Comprehensive REVIEWS in Food Science and Food Safety

Why Sugar Is Added to Food: Food Science 101

Kara R. Goldfein and Joanne L. Slavin

Abstract: Avoiding too much sugar is an accepted dietary guidance throughout the world. The U.S. Nutrition Facts panel includes information on total sugars in foods. A focus on added sugars is linked to the concept of discretionary calories and decreasing consumption of added sugars or free sugars as a means to assist a consumer to identify foods that are nutrient-dense. On March 14, 2014, the U.S. Food and Drug Administration proposed that including "added sugars" declaration on the Nutrition Facts panel would be another tool to help consumers reduce excessive discretionary calorie intake from added sugars. Through deductive reasoning, labeling added sugars is one tactic to potentially curb the obesity epidemic in the United States. This review discusses the functions of sugar in food and shows that the methods used to replace added sugars in foods can result in no reduction in calorie content or improvement in nutrient density. Without clear benefit to the consumer for added sugars labeling, this review highlights the complex business obstacles, costs, and consumer confusion resulting from the proposed rule.

Keywords: food labeling, nutrition facts, public health, sucrose, sugars

Introduction

The obesity epidemic in the United States has been a key public health issue due to the high rate of obesity and the increased healthcare cost associated with it. More than one-third (34.9% or 78.6 million) of adults and 17% of youth are obese in the United States (Ogden and others 2014) and, in 2008, the estimated annual medical cost of obesity was $147 billion (Finkelstein and others 2009). According to the 2010 Dietary Guidelines for Americans, poor diet and lack of physical activity are the most important factors contributing to this epidemic (U.S. Department of Agriculture [USDA] and U.S. Department of Health and Human Services [HHS] 2010). These factors are the basis for the 2 overarching concepts of the 2010 Dietary Guidelines for Americans: maintain calorie balance over time to achieve and sustain a normal healthy weight and focus on consuming nutrient-dense foods and beverages (USDA and HHS 2010). Added sugars can violate both of these overarching concepts by resulting in extra calories being consumed and replacing nutrient-dense foods and beverages, and this is why the 2010 Dietary Guidelines for Americans recommend limiting the intake of added sugars in the American diet. This same principle of displacing nutrient-dense foods was recently highlighted in the Scientific Report of the 2015 Dietary Guidelines Advisory Committee, but the committee took it a step further by stating that the overconsumption of added sugars has been linked with negative health outcomes, such as increased body weight, type II diabetes, and cardiovascular disease (USDA and HHS 2015).

On March 3, 2014, the U.S. Food and Drug Administration (FDA) released its proposal for the nutrition and supplement facts labels. Given the recent public attention on added sugars, it was not a surprise to see that "added sugars" is one of the suggested changes. FDA is proposing the mandatory declaration of added sugars on the nutrition facts label to assist consumers in maintaining health-beneficial dietary practices (FDA 2014b). However, there is no clear correlation that the labeling of added sugars will benefit the consumer, and the challenges of labeling added sugars will fall onto the food industry.

The objectives of this article are to review (1) the relationship of carbohydrates, sugars, added sugars, and sweeteners; (2) the purpose of sugar in food products; (3) the challenges of labeling added sugars; (4) the issues with current food technology to replace added sugars in products; and (5) a discussion on whether labeling added sugars is an appropriate public health strategy to address the obesity epidemic.

Carbohydrates, Sugars, Added Sugars, and Sweeteners

Sugars and carbohydrates

The most commonly understood added sugar is sucrose or table sugar. Sucrose is a simple carbohydrate and occurs naturally in plants because they make sucrose via photosynthesis (Kitts 2010). The highest concentrations of sucrose are found in sugar cane and sugar beets, which are the main sources for making commercial sugar (Kitts 2010).

Sucrose is one of many different types of carbohydrates that are widely distributed in nature. Structurally, carbohydrates are molecules of carbon, hydrogen, and oxygen, and there are 3 major classifications of carbohydrates: monosaccharides, oligosaccharides, and polysaccharides (Varzakas and others 2012). The term saccharide is a synonym for carbohydrate.

As the name implies, a monosaccharide consists of a single molecular unit and is the fundamental unit of almost all carbohydrates. Common monosaccharides found in nature include

MS 20150834 Submitted 18/5/2015, Accepted 22/6/2015. *Authors are with Dept. of Food Science and Nutrition, Univ. of Minnesota, 1334 Eckles Ave., St. Paul, MN, 55108, U.S.A. Direct inquiries to author Slavin (E-mail: jslavin@umn.edu).*

doi: 10.1111/1541-4337.12151

glucose (dextrose), galactose, mannose, and fructose. Honey and fruit juices are common food sources of free glucose and fructose.

Oligosaccharides consist of more than one monosaccharide usually, 2 to 10 monosaccharides. Disaccharides are the most common type of oligosaccharides found in food. Sucrose is officially classified as a disaccharide, and it is composed of one molecule of glucose and fructose and occurs naturally in fruits and vegetables. Lactose is composed of galactose and glucose and occurs naturally only in milk. Maltose is composed of 2 glucoses, and it is a byproduct of the enzymatic degradation of starch by amylase. With a similar chemical structure as maltose, trehalose also contains 2 glucose molecules, which are linked by an α1,1-glyosidic bond versus an α1,4-glyosidic bond in maltose (Wilson 2007). It is widely distributed in nature, and mushrooms can contain up to 10% to 25% of trehalose by dry weight (Varzakas and others 2012).

Polysaccharides are composed of a large number of monosaccharides, and the most common ones in nature are starch (energy storage for plants), glycogen (energy storage in animals, including humans), and cellulose (supporting material and structural component in plants). Dietary fiber is another common polysaccharide discussed in the human diet.

Monosaccharides and disaccharides are also known as sugars, simple carbohydrates, or simple sugars. Sugars occur naturally in food or can be added during the processing of foods. Naturally occurring sugars in food can also be termed intrinsic or inherent sugars. Natural sources of sugars include vegetables, fruits, milk, and honey (Figure 1). The most common sugar added to food is sucrose, also called table sugar

The role and metabolism of carbohydrates

Carbohydrates are an integral part of a "healthy" diet. Once consumed, carbohydrates are digested and broken down into glucose. Carbohydrates (starch and sugar) are the primary source of energy for the human body providing on average 4 calories per gram, and glucose is essential for the central nervous system to function (Slavin and Carlson 2014). Because of this, the Inst. of Medicine (IOM) set an RDA for carbohydrates of 130 g/d for adults and children aged ≥1-year-old and an acceptable macronutrient distribution range for carbohydrates at 45% to 65% of total calories (IOM 2005).

Because all sugars are carbohydrates, the body metabolizes them similarly by breaking them down into glucose to be used for energy (USDA and HHS 2010). Regardless, if the sugars are naturally occurring or added during food processing, the molecular structure and nutritional value are the same, providing 4 calories per gram. In other words, the human body does not distinguish between added sugars and naturally occurring sugars in foods, so whether a person consumes 10 g of added sugars or 10 g of inherent sugars, it makes no difference to the body (Hess and others 2012).

Sweeteners

A sweetener is any naturally occurring or synthetically made substance that provides a sweet taste in food and beverages. Sucrose (table sugar) is regarded as the "gold" standard for sweet taste and is the most common sweetener in the food industry (Varzakas and others 2012). Sweeteners can generally be classified as nutritive or nonnutritive. Nutritive or caloric sweeteners are usually made by fruits, sugar cane, and sugar beets and on average provide 4 calories per gram (Varzakas and others 2012). Common nutritive sweeteners include sucrose, the other simple carbohydrates, liquid sugars, honey, syrups, and fruit juice concentrates. Nonnutritive or high-intensity sweeteners provide sweetness to food but very little or no calories, or glycemic response in the body, when they are metabolized, unlike carbohydrates (Varzakas and others 2012). Some nonnutritive sweeteners are not metabolized and are excreted unchanged by the body (Varzakas and others 2012). Other nonnutritive sweeteners can be partially metabolized, to a limited degree, and their metabolites are readily excreted (Varzakas and others 2012; Carakostas and others 2012). Nonnutritive sweeteners can be derived from plant sources, such as monk fruit or stevioside, or synthetically made, such as acesulfame K, aspartame, sucralose, or saccharine. Synthetically made nonnutritive sweeteners are also known as artificial sweeteners.

Sugar alcohols

Sugar alcohols could be placed in the nutritive sweetener group because they technically provide calories and taste similar to sucrose. However, they deserve their own discussion because of their reduced caloric value ranging from 0.2 to 3 kcal/g (Varzakas and others 2012). Unlike nutritive sweeteners, their digestion requires little or no insulin synthesis, and they are noncariogenic. When consumed in excessive, some of the sugar alcohols such as mannitol and sorbitol can have a laxative effect unlike nutritive sweeteners. Sugar alcohols are derivatives of monosaccharides, disaccharides, and other oligosaccharides, and they can occur naturally in many fruits and vegetables (Varzakas and others 2012). Because they can contribute to sweetness with fewer calories, they are commonly used as bulk sweeteners in some food products. Other products that use sugar alcohols include mouthwash, toothpaste, breath mints, chewing gum, and special foods for diabetics.

FDA definition of added sugars

In FDA's proposal, the term "added sugars" is defined as "sugars that are either added during the processing of food, or are packaged as such, and include sugars (free monosaccharides and disaccharides), syrups, naturally occurring sugars that are isolated from a whole food and concentrated so that sugar is the primary component (such as fruit juice concentrates), and other caloric sweeteners" (FDA 2014b). In other words, FDA is proposing that nutritive sweeteners that are added during the processing of food are considered added sugars. Names for added sugars in the proposal included brown sugar, corn sweetener, corn syrup, dextrose, fructose, fruit juice concentrates, glucose, high-fructose corn syrup, honey, invert sugar, lactose, maltose, malt sugar, molasses, raw sugar, turbinado sugar, trehalose, and sucrose. FDA further specified that sugar alcohols are not considered added sugars.

