal of Agriculture and Food Chemistry*, 47(2), 648–654.
- Martin, M. L. G. M., Ji, W., Luo, R., Hutchings, J., & Heredia, F. J. (2007). Measuring colour appearance of red wines. *Food Quality and Preference*, 18, 862–871.
- Matiacevich, S., Silva, P., Enrione, J., & Osorio, F. (2011). Quality assessment of blueberries by computer vision. *Procedia Food Science*, 1, 421–425.
- McKenna, B. M., & Lyng, J. G. (2013). Principles of food viscosity analysis. *Instrumental Assessment of Food Sensory Quality*, 130–162.

- McDevitt, R. M., Gavin, A. J., Andres, S., & Murray, I. (2005). The ability of visible and near infrared reflectance spectroscopy (NIRS) to predict the chemical composition of ground chicken carcasses and to discriminate between carcasses from different genotypes. *Journal of Near Infrared Spectroscopy*, 13, 109–117.
- McDonald, K., & Sun, D. W. (2001). Effect of evacuation rate on the vacuum cooling process of a cooked beef product. *Journal of Food Engineering*, 48(3), 195–202.
- McDonald, K., Sun, D. W., & Kenny, T. (2001). The effect of injection level on the quality of a rapid vacuum cooled cooked beef product. *Journal of Food Engineering*, 47(2), 139–147.
- McMillin, K. W. (2008). Where is MAP going? A review and future potential of modified atmosphere packaging for meat. *Meat Science*, 80, 43–65.
- Meza-Márquez, O. G., Gallardo-Velázquez, T., & Osorio-Revilla, G. (2010). Application of mid-infrared spectroscopy with multivariate analysis and soft independent modeling of class analogies (SIMCA) for the detection of adulterants in minced beef. *Meat Science*, 86, 511–519.
- Mrček, J., Rop, O., Dohnal, V., & Šustová, K. (2011). Application of near infrared spectroscopy to estimate selected free amino acids and soluble nitrogen during cheese ripening. *Acta Veterinaria Brno*, 80, 293–297.
- Mohareb, F., Papadopoulou, O., Panagou, E., Nychas, G.-J., & Bessant, C. (2016). Ensemble-based support vector machine classifiers as an efficient tool for quality assessment of beef fillets from electronic nose data. *Anal. Methods*, 8, 3711–3721.
- Moreira, J. L., Marcos, A. M., & Barros, P. (2002). Analysis of Portuguese wine by Fourier transform infrared spectrometry. *Ciência e Técnica Vitivinícola/Journal of Viticulture and Enology*, 17, 27–33.
- Newman, J., Harbourn, N., O'Riordan, D., Jacquier, J. C., & O'Sullivan, M. (2014). Comparison of a trained sensory panel and an electronic tongue in the assessment of bitter dairy protein hydrolysates. *Journal of Food Engineering*, 128, 127–131.
- O'Connell, M., Valdora, G., Peltzer, G., & Negri, R. M. (2001). A practical approach for fish freshness determinations using a portable electronic nose. *Sensors and Actuators*, 80, 149–154.
- Ólafsdóttir, G., Martindóttir, E., & Jónsson, E. H. (1997). Rapid gas sensor measurements to determine spoilage of capelin (*Mallotus villosus*). *Journal of Agriculture and Food Chemistry*, 45, 2654–2659.
- Ortiz-Somovilla, V., Espana-Espana, F., Gaitan-Jurado, A. J., Perez-Aparicio, J., & De Pedro-Sanz, E. J. (2007). Proximate analysis of homogenized and minced mass of pork sausages by NIRS. *Food Chemistry*, 101, 1031–1040.
- Osborne, B. G., Fearn, T., & Hindle, P. H. (1993). *Near infrared spectroscopy in food analysis*. Harlow, Essex, UK: Longman Scientific and Technical.
- O'Sullivan, M. G. (2011). CH 4, Sensory shelf-life evaluation. In J. R. Piggott (Ed.), *Alcoholic beverages: Sensory evaluation and consumer research*. Cambridge, UK: Woodhead Publishing Limited.
- O'Sullivan, M. G. (2017). CH8. Instrumental assessment of the sensory quality of food and beverage products. *A handbook for sensory and consumer driven new product development: Innovative technologies for the food and beverage industry* (pp. 151–175). United Kingdom: Woodhead Publishing Ltd.
- O'Sullivan, M. G., Byrne, D. V., Martens, H., Gidskehaug, L. H., Andersen, H. J., & Martens, M. (2003). Evaluation of pork meat colour: Prediction of visual sensory quality of meat from instrumental and computer vision methods of colour analysis. *Meat Science*, 65, 909–918.
- O'Sullivan, M. G., Byrne, D. V., Jensen, M. T., Andersen, H. J., & Vestergaard, J. (2003). A comparison of warmed-over flavour in pork by sensory analysis, GC/MS and the electronic nose. *Meat Science*, 65, 1125–1138.

