Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: http://www.tandfonline.com/loi/bfsn20

Sugar reduction without compromising sensory perception. An impossible dream?

Scott C. Hutchings, Julia Y. Q. Low & Russell S. J. Keast

To cite this article: Scott C. Hutchings, Julia Y. Q. Low & Russell S. J. Keast (2018): Sugar reduction without compromising sensory perception. An impossible dream?, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2018.1450214

To link to this article: https://doi.org/10.1080/10408398.2018.1450214

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2018.1450214

Sugar reduction without compromising sensory perception. An impossible dream?

Scott C. Hutchings [a], Julia Y. Q. Low [b], and Russell S. J. Keast [c]

[a]Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, Victoria, Australia; [b]Riddet Institute, Massey University, Palmerston North, New Zealand; [c]Centre for Advanced Sensory Science, School of Exercise and Nutrition Sciences, Deakin University, Burwood, Victoria, Australia

ABSTRACT

Sugar reduction is a major technical challenge for the food industry to address in response to public health concerns regarding the amount of added sugars in foods. This paper reviews sweet taste perception, sensory methods to evaluate sugar reduction and the merits of different techniques available to reduce sugar content. The use of sugar substitutes (non-nutritive sweeteners, sugar alcohols, and fibres) can achieve the greatest magnitude of sugar and energy reduction, however bitter side tastes and varying temporal sweet profiles are common issues. The use of multisensory integration principles (particularly aroma) can be an effective approach to reduce sugar content, however the magnitude of sugar reduction is small. Innovation in food structure (modifying the sucrose distribution, serum release and fracture mechanics) offers a new way to reduce sugar without significant changes in food composition, however may be difficult to implement in food produced on a large scale. Gradual sugar reduction presents difficulties for food companies from a sales perspective if acceptability is compromised. Ultimately, a holistic approach where food manufacturers integrate a range of these techniques is likely to provide the best progress. However, substantial reduction of sugar in processed foods without compromising sensory properties may be an impossible dream.

KEYWORDS

Sugar reduction; sweetness; obesity; taste; sugar substitutes; food structure

1. Introduction

As a result of the obesity epidemic, the high level of sugar in processed food products is a major concern for health organisations and consumers. While sugars role in obesity is complex (Hu 2013; Stanhope 2016), health bodies and governments are seeking a reduction in the sugar content of processed food as soon as possible (Popkin and Hawkes 2016). The World Health Organisation (WHO) has recommended sugar intake to be less than 10% of total energy intake (WHO 2015), and significant proportions of consumers are actively seeking out reduced sugar alternatives (Piernas, Ng, and Popkin 2013). A tax on sugar (predominantly on sugar sweetened drinks) has already been introduced in a number of countries, and is likely to be eventually adopted by many others (Johnson 2017).

Despite the push for reduced sugar products consumers also demand products with an appealing sensory profile. Food scientists have been responding to this demand by developing alternative strategies to sweeten products. This challenge is technically difficult, as sugar not only has a unique sweetness profile that is difficult to replicate (Larson-Powers and Pangborn 1978; Palazzo and Bolini 2014), but sugar also plays an important role in product structure, texture, flavour enhancement, and product preservation (Koeferli, Piccinali, and Sigrist 1996; Pareyt et al., 2009). The most well studied approaches to maintain sweetness while reducing sugar content include the use of sweetness substitutes (such as non-nutritive sweeteners (NNS), sugar alcohols, and fibres), multi-sensory integration principles (such as the use of aroma and colour), and the modification of food structure (such as the inhomogeneous distribution of sugar, modification of fracture mechanics and serum release). Some research has also considered the prospect of gradual sugar reduction to adjust the levels of sweetness desired by the consumer.

The aim of this review is to discuss sugar reduction strategies available to food industry, and critically compare the merits of each option. The scope included strategies to reduce sugar content in food products without a reduction in the intensity of sweetness levels, strategies to enhance sweetness intensity without the addition of more sugar, strategies to replace the textural properties of sugar when it is removed, and gradual sugar reduction to reduce the sweetness levels desired by consumers. The different sensory methods to assess sugar reduction are also reviewed to understand the numerous options sensory and food scientists have to measure the effectiveness of sugar reduction in a given product. Recommendations are then put forward for the most suitable avenues for the food industry to reduce the sugar content of processed foods in the future. The physiological basis of sweetness perception and sugar's influence on health is discussed to provide vital background to the issue of sugar reduction. The term sugar in this review refers specifically to the disaccharide sucrose.

CONTACT Scott C. Hutchings scott.hutchings@unimelb.edu.au The University of Melbourne, Level 2, Building 184, Royal Parade, Parkville, Victoria 3010, Australia.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/bfsn.

2. Sugar intake and health

There is significant epidemiological evidence associating sugar consumption with obesity and type-2 diabetes, particularly in relation to consumption of sugar sweetened beverages (Malik et al. 2010; Olsen and Heitmann 2009). A review and meta-analysis of randomised control trials suggested that diets high in sugars increased body fatness although most studies were short term (<8 weeks) (Te Morenga, Mallard, and Mann 2013). This has prompted health organisations such as the World Health Organisation (WHO) and the American Heart Association to propose an upper limit of no more than 10% of energy from sugar (Mathers 2008; Johnson et al. 2009). Moreover, the US FDA (Food and Drug Administration) recommends listing added sugars as a separate line on Nutrition Panels (FDA 2015). However, despite the development of public health initiatives to reduce consumption of sugar, there is little direct evidence of detrimental effects of sugar on health, as long as sugar consumption is below 25% of total energy (Evans 2017; Marriott, Fink, and Krakower 2014). The lack of direct evidence may be due to the difficulty in running long term sugar reduction randomised control trials as added sugars are ubiquitous in the food supply, and regulating intake below 5% total energy for time periods longer than a month would be very difficult. For a review of the influence of sugar on health please read Evans (2017), Marriott, Fink, and Krakower (2014), and Rippe and Angelopoulos (2016).

3. Physiology of sweetness perception and its role in the human body

Before discussing sugar reduction, it is important to have a basic understanding of sweetness perception. It is thought that the individual's ability to detect or sense sweetness in the oral cavity (the initial process of sweet taste perception) is one of many factors influencing food acceptance, and as such, taste may play an essential role in modulating food acceptance and/or energy intake (Drewnowski 1998). In addition, research shows that the sweet taste signalling mechanisms identified in the oral cavity also operate in the gastrointestinal (GI) system, which may possibly influence satiety (Beglinger and Degen 2006; Dyer et al. 2005a; Egan and Margolskee 2008; Gerspach et al. 2011; Horio et al. 2010; Mace et al. 2007; Montmayeur and Matsunami 2002; Sclafani et al. 2010; Steinert et al. 2011). Therefore, a fundamental understanding of taste reception throughout the alimentary canal may possibly be an important factor in understanding the causes for excess energy intake.

While it is commonly agreed that there is one sweetness signal, such a statement is potentially misleading as there are obvious difference between sweetness of sucrose and sweetness of aspartame for example. There are four dimensions that make taste sensations from sucrose or aspartame or any other tastant unique: their quality, intensity, temporal, and spatial patterns. The attribute "quality" is a descriptive noun given to categorise sensations that taste compounds elicit; there are five major taste quality descriptors: sweet, sour, salty, bitter, and umami. The quality of a taste sensation is its single most important defining feature. The attribute "intensity" is a measure of the magnitude of sensation(s) elicited by a compound at a given time and is modified by changing concentration of the compound. The perceived intensity of compound may be plotted against its concentration to produce a psychophysical function. The "temporal" pattern of a compound is related to the time course of the intensities. Finally the "spatial" topography relates to the location of taste sensations on the tongue and oral cavity. When we think of the sweetness of sugars and NNS the dimensions that allow discrimination are the temporal (time based) aspects and also the side tastes aspects that may be present (for example, bitterness of aspartame). Most NNS have a lingering sweetness, and some also have bitter and metallic side notes (Schiffman, Crofton, and Becker 1985; Riera et al. 2007) both of which detract from a unitary sweetness signal experienced with carbohydrate sweeteners. These aspects have the potential to influence consumer liking as expectations are not met when sugar is reduced or replaced with NNS.

3.1. Taste function

Humans experience five basic taste qualities (sweet, salty, bitter, sour, umami) and one additional taste fat that is not a traditional taste quality (Chalé-Rush, Burgess, and Mattes 2007; Mattes 2009, 2011; Newman, Haryono, and Keast 2013; Newman et al. 2016; Newman and Keast 2013; Running, Craig, and Mattes 2015; Stewart and Keast 2012; Stewart et al. 2010; Stewart, Feinle-Bisset, and Keast 2011; Tucker et al. 2014). From an evolutionary perspective, it is postulated that the human taste system functions as a gatekeeper of the digestive system to ensure that we consume essential nutrients for survival and functioning, while rejecting potentially harmful or toxic foods (Simon et al. 2006).

Taste perception for a particular taste quality is experienced when the concentration of that particular compound in the oral cavity reaches a level that activates a taste receptor (Keast and Roper 2007). For instance, when 1 mM sucrose is dissolved in water, an individual may find it challenging to differentiate the sucrose-containing solution from plain water. However, as the concentration of sucrose is increased, differentiation becomes possible (Bartoshuk 1978; Keast and Roper 2007; Webb et al. 2015). The lowest concentration level at which a difference can be detected is termed the sucrose detection threshold (DT). At this concentration level, the individual cannot accurately identify the sucrose solution as sweet, and only when the concentration of sucrose is further increased does the sweet taste quality become apparent (Amerine, Pangborn, and Roessler 1965). The lowest concentration at which sweetness is identified is termed the sucrose recognition threshold (RT) (Amerine, Pangborn, and Roessler 1965; Keast and Roper 2007; Snyder, Prescott, and Bartoshuk 2006). As sucrose is progressively added beyond this point, the perceived sweetness will range from weak to strong, until it reaches the individual's terminal threshold for sucrose, beyond which any increase in concentration no longer causes consequential increase in perceived sweetness intensity (Bartoshuk et al., 2004b; Keast and Roper 2007; Paulus and Reisch 1980). Perceived sweetness above the RT is defined as the suprathreshold intensity perception (ST) range (Bartoshuk 1978; Bartoshuk et al. 2006).

3.2. Peripheral mechanisms for sweet taste detection

It has been shown that there are similarities for sweet detection in the oral cavity and gastrointestinal tract (GIT), between sweet oral taste receptor cells (TRC) and the gastrointestinal sweet TRC (Figure 1) (Bezençon, Le Coutre, and Damak 2007; Dyer et al. 2005b; Höfer, Püschel, and Drenckhahn 1996; Kojima and Nakagawa 2011; Raybould 2010; Rozengurt and Sternini 2007; Sclafani 2007). The existence of an almost identical nutrient-sensing mechanism in the oral cavity and GIT seems reasonable, given that both are part of the alimentary canal and responsible for the identification of nutrients and non-nutrients in foods (Nelson et al. 2001). Further, both the oral cavity and GIT initiate the appropriate functional responses, such as taste perception (oral cavity) and hormone release (e.g., satiety hormones) (GIT) (Nelson et al. 2001).

3.3. Sweet taste detection in the oral cavity

Compounds perceived as sweet bind to the sweet TRC, a heterodimer of two G-protein coupled receptors (GPCR), T1R2 and T1R3 (Bachmanov and Beauchamp 2007; Bachmanov et al. 2001; Cui et al. 2006; Hayes 2008; Hoon et al. 1999; Kitagawa et al. 2001; Margolskee 2002; Max et al. 2001; Montmayeur et al. 2001; Nelson et al. 2001; Nie et al. 2005; Pin, Galvez, and Prézeau 2003; Prinster, Hague, and Hall 2005; Xu et al. 2004), which causes intracellular signalling elements to be activated (Figure 1) (Rössler et al. 1998; Wong, Gannon, and Margolskee 1996). Once activated by sugar or NNS, sweet TRC transmit the information via sensory afferent fibres to the brain areas involved in sweet taste processing (Sclafani 2007). The oral sweet information is also sent to the stomach via the vagus nerve to proceed with the cephalic phase response (i.e., gastric juice secretion) (Sclafani 2007). This process further initiates functional responses in the GIT, such as glucose uptake and hormone release (Renwick and Molinary 2010).

3.4. Sweet taste detection in the gastrointestinal tract

Expressions of the functional sweet TRC occur in the intestinal enteroendocrine cells (Bezençon, Le Coutre, and Damak 2007; Dyer et al. 2005b) and other tissues, such as the pancreas (Nakagawa et al. 2009). Upon stimulation with sugars or NNS by the GI sweet TRC, digestive and absorptive processing of the ingested food is further coordinated by the secretion of gut hormones, including PYY, GLP-1 and GIP, further regulating insulin release from pancreatic β-cells (Beglinger and Degen 2006; Egan and Margolskee 2008; Jang et al. 2007). These gut hormones are associated with the metabolism of nutrients and fullness (Jang et al. 2007). Two types of glucose transporters facilitate the glucose uptake in the GI lumen: sodium-glucose transport protein-1 (SGLT-1) and glucose transporter 2 (GLUT2) (Mace et al. 2007; Margolskee 2002; Renwick and Molinary 2010).

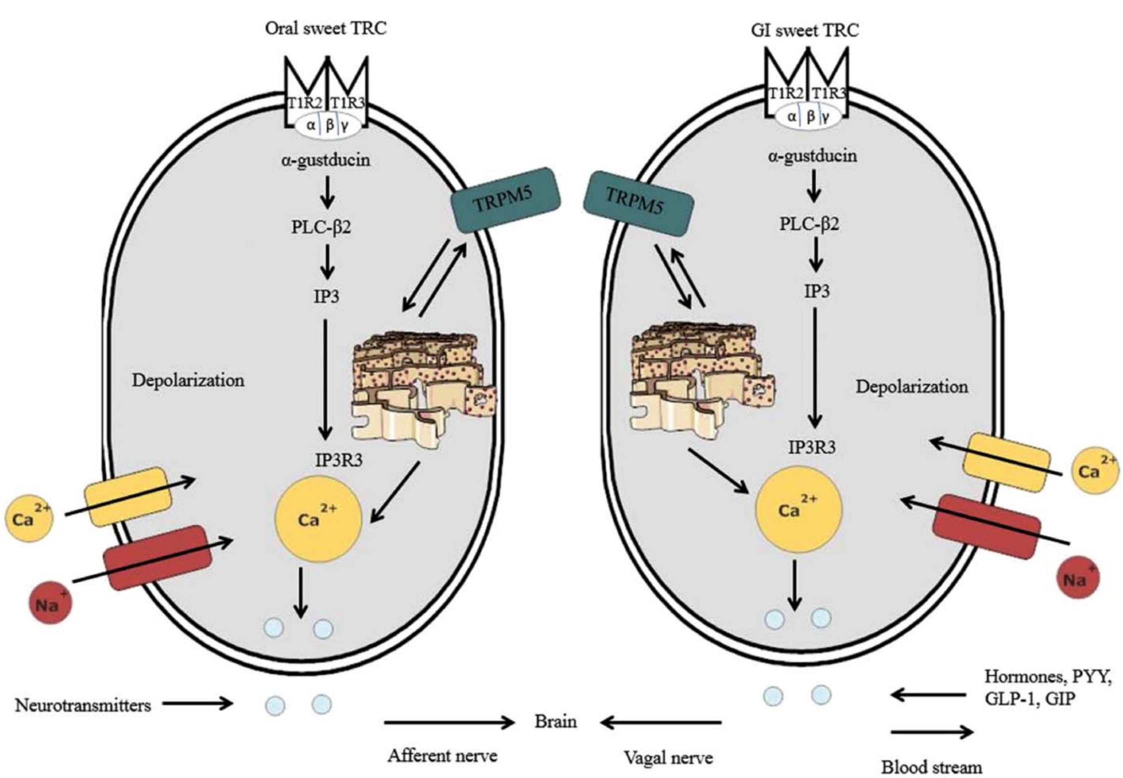

Figure 1. Schematic representation of lingual sweet taste receptor cells (TRC) and GI sweet TRC consisting of TIR2-T1R3 dimer receptors. Once the compound binds to the TIR2-T1R3 receptor, intracellular signalling elements are activated, including α-gustducin, which, in turn, activates PLC-β2. The stimulation of PLC-β2 leads to the generation of IP3, where the IP3R3 further activates the calcium ions from the endoplasmic reticulum. After the calcium ions are released, the TRPM5 channel is activated, resulting in sodium entry in the plasma membrane. Sodium entry leads to depolarization, thus inducing calcium entry through the calcium channel. The calcium ions then induce the discharge of neurotransmitters from oral sweet TRC, which are then relayed via the afferent nerve to the brain areas involved in sweet taste processing. In the GI sweet TRC, satiety hormones, such as peptide tyrosine tyrosine (PYY), glucagon-like peptide 1 (GLP-1) and glucose-dependent insulinotropic peptide (GIP), are released upon secretion of calcium ions within the cell. These satiety signals are then relayed to the brain via the vagal nerve (from Low, Lacy, and Keast 2013).

3.5. Non-nutritive sweeteners and their role in the gastrointestinal tract

Sweet TRC can bind to molecules of varying structures, including caloric sugars and a range of NNS. However, the metabolic fate of NNS varies in the GIT depends on the chemical structure of each NNS (Brown and Rother 2012). The signalling transduction and downstream actions, such as satiety hormone release in the GI system upon activation by NNS is controversial. Some studies support the hypothesis that NNS bind to the sweet TRC on the enteroendocrine cells, resulting in similar downstream actions as caloric sugars, such as satiety hormone secretion in humans (Brown and Rother 2012; Jang et al. 2007; Mace et al. 2007; Whitehouse, Boullata, and McCauley 2008). Nevertheless, the majority of in vivo studies have failed to confirm this (Fujita et al. 2009).

