Food Sci Biotechnol (2022) 31(4):387–398
https://doi.org/10.1007/s10068-022-01046-7

REVIEW

Sugar reduction methods and their application in confections: a review

Elle McKenzie[1] · Soo-Yeun Lee[2]

Received: 4 November 2021 / Revised: 20 January 2022 / Accepted: 8 February 2022 / Published online: 8 March 2022

Abstract Many American adults consume almost double the daily recommended amount of sugar. With excess consumption of sugar and consequential health problems arising, food manufacturers are investigating methods to reduce sugar while maintaining similar functional and sensory properties. The body of literature was searched for papers regarding sugar reduction, and the main methods of sugar reduction are summarized herein with a specific focus on high sugar products. Reducing sugar in confections is possible; however, the challenge is maintaining the balance between texture and sweetness perception. Texture plays a large role in the sweetness perception of confections, with firmer products often being perceived as less sweet. Depending on the method, 20–40% of sugar can be removed from confections without sacrificing sensory acceptance, often replaced with multiple ingredients. Further investigation is needed on confection models and how the emerging health trends set the foundation for sugar reduction.

Keywords Sugar reduction · Confections · Gels · Sugar replacement · Sugar substitution · High sugar

✉ Soo-Yeun Lee
soolee@illinois.edu

Elle McKenzie
ellenm3@illinois.edu

1 Department of Food Science and Human Nutrition, University of Illinois Urbana-Champaign, 905 South Goodwin Ave., 486A Bevier Hall, Urbana, IL 61801, USA

2 Department of Food Science and Human Nutrition, University of Illinois Urbana-Champaign, 905 South Goodwin Ave., 351 Bevier Hall, Urbana, IL 61801, USA

Introduction

The mean adjusted intake of added sugar in the United States is nearly double the daily recommended amount, accounting for about 300 daily calories of added sugar alone out of an average 2000 calorie diet (Pacheco et al., 2020; Powell et al., 2016). The average sugar consumption is about 15% of US adults total caloric intake, while the World Health Organization and the American Heart Association recommend less than 10% of caloric intake from sugar, or less than 12–15 teaspoons a day (Herrick et al., 2019). In additional studies, higher numbers of consumption are reported, stating that the whole US population eats more than three times the daily recommended value of sugar (Faruque et al., 2020), about 36–45 teaspoons per day. In 2001, many adults received 9.2% of their daily calories from sugar sweetened beverages, such as soda and juice, making them the single largest source of added sugar in the US diet (Malik et al., 2019). Similarly in 2020, it was estimated that nearly half of added sugar consumption came from sugar sweetened beverages (Pacheco et al., 2020).

Overconsumption of sugar leads to many long-term health problems caused by the consequential weight gain, such as type 2 diabetes mellitus (Hu and Malik, 2010) and cardiovascular disease (Pacheco et al., 2020). In 2018, the National Center for Health Statistics (NCHS) reported that cardiovascular disease and diabetes were the first and seventh leading causes of death (Murphy et al., 2018). Based on 2017 data, the age-adjusted death rate attributed to cardiovascular disease was 219.4 per 100,000 (Virani et al., 2020), and for diabetes, the rate was 25.7 per 100,000 (CDC, 2020). In 2019, health care costs directly related to obesity were around $210 billion dollars in the US

(Faruque et al., 2020), while indirect costs were around $90 billion (CDC, 2020).

Both consumers and government bodies have demanded initiatives to reduce sugar in products with consumers reporting that limiting sugar intake was the main change to their diet for healthier eating (IFIC, 2019). Many countries have implemented sugar or health taxes on high sugar products, such as sugar sweetened beverages (Miller, 2019). In 2017, the UK began an initiative to reduce the amount of added sugar in products 20% by 2020 (Griffith et al., 2020; Public Health England, 2017). In a report detailing the progress from 2015 to 2019, the Public Health England stated a 3% overall decrease in sugar content of products with significant decreases in breakfast cereals (13.3%) and yogurts (12.9%) (Public Health England, 2020). Although the US has not implemented policies for sugar reduction, in the beginning of 2020, the FDA began requiring nutrition labels to report added sugars (FDA, 2020a).

For a product to be labeled as reduced sugar in the US, it must have at least 25% less sugar than the reference amount (FDA, 2020b). Reducing sugar heavily depends on the product type, but a successful sugar reduction is indicative of a final product that maintains the structural integrity, flavor balance, and sensory acceptance of the original. The simplest method of sugar reduction is to remove the sugar from the product. However, once the sugar is removed, the product formulation must be adjusted to maintain functional and sensory properties, which remains one of the main challenges of sugar reduction. The sweetness of sugar is simple to substitute, due to a surplus of alternatives, including high intensity sweeteners, both artificial and natural, sugar alcohols, and rare sugars. These alternative sweeteners range anywhere from 0.5 to 700 times the sweetness of sucrose, but sometimes have a different taste profile, including varying sweetness onset times, peak sweetness citations, and side taste profiles (Tan et al., 2019). Other attributes of sugar are more difficult to replace. For instance, sweetness can be maintained in diet sodas, but viscosity differences caused by alternative sweeteners are significant enough for consumers to detect "mouthfeel" differences compared to their full sugar counterpart (Kappes et al., 2006). A greater challenge is observed in solid foods compared to liquid foods, because sugar plays a critical role in the texture and functional properties of the products. Sugar has bulk and a stabilization effect that cannot easily be replicated with alternative sweeteners (Cardoso and Bolini, 2008; Evageliou et al., 2000; Shimizu and Matubayasi, 2014). Bulk agents used to replace sugar, including sugar alcohols and oligosaccharides, typically provide less sweetness than sucrose but can add functional benefits, such as acting as dietary fiber, due to their non-digestible nature (Mitchell, 2007; Roberfroid and Slavin, 2000). As a co-solute in many foods, sugar plays a role in boiling point elevation and freezing point depression of the product, which leads to changes in the structure and functionality. It can also act as a preservative through reducing the water activity and contribute to a product's viscosity or browning (Erickson and Carr, 2020). When sugar is removed from a product, the loss of these functional properties will need to be replaced by additional ingredients (McCain et al., 2018) to maintain product quality. Often high intensity sweeteners, such as aspartame and sucralose, have different chemical and thermal properties than sugar and cannot withstand the same processing conditions because of their instability or decomposition at high temperature and moisture content or at low pH (Bell and Hageman, 1994; Dodson and Pepper, 1985; Grembecka, 2015; Hanger et al., 1996).

Formulation of confections can be anywhere from 15 to 50% sugar (Haribo, 2020; Jell-O, 2020; Smucker's, 2020), and thus a large removal of the product bulk will have a significant impact on the food structure and functionality. Before a substitution can be made for an essential ingredient as sugar, understanding its role in the food matrix and how changing the composition will affect the final functional and sensory characteristics is important for a successful reduction of sugar.