Functional Properties of Sugar

Sugar (sucrose) has several functional properties in food and, so far, no other sweetener has been found or developed to duplicate all or even many of them. These functional properties are derived from the sensory and physical properties of sugar and its many reactions and interactions with the other food ingredients present (Spillane 2006). Understanding the function of sugar in a food product is an important point to consider when reducing or removing sugar from the product.

Sweetness, flavor enhancement, and flavor balance

The most notable function of sugar in food is its sweet taste. Sweet taste serves as a sensory cue for energy as well as a source of pleasure. Sweetness is one of a few tastes which are innate, and it has been argued that a preference for sweet taste evolved to ensure that animals and humans chose foods that are high in calories and nontoxic (Spillane 2006). During infancy, the heightened preference for sweet tastes may have ensured the acceptance of nature's

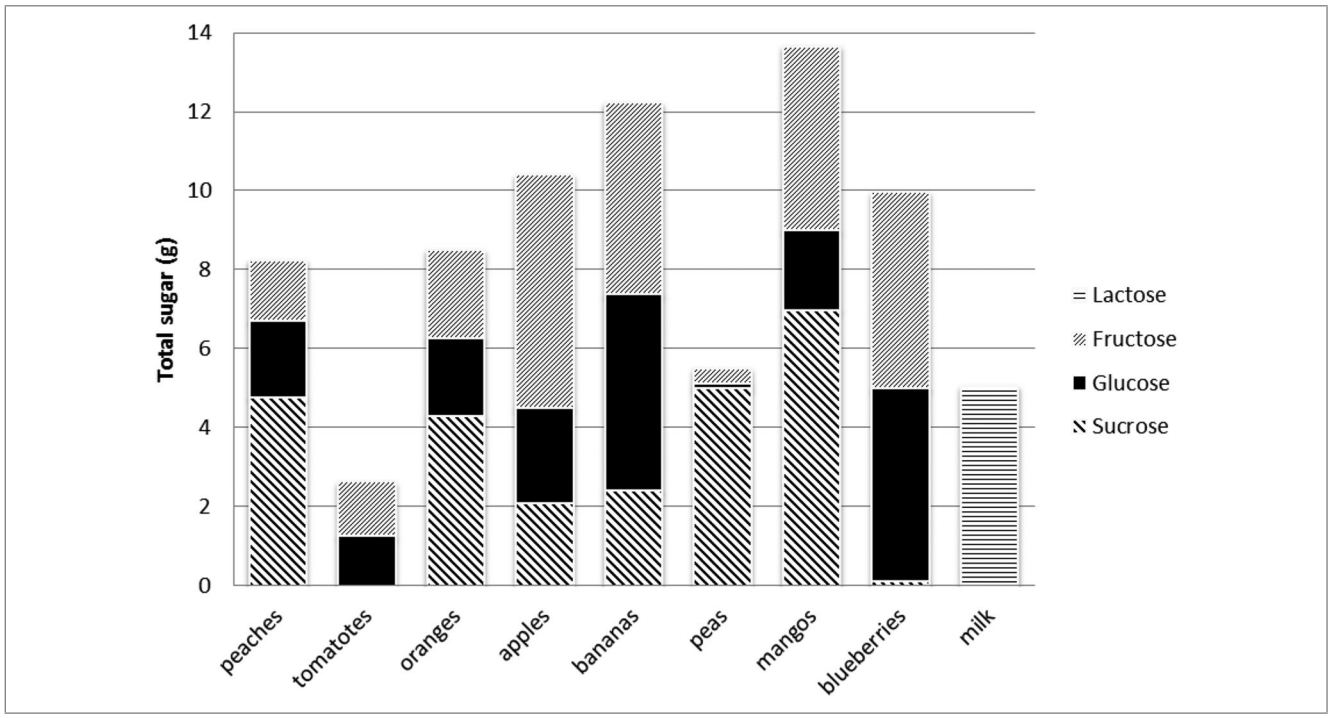

Figure 1–Naturally occurring sugar in foods per 100 g (USDA Natl. Nutrient Database for Standard Reference 2014).

first food—mothers' milk. Human breastmilk naturally contains 2.12 g of sugar per 1 fluid ounce (USDA 2014). Therefore, these taste mechanisms apparently had a significant effect on survival.

Sweetness improves the palatability of food. Thus, adding sugar to foods with high nutrient quality may increase the chance that they are consumed. Chocolate milk is an example of increasing the palatability of milk for kids, which provides important nutrients particularly calcium, potassium, and vitamin D (Slavin 2014). Sweetness from sugar can also improve the palatability of foods for the elderly by compensating for the chemosensory losses that the elderly experience (Spillane 2006).

In food products, sugar plays an important and unique role in contributing to the flavor profile by interacting with other ingredients to enhance or lessen certain flavors. The addition of sugar enhances flavors by increasing the aroma of the flavor. A flavor aroma possesses no taste properties, but once combined with sugar, the sweetness of sugar and the flavor aroma work synergistically (Spillane 2006). For example, if a peach aroma is added to a solution with no sugar, the solution would have no taste, but with sugar added in the solution, sweetness and the peach flavor can be perceived. Small amounts of sugar can be added to cooked vegetables and meat to enhance the food's natural flavors without making them taste sweet (Kitts 2010). The addition of sugar also balances the sweetness and acidity in fruit-based products such as beverages, sauces, and preserves (Gwinn 2013). In reduced-fat ice cream, sugar is added to balance out flavor (Varzakas and others 2012), and the sweetness of sugar balances the bitterness of cocoa in chocolate (Spillane 2006).

Color and flavor formation

The Maillard browning reaction and caramelization are fundamental to the formation of color and flavor in several food products. Caramelization occurs when sugars are heated above their melting point in the absence of proteins causing the sugars to degrade (Varzakas and others 2012). This produces a dark brown color and imparts caramel taste and aroma in food products. Caramelization is used in a wide range of products including sauces, candies, desserts, breads, jams, and dessert wine (Kroh 1994). This reaction can also be used to commercially produce caramel colors and flavors (Kitts 2010).

The Maillard reaction is another form of nonenzymatic browning, which is the result of a reaction between an amino acid and sugar (Hwang and others 2011). This is a complex reaction that depends on several factors: reactant types and concentrations, temperature, reaction time, pH, and water activity (Hwang and others 2011). Besides color formation in food, the Maillard reaction provides desirable flavor formation in several food products, such as baked goods, chocolate, coffee, and meat (Danehy and Wolnak 1983). In bread-baking, the early stages of the Maillard reaction are responsible for the pleasant aroma whereas the late-stage reactions produce the recognizable brown crust (Kitts 2010).

Bulk and texture

Because sugar can be used as one of the primary ingredients in products, it affects the physical characteristics of food to a significant degree. Sugar provides bulk which impacts the mouthfeel and texture of many food products. Instead of being used for their sweetening properties, sometimes specific sugars are used as bulking agents or carriers for other ingredients, especially the sugars that are less sweet than sucrose (Spillane 2006). Sucrose is given an arbitrary sweetness level of 1 to allow its comparison with other sweeteners, and there is a 4 to 5-fold change in relative sweetness between the various sugars (Table 1).

Sugar plays an important role in the texture of bakery products. It tenderizes bakery products by competing with starch molecules and proteins for liquid components in the dough, which prevents overdevelopment of gluten and slows down gelanization (Varzakas and others 2012). During the mixing of dough, sugar promotes lightness by incorporating air in the form of small air cells into the shortening, and these air cells will expand due to

Table 1–Relative sweetness of various sugars.

Sugar	Relative sweetness	Reference
Sucrose	1	Varzakas and others 2012
Fructose	1.7	Varzakas and others 2012
Glucose	0.75	Varzakas and others 2012
Maltose	0.30	Varzakas and others 2012
Galactose	0.30	Varzakas and others 2012
Lactose	0.15	Varzakas and others 2012
Mannose	0.60	Tamime and Robinson 1999
Trehalose	0.45	Wilson 2007

the gases generated by the leavening agents (Varzakas and others 2012). For cookies, sugar influences the spread of dough and surface cracking (Pareyt and Delcour 2008). In foam-type cakes, sugar interacts with egg proteins to stabilize the whipped foam structure making it more elastic, so that the air cells can expand (Varzakas and others 2012).

The level of sugar can affect the ice and crystal crystallization size in the manufacturing of ice cream and other frozen desserts. The sugar's ability to attract and hold water diminishes the water available for crystallization during freezing and, as a result, the freezing point for these frozen desserts drops, thus allowing colder temperatures to be used during processing (Varzakas and others 2012). This combination of lower freezing point and colder temperatures during processing produces a frozen product with extremely small ice crystals, and these tiny ice crystals give frozen desserts their desirable smooth, creamy texture.

Sugar crystallization is a major determinant of the texture for candies. It is minimized to create the soft texture of taffy candies and fudge and, on the contrary, it is maximized to create the desirable grainy texture of hard candies (Kitts 2010). Besides impacting the freezing point in frozen desserts, a higher concentration of sugar increases the boiling point of solutions used to make candies (Kitts 2010). This allows more sugar to be dissolved, which optimizes the final consistency of the candy.

In beverages, the high solubility of sugar contributes to the mouthfeel of the product by giving the product body (Gwinn 2013). Sugar is also essential in the gelation of jams, preserves, and jellies. Pectin, a natural component of fruits, has the ability to form this gel, but only in the presence of sugar and acid (Varzakas and others 2012).

Fermentation

Fermentation is a process in which microorganisms in the absence of oxygen generate energy by oxidizing carbohydrates. In other words, carbohydrates including sugars are the food sources for these microorganisms. Fermentation has a long history of being used in food production. Common food and beverages produced from fermentation include yogurt, vinegar, sour cream, wine, beer, bread, cheese, soy sauce, and sauerkraut.