Recent studies investigating the role of SGLT-1 in cultured L-cells have suggested that the SGLT-1 is more involved in sugar sensing in the GIT in comparison to the T1R2-T1R3 dimer (Nguyen, Akiba, and Kaunitz 2012). SGLT-1 has an important function in glucose homeostasis, as it is the primary transporter of dietary sugars in the GI lumen (Dyer, Hosie, and Shirazi-Beechey 1997) and has been found to be involved in the mechanism of glucose-induced incretin release in cultured mice L-cells (Gribble et al. 2003; Reimann et al. 2008). Collectively, studies suggest that NNS generate taste signals from the sweet TRC in the oral cavity, but do not stimulate gut receptor mechanisms that are involved in satiety. This illustrates a key difference between sugars and NNS, in that NNS may not be providing postingestive feedback associated with sugars therefore may not have the same long term acceptance of sugar.

3.6. Sweet taste processing in the brain

Taste signals generated from the oral cavity are forwarded to the brain via the sensory afferent fibres (Janssen and Depoortere 2013; Sclafani and Ackroff 2012; Tomchik et al. 2007). Taste information is then transmitted to the primary taste cortex (Kelley and Berridge 2002; O'Doherty et al. 2002; Zheng and Berthoud 2007). The neurons in the primary taste cortex relay information to pathways involved in the central processing of the food reward along the dopaminergic midbrain (Kelley and Berridge 2002; O'Doherty et al. 2002; Zheng and Berthoud 2007). Neurons within the midbrain subsequently inform other brain regions which may result in release of dopamine, a neurotransmitter frequently linked with reward (Kelley and Berridge 2002; O'Doherty et al. 2002; Zheng and Berthoud 2007). Brain autonomic centres may also relay and receive information from the GI system via the vagal nerve to coordinate with satiety hormones to prepare the digestive system for the incoming sugar-rich food (Berthoud and Morrison 2008; Zheng and Berthoud 2007).

The question is whether NNS can impact the central taste and reward pathways similarly to caloric sugars in the brain, given that NNS are able to activate TRC in the oral cavity, or whether the NNS signal can be differentiated from sugars. In a study by Smeets et al. (2011), 20 healthy men were asked to rate the satisfaction and sweetness of solutions sweetened with either sucrose or a NNS while undergoing fMRI scans. It was found that the human brain responds differentially to sucrose and NNS, particularly in the activation of striatum (i.e., striatum, a brain region involved in the reward pathway, was not activated upon ingestion of a NNS sweetened solution in comparison to sucrose) (Smeets et al. 2011). Similarly, in another study by Frank et al. (2008), researchers found that both caloric sugar and NNS were able to activate the primary taste pathway in the brain, but only caloric sugars were able to activate a significant response from brain regions involved in the brain's reward pathway. It appears, at least at the brain level that NNS will not deliver the same level of satisfaction and pleasure compared to sugar. From the GIT, it also appears that NNS may increase appetite or reduce satiety in comparison to equally sweet foods containing sugar. The biology underpinning sweet taste perception is complex and not fully understood. While sugars and other sweeteners have some commonality in perception, there are also significant differences in how sugars and NNS are processed in the body making sugar reduction problematic, particularly if reward systems are not fully activated by NNS.

4. Different sensory methods used in the assessment of sweet foods

Depending on the type of information required, there are multiple sensory methods used to assess sweetness, liking and preference of sweet foods. Currently, the existing instruments used in assessing sensory perception of sweet foods are mainly derived from experimental psychology and behavioural science. An understanding of the sensory methods used in assessment of sweet foods is crucial when considering the currently available evidence on sugar reduction strategies.

4.1. Experimental psychology

Experimental psychology encompasses the methods to investigate the response of individuals in a controlled setting. Six classical methods (scaling, preference, ranking, difference, Just-About-Right (JAR) scales, and attribute analysis) and its application in sweet taste research will be discussed in the following sections.

4.1.1. Scaling

Scaling involves the utilisation of numbers or words assigned to values to quantify the intensity of a perceived sweetness or a reaction to such attribute such as hedonics (Meilgaard, Carr, and Civille 2006). Three commonly used scales to quantify sweetness intensity perception include the visual analogue scale (VAS) (Aitken 1969), Labeled Magnitude Scale (LMS) (Green, Shaffer, and Gilmore 1993), and general Labeled Magnitude Scale (gLMS) (Bartoshuk 2000). Visual analogue scales are commonly used to investigate sweet taste intensity in sucrose solutions (de Matos et al. 2010; Har-Zion, Brin, and Steiner 2004; Hardikar et al. 2017; Hogenkamp et al. 2017; Perros et al. 1996; Rahemtulla et al. 2005; Soenen and Westerterp-Plantenga 2007; Srivastava et al. 2013; Strasser et al. 2008) and sweet taste intensity in foods (Akyol et al. 2014; Harington et al. 2016; Olsen et al. 2011; Tatano et al. 2016). Participants are typically asked to mark on a 100 mm horizontal line (anchored 0 = no sensation and 100 = strongest imaginable sensation of any kind) the point that corresponds to the sweetness intensity they perceive (Hayes, Allen, and Bennett 2013). In contrast to a VAS scale, the LMS scale (Green et al. 1996; Green, Shaffer, and Gilmore 1993; Schifferstein 2012) is a hybrid scaling technique using a verbally labelled line with quasi-logarithmic spacing between each label. LMS is commonly used to investigate sweet taste intensity in sweet taste solutions (Eguchi et al. 2016; Green et al. 1996; Holt et al. 2000; Isogai and Wise 2016; Kauer et al. 2015; Lawless, Horne, and Spiers 2000). A gLMS scale is similar to the LMS scale except that the top of the scale is labelled as the 'strongest imaginable sensation of any kind' (Bartoshuk et al., 2006). However, in comparison to LMS, training sessions are provided in gLMS to participants prior using the scales to standardise the data (i.e., use of non-oral standards within a training session such as a remembered sensation like the brightness of sun) thus allowing a more valid across-subject comparison (Bartoshuk et al., 2006). gLMS has also been used extensively in modern sweet sensory research to investigate sweet taste intensity from sweet (both caloric and non-nutritive sweetened) taste solutions (Bartoshuk et al., 2006; Cicerale, Riddell, and Keast 2012; Feeney and Hayes 2014) and sweetness intensity in sweet foods (Monteleone et al. 2017; Wise et al. 2016).

Two commonly used rating scales to measure the degree of liking in sweet taste solutions and foods include the 9-point hedonic scale (Divert et al. 2017; Greene et al. 2006; Leitch et al. 2015; Li, Hayes, and Ziegler 2014; Mahar and Duizer 2007; Mennella et al. 2014; Morais et al., 2014a; Oliveira et al. 2015; Orjuela-Palacio, Zamora, and Lanari 2014; Rognlien et al. 2012; Taylor, Fasina, and Bell 2008; Ungure et al. 2013; Urbano et al. 2016), as well as a range of category-ratio scales such as the Labeled Affective Magnitude (LAM) scale, hedonic gLMS, and the labeled hedonic scale (LHS) (Booth 2016; Cornelis et al. 2017; Duffy et al. 2016; Eguchi et al. 2016; Hayes, Allen, and Bennett 2013; Hogenkamp et al. 2017; Kalva et al. 2014; Kim, Prescott, and Kim 2017; Lim and Fujimaru 2010; Lim, Wood, and Green 2009; Pepino and Mennella 2012). The 9-point hedonic scale is a bipolar scale, neutral at the centre with four positive and four negative categories on each side (1 = like extremely to 9 = dislike extremely) (Peryam and Haynes 1957). In a study by Divert et al. (2017) investigating the relation between sweet food consumption and liking for sweet taste in 101 French children aged between 7 and 12 years, children were asked to taste and rate liking of a range of sweet products (sugar water, strawberry syrup with water, and cereal in milk) using a modified 9-point hedonic scale that was illustrated by cartoon smiley faces with labels (1 = do not like it at all to 9 = I really like it a lot) (Divert et al. 2017). Although the 9-point hedonic scale is one of the most widely used rating scales to measure the degree of liking in sweet foods and beverages, line scales such as category-ratio scales may provide greater sensitivity as participants can express subtle differences in preference rather than being confined to categorical scales (Lim 2011; Lim and Fujimaru 2010). Category-ratio scales such as LAM, hedonic gLMS, and LHS are all bipolar hedonic scales, except with differences such as the adjectives used and the spacing between the adjectives (e.g., hedonic gLMS with neutral at its centre-point and with positive and negative ratings at each side, strongest imaginable) (Bartoshuk et al. 2004a). For published reviews of psychophysical scaling on intensity scaling methods, please read Bartoshuk et al. (2002), Gescheider (1988), and Stevens, (1969), and for hedonic scaling methods, please read (Lim 2011).

4.1.2. Preference

The preference test can be used to determine preference of deferring levels of sweetness in sugar reduced foods and beverages (although does not indicate the degree of liking). Preference tests have been used to investigate preference of sweetness for coffee flavoured milk (Li, Hayes, and Ziegler 2015), tea (Chung and Vickers 2007), orange juices (Cordelle, Piper, and Schlich 2005), and sweet snacks (Hetherington, Bell, and Rolls 2000). Mennella et al. 2010 used a Monell forced-choice test (paired-comparison tracking procedure) to measure sucrose preference, where participants were asked to taste a pair of sucrose solutions (with different concentrations) and to select the preferred solution.

4.1.3. Difference

Difference tests can be used to determine if two sweetened samples are perceptibly different or if two sweetened samples are sufficiently similar to be used interchangeably. There are two different categories for a difference test depending on whether the objective is to measure if there is an overall difference between samples (overall difference tests), or if participants are asked to concentrate on a single attribute instead of an overall difference (i.e., an attribute difference test for sweetness). The triangle test and duo-trio test are two classical methods used to measure overall difference. Some examples of the triangle test being used in studies on sugar reduction include the addition of galacto oligosaccharide in vanilla ice-cream (Balthazar et al. 2015), children's discrimination of sugar sweetened and non-nutritively sweetened beverages (de Ruyter et al. 2012), grape juice as a sweetener for blueberry drinks (Tipton et al. 1999), sweetened lemonade with sucrose-malto mixtures (Bingham et al. 1990), and sweetening of soft drinks with mixtures of sugars and saccharin (Hyvonen, Koivistoinen, and Ratilainen 1978). In a triangle test, participants are told to taste a tray containing three sweetened samples (two identical, one different) and to pick the odd sample out, whereas in a duo-trio test, participants are told to match samples to a reference sample (Francois and Sauvageot 1988; Meilgaard, Carr, and Civille 2006). The 3-alternate forced choice (AFC) test is a classical attribute difference test method used to measure differences between samples based on a single attribute. Attribute difference tests have been used to measure individual sensitivity to sweet taste using a range of sweeteners in solutions (Fogel and Blissett 2014; Ishii, Yamaguchi, and O'Mahony 1992; Joseph, Reed, and Mennella 2016; Low et al. 2016; Mattes 2007; Narukawa et al. 2009; Peng et al. 2016; Pickering and Kvas 2016; Shepherd, Quek, and Pathirana 2008; Stevenson et al. 2016; Walter and Soliah 1995; Zhang et al. 2009).

4.1.4. Just about right (JAR) scale

In sugar reduction studies, JAR scales can be used to measure the appropriateness of the level of sweetness and to determine the optimum sweetness level in a sugar reduced product desired by consumers (Lawless and Heymann 2010). These scales involve bi polar scales typically labelled 'too sweet' and 'not sweet enough' at each end of the scale. JAR scales have been used to determine ideal equivalent sweetness in products such as passionfruit juice (de Oliveira Rocha and Bolini 2015), chocolate milk (Rodrigues et al. 2015), orange nectars (de Oliveira Pineli et al. 2016), flavoured liquid milk (Zhi, Zhao, and Shi 2016), and mango nectar (Cadena and Bolini 2012).

4.1.5. Attribute analysis techniques

To assess the sensory characteristics (attributes) of sugar-reduced foods, attribute analysis techniques based on descriptive analysis with trained panels is considered the gold standard approach. Descriptive analysis is expensive and time consuming, however well trained descriptive panels are highly sensitive at analysing a sensory properties of series of products (the intensity of taste, flavour, and texture attributes are typically analysed together to produce an objective sensory profile of a product). Traditionally, the undertaking of descriptive analysis to measure sweetness and study sugar reduction has been based on either the Quantitative Descriptive QDA® method or the Sensory Spectrum Method ®. Both approaches involve extensive training of panellists, however with QDA panellists generate their own vocabulary to describe sensory attributes of products as a group, whereas with Spectrum panellists use a standardized lexicon of terms. Today, most descriptive analysis if often a hybrid of both QDA and Spectrum methods (Lawless and Heymann 2010; Murray, Delahunty, and Baxter 2001).

The QDA method has been used in sweet foods such as mango nectar sweetened with different concentrations and types of sweeteners (Cadena and Bolini 2012), artisanal honeys (González, De Lorenzo, and Pérez 2010), soy milks (Keast and Lau 2006) and custard desserts (Weenen, Jellema, and De Wijk 2005). The Sensory Spectrum Method ® has also been well used to study in sweet foods such as cookies (Perry et al. 2003) and strawberry yoghurts (Lovely and Meullenet 2009).

There are also several rapid attribute analysis techniques used in the sensory analysis of sweet foods which can be performed without prior training [e.g., check-all-that-apply (CATA), projective mapping or Napping, free-choice profiling] (Cadena et al. 2014). With CATA, participants are asked to select from a list of words or phrases pre-determined by the researcher. Some examples of the use of CATA with sweetened products include yogurts (Farah, Araujo, and Melo 2017), and fibre enriched apple purees (Laureati et al. 2017). With projective mapping or Napping, participants are asked to sort a range of sweet products according their own descriptive criteria on a large sheet of paper (60 cm × 60 cm) to assess key attribute similarities and differences between sweet products (Delarue and Sieffermann 2004). With free choice profiling, participants are allowed to invent their own terminologies to describe the sensory characteristics of a sweetened product (Tormena et al. 2017).

For certain foods and beverages, the perception's intensity varies with time (e.g., lingering sweetness or bitterness from NNS differs) (Cliff and Heymann 1993; Meilgaard, Carr, and Civille 2006). Therefore, temporal methods are also critical to study how the sensory characteristics of sweet foods change with time. Temporal attribute analysis techniques such as the time-intensity (Ketelsen, Keay, and Wiet 1993; Morais et al., 2014b; Palazzo et al. 2011), temporal dominance of sensations (TDS) (Hutchings et al. 2017; Morais et al., 2014b; Zorn et al. 2014b), and temporal check all that apply (TCATA) (Castura et al. 2016) have all been used in the assessment of sweetened or sweet foods and beverages. Time intensity can provide a temporal analysis of the intensity of sweetness (and other attributes if conducting multiple sessions with panellists), while TDS and TCATA can provide a broader picture of the complete temporal profile of all of the attributes of the product (sweetness, but also taste, flavour and textural attributes) from a single session with panellists.

4.2. Behavioural science

Behavioural science is defined as the methods used to investigate the decision process regarding foods within and between people. Insights from behavioural sciences are commonly applied and practiced in the study of consumer behaviour. Quantitative tests such as surveys, questionnaires, or consumption responses are used to determine the responses of a large group of participants (> 50 participants) to a set of questions regarding sweet foods liking, habitual intake of sweet foods, eating behaviours, demographics, and many more (Meilgaard, Carr, and Civille 2006). Some common examples are the Food Frequency Questionnaire (Divert et al. 2017; Duffy et al. 2009; Eny et al. 2010; Holt et al. 2000; Low et al. 2016; Negri et al. 2012; Tepper and Seldner 1999) and the Dietary Fat and Sugar Questionnaire (Stevenson et al. 2016). Qualitative tests such as focus groups are commonly used to measure the subjective responses of consumers to the sensory properties of newly developed sweet products (Meilgaard, Carr, and Civille 2006). Qualitative testing is normally conducted by having consumers discuss their feelings/thoughts in an interview or small group setting (Meilgaard, Carr, and Civille 2006).

5. The role of sugar in foods and the technical difficulties associated with sugar reduction

Sugar plays an important role delivering a pleasant sensory experience across a wide range of food products. Its most obvious function is the sweetness it delivers to food (Johnson and Clydesdale 1982). Sweetness drives liking in many food categories, such dairy products (Ares et al. 2010), beverages (Tuorila-Ollikainen, Mahlamaki-Kultanen, and Kurkela 1984), chocolate (Kim, Greve, and Lee 2016) and biscuits (Biguzzi, Schlich, and Lange 2014). The sweetness delivered from sugar also improves the general sensory profile of the product: it can suppress bitterness (Pineli et al. 2016), saltiness (Gillan 1982), and sourness (Baldwin, Goodner, and Plotto 2008) in many foods and beverages through taste interactions (Keast and Breslin 2003). Moreover, sugar can also enhance the intensity of flavours we experience. Sugar has been shown to increase the intensity of strawberry aroma in strawberry flavoured solutions (Pfeiffer et al. 2006), increase vanilla and caramel flavours in milk chocolate (Guinard and Mazzucchelli 1999), increase fruity aromas in blueberry juice and cranberry juice (von Sydow et al. 1974), and increase a range of fruity and leafy aromas in dairy desserts (Lethuaut et al. 2005). This effect is typically explained as result of the psychological effect of congruent aroma-taste interactions (Pfeiffer et al. 2006; von Sydow et al. 1974; Lethuaut et al. 2005), and in some cases is explained by a physicochemical effect, where the presence of sucrose is reported to enhance the release of volatiles from solution (Hansson, Andersson, and Leufvén 2001; Nahon et al. 1998).