Objective

The overall goal of this paper was to compile and organize the body of literature which covers the application of sugar reduction strategies in various food categories and how these applications are used in confections, specifically gels. The specific objectives of this review paper were to: (a) compile and summarize the main methods of sugar reduction in foods and how they are implemented and (b) discuss the current methods of sugar reduction in confections and determine the gaps in the knowledge.

Method

Three databases (Scopus, Ebsco, Science Direct) were searched using a string similar to "(sugar OR sucrose OR sweet*) AND (reduc* OR remov* OR substit*) AND (process OR technol* OR develop* OR intervention OR strateg* OR method*) AND (food OR product) AND (sensory OR consumer) AND (liking OR hedonic OR intensity)". The searches included only primary literature in the English language which was published between the years 1996 and 2021.

The collected literature (n = 415) was screened for duplicates, and the initial count of unique papers was 396.

The abstracts were screened, and papers were excluded due to irrelevance to the specific questions asked. Some common reasons for exclusion included literature not about sugar reduction, not related to a food product, policy based, in which test subjects were not human, medically focused, and those which did not include a sensory component. The final count of studies included for qualitative analysis was 192. Twenty studies were further discussed in this review (Fig. 1).

Sugar reduction methods

The main methods of sugar reduction in food products include sugar removal, sugar replacement, physical modification, flavor modification, and formulation changes (Table 1). The preferred method of sugar reduction in the literature was to replace the sucrose with an alternative sweetener (n = 74), and the most popular food categories for sugar reduction were high sugar products, such as sugar-sweetened beverages (n = 39) and confections (n = 23). Confections includes products such as hard candies, gummies, chocolate, jams, and preserves. In each of these products, sugar provides essential properties to taste, structure, and texture. Sugar reduction in confections is a challenge of balancing the loss of flavor and sweetness, while ensuring products retain the desired texture and stability. Current literature included in this review on sugar reduction methods in confections and other high sugar foods can be viewed in Table 1.

Sugar reduction

The viability of sugar reduction without substitution is first determined by the removal of sugar from the product. This research has two main focuses: threshold tests to determine at what percentage of sugar reduction consumers notice a difference in the product (Oliveira et al., 2016; Oliveira et al., 2018b; Oliveira de Souza et al., 2018; Tsitlakidou et al., 2019) and characterization to analyze how the sugar reduction affects not only the consumer acceptance, but also the food system itself (Drewnowski et al., 2012; Mayhew et al., 2017a; 2017b; Torrico et al., 2020).

One product that has seen successful sugar reduction is fruit juices. In a study done by Oliveira et al. (2018b), the impact of sugar reduction in fruit juices on consumer's hedonic perception was studied. No significant difference was found in the overall liking between the control juice and one with 20% sugar reduction. Because fruit juices contain naturally occurring sugars, a 20% sugar reduction is easily done in the beverage model. On the other hand, in a jam system made with high methoxy pectin, a complete sugar reduction for a sugar-free jam was not successful (Basu et al., 2013). High methoxy pectin relies on the

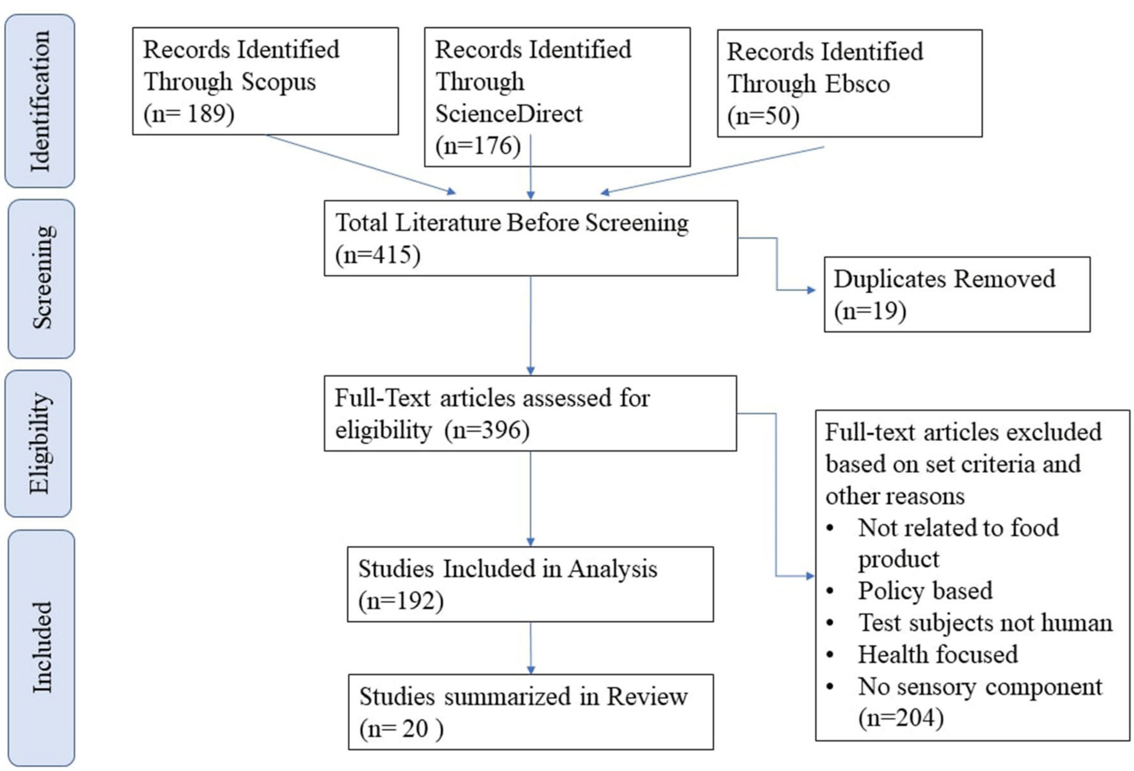


Fig. 1 Flow chart documenting the screening and selection process for the review

Table 1 Main methods of sugar reduction in food products and studies summarized in the review

