Beyond Sweetness: The Functional Roles of Sugar in Foods and the Challenges in Replacing/Reducing It

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Sugar (sucrose) is best known to provide sweetness to foods, and as such is one of the main ingredients used in desserts, confections, and sweetened beverages. However, sugar is a versatile ingredient and contributes many other functional properties to food products. As a result, it can be a challenge to reduce or remove sugar in recipes because there is no single universal sugar replacer that can be used in every application.

This resource provides a comprehensive review of sugar's multi-functionality, sugar substitutes commonly used in foods and misconceptions in relation to sugar replacement.

Table 1: Functional properties of sugar in foods beyond sweetness[1]

Function	Explanation and Examples
Preservation	• Sugar lowers water activity (the availability of water to support microbial growth), reducing microbial growth potential and increasing room temperature shelf-life
Fermentation	• Sugar acts as a growth substrate for bacteria and yeasts in fermented foods. Gas (i.e. carbon dioxide) is produced from fermentation, making bread rise and giving it a light crumb structure
Browning (Caramelization and Maillard Reaction)	• Caramelization: Sugars are heated in the absence of proteins and degraded, producing a dark brown colour and caramel flavours in foods such as peanut brittle, caramels, toffees, molasses • Maillard reaction: Sugar reacts with amino acids in proteins, resulting in the characteristic brown colour and flavour in baked goods
Tenderization	• Sugar softens starch gels or gluten networks in puddings and doughs
Crystallization control	• In candy and confectionery products, sugar crystallization is minimized for a soft texture in taffy candies and maximized for a grainy texture in hard candies
Boiling point increase	• Sugar increases the boiling point of solutions used to make candies, which allows more sugar to be dissolved and optimizes the final consistency of the candies
Freezing point depression	• Sugar reduces the freezing point and provides softness and scoopability to frozen desserts such as ice creams
Texture	• Sugar provides viscosity or syrupy textures in sauces by interacting with water • Sugar provides bulk, which impacts mouthfeel and texture • Sugar stabilizes egg whites in foam-type cakes
Flavour	• Sugar enhances flavour, releases aromas, balances the bitterness of cocoa in chocolate, the sourness of yogurt, and the acidity of tomatoes

Functional Properties of Sugar

Table sugar (sucrose) is a traditional ingredient that has been used for many centuries to deliver safe affordable foods. Sugar plays versatile functional roles in foods due to its chemical structure and its interaction with other food components such as water and protein. For example, sugar

- is very soluble and delivers a viscous syrupy effect to solutions providing a desired mouth feel;
- reduces the water available for microbial growth, extending the shelf-life of foods;
- competes for water with starch molecules and proteins in dough and prevents over-development of gluten, which would otherwise make bread too tough[1].

In addition, sugar also provides a sweet taste in foods and improves palatability. Adding a small amount of sugar to foods with high nutrient density can help increase consumption; for example,

- chocolate milk increases children's consumption of Calcium and vitamin D[1];
- whole-grain breakfast cereals increase the consumption of fibre[1].

Table 1 (first page) summarizes how sugar achieves individual functional roles and Table 2 (below) provides an overview of the many functions of sugar in various food categories.

Table 2: Examples of the multiple functions sugar plays in various food categories.

Functions	Cereals	Beverages	Baked Goods	Cakes, Cookies	Jams, Jellies	Puddings and Sauces	Confections	Dairy	Frozen Desserts
Improve palatability	●					●		●	
Texturizer	●						●		●
Tenderizer			●	●		●			
Colour and Flavour									
• Caramelization			●	●			●		
• Maillard Reaction	●		●	●					
Solubility		●			●	●	●		●
Freezing Point									●
Boiling Point							●		
Preservative									
• Antioxidant					●				
• Shelf Life Extender					●	●	●		
Fermentation			●						
Sweetener	●	●	●	●	●	●	●	●	●