As well as providing sweetness, sugar plays a critical role in the physical structure of food. During baking sugar reduces dough viscosity, reduces relaxation time, and assists in volume formation (Khouryieh, Aramouni, and Herald 2005; Maache-Rezzoug et al. 1998). Sugar has been shown to influence porosity, cell size distributions and cell wall thickness in the structure of cookies (Pareyt et al. 2009), and it improves emulsion stability in sunflower-water emulsions (Maskan and Göğüş 2000). Sugar can influence the unfolding and aggregation of proteins during heat treatment (Kulmyrzaev, Bryant, and McClements 2000), and increases the gelatinisation temperatures of starches (Chantaro and Pongsawatmanit 2010). In ice-cream, sugar has been shown to reduce ice crystal growth, reduce melting rate, and lower freezing temperatures (Guinard et al. 1997). Sugar therefore has a significant influence on the perception of texture of food. It affects crispiness in many baked goods (Biguzzi, Schlich, and Lange 2014), and increases the physical viscosity of beverages (Pangborn, Trabue, and Szczesniak 1973), thus providing a thicker mouthfeel (Oliveira et al. 2015). In chocolate, sugar has been shown to increase hardness and reduce grittiness (Guinard and Mazzucchelli 1999). Sugar can also influence the colour of many products (Pareyt et al. 2009). Furthermore, sugar is also important in food preservation as increasing levels of sugar decreases water activity. It can inhibit microbial growth and increase the shelf life of products (Leistner 1992; Smith et al. 2004; Farkas 2007). Consequently, any reduction in the sugar content of processed food products presents significant technical difficulties for food manufacturers to avoid changes in sensory perception, product quality, and consumer acceptance (Markey, Lovegrove, and Methven 2015).

6. Strategies to reduce the sugar content of foods

The strategies available for reducing the sugar content of foods can be broken down into four categories: sugar substitutes, multisensory integration, food structure technologies, and gradual sugar reduction. A summary is provided in Figure 2.

6.1. Sugar substitutes to reduce sucrose content

The most common approach taken by the food industry to reduce sugar content while attempting to limit changes in sensory perception is through the use of sugar substitutes: NNS to replace the sweetness of sucrose, often combined with sugar alcohols or fibres to replace the bulk of sucrose to achieve a suitable body and mouthfeel in the product. A wide range of these compounds are commercially available for food manufacturers to safely and legally use. A summary of the basic sensory properties of the most widely used sugar substitutes is provided in Table 1 (NNS) and Table 2 (bulking agents). The list is not exhaustive. The relative sweetness of each compound is approximate and varies with the concentration of the compound (Stone and Oliver 1969).

While NNS successfully reduce or eliminate the calorific content of food products, differences in the temporal sensory profile (Zorn et al. 2014), and the presence of bitter aftertastes remain common issues (DuBois and Prakash 2012; Cardosa,

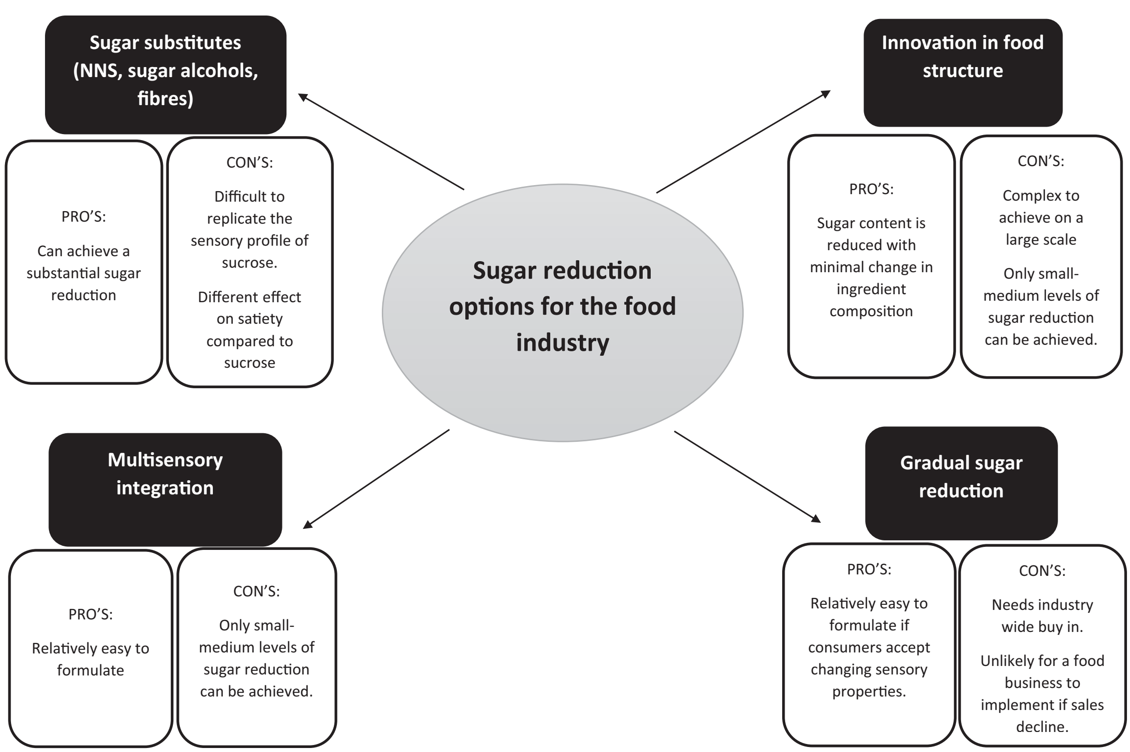

Figure 2. A summary of the options currently available for the food industry to reduce the content of added sugars in food and beverages.

Table 1. A summary of the most commonly used Non-nutritive sweeteners (NNS). Basic production methods, sensory properties, and energy content are presented.

Sugar substitute Non-Nutritive Sweeteners	Production method	Approximate sweetness relative to sucrose by weight (at moderate sweetness intensities)	Sensory properties compared to sucrose at equi-sweet levels	Approximate energy contribution to the body (sucrose ≈ 4 kcal/g)
Sucralose	Selective chlorination of sucrose at three of the primary hydroxyl groups (Grotz and Munro 2009).	700–550 times sweeter than sucrose (Wiet and Beyts 1992).	Subtle differences in aftertaste are reported compared to sucrose – slightly greater astringency and sourness (Zorn et al. 2014).	Negligible (Shankar, Ahuja, and Sriram 2013).
Aspartame	Chemical or enzymatic synthesis of the amino acids phenylalanine and aspartic acid (Magnuson et al. 2007).	200 times sweeter than sucrose (Wiet and Beyts 1992).	Similar sweet aftertaste compared to sucrose at moderate sweetness intensities, but has a slightly more bitter aftertaste. Tends to have a longer and slightly more intense sweet aftertaste compared to sucrose (Ott, Edwards, and Palmer 1991).	4 kcal/g (Kroger, Meister, and Kava 2006).
Acesulfame potassium (Ace K)	Synthesised using ketones, β-diketones, derivatives of β-oxocarbonic acids, alkynes, and halogen sulfonyl isocyanates (von Rymon Lipinski and Hanger 2001)	150–250 times sweeter than sucrose (Wiet and Beyts 1992).	Typically more bitter than sucrose (Ott, Edwards, and Palmer 1991). Often used in combination with other sweeteners (particularly aspartame) for synergistic sweetness enhancement and a temporal profile with greater similarity to sucrose (Ayya and Lawless, 1992).	Negligible (ADA 2004).
Saccharin	Methyl anthranilate treated with sodium nitrite, sulfuric acid, sulfur dioxide, and chlorine (O'Donnell and Kearsley 2012).	450–400 times sweeter than sucrose (Wiet and Beyts 1992).	More bitter than sucrose (Larson-Powers and Pangborn 1978), and has a different temporal sensory profile (Wiet and Beyts 1992). More suitable in blends with other sweeteners (Schiffman et al. 1995).	Negligible (Kroger, Meister, and Kava 2006).
Stevia	Steviol glycosides are extracted from the dried leaves of the plant *Stevia Rebaudiana* (Goyal and Goyal 2010).	100–150 times sweeter than sucrose (Cardello, Da Silva, and Damasio 1999).	Bitter aftertaste (Fujimaru, Park, and Lim 2012), and doesn't match the temporal profile of sucrose as well as many artificial sweeteners (Zorn et al. 2014). Is more often used to reduce sucrose content (sucrose in combination with stevia) rather than completely replace it.	2.7 kcal/g (Savita et al. 2004).
Thaumatin	Sweet protein extracted from the berry *Thaumatococcus daniellii* (Bennett) (Kurihara 1992).	2000–6000 times sweeter than sucrose (the dose response curve shows sweetness intensity plateaus quickly at low concentrations) (O'Donnell and Kearsley 2012).	Shows a delay to peak intensity in comparison to sucrose and has long a persisting sweet aftertaste (Calviño, Garrido, and García 2000).	Unknown.
Siraitia grosvenorii (Monk fruit/Luo Han Guo)	Compounds known as triterpene glycosides (or mogrosides) are extracted from Monk Fruit (Kinghora, Soejarto, and Inglett 1986).	150–200 times that of sucrose (O'Donnell and Kearsley 2012).	Has a slight honey-like flavor and liquorice flavour (Kim et al. 2015). Temporal profile shows a delay to peak intensity and a long sweet aftertaste (Kim et al. 2015).	Unknown.

Table 2. A summary of the most commonly used bulking agents. Basic production methods, functional and sensory properties, and energy content are presented.

Bulking agent	Production method	Approximate sweetness relative to sucrose by weight (at moderate sweetness intensity levels)	Functional and sensory properties	Approximate energy contribution to the body (sucrose ≈ 4 kcal/g)
Sugar alcohols: Sorbitol, isomalt, xylitol, mannitol, and erythritol	Typically produced via reduction using hydrogenation of the original sugar (e.g., glucose to produce sorbitol, or xylose to product xylitol).	Sweetness is typically less than sucrose Sorbitol: 50–70% Isomalt: 45–65% Xylitol: 100% Mannitol: 90% Erythritol: 60–80% (Grembecka 2015).	Replace the bulk properties provided by sucrose (Ghosh and Sudha 2012) and can also act as thickeners, humectants, and emulsifiers in reduced sugar products (Beereboom and Glicksman 1979; Ghosh and Sudha 2012). Textural properties often differ from sucrose – differences in firmness often reported (Belščak-Cvitanović et al. 2015; Ronda et al. 2005).	Approximately 1.5 −3.0 kcal/g (Livesey, 1992). Erythritol an exception (0.3 kcal/g) (Röper and Goossens 1993).
Inulins and fructo-oligosaccarides	Most commonly extracted from chicory and Jerusalem artichoke (Aidoo et al. 2013) (the production of fructoligosaccaharides requires an additional step of partial enzymatic hydrolysis).	Inulin has a slight sweet taste (10% of sucrose) (O'Donnell and Kearsley 2012), while fructoligosaccaharides are sweeter (35% of sucrose) (Franck 2002).	Replace the bulk properties of sucrose (Burdock and Flamm 1999; Franck 2002). Textural differences often remain. E.g. The substitution of inulin for sucrose can lead to greater firmness and reduced springiness in baked goods (Gao et al. 2016), and fructo-oligosaccarides can lead to a decrease in gel strength of semi solid products (Protonotariou et al. 2013).	Approximately 1.5 kcal/g (Roberfroid 1999).
Polydextrose	Produced by the polycondensation of glucose and sorbitol.	No sweet taste.	Replace bulk lost from sucrose, (Burdock and Flamm 1999; Franck 2002). Textural differences are common when replacing sucrose with polydextrose. E.g The structure can be weaker and more brittle in baked goods (Pateras 1991).	1 kcal/g (Auerbach et al. 2007).

Bolini, and Maria 2008). Some improvements in the taste profile can be achieved using binary and ternary mixtures of sweeteners (Schiffman et al. 1995; Schiffman et al. 2000). NNS typically loose potency as concentrations are increased closer to the sweetness intensity of sucrose at 100% (Calviño, Garrido, and García 2000), often due to bitter or metallic tastes causing mixture suppression at higher concentrations (Antenucci and Hayes 2015). There is also a trend in some consumer segments to move away from artificially produced sweeteners such as aspartame and sucralose, which has led to the recent development and distribution of natural sweeteners such as stevia, thaumatin, and monk fruit.

Replacing bulk with sugar alcohols and fibres is also only partially effective from a sensory perspective, as differences in textural properties can still be significant in comparison to the original sucrose variants. Differences in specific volume and firmness was reported in sponge cakes where sucrose was replaced with either sugar alcohols, oligofructose or polydextrose (Baeva, Panchev, and Terzieva 2000; Ronda et al. 2005). Erythritol increased hardness, while sorbitol and maltitol decreased hardness, compared to a sucrose control in muffins (Martínez-Cervera, Salvador, and Sanz 2014), and inulin increased firmness and reduced springiness in muffins compared to a sucrose control (Gao et al. 2016). Particle size and hardness increased in sucrose reduced chocolate replaced with a range of sugar alcohols (Belščak-Cvitanović et al. 2015).

6.2. Multisensory integration principles to reduce sucrose content

Sucrose reduction can also be achieved without the use of NNS. The use of multisensory integration principles, where the enhancement of other sensations can enhance perceived sweetness, is one effective approach.

6.2.1. Aroma

Odours have been shown to increase the perceived sweetness intensity of food when they are associated (through previous exposure) with a sweet product. This is summarised best in a study by Frank and Byram (1988). Subjects were asked to rate sweetness intensity of whipped cream with and without a strawberry odour (whipped creams at different sucrose levels were tested), and found that strawberry odour increased maximum sweetness intensity and duration. Subjects then rated the whipped cream with and without a peanut butter odour for sweetness (whipped creams with the same series of different sucrose levels were tested), and found no change in sweetness ratings. Finally, subjects rated the whipped cream with and without strawberry odour for saltiness (whipped creams at different NaCl levels were tested), and found no difference in the intensity of saltiness. The effect of sweetness enhancement was also repeated with strawberry aroma in sucrose solutions by Frank, Ducheny, and Mize (1989). Stevenson, Prescott, and Boakes (1999) used sucrose solutions with a wider range of odorants (15 odorants). Sweet smelling food aromas (e.g., caramel, strawberry) were found to enhance the intensity of sweetness, while non-food odours suppressed sweetness intensity (e.g., angelica oil).

The mechanism behind this effect is believed to occur via learning and associating the perception of sweetness with a particular product (Prescott, Johnstone, and Francis 2004), as taste-smell integration in the brain is dependent on previous experience with taste-smell combinations. Both tastants and odourants have been shown to produce overlapping activations in certain areas of the brain (Small et al. 2004). The magnitude of sweetness enhancement using aromas associated with sweetness will differ for different odours. Tournier et al. (2009) demonstrated sweetness enhancement in custard desserts flavoured with benzaldehyde (almond aroma) was greater than custard desserts flavoured with allyl caproate (pineapple aroma).

The use of aroma as a tool for sugar reduction is a practical and viable option for the food manufacturer, which is relatively easy to achieve. However, the magnitude by which sugar content can be reduced is smaller in comparison to approaches with NNS. The majority of research in this area has examined sweetness enhancement, however some recent research has also investigated sugar reduction to maintain sweetness levels. Alcaire et al. 2017 demonstrated a reduction of 30–40% sucrose without compromising sweetness intensity was achieved by adding vanilla flavour to sugar reduced milk desserts.

6.2.2. Colour

The effect of colour on the intensity of sweetness is unclear in current literature. Some studies have shown that particular colours or shades of a colour will change sweetness intensity, while others report no significant effect. Johnson and Clydesdale (1982) observed increased sweetness intensity in dark coloured sucrose solutions compared to lighter coloured ones, while Frank, Ducheny, and Mize (1989) showed that a red colour had no influence on the sweetness of sucrose solutions, and Alley and Alley (1998) reported no significant effect of colour (red, blue, yellow, green, and a colourless control) on sweetness in sucrose solutions and in gelatine gels containing sucrose. Lavin and Lawless (1998) showed dark red increased sweetness intensity compared to light red in adults in sweet aspartame solutions, but the same effect was not seen with children. Light green increased sweetness ratings compared to dark green in adults in sweet aspartame solutions, but again, the same effect was not seen in children (Lavin and Lawless 1998). Bayarri et al. (2001) investigated the effect of colour on sweetness and flavour perception in fruit juices, through the addition of colourants without altering any other aspect of the composition. Colour influenced sweetness only in orange juices, but not in kiwifruit, berry, or peach juices (Bayarri et al. 2001).

Any increase in sweetness intensity as a result of colour change is likely to be a result of prior product experiences, in a similar way that aroma enhances sweetness intensity. Spence et al. (2010) reviewed the broader issue of colours influence on taste and flavour perception, and concluded that while colour has been conclusively shown to influence flavour identification, the effect of colour on flavour intensity and taste intensity is ambiguous. The application of colour for the food industry to reduce sucrose content is limited, however it may still be effective in specific product-colour combinations to achieve a small reduction in sucrose.

6.2.3. Other stimuli

Other avenues may also exist to change the expectation and association with a product to modify sweetness. Woods et al. (2011) demonstrated that sweetness intensity can be increased by changing of the description (label) of the sweetness level of juice. The authors showed this manipulation of expectation directly influenced activation in the primary taste cortex. By changing the taste experience of the first bite of food products, the taste intensity of subsequent bites can also be modified. Le Berrre et al. (2013) showed this effect with bitterness in ice-cream bars, Dijksterhuis, Boucon, and Le Berre (2014) showed a similar effect with saltiness in sandwiches.

6.3. Food structure approaches to reduce sucrose content

Advances in the field of food structure are also providing novel ways to reduce the sucrose content of food products without the use of NNS. These techniques include inhomogeneously distributing sucrose, modifying fracture mechanics, and modifying tastant release from food structures.

