Nutrition and Food Sciences Research Vol 3, No 4, Oct-Dec 2016, pages: 3-11

Review Article

Effect of Substitution of Sugar by High Fructose Corn Syrup on the Physicochemical Properties of Bakery and Dairy Products: A Review

Azizollaah Zargaraan[1], Leila Kamaliroosta[2], Amin Seyed Yaghoubi[2], Leila Mirmoghtadaie[1]*

1- National Nutrition & Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran

2- Zar Knowledge-based Center of Research and Industrial Group, Tehran, Iran

Received: August 2016 **Accepted:** October 2016

ABSTRACT

High fructose corn syrup (HFCS) is commonly found in soft drinks and juice beverages, as well as in many pre-packaged foods such as breakfast cereals, baked goods and dairy desserts. Historically, sucrose (table sugar) was primarily added to processed foods and beverages as the sweetening agent. In recent years, the use of HFCS has significantly increased in popularity due to its sweetness, ability to enhance flavor and shelf life, and its low cost. HFCF made by enzymatic isomerization of glucose to fructose was introduced as HFCS-42 (42% fructose) and HFCS-55 (55% fructose) and opened a new frontier for the sweetener and soft drink industries. Using a glucose isomerase, the starch in corn can be efficiently converted into glucose and then to various amounts of fructose. Hydrolysis of sucrose produces a 50:50 molar mixture of fructose and glucose. The primary difference is that these monosaccharides exist free in solution in HFCS, but in sucrose bonded together. The disaccharide sucrose is easily cleaved in the small intestine, so free fructose and glucose are absorbed from both sucrose and HFCS. The advantage to food manufacturers is that the free monosaccharide in HFCS provides better flavor enhancement, stability, freshness, texture, color, pourability, and consistency in foods in comparison to sucrose. The development of these inexpensive, sweet corn-based syrups made it profitable to replace sucrose (sugar) and simple sugars with HFCS in our diet. In the present study, the replacement of sucrose with HFCS and its effect on the functionality and organoleptic properties of different food products were reviewed.

Keywords: High fructose corn syrup, Bakery products, Dairy products

Introduction

Sensory evaluation is a key point on the market success of food products. Taste perception plays a vital role in the sensory evaluation process. Sweet, salty, sour and bitter are main tastes, which could be perceived by human beings gustatory system. In recent years, umami taste has been introduced as the fifth taste (1, 2).

There is a consensus among the sensory scientists on sweet taste preferring between newborn infants (3). It is believed that sweetness is a sign of caloric content for the human beings' gustatory system. So some researchers call this system as a *gatekeeper*, which controls the ingestion and rejection of pleasant and harmful foods, respectively (4).

There are many choices in sweeteners for food industry. Sweeteners can be categorized in nutritive and non-nutritive groups. Nutritive sweeteners contain monosaccharides (fructose, and galactose), disaccharides (sucrose, maltose, and corn-based sweeteners) and polyols (sugar alcohols), which can produce energy (5). Non-nutritive sweeteners such as acesulfame K, aspartame, neotame, saccharin, and sucralose are calorie-free substances with sweet taste. Use of non-nutritive sweeteners within the approved regulations is safe. However, it should be more concerned within children and pregnant women (6). Non-nutritive sweeteners are much sweeter than sucrose but they do not have the same functionality

***Address for correspondence:** Leila Mirmoghtadaie, Assistant Prof, Dept.of Food Science and Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran. E-mail address: Mirmoghtadaie@sbmu.ac.ir

[DOI: 10.18869/acadpub.nfsr.3.4.3]

such as microbial inhibition, crystallization and browning (7).

From the clinical viewpoint, Glycemic Index (GI) of sweeteners is of interest (8). Maltose with GI 105 and glucose with GI 100 have the highest, and lactulose, mannitol and tagatose with GI=0 have the lowest GI among the nutritive sweeteners (6).

Until now, sucrose (GI 61-68) was the optimum and the most used sweetener in the food industry. Sucrose not only can affect the sweetness of the food products but also can be effective on their rheological properties (9).