Understanding Sugars and Substitute Sweeteners

Sugars, sugar alcohols and high intensity sweeteners are all used to sweeten foods (Table 3). Mono- and disaccharides are collectively referred to as "sugars" (Figure 1). Sugar alcohols (polyols), unlike what the name may suggest, are neither alcohol (ethanol) found in alcoholic beverages nor sugars. Instead, they are a type of carbohydrate commercially produced from other carbohydrates such as glucose, starch and sucrose. They contribute lower Calories (via bacterial fermentation of unabsorbed sugar alcohols in the gut) and produce no insulin response after their ingestion. However, consumption of large amounts of sugar alcohols can lead to abdominal gas and laxative effects. For this reason, the type and quantity of sugar alcohols must be declared on Nutrition labels[2].

Sugars and substitute sweeteners deliver different functionalities due to their different compositions and structures. However, sugar alcohols and high intensity sweeteners cannot perform all the functional roles of sugar.

Figure 1. Sugars commonly found in foods

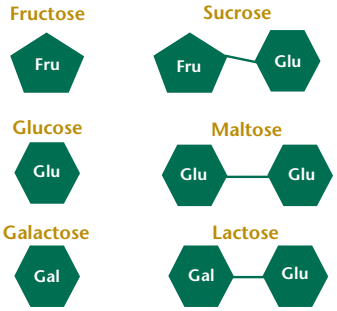

Table 3: Sugars and substitute sweeteners commonly used in foods

Category	Caloric Value	Examples
Sugars	4 Calories/gram	Sugar (sucrose), honey, maple syrup, high fructose corn syrup, agave
Sugar alcohols	0.2-3 Calories/gram	Sorbitol, xylitol, erythritol, maltitol, lactitol
High intensity sweeteners	0 to negligible due to the very small amounts used in food	Sucralose (e.g. Splenda®), Aspartame (e.g. Equal®, NutraSweet®), Steviol Glycosides (e.g. Stevia, Truvia®)

Challenges in Sugar Replacement and Reformulation

Due to the multiple functional roles sugar has in foods, the removal or reduction of sugar from food is not a simple exchange of one ingredient with another[3]. The reformulated product will typically have more ingredients than the original ingredients list. Some of these may not be recognized by the general consumer and will typically be additives (See Ice Cream example below).

The overall objective of reformulation is to improve the nutritional profile (such as reduced Caloric content, lowered glycemic index, etc), which may not always be achieved in the final product. For example in breakfast cereals, if sugar is removed without any replacement, the overall proportion of starch increases with no reduction in Calories and the glycemic index of the product may actually increase depending on the type of starch used. Another example is ice cream.

Ice Cream: a Closer Look:

Sugar provides sweetness, freezing point depression and total solids to ice cream. Sugar reduces the freezing point by reducing ice crystal formation when the solution is cooled. In a sugar-reduced version, high-intensity sweeteners can provide sweetness but they cannot achieve the freezing point depression provided by sugar. As a result, another ingredient like glycerol may be needed to deliver the freezing properties, but it does not provide sufficient total solids. Sugar alcohols can be also used to match freezing characteristics, but the resulting product may not have appropriate sweetness. Ingredients such as starch hydrolysis products (maltodextrins) are used to achieve desirable bulk; however, because of this, both the Calorie content and the glycemic index may increase.

One example of a "No Sugar Added" ice cream in the Canadian market uses a blend of maltitol and sucralose (Figure 2). The maltitol replaces the freezing characteristics of sugar while the sucralose boosts sweetness. The glycemic index is thus lowered, but the Calorie content is the same as the regular formulation and the addition of sugar alcohols requires additional declaration on the label.

Figure 2. Ingredient lists and Nutrition Facts tables of a "No Sugar Added" ice cream and a regular ice cream.