6.3.1. Discontinuous stimulation of taste receptors (tastant inhomogeneity)

One of the most recent advances in sweetness enhancement has been based around discontinuous stimulation of taste receptors. This work began with the use of pulsated delivery of tastant solutions through small tubes directed into the mouth (Burseg et al. 2010), where the ‘on-off’ nature of tastant stimulation delivers an increase in the intensity of a tastant in comparison to the delivery of the same quantity of tastant at a constant rate. This technique was then applied to solid food structures by inhomogeneously distributing sucrose. Most research has been conducted in this area using sucrose within agar and gelatine composite gels (Holm, Wendin, and Hermansson 2009; Mosca et al. 2015; Mosca et al. 2010). As particles from a solid food structure are reduced in size during mastication, they will stimulate taste receptors as the particles that make up the bolus are mixed and moved around the oral cavity. When a solid structure contains sucrose that is distributed inhomogeneously, some particles will contain very high concentrations of sucrose which contact taste receptors, while some particles that contact taste receptors will not contain any sucrose. This generates the discontinuous stimulation of sweet taste receptors, and increases the perceived intensity of sweetness, in comparison to a solid structure containing homogeneously distributed sucrose, where the stimulation of sweet taste receptors is continuous. The principle behind this effect was originally shown through enhancement of sweetness rather than sugar reduction to maintain sweetness levels (Holm, Wendin, and Hermansson 2009; Burseg et al. 2010). However, Mosca et al. 2010 showed that a 20% sugar reduced gel with an inhomogeneous distribution had similar levels of sweetness to a homogenous control. Consequently sugar reduction of at least 20% appears to be feasible using this technique, and could be higher when discontinuous stimulation of both sweetness and aroma is introduced (Burseg et al. 2010).

However, application of this technology in the food industry is not straight forward, as achieving an inhomogeneous distribution of a tastant in foods manufactured on a large scale is difficult for certain products, and could require significant investment in process redesign for some manufacturers. The technology is likely to be easier to apply in solid food products rather than beverages or semisolids.

6.3.2. Modification of serum release

Another technique with potential to enhance sweetness perception and reduce sucrose content in solid food products is through modification of the serum or fluid released from solid food structures. A greater quantity of fluid containing solubilised sucrose released from a structure during mastication can increase the quantity of sucrose delivered to sweet taste receptors. Sala, Stieger, and van de Velde (2010) demonstrated this principle through the development of mixed whey protein isolate/gellan gum gels. This work involved changing the composition of the gels to develop structures that had very similar large deformation textural properties but varied in serum release. Sensory testing revealed that an increase in serum increased sweetness intensity, where the sweetness of gels with 12% serum release were the same as for gels that only displayed 2% serum release but had a 30% higher sucrose concentration.

This technique also has potential for the food manufacturer to adopt, and it may be relatively easy to achieve on a large scale in semi solid food products with a high water content via the manipulation of hydrocolloids. However, changing serum release could have a negative influence on the acceptability of mouthfeel and texture. Furthermore applications may also be limited in drier products with low water content.

6.3.3. Modification of fracture mechanics (particle size reduction during oral processing)

Changing the rate particles breakdown during mastication can also influence sweetness perception. Sala and Stieger (2013) investigated the influence of changing the fracture mechanics of agar-gelatine-oil composite gels containing 6% sucrose by weight. The gels fracture properties were modified by changing the agar-gelatine ratio and changing the particle size of the oil droplets within the gels, which achieved differences in fracture strain and Youngs modulus, thus resulting in different particle size reduction rates during mastication (differences in brittleness). Results showed that the maximum sweetness intensity of the most brittle gel was twice as intense as the least brittle gel, and reached maximum intensity in less than half the time. However, sweetness intensity measured after the maximum intensity did not differ between gel structures. The authors concluded that the rate of particle breakdown influenced the rate of sucrose release as a result of differences in the generation of surface area between the different structures. In gel systems where sucrose was distributed inhomogeneously to enhance sweetness, Mosca et al. (2015) found the modification of fracture mechanics had an even more pronounced influence on sweetness intensity. More brittle gels, with lower fracture stress and fracture strain, were reduced in size more quickly during mastication, resulting in more rapid discontinuous stimulation of taste receptors, and thus increased perceived sweetness intensity (Mosca et al. 2015).

The modification of fracture mechanics or brittleness in food products is a relatively simple task for food manufacturers to achieve through changes in formulation or processes.

However only maximum sweetness intensity was enhanced using this approach, and once again the impact on the acceptability of texture through this approach is likely to be significant, making this approach unlikely to be adopted by many manufacturers. Furthermore sensory testing using this technique has only examined sweetness enhancement, using changes in fracture mechanics to maintain sweetness levels in a sugar reduced structure has not been assessed.

6.3.4. Viscosity

While the potential for sweetness enhancement using developments in food structure covered in Sections 6.3.1–6.3.3 primarily relates to solid food products, capacity also exists for enhancing sweetness by reducing the viscosity or solids content of beverages and semi solid products. An increase in the viscosity of a beverage, will in general, decrease the sweetness intensity of a sugar solution (Hollowood, Linforth, and Taylor 2002; Izutsu et al. 1981; Kokini et al. 1982; Stone and Oliver 1966). This effect has been shown with a wide range of hydrocolloids, such as carboxymethyl cellulose, hydroxypropyl methylcellulose, guar gum, and k-carrageenan (Cook et al. 2002; Izutsu et al. 1981). The phenomenon is attributed to hydrocolloids or other solids within a food system slowing down the mass transfer of sucrose from a food or beverage into saliva to make contact with taste receptors (Delwiche 2004).

However, reducing viscosity may again have a negative influence on consumer acceptability of some products by changing the mouthfeel of a beverage. Consequently approaches to build viscosity while minimising the suppression of sweetness need to be considered. Careful selection of the appropriate hydrocolloid can achieve this. Mälkki, Heiniö, and Autio (1993) observed reduced sweetness after the addition of oat gum, guar gum and carboxymethyl cellulose to sucrose, fructose, and aspartame solutions, but also found that the type of thickener has a greater influence on sweetness perception than the level of viscosity. Arancibia, Costell, and Bayarri (2013) showed that dairy desserts formulated with the same sucrose content and viscosity, but formulated with different thickeners, can produce different sweetness intensities. This effect may be due to different thickeners influencing sucrose release rates into saliva from a food product. The use of corn starch as a thickener has also been reported to limit sweetness suppression in comparison to other gums (Hill, Mitchell, and Sherman 1995; Vaisey, Brunon, and Cooper 1969). Again this may be a result of differences in gum structure influencing sucrose delivery to taste receptors, but also possibly as a result of hydrolysis of starch into sugars by alpha amylase during consumption in the mouth. Alcaire et al. (2017) also reported the addition of starch can even increase sweetness intensity in vanilla milk desserts.

7. Gradual sugar reduction to reduce sucrose content

Another strategy for sugar reduction is the gradual decrease of the level of sugar in food over time to reduce the levels of sweetness desired by consumers (Wise et al., 2016). Such a strategy could be implemented in food prepared at home, but an industry wide intervention of processed food products offers greater potential for improving public health. Organisations such as Action on Sugar (Action on Sugar 2017) propose that sugar could be reduced in this manner, in a similar way to the salt reduction program in the United Kingdom. However, if sweetness is the salient signal that needs to be modified to allow acceptance of sugar reduced foods, strategies that reduce sugar but maintain sweetness are working against the gradual reduction strategy.

Opportunity also exists to reduce sucrose content in the short term without influencing acceptability, as some recent studies suggest are consumers showing a preference for less sweet products than what is currently on the market (even without knowing the nutritional content). A study on yoghurt with Swiss consumers showed that no difference in acceptance was reported between yoghurt sweetened at 10% sucrose (more common in the Swiss market) to that of 7% sucrose (Chollet et al. 2013). Research on chocolate milk with Uruguayan consumers showed that a sucrose reduction of up to 40% did not influence consumers liking (Oliveira et al. 2015). Pineli et al. (2016) investigated sucrose reduction in orange nectars with Brazilian consumers. Lowering sucrose content from 10% to 8.5% did not influence acceptance, and an average ideal sweetness of 7.3% was reported (Pineli et al. 2016). All of these studies suggest that sugar levels of foods can be reduced, in a lab setting. However it is unlikely 40% reductions in sugar are possible as consumers' satisfaction over time and repeated sampling may be negatively affected, where as a one off assessment in a lab may not be an accurate representation of long term liking of the sugar reduced product.

8. Progress made to date by the food industry and government, and plans for the future

The major food manufacturers globally have policy or aims addressing sugar reduction (Table 3). There is a realisation that

Table 3. Examples of current policy of some of the world's largest food companies on sugar reduction.

Company	Policy	Web
Nestle	Further reduce sugar content by 10% in products that do not meet the Nestlé Nutritional Foundation (NF) criteria with respect to sugar	http://www.nestle.com/csv/individuals-families/sugar-salt-fat
Pepsico	By 2025 at least two thirds of its drinks will have 100 calories or fewer from added sugar per 12 oz serving, up from about 40 percent now.	http://www.pepsico.com/sustainability/performance-with-purpose/our-goals
Mars	Reduce added sugar in a limited number of sauces and light meals by 2018	http://www.mars.com/global/about-us/policies-and-practices/mars-food-nutrition-criteria
Kellogg's	Coco Pops Original will contain 14% less sugar, reducing from 35 g to 30 g per 100 g, along with an increase in fibre content to 3 g per 100 g	https://www.kelloggsnutrition.com/en_UK/knowledge/featured/reducing_sugar.html
Unilever	Reduce sugar levels in their ready-to-drink teas to achieve a goal of removing 25% sugar by 2020	https://www.unilever.com/Images/unilever-position-on-sugar-reduction_tcm244-423167_en.pdf

consumers are eating too much sugar (as well as too much salt and fat) and that the food industry is at least partially responsible, and have a role to produce healthier foods by reducing added sugars to their products. However, there is also a business imperative to maintain consumer acceptance of their foods.

There is a new initiative where public health organisations are working with the food industry to set achievable or realistic goals. For example, Public Health England (PHE) published a report based on food industry stakeholder consultation in March 2017 (PHE 2017). The report proposes a strategy to achieve a 20% sugar reduction in a variety of food products by 2020. The target food categories are biscuits; breakfast cereals; cakes; chocolate confectionery; ice-cream, lollies and sorbets; morning goods (e.g., pastries, buns and waffles); puddings (including pies and tarts); sweet confectionery; sweet spreads and sauces; and yoghurt and fromage frais.

The balance for food manufacturers is to reduce added sugars but maintain consumer acceptance. If sales of sugar reduced products start to fall, no doubt business decisions will be made to increase sugar back to levels where sales are not compromised. So while the food industry will aim to meet targets, they will require efficient strategies to maintain liking of their products.

9. Conclusions and recommendations

Health bodies and governments are calling for added sugars to be reduced in foods and beverages in response to epidemiological evidence linking sugar intake with obesity. However, reducing sugar in manufactured foods is not as simple as just removing the sugar as sugar has multiple functions in the body and in the food. Sugar delivers a sweet taste in food by binding to TIR2-T1R3 dimer receptors on taste receptor cells in the oral cavity and GIT, triggering functional responses at those locations, and signalling the brain. Furthermore sugar is vital for texture and flavour, and consequently sugar reduction without influencing sensory perception is a technically difficult challenge for food manufacturers. Sensory and consumer scientists have the responsibility for evaluating consumer responses to sugar reduced foods. The measurement of changes in sensory properties in sugar reduced foods can be assessed by a wide range of different sensory methods, based on experimental psychology and behavioural science.

The use of sugar substitutes, in particular NNS, sugar alcohols, and fibres is the most effective tool for substantially reducing sugar content, however replicating the profile of sucrose is difficult, bitter side tastes and a different temporal profile are common issues, and textural issues are also common. Sugar substitutes also influence satiety differently to sugar which may have a negative effect on long term acceptance of the product. Multi-sensory integration principles, particularly the use of aroma, can be used to reduce sugar content to some extent, however the levels of sucrose reduction possible are smaller than with sugar substitutes. Innovation in the field of food structure, though sucrose inhomogeneity, modification of fracture mechanics, serum release, and viscosity provide new avenues for sugar reduction, but this approach can be difficult to achieve on a large scale and the magnitude of reduction is also relatively small compared to sugar substitutes. Gradual sugar reduction has been demonstrated to have potential in a lab setting however the long term effectiveness of this approach is unknown (i.e., influence on repeated acceptance or repeated purchase). Furthermore if gradual sugar reduction to adjust acceptable consumer sweetness levels is an approach the food industry adopts, all other sugar reduction strategies (which maintain sweetness levels in products) may work against this.

The food industry is acknowledging the role it has to play in sugar reduction, with many companies setting targets for a reduction in some of their product categories. A holistic approach to reduce added sugar in foods and beverages is likely to be the most effective way forward for the food industry. Some sugar reduction strategies will suit certain products and consumer segments and not others. However, a substantial reduction in sugar content in any one food without changing sensory perception is an incredibly challenging technical task. Perhaps the best way forward is using multiple strategies outlined in this paper to have small reductions in sugar that do not compromise consumer acceptance in foods that are highly consumed. Even relatively small sugar reductions in highly consumed products will equal significant population health benefits (Keast et al. 2011).

ORCID

Scott C. Hutchings http://orcid.org/0000-0002-5925-2208
Julia Y. Q. Low http://orcid.org/0000-0003-2147-7687
Russell S. J. Keast http://orcid.org/0000-0001-6882-2877

References

Action on Sugar. 2017, December 15. Retrieved from http://www.actiononsugar.org/

ADA. 2004. Position of the American Dietetic Association: Use of nutritive and nonnutritive sweeteners. *Journal of The American Dietetic Association* 104 (2):255. doi:10.1016/j.jada.2003.12.001.

Aidoo, R. P., F. Depypere, E. O. Afoakwa, and K. Dewettinck. 2013. Industrial manufacture of sugar-free chocolates–Applicability of alternative sweeteners and carbohydrate polymers as raw materials in product development. *Trends Food Science Technology* 32 (2):84–96. doi:10.1016/j.tifs.2013.05.008.

Aitken, R. C. 1969. A growing edge of measurement of feelings [Abridged] Measurement of feelings using visual analogue scales. *SAGE Publications* 2:989–93.

Akyol, A., H. Dasgin, A. Ayaz, Z. Buyuktuncer, and H. T. Besler. 2014. β-Glucan and dark chocolate: a randomized crossover study on short-term satiety and energy intake. *Nutrients* 6 (9):3863–77. doi:10.3390/nu6093863.

Alcaire, F., L. Antúnez, L. Vidal, A. Giménez, and G. Ares. 2017. Aroma-related cross-modal interactions for sugar reduction in milk desserts: Influence on consumer perception. *Food Research International* 97:45–50. doi:10.1016/j.foodres.2017.02.019.

Alley, R. L., and T. R. Alley. 1998. The influence of physical state and color on perceived sweetness. *The Journal of Psychology* 132 (5):561–68. doi:10.1080/00223989809599289.

Amerine, M. A., R. M. Pangborn, and E. B. Roessler. 1965. *Principles of sensory evaluation of food*. NY: Elsevier, Academic Press Inc.

Antenucci, R. G., and J. E. Hayes. 2015. Nonnutritive sweeteners are not supernormal stimuli. *International Journal of Obesity* 39 (2):254–59. doi:10.1038/ijo.2014.109.

Arancibia, C., E. Costell, and S. Bayarri. 2013. Impact of structural differences on perceived sweetness in semisolid dairy matrices. *Journal of Texture Studies* 44 (5):346–56. doi:10.1111/jtxs.12019.

Ares, G., A. Giménez, C. Barreiro, and A. Gámbaro. 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 (3):286–94. doi:10.1016/j.foodqual.2009.05.006.

Auerbach, M. H., S. A. Craig, J. F. Howlett, and K. C. Hayes. 2007. Caloric availability of polydextrose. *Nutrition Reviews* 65 (12):544–49. doi:10.1111/j.1753-4887.2007.tb00279.x.

Ayya, N., and H. T. Lawless. 1992. Quantitative and qualitative evaluation of high-intensity sweeteners and sweetener mixtures. *Chemical Senses* 17 (3):245–59. doi:10.1093/chemse/17.3.245.

Bachmanov, A. A., and G. K. Beauchamp. 2007. Taste receptor genes. *Annual Review of Nutrition* 27:389–414. doi:10.1146/annurev.nutr.26.061505.111329.

Bachmanov, A. A., X. Li, D. R. Reed, J. D. Ohmen, S. Li, Z. Chen, M. G. Tordoff, P. J. de Jong, C. Wu, and D. B. West. 2001. Positional cloning of the mouse saccharin preference (Sac) locus. *Chemical Senses* 26 (7):925–33. doi:10.1093/chemse/26.7.925.

Baeva, M., I. Panchev, and V. Terzieva. 2000. Comparative study of texture of normal and energy reduced sponge cakes. *Molecular Nutrition & Food Research* 44 (4):242–46.

Baldwin, E. A., K. Goodner, and A. Plotto. 2008. Interaction of volatiles, sugars, and acids on perception of tomato aroma and flavor descriptors. *Journal of Food Science* 73 (6):S294–S307. doi:10.1111/j.1750-3841.
2008.00825.x.

Balthazar, C., H. Silva, R. Celeguini, R. Santos, G. Pastore, C. C. Junior, M. Freitas, L. Nogueira, M. Silva, and A. Cruz. 2015. Effect of galactooligosaccharide addition on the physical, optical, and sensory acceptance of vanilla ice cream. *Journal of Dairy Science* 98 (7):4266–72. doi:10.3168/jds.2014-9018.

Bartoshuk, L. M. 1978. The psychophysics of taste. *The American Journal of Clinical Nutrition* 31 (6):1068–77. doi:10.1093/ajcn/31.6.1068.

Bartoshuk, L. M. 2000. Comparing sensory experiences across individuals: recent psychophysical advances illuminate genetic variation in taste perception. *Chemical Senses* 25 (4):447–60. doi:10.1093/chemse/25.4.447.

Bartoshuk, L. M., V. B. Duffy, A. K. Chapo, K. Fast, J. H. Yiee, H. J. Hoffman, C.-W. Ko, and D. J. Snyder. 2004a. From psychophysics to the clinic: missteps and advances. *Food Quality and Preference* 15 (7):617–32. doi:10.1016/j.foodqual.2004.05.007.