Sugar reduction method	Definition	Foods investigated
Sugar reduction (n = 39)	Sugar concentration was reduced in the product	Pound cake (Oliveira de Souza et al., 2018) Chocolate milk (Oliveira et al., 2016) Fruit nectar (Denize Oliveira et al., 2018b) Orange juice (Tsitlakidou et al., 2019) Caramel system (Mayhew et al., 2017a) Strawberry yogurt (Torrico et al., 2020) Jam (Basu et al., 2017)
Sugar replacement (n = 74)	Sugar concentration was reduced in the product and replaced with another sweetener	Apple preserves (Pielak et al., 2020) Jelly (Akesowan and Choonhahirun, 2019)
Physical modification (n = 10)	Sugar granules were physically modified, or the structure of the product was altered	Brownies (Richardson et al., 2018) Gel model (Mosca et al., 2010) Chocolate model ((Kistler et al., 2021)
Flavor modification (n = 9)	Flavor components were added to mitigate flavor loss from sugar reduction	Sugar pastry (Bertelsen et al., 2021) Oatmeal, Apple crisp (Peters et al., 2018) Yogurt (Oliveira et al., 2021)
Formula change (n = 28)	Added ingredients to functionalize or aid with the sensory acceptance of reduced sugar products—not a sugar replacement	Cake (Stavale et al., 2019) Cake (Milner et al., 2020) Gummy candy (Gok et al., 2020) Gummy candy (Riedel et al., 2015) White chocolate (Morais Ferreira et al., 2017)

stabilization of sucrose, which largely influences the network structure and association pattern, to help form the gel structure. Without the added sugar, a firm gel of high methoxy pectin was not able to form. Due to the large percentage of sugar in the composition of confections, such as jams with about 45% added sugar (Smucker's, 2020), simply removing sugar from confections is not always feasible, and thus must be coupled with other sugar reduction strategies.

Sugar replacement

Sugar replacement is the most popular method of sugar reduction with many different options (Table 2), and usually involves a high intensity sweetener paired with a low intensity bulking agent, for example, aspartame combined with a sugar alcohol (O'Donnell and Kearsley, 2012). With sucrose being equivalent to a sweetness intensity of 1, alternative sweeteners can range anywhere from 0.5 to 700 times the sweetness of sucrose. Most high intensity sweeteners, such as saccharin or sucralose, are non-nutritive, providing no caloric value and are marketed as no calorie alternatives to sugar, while some sugar alcohols and rare sugar provide less calories per gram, ranging from 0.2 to 2.4 kcal/g, compared to sucrose's 4 kcal/g. The most successful replacement of sugar has been in the soda industry, where diet sodas are a staple in the market (Fakhouri et al., 2012). The success of these

Table 2 Summary of alternative sweeteners

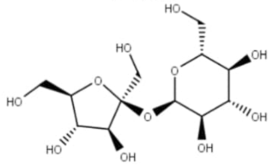
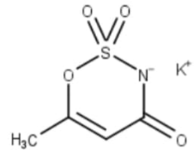
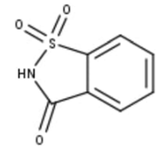
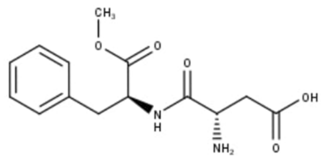
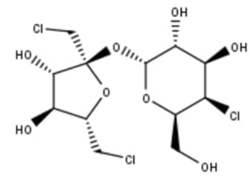
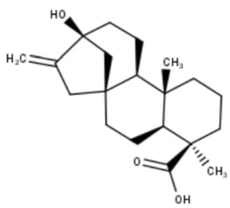
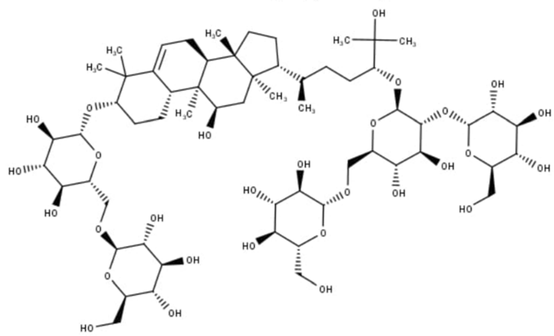
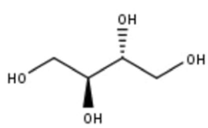
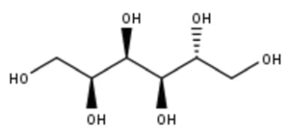
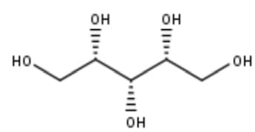
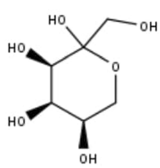
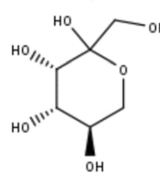
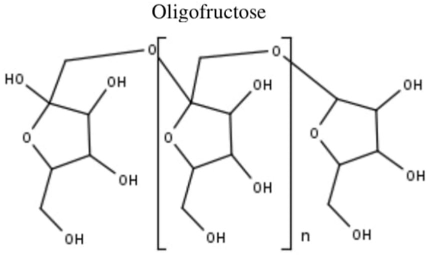
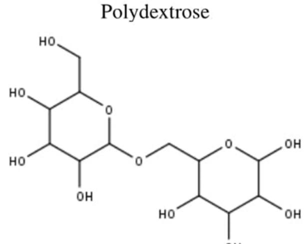
Category	Sweetener name	Description (chemical formula)	Sweetness intensity	Nutritive/ Nonnutritive	Properties
Artificial high intensity	Sucrose	Main component of beet and cane sugar ($C_{12}H_{22}O_{11}$)	1	4 kcal/g	Heat stable; M_p (melting point) = 186 °C
	Acesulfame K (Ace K)	The potassium salt of acesulfame ($C_4H_4KNO_4S$)	200	Non-nutritive	Heat stable; M_p is greater than 200 °C; slightly bitter aftertaste
	Aspartame	A methyl ester of the aspartic acid ($C_{14}H_{18}N_2O_5$)	200	Nutritive	Not heat stable— decomposes before melting; Some solubility issues; May have bitter or off-flavor aftertastes
	Saccharin	*N*-sulfonylcarboxamide ($C_7H_5NO_3S$)	200–700	Non-nutritive	Heat stable; M_p is greater than 300 °C; Bitter or metallic aftertaste
	Sucralose	Derivation of sucrose from chlorination ($C_{12}H_{19}Cl_3O_8$)	600	Non-nutritive	Heat stable up to 125 °C
Natural high intensity	Steviol glycosides (Stevia)	Derivation from the leaves of the plant species *Stevia rebaudiana*	200–400	Non-nutritive	Heat stable up to 205 °C Some solubility issues; Bitter or licorice-like aftertaste
	Siraitia grosvenorii Swingle (Luo Han Guo/Monk) fruit extracts	Mainly mogrosides from the flesh of the Monk fruit	250–400	Non-nutritive	Heat stable; M_p = 197–201 °C
Bulking; Sugar alcohols	Sorbitol	Reduction of glucose; isomer of mannitol ($C_6H_{14}O$)	0.5	2.6 kcal/g	Heat stable M_p = 97 °C; Sugar alcohols do not contribute to browning
	Erythritol	Derivation made from corn using enzymes and fermentation ($C_4H_{10}O_4$)	0.7	0.2 kcal/g—Non-nutritive	Heat stable; M_p = 121 °C
	Xylitol (Birch sugar)	Naturally occurring in small amounts in plums, strawberries, cauliflower, and pumpkin ($C_5H_{12}O_5$)	1.0	2.4 kcal/g	Heat stable; M_p = 94 °C
Rare sugars	Allulose	A low-calorie epimer of the monosaccharide sugar fructose ($C_6H_{12}O_6$)	0.7	0.4 kcal/g	Heat stable; May contribute to browning; M_p = 110 °C
	Tagatose	A natural sweetener present in only small amounts in fruits, cacao, and dairy products ($C_6H_{12}O_6$)	0.9	1.5 kcal/g	Heat stable; M_p = 135 °C