Fructose is a natural monosaccharide (GI 19-23) with 4g/g H_2O which has been used as a commercial sweetener in the food industry. HFCS is a liquid alternative for sucrose with 42 or 55% (dry basis) fructose. HFCS has been obtained from the hydrolyis of corn starch to glucose using glucoamylase and α-amylase followed by partial isomerization of glucose to fructose that results in production of a mixture of glucose and fructose (10, 11). In various food products with respect to their complicated matrixes, HFCS have different functional properties. It is revealed that HFCS can provide better flavor, color, texture, stability and freshness in comparison to sucrose in some branches of food products such as beverages, processed foods, baking products, ice cream and confectionaries (12). There is no such difference in composition or metabolism from other fructose glucose sweeteners (for instance, sucrose, honey, and fruit juice concentrates). It, generally, contains either 42 % or 55 % fructose, the remaining sugars being primarily glucose or higher sugars. Its caloric content is equivalent to sugar and thus it shares the same concerns from consumers and industry as those of sugar. Furthermore, the human body metabolizes fructose differently than glucose; so high consumption of HFCS has been attributed to increasing rates of obesity. HFCS has been widely adopted by the U.S. food manufacturers because it offers advantages over granulated sucrose; for instance, it is easy to supply, and good for stability, and enjoys ease of handling. Corn is an abundant and reliable crop grown widely across the U.S., while sucrose production is limited. This means most supplies must be imported into the U.S. from sugar-growing countries, which leaves the supply vulnerable to changes in the weather and political conditions in those countries (13).

Therefore, the present study aims to investigate the effect of substitution of sucrose with HFCS on the physicochemical properties of food products.

Effect of using HFCS in different food products

Effect of HFCS on beverage properties: Beverage industry is the first consumer market of HFCS due to its liquid form that makes it easier substance than sucrose for mixing with other ingredients, and its stability in acidic beverages (13). Unfortunately, despite the widespread use of this sweetener in the beverage industry, no paper was found to compare and evaluate the effects of sugar substitution with HFCS on the sensory, physical and rheological properties of different drinks.

Effect of HFCS on bakery products properties: Baking industry is the second largest consumer of HFCS. HFCS as a bulk liquid sweetener is suitable for both of the fermented and unfermented bakery products. It plays an important role as direct fermentable saccharide for yeast nutrition without requiring inverting action that happens before sucrose using. Generally, application of HFCS at equal solids levels leads to shorter proof times, and the same flavor, volume and grain in comparison with sucrose. In addition, it is used in different bakery products as a humectant. Humectant can improve texture, eating quality and shelf-life of the food products. HFCS can be used suitably in replace of glycerin and sorbitol as common humectant (14). Additionally, the reducing sugar is incorporated in color development during the Maillard reaction. Bakers can give distinctive brown color to bread crust even in microwaved products. The established brown color can be controlled by changing the pH, temperature and time of process and storage. Furthermore, fructose can increase functionality of starch in baking products due to decrease in starch's gelatinization temperature that leads to faster texture setting. On the other hand, fructose causes higher viscosity compared to sucrose. However, bakers found that the use of HFCS resulted in finished product similar to those having sucrose in formulation (14). Many studies have been done on the effect of sucrose substitution in high level with HFCS on the properties of finished bakery product that are mentioned in following.

Fermented Bakery Products: Although there are many different ways of making yeast fermented baked goods such as bread, they all contain three basic stages: mixing, fermentation and baking. When the flour, water and yeast are mixed to make the dough, two reactions occur simultaneously. One concerns the amylase enzyme's activity in the flour, which starts to convert the starch of the flour into sugars, predominantly maltose. The other concerns the gliadin and glutenin proteins of the flour, which are hydrated to form the viscoelastic gluten. During the fermentation stage, the yeast converts the maltose first into dextrose and then into carbon dioxide and alcohol (15). In some situations, extra fermentable sugars are required. The choice of which sugar use will depend upon their fermentability and relative costs, and both dextrose and HFCS being more fermentable and frequently cheaper than sucrose: so they are often the preferred sugars. One major difference between sucrose and HFCS is that sucrose is a non-reducing sugar, and therefore, will not react with the protein in the flour to produce the well-known Maillard browning reaction. HFCS, on the other hand, contains reducing sugars, which will react with the protein in the flour to give the Maillard brown color (15, 16). Both of the features mentioned about HFCS can lead to reduce the fermentation time and baking time and temperature in fermented bakery products and ultimately, increase production efficiency. In addition, since HFCS can absorb and retain more moisture than sucrose, the shelf-life of bakery products containing fructose syrup will be longer, and staling can be postponed. Therefore, due to desired functional characteristics of HFCS in fermented bakery products, sugar and invert syrup used in these products can be completely replaced with HFCS (17, 18).