Bartoshuk, L. M., V. B. Duffy, B. G. Green, H. J. Hoffman, C.-W. Ko, L. A. Lucchina, L. E. Marks, D. J. Snyder, and J. M. Weiffenbach. 2004b. Valid across-group comparisons with labeled scales: the gLMS versus magnitude matching. *Physiology & Behavior* 82 (1):109–14. doi:10.1016/j.physbeh.2004.02.033.

Bartoshuk, L. M., V. B. Duffy, J. E. Hayes, H. R. Moskowitz, and D. J. Snyder. 2006. Psychophysics of sweet and fat perception in obesity: problems, solutions and new perspectives. *Philosophical Transactions of the Royal Society B* 361 (1471):1137–48. doi:10.1098/rstb.2006.1853.

Bayarri, S., C. Calvo, E. Costell, and L. Durán. 2001. Influence of color on perception of sweetness and fruit flavor of fruit drinks. *Revista de Agroquimica y Tecnologia de Alimentos* 7 (5):399–404.

Beereboom, J. J., and M. Glicksman. 1979. Low calorie bulking agents. *Critical Reviews in Food Science and Nutrition* 11 (4):401–13. doi:10.1080/10408397909527269.

Beglinger, C., and L. Degen. 2006. Gastrointestinal satiety signals in humans—Physiologic roles for GLP-1 and PYY?. *Physiology & Behavior* 89 (4):460–64. doi:10.1016/j.physbeh.2006.05.048.

Belščak-Cvitanović, A., D. Komes, M. Dujmović, S. Karlović, M. Biškić, M. Brnčić, and D. Ježek. 2015. Physical, bioactive and sensory quality parameters of reduced sugar chocolates formulated with natural sweeteners as sucrose alternatives. *Food chemistry* 167:61–70. doi:10.1016/j.foodchem.2014.06.064.

Berthoud, H.-R., and C. Morrison. 2008. The brain, appetite, and obesity. *Annual Review of Psychology* 59:55–92. doi:10.1146/annurev.psych.59.103006.093551.

Bezençon, C., J. Le Coutre, and S. Damak. 2007. Taste-signaling proteins are coexpressed in solitary intestinal epithelial cells. *Chemical Sense* 32 (1):41–49. doi:10.1093/chemse/bjl034.

Biguzzi, C., P. Schlich, and C. Lange. 2014. The impact of sugar and fat reduction on perception and liking of biscuits. *Food Quality and Preference* 35:41–47. doi:10.1016/j.foodqual.2014.02.001.

Bingham, A. F., G. G. Birch, C. de Graaf, J. M. Behan, and K. D. Perring. 1990. Sensory studies with sucrose-maltol mixtures. *Chemical Sense* 15 (4):447–56. doi:10.1093/chemse/15.4.447.

Booth, D. A. 2016. “I like it!” Preference actions separated from hedonic reactions. *Journal of Sensory Studies* 31 (3):213–32. doi:10.1111/joss.12205.

Brown, R. J., and K. I. Rother. 2012. Non-nutritive sweeteners and their role in the gastrointestinal tract. *The Journal of Clinical Endocrinology & Metabolism* 97 (8):2597–605. doi:10.1210/jc.2012-1475.

Burdock, G. A., and W. G. Flamm. 1999. A review of the studies of the safety of polydextrose in food. *Food and Chemical Toxicology* 37 (2–3):233–64. doi:10.1016/S0278-6915(98)00113-6.

Burseg, K. M. M., S. Camacho, J. Knoop, and J. H. F. Bult. 2010. Sweet taste intensity is enhanced by temporal fluctuation of aroma and taste, and depends on phase shift. *Physiology & Behavior* 101 (5):726–30. doi:10.1016/j.physbeh.2010.08.014.

Cadena, R. S., and H. M. A. Bolini. 2012. Ideal and relative sweetness of high intensity sweeteners in mango nectar. *International Journal of Food Science & Technology* 47 (5):991–96. doi:10.1111/j.1365-2621.2011.02932.x.

Cadena, R. S., D. Caimi, I. Jaunarena, I. Lorenzo, L. Vidal, G. Ares, R. Deliza, and A. Giménez. 2014. Comparison of rapid sensory characterization methodologies for the development of functional yogurts. *Food Research International* 64:446–55. doi:10.1016/j.foodres.2014.07.027.

Calviño, A., D. Garrido, and M. García. 2000. Potency of sweetness of aspartame, d−tryptophan and thaumatin evaluated by single value and time−intensity measurements. *Journal of Sensory Studies* 15 (1):47–64. doi:10.1111/j.1745-459X.2000.tb00409.x.

Cardello, H., M. Da Silva, and M. Damasio. 1999. Measurement of the relative sweetness of stevia extract, aspartame and cyclamate/saccharin blend as compared to sucrose at different concentrations. *Plant Foods for Human Nutrition* 54 (2):119–29. doi:10.1023/A:1008134420339.

Cardosa, J., A. Bolini, and H. Maria. 2008. Descriptive profile of peach nectar sweetened with sucrose and different sweeteners. *Journal of Sensory Studies* 23 (6):804–16. doi:10.1111/j.1745-459X.2008.00187.x.

Castura, J. C., L. Antúnez, A. Giménez, and G. Ares. 2016. Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference* 47:79–90. doi:10.1016/j.foodqual.2015.06.017.

Chalé-Rush, A., J. R. Burgess, and R. D. Mattes. 2007. Evidence for human orosensory (taste?) sensitivity to free fatty acids. *Chemical Senses* 32 (5):423–31. doi:10.1093/chemse/bjm007.

Chantaro, P., and R. Pongsawatmanit. 2010. Influence of sucrose on thermal and pasting properties of tapioca starch and xanthan gum mixtures. *Journal of Food Engineering* 98 (1):44–50. doi:10.1016/j.jfoodeng.2009.12.006.

Chollet, M., D. Gille, A. Schmid, B. Walther, and P. Piccinali. 2013. Acceptance of sugar reduction in flavored yogurt. *Journal of Dairy Science* 96 (9):5501–11. doi:10.3168/jds.2013-6610.

Chung, S.-J., and Z. Vickers. 2007. Long-term acceptability and choice of teas differing in sweetness. *Food Quality and Preference* 18 (7):963–74. doi:10.1016/j.foodqual.2007.03.011.

Cicerale, S., L. J. Riddell, and R. S. Keast. 2012. The association between perceived sweetness intensity and dietary intake in young adults. *Journal of Food Science* 77 (1):H31–H5. doi:10.1111/j.1750-3841.2011.02473.x.

Cliff, M., and H. Heymann. 1993. Development and use of time-intensity methodology for sensory evaluation: A review. *Food Research International* 26 (5):375–85. doi:10.1016/0963-9969(93)90081-S.

Cook, D. J., T. A. Hollowood, R. S. T. Linforth, and A. J. Taylor. 2002. Perception of taste intensity in solutions of random-coil polysaccharides above and below c∗. *Food Quality and Preference* 13 (7–8):473–80. doi:10.1016/S0950-3293(02)00066-6.

Cordelle, S., D. Piper, and P. Schlich. 2005. On the consistency of liking scores: a validation study run in France and Germany. *Food Quality and Preference* 16 (6):493–503. doi:10.1016/j.foodqual.2004.10.003.

Cornelis, M. C., M. G. Tordoff, A. El-Sohemy, and R. M. van Dam. 2017. Recalled taste intensity, liking and habitual intake of commonly consumed foods. *Appetite* 109:182–89. doi:10.1016/j.appet.2016.11.036.

Cui, M., P. Jiang, E. Maillet, M. Max, R. F. Margolskee, and R. Osman. 2006. The heterodimeric sweet taste receptor has multiple potential ligand binding sites. *Current Pharmaceutical Design* 12 (35):4591–600. doi:10.2174/138161206779010350.

de Matos, L. F., S. M. Pereira, E. Kaminagakura, L. S. Marques, C. V. Pereira, A. van der Bilt, and L. J. Pereira 2010. Relationships of beta-blockers and anxiolytics intake and salivary secretion, masticatory performance and taste perception. *Archives of Oral Biology* 55 (2):164–69. doi:10.1016/j.archoralbio.2009.11.011.

de Oliveira Pineli, L. D. L., L. A. de Aguiar, A. Fiusa, R. B. de Assunção Botelho, R. P. Zandonadi, and L. Melo 2016. Sensory impact of lowering sugar content in orange nectars to design healthier, low-sugar industrialized beverages. *Appetite* 96:239–44. doi:10.1016/j.appet.2015.09.028.

de Oliveira Rocha, I. F., and H. M. A. Bolini 2015. Different sweeteners in passion fruit juice: Ideal and equivalent sweetness. *LWT - Food Science and Technology* 62 (1):861–67. doi:10.1016/j.lwt.2014.10.055.

de Ruyter, J. C., M. R. Olthof, J. C. Seidell, and M. B. Katan 2012. A trial of sugar-free or sugar-sweetened beverages and body weight in children. *The New England Journal of Medicine* 367 (15):1397–406. doi:10.1056/NEJMoa1203034.

Delarue, J., and J.-M. Sieffermann. 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 (4):383–92. doi:10.1016/S0950-3293(03)00085-5.

Delwiche, J. 2004. The impact of perceptual interactions on perceived flavor. *Food Quality and Preference* 15 (2):137–46. doi:10.1016/S0950-3293(03)00041-7.

Dijksterhuis, G., C. Boucon, and E. Le Berre. 2014. Increasing saltiness perception through perceptual constancy created by expectation. *Food Quality and Preference* 34:24–28. doi:10.1016/j.foodqual.2013.12.003.

Divert, C., C. Chabanet, R. Schoumacker, C. Martin, C. Lange, S. Issanchou, and S. Nicklaus. 2017. Relation between sweet food consumption and liking for sweet taste in French children. *Food Quality and Preference* 56:18–27. doi:10.1016/j.foodqual.2016.09.009.

Drewnowski, A. 1998. Energy density, palatability, and satiety: implications for weight control. *Nutrition Reviews* 56 (12):347–53. doi:10.1111/j.1753-4887.1998.tb01677.x.

DuBois, G. E., and I. Prakash. 2012. Non-caloric sweeteners, sweetness modulators, and sweetener enhancers. *Annual Review of Food Science and Technology* 3:353–80. doi:10.1146/annurev-food-022811-101236.

Duffy, V. B., J. E. Hayes, B. S. Sullivan, and P. Faghri. 2009. Surveying food and beverage liking. *Annals of the New York Academy of Sciences* 1170 (1):558–68. doi:10.1111/j.1749-6632.2009.04593.x.

Duffy, V. B., S. Rawal, J. Park, M. H. Brand, M. Sharafi, and B. W. Bolling. 2016. Characterizing and improving the sensory and hedonic responses to polyphenol-rich aronia berry juice. *Appetite* 107:116–25. doi:10.1016/j.appet.2016.07.026.

Dyer, J., K. Hosie, and S. Shirazi-Beechey. 1997. Nutrient regulation of human intestinal sugar transporter (SGLT1) expression. *Gut* 41 (1):56–59. doi:10.1136/gut.41.1.56.

Dyer, J., K. Salmon, L. Zibrik, and S. Shirazi-Beechey. 2005a. Expression of sweet taste receptors of the T1R family in the intestinal tract and enteroendocrine cells. *Biochemical Society Transactions* 33 (1):302–305. doi:10.1042/BST0330302.

Dyer, J., K. Salmon, L. Zibrik, and S. Shirazi-Beechey. 2005b. Expression of sweet taste receptors of the T1R family in the intestinal tract and enteroendocrine cells. *Biochemical Society Transactions* 33 (1):302–305. doi:10.1042/BST0330302.

Egan, J. M., and R. F. Margolskee. 2008. Taste cells of the gut and gastrointestinal chemosensation. *Molecular Interventions* 8 (2):78. doi:10.1124/mi.8.2.5.

Eguchi, K., H. Kashima, A. Yokota, K. Miura, M. Y. Endo, H. Hirano, T. Tsuji, and Y. Fukuba. 2016. Acute effect of oral sensation of sweetness on celiac artery blood flow and gastric myoelectrical activity in humans. *Autonomic Neuroscience* 197:41–45. doi:10.1016/j.autneu.2016.03.002.

Eny, K. M., T. M. Wolever, P. N. Corey, and A. El-Sohemy. 2010. Genetic variation in TAS1R2 (Ile191Val) is associated with consumption of sugars in overweight and obese individuals in 2 distinct populations. *American Journal of Clinical Nutrition* 92(6):1501–10. doi:10.3945/ajcn.2010.29836.

Evans, C. E. L. 2017. Sugars and health: a review of current evidence and future policy. *The Proceedings of the Nutrition Society* 76 (3):400–407. doi:10.1017/S0029665116002846.

Farah, J. S., C. B. Araujo, and L. Melo. 2017. Analysis of yoghurts', whey-based beverages' and fermented milks' labels and differences on their sensory profiles and acceptance. *International Dairy Journal* 68:17–22. doi:10.1016/j.idairyj.2016.12.008.

Farkas, J. 2007. Physical methods of food preservation. In *Food Microbiology: Fundamentals and Frontiers*, 3rd ed., pp. 685–712. Washington, DC: American Society of Microbiology, ASM Press.

FDA. 2015. Food labeling: revision of the nutrition and supplement facts labels; supplemental proposed rule to solicit comment on limited additional provisions a proposed rule by the food and drug administration on 7/27/2015. http://www.federalregister.gov/articles/2015/07/27/2015-17928/food-labeling-revision-ofthe-nutrition-and-supplement-facts-labels-supplemental-proposed-rule-to.

Feeney, E. L., and J. E. Hayes. 2014. Regional differences in suprathreshold intensity for bitter and umami stimuli. *Chemosensory Perception* 7 (3–4):147–57. doi:10.1007/s12078-014-9166-3.

Fogel, A., and J. Blissett. 2014. Effects of sucrose detection threshold and weight status on intake of fruit and vegetables in children. *Appetite.* 83:309–16. doi:10.1016/j.appet.2014.09.003.

Franck, A. 2002. Technological functionality of inulin and oligofructose. *British Journal of Nutrition* 87 (S2):S287–91. doi:10.1079/BJN/2002550.

Francois, P., and F. Sauvageot. 1988. Comparison of the efficiency of pair, duo-trio and triangle tests. *Journal of Sensory Studies* 3 (2):81–94. doi:10.1111/j.1745-459X.1988.tb00432.x.

Frank, G. K., T. A. Oberndorfer, A. N. Simmons, M. P. Paulus, J. L. Fudge, T. T. Yang, and W. H. Kaye. 2008. Sucrose activates human taste pathways differently from artificial sweetener. *Neuroimage* 39 (4):1559–69. doi:10.1016/j.neuroimage.2007.10.061.

Frank, R. A., and J. Byram. 1988. Taste–smell interactions are tastant and odorant dependent. *Chemical Senses* 13 (3):445–55. doi:10.1093/chemse/13.3.445.

Frank, R. A., K. Ducheny, and S. J. S. Mize. 1989. Strawberry odor, but not red color, enhances the sweetness of sucrose solutions. *Chemical Senses* 14 (3):371–77. doi:10.1093/chemse/14.3.371.

Fujimaru, T., J.-H. Park, and J. Lim. 2012. Sensory characteristics and relative sweetness of tagatose and other sweeteners. *Journal of Food Science* 77 (9):S323–8. doi:10.1111/j.1750-3841.2012.02844.x.

Fujita, Y., R. D. Wideman, M. Speck, A. Asadi, D. S. King, T. D. Webber, M. Haneda, and T. J. Kieffer. 2009. Incretin release from gut is acutely enhanced by sugar but not by sweeteners in vivo. *American Journal of Physiology. Endocrinology and Metabolism* 296 (3):E473–E9. doi:10.1152/ajpendo.90636.2008.

Gao, J., M. A. Brennan, S. L. Mason, and C. S. Brennan. 2016. Effect of sugar replacement with stevianna and inulin on the texture and predictive glycaemic response of muffins. *International Journal of Food Science and Technology* 51 (9):1979–87. doi:10.1111/ijfs.13143.

Gerspach, A. C., R. E. Steinert, L. Schönenberger, A. Graber-Maier, and C. Beglinger. 2011. The role of the gut sweet taste receptor in regulating GLP-1, PYY, and CCK release in humans. *American Journal of Physiology. Endocrinology and Metabolism* 301 (2):E317–E25. doi:10.1152/ajpendo.00077.2011.

Gescheider, G. A. 1988. Psychophysical scaling. *Annual Review of Psychology* 39 (1):169–200. doi:10.1146/annurev.ps.39.020188.001125.

Ghosh, S., and M. Sudha. 2012. A review on polyols: new frontiers for health-based bakery products. *International Journal of Food Sciences and Nutrition* 63 (3):372–79. doi:10.3109/09637486.2011.627846.

Gillan, D. J. 1982. Mixture suppression: The effect of spatial separation between sucrose and NaCl. *Attention, Perception, & Psychophysics* 32 (6):504–10. doi:10.3758/BF03204203.

González, M., C. De Lorenzo, and R. Pérez. 2010. Development of a structured sensory honey analysis: Application to artisanal madrid honeys. *Food Science and Technology International* 16 (1):19–29. doi:10.1177/1082013209351869.

Goyal, S., and R. Goyal. 2010. Stevia (Stevia rebaudiana) a bio-sweetener: a review. *International Journal of Food Sciences and Nutrition* 61 (1):1–10. doi:10.3109/09637480903193049.

Green, B. G., G. S. Shaffer, and M. M. Gilmore. 1993. Derivation and evaluation of a semantic scale of oral sensation magnitude with apparent ratio properties. *Chemical Senses* 18 (6):683–702. doi:10.1093/chemse/18.6.683.

Green, B. G., P. Dalton, B. Cowart, G. Shaffer, K. Rankin, and J. Higgins. 1996. Evaluating the 'Labeled Magnitude Scale'for measuring sensations of taste and smell. *Chemical Senses* 21 (3):323–34. doi:10.1093/chemse/21.3.323.