Lactic acid bacteria fermentations are among the most ancient and important fermentations in the world (Steinkraus 2004). This type of fermentation was significant for increasing the shelf-life of milk and preventing pathogens from growing in it. Today, it is well known for its application in fermenting dairy products. Lactic acid bacteria utilize the sugar lactose in the milk as a food source and produces lactic acid and other organic molecules. These metabolic products contribute significantly to flavor development and the final aroma and taste of fermented dairy products such as sour cream, yogurt, and cheeses. The bacteria can also produce compounds that contribute to the viscosity, body, and mouthfeel of the product (Gürakn and Altay 2010).

Yeast fermentation is another type of food fermentation. It is used in the production of yeast-leavened bakery products. Yeast can utilize starch as a food source but prefers simple sugars, such as glucose or sucrose, in the dough (Poitrenaud 2004). The fermentation of the carbohydrates produces gas causing the product to rise. This, in turn, affects the volume, crumb texture, and softness of the final product (Varzakas and others 2012).

Preservation

The hygroscopic nature of sugar plays a crucial role in reducing water activity in foods (Kitts 2010). *Hygroscopic* is defined as the ability to absorb water from the surrounding environment, which helps in preserving and extending the shelf-life of food products (Kitts 2010).In other words, the water in a food item is controlled so that it is unavailable for chemical or biochemical reactions. Sugar prevents spoilage of jams, jellies, and preserves after the jar has been opened. Its ability to attract water dehydrates microorganisms (yeast and bacteria), so they cannot multiply and thereby spoil the food (Varzakas and others 2012). Sugar also acts as a humectant in baked goods, which prevents drying out and staleness, thus extending the shelf-life of these products (Spillane 2006).

Sugar also preserves the color of frozen fruits and jellies. In the freezing of fruit, sugar prevents enzymatic browning discoloration of the fruit by protecting the surfaces of the fruit from contact with air (Varzakas and others 2012). For preserves and jellies, sugar inhibits the fruit from absorbing water, so that the color of the fruit will not fade (Varzakas and others 2012).

Pharmaceuticals

In addition to sweetening food, the sweetness of sugar can help the palatability of medicine to ensure patient compliance (Spillane 2006). Sugar also provides other desirable functional properties in pharmaceuticals due to its low toxicity, high purity, and diverse physicochemical properties. It can act as an excipient by which the active ingredient of medication is introduced to the body (Spillane 2006). The correct formulation of the excipient (sugar) and the active ingredients in the medication can provide accurate delivery of the required dose and control the release of the active ingredients to the targeted site of the body (Spillane 2006). In glucose tablets, dextrose (D-glucose) is the primary ingredient, and they are used by diabetics to quickly raise their blood sugar levels in the event of uncomfortable or disabling hypoglycemia. Given the desirable functional properties of sugar, there will always be opportunities for sugar-based products in the pharmaceutical industry.

Challenges of Labeling Added Sugars

Added sugars cannot be differentiated from total sugars chemically and analytically

There are no chemical differences between added sugars and naturally occurring sugars in food. Added sugars and inherent sugars are both simple carbohydrates composed of molecules of carbon, hydrogen, and oxygen. FDA's overall approach is to rely on chemical definitions of nutrients as the basis for regulatory definitions for food labeling. This was noted in FDA's proposal for the inclusion of stearic acid in the definition of saturated fat (2014b). FDA had received comments to exclude stearic acid from the definition of saturated fat because there is evidence indicating that stearic acid does not raise LDL-cholesterol levels or the risk of cardiovascular heart disease unlike saturated fat (2014b). However, FDA responded that "the definitions of nutrients for food labeling purposes have traditionally been based on chemical definitions, rather than individual physiological effects" (2014b). Thus, "added

sugars" will be a unique nutrient on the proposed food label because it will be not be chemically or physiologically different than the nutrient "sugars" listed on the current food label.

Because there are no chemical differences, current analytical methods cannot distinguish between added sugars and naturally occurring sugars in food. In food analysis, chromatographic methods can be used for qualitative analysis (identification) and quantitative analysis (amount) of sugars in food products. High performance liquid chromatography (HPLC) is the method of choice for the analysis of simple carbohydrates (mono- and disaccharides) (BeMiller 2003). Gas chromatography is another method that can be used, but in recent decades, it has been replaced by HPLC (BeMiller 2003). Neither of these analytical methods can distinguish whether the sugar was added to or naturally occurring in a food. Once again, "added sugars" will be unique in the fact that it will be the only nutrient on the proposed label not capable of analytical determination.

The lack of an analytical method will present challenges to determine compliance of added sugars values on the label under FDA 21 C.F.R. § 101.9 (2014a). Current FDA regulations state nutrition labeling compliance will be determined by "a composite of 12 subsamples that shall be analyzed by appropriate methods as given in the Official Methods of Analysis of the AOAC Intl. . . . if no AOAC method is available or appropriate, by other reliable and appropriate analytical procedures" (21 C.F.R. § 101.9 2014a). FDA acknowledges the fact in the proposal that they will not be able to rely on an analytical method to determine compliance with the declaration of added sugars in foods that contain both added sugars and naturally occurring sugars. As a result, FDA is proposing to require manufacturers to create and keep certain records necessary to verify the amount of added sugars present in a food that could be requested for review by the FDA (2014b). Overall, straying away from an analytical-based method to differentiate nutrients on the Nutrition Facts label will lead to challenges for implementation across the food industry and potentially inaccurate declaration of added sugars values.

No universal definition for added sugars

There is no universal definition for added sugars. Table 2 summarizes the various definitions of added sugars across organizations. Compounded by the fact there is no analytical method to determine the amount of added sugars, multiple definitions for added sugars can result in inconsistencies and misinterpretations by consumers, scientists, food manufacturers, ingredient suppliers, and regulators alike. This would be true for any nutrient not just for added sugars.

For example, FDA uses the term "added sugars" whereas the World Health Organization (WHO) uses the term "free sugars" (WHO 2015). WHO definition of "free sugars" includes fruit juices whereas the FDA definition of "added sugars" is limited to fruit juice concentrate (WHO 2015). This could create a challenge for food manufacturers that use international suppliers. An international supplier may mistake that "free sugars" and "added sugars" are identical and count any fruit juice in the formulation as added sugars, which would result in overdeclaring the amount of added sugars on the ingredient's nutrition information as proposed by the FDA regulations.

No added sugar claim and reconstituted fruit juice concentrates

Current FDA regulations do allow for a "no added sugar" claim under 21 FDA C.F.R. § 101.60 (2014a). Overall, the criteria for this claim and the proposed definition of added sugars are similar. However, there are some inconsistencies that can be emphasized with current food products making this claim, such as juices or other beverages.

According to the current regulations, foods bearing the "no added sugar" claim in food labeling must not contain an ingredient that is added during processing or packaging that is "sugar," as defined in FDA 21 C.F.R. §101.9 (2014a), or is an ingredient that contains sugars that functionally substitutes for added sugars. Sugars are defined in FDA 21 C.F.R. §101.9 (2014a) to mean "the sum of all free mono- and disaccharides (such as glucose, fructose, lactose, and sucrose), and examples of any other ingredient containing added sugars include jam, jelly, or concentrated fruit juice. FDA further clarified in the 1993 preamble to the final ruling that the mere presence in a food of an ingredient containing intrinsic sugars, such as fruit juice or concentrated juice, would not disqualify a food from bearing a "no added sugar" claim as long as the ingredient was not added to functionally substitute for added sugars (FDA 1993). For instance, the addition of a concentrate of the same juice, to achieve uniformity, or the addition of water to a juice concentrate, to produce a single strength juice, would not preclude the use of a "no sugar added" claim (FDA 1993).

Fruit juice concentrates are often preferred by food manufacturers for several reasons including sustainability, sourcing, and logistics. Essentially, it is a lower-cost ingredient than fruit juice, because removing the water from fruit significantly reduces the volume and weight of the product that must be shipped. Thus, a food manufacturer may purchase fruit juice concentrate and partially or fully reconstitute it back to single strength fruit juice as a step in the manufacturing of the finished product.

In FDA's proposal, fruit juice concentrates are considered added sugars whereas single strength fruit juice is not. This presents the important question whether a fruit juice concentrate that has been fully reconstituted back to juice would be considered added sugars under the proposal.

For example, a manufacturer is making a 100% apple juice product with apple juice concentrate and water. The ingredient apple juice concentrate contains approximately 39% sugar, and in order to make a 100% apple juice product with the minimum Brix level of 11.5 per FDA 21 C.F.R. § 101.31 (2014a), at least 29.5% of the apple juice concentrate is needed in the finished product formula. Because water is the only other ingredient used in the formula, all the sugar in the finished product is coming from the apple juice concentrate, and on an 8 fluid ounce serving size, the total sugars label at a rounded value of 29 g. Because the apple juice concentrate has been fully reconstituted back to single strength, the product qualifies for the current "no added sugar claim," but it could nonetheless be required to declare 29 g of added sugars on the label under the proposed rule because a fruit juice concentrate has been added during the processing of the finished product.

Thus, this example illustrates that it is imperative that the proposed definition of added sugars be consistent with the current "no added sugar" claim definition. Overall, the individual consuming the food with fruit juice or reconstituted fruit juice concentrate will be consuming the same amount of sugar from the same source, fruit (GMA 2014).

Functionality of added sugars

As discussed in the previous section, sugars are added to food for various reasons in addition to providing sweetness. Therefore, this poses the question on whether sugars added to food for

Table 2–Various added sugar definitions.