No Sugar Added Vanilla Ice Cream

Ingredients:

Modified Milk Ingredients, Cream, Maltitol Syrup, Skim Milk Powder, Mono and Diglycerides, Guar Gum, Locust Bean Gum, Cellulose Gum, Carrageenan, Natural Flavour, Sucralose, Lactase.

Sweetened with Maltitol and Sucralose

Original Vanilla Ice Cream

Ingredients:

Cream, Modified Milk Ingredients, Sugar, Glucose, Mono and Diglycerides, Locust Bean Gum, Cellulose Gum, Guar Gum, Carrageenan, Dextrose, Natural Flavour.

The impact (or lack of it) on total Calories in reformulated sugar-reduced products has been a source of confusion among health professionals and consumers[1,4,5]. When consumers in the UK[4] and registered dietitians in Canada[5] were polled, Calorie reduction was expected in products with reduced sugar content. On the contrary, Canadian market research revealed that 15% of products were higher in calories, 18% higher in carbohydrates and 6% higher in sugars compared with reference products[5].

No Sugar Added

Nutrition Facts

Per 1/2 cup (125 mL)

Amount	% Daily Value
Calories 120	
Fat 7 g	**11 %**
Saturated 4 g + Trans 0.3 g	**22 %**
Cholesterol 20 mg	
Sodium 85 mg	**4 %**
Carbohydrate 14 g	**5 %**
Fibre 0 g	**0 %**
Sugars 7 g	
Sugar Alcohols 8 g	
Protein 3 g	
Vitamin A	**4 %**
Vitamin C	**0 %**
Calcium	**6 %**
Iron	**0 %**

Regular Ice Cream

Nutrition Facts

Per 1/2 cup (125 mL)

Amount	% Daily Value
Calories 120	
Fat 6 g	**9 %**
Saturated 3.5 g + Trans 0.2 g	**18 %**
Cholesterol 20 mg	
Sodium 40 mg	**2 %**
Carbohydrate 17 g	**6 %**
Fibre 1 g	**4 %**
Sugars 11 g	
Protein 3 g	
Vitamin A	**6 %**
Vitamin C	**0 %**
Calcium	**4 %**
Iron	**0 %**

Clean Label Initiative

Sugar is a traditional, natural ingredient that has been used for many centuries to deliver safe, affordable foods. As an ingredient it is easily recognized and most people have it in their cupboard at home. To reduce sugar content of a product is not a simple exchange of one ingredient with another, nor is there necessarily a reduction in Calories. The reformulated product will typically have more ingredients on the ingredients list, some of which may not be recognized by the general consumer and will typically include additives (Table 4). Some of these ingredients may have limitations to their use and some will also require additional labelling. Consequently, reformulation can be a significant challenge when consumers expect "clean" labels and fewer ingredients.

"Clean label" represents sensible, clear and understandable declaration on food labels and advocates for natural origins of the ingredients.

Table 4: Ingredients that could replace some of the functions of sugar.

Sugar Function	Alternative Ingredients
Mouthfeel/texture	Gums, thickeners, sugar alcohols
Bulk	Bulking agents, starches, dietary fibers, sugar alcohols, gels, gums
Colour	Colours (additives)
Flavour	Flavours (additives)
Preservative	Preservatives (additives)
Sweetness	High intensity sweeteners, sugar alcohols

Conclusions

Sugar contributes many functional properties to foods beyond sweetness. All of these properties arise due to the underlying chemical composition and structure of the sugar molecule and the various interactions it has with water and other food components. In most cases, where more than one function is involved, one-to-one replacement of sugar with another ingredient is not possible. Replacement of sugar with a high intensity sweetener alone may be difficult depending on the application. Thus sugar reduction/replacement is an application-specific product development challenge that in many cases is difficult to overcome. Ultimately the goal of sugar replacement should be to improve the nutritional profile of the product and deliver a caloric reduction and/or lower glycemic index; however both are difficult to achieve without sacrificing functionality or consumer-friendly clean labeling.

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