Greene, J., K. Bratka, M. Drake, and T. Sanders. 2006. Effectiveness of category and line scales to characterize consumer perception of fruity fermented flavor in peanuts. *Journal of Sensory Studies* 21 (2):146–54. doi:10.1111/j.1745-459X.2006.00057.x.

Grembecka, M. 2015. Sugar alcohols—their role in the modern world of sweeteners: a review. *European Food Research and Technology* 241 (1):1–14. doi:10.1007/s00217-015-2437-7.

Gribble, F. M., L. Williams, A. K. Simpson, and F. Reimann. 2003. A novel glucose-sensing mechanism contributing to glucagon-like peptide-1 secretion from the GLUTag cell line. *Diabetes* 52 (5):1147–54. doi:10.2337/diabetes.52.5.1147.

Grotz, V. L., and I. C. Munro. 2009. An overview of the safety of sucralose. *Regulatory Toxicology and Pharmacology* 55 (1):1–5. doi:10.1016/j.yrtph.2009.05.011.

Guinard, J. X., and R. Mazzucchelli. 1999. Effects of sugar and fat on the sensory properties of milk chocolate: descriptive analysis and instrumental measurements. *Journal of the Science of Food and Agriculture* 79 (11):1331–39. doi:10.1002/(SICI)1097-0010(199908)79:11%3c1331::AID-JSFA365%3e3.0.CO;2-4.

Guinard, J.-X., C. Zoumas-Morse, L. Mori, B. Uatoni, D. Panyam, and A. Kilara. 1997. Sugar and fat effects on sensory properties of ice cream. *Journal of Food Science* 62 (5):1087–94. doi:10.1111/j.1365-2621.1997.tb15044.x.

Hansson, A., J. Andersson, and A. Leufvén. 2001. The effect of sugars and pectin on flavour release from a soft drink-related model system. *Food chemistry* 72 (3):363–68. doi:10.1016/S0308-8146(00)00243-0.

Hardikar, S., R. Höchenberger, A. Villringer, and K. Ohla. 2017. Higher sensitivity to sweet and salty taste in obese compared to lean individuals. *Appetite* 111:158–65. doi:10.1016/j.appet.2016.12.017.

Harington, K., R. Smeele, F. Van Loon, J. Yuan, J. J. Haszard, A. Drewer, and B. J. Venn. 2016. Desire for sweet taste unchanged after eating: Evidence of a dessert mentality? *Journal of the American College of Nutrition* 35 (6):581–86. doi:10.1080/07315724.2015.1117956.

Har-Zion, G., I. Brin, and J. Steiner. 2004. Psychophysical testing of taste and flavour reactivity in young patients undergoing treatment with removable orthodontic appliances. *European Journal of Orthodontics* 26 (1):3–8. doi:10.1093/ejo/26.1.73.

Hayes, J. E. 2008. Transdisciplinary perspectives on sweetness. *Chemosensory Perception* 1 (1):48–57. doi:10.1007/s12078-007-9003-z.

Hayes, J. E., A. L. Allen, and S. M. Bennett. 2013. Direct comparison of the generalized visual analog scale (gVAS) and general labeled magnitude scale (gLMS). *Food Quality and Preference* 28 (1):36–44. doi:10.1016/j.foodqual.2012.07.012.

Hetherington, M. M., A. Bell, and B. J. Rolls. 2000. Effects of repeat consumption on pleasantness, preference and intake. *British Food Journal* 102 (7):507–21. doi:10.1108/00070700010336517.

Hill, M. A., J. R. Mitchell, and P. A. Sherman. 1995. The relationship between the rheological and sensory properties of a lemon pie filling. *Journal of Texture Studies* 26 (4):457–70. doi:10.1111/j.1745-4603.1995.tb00983.x.

Höfer, D., B. Püschel, and D. Drenckhahn. 1996. Taste receptor-like cells in the rat gut identified by expression of alpha-gustducin. *Proceedings of the National Academy of Sciences* 93 (13):6631–34. doi:10.1073/pnas.93.13.6631.

Hogenkamp, P., A. Shechter, M. St-Onge, A. Sclafani, and H. Kissileff. 2017. A sipometer for measuring motivation to consume and reward value of foods and beverages in humans: Description and proof of principle. *Physiology &Amp; Behavior* 171:216–27. doi:10.1016/j.physbeh.2017.01.023.

Hollowood, T., R. Linforth, and A. Taylor. 2002. The effect of viscosity on the perception of flavour. *Chemical Senses* 27 (7):583–91. doi:10.1093/chemse/27.7.583.

Holm, K., K. Wendin, and A. M. Hermansson. 2009. Sweetness and texture perceptions in structured gelatin gels with embedded sugar rich domains. *Food Hydrocolloids* 23 (8):2388–93. doi:10.1016/j.foodhyd.2009.06.016.

Holt, S., L. Cobiac, N. Beaumont-Smith, K. Easton, and D. Best. 2000. Dietary habits and the perception and liking of sweetness among Australian and Malaysian students: A cross-cultural study. *Food Quality and Preference* 11 (4):299–312. doi:10.1016/S0950-3293(99)00076-2.

Hoon, M. A., E. Adler, J. Lindemeier, J. F. Battey, N. J. Ryba, and C. S. Zuker. 1999. Putative mammalian taste receptors: a class of taste-specific GPCRs with distinct topographic selectivity. *Cell* 96 (4):541–51. doi:10.1016/S0092-8674(00)80658-3.

Horio, N., M. Jyotaki, R. Yoshida, K. Sanematsu, N. Shigemura, and Y. Ninomiya. 2010. New frontiers in gut nutrient sensor research: nutrient sensors in the gastrointestinal tract: modulation of sweet taste sensitivity by leptin. *Journal of Pharmacological Sciences* 112 (1):8–12. doi:10.1254/jphs.09R07FM.

Hu, F. B. 2013. Resolved: there is sufficient scientific evidence that decreasing sugar−sweetened beverage consumption will reduce the prevalence of obesity and obesity−related diseases. *Obesity Reviews* 14 (8):606–19. doi:10.1111/obr.12040.

Hutchings, S. C., A. de Casanove, P. Schlich, and D. O'Riordan. 2017. The effect of training on the temporal dominance of sensations method: A study with milk protein hydrolysates. *Journal of Sensory Studies* 32 (6):e12303. doi:10.1111/joss.12303.

Hyvonen, L., P. Koivistoinen, and A. Ratilainen. 1978. Sweetening of soft drinks with mixtures of sugars and saccharin. *Journal of Food Science* 43 (5):1580–84. doi:10.1111/j.1365-2621.1978.tb02548.x.

Ishii, R., S. Yamaguchi, and M. O'Mahony. 1992. Measures of taste discriminability for sweet, salty and umami stimuli: Japanese versus Americans. *Chemical Senses* 17 (4):365–80. doi:10.1093/chemse/17.4.365.

Isogai, T., and P. M. Wise. 2016. The effects of odor quality and temporal asynchrony on modulation of taste intensity by retronasal odor. *Chemical Senses* 41 (7):557–66.

Izutsu, T., S. I. Taneya, E. Kikuchi, and T. Sone. 1981. Effect of viscosity on perceived sweetness intensity of sweetened sodium carboxymethylcellulose solutions. *Journal of Texture Studies* 12 (2):259–73. doi:10.1111/j.1745-4603.1981.tb01235.x.

Jang, H.-J., Z. Kokrashvili, M. J. Theodorakis, O. D. Carlson, B.-J. Kim, J. Zhou, H. H. Kim, X. Xu, S. L. Chan, and M. Juhaszova. 2007. Gut-expressed gustducin and taste receptors regulate secretion of glucagon-like peptide-1'. *Proceedings of the National Academy of Sciences* 104 (38):15069–74. doi:10.1073/pnas.0706890104.

Janssen, S., and I. Depoortere. 2013. Nutrient sensing in the gut: new roads to therapeutics? *Trends in Endocrinology and Metabolism* 24 (2):92–100. doi:10.1016/j.tem.2012.11.006.

Johnson, C. 2017. Taxing times over sugar. *Aust. Med.* 29 (3):10.

Johnson, J., and F. Clydesdale. 1982. Perceived sweetness and redness in colored sucrose solutions. *Journal of Food Science* 47 (3):747–52. doi:10.1111/j.1365-2621.1982.tb12706.x.

Johnson, R. K., L. J. Appel, M. Brands, B. V. Howard, M. Lefevre, R. H. Lustig, F. Sacks, L. M. Steffen, and J. Wylie-Rosett. 2009. American heart association nutrition committee of the council on nutrition, physical activity, and metabolism and the council on epidemiology and prevention. dietary sugars intake and cardiovascular health: A scientific statement from the American Heart Association. *Circulation* 120 (11):1011–20. doi:10.1161/CIRCULATIONAHA.109.192627.

Joseph, P. V., D. R. Reed, and J. A. Mennella. 2016. Individual differences among children in sucrose detection thresholds: Relationship with age, gender, and bitter taste genotype. *Nursing Research* 65 (1):3–12.

Kalva, J. J., C. A. Sims, L. A. Puentes, D. J. Snyder, and L. M. Bartoshuk. 2014. Comparison of the hedonic general labeled magnitude scale with the hedonic 9−point scale. *Journal of Food Science* 79 (2):S238–S45. doi:10.1111/1750-3841.12342.

Kauer, J., M. L. Pelchat, P. Rozin, and H. F. Zickgraf. 2015. Adult picky eating. Phenomenology, taste sensitivity, and psychological correlates. *Appetite* 90:219–28. doi:10.1016/j.appet.2015.03.001.

Keast, R. S., and J. Roper. 2007. A complex relationship among chemical concentration, detection threshold, and suprathreshold intensity of bitter compounds. *Chemical Senses* 32 (3):245–53. doi:10.1093/chemse/bjl052.

Keast, R. S., and P. A. Breslin. 2003. An overview of binary taste–taste interactions. *Food Quality and Preference* 14 (2):111–24. doi:10.1016/S0950-3293(02)00110-6.

Keast, R. S., D. Sayompark, G. Sacks, B. A. Swinburn, and L. J. Riddell. 2011. The influence of caffeine on energy content of sugar-sweetened beverages: 'the caffeine-calorie effect'. *European Journal of Clinical Nutrition* 65 (12):1338–44. doi:10.1038/ejcn.2011.123.

Keast, R., and J. Lau. 2006. Culture−specific variation in the flavor profile of soymilks. *Journal of Food Science* 71 (8):S567–S72. doi:10.1111/j.1750-3841.2006.00146.x.

Kelley, A. E., and K. C. Berridge. 2002. The neuroscience of natural rewards: Relevance to addictive drugs. *Journal of Neuroscience* 22 (9):3306–11.

Ketelsen, S., C. Keay, and S. Wiet. 1993. Time−intensity parameters of selected carbohydrate and high potency sweeteners. *Journal of Food Science* 58 (6):1418–21. doi:10.1111/j.1365-2621.1993.tb06196.x.

Khouryieh, H. A., F. M. Aramouni, and T. J. Herald. 2005. Physical and sensory characteristics of no−sugar−added/low−fat muffin. *Journal of Food Quality* 28 (5–6):439–51. doi:10.1111/j.1745-4557.2005.00047.x.

Kim, J.-Y., J. Prescott, and K.-O. Kim. 2017. Emotional responses to sweet foods according to sweet liker status. *Food Quality and Preference* 59:1–7. doi:10.1016/j.foodqual.2017.01.013.

Kim, M. K., P. Greve, and Y. Lee. 2016. Identification of drivers of liking for bar−type snacks based on individual consumer preference. *Journal of Food Science* 81 (1):S174–81. doi:10.1111/1750-3841.13154.

Kim, M.-J., S.-H. Yoo, S. Jung, M.-K. Park, and J.-H. Hong. 2015. Relative sweetness, sweetness quality, and temporal profile of xylooligosaccharides and luo han guo (Siraitia grosvenorii) extract. *Food Science and Biotechnology* 24 (3):965–73. doi:10.1007/s10068-015-0124-x.

Kinghora, A. D., D. D. Soejarto, and G. E. Inglett. 1986. Sweetening agents of plant origin. *Critical Reviews in Plant Sciences* 4 (2):79–120. doi:10.1080/07352688609382220.

Kitagawa, M., Y. Kusakabe, H. Miura, Y. Ninomiya, and A. Hino. 2001. Molecular genetic identification of a candidate receptor gene for sweet taste. *Biochemical and Biophysical Research Communications* 283 (1):236–42. doi:10.1006/bbrc.2001.4760.

Koeferli, C. R. S., P. Piccinali, and S. Sigrist. 1996. The influence of fat, sugar and non-fat milk solids on selected taste, flavor and texture parameters of a vanilla ice-cream. *Food Quality and Preference* 7 (2):69–79. doi:10.1016/0950-3293(95)00038-0.

Kojima, I., and Y. Nakagawa. 2011. The role of the sweet taste receptor in enteroendocrine cells and pancreatic β-cells. *Diabetes & Metabolism Journal* 35 (5):451–57. doi:10.4093/dmj.2011.35.5.451.

Kokini, J. L., K. Bistany, M. Poole, and E. Stier. 1982. Use of mass transfer theory to predict viscosity−sweetness interactions of fructose and sucrose solutions containing tomato solids. *Journal of Texture Studies* 13 (2):187–200. doi:10.1111/j.1745-4603.1982.tb01394.x.

Kroger, M., K. Meister, and R. Kava. 2006. Low-calorie sweeteners and other sugar substitutes: A review of the safety issues. *Comprehensive Reviews in Food Science and Food Safety* 5 (2):35–47. doi:10.1111/j.1541-4337.2006.tb00081.x.

Kulmyrzaev, A., C. Bryant, and D. J. McClements. 2000. Influence of sucrose on the thermal denaturation, gelation, and emulsion stabilization of whey proteins. *Journal of Agricultural and Food Chemistry* 48 (5):1593–97. doi:10.1021/jf9911949.

Kurihara, Y. 1992. Characteristics of antisweet substances, sweet proteins, and sweetness−inducing proteins. *Critical Reviews in Food Science and Nutrition* 32 (3):231–52. doi:10.1080/10408399209527598.

Larson-Powers, N., and R. Pangborn. 1978. Paired comparison and time−intensity measurements of the sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. *Journal of Food Science* 43 (1):41–46. doi:10.1111/j.1365-2621.1978.tb09732.x.

Laureati, M., C. Cattaneo, V. Lavelli, V. Bergamaschi, P. Riso, and E. Pagliarini. 2017. Application of the check−all−that−apply method (CATA) to get insights on children's drivers of liking of fiber−enriched apple purees. *Journal of Sensory Studies* 32 (2):e12253. doi:10.1111/joss.12253.

Lavin, J. G., and H. T. Lawless. 1998. Effects of color and odor on judgments of sweetness among children and adults. *Food Quality and Preference* 9 (4):283–89. doi:10.1016/S0950-3293(98)00009-3.

Lawless, H. T., J. Horne, and W. Spiers. 2000. Contrast and range effects for category, magnitude and labeled magnitude scales in judgements of sweetness intensity. *Chemical Senses* 25 (1):85–92. doi:10.1093/chemse/25.1.85.

Lawless, H., and H. Heymann. 2010. *Sensory evaluation of food: Practices and principals*. 2nd ed. New York: Springer.

Le Berrre, E., C. Boucon, M. Knoop, and G. Dijksterhuis 2013. Reducing bitter taste through perceptual constancy created by an expectation. *Food Quality and Preference* 28 (1):370–74. doi:10.1016/j.foodqual.2012.10.010.

Leistner, L. 1992. Food preservation by combined methods. *Food Research International* 25 (2):151–58. doi:10.1016/0963-9969(92)90158-2.

Leitch, K., S. Duncan, S. O'Keefe, R. Rudd, and D. Gallagher. 2015. Characterizing consumer emotional response to sweeteners using an emotion terminology questionnaire and facial expression analysis. *Food Research International* 76:283–92. doi:10.1016/j.foodres.2015.04.039.

Lethuaut, L., C. Brossard, A. Meynier, F. Rousseau, G. Llamas, B. Bousseau, and C. Genot. 2005. Sweetness and aroma perceptions in dairy desserts varying in sucrose and aroma levels and in textural agent. *International Dairy Journal* 15 (5):485–93. doi:10.1016/j.idairyj.2004.09.002.

Li, B., J. E. Hayes, and G. R. Ziegler. 2014. Just-about-right and ideal scaling provide similar insights into the influence of sensory attributes on liking. *Food Quality and Preference* 37:71–78. doi:10.1016/j.foodqual.2014.04.019.

Li, B., J. E. Hayes, and G. R. Ziegler. 2015. Maximizing overall liking results in a superior product to minimizing deviations from ideal ratings: An optimization case study with coffee-flavored milk. *Food Quality and Preference* 42:27–36. doi:10.1016/j.foodqual.2015.01.011.

Lim, J. 2011. Hedonic scaling: A review of methods and theory. *Food Quality and Preference* 22 (8):733–47.

Lim, J., A. Wood, and B. G. Green. 2009. Derivation and evaluation of a labeled hedonic scale. *Chemical Senses* 34 (9):739–51. doi:10.1093/chemse/bjp054.

Lim, J., and T. Fujimaru. 2010. Evaluation of the labeled hedonic scale under different experimental conditions. *Food Quality and Preference* 21 (5):521–30. doi:10.1016/j.foodqual.2010.02.001.

Livesey, G. 1992. The energy values of dietary fibre and sugar alcohols for man. *Nutrition Research Reviews* 5 (1):61–84.

Lovely, C., and J. F. Meullenet. 2009. Comparison of preference mapping techniques for the optimization of strawberry yogurt. *Journal of Sensory Studies* 24 (4):457–78. doi:10.1111/j.1745-459X.2009.00221.x.

Low, J. Y., K. E. Lacy, R. McBride, and R. S. Keast. 2016. The association between sweet taste function, anthropometry, and dietary intake in adults. *Nutrients* 8 (4):241. doi:10.3390/nu8040241.

Low, Y. Q., K. Lacy, and R. Keast. 2013. The role of sweet taste in satiation and satiety. *Nutrients* 6 (9):3431–50. doi:10.3390/nu6093431.