Information summarized from (Chattopadhyay et al., 2014; FDA, 2018, 2020c; Grembecka, 2015; Mitchell, 2007; O'Donnell & Kearsley, 2012; Shankar et al., 2013)

products stems from the fact that soda does not rely heavily on sugar for structure or functionality, and the manufacturing of sodas does not involve harsh processing conditions (Abu-Reidah, 2020; Acevedo et al., 2018). Often in other products, replacement is challenging due to the loss of sucrose's textural and functional properties. Additionally, alternative sweeteners have different thermal properties than sucrose, often being heat sensitive, therefore limiting their application (De Carvalho et al., 2009). For example, aspartame, a sweetener commonly used in diet sodas, is not heat stable and loses it sweetness when heated (FDA, 2020a). On the other hand, tagatose, a rare sugar, is heat stable, but browns more than sucrose (Taylor et al., 2008) compared to sugar alcohols, which do not contribute to browning (Mitchell, 2007).

There are four main categories of alternative sweeteners: high intensity sweeteners, both artificial and natural, sugar alcohols, and rare sugars, in addition to other bulking agents like oligosaccharides that provide minimal sweetness. The selection of an alternative sweetener depends on the product, and the main problem with replacing sucrose with alternative sweeteners is that they do not interact with the food product or our bodies in the same way, due to differences in chemical structure from sucrose (Table 3). Most alternative sweeteners in small quantities are non-nutritive, meaning that they do not provide any calories and have no glycemic response from the body, such as high

Table 3 Chemical structures of mentioned alternative sweeteners and bulking agents

Artificial High Intensity	Sucrose  Acesulfame K  Saccharin  Aspartame  Sucralose 
Natural High Intensity	Stevia (steviol glycosides)  Monk Fruit (mogroside-5) 
Bulking: Sugar Alcohols	Erythritol  Sorbitol  Xylitol 
Rare Sugars	D-allulose  D-tagatose 
Oligosaccharides	Oligofructose  Polydextrose 

intensity sweeteners both from artificial and natural sources, but sugar alcohols, such as xylitol and erythritol for example, have low gastrointestinal tolerance (O'Donnell and Kearsley, 2012; Shankar et al., 2013). While high intensity sweeteners, even at lower concentrations, have a noticeable bitter or metallic after taste, specifically aspartame, acesulfame k, and stevia (Tan et al., 2019, 2020), which can limit the amount of these sweeteners used, as there is a threshold where the bitterness can dominate the sweetness.

In gel confections, both Pielak et al. (2020) and Akesowan and Choonhahirun (2019) studied the impact of sugar alternatives on a jam-like product. The main objective of both studies was to determine the impact of sugar substitution on the sensory profile and consumer response to the modified product. Pielak et al. (2020) studied the partial substitution of sucrose with stevia glycosides in apple preserves. In this study, stevia glycosides were chosen because of their natural origin from the *Stevia rebaudiana* plant, the ability to mimic the taste of sugar, and the technological properties. Providing 250–450 times the sweetness of sucrose, stevia is non-nutritive, but has the limitation of a bitter and licorice taste (Jahangir Chughtai et al., 2020). It was found that without additional additives, such as citric acid and pectin, the apple preserves were considered unbalanced with bitterness and metallic taste overpowering the sweet taste or apple flavor. However, with the addition of pectin and citric acid, substitution of sugar with stevia glycosides was possible up to 40% without diminishing the sensory balance. It was hypothesized that the firmer apple preserves produced with pectin and citric acid were thought to be able to mask some of the bitterness of stevia through compensatory effect of texture on flavor.

A similar result was seen in Akesowan and Choonhahirun (2019), where a sugar-free xanthan gum-konjac jam was created using an erythritol-sucralose blend. Konjac gum and xanthan gum are both carbohydrates, typically used as thickening agents (Kohyama and Nishinari, 1997; Milani and Maleki, 2012). The blend of konjac gum with xanthan gum allows the formation of a thermally reversible gel, which is desired in jams (Huang and Lin, 2004). The sweetener blend of erythritol and sucralose is a combination of a sugar alcohol with a high intensity sweetener and was chosen by the authors because the blend had "no contribution to tooth decay, eightfold greater sweetness than sucrose, low caloric value, desirable sweet taste, bulking properties and improved cost availability" (Akesowan and Choonhahirun, 2019). While adjusting the texture of the sugar-free jam through the gelling agent ratio, all jams made with the sweetener blend were harder than the sucrose control and perceived as less sweet. The "harder" gels were the preferred texture, but overall, the sugar-free jams were still only "moderately liked" by panelists. In conventional jams, the increased soluble solids due to added sucrose restricts the hydration and solubility of the gelling agents, therefore creating weaker junction zones and an overall weaker gel network. The softer jams are easily chewed into smaller fragments for increased surface area contact between sweeteners and taste receptors. However, the preferred products in these studies were firmer in texture, demonstrating the importance of a balance between texture and flavor release.

While beverages have had the most successful sugar replacement, Pielak et al. (2020) and Akesowan and Choonhahirun (2019) highlight the impact of solid food's texture on the perception of these off-tastes such as bitterness caused by stevia glycosides, where the firmer gels could have an acceptance up to 40% sugar reduction. Generally, alternative sweeteners have been successfully integrated into current reduced sugar and sugar-free products, but these studies emphasize the challenges in successfully swaying consumer preference and acceptance towards the modified products.

Physical modification

While less explored, the physical modification of sugar has shown great potential in altering the perceived sweetness of foods. Successful utilization of physical modification has been reported in sodium reduction literature which further supports the potential application in sugar reduction (Noort et al., 2012; Rios-Mera et al., 2019; Sun et al., 2021). To increase the perceived sweetness, physical modification can be a manipulation of the sugar particle size or the spatial distribution of sweetness in a product. Decreasing the particle size of sucrose aids in faster dissolution and increased sweetness perception but may impact the structure of the food. Altering the spatial distribution of sucrose in a product creates high contrast areas of sweetness.