- O'Sullivan, M. G., Byrne, D. V., Stagsted, J., Andersen, H. J., & Martens, M. (2002). Sensory colour assessment of fresh meat from pigs supplemented with iron and vitamin E. *Meat Science*, 60, 253–265.
- O'Sullivan, M. G., & Kerry, J. P. (2008). CH 27, Sensory evaluation of fresh meat. In J. P. Kerry, & D. A. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh meat*. Cambridge, UK: Woodhead Publishing Limited.
- O'Sullivan, M. G., & Kerry, J. P. (2013). In D. Kilcast (Ed.), *CH 10, Instrumental assessment of the sensory quality of meat, poultry and fish*. Cambridge, UK: Woodhead Publishing Limited.
- Ozen, B. F., & Mauer, L. J. (2002). Detection of hazelnut oil adulteration using FT-IR spectroscopy. *Journal of Agricultural and Food Chemistry*, 50, 3898–3901.
- Panigrahi, S., Balasubramanian, S., Gub, H., Logue, C. M., & Marchello, M. (2006). Design and development of a metal oxide based electronic nose for spoilage classification of beef. *Sensors and Actuators B*, 119, 2–14.
- Papadakis, S. E., Abdul-Malek, S., Emery-Kamdem, R., & Yam, K. L. (2000). A versatile and inexpensive technique for measuring colour of foods. *Food Technology*, 54, 48–51.
- Persaud, K., & Dodd, G. (1982). Analysis of discrimination mechanisms in the mammalian olfactory system using a model nose. *Nature*, 299, 352–355.
- Petit, T., & Tuskar, L. (2018). FTIR spectroscopy of nanodiamonds: Methods and interpretation. *Diamond & Related Materials*, 89, 52–66.
- Platter, W. J., Tatum, J. D., Belk, K. E., Chapman, P. L., Scanga, J. A., & Smith, G. C. (2003). Relationship of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science*, 81, 2741–2750.
- Plutowska, B., & Wardencki, W. (2008). Application of gas chromatography-olfactometry (GC-O) in analysis and quality assessment of alcoholic beverages - A review. *Food Chemistry*, 107(1), 449–463.
- Power, P. C. (1996). *The formulation, testing and stability of 16% fat cream liqueurs* (Ph.D. thesis). Cork: National University of Ireland.
- Prieto, N., Andres, S., Giraldez, F. J., Mantecon, A. R., & Lavin, P. (2006). Potential use of near infrared reflectance spectroscopy (NIRS) for the estimation of chemical composition of oxen meat samples. *Meat Science*, 74, 487–496.
- Prevolnik, M., Čandek-Potokar, M., & Škorjanc, D. (2004). Ability of NIR spectroscopy to predict meat chemical composition and quality: a review. *Czechoslovak Journal of Animal Science*, 49, 500–510.
- Prevolnik, M., Čandek-Potokar, M., Škorjanc, D., Velikonja-Bolta, Š., Škrlep, M., Žnidaršič, T., et al. (2005). Predicting intramuscular fat content in pork and beef by near infrared spectroscopy. *Journal of Near Infrared Spectroscopy*, 13, 77–85.
- Prieto, N., Roehe, R., Lavín, P., Batten, G., & Andrés, S. (2009). Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review. *Meat Science*, 83, 175–186.
- Pryzbylski, R., & Eskin, N. A. M. (1995). Methods to measure volatile compounds and the flavour significance of volatile compounds. In K. Warner, & N. A. M. Eskin (Eds.), *Methods to assess quality and stability of oils and fat-containing foods* (pp. 107–133). IL: AOCS Press.
- Quevedo, R. A., Aguilera, J. M., & Pedreschi, F. (2010). Color of salmon fillets by computer vision and sensory panel. *Food and Bioprocess Technology*, 3(5), 637–643.
- Raes, K., De Smet, S., & Demeyer, D. (2004). Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: A review. *Animal Feed Science and Technology*, 113, 199–221.