Unfermented Bakery Products

Biscuit and cookie: The quantity, size and type of sugar could affect the consistency, spreadability and machining properties of biscuit dough (19), as well as the firmness, thickness, sweetness, and color of the product (20). Manohar and Rao compared the effect of different sugars on the rheological properties of biscuit dough and quality of the final biscuit (20).

Incorporation of reducing sugars such as HFCS, dextrose, liquid glucose and invert syrup led to a desirable golden brown color to the biscuits but HFCS led to the best color of the biscuits. The application of reducing sugars made more cohesive, adhesive and sticky, and less viscous dough in comparison with the control (20).

Cookies are softer and plumper with less spread and lower a_w (14). Also the effect of sugar type on the surface cracking pattern of sugar-snap cookies was studied. The substitution of small levels of glucose, HFCS, fructose and maltose in replace of sucrose changed the cracking pattern. The cookies containing fructose syrup or glucose syrup did not crack. The surface crack of granular sucrose containing cookies could be due to the possibility of recrystallization of sucrose at the surface of cookie during baking (21).

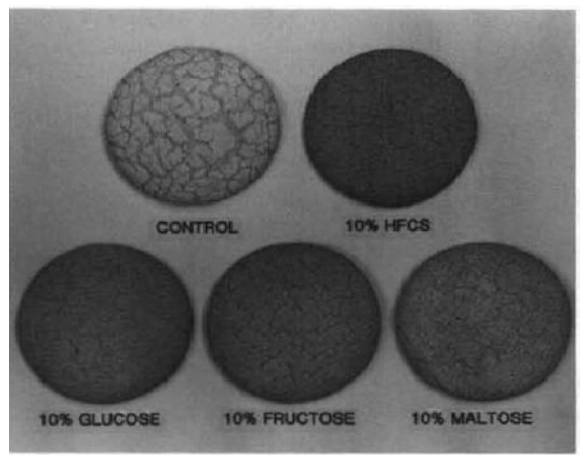

Fig. 1. Effect of different sugar syrups on the cookies surface cracking

Table 1. Effect of sugar type on the rheological properties of biscuit dough (20)

Sugar type	Extrusion time (s)	Compliance (%)	Elastic recovery* 10 (mm)	ABVE* 10^{-5} (Pa s)	Consistency (N s)	Hardness (N)	Cohessiveness	Adhessiveness (N s)	Sticknes s
Flour A									
Control	45 a	40.6 a	4.60 a	1.91 a	786 a	662 a	0.194 d	54.3 c	50.3 c
Dextrose	36 b	44.2 b	4.10 b	1.64 b	654 b	586 b	0.202 cd	55.8 bc	54.8 b
LG	26 c	48.8 a	3.80 d	1.42 c	524 c	492 c	0.220 bc	57.8 b	70.5 a
IS	24 c	48.6 a	3.95 c	1.41 c	538 c	476 c	0.210 bc	62.5 a	69.8 a
HFCS	22 c	49.8 a	3.80 d	1.36 d	530 c	474 c	0.230 a	64.3 a	71.5 a
SEM	1.9	0.58	0.03	0.02	10.8	9.9	0.003	0.87	0.90
Flour B									
Control	45 a	39.5 d	5.55 a	1.91 a	848 a	664 a	0.194 c	48.2 c	48.6 d
Dextrose	37 b	42.5 c	4.95 b	1.87 a	627 b	519 b	0.210 b	50.2 b	57.3 c
LG	34 bc	47.3 b	4.95 b	1.47 b	629 b	530 b	0.224 a	56.3 a	63.5 b
IS	30 cd	48.7 ab	5.05 b	1.48 b	582 c	479 c	0.228 a	52.5 b	68.7 a
HFCS	28 d	49.8 a	5.00 b	1.47 b	594 c	472 c	0.220 ab	58.0 a	70.5 a
SEM	1.5	0.54	0.034	0.022	9.3	12.4	0.003	0.89	0.98