In the study by Richardson et al. (2018), the sucrose crystal particle sizes were adjusted in chocolate brownies, while maintaining a constant sucrose mass, to determine the impact on structure and sensory perception. The smallest particle size (459–972 μm) was perceived as significantly sweeter than other samples, in addition to being the softest and moistest samples due to quicker dissolution of the sugar crystals. Decreasing the sugar size could be used to improve the texture and sweetness of products, but the method has not been heavily investigated regarding confections. The study demonstrates how physical changes in the sucrose crystal have a significant impact on the solid structure. These findings could be utilized in confections for slight modifications to the final texture.

Another method studied particularly in confection models involves changing the spatial distribution of sweetness in products. In a study conducted by Mosca et al. (2010), the inhomogeneous distribution of sucrose in agar-gelatin systems was investigated. The group hypothesized that taste enhancement was possible by inhomogeneous spatial distribution of sucrose. They created gels with four horizontal layers and a total sucrose concentration of 10%. Samples with low or high concentration gradients between layers were compared with homogenous controls through sensory testing. From their sensory testing, samples with high concentration gradients (0–40%) were perceived 20% sweeter than the homogenous control. In their discussion, the increased sweetness perception was due to the discontinuous stimulation of taste receptors with the sugar-free layers acting as a control before the sweeter ones, and the location of the layers did not impact this perception. In conclusion, the inhomogeneous spatial distribution could be applied to products and allow for a 20% sugar reduction without decreasing perceived sweetness or compromising sensory performance.

A similar study was done by Kistler et al. (2021) with model chocolate products. With the use of a 3-D printer, the group tested two different spatial models, the layer technique and an alternative cube-in-cube shape. From their studies, a high concentration difference between the outer to inner shell created a sample that had a sweetness intensity 33% higher than the homogenous control. They concluded that the first sweeter contact layer had significant effect on the overall perceived sweetness. However, they also determined that the large concentration difference was only successful if the sweeter layer was the outer shell, compared to Mosca et al. (2010), where the location of the layers containing sucrose did not influence the sweetness perception. This difference could be because Kitsler et al. (2021) used layers of low sweetness as the contrast, while Mosca et al. (2010) had intermittent sugar-free layers.

Both studies show evidence that spatial distribution of sucrose can influence the perceived sweetness, and a potential reduction of 33% meets the FDA's regulation to be labeled as reduced sugar. But even with promising results, the need for a high gradient presents technical challenges for more complicated food products, as both models were simple confections. Additionally, the inconsistencies between similar studies warrant more research. With future work on more complex food systems, the applicability of physical modification shows potential.

Flavor modification

Flavor modification is the addition of an aroma, flavor, or spice to elevate the overall liking or acceptance of a reduced sugar product. Some examples of this are vanilla aroma in reduced sugar pastries (Bertelsen et al., 2021) or adding spices to foods (Peters et al., 2018). In a study done by (Oliveira et al., 2021), the researchers characterized the sweetness perception over time by evaluating the consumer acceptance of reduced sugar yogurts that contained added flavors in different concentrations, such as strawberry and vanilla. By increasing the added flavor, they successfully reduced the sugar content by 25% without adding non-nutritive sweeteners. This paper highlights the relevance of flavor in the perception of sweetness, as often flavor is aided or enhanced by sugar. Similar to sugar reduction, flavor modification is often paired with other sugar reduction strategies, as was the case in Pielak et al. (2020), where sucrose was replaced with stevia, and citric acid was added to improve the flavor balance of the apple preserves. Because sugar aids the flavor of a product and plays a significant role in the texture, flavor modification is combined with formulation changes to enhance flavor perception and mitigate texture differences from the full sugar version.

Formulation change

Formulation change often pairs sugar reduction with the addition of functional ingredients, such as added fiber or antioxidants, due to consumers' interest in ingredients that can benefit overall health. Formulation changes are essential in baked goods where sugar has multiple roles in the structure and flavor of the product. In a paper by Stavale et al. (2019), sucrose was completely substituted in cakes with apple puree. The apple puree changed the overall color, flavor, and texture, but the acceptance of the cakes was similar to those of the control. In a similar substitution by Milner et al. (2020), apple pomace was studied in reduced sucrose cakes. The final cakes were firmer, but the reduced sugar version still showed acceptance from panelists compared to the control cake, indicating that a 25% sugar reduction was possible with the addition of apple pomace. The added apple in both papers was a multifunctional ingredient, providing nutrients as fiber, and textural support as added bulk and moisture retention. Although the final cakes with apple substitutions were significantly different from the controls, the acceptance by the consumers demonstrate the potential of these multifunctional ingredients that provide more than sweetness.

Because sugar reduction has a significant impact on the taste, texture, and functional properties of products, many confection studies also utilize these multifunctional ingredients to create a versatile and healthy product when replacing its main ingredient, sucrose. These ingredients provide not only added bulk, texture, or flavor, but can also introduce nutritional benefits, such as fiber or antioxidants. An example of this is a study done by Gok et al. (2020), which uses soluble wheat fiber and mannitol in sugar reduced gummies. The soluble wheat fiber is an innovative bulking agent compared to the conventional method of sugar alcohols, which in large doses has a laxative effect. With mannitol's low water solubility, its combination with soluble wheat fiber maintains the soluble solids content compared to the full sugar control, in order to retain both the product stability and textural properties. As mannitol concentration was increased, the water activity of the gummy also increased, due to the mannitol's limited solubility and tendency to recrystallize, a problem circumvented in sucrose-based gummies through the addition of glucose syrup. The addition of mannitol resulted in a harder gummy texture, which decreased sweetness perception and flavor release, suggesting that mannitol may not have been the proper alternative sweetener and emphasizing the technical challenges when selecting an alternative sweetener. The soluble wheat fiber had similar sensory and textural results to the control, due to its hydrocolloid nature thickening the confectionery structure. Alternatively, with more research, reduced sugar gummies using soluble wheat fiber show promise for a confection that could meet consumer expectations.

In a study by Riedel et al. (2015), various functional ingredients were added to agar-based fruit gummies to create a healthier formulation of a sugar-free gummy. A combination of sweeteners was used to match the profile of sucrose and maintain the bulk, including polydextrose and oligofructose, both potential prebiotics, and a sucralose/erythritol blend. Polydextrose and oligofructose are oligosaccharides, which have similar functional properties to dietary fibers as they are non-digestible to the hydrolytic activity of the human digestive enzymes (do Carmo et al., 2016; Franck, 2002). While polydextrose has a neutral taste, not providing any sweetness, oligofructose has about 35% of the sweetness of sucrose and a synergy with high intensity sweeteners, which is why an additional sweetener blend of sucralose/erythritol was used. Apple fiber and cellulose were also tested for their fiber enrichment, texturization, and coloration. When formulating the gummies, the researchers were able to maintain textural and sensory properties up to 37.5% sugar reduction, meeting the reduced sugar declaration in the EU of 30% reduction (European Parliament Council, 2006). For the finalized sugar-free formulation, average acceptance of the sugar-free gummy was around 4 out of 5 points, indicating high consumer acceptance from gummies with a wide range of functional modifiers to mimic sucrose. The researchers underscore the importance of understanding the impact of sucrose on gelation and formation of the texture in creating gummies that meets sensory expectations with added nutritional benefits, such as fiber and prebiotics.