- Rajamäki, T., Alakomi, H. L., Ritvanen, T., Skyttä, E., Smolander, M., & Ahvenainen, R. (2006). Application of an electronic nose for quality assessment of modified atmosphere packaged poultry meat. *Food Control*, 17, 5–13.
- Renden, J. A., Oates, S. S., & Reed, R. B. (1986). Determination of body fat and moisture in dwarf hens with near infrared reflectance spectroscopy. *Poultry Science*, 65, 1539–1541.
- Ripoche, A., & Guillard, A. S. (2001). Determination of fatty acid composition of pork fat by Fourier transform infrared (FTIR) spectroscopy. *Meat Science*, 58, 299–304.
- Rodriguez-Mendez, M. L., Apetrei, C., & de Saja, J. A. (2008). Evaluation of the polyphenolic content of extra virgin olive oils using an array of voltammetric sensors. *Electrochimica Acta*, 53(20), 5867–5872.
- Rodriguez-Otero, J. L., Hermida, M., & Cepeda, A. (1995). Determination of fat, protein, and total solids in cheese by near-infrared reflectance spectroscopy. *Journal of AOAC International*, 78, 802–806.
- Ross, C. F. (2009). Sensory science at the human-machine interface. *Trends in Food Science & Technology*, 20, 1–10.
- Ruiz de Huidobro, F., Cañeque, V., Lauzurica, S., Velasco, S., Pérez, C., & Onega, E. (2001). Sensory characterization of meat texture in sucking lambs. Methodology. *Investigación Agraria: Producción y Sanidad Animales*, 16(2), 223–234.
- Saldaña, E., Behrens, J. H., Serrano, J. S., Ribeiro, F., de Almeida, M. A., & Contreras-Castillo, C. J. (2015). Microstructure, texture profile and descriptive analysis of texture for traditional and light mortadella. *Food Structure*, 6, 13–20.
- Sanaeifar, A., Jafari, A., & Golmakanic, M. T. (2018). Fusion of dielectric spectroscopy and computer vision for quality characterization of olive oil during storage. *Computers and Electronics in Agriculture*, 145, 142–152.
- Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1997). Tenderness classification of beef: 1 Evaluation of beef longissimus shear force at 1 or 2 days post mortem as a predictor of aged beef tenderness. *Journal of Animal Science*, 75, 2417–2422.
- Shrivastava, S., Singh, S. K., & Hooda, D. S. (2016). Soybean plant foliar disease detection using image retrieval approaches. *Multimedia Tools and Applications*, 76, 1–28.
- Siegmund, B., & Pfannhauser, W. (1999). Changes of the volatile fraction of cooked chicken meat during chill storing: results obtained by the electronic nose in comparison to GC-MS and GC olfactometry. *Zeitschrift Für Lebensmittel-Untersuchung und forschung A*, 208, 336–341.
- Sinelli, N., Barzaghi, S., Giardina, C., & Cattaneo, T. M. P. (2005). A preliminary study using Fourier transform near infrared spectroscopy to monitor the shelf-life of packed industrial ricotta cheese. *Journal of Near Infrared Spectroscopy*, 13, 293–300.
- Song, S., Yuan, L., Zhang, X., Hayat, K., Chen, H., Liu, F., . . . Niu, Y. (2013). Rapid measuring and modelling flavour quality changes of oxidised chicken fat by electronic nose profiles through the partial least squares regression analysis. *Food Chemistry*, 141(4), 4278–4288.
- Sutherland, J. P., Varnum, A. H., & Evans, M. G. (1986). *A color atlas of food quality control*. Weert: CRC Press.
- Stevens, S. S. (1975). *Psychophysics: Introduction to its perceptual, Neural, and Social Prospects*. New York: John Wiley.
- Stokes, J. R., Boehm, M. W., & Baier, S. K. (2013). Oral processing, texture and mouth-feel: From rheology to tribology and beyond. *Current Opinion in Colloid & Interface Science*, 18, 349–359.
- Terpstra, M. E. J., Janssen, A. M., Prinz, J. F., De Wijk, R. A., Weenen, H., & Van der Linden, E. (2005). Modeling of thickness for semisolid foods. *Journal of Texture Studies*, 36, 213–233.