Organization	Definition	Exceptions
FDA 2014b	Sugars that are either added during the processing of food, or are packaged as such, and include sugars (free monosaccharides and disaccharides), syrups, naturally occurring sugars that are isolated from a whole food and concentrated so that sugar is the primary component (fruit juice concentrates), and other caloric sweeteners.	Sugar alcohols and naturally occurring sugars such as lactose in milk or fructose in fruits
IOM 2005	Sugars and syrups that are added to foods during processing or preparation. Specifically, added sugars include white sugar, brown sugar, raw sugar, corn syrup, corn-syrup solids, high-fructose corn syrup, malt syrup, maple syrup, pancake syrup, fructose sweetener, liquid fructose, honey, molasses, anhydrous dextrose, and crystal dextrose.	Naturally occurring sugars such as lactose in milk or fructose in fruits
WHO 2015	Free sugars refer to mono- and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices, and fruit juice concentrates.	Intrinsic sugars (incorporated within the structure of intact fruit and veggies) and sugars from milk (lactose)
AHA 2014	Added sugars include any sugars or caloric sweeteners that are added to foods or beverages during processing or preparation. Added sugars (or added sweeteners) can include natural sugars such as white sugar, brown sugar and honey as well as other caloric sweeteners that are chemically manufactured (such as high-fructose corn syrup).	Naturally occurring sugars found in foods such as fruit (fructose) and milk (lactose)
DGA 2010 (USDA and HHS 2010)	Caloric sweeteners that are added to foods during processing, preparation, or consumed separately.	Naturally occurring sugars such as lactose in milk or fructose in fruits
DGAC Technical Report 2015 (USDA and HHS 2015)	Used the same definition proposed by FDA (2014b).	

other reasons than sweetening should be considered added sugars. Under FDA 21 C.F.R. § 101.60 (2014a), one could argue it would be inappropriate to include sugars that are added to food for purposes other than sweetening as "added sugars" (GMA 2014). For example, some natural flavor preparations may analyze for a trace amount of sugars but their intended purpose is not to function as a sweetener but as a flavor enhancer. On the contrary, one could argue any substance with calories that can contribute to the sweetness of a product could be considered a "caloric sweetener" (General Mills 2014).

For yeast-leavened bread, the yeast prefers mono- or disaccharides (simple carbohydrates) over starch during fermentation (Poitrenaud 2004). Additional sugar is added during bread fermentation because the composition of flour is insufficient in mono- or disaccharides. If no sugar is added, then maltose from the starch must be degraded once the naturally present simple sugars in flour are exhausted. Not all yeast types can break down maltose without a lag adjustment, which results in a depression of gas production during the fermentation process (Poitrenaud 2004). Thus, the addition of a small amount of sugar (about 2% to 7%) is added to dough to increase the effectiveness of yeast during fermentation (Poitrenaud 2004). The added sugar acts as a temporary leavening agent, while being used by the yeast, causing the dough to rise at a quicker and more consistent rate.

As stated earlier, sugars such as dextrose or lactose are also used as a carrier for other ingredients because of their bulking properties. The sugars associated with these ingredients are incidentally added to the finished product with no intention of them to function as a sweetener. Isomaltulose and tagatose could be classified as sugars from a structural standpoint, and they are commonly used as bulking agents, like lactose, but are also used for their sweetness (Wilson 2007; Sentko and Bernard 2012). When comparing relative sweetness, both are sweeter than lactose (Table 1 and Table 6) and, therefore, a more accurate description of them is "bulk sweeteners" versus "bulking agents." However, they were not discussed in the FDA's proposal as added sugars, even though tagatose and isomaltulose could be added to a food product as a free monosaccharide or disaccharide, respectively. Perhaps FDA did not include these sugar-like compounds because they differ from a physiological standpoint when compared to a typical sugar. They do not promote tooth decay and have lower glycemic values compared to sugar (Sentko and Bernard 2012; Vastenavond and others 2012). Thus, they are more like sugar alcohols than typical sugars, so it brings up the question whether they should be considered "added sugars."

The various functionalities of added sugars become more evident with the other nutritive sweeteners that FDA classified as "added sugars" and multicomponent ingredients that can contain both inherent sugar and sugar added during processing. For some food products, fruit juice concentrates are added to food for the sole function of providing color, following section FDA 21 C.F.R. § 73.250 (2014a). Juice concentrates are also commonly used to adjust the Brix levels of directly expressed juice, and these juice concentrates are not required to be reflected in the common or usual name of such juices under FDA 21 C.F.R. § 102.33(2014a). Fruit and fruit puree ingredients that contain some sugar added during processing are often added to foods for several purposes, such as providing texture, flavor, nutrients, sweetness, or adjusting soluble solids (GMA 2014).

One example with fruit purees is applesauce that may be used as a substitution for oil in baked goods in order to reduce the fat content (GMA 2014). Applesauce exists in both sweetened and unsweetened forms. In both, there are inherent sugars from the apples, but in the sweetened form, there are also sugars added during processing. Both the inherent sugars and the added sugars may contribute to the sweetness of the product. In this case, the main functionality of the applesauce is an oil substitution, but because it may also contribute to sweetness, it brings up the question whether the sugars, inherent or added, in the applesauce should also be considered added sugars.

Conversely, sweetened condensed milk is added to dessert products for sweetness and flavor. Condensed milk is made from milk that has been heated to remove some of the water, and this evaporation of the water concentrates the inherent sugar (lactose) in the product (FDA 21 C.F.R. § 131.120 2014a). A nutritive carbohydrate sweetener such as sucrose is also added during its

Table 3–Summary of various labeled added sugars values based on different interpretations for a fruit-flavored soy-based yogurt alternative product

	Interpretation 1	Interpretation 2	Interpretation 3	Interpretation 4
Ingredient(s) considered added sugars	Sugar, fruit, soymilk, natural flavor, juice concentrate	Sugar, natural flavor, juice concentrate	Sugar	Sugar (fermentation loss from added sugars only)
Ingredient(s) excluded from added sugars calculation		Inherent sugar in soymilk and fruit	Inherent sugar in fruit and soymilk, natural flavor, juice concentrate	Inherent sugar in fruit and soymilk, natural flavor, juice concentrate
Added sugars (unrounded)[a]	22.78 g	22.1 g	21.92 g	21.22 g
Total sugars (unrounded)[b]	22.78 g	22.78 g	22.78 g	22.78 g

Interpretation one: The manufacturer interprets that any substance with calories that contributes to the sweetness of a product could be considered a "caloric sweetener."

Interpretation two: The manufacturer subtracts the inherent sugars from the soymilk and the blueberries from the added sugars value, but keeps the trace amount of sugars in the natural flavor and the fruit juice concentrate as added sugars.

Interpretation three: The manufacturer only counts the added sugars from the sweetened soymilk, the fruit blend, and the entire amount of cane sugar directly added in the formula. In this case, the manufacturer rationalizes that the functionality of the natural flavor and fruit juice concentrate is not for sweetening. The natural flavor is for flavoring, and the fruit juice concentrate is for coloring.

Interpretation four: The manufacturer is following the same rationale as Interpretation three, but also assumes that the cultures only metabolize the added sucrose versus the inherent sucrose in the soymilk.

[a] This is the unrounded figure in order to show the variation.
[b] This is the total with a 2 g fermentation sugar loss.

manufacture, hence, the name sweetened condensed milk (FDA 21 C.F.R. § 131.120 2014a). Thus, it contains a mixture of both inherent concentrated lactose sugar and added sucrose sugar. Given that sweetened condensed milk can substitute for added sugars in the finished product, it highlights whether the inherent lactose sugar, which has been concentrated similar to fruit juice concentrates, should also be considered as "added sugars" in addition to the added sucrose. This is further complicated when the manufacturer adds water in conjunction with the sweetened condensed milk in any finished product. Then the water would fully or partially reconstitute the concentrated lactose.

In summary, depending on how a food manufacturer interprets the definition and the functionality of the "added sugars" in the product, various added sugars values could be declared on the label. FDA not only needs to specify the functionality of added sugars in the definition but may need to specify the physiological characteristics as well.

Some sweeteners are not 100% sugars

FDA's proposed definition includes syrups, honey, and molasses as "added sugars," but these sweeteners are not 100% sugars. They are always mixtures of sugars and water, and some of them also include other nutrients or substances. For instance, molasses naturally contains high levels of vitamins and minerals, such as calcium, potassium, iron, and B vitamins (Varzakas and others 2012). Figure 2 summarizes the amounts of water, sugars, and other substances in these types of sweeteners. Thus, the "added sugars" definition should be clarified further that the sugars in syrups, honey, molasses, and similar products should be considered on a dry weight basis ensuring that the contribution of the sugars in these foods is represented accurately (GMA 2014).

Ingredient supplier complications

The lack of an analytical method for added sugars not only causes challenges for the FDA but for food manufacturers as well. Food manufacturers would need access to certain records or information from ingredient suppliers in order to determine the finished product added sugars values. This could be challenging for food manufacturers that use hundreds, or many more, of ingredients. Some ingredient suppliers are small and do not have the current databases or resources to provide this information immediately. Furthermore, suppliers may not want to overshare information, due to proprietary reasons, because there is the potential risk of formula information getting in the hands of competitors. Besides these issues, ingredient suppliers can also interpret the definition of added sugars differently. As stated earlier, this becomes evident with multi-component ingredients and other functional uses of added sugars in ingredients. For example, a supplier may provide an ingredient that contains multiple components, such as honey, fruit juice concentrates, and fruit puree with intrinsic and added sugars. Depending on how the definition is interpreted, the supplier may consider all of these components as "added sugars" or may only consider some of them as "added sugars." These different interpretations along with minor differences in calculations, compounded by rounding-off numbers, can result in a variety of declared values for added sugars. Thus, this could be a time-consuming process for food manufacturers and ingredient suppliers to agree on an added sugars value for an ingredient.