The final example is sugar-reduced white chocolate with goji berries. In the study, Morais Ferreira et al. (2017) evaluated the sensory properties and the consumer acceptance of sugar reduced white chocolate that had been functionalized with fructooligosaccharides (FOS) as a prebiotic and goji berries as a source of antioxidants. FOS are a specific subset of oligosaccharides made out of a short chain of fructose molecules and ranging in 15–35% sweetness of sucrose (Yun, 1996). They are often used as bulking agents because they are calorie-free and provide fiber. Additionally, the FOS provided increased viscosity which could benefit the mouthfeel of the chocolate (Dominguez et al., 2014), similar to their use in the study done by Riedel et al. (2015). Two alternative sweeteners were tested: sucralose and stevia, both with and without the addition of goji berries. Regardless of the sweetener used, samples with goji berries received higher scores of bitter and astringency. During consumer testing, chocolates with goji berries received lower consumer scores for overall liking; however, the scores were above 6 on a 9-cm linear hedonic scale, which indicates an overall positive consumer response. The added benefits of goji berries and antioxidants to the chocolate could be a potential method for attracting health concerned customers.

Although formulation changes have shown progress towards creating healthier foods with innovative ingredients, there is still insufficient evidence to support the notion that consumers would be willing to buy reduced-sugar product alternatives. In the studies found in the literature, although the consumer acceptance of reduced-sugar products is above the median, the scores are usually lower than the full sugar control. A method to increase consumer acceptance of reduced sugar confections could mimic studies done in the beverage industry. When consumers were informed of nutritional characteristics, product acceptance and receptiveness to changes increased for reduced-sugar products (Oliveira et al., 2018a; Reis et al., 2017). Informing consumers of potential nutritional benefits, such as added fiber and antioxidants in addition to sugar reduction, could appeal to more health focused consumers.

The reviewed literature demonstrates a variety of techniques implemented to reduce sugar in high concentration products comparable to confections. While sugar-reduction is feasible through these methods, the consumer acceptance or liking of the product is typically lower than that of the full sugar versions. The texture of a product and its resulting flavor release have a significant impact on sensory scores and sweetness perception, as seen with the gels and other model confections where firmer texture was appreciated, but the flavor and sweetness perception decreased. Physical modification of the product and of the sugar crystal itself was explored in simple model products, but more research is required for application in complex products. While sugar replacement is the most reported method for sugar reduction, the addition of alternative sweeteners presents the issues of bitter aftertaste, large replacement of bulk, and gastric distress. Some of these problems may be mitigated with additional bulking ingredients, such as fiber. However, determining the appropriate fiber type and concentration for each product would warrant further research in specific products.

Changes in labeling may attract consumers to these functionalized confections with added nutrients and increase their receptiveness towards sugar reduction. Future research will need to increase the sensory acceptance of reduced-sugar products or provide a nutritional benefit in order for consumers to willingly accept any resulting changes in texture or taste. Sugar reduction still has many challenges to overcome before increased acceptance by the conventional consumer, but with recent innovations being developed by ingredient manufacturers and product developers, the goal of creating highly palatable sugar reduced confections is becoming increasingly possible.

Acknowledgements We are grateful to our colleague Aubrey Dunteman for her valuable comments during the editing process.

Declarations

Conflict of interest None of the authors of this study has any financial interest or conflict with industries or parties.

References

Abu-Reidah IM. Chapter 1 - Carbonated beverages. 1st Edition. Academic Press. In C. M. Galanakis, (Ed) Trends in Non-Alcoholic Beverages 1-36 (2020). https://doi.org/10.1016/B978-0-12-816938-4.00001-X.

Acevedo W, Capitaine C, Rodríguez R, Araya-Durán I, González-Nilo F, Pérez-Correa JR, Agosin E. Selecting optimal mixtures of natural sweeteners for carbonated soft drinks through multi-objective decision modeling and sensory validation. Journal of Sensory Studies. 33: e12466 (2018)

Akesowan A, Choonhahirun A. Optimization of sugar-free konjac gel texture containing erythritol-sucralose sweetener for producing healthy jam. Food Research. 3: 241-48 (2019)

Basu S, Shivhare US, Chakraborty P. Chapter 14 - Influence of sugar substitute in rheology of fruit gel. 1st Edition. Woodhead Publishing. In J. Ahmed, P. Ptaszek, S. Basu (Eds) Advances in Food Rheology and Its Applications 355-376 (2017)

Basu S, Shivhare US, Singh TV. Effect of substitution of stevioside and sucralose on rheological, spectral, color and microstructural characteristics of mango jam. Journal of Food Engineering. 114: 465-76 (2013)

Bell LN, Hageman MJ. Differentiating between the effects of water activity and glass transition dependent mobility on a solid state chemical reaction: aspartame degradation. Journal of Agricultural and Food Chemistry. 42: 2398-2401 (1994)

Bertelsen AS, Zeng Y, Mielby LA, Sun YX, Byrne DV, Kidmose U. Cross-modal effect of vanilla aroma on sweetness of different sweeteners among Chinese and Danish consumers. Food Quality and Preference. 87: 104036 (2021)

Cardoso JMP, Bolini HMA. Descriptive profile of peach nectar sweetened with sucrose and different sweeteners. Journal of Sensory Studies. 23: 804-16 (2008)

CDC. National diabetes statistics report. National Diabetes Statistics Report 2 (2020)

Chattopadhyay S, Raychaudhuri U, Chakraborty R. Artificial sweeteners - a review. Journal of Food Science and Technology. 51: 611-21 (2014)

De Carvalho LC, Segato MP, Nunes RS, Novak C, Cavalheiro ETG. Thermoanalytical studies of some sweeteners. Journal of Thermal Analysis and Calorimetry. 97: 359-65 (2009)

do Carmo MMR, Walker JCL, Novello D, Caselato VM, Sgarbieri VC, Ouwehand AC, Andreollo NA, Hiane PA, dos Santos EF. Polydextrose: physiological function, and effects on health. Nutrients. 8: 1-13 (2016)

Dodson AG, Pepper T. Confectionery technology and the pros and cons of using non-sucrose sweeteners. Food Chemistry. 16: 271-80 (1985)

Dominguez AL, Rodrigues LR, Lima NM, Teixeira JA. An overview of the recent developments on Fructooligosaccharide production and applications. Food and Bioprocess Technology. 7: 324-37 (2014)