Curley and Hoseney studied the effect of corn sweetener on cookie quality. Granular sucrose was replaced up to 50% with HFCS in sugar-snap cookie. Dough rheology (stickiness), surface cracking and the characteristic snap associated with this type of cookie were affected. Soft, sticky dough resulted when sucrose was replaced with HFCS; the significance of this change was depending on the amount of HFCS substituted. Replacing sucrose with HFCS changed the appearance of the baked cookies. Cookie color darkened as the level of HFCS increased. This color change resulted from the reducing sugars in the corn syrup. Cookie diameter and thickness were measured for the cookies made with HFCS (0-50%), replacing granular sucrose solid (Table 2). The cookies' diameter decreased gradually and their thickness increased (22).

Table 2. Effect of levels of High Fructose Corn Syrup on the cookies' diameter and thickness (17)

Sucrose replaced by HFCS (%)	Cookie diameter (cm)	Cookie thickness (mm)[b]
0[a]	9.45	15.50
10	9.15	16.30
20	9.10	17.95
30	8.90	18.00
40	8.55	19.75
50	8.45	20.60

A Control

B Measurements are the thickness of two cookies.

The amount of water loss during baking was measured for the cookies containing sucrose and HFCS, and no significant differences were found between any of the sweeteners in the water loss during baking. Time–lapse photographs taken during cookie baking showed that the outer surface of the granular sucrose cookie dried rapidly and cracked when the cookie started to spread. The outer surface of HFCS cookies did not dry but remained moist during the early stages of baking. Surface cracking appeared to be a function of the rate of surface drying that is controlled by internal water diffusion to the cookie surface rather than the rate of vaporization at cookie surface, because the water loss from the cookie was constant. When corn syrup replaced small amounts of sucrose in the sugar snap cookies, the character of snap changed. The time required for the snap to develop increased with increasing levels of corn syrup. This delay in snap development appeared to coincide with sugar recrystallization (21, 22).

Doescher et al. (1987) studied the expansion rate and setting time of cookies contained different sugars during baking by using Time-lapse photography. The control sample set at the maximum baking time, but the cookie contained sucrose syrup set at a lower time than the control. The sucrose contained cookie diameter was not significantly different from the control that was due to its faster spread rate than the other cookies. The time of setting of cookies contained glucose syrup and fructose syrup was significantly shorter than the control. Use of glucose and fructose syrup in cookies formulation did not have significant effect on the expansion rate in compare to the control. The diameter of cookies contained fructose or glucose syrup was significantly smaller than that of both the sucrose syrup cookies and the control (23).

Cake: In another study, Coleman and Harbers (1983) replaced sucrose in 25, 50, 75 or 100% with HFCS in angel cake. Replacement of HFCS in 25% of sucrose did not influence greatly the physical or sensory properties, but replacement in higher amounts (50, 75 or 100%) of sucrose resulted in decrease in the egg white foams' specific gravities, lower egg white foam beating time, and lower cake volume and browner cake crust. In addition, the firmness of cake did not show any difference between the 25% HFCS and the control cakes. The higher amount of HFCS led to firmer cake texture ($P<0.05$) than lower amount of HFCS that could be due to either lower stiffness of the foams, and also decrease in starch's gelatinization temperature (24, 25).

Marx et al. (1990) studied the effect of type of flour (all-purpose flour and cake flour) on the cake properties contained different levels of HFCS. The type of flour did not show significant effect at the levels of 0 and 50% HFCS. However, with increase in HFCS level, the use of cake flour produced more tender all-purpose flour cake. The use of cake flour can compensate the undesirable effect of HFCS in the field of higher browning and lower volume of cake (26, 27). The use of cake flour that have lower protein content, increased the tenderness and volume of the cakes contained higher level of HFCS (26); this result is in agreement with the results of Conforti et al. (28). Therefore, application of cake flour with HFCS in baked products could lead to overcome the loss of volume and tenderness (26).