Complexity of chemical reactions

There are significant difficulties calculating the added sugars in products subjected to fermentation, carmalization, and Maillard reactions. These reactions metabolize or transform sugars into other compounds that are no longer detectable as sugars through conventional analytical methods (Perez-Locas and Yaylayan 2010). FDA acknowledges these complications from these reactions and requested more information from manufacturers of such products. The FDA (2014b) does not have adequate data to assess the degradation themselves.

Yeast-leavened bread shows all 3 reactions during breadmaking, and the American Bakery Association in its comments to FDA's proposal responded that it would be extremely difficult to calculate the reduction in added sugars in yeast-leavened products with both naturally occurring and added sugars. As discussed earlier, additional sugars are added for improved fermentation because the inherent composition of flour is insufficient in mono- or disaccharides. This fermentation process in yeast-leavened bread is influenced by several "factors including but not limited to, variations within ingredients (such as yeast activity and flour quality), ingredients (such as the type and/or amount of sugar, salt, malt, vinegar, spices, and other components), varying types of fermentation systems (water brews, flour brews, sponge and dough, straight dough), and variation in make-up and proof times and temperatures" (American Baking Association 2014). Besides

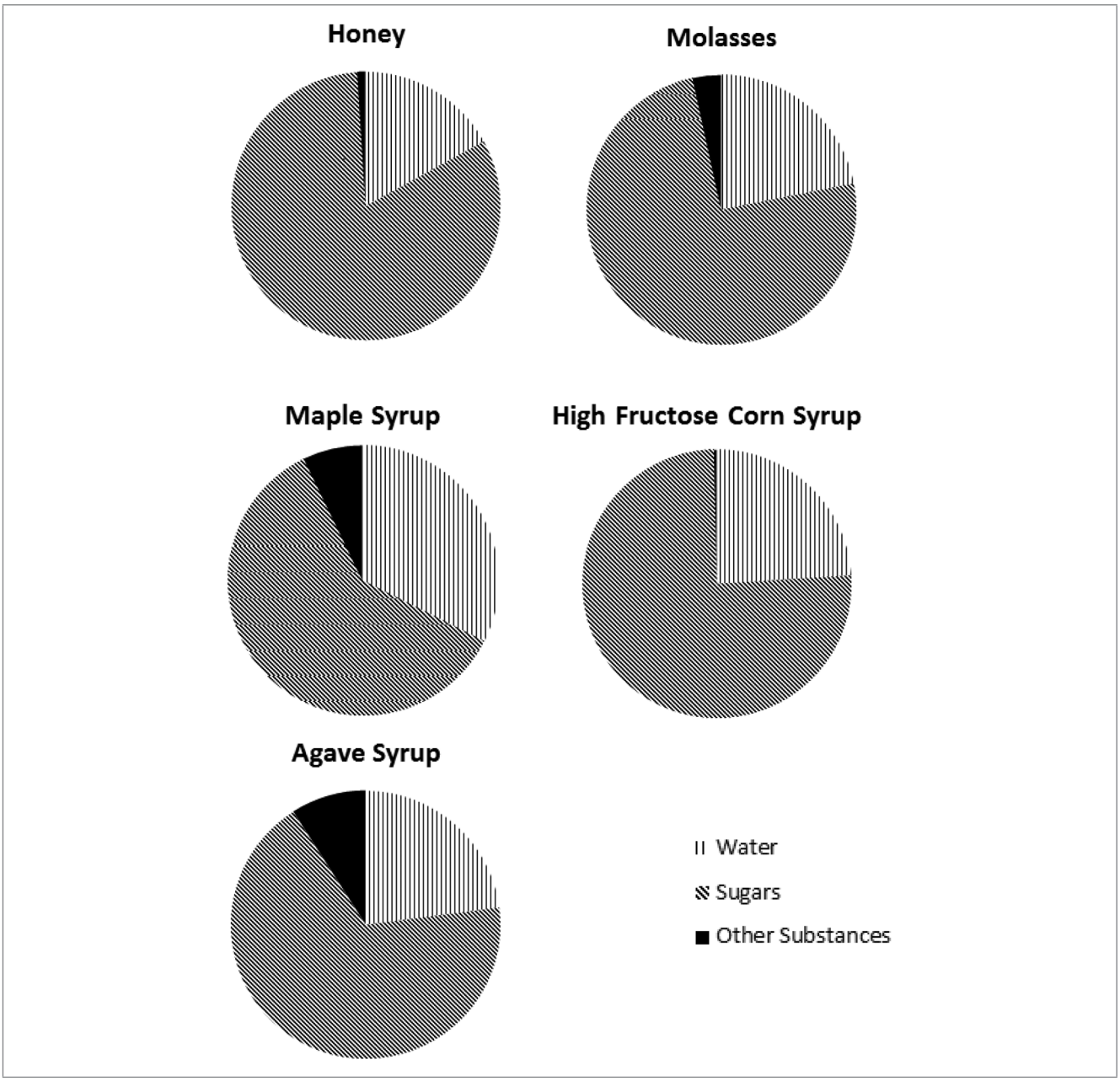

Figure 2–Composition of different sweeteners (USDA Natl. Nutrient Database for Standard Reference 2014).

sugar loss during fermentation, sugars can also disappear during the baking process through caramelization and Maillard reactions, which cause the browning of the crust in bread (Purlis 2010).

Other fermented products, such as yogurts, are another example that may have potential challenges quantifying the amount of added sugars lost during fermentation. The bacteria cultures required by the yogurt standard of identity, *Lactobacillus, bulgaricus*, and *Streptococcus thermophilus*, prefer the naturally occurring lactose in the milk during fermentation. In regular, unsweetened milk, it naturally contains about 5% lactose sugar, and some of the lactose is metabolized to 1.2% to 1.4% lactic acid, which results in the pH drop in yogurt (Tamime and Robinson 1999; Gürakn and Altay 2010). However, *S. thermophilus* also has the capability to metabolize sucrose (Nauth 2004), and in the production of yogurt, manufacturers can add sucrose (dry or liquid) to the milk blend before it is fermented. Studies with fermented soymilk utilizing similar cultures as in dairy yogurt have confirmed this, showing that *S. thermophilus* is well able to grow in soy beverages because of its ability to use sucrose, which occurs naturally in soymilk (Garro and others 1999; Farnworth and others 2007). In addition to the required cultures, according to the yogurt standard identity, other optional cultures can be incorporated via the starter culture in the yogurt, such as *Lb. acidophilus* or *Lb. casei*. Both of these cultures are capable of metabolizing sucrose as well (Nauth 2004). Thus, depending on the types of cultures and milk used to produce a yogurt-like product compounded with processing variability, the amount of added sugars consumed during fermentation will vary, and more studies are needed in these types of products in order to understand the complexities of added sugars loss during fermentation.

Without an analytical test to distinguish added sugars from those naturally occurring in food, manufacturers will not be able to discern where the sugar loss is occurring as result of these reactions. These chemical reactions depend on several variables, which are unique to each formula and process, and it would be impossible to come up with a standard equation that could be applied across each similar food product. Therefore, it would be a time-consuming process to research each unique product formula, and manufacturers may resign themselves to declaring all added sugars without a reduction from these reactions, thereby resulting in an overstatement of the amount of added sugars in these products.

Fruit-flavored soy-based yogurt alternative case study

The following is a case study summarizing the complexities and challenges of labeling added sugars in a fruit-flavored soy-based yogurt alternative. A typical ingredient deck for this type of food product is below, and the ingredients underlined could be or could not be considered "added sugars" depending on the various interpretations of FDA's proposed definition. This example also highlights the impact of fermentation. Table 3 summarizes the interpretations and how different added sugars labeled values could be derived for the same product.

Ingredients: cultured pasteurized *soymilk*, *cane sugar*, *blueberries*, pectin, calcium carbonate, *elderberry juice concentrate* (for color), *natural flavor*.

In this particular case, the manufacturer is receiving a sweetened plain soymilk with sucrose. According to the USDA database (2014), an unsweetened plain soymilk naturally contains 1 g of sucrose per cup (243 g). The serving size of the soy yogurt is 6 oz (170.1 g). The formula assumptions of the finished product are listed in Table 4, and the amount of sugar from each ingredient was determined by using the USDA database (2014). The amount of sugar lost as a result of fermentation was estimated to be 2 g (Farnworth and others 2007).

Issues with Replacing Added Sugars

Sugar (sucrose) has several functional properties in food, which makes it challenging to replace. No other sweetener has been developed to duplicate all of its functional properties. Thus, it is imperative to understand how the sugar is functioning in a particular food product before replacing it. Other nutritive sweeteners, such as honey, high-fructose corn syrup, or fruit juice concentrates, have been used in the past. However, because nutritive sweeteners are considered added sugars, more manufacturers will be looking at using nonnutritive sweeteners to replace sugar in their products.

Synergistic relationship of nonnutritive sweeteners and bulking agents

Nonnutritive sweeteners are also called high-intensity sweeteners because of their very intense sweetness compared to sucrose. Sucrose is given an arbitrary sweetness level of 1 to allow its comparison with other sweeteners (Table 5). Given their intense sweetness, nonnutritive sweeteners are used in small amounts in food products, and as stated earlier, many are not completely metabolized by the body. Both of which explain why nonnutritive sweeteners do not provide calories like sugar. Because of their low usage levels, something else needs to replace the reminder of the missing sugar amount in the product, and this is where bulking agents or bulk sweeteners come into play.

This is similar technology that is utilized to replace fat in products. Fat, like sugar, provides bulk, mouthfeel, and texture to food products. Without the use of bulking agents, food products would not be appealing to the consumer. For example, if sugar is removed from bran cereal, it would have the consistency of sawdust (Varzakas and others 2012).Bulking agents can provide some sweetness but their primary function is providing bulk (Wilson 2007). Table 6 lists some common bulking agents, and their relative sweetness is below that of sucrose with some even at 0. It is important to find bulking agents that can work synergistically with nonnutritive sweeteners.