- Tian, X., Wang, J., & Cui, S. (2013). Analysis of pork adulteration in minced mutton using electronic nose of metal oxide sensors. *Journal of Food Engineering*, 119, 744749.
- Tian, X.-Y., Cai, Q., & Zhang, Y.-M. (2012). Rapid classification of hairtail fish and pork freshness using an electronic nose based on the PCA method. *Sensors*, 12(1), 260–277.
- Tikk, K., Haugen, J. E., Andersen, H. J., & Aaslyng, M. D. (2008). Monitoring of warmed-over flavour in pork using the electronic nose – Correlation to sensory attributes and secondary lipid oxidation products. *Meat Science*, 80(4), 1254–1263.
- Tomasevic, I., Tomovic, V., Milovanovic, B., Lorenzo, J., Đorđević, V., Karabasil, N., & Djekic, I. (2019). Comparison of a computer vision system vs. traditional colorimeter for color evaluation of meat products with various physical properties. *Meat Science*, 148, 5–12.
- Tøgersen, G., Arnesen, J. F., Nilsen, B. N., & Hildrum, K. I. (2003). On-line prediction of chemical composition of semi-frozen ground beef by non-invasive NIR spectroscopy. *Meat Science*, 63, 515–523.
- Tøgersen, G., Isaksson, T., Nilsen, B. N., Bakker, E. A., & Hildrum, K. I. (1999). On-line NIR analysis of fat, water and protein in industrial scale ground meat batches. *Meat Science*, 51, 97–102.
- Valdes, E. V., & Summers, J. D. (1986). Determination of crude protein in carcass and breast muscle samples of poultry by near infrared reflectance spectroscopy. *Poultry Science*, 65, 485–490.
- Valous, N. A., Mendoza, F., Sun, D. W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat Science*, 81(1), 132–141.
- Van de Voort, F. F., Sedan, J., Emo, G., & Ismail, A. A. (1992). Rapid and direct iodine value and saponification number determination of fats and oils by attenuated total reflectance/Fourier transform infrared spectroscopy. *Journal of the Oil Chemistry Society*, 69, 1118–1123.
- Van Kempen, L. (2001). Infrared technology in animal production. *World's Poultry Science Journal*, 57, 29–48.
- Vestergaard, J. S., Martens, M., & Turkki, P. (2007). Application of an electronic nose system for prediction of sensory quality changes of a meat product (pizza topping) during storage. *LWT - Food Science and Technology*, 40(6), 10951101.
- Viljoen, M., Hoffman, L. C., & Brand, T. S. (2007). Prediction of the chemical composition of mutton with near infrared reflectance spectroscopy. *Small Ruminant Research*, 69, 88–94.
- Villiers, A., Alberts, P., Tredoux, A. G., & Nieuwoudt, H. H. (2012). Analytical techniques for wine analysis: An African perspective; a review. *Analytica Chimica Acta*, 730, 2–23.
- Vlachos, N., Skopelitis, Y., Psaroudaki, M., Konstantinidou, V., Chatzilazarou, A., & Tegou, E. (2006). Applications of Fourier transform-infrared spectroscopy to edible oils. *Analytica Chimica Acta*, 573-574, 459–465.
- Wang, X., & Cheng, J. (2017). Food oral processing: Recent developments and challenges. *Current Opinion in Colloid & Interface Science*, 28, 22–30.
- Wardencki, W., Chmiel, T., & Dymerski, T. (2013). Gas chromatography-olfactometry (GC-O), electronic noses (e-noses) and electronic tongues (e-tongues) for in vivo food flavour measurement. In D. Kilcast, & P. Subramaniam (Eds.), *The stability and shelf-life of food*. Cambridge, UK: Woodhead Publishing Limited.
- Warner, K. F. (1928). Progress report of the mechanical test for tenderness of meat. *Proceedings of the American Society of Animal Production*, 21, 114.