Table 3. Results of pH of batter, crumb, crust, total browning and 5-hydroxymethylfurfural (HMF) content in the crust

Cake	pH Batter	pH Crumb	pH Crust	Total Browning (absorbance units/100g of solid)	HMF (mg/100g)
0% HFCS, with acidulant[c]	7.133c	7.033d	6.300c	23.15f	1.93f
0% HFCS, no acidulant	7.933a	8.100a	6.800a	33.84ef	3.969e
50% HFCS, with acidulant	6.900d	7.000d	6.300c	41.51e	4.235e
50% HFCS, no acidulant	7.366b	7.833b	6.466b	76.33c	6.268d
75% HFCS, with acidulant	6.900d	7.000d	6.133d	56.66d	7.923c
75% HFCS, no acidulant	7.366b	7.900b	6.500b	93.99b	18.250b
100% HFCS, with acidulant	6.800d	7.033d	6,166d	60.55d	8.749c
100% HFCS, no acidulant	7.400b	7.633c	6.200d	114.86a	30.140a

[a]Mean values of three replicates.
[b] Means in the same column followed by the same letter are not significantly different ($p<0.05$)
[c] Contains 100% sucrose.

In another study, sucrose was replaced with 0, 50, 75, and 100% HFCS with and without an acidulant to control browning of white layer cakes. The results of color evaluation and HMF evaluation showed the ability of acidulant in control of excessive browning. The pH of the crust was not altered by the addition of an acidulant when sucrose was replaced with 100% HFCS (Table 3). Enhance in HFCS concentration over 25% led to decrease in the onset temperature of starch gelatinization and then causing too early set of the structure during the baking process and decreasing the volume (24, 29). Differential scanning calorimetry (DSC) was applied to demonstrate the transition of the cake batters and impact of HFCS on starch gelatinization during baking. The results showed that the color, tenderness and flavor of the cake did not have any significant changes in the sensory evaluation of the cakes contained different concentration of HFCS and an acidulant (29).

Murano and Johnson (1998) studied the effects of HFCS and corn oil on volume and deformation and effects of mono- and diglyceride (MDG) and sucrose ester (SE) emulsifiers on the volume and sensory properties of yellow cakes. Fifteen percent HFCS gave the greatest volume; 100% HFCS decreased volume; and corn oil increased volume. Deformation was greatest in 50% HFCS cakes with 50% or 100% corn oil. HFCS affected tenderness and aftertaste but not sweetness in the cakes formulated with 100% corn oil. Emulsifiers did not affect sensory tenderness or aftertaste but the sucrose ester appeared to potentate the perceived sweetness of 50 and 100% HFCS cakes. They suggested that although neither MDG nor SE increased the volume of the 100% HFCS cakes, other formula manipulations may accomplish this and may mask or eliminate after-taste and reduce crust browning to produce a more satisfactory 100% HFCS cake (30).

Ahmad and Williams (1999) investigated the effect of different sugars on sago starch gelatinization. They found increase in the gelatinization temperature in the following order: control (water alone) < ribose < fructose < glucose < maltose < sucrose (31). The type of interaction between sugars and starch granules can influence the starch gelatinization.

The results of 13C-NMR presented occurring sugar–starch interactions before the start of gelatinization process. The interaction sites for sucrose at the 5 carbon atoms of G1, G5, and G6 (G-glucose) and F1 and F6 (F-fructose) were greater than glucose (3 carbon atoms) and fructose (2 carbon atoms), individually. Therefore, sucrose has more effect than monosaccharids on the formation of sugar–starch bridges (31). This result was confirmed by McCullough et al. (1986) who used HFCS in replace of 0, 50 and 75% sucrose in shortened cake (32). Furthermore, Volpe and Meres (1976) implied to undesirable taste of sour flavor in white layer cakes in which HFCS was used in replace of 60% sucrose. This sourness could be attributed to the high-acid leavening system and might be masked by a flavor such as vanilla (33).