Other functional considerations

Besides the lack of bulk, there are other functional issues that will need to be addressed when replacing sugar in food products. One of the key issues is taste. Nonnutritive sweeteners may have a bitter, metallic, and licorice aftertaste (Varzakas and others 2012). Blends of various nonnutritive sweeteners can be used to mask these off-flavors and improve the sweetness profile of food products. These blends make use of sweetener synergy where the sweetness intensity of the blend is greater than the total sweetness of the individual components (Wilson 2007). The use of flavor technology is another area that can be utilized to help address these undesirable aftertastes as the result of using nonnutritive sweeteners.

As mentioned earlier, ingredients that are used as fat-replacers can also be utilized in replacing sugar in food products. This is why some of the bulking agents listed in Table 6, such as maltodextrins and polydextrose, can also be used as fat-replacers. Other ingredients, which may be used when replacing sugar or fat in a product, include starches, modified starches, cellulose, guar gum, gelatin, and carrageenan. They are used to modify the physical properties of food, such as acting as a thickener, to help replace the structural characteristics that were originally contributed by sugar or fat. Thus, they are utilized for the same reasons as bulking agents to help improve the mouthfeel of the product. However, these ingredients must be chosen carefully because they can affect the flavor and viscosity of the product. Some have shown to reduce the perceived sweetness of a product (Spillane 2006). Thus, the sweetener blend may need to be modified, such as increasing the level. Others, such as cellulose, have caused the products to become too viscous with a gummy mouthfeel (Varzakas and others 2012).

Another consideration is whether the sugar is participating in any chemical reactions, such as the Maillard reaction in baked goods. In this case, the brown color as the result of this reaction is important to the finished product. Some of the nonnutritive sweeteners may be capable of participating in the Maillard reaction but cannot produce the brown color due to their low usage levels (Kitts 2010). Furthermore, all sweetness is lost if they do participate in the reaction (Varzakas and others 2012). Therefore, it is important to select the right nonnutritive sweetener and a bulking agent that could participate in the reaction versus the sweetener. Finally, there is no known nonnutritive sweetener that can participate in caramelization (Varzakas and others 2012).

Replacing sugar in a product is a trial and error process given all the functional properties that sugar can contribute. Each product formula is unique and one size does not fit all. For example, a study was done to evaluate the effects of fat and sugar replacements in cookies, and one of the combination ingredients was polydextrose as the fat mimetic and maltitol as the sugar substitute (Zoulias and others 2002). The use of these ingredients resulted in very hard and brittle cookies, and the study concluded that the textural properties were improved by either decreasing the amount of alternative

Table 4–Formula assumptions for fruit-flavored soy-based yogurt alternative case study.

Ingredient	% of Finished product	Grams per serving size (170.1 g)		
		Inherent	Added	Total
Sweetened plain soymilk	80	0.7	3.5	4.2
Cane sugar	10		17	17
Blueberry fruit blend (50% fruit and 20% sugar)	8	0.678	2.72	3.398
Pectin	1			0
Calcium carbonate	0.5			0
Elderberry juice concentrate	0.3			0.1
Natural flavor	0.2			0.08
Total	100			24.778[a]

[a] This is the total before the 2 g are subtracted for fermentation.

Table 5–Nonnutritive sweeteners comparison to sucrose at relative sweetness 1.

Nonnutritive sweetener	Relative sweetness	kcal/g	Source	Aftertaste	Reference
Aspartame	160–220	4	Synthetic	Prolonged sweetness	Varzakas and others 2012
Acesulfame K	150–200	0	Synthetic	Very slightly bitter	Varzakas and others 2012
Sucralose	400–800	0	Synthetic	Not unpleasant	Varzakas and others 2012
Saccharin	300—600	0	Synthetic	Bitter, metallic	Varzakas and others 2012
Steviol Glycosides	200-300	0	Plant	Bitter, unpleasant	Varzakas and others 2012
Glycyrrhizin	50–100	0	Plant	Prolonged sweetness, licorice	Varzakas and others 2012
Neohesperidin dihydrochalcone	1000–2000	2	Semis-synthetic	Lingering menthol-licorice	Varzakas and others 2012
Neotame	7000–13000	0	Synthetic	Not unpleasant	Varzakas and others 2012
Thaumatin	2000	4	Plant	Licorice	Varzakas and others 2012
Cyclamate[a]	30–40	0	Synthetic	Prolonged sweetness	Varzakas and others 2012

[a] Banned in the United States due to controversial toxicity studies but permitted in other countries (EU, Australia, Canada, New Zealand).

Table 6–Bulking agents comparison to sucrose at relative sweetness 1.

Bulking agent	Relative sweetness	kcal/g	Reference
Xylitol	1	2.5	Varzakas and others 2012
Maltitol	0.75	2.7	Varzakas and others 2012
Erythritol	0.7	0.2	Varzakas and others 2012
Sorbitol	0.60	2.5	Varzakas and others 2012
Mannitol	0.60	1.5	Varzakas and others 2012
Isomalt	0.55	2.1	Varzakas and others 2012
Lactitol	0.35	2	Varzakas and others 2012
Hydrogenated starch hydrolysates	0.4–0.9	2.4–3.0	Deis 2012; Varzakas and others 2012
Polydextrose	0	1	Varzakas and others 2012
Isomaltulose	0.48	4	Sentko and others 2012; Varzakas and others 2012
Tagatose	0.92	1.5	Vastenavond and others 2012
Maltodextrin (depends on DE value)	0.1–0.2	1–3.8	Varzakas and others 2012
Fructooligosaccharides	0.3–0.6	2	Gwinn 2013
Inulin	0	1	Gwinn 2013

sweetener or increasing the concentration of fat mimetic in the gel which was added to the cookies. Thus, it can be a costly and lengthy process to find the right ingredients, the correct amounts, and manufacturing parameters to create similar-quality products without sugar. In the end, it is not possible to match exactly the same quality characteristics of the nutritive sweetener-containing counterparts, and the consumers will ultimately decide what they find acceptable.

Calorie reduction may not be achieved

The driving force of replacing added sugars in a product is to reduce the calories. However, in some cases, calorie reduction may be insignificant or may even increase. When sugar is removed, it generally must be replaced with something else, so that the bulk of the product is not affected. As stated earlier, this is why bulking agents are utilized. However, these bulking agents usually provide energy because they are carbohydrate-based (Table 6).

Isomaltulose is a prime example. As discussed earlier, it is a disaccharide-type carbohydrate that could be classified as a sugar, but it is not a typical sugar from a physiological point of view (Wilson 2007). Isomaltulose is completely absorbed by the small intestine, thus providing the same calorie value as sucrose at 4 kcal/g (Wilson 2007). Other bulking agents, such as maltodextrins or hydrogenated starch hydrolysates, can still contribute above 3 kcal/g, so that calorie reduction may be insignificant in the final product (Deis 2012; Varzakas and others 2012). Depending on the functionality needs in the product, using lower or noncaloric bulking agents may not be an option.

In one particular instance, a sugar-free baking batter was formulated using an increased level of flour and water, a hydrogenated starch hydrolysate (Hystar® 5875), and the nonnutritive sweetener aspartame (Wallin 1996). The hydrogenated starch hydrolysate Hystar® 5875 that was used had about 4 kcal/g of solids, and the flour of the product was increased, which contributes 4 kcal/g as well. Thus, the total calorie content of the product was not significantly reduced, but it was essentially free of added sugars.

Besides adjusting a carbohydrate-based ingredient, such as flour or starch, fat is another option to replace bulk and mouthfeel of

the product. Fat contributes 9 kcal/g. Thus, the calorie reduction of the total product may be negated or even increased depending on how much of the fat is used in the product. One study developed a cookie dough with acesulfame-K instead of sugar and polydextrose as a bulking agent (Bullock and others 1992). Nutrient analysis revealed that calorie reduction in the formulation was rather insignificant(less than 10%), because the fat proportion increased in the end product. This sugar-fat seesaw effect has also been shown through a systematic review of dietary intake studies for countries with cultural similarities: United Kingdom, Ireland, other European countries, United States, and Australia (Sadler and others 2014). This review demonstrated there is a strong and consistent inverse association between total sugars and total fat intakes expressed as percentage energy. Thus, multiple guidelines in regards to fat and sugar may be difficult to achieve in practice at the population level and may not result in the calorie reduction as intended.

Other concerns with added sugars replacements

Another main hurdle that manufacturers will face with replacing added sugars in products is the consumer movement for "cleaner" labels and "natural" ingredients. As discussed earlier, several ingredients may need to be added, such as multiple high-potency sweeteners, fat, bulking agents, thickeners, and flavoring, in order to replace one ingredient (sugar). Thus, the numbers and amount of food additives on the food label will increase, which will be viewed negatively by some consumers. Some of these ingredients are produced synthetically or via chemical modification. Thus, they would not be considered "natural." In some cases, consumers may prefer naturally occurring nutritive sweeteners such as honey. Even though honey consists mainly of sugars, it also provides vitamins, minerals, and antioxidants (Varzakas and others 2012), which may be regarded more positively compared to other sweeteners by some consumers. These consumers like that they understand what the ingredient is and where it is coming from.

There may also be general public health concerns in regards to the food technology used to replace added sugars. Commonly used nonnutritive sweeteners to replace sugars are artificial sweeteners, such as aspartame, acesulfame K, sucralose, and saccharin. There is a public perception that artificial sweeteners are unsafe to consume. This is mainly driven by animal studies conducted in the 1970s that linked saccharin to cancer (Intl. Food Information Council [IFIC] 2003). However, those studies used extremely high doses compared to what is normally consumed in the human diet, and several epidemiological studies since then have been carried out showing no link between cancer and saccharin consumption (IFIC 2003). Yet, the public perception that artificial sweeteners can cause cancer still remains today.