- Wei, Z., & Wang, J. (2013). The evaluation of sugar content and firmness of non-climacteric pears based on voltammetric electronic tongue. *Journal of Food Engineering*, 117(1), 158–164.
- Winquist, F., Lundström, I., & Wide, P. (1999). The combination of an electronic tongue and an electronic nose. *Sensors and Actuators B*, 58(1–3), 512.
- Winquist, F., Wide, P., & Lundström, I. (1997). An electronic tongue based on voltammetry. *Analytica Chimica Acta*, 357(1–2), 21–31.
- Wood, F. (1968). Psychophysical studies on the consistency of liquid foods. In S. C. I. monograph (Ed.), *Rheology and texture of food stuffs* (pp. 40–49). London: Society of Chemical Industry.
- Wu, D., & Sun, D. W. (2013a). Food colour measurement using computer vision. *Instrumental Assessment of Food Sensory Quality*, 165–195.
- Wu, D., & Sun, D.-W. (2013b). Colour measurements by computer vision for food quality control—A review. *Trends in Food Science and Technology*, 29, 5–20.
- Xu, M., Wang, J., & Gu, S. (2019). Rapid identification of tea quality by E-nose and computer vision combining with a synergetic data fusion strategy. *Journal of Food Engineering*, 241, 10–17.
- Yang, C. C., Chao, K., & Kim, M. S. (2009). Machine vision system for online inspection of freshly slaughtered chickens. *Sensing and Instrumentation for Food Quality and Safety*, 3(1), 70–80.
- Zakrys, P. I., Hogan, S. A., O'Sullivan, M. G., Allen, P., & Kerry, J. P. (2008). Effects of oxygen concentration on sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. *Meat Science*, 79, 648–655.
- Zakrys, P. I., O'Sullivan, M. G., Allen, P., & Kerry, J. P. (2009). Consumer acceptability and physiochemical characteristics of modified atmosphere packed beef steaks. *Meat Science*, 81, 720–725.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., Allen, P., O'Neill, E. E., & Kerry, J. P. (2010). Investigation of the effects of commercial carcass suspension (24 and 48 hours) on meat quality in modified atmosphere packed beef steaks during chill storage. *Food Research international*, 43, 277–284.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., O'Neill, E. E., & Kerry, J. P. (2011). The effects of high oxygen modified atmosphere packaging on protein oxidation of bovine M. longissimus dorsi muscle during chilled storage. *Food Chemistry*, 2, 527–532.
- Zakrys-Waliwander, P. I., O'Sullivan, M. G., Walshe, H., Allen, P., & Kerry, J. P. (2011). Sensory comparison of commercial low and high oxygen modified atmosphere packed sirloin beef steaks. *Meat Science*, 88, 198–202.
- Zapotoczny, P., & Majewska, K. (2010). A comparative analysis of colour measurements of the seed coat and endosperm of wheat kernels performed by various techniques. *International Journal of Food Properties*, 13, 75–89.
- Zapotoczny, P., Szczypiński, P. M., & Daszkiewicz, T. (2016). Evaluation of the quality of cold meats by computer-assisted image analysis. *Lebensmittel-Wissenschaft + [i.e. und] Technologie*, 67, 37–49.
- Zhang, B., Huang, W., Li, J., Zhao, C., Fan, S., Wu, J., & Liu, C. (2014). Principles, developments and applications of computer vision for external quality inspection of fruits and vegetables: A review. *Food Research International*, 62, 326–343.
- Zhang, H., Wu, Y., Li, Y., Wang, B., Han, J., Ju, X., et al. (2012). PCR-CE-SSCP used to authenticate edible oils. *Food Control*, 27, 322–329.
- Zhang, Q., Liu, C., Sun, Z., Hu, X., Shen, Q., & Wu, J. (2012). Authentication of edible vegetable oils adulterated with used frying oil by Fourier Transform Infrared Spectroscopy. *Food Chemistry*, 132, 1607–1613.