Drewnowski A, Mennella JA, Johnson SL, Bellisle F. Sweetness and food preference. Journal of Nutrition. 142: 1142S-1148S (2012)

Erickson S, Carr J. The technological challenges of reducing the sugar content of foods. Nutrition Bulletin. 45: 309-14 (2020)

European Parliament Council. Regulation (EC) No 1924/2006 of the european parliament and of the council of 20 December 2006 on nutrition and health claims made on foods (2006)

Evageliou V, Richardson RK, Morris ER. Effect of sucrose, glucose and fructose on gelation of oxidized starch. Carbohydrate Polymers. 42: 261-72 (2000)

Fakhouri THI, Kit BK, Ogden CL. Consumption of diet drinks in the united states, 2009-2010. NCHS Data Brief 109: 1-8 (2012)

Faruque S, Tong J, Lacmanovic V, Agbonghae C, Minaya DM, Czaja K, Veterinary biosciences. The dose makes the poison: sugar obesity in the United States - a review. Polish Journal of Food and Nutrition Science. 69: 219-33 (2020)

Food and Drug Administration. Additional information about high-intensity sweeteners permitted for use in food in the united states. Food Additives and Petitions (2018)

Food and Drug Administration. Added sugars on the new nutrition facts label. Food and Drug Administration. Available from: https://www.fda.gov/food/new-nutrition-facts-label/added-sugars-new-nutrition-facts-label. Accessed June 28th, 2021 (2020a)

Food and Drug Administration. CFR - code of federal regulation title 21. Food and Drug Administration (2020b)

Food and Drug Administration. The declaration of allulose and calories from allulose on nutrition and supplement Facts Labels (2020c)

Franck A. Technological functionality of inulin and oligofructose. British Journal of Nutrition. 87: S287-91 (2002)

Gok S, Toker OS, Palabiyik I, Konar N. Usage possibility of mannitol and soluble wheat fiber in low calorie gummy candies. LWT - Food Science and Technology. 128: 109531 (2020)

Grembecka M. Sugar alcohols - their role in the modern world of sweeteners: a review. European Food Research and Technology. 241: 1-14 (2015)

Griffith R, O'Connell M, Smith K, Stroud R. What's on the menu? Policies to reduce young people's sugar consumption. Fiscal Studies. 41: 165-97 (2020)

Hanger LY, Lotz A, Lepeniotis S. Descriptive profiles of selected high intensity sweeteners (HIS), HIS blends, and sucrose. Journal of Food Science. 61: 456-59 (1996)

Haribo. Haribo product. Haribo. Available from: https://www.haribo.com/en-us/products/goldbears. Accessed June 28th, 2021 (2020)
Herrick KA, Fryar CD, Hamner HC, Park S, Ogden CL. Added sugars intake among US infants and toddlers. Journal of the Academy of Nutrition and Dietetics. 120: 23-32 (2019)
Hu F, Malik V. Sugar-sweetened beverages and risk of obesity and type 2 diabetes: epidemiologic evidence. Physiology & Behavior. 100: 47-54 (2010)
Huang HY, Lin KW. Influence of pH and added gums on the properties of konjac flour gels. International Journal of Food Science and Technology. 39: 1009-16 (2004)
IFIC. 2019 Food & Health Survey. 1: 50 (2019)
Jahangir Chughtai MF, Pasha I, Zahoor T, Khaliq A, Ahsan S, Wu Z, Nadeem M, Mehmood T, Amir RM, Yasmin I, Liaqat A, Tanweer S. Nutritional and therapeutic perspectives of *Stevia rebaudiana* as emerging sweetener; a way forward for sweetener industry. CYTA - Journal of Food. 18: 164-77 (2020)
Jell-O. Jell-O original strawberry gelatin snacks. Kraft-Heinz. Available from: https://www.myfoodandfamily.com/brands/kraft-jello/product/00043000045749/jell-o-ready-to-eat-strawberry-gelatin-snacks-135-oz-sleeve-4-cups?categoryid=25001. Accessed June 28th, 2021 (2020)
Kappes SM, Schmidt SJ, Lee SY. Mouthfeel detection threshold and instrumental viscosity of sucrose and high fructose corn syrup solutions. Journal of Food Science. 71: S597-602 (2006)
Kistler T, Pridal A, Bourcet C, Denkel C. Modulation of sweetness perception in confectionary applications. Food Quality and Preference. 88: 104087 (2021)
Kohyama K, Nishinari K. New application of konjac glucomannan as a texture modifier. Japan Agricultural Research Quarterly. 31: 301-6 (1997)
Malik VS, Li Y, Pan A, De Koning L, Schernhammer E, Willett WC, Hu FB. Long-term consumption of sugar-sweetened and artificially sweetened beverages and risk of mortality in US adults. Circulation. 139: 2113-25 (2019)
Mayhew EJ, Schmidt SJ, Lee SY. Sensory and physical effects of sugar reduction in a caramel coating system. Journal of Food Science. 82: 1935-46 (2017a)
Mayhew EJ, Schmidt SJ, Schlich P, Lee SY. Temporal texture profile and identification of glass transition temperature as an instrumental predictor of stickiness in a caramel system. Journal of Food Science. 82: 2167-76 (2017b)
McCain HR, Kaliappan S, Drake MA. Invited review: sugar reduction in dairy products. Journal of Dairy Science. 101: 8619-40 (2018)
Milani J, Maleki G. Hydrocolloids in food industry. 1st Edition. InTechOpen. Food Industrial Processes - Methods and Equipment Hydrocolloids in Food Industry. 17-38 (2012)
Miller G. The Global Soda Tax Experiment. Knowable magazine from annual reviews. Retrieved (https://knowablemagazine.org/article/health-disease/2019/do-soda-taxes-work) (2019)
Milner L, Kerry JP, O'Sullivan MG, Gallagher E. Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients. Innovative Food Science & Emerging Technologies. 59: 102235 (2020)
Mitchell H. Sweeteners and sugar alternatives in food technology (2007)
Morais Ferreira JM, Azevedo BM, Luccas V, Bolini HM. Sensory profile and consumer acceptability of prebiotic white chocolate with sucrose substitutes and the addition of Goji berry (*Lycium barbarum*). Journal of Food Science. 82: 818-24 (2017)
Mosca AC, van de Velde F, Bult JH, van Boekel MA, Stieger M. Enhancement of sweetness intensity in gels by inhomogeneous distribution of sucrose. Food Quality and Preference. 21: 837-42 (2010)
Murphy SL, Xu J, Kochanek KD, Arias E. Mortality in the united states, 2017. NCHS Data Brief 328: 1-8 (2018)
Noort MWJ, Bult JHF, Stieger S. Saltiness enhancement by taste contrast in bread prepared with encapsulated salt. Journal of Cereal Science. 55: 218-25 (2012)
O'Donnell K, Kearsley M. Sweeteners and sugar alternatives in food technology (2012)
Oliveira AAA, Andrade AC, Bastos SC, Condino JPF, Júnior AC, Pinheiro ACM. Use of strawberry and vanilla natural flavors for sugar reduction: a dynamic sensory study with yogurt. Food Research International. 139: 109972 (2021)
Oliveira D, Ares G, Deliza R. The effect of health/hedonic claims on consumer hedonic and sensory perception of sugar reduction: case study with orange/passionfruit nectars. Food Research International. 108: 111-18 (2018a)
Oliveira de Souza NC, de Lacerda de Oliveira L, de Alencar ER, Moreira GP, dos Santos Leandro E, Ginani VC, Zandonadi RP. Textural, physical and sensory impacts of the use of green banana puree to replace fat in reduced sugar pound cakes. LWT - Food Science and Technology. 89: 617-23 (2018)
Oliveira D, Galhardo J, Ares G, Cunha LM, Deliza R. Sugar reduction in fruit nectars: impact on consumers' sensory and hedonic perception. Food Research International. 107: 371-77 (2018b)
Oliveira D, Reis F, Deliza R, Rosenthal A, Giménez A, Ares G. Difference thresholds for added sugar in chocolate-flavoured milk: recommendations for gradual sugar reduction. Food Research International. 89: 448-53 (2016)
Pacheco LS, Lacey Jr JV, Martinez ME, Lemus H, Araneta MR, Sears DD, Talavera GA, Anderson CAM. Sugar-sweetened beverage intake and cardiovascular disease risk in the California teachers study. Journal of the American Heart Association. 9: e014883 (2020)
Peters JC, Marker R, Pan Z, Breen JA, Hill JO. The influence of adding spices to reduced sugar foods on overall liking. Journal of Food Science. 83: 814-21 (2018)
Pielak M, Czarniecka-Skubina E, Głuchowski A. Effect of sugar substitution with steviol glycosides on sensory quality and physicochemical composition of low-sugar apple preserves. Foods. 9: 1-19 (2020)
Powell ES, Smith-Taillie LP, Popkin BM. Added sugars intake across the distribution of US children and adult consumers: 1977-2012. Journal of the Academy of Nutrition and Dietetics. 116: 1543-1550.e1 (2016)
Public Health England. Sugar reduction and wider formulation. GOV.UK. Retrieved (https://knowablemagazine.org/article/health-disease/2019/do-soda-taxes-work) (2017)
Public Health England. Sugar reduction: Report on progress between 2015 and 2019. Public Health England September:1-108 (2020)
Reis F, Alcaire F, Deliza R, Ares G. The role of information on consumer sensory, hedonic and wellbeing perception of sugar-reduced products: case study with orange/pomegranate juice. Food Quality & Preference. 62: 227-36 (2017)
Richardson AM, Tyuftin AA, Kilcawley KN, Gallagher E, O'Sullivan MG, Kerry JP. The impact of sugar particle size manipulation on the physical and sensory properties of chocolate brownies. LWT - Food Science and Technology. 95: 51-57 (2018)
Riedel R, Böhme B, Rohm H. Development of formulations for reduced-sugar and sugar-free agar-based fruit jellies. International Journal of Food Science and Technology. 50: 1338-44 (2015)
Rios-Mera JD, Saldaña E, Cruzado-Bravo ML, Patinho I, Selani MM, Valentin D, Contreras-Castillo CJ. Reducing the sodium content without modifying the quality of beef burgers by adding micronized salt. Food Research International. 121: 288-95 (2019)