Another health concern with the artificial sweetener aspartame is that it contains phenylalanine. Certain individuals (with a genetic disorder) lack the enzyme phenylalanine hydroxylase (PAH) to metabolize phenylalanine. This accumulation of phenylalanine, which is further converted to phenylpyruvate, can cause serious damage in brain development (Varzakas and others 2012). As a result of this health risk, products that contain aspartame must have a warning label stating that it contains phenylalanine (FDA 21 C.F.R. § 172.804 2014a). Besides products with aspartame carrying a warning label, some products containing sugar alcohols also need one stating that excessive consumption can have a laxative effect (FDA 21 C.F.R. §§ 180.25, 184.1835 2014a).

Like fat, salt may also be increased in foods with reduced or replaced sugar contents. It has been known for some time that the additions of salt and sugar work synergistically to increase the intensity of sweetness (Kilcast and Ridder 2008). Thus, it is a potential tool for manufacturers to increase salt in order to increase the sweetness of the product to compensate for the reduction of sugar. Nonetheless, salt is a nutrient of concern given its link to cardiovascular diseases (Dötsch and others 2009). In a sense, replacing sugar or reducing sodium in a product can become a "lesser of 2 evils game."

The effectiveness of nonnutritive sweeteners

The theory behind replacing added sugars is to reduce calories which, consequently, could lead to weight loss. Nonnutritive sweeteners can help achieve the similar sweetness characteristics as sweetened foods without adding calories. However, in the recent release of the Scientific Report of the 2015 Dietary Guidelines, the advisory committee cited that there is insufficient evidence to recommend the use of nonnutritive sweeteners as an effective strategy for long-term weight loss and weight maintenance and that added sugars should not be replaced with nonnutritive sweeteners in foods and beverages (USDA and HHS 2015). This could be related to the fact that calorie reduction in the total product is ultimately not reduced or that consumers use it as an excuse to ingest calories in other forms. Yet, nonnutritive sweeteners in conjunction with bulking agents are the most effective strategies to replace added sugars in the food industry as of now. It is very unlikely that there will be many new sugar replacers developed over the next decade. The time and cost of development alone and the regulatory hurdles for new food ingredients will inhibit their speed to market (Spillane 2006).

The Effectiveness of Labeling Added Sugars

Obesity is growing at an alarming rate in the United States, and added sugars are being targeted by governmental regulatory agencies in an attempt to reduce the calorie intake of the population. FDA's theory is that labeling added sugars will assist consumers to identify foods that are nutrient-dense and to reduce calorie intake from added sugars by decreasing their consumption (FDA 2014b). Yet, it is not clear that the labeling of added sugars will benefit consumers.

Consumer confusion with proposed label

The IFIC conducted a national survey of adult U.S. consumers to investigate consumer understanding of the "added sugars" declaration on the proposed label. Consumers were shown 3 Nutrition Facts panels for the same food product. Version S was in the proposed format panel with the "Sugars" designation as shown in the current Nutrition Facts panel. Another version, Version S+A, was the exact format in FDA's proposal with the "Sugars" designation and "Added Sugars" as a subgroup designation. The third version, Version TS+S, matched Version S+A except that the "Sugars" designation included the word "Total" in front of it. When asked to report the total amount of sugars in the product, 92% answered correctly with version S, but only 55% answered correctly with version S+A (IFIC 2014).

IFIC (2014) research also demonstrated that consumer understanding of the "Added Sugars" line varies with 19% of consumers stating that they did not know what it means. This was further exemplified when consumers were given a list of 23 types of nutritive and nonnutritive sweeteners and asked to indicate which would be included in the "Added Sugars" line on the Nutrition Facts panel. Over one-third of respondents indicated that nonnutritive sweeteners would be considered added sugars: Sweet 'n Low (39%),

Splenda (38%), Aspartame (35%), and Stevia (34%) (IFIC 2014). In summary, this study showed that the most useful terminology for consumers is "total sugars," and consumer education will be key to ensure proper understanding of added sugars.

Food sources of added sugars

In the Scientific Report of the 2015 Dietary Guidelines, food sources of added sugars were broken down by categories. Beverages, excluding milk and 100% fruit juice, accounted for 47% of added sugars consumption (USDA and HHS 2015). In these types of beverage products, the current total sugars declaration reflects the amount of added sugars because virtually all the sugar is added. The food categories dairy and grains, for which labeling added sugars will be more of a challenge, only accounted for 4% and 8% of added sugars consumption, respectively (USDA and HHS 2015). These categories included the yeast-leavened and fermented products, which transform added sugars into other compounds via chemical reactions. Again, these chemical reactions depend on several variables which are unique to each formula and process, and it will be a time-consuming process to research each unique product formula to understand the amount of added sugars lost. These categories also provide other nutrients besides added sugars, such as vitamin D, calcium, dietary fiber, B vitamins, whole grain, and iron. The category snacks and sweets provided 31% of added sugars consumption (USDA and HHS 2015). These included desserts, such as cakes, cookies, and chocolate, and these types of products may also have a challenge in labeling the exact amount of added sugars due to the Maillard and caramelization reactions. However, one could reason that consumers understand and consume these types of products as indulgent treats in their diet. Thus, consumers are enjoying these types of products for pleasure and not for their nutritional value.

Added sugars and link with public health concerns

FDA did not provide a daily recommended value (DRV) for added sugars consumption. The reason for excluding a DRV is that there is no sound scientific evidence for the establishment of a quantitative intake recommendation for which a DRV for added sugars can be derived (FDA 2014b). Policy decisions must be based on scientific evidence, and in the case of added sugars, the scientific evidence that decreasing added sugars intake will decrease the risk of obesity and other diseases is neither complete nor perfect.

Yet, the Scientific Report of the 2015 Dietary Guidelines Advisory Committee urges FDA that added sugars should be labeled and a DRV should be established. Their recommendation is limiting added sugars to a maximum of 10% of total daily caloric intake based on strong evidence that limiting added sugars intake will reduce health risks, such as excessive body weight and type II diabetes (USDA and HHS 2015). However, when reviewing the sources cited in the report, most of the systemic reviews and meta-analyses focused on sugar-sweetened beverages. As discussed earlier, the total amount of sugars would be the same as the amount of added sugars in these types of products. More studies are needed with food, especially food with both naturally occurring sugars and added sugars, to determine if "added sugars" is directly linked to negative health outcomes or whether it is an outcome of excessive calorie consumption.

The etiology of obesity is complex, and confounding factors, such as total energy intake, BMI, sex, age, physical activity, ethnicity, and family culture can contribute to weight gain. Thus, focusing on a single nutrient, as in this case of added sugars, will not completely solve the obesity issue. Even though the research is mixed, the overall consensus is that balancing total energy intake with calorie expenditure is the best approach to prevent weight gain (Marriott and others 2010; Jebb 2014). Foods containing added sugars do not contribute to weight gain any more than another calorie source (Van Baak and Astrup 2009; Gibson and others 2013). Finally, sugar consumption is already decreasing in the United States without added sugars being on the Nutrition Facts label (USDA and HHS 2015; Wittekind and Walton 2014).

Cost of implementation

Labeling added sugars will result in additional costs for ingredient and food manufacturers. A partnership between manufacturers and suppliers will be needed to ensure that the added sugars definition is interpreted consistently, so that the sources of added sugars are identified and reported correctly. In addition, a plan for record-keeping requirements and database updates will need to be implemented by the food industry because there is no analytical method to distinguish between naturally occurring and added sugars in food products. This record-keeping will be more taxing for food products that add sugar for other reasons besides sweetening and contain both inherent and added sugars, and further research will be needed to understand the added sugars loss as a result of chemical reactions in certain types of food products. Ultimately, this additional cost will be passed on to the consumer.

Conclusion

Labeling "added sugars" will have its challenges in the food industry, and it is not clear that it will benefit the consumer either. The scientific evidence linking added sugars intake to obesity and other diseases is neither complete nor perfect. Overall, the public health recommendations about "added sugars" must be balanced with the reality that sugar added to food is an important piece in the food science puzzle given its several functionalities in food. Not only can a spoonful of sugar help the medicine go down, but it can help fruits, vegetables and fiber go down as well.

Acknowledgment

Kara R. Goldfein held employment at General Mills while writing this article.

Authors' Contributions

Kara R. Goldfein wrote the article under the supervision of Joanne L. Slavin.

References

American Baking Association. 2014. Comment. Food labeling: revision of the nutrition and supplement facts labels. Proposed rule.

American Heart Association [AHA]. 2014. Sugar 101. Nutrition basics-sugar. Available from http://www.heart.org/HEARTORG/GettingHealthy/NutritionCenter/HealthyEating/Sugar-101_UCM_306024_Article.jsp. Accessed 2015 March 23.

BeMiller JN. 2003. Carbohydrate analysis. In: Nielsen S, editor. Food analysis. New York: Springer. p. 150–4.

Bullock LM, Handel AP, Segall S, Wasserman PA. 1992. Replacement of simple sugars in cookie dough. Food Technol 1:82–6.

Carakostas M, Prakash I, Kinghorn AD, Wu CD, Soejarto DD. 2012. Steviol glycosides. In: Nabors L, editor. Alternative sweeteners. Boca Raton, FL: CRC Press. p. 159–80.

Danehy J, Wolnak B. 1983. Maillard technology: manufacturing applications in food products. In: Waller G, editor. The Maillard reaction in foods and nutrition. Washington, DC: American Chemical Society. p. 303–15.

Deis RC. 2012. Maltitol syrups and polyglycitols. In: Nabors L, editor. Alternative sweeteners. Boca Raton, FL: CRC Press. p. 265–75.