Maache-Rezzoug, Z., J.-M. Bouvier, K. Allaf, and C. Patras. 1998. Effect of principal ingredients on rheological behaviour of biscuit dough and on quality of biscuits. *Journal of Food Engineering* 35 (1):23–42. doi:10.1016/S0260-8774(98)00017-X.

Mace, O. J., J. Affleck, N. Patel, and G. L. Kellett. 2007. Sweet taste receptors in rat small intestine stimulate glucose absorption through apical GLUT2. *Journal De Physique* 582 (1):379–92.

Magnuson, B., G. Burdock, J. Doull, R. Kroes, G. Marsh, M. Pariza, and G. Williams. 2007. Aspartame: a safety evaluation based on current use levels, regulations, and toxicological and epidemiological studies.

Critical Reviews in Toxicology 37 (8):629–727. doi:10.1080/10408440701516184.

Mahar, A., and L. Duizer. 2007. The effect of frequency of consumption of artificial sweeteners on sweetness liking by women. *Journal of Food Science* 72 (9):S714–S8. doi:10.1111/j.1750-3841.2007.00573.x.

Malik, V. S., B. M. Popkin, G. A. Bray, J.-P. Després, W. C. Willett, and F. B. Hu. 2010. Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes. *Diabetes Care* 33 (11):2477–83. doi:10.2337/dc10-1079.

Mälkki, Y., R. L. Heiniö, and K. Autio. 1993. Influence of oat gum, guar gum and carboxymethyl cellulose on the perception of sweetness and flavour. *Food Hydrocolloids* 6 (6):525–32. doi:10.1016/S0268-005X(09)80076-3.

Margolskee, R. F. 2002. Molecular mechanisms of bitter and sweet taste transduction. *Journal of Biological Chemistry* 277 (1):1–4. doi:10.1074/jbc.R100054200.

Markey, O., J. A. Lovegrove, and L. Methven. 2015. Sensory profiles and consumer acceptability of a range of sugar-reduced products on the UK market. *Food Research International* 72:133–39. doi:10.1016/j.foodres.2015.03.012.

Marriott, B. P., C. J. Fink, and T. Krakower. 2014. Worldwide consumption of sweeteners and recent trends. In *Fructose, High Fructose Corn Syrup, Sucrose and Health*, ed. J. M. Rippe, pp. 87–111. New York: Springer.

Martínez-Cervera, S., A. Salvador, and T. Sanz. 2014. Comparison of different polyols as total sucrose replacers in muffins: Thermal, rheological, texture and acceptability properties. *Food Hydrocolloids* 35:1–8. doi:10.1016/j.foodhyd.2013.07.016.

Maskan, M., and F. Göğüş. 2000. Effect of sugar on the rheological properties of sunflower oil–water emulsions. *Journal of Food Engineering* 43 (3):173–77. doi:10.1016/S0260-8774(99)00147-8.

Mathers, C. 2008. *The global burden of disease: 2004 update*. Geneva, Switzerland: World Health Organization.

Mattes, R. D. 2007. Effects of linoleic acid on sweet, sour, salty, and bitter taste thresholds and intensity ratings of adults. *American Journal of Physiology-Gastrointestinal and Liver Physiology* 292 (5):G1243–G8. doi:10.1152/ajpgi.00510.2006.

Mattes, R. D. 2009. Oral fat exposure pattern and lipid loading effects on the serum triacylglycerol concentration of humans. *Chemosensory Perception* 2 (4):180. doi:10.1007/s12078-009-9062-4.

Mattes, R. D. 2011. Accumulating evidence supports a taste component for free fatty acids in humans. *Physiology &Amp; Behavior* 104 (4):624–31. doi:10.1016/j.physbeh.2011.05.002.

Max, M., Y. G. Shanker, L. Huang, M. Rong, Z. Liu, F. Campagne, H. Weinstein, S. Damak, and R. F. Margolskee. 2001. Tas1r3, encoding a new candidate taste receptor, is allelic to the sweet responsiveness locus Sac. *Nature Genetics* 28 (1):58–63. doi:10.1038/ng0501-58.

Meilgaard, M. C., B. T. Carr, and G. V. Civille. 2006. *Sensory evaluation techniques*. FL: CRC Press.

Mennella, J. A., M. Y. Pepino, S. M. Lehmann−Castor, and L. M. Yourshaw. 2010. Sweet preferences and analgesia during childhood: effects of family history of alcoholism and depression. *Addiction* 105 (4):666–75. doi:10.1111/j.1360-0443.2009.02865.x.

Mennella, J. A., S. Finkbeiner, S. V. Lipchock, L.-D. Hwang, and D. R. Reed. 2014. Preferences for salty and sweet tastes are elevated and related to each other during childhood. *Plos One* 9 (3):e92201. doi:10.1371/journal.pone.0092201.

Monteleone, E., S. Spinelli, C. Dinnella, I. Endrizzi, M. Laureati, E. Pagliarini, F. Sinesio, F. Gasperi, L. Torri, and E. Aprea. 2017. Exploring influences on food choice in a large population sample: The Italian Taste project. *Food Quality and Preference* 59:123–40. doi:10.1016/j.foodqual.2017.02.013.

Montmayeur, J.-P., and H. Matsunami. 2002. Receptors for bitter and sweet taste. *Current Opinion in Neurobiology* 12 (4):366–71. doi:10.1016/S0959-4388(02)00345-8.

Montmayeur, J.-P., S. D. Liberles, H. Matsunami, and L. B. Buck. 2001. A candidate taste receptor gene near a sweet taste locus. *Nature Neuroscience* 4 (5):492–98. doi:10.1038/87440.

Morais, E., A. Morais, A. Cruz, and H. Bolini. 2014a. Development of chocolate dairy dessert with addition of prebiotics and replacement of sucrose with different high-intensity sweeteners. *Journal of Dairy Science* 97 (5):2600–2609. doi:10.3168/jds.2013-7603.

Morais, E., A. Pinheiro, C. Nunes, and H. Bolini. 2014b. 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 (5):339–50. doi:10.1111/joss.12115.

Mosca, A. C., F. van de Velde, J. H. F. Bult, M. A. J. S. van Boekel, and M. Stieger. 2015. Taste enhancement in food gels: Effect of fracture properties on oral breakdown, bolus formation and sweetness intensity. *Food Hydrocolloids* 43:794–802. doi:10.1016/j.foodhyd.2014.08.009.

Mosca, A. C., F. Velde v. d., J. H. F. Bult, M. A. J. S. van Boekel, and M. Stieger. 2010. Enhancement of sweetness intensity in gels by inhomogeneous distribution of sucrose. *Food Quality and Preference* 21 (7):837–42. doi:10.1016/j.foodqual.2010.04.010.

Murray, J. M., C. M. Delahunty, and I. A. Baxter. 2001. Descriptive sensory analysis: past, present and future. *Food Research International* 34 (6):461–71. doi:10.1016/S0963-9969(01)00070-9.

Nahon, D. F., P. A. Navarro y Koren, J. P. Roozen, and M. A. Posthumus. 1998. Flavor release from mixtures of sodium cyclamate, sucrose, and an orange aroma. *Journal of Agricultural and Food Chemistry* 46 (12):4963–68. doi:10.1021/jf980679e.

Nakagawa, Y., M. Nagasawa, S. Yamada, A. Hara, H. Mogami, V. O. Nikolaev, M. J. Lohse, N. Shigemura, Y. Ninomiya, and I. Kojima. 2009. Sweet taste receptor expressed in pancreatic β-cells activates the calcium and cyclic AMP signaling systems and stimulates insulin secretion. *Plos One* 4 (4):e5106. doi:10.1371/journal.pone.0005106.

Narukawa, M., U. Hidetoshi, K. Morita, T. Isaka, and Y. Hayashi. 2009. Change in taste sensitivity to sucrose due to physical fatigue. *Food Science and Technology Research* 15 (2):195–98. doi:10.3136/fstr.15.195.

Negri, R., M. Di Di Domenico, S. Feola, M. G. Scala, G. Artesi, S. Valente, A. Smarrazzo, F. Turco, G. Morini, and L. Greco. 2012. Taste perception and food choices. *Journal of Pediatric Gastroenterology and Nutrition* 54 (5):624–29. doi:10.1097/MPG.0b013e3182473308.

Nelson, G., M. A. Hoon, J. Chandrashekar, Y. Zhang, N. J. Ryba, and C. S. Zuker. 2001. Mammalian sweet taste receptors. *Cell* 106 (3):381–90. doi:10.1016/S0092-8674(01)00451-2.

Newman, L. P., and R. S. Keast. 2013. The test–retest reliability of fatty acid taste thresholds. *Chemosensory Perception* 6 (2):70–77. doi:10.1007/s12078-013-9143-2.

Newman, L. P., D. P. Bolhuis, S. J. Torres, and R. S. Keast. 2016. Dietary fat restriction increases fat taste sensitivity in people with obesity. *Obesity* 24 (2):328–34. doi:10.1002/oby.21357.

Newman, L., R. Haryono, and R. Keast. 2013. Functionality of fatty acid chemoreception: A potential factor in the development of obesity? *Nutrients* 5 (4):1287–300. doi:10.3390/nu5041287.

Nguyen, C. A., Y. Akiba, and J. D. Kaunitz. 2012. Recent advances in gut nutrient chemosensing. *Current Medicinal Chemistry* 19 (1):28–34. doi:10.2174/092986712803414033.

Nie, Y., S. Vigues, J. R. Hobbs, G. L. Conn, and S. D. Munger. 2005. Distinct contributions of T1R2 and T1R3 taste receptor subunits to the detection of sweet stimuli. *Current Biology* 15 (21):1948–52. doi:10.1016/j.cub.2005.09.037.

O'Doherty, J. P., R. Deichmann, H. D. Critchley, and R. J. Dolan. 2002. Neural responses during anticipation of a primary taste reward. *Neuron* 33 (5):815–26. doi:10.1016/S0896-6273(02)00603-7.

O'Donnell, K., and M. Kearsley. 2012. *Sweeteners and sugar alternatives in food technology*. West Sussex, United Kingdom: John Wiley & Sons, Ltd.

Oliveira, D., L. Antúnez, A. Giménez, J. C. Castura, R. Deliza, and G. Ares. 2015. Sugar reduction in probiotic chocolate-flavored milk: impact on dynamic sensory profile and liking. *Food Research International* 75:148–56. doi:10.1016/j.foodres.2015.05.050.

Olsen, A., C. Ritz, D. L. Hartvig, and P. Møller. 2011. Comparison of sensory specific satiety and sensory specific desires to eat in children and adults. *Appetite* 57 (1):6–13. doi:10.1016/j.appet.2011.03.009.

Olsen, N., and B. Heitmann. 2009. Intake of calorically sweetened beverages and obesity. *Obesity Reviews* 10 (1):68–75. doi:10.1111/j.1467-789X.2008.00523.x.

Orjuela-Palacio, J., M. Zamora, and M. Lanari. 2014. Consumers' acceptance of a high-polyphenol yerba mate/black currant beverage: Effect of repeated tasting. *Food Research International* 57:26–33. doi:10.1016/j.foodres.2014.01.017.

Ott, D. B., C. L. Edwards, and S. J. Palmer. 1991. Perceived taste intensity and duration of nutritive and non-nutritive sweeteners in water using Time-intensity (T-I) evaluations. *Journal of Food Science* 56 (2):535–42. doi:10.1111/j.1365-2621.1991.tb05319.x.

Palazzo, A., and H. Bolini. 2014. Multiple time−intensity analysis: Sweetness, bitterness, chocolate flavor and melting rate of chocolate with sucralose, rebaudioside and neotame. *Journal of Sensory Studies* 29 (1):21–32. doi:10.1111/joss.12078.

Palazzo, A., M. Carvalho, P. Efraim, and H. Bolini. 2011. The determination of isosweetness concentrations of sucralose, rebaudioside and neotame as sucrose substitutes in new diet chocolate formulations using the time−intensity analysis. *Journal of Sensory Studies* 26 (4):291–97. doi:10.1111/j.1745-459X.2011.00344.x.

Pangborn, R., I. M. Trabue, and A. Szczesniak. 1973. Effect of hydrocolloids on oral viscosity and basic taste intensities. *Journal of Texture Studies* 4 (2):224–41. doi:10.1111/j.1745-4603.1973.tb00666.x.

Pareyt, B., F. Talhaoui, G. Kerckhofs, K. Brijs, H. Goesaert, M. Wevers, and J. A. Delcour. 2009. The role of sugar and fat in sugar-snap cookies: Structural and textural properties. *Journal of Food Engineering* 90 (3):400–408. doi:10.1016/j.jfoodeng.2008.07.010.

Pateras, I. 1991. Effects of sucrose replacement by polydextrose on structure development of cakes (Doctoral dissertation), Oxford Polytechnic.

Paulus, K., and A. M. Reisch. 1980. The influence of temperature on the threshold values of primary tastes. *Chemical Senses* 5 (1):11–21. doi:10.1093/chemse/5.1.11.

Peng, M., M. J. Hautus, I. Oey, and P. Silcock. 2016. Is there a generalized sweetness sensitivity for an individual?. A psychophysical investigation of inter-individual differences in detectability and discriminability for sucrose and fructose. *Physiology &Amp; Behavior* 165:239–48. doi:10.1016/j.physbeh.2016.08.004.

Pepino, M. Y., and J. A. Mennella. 2012. Habituation to the pleasure elicited by sweetness in lean and obese women. *Appetite* 58 (3):800–805. doi:10.1016/j.appet.2012.01.026.

Perros, P., T. W. MacFarlane, C. Counsell, and B. M. Frier. 1996. Altered taste sensation in newly-diagnosed NIDDM. *Diabetes Care* 19 (7):768–70. doi:10.2337/diacare.19.7.768.

Perry, J. M., R. B. Swanson, B. G. Lyon, and E. M. Savage. 2003. Instrumental and sensory assessment of oatmeal and chocolate chip cookies modified with sugar and fat replacers. *Cereal Chemistry* 80 (1):45–51. doi:10.1094/CCHEM.2003.80.1.45.

Peryam, D. R., and J. G. Haynes. 1957. Prediction of soldiers' food preferences by laboratory methods. *Journal of Applied Psychology* 41 (2):2. doi:10.1037/h0047333.

Pfeiffer, J. C., J. Hort, T. A. Hollowood, and A. J. Taylor. 2006. Taste-aroma interactions in a ternary system: A model of fruitiness perception in sucrose/acid solutions. *Attention, Perception, & Psychophysics* 68 (2):216–27. doi:10.3758/BF03193671.

Pickering, G. J., and R. Kvas. 2016. Thermal tasting and difference thresholds for prototypical tastes in wine. *Chemosens Percept* 9 (1):37–46. doi:10.1007/s12078-016-9203-5.

Piernas, C., S. W. Ng, and B. Popkin. 2013. Trends in purchases and intake of foods and beverages containing caloric and low−calorie sweeteners over the last decade in the United States. *Pediatric Obesity* 8 (4):294–306. doi:10.1111/j.2047-6310.2013.00153.x.

Pin, J.-P., T. Galvez, and L. Prézeau. 2003. Evolution, structure, and activation mechanism of family 3/C G-protein-coupled receptors. *Pharmacology & Therapeutics* 98 (3):325–54. doi:10.1016/S0163-7258(03)00038-X.

Pineli, L., L. A. D. Aguiar, A. Fiusa, R. B. D. A. Botelho, R. P. Zandonadi, and L. Melo. 2016. Sensory impact of lowering sugar content in orange nectars to design healthier, low-sugar industrialized beverages. *Appetite* 96:239–44. doi:10.1016/j.appet.2015.09.028.

Popkin, B. M., and C. Hawkes. 2016. Sweetening of the global diet, particularly beverages: patterns, trends, and policy responses. *Lancet Diabetes Endocrinol* 4 (2):174–86. doi:10.1016/S2213-8587(15)00419-2.

Prescott, J., V. Johnstone, and J. Francis. 2004. Odor–taste interactions: Effects of attentional strategies during exposure. *Chemical Senses* 29 (4):331–40. doi:10.1093/chemse/bjh036.

Prinster, S. C., C. Hague, and R. A. Hall. 2005. Heterodimerization of g protein-coupled receptors: specificity and functional significance. *Pharmacological Reviews* 57 (3):289–98. doi:10.1124/pr.57.3.1.

Protonotariou, S. V., E. Karali, V. Evageliou, S. Yanniotis, and I. Mandala. 2013. Rheological and sensory attributes of cream caramel desserts containing fructooligosaccharides as substitute sweeteners. *International Journal of Food Science and Technology* 48 (3):663–69. doi:10.1111/ijfs.12013.

Public Health England (PHE). 2017. Sugar reduction: achieving the 20%. A technical report outlining progress to date, guidelines for industry, 2015 baseline levels in key foods and next steps. London, UK: Public Health England.

Rahemtulla, Z., C. Baldwin, A. Spiro, C. McGough, A. R. Norman, G. Frost, D. Cunningham, and H. J. N. Andreyev. 2005. The palatability of milk-based and non-milk-based nutritional supplements in gastrointestinal cancer and the effect of chemotherapy. *Clinical Nutrition* 24 (6):1029–37. doi:10.1016/j.clnu.2005.08.003.

Raybould, H. E. 2010. Gut chemosensing: interactions between gut endocrine cells and visceral afferents. *Autonomic Neuroscience* 153 (1):41–46. doi:10.1016/j.autneu.2009.07.007.

Reimann, F., A. M. Habib, G. Tolhurst, H. E. Parker, G. J. Rogers, and F. M. Gribble. 2008. Glucose sensing in L cells: A primary cell study. *Cell Metabolism* 8 (6):532–39. doi:10.1016/j.cmet.2008.11.002.

Renwick, A. G., and S. V. Molinary. 2010. Sweet-taste receptors, low-energy sweeteners, glucose absorption and insulin release. *British Journal of Nutrition* 104 (10):1415–20. doi:10.1017/S0007114510002540.