- Zhang, X., Zhang, Y., Meng, Q., & Ren, L. (2015). Evaluation of beef by electronic tongue system TS-5000Z: Flavour assessment, recognition and chemical composition according to its correlation with flavour. *PLoS One*, 10(9).
- Zheng, C., Sun, D. W., & Zheng, L. Y. (2006a). Correlating colour to moisture content of large cooked beef joints by computer vision. *Journal of Food Engineering*, 77(4), 858–863.
- Zheng, C., Sun, D. W., & Zheng, L. (2006b). Recent developments and applications of image features for food quality evaluation and inspection—A review. *Trends in Food Science & Technology*, 17(12), 642–655.
- Zou, X. B., Zhao, J. W., Li, Y. X., & Holmes, M. (2010). In-line detection of apple defects using three color cameras system. *Computers and Electronics in Agriculture*, 70(1), 129–134.
- Zou, Y., Wan, H., Zhang, X., Ha, D., & Wang, P. (2015). Electronic nose and electronic tongue. In P. Wang, Q. Liu, C. Wu, & K. J. Hsia (Eds.), *Bioinspired smell and taste sensors*. The Netherlands: Springer, pp. 19e44.

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Salt, Fat and Sugar Reduction explores the major negative targeted ingredients, salt, sugar and fat, and their current scientific basis for linking them to the civilization diseases. The sensory techniques that can be used for developing consumer appealing nutritional optimized products as well as other aspects such as shelf life and physicochemical analysis will be discussed.

Consumer awareness of the negative nutritional impact of these ingredients will be presented through feedback from some recent survey work and government initiatives such as sequential ingredient reduction programs.

Sugar, fat and salt taxes will also be discussed, as will the factors that are drivers for nutritional optimization through reformulation in the food and beverage industries.

The book will be a welcomed resource for undergraduate and postgraduate students and academics, including food scientists and food and nutrition researchers, as well as those who work in the food and beverage industries, specifically in production, R&D, and quality.

This book:

- Provides a clear outline of current legislation of global ingredient taxes.
- Demonstrates effective protocols, sensory, multivariate, and physicochemical for salt, fat, and sugar reduction.
- Outlines reduction protocols, with and without the use of replacer ingredients for salt, fat, sugar reduction.
- Illustrates the full process chain, consumer to packaging, and the effects of reformulation by reduction.

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