Dötsch M, Busch J, Batenburg M, Liem G, Tareilus E, Mueller R, Meijer G. 2009. Strategies to reduce sodium consumption: a food industry perspective. Crit Rev Food Sci Nutr 49:841–51. doi:10.1080/10408390903044297.

Farnworth E, Mainville I, Desjardins M, Gardner N, Fliss I, Champagne C. 2007. Growth of probiotic bacteria and bifidobacteria in a soy yogurt formulation. Int J Food Microbiol 116:174–81. doi:10.1016/j.ijfoodmicro.2006.12.015.

Finkelstein E, Trogdon JG, Cohen JW, Dietz W. 2009. Annual medical spending attributable to obesity: payer- and service-specific estimates. Health Aff 28:w822–31. doi:10.1377/hlthaff.28.5.w822.

Food and Drug Administration [FDA]. 1993. Food labeling: Nutrient content claims, general principles, petitions, definition of terms; definitions of nutrient content claims for the fat, fatty acid, and cholesterol content of food, 58 Fed. Reg. 2326-8 (Jan. 6, 1993) (to be codified at 21 C.F.R. pt. 101).

Food and Drug Administration [FDA]. 2014a. 21 C.F.R. §§ 73.250, 101.9, 101.30, 101.60, 102.33, 131.120, 172.804, 180.25, 184.1835 (2014).

Food and Drug Administration [FDA]. 2014b. Food labeling: Revision of the nutrition and supplement facts labels. 79 Fed. Reg. 11902-8 (proposed Mar. 3, 2014) (to be codified at 21 C.F.R. pt. 101).

Garro MS, deValdez GF, Oliver G, deGiori GS. 1999. Starter culture activity in refrigerated fermented soymilk. J Food Prot 62:808–10.

General Mills. 2014. Comment. Food labeling: revision of the nutrition and supplement facts labels. Proposed rule.

Gibson S, Gunn P, Wittekind A, Cottrell R. 2013. The effects of sucrose on metabolic health: a systematic review of human intervention studies in healthy adults. Crit Rev Food Sci Nutr 53:591-614. doi:10.1080/10408398.2012.691574.

Grocery Manufacturers Association [GMA]. 2014. Comment. Food labeling: Revision of the nutrition and supplement facts labels. Proposed rule.

Gürakn GC, Altay N. 2010. Yogurt microbiology and biochemistry. In: Yildiz F, editor. Development and manufacture of yogurt and other functional dairy products. Boca Raton, FL: CRC Press. p. 97–116.

Gwinn R. 2013. Technology and ingredients to assist with the reduction of sugar in food and drink. Available from: http://www.foodhealthinnovation.com/media/8821/industry-position-papers-technologies-to-reduce-sugar.pdf. Accessed 2014 October 25.

Hess J, Latulippe ME, Ayoob K, Slavin J. 2012. The confusing world of dietary sugars: definitions, intakes, food sources and international dietary recommendations. Food Funct 3:477–86. doi:10.1039/c2fo10250a.

Hwang IG, Kim HY, Woo KS, Lee J, Jeong HS. 2011. Biological activities of Maillard reaction products (MRPs) in a sugar-amino acid model system. Food Chem 126:221–7. doi:10.1016/j.foodchem.2010.10.103.

Inst. of Medicine [IOM]. 2005. Dietary reference intakes for energy, carbohydrates, fiber, fat, fatty acids, cholesterol, protein and amino acids. Washington, DC: The National Academies Press.

Intl. Dairy Foods Association [IDFA]. 2014. Comment. Food labeling: Revision of the nutrition and supplement facts labels. Proposed rule.

Intl. Food Information Council [IFIC]. 2003. Low-calorie sweeteners and health. IFIC review. Available from: http://www.foodinsight.org/Content/76/Low-Calorie-Sweeteners-and-Health.pdf. Accessed 2015 March 23.

Intl. Food Information Council [IFIC]. 2014. Consumer investigation into nutrition facts panels and sugars labeling. Available from http://www.foodinsight.org/sites/default/files/IFIC Foundation Preliminary NFP Survey. Accessed 2014 October 25.

Jebb SA. 2014. Carbohydrates and obesity: from evidence to policy in the UK. Proceedings of the Nutrition Society; Univ. of Glasgow, 14–17 July 2014. Cambridge University Press. doi:10.1017/S0029665114001645

Kilcast D, Ridder CD. 2008. Challenges to reducing sugar in foods. In: Weerasinghe D, editor, Sweetness and sweeteners. Washington DC: American Chemical Society. American Chemical Society. p. 481–91.

Kitts DD. 2010. Sucrose: from field to table. Carbohydrate news. Available from: http://www.sugar.ca/SUGAR/media/Sugar-Main/News/CarboNews2010.pdf. Accessed 2015 March 23.

Kroh L. 1994. Caramelisation in food and beverages. Food Chem 51:373–9. doi:10.1016/0308-8146(94)90188-0.

Marriott BP, Olsho L, Hadden L, Connor P. 2010. Intake of added sugars and selected nutrients in the United States, Natl. Health and Nutrition Examination Survey (NHANES) 2003–2006. Crit Rev Food Sci Nutr 50:228–58. doi:10.1080/10408391003626223.

Nauth KR. 2004. Yogurt. In: Hui Y, Meunier-Goddik L, Hansen A, Josephsen J, Nip W, Stanfield PS, Toldrá F, editors. Handbook of food and beverage fermentation technology. New York: Marcel Dekker. p. 125–47.

Ogden CL, Carroll MD, Kit BK, Flegal KM. 2014. Prevalence of childhood and adult obesity in the United States, 2011–2012. JAMA 311:806–14.

Pareyt B, Delcour JA. 2008. The role of wheat flour constituents, sugar, and fat in low-moisture cereal-based products: a review on sugar-snap cookies. Crit Rev Food Sci Nutr 48:824–39. doi:10.1080/10408390701719223.

Perez-Locas C, Yaylayan VA. 2010. The Maillard reaction and food quality deterioration. In: Skibsted LH, Risbo, JA, Morgens L, editors. Chemical deterioration and physical instability of food and beverages. Boca Raton, FL: CRC Press. p. 70–94.

Poitrenaud B. 2004. Baker's yeast. In: Hui Y, Meunier-Goddik L, Hansen A, Josephsen J, Nip W, Stanfield PS, Toldrá F, editors. Handbook of food and beverage fermentation technology. New York: Marcel Dekker. p. 695–721.

Purlis E. 2010. Browning development in bakery products—a review. J Food Eng 99:239–49. doi:10.1016/j.jfoodeng.2010.03.008.

Sadler MJ, McNulty H, Gibson S. 2014. Sugar-fat seesaw: a systematic review of the evidence. Crit Rev Food Sci Nutr 55:338–56. doi:10.1080/10408398.2011.654013.

Sentko A, Bernard J. 2012. Isomaltulose. In: Nabors L, editor. Alternative sweeteners. Boca Raton, FL: CRC Press. p. 423–39.

Slavin J. 2014. Two more pieces to the 1000-piece carbohydrate puzzle. Am J Clin Nutr 100:4–5. doi:10.3945/ajcn.114.090423.

Slavin J, Carlson J. 2014. Carbohydrates 1. Adv Nutr 4:696–733. doi:10.3945/an.114.006163

Spillane WJ. 2006. Optimising sweet taste in foods. Boca Raton, FL: CRC Press. 415 p.

Steinkraus KH. 2004. Origin and history of food fermentations. In: Hui Y, Meunier-Goddik L, Hansen A, Josephsen J, Nip W, Stanfield PS, Toldrá F, editors. Handbook of food and beverage fermentation technology. New York: Marcel Dekker. p 5.

Tamime AY, Robinson RK. 1999. Background to manufacturing practice. In: Tamime AY, Robinson RK, editors. Yoghurt science and technology. 2nd ed. Boca Raton, FL: CRC Press. p. 12–128.

U.S. Department of Agriculture [USDA], Agricultural Research Service. 2014. USDA Natl. Nutrient Database for Standard Reference. Release 27. Nutrient data laboratory homepage. Available from http://www.ars.usda.gov/ba/bhnrc/ndl. Assessed 2015 March 21.

U.S. Department of Agriculture [USDA] and U.S. Department of Health and Human Services [HHS]. 2010. Dietary guidelines for Americans, 2010. 7th ed. Washington, DC: U.S. Government Printing Office.

U.S. Department of Agriculture [USDA] and U.S. Department of Health and Human Services [HHS]. 2015. Scientific report of the 2015 Dietary Guidelines Advisory Committee. Washington, DC.

VanBaak MA, Astrup A. 2009. Consumption of sugars and body weight. Obes Rev 10:9–23.

Varzakas S, Labropoulos A, Anestis S. 2012. Sweeteners. Nutritional aspects, applications, and production technology. Boca Raton, FL: CRC Press. 437 p.

Vastenavond CM, Bertelsen H, Hansen SJ, Laursen RS, Saunders J, Eriknauer K. 2012. Tagatose (D-tagatose). In: Nabors L, editor. Alternative sweeteners. Boca Raton, FL: CRC Press. p. 197–220.

Wallin G, inventor. 1996. Sugarless bakery goods, e.g. cakes and muffins. U.S. Patent No. 5523107.

Wilson R. 2007. Sweeteners. Oxford: Blackwell Publishing. 297 p.

Wittekind A, Walton J. 2014. Worldwide trends in dietary sugars intake. Nutr Res Rev 27:330–45. doi:10.1017/S0954422414000237.

World Health Organization [WHO]. 2015. Guideline: sugars intake for adults and children. Geneva: WHO Press.

Zoulias EI, Oreopoulou V, Kounalaki E. 2002. Effect of fat and sugar replacement on cookie properties. J Sci Food Agric 82:1637–44. doi: 10.1002/jsfa.1230.