Roberfroid M, Slavin J. Nondigestible oligosaccharides. Critical Reviews in Food Science and Nutrition. 40: 461-80 (2000)

Shankar P, Ahuja S, Sriram K. Non-nutritive sweeteners: review and update. Nutrition. 29: 1293-99 (2013)

Shimizu S, Matubayasi N. Gelation: the role of sugars and polyols on gelatin and agarose. Journal of Physical Chemistry B. 118: 13210-16 (2014)

Smucker's. Concord Grape Jelly. Smucker's. Available from: https://www.smuckers.com/products/fruit-spreads/jelly/concord-grape-jelly. Accessed June 28th, 2021 (2020)

Stavale MDO, Assunção Botelho RB, Zandonadi RP. Apple as sugar substitute in cake. Journal of Culinary Science and Technology. 17: 224-31 (2019)

Sun C, Zhou X, Hu Z, Lu W, Zhao Y, Fang Y. Food and salt structure design for salt reducing. Innovative Food Science and Emerging Technologies. 67: 102570 (2021)

Tan VWK, Wee MSM, Tomic O, Forde CG. Temporal sweetness and side tastes profiles of 16 sweeteners using temporal check-all-that-apply (TCATA). Food Research International. 121: 39-47 (2019)

Tan VW, Wee MS, Tomic O, Forde CG. Rate-all-that-apply (RATA) comparison of taste profiles for different sweeteners in black tea, chocolate milk, and natural yogurt. Journal of Food Science. 85: 486-92 (2020)

Taylor TP, Fasina O, Bell LN. Physical properties and consumer liking of cookies prepared by replacing sucrose with tagatose. Journal of Food Science. 73: S145-51 (2008)

Torrico DD, Tam J, Fuentes S, Gonzalez Viejo C, Dunshea FR. Consumer rejection threshold, acceptability rates, physicochemical properties, and shelf-life of strawberry-flavored yogurts with reductions of sugar. Journal of the Science of Food and Agriculture. 100: 3024-35 (2020)

Tsitlakidou P, Van Loey A, Methven L, Elmore JS. Effect of sugar reduction on flavour release and sensory perception in an orange juice soft drink model. Food Chemistry. 284: 125-32 (2019)

Virani SS, Alonso A, Benjamin EJ, Bittencourt MS, Callaway CW, Carson AP, Chamberlain AM, Chang AR, Cheng S, Delling FN, Djousse L, Elkind MSV, Ferguson JF, Fornage M, Khan SS, Kissela BM, Knutson KL, Kwan TW, Lackland DT, Lewis TT, Lichtman JH, Longenecker CT, Loop MS, Lutsey PL, Martin SS, Matsushita K, Moran AE, Mussolino ME, Perak AM, Rosamond WD, Roth GA, Sampson UKA, Satou GM, Schroeder EB, Shah SH, Shay CM, Spartano NL, Stokes A, Tirschwell DL, VanWagner LB, Tsao CW, Wong SS, Debra G. Heard DG. 2020. Heart disease and stroke statistics—2020 update: a report from the American Heart Association (2020)

Yun JW. Fructooligosaccharides - occurrence, preparation, and application. Enzyme and Microbial Technology. 19: 107-17 (1996)