Hartnett (1981) patented the invention in relation with cake compositions containing HFCS. The object of this invention was to provide a formulation and process for manufacturing satisfactory cakes wherein HFCS is employed in place of sucrose. These objects were accomplished by a series of counteracting adjustments of reaction rates, which took place between starch and fructose when HFCS was used. Amylograph studies have shown that the starch-fructose-water slurries containing 100% HFCS gelled at a lower temperature and a faster rate than systems containing sucrose. It was further discovered that addition of mono and diglycerides of fatty acids, especially saturated fatty acids retarded starch gelatinization by reacting within swelling granules or

[DOI: 10.18869/acadpub.nfsr.3.4.3]

by reducing the rate of water absorption. Furthermore, it was discovered that emulsifiers such as polyoxyethylene and sorbitan monostearate tend to increase the water binding capacity (adsorption) of the flour, and reduce the amount of starch granule birefringence loss due to heating and rupturing and thus the amount of starch gelatinization. Hence, by blending a mono and diglyceride with another emulsifier, it was possible to retard the rate and amount of starch gelatinization. The use of an air classified four increased the absorption in the slurry and produced a much higher viscosity at 90°C. Single stage non-nucleating leavening agents such as sodium aluminum phosphate did not react with sodium bicarbonate when initially dispersed in the batter to form bubbles of carbon dioxide, in addition to the regularly-included cake ingredients. This patent illustrated the preparation of several cakes employing the emulsifier blend in combination with HFCS/ corn syrup and a chemical leavening agent (34).

Conforti et al. studied the synergistic effect of HFCS 90 and maltodextrine on the physical characteristics of reduced calorie muffin. Application of HFCS 90 in 0, 25, 50 and 75% amounts of sucrose and maltodextrine resulted in higher maintenance of moisture and lower water activity of dietetic muffins than the control because of lower free water content of muffins. The tenderness of reduced fat cakes was lower than the control. Neither maltodextrin nor HFCS 90 could affect muffin's tenderness. The crumb hardness and product freshness determined of cake staling. Staling starts immediately after baking. Fat can decrease crumb firmness due to surfactant properties. In addition, application of maltodextrin as fat replacer led to decrease in the staling rate of muffins, but with increase in HFCS 90 level, the staling rate was increased (35).

Effect of HFCS on dairy products' properties: Liquid nature of the HFCS makes it a suitable ingredient in dairy products. As mentioned before, functional property of HFCS directly depends on the complex matrix of food products. This is more complex in a product like ice cream in which three phases of substances are present in the processing (35). Ice crystallization is a critical step in production of ice cream (36). This phenomenon occurs in two stages: first, at the freezer barrel, and second, in the hardening and storage phase (37). Sweetener type, total solids, initial freezing temperature, unfrozen water, stabilizer type, and storage temperature are the main factors that may affect the crystallization process. Altering the freeze point of the ice cream mix is the main effect of various sweeteners. Sweeteners can also change freezing point and the viscosity of the unfrozen part of frozen dairy desserts in different concentrations (38).

Like other sweetened food products, sucrose is the main sweetener in ice cream and frozen desserts (39). Sweeteners with proper melting slope can be replaced in order to reach low sugar products or texture improvement (40).

HFCS can affect ice cream's frozen water in order to control recrystallization during the storage time in both stabilized and unstabilized formulations (41). According to Pearson and Ennis' research results, ice cream formulation containing up to 33% fructose from its total sweetener portion can improve mouth feel, sweetness and gumminess in comparison to sucrose (42).

Sucrose, fruits and non-nutritive sweeteners such as stevia are the main sweeteners, which are used in the production of flavored yoghurts (43-45). In dairy desserts, viscosity is one of main effective factors in organoleptic properties. For example, Zargaraan et al. reported that based on product type, sensory acceptance of dairy desserts may vary with the change in the apparent viscosity (46).

Keating and White studied the effect of alternative sweeteners on plain and fruit flavored yogurt properties such as apparent viscosity, microbiological status, and sensory profiles. The studied sweeteners were sucrose (control), aspartame, calcium saccharin, sodium saccharin, sorbitol and HFCS. The used amount of sweetener depended on relative sweetening intensity to obtain the desired 16% total solids. Among these sweeteners, HFCS