Riera, C. E., H. Vogel, S. A. Simon, and J. le Coutre. 2007. Artificial sweeteners and salts producing a metallic taste sensation activate TRPV1 receptors. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 293 (2):R626–34. doi:10.1152/ajpregu.00286.2007.

Rippe, J. M., and T. J. Angelopoulos. 2016. Relationship between added sugars consumption and chronic disease risk factors: Current understanding. *Nutrients* 8 (11):697. doi:10.3390/nu8110697.

Roberfroid, M. B. 1999. Caloric value of inulin and oligofructose. *Journal of Nutrition* 129 (7):1436S–7s. doi:10.1093/jn/129.7.1436S.

Rodrigues, J., J. Paixão, A. Cruz, and H. Bolini. 2015. Chocolate milk with chia oil: Ideal sweetness, sweeteners equivalence, and dynamic sensory evaluation using a time−intensity methodology. *Journal of Food Science* 80 (12):S2944–9. doi:10.1111/1750-3841.13120.

Rognlien, M., S. Duncan, S. O'Keefe, and W. Eigel. 2012. Consumer perception and sensory effect of oxidation in savory-flavored yogurt enriched with n-3 lipids. *Journal of Dairy Science* 95 (4):1690–98. doi:10.3168/jds.2011-5010.

Ronda, F., M. Gómez, C. A. Blanco, and P. A. Caballero. 2005. Effects of polyols and nondigestible oligosaccharides on the quality of sugar-free sponge cakes. *Food Chemistry* 90 (4):549–55. doi:10.1016/j.foodchem.2004.05.023.

Röper, H., and J. Goossens. 1993. Erythritol, a new raw material for food and non-food applications. *Starch – Stärke* 45 (11):400–405. doi:10.1002/star.19930451107.

Rössler, P., C. Kroner, J. Freitag, J. Noè, and H. Breer. 1998. Identification of a phospholipase C β subtype in rat taste cells. *European Journal of Cell Biology* 77 (3):253–61. doi:10.1016/S0171-9335(98)80114-3.

Rozengurt, E., and C. Sternini. 2007. Taste receptor signaling in the mammalian gut. *Current Opinion in Pharmacology* 7 (6):557–62. doi:10.1016/j.coph.2007.10.002.

Running, C. A., B. A. Craig, and R. D. Mattes. 2015. Oleogustus: The unique taste of fat. *Chemical Senses* 40 (7):507–16. doi:10.1093/chemse/bjv036.

Sala, G., and M. Stieger. 2013. Time to first fracture affects sweetness of gels. *Food Hydrocolloids* 30 (1):73–81. doi:10.1016/j.foodhyd.2012.05.003.

Sala, G., M. Stieger, and F. van de Velde. 2010. Serum release boosts sweetness intensity in gels. *Food Hydrocolloids* 24 (5):494–501. doi:10.1016/j.foodhyd.2009.12.001.

Savita, S., K. Sheela, S. Sunanda, A. Shankar, and P. Ramakrishna. 2004. Stevia rebaudiana–A functional component for food industry. *Journal of Human Ecology* 15 (4):261–64. doi:10.1080/09709274.2004.11905703.

Schifferstein, H. N. 2012. Labeled magnitude scales: A critical review. *Food Quality and Preference* 26 (2):151–58. doi:10.1016/j.foodqual.2012.04.016.

Schiffman, S. S., B. Booth, B. Carr, M. Losee, E. Sattely-Miller, and B. Graham. 1995. Investigation of synergism in binary mixtures of sweeteners. *Brain Research Bulletin* 38 (2):105–20. doi:10.1016/0361-9230(95)00062-J.

Schiffman, S. S., B. G. Graham, E. A. Sattely-Miller, and M. Peterson-Dancy. 2000. Elevated and sustained desire for sweet taste in African-Americans: A potential factor in the development of obesity. *Nutrition (Burbank, Los Angeles County, Calif.)* 16 (10):886–93. doi:10.1016/S0899-9007(00)00403-2.

Schiffman, S. S., V. A. Crofton, and T. G. Becker. 1985. Sensory evaluations of soft drinks with various sweeteners. *Physiology &Amp; Behavior* 34:369–77. doi:10.1016/0031-9384(85)90198-2.

Sclafani, A. 2007. Sweet taste signaling in the gut. *Proceedings of the National Academy of Sciences* 104 (38):14887–88. doi:10.1073/pnas.0707410104.

Sclafani, A., and K. Ackroff. 2012. Role of gut nutrient sensing in stimulating appetite and conditioning food preferences. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 302 (10):R1119–R33. doi:10.1152/ajpregu.00038.2012.

Sclafani, A., D. S. Glass, R. F. Margolskee, and J. I. Glendinning. 2010. Gut T1R3 sweet taste receptors do not mediate sucrose-conditioned flavor preferences in mice. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 299 (6):R1643–R50. doi:10.1152/ajpregu.00495.2010.

Shankar, P., S. Ahuja, and K. Sriram. 2013. Non-nutritive sweeteners: Review and update. *Nutrition (Burbank, Los Angeles County, Calif.)* 29 (11):1293–99. doi:10.1016/j.nut.2013.03.024.

Shepherd, D., S. Y. Quek, and S. Pathirana. 2008. Sucrose detection and the stability of the 2-AFC procedure in the presence of a confounding variable. *Journal of Sensory Studies* 23 (5):600–13. doi:10.1111/j.1745-459X.2008.00175.x.

Simon, S. A., I. E. de Araujo, R. Gutierrez, and M. A. Nicolelis. 2006. The neural mechanisms of gustation: A distributed processing code. *Nature Reviews Neuroscience* 7 (11):890–901. doi:10.1038/nrn2006.

Small, D. M., J. Voss, Y. E. Mak, K. B. Simmons, T. Parrish, and D. Gitelman. 2004. Experience-dependent neural integration of taste and smell in the human brain. *Journal of Neurophysiology* 92 (3):1892–903. doi:10.1152/jn.00050.2004.

Smeets, P. A., P. Weijzen, C. de Graaf, and M. A. Viergever. 2011. Consumption of caloric and non-caloric versions of a soft drink differentially affects brain activation during tasting. *Neuroimage* 54 (2):1367–74. doi:10.1016/j.neuroimage.2010.08.054.

Smith, J. P., D. P. Daifas, W. El-Khoury, J. Koukoutsis, and A. El-Khoury. 2004. Shelf life and safety concerns of bakery products—a review. *Critical Reviews in Food Science and Nutrition* 44 (1):19–55. doi:10.1080/10408690490263774. doi:10.1080/10408690490263774.

Snyder, D., J. Prescott, and L. Bartoshuk. 2006. Modern psychophysics and the assessment of human oral sensation. *Taste Smell* 63:221–41. doi:10.1159/000093762.

Soenen, S., and M. S. Westerterp-Plantenga. 2007. No differences in satiety or energy intake after high-fructose corn syrup, sucrose, or milk preloads. *American Journal of Clinical Nutrition* 86 (6):1586–94. doi:10.1093/ajcn/86.5.1586.

Spence, C., C. A. Levitan, M. U. Shankar, and M. Zampini. 2010. Does food color influence taste and flavor perception in humans? *Chemosensory Perception* 3 (1):68–84. doi:10.1007/s12078-010-9067-z.

Srivastava, S., L. F. Donaldson, D. Rai, J. K. Melichar, and J. Potokar. 2013. Single bright light exposure decreases sweet taste threshold in healthy volunteers. *Journal of Psychopharmacology* 27 (10):921–29. doi:10.1177/0269881113499206.

Stanhope, K. L. 2016. Sugar consumption, metabolic disease and obesity: The state of the controversy. *Critical Reviews in Clinical Laboratory Sciences* 53 (1):52–67. doi:10.3109/10408363.2015.1084990.

Steinert, R., A. Gerspach, H. Gutmann, L. Asarian, J. Drewe, and C. Beglinger. 2011. The functional involvement of gut-expressed sweet taste receptors in glucose-stimulated secretion of glucagon-like peptide-1 (GLP-1) and peptide YY (PYY). *Clinical Nutrition* 30 (4):524–32. doi:10.1016/j.clnu.2011.01.007.

Stevens, S. 1969. Sensory scales of taste intensity. *Attention, Perception, & Psychophysics* 6 (5):302–308. doi:10.3758/BF03210101.

Stevenson, R. J., J. Prescott, and R. A. Boakes. 1999. Confusing tastes and smells: how odours can influence the perception of sweet and sour tastes. *Chemical Senses* 24 (6):627–35. doi:10.1093/chemse/24.6.627.

Stevenson, R. J., R. A. Boakes, M. J. Oaten, M. R. Yeomans, M. Mahmut, and H. M. Francis. 2016. Chemosensory abilities in consumers of a western-style diet. *Chemical Senses* 41 (6):505–13. doi:10.1093/chemse/bjw053.

Stewart, J. E., C. Feinle-Bisset, and R. S. Keast. 2011. Fatty acid detection during food consumption and digestion: associations with ingestive behavior and obesity. *Progress in Lipid Research* 50 (3):225–33. doi:10.1016/j.plipres.2011.02.002.

Stewart, J. E., C. Feinle-Bisset, M. Golding, C. Delahunty, P. M. Clifton, and R. S. Keast. 2010. Oral sensitivity to fatty acids, food consumption and BMI in human subjects. *British Journal of Nutrition* 104 (1):145–52. doi:10.1017/S0007114510000267.

Stewart, J., and R. Keast. 2012. Recent fat intake modulates fat taste sensitivity in lean and overweight subjects. *International Journal of Obesity* 36 (6):834. doi:10.1038/ijo.2011.155.

Stone, H., and S. M. Oliver. 1969. Measurement of the relative sweetness of selected sweeteners and sweetener mixtures. *Journal of Food Science* 34 (2):215–22. doi:10.1111/j.1365-2621.1969.tb00922.x.

Stone, H., and S. Oliver. 1966. Effect of viscosity on the detection of relative sweetness intensity of sucrose solutions. *Journal of Food Science* 31 (1):129–34. doi:10.1111/j.1365-2621.1966.tb15425.x.

Strasser, F., R. Demmer, C. Böhme, S.-F. H. Schmitz, B. Thuerlimann, T. Cerny, and S. Gillessen. 2008. Prevention of docetaxel-or paclitaxel-associated taste alterations in cancer patients with oral glutamine: a randomized, placebo-controlled, double-blind study. *The Oncologist* 13 (3):337–46. doi:10.1634/theoncologist.2007-0217.

Tatano, H., H. Yamanaka-Okumura, B. Zhou, C. Adachi, Y. Kawakami, T. Katayama, M. Masuda, E. Takeda, and Y. Taketani. 2016. Association of habitual high-fat intake and desire for protein and sweet food. *Journal of Medical Investigation* 63 (3.4):241–47. doi:10.2152/jmi.63.241.

Taylor, T., O. Fasina, and L. Bell. 2008. Physical properties and consumer liking of cookies prepared by replacing sucrose with tagatose. *Journal of Food Science* 73 (3):S145–S51. doi:10.1111/j.1750-3841.2007.00653.x.

Te Morenga, L., S. Mallard, and J. Mann 2013. Dietary sugars and body weight: Systematic review and meta-analyses of randomised controlled trials and cohort studies. *Bmj (Clinical Research Ed.)* 346:e7492.

Tepper, B. J., and A. C. Seldner. 1999. Sweet taste and intake of sweet foods in normal pregnancy and pregnancy complicated by gestational diabetes mellitus. *The American Journal of Clinical Nutrition* 70 (2):277–84. doi:10.1093/ajcn.70.2.277.

Tipton, S., J. Morris, G. Main, C. Sharp, and R. McNew. 1999. Grape juice as an extender and sweetener for blueberry drinks. *Journal of Food Quality* 22 (3):275–85. doi:10.1111/j.1745-4557.1999.tb00557.x.

Tomchik, S. M., S. Berg, J. W. Kim, N. Chaudhari, and S. D. Roper. 2007. Breadth of tuning and taste coding in mammalian taste buds. *Journal of Neuroscience* 27 (40):10840–48. doi:10.1523/JNEUROSCI.1863-07.2007.

Tormena, M. M. L., L. T. de Medeiros, P. C. de Lima, G. Possebon, R. H. B. Fuchs, and E. Bona. 2017. Application of multi−block analysis and mixture design with process variable for development of chocolate cake containing yacon [Smallanthus sonchifolius] and maca [Lepidium meyenii]. *Journal of the Science of Food and Agriculture* 97 (11):3559–67. doi:10.1002/jsfa.8211.

Tournier, C., C. Sulmont-Rossé, E. Sémon, A. Vignon, S. Issanchou, and E. Guichard. 2009. A study on texture–taste–aroma interactions: Physico-chemical and cognitive mechanisms. *International Dairy Journal* 19 (8):450–58. doi:10.1016/j.idairyj.2009.01.003.

Tucker, R. M., C. Edlinger, B. A. Craig, and R. D. Mattes. 2014. Associations between BMI and fat taste sensitivity in humans. *Chemical Senses* 39 (4):349–57. doi:10.1093/chemse/bju006.

Tuorila-Ollikainen, H., S. Mahlamaki-Kultanen, and R. Kurkela. 1984. Relative importance of color, fruity flavor and sweetness in the overall liking of soft drinks. *Journal of Food Science* 49 (6):1598–600. doi:10.1111/j.1365-2621.1984.tb12852.x.

Ungure, E., E. Straumīte, S. Muižniece-Brasava, and L. Dukaļska. 2013. Consumer attitude and sensory evaluation of marshmallow. *Proceedings of the Latvian Academy of Sciences. Section B* 67:442–47.

Urbano, C., A. Deglaire, E. Cartier-Lange, V. Herbreteau, S. Cordelle, and P. Schlich. 2016. Development of a sensory tool to assess overall liking for the fatty, salty and sweet sensations. *Food Quality and Preference* 48:23–32. doi:10.1016/j.foodqual.2015.08.003.

Vaisey, M., R. Brunon, and J. Cooper. 1969. Some sensory effects of hydrocolloid sols on sweetness. *Journal of Food Science* 34 (5):397–400. doi:10.1111/j.1365-2621.1969.tb12788.x.

von Rymon Lipinski, G.-W., and L. Y. Hanger. 2001. In *Alternative Sweeteners*, ed. K. Acesulfame and N. Lyn O'Brien, 3rd ed., Revised and Expanded, pp. 13–30. New York: Marcel Dekker, Inc.

von Sydow, E., H. Moskowitz, H. Jacobs, and H. Meiselman 1974. Odor-taste interaction in fruit juices. *LWT - Food Science and Technology* 7 (1):18–24.

Walter, J. M., and L. Soliah. 1995. Sweetener preference among non-institutionalized older adults. *Journal of Nutrition for the Elderly* 14 (2–3):1–13. doi:10.1300/J052v14n02_01.

Webb, J., D. P. Bolhuis, S. Cicerale, J. E. Hayes, and R. Keast. 2015. The relationships between common measurements of taste function. *Chemosensory Perception* 8 (1):11–18. doi:10.1007/s12078-015-9183-x.

Weenen, H., R. Jellema, and R. De Wijk. 2005. Sensory sub-attributes of creamy mouthfeel in commercial mayonnaises, custard desserts and sauces. *Food Quality and Preference* 16 (2):163–70. doi:10.1016/j.foodqual.2004.04.008.

Whitehouse, C. R., J. Boullata, and L. A. McCauley. 2008. The potential toxicity of artificial sweeteners. *Aaohn Journal* 56 (6):251–61. doi:10.3928/08910162-20080601-02.

WHO. 2015. Guideline: sugars intake for adults and children. *World Health Organization*. Geneva, Switzerland: WHO Press.

Wiet, S. G., and P. K. Beyts. 1992. Sensory characteristics of sucralose and other high intensity sweeteners. *Journal of Food Science* 57 (4):1014–19. doi:10.1111/j.1365-2621.1992.tb14345.x.

Wise, P. M., L. Nattress, L. J. Flammer, and G. K. Beauchamp. 2016. Reduced dietary intake of simple sugars alters perceived sweet taste intensity but not perceived pleasantness. *American Journal of Clinical Nutrition* 103 (1):50–60. doi:10.3945/ajcn.115.112300.

Wong, G. T., K. S. Gannon, and R. F. Margolskee. 1996. Transduction of bitter and sweet taste by gustducin. *Nature* 381 (6585):796. doi:10.1038/381796a0.

Woods, A. T., D. M. Lloyd, J. Kuenzel, E. Poliakoff, G. B. Dijksterhuis, and A. Thomas. 2011. Expected taste intensity affects response to sweet drinks in primary taste cortex. *Neuroreport* 22 (8):365–69. doi:10.1097/WNR.0b013e3283469581.

Xu, H., L. Staszewski, H. Tang, E. Adler, M. Zoller, and X. Li. 2004. Different functional roles of T1R subunits in the heteromeric taste receptors. *Proceedings of the National Academy of Sciences of the United States of America* 101 (39):14258–63. doi:10.1073/pnas.0404384101.

Zhang, G.-H., H.-Y. Zhang, X.-F. Wang, Y.-H. Zhan, S.-P. Deng, and Y.-M. Qin. 2009. The relationship between fungiform papillae density and detection threshold for sucrose in the young males. *Chemical Senses* 34 (1):93–99. doi:10.1093/chemse/bjn059.

Zheng, H., and H.-R. Berthoud. 2007. Eating for pleasure or calories. *Current Opinion In Pharmacology* 7 (6):607–12. doi:10.1016/j.coph.2007.10.011.

Zhi, R., L. Zhao, and J. Shi. 2016. Improving the sensory quality of flavored liquid milk by engaging sensory analysis and consumer preference. *Journal of Dairy Science* 99 (7):5305–17. doi:10.3168/jds.2015-10612.

Zorn, S., F. Alcaire, L. Vidal, A. Giménez, and G. Ares. 2014. Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners. *Food Quality and Preference* 36:135–43. doi:10.1016/j.foodqual.2014.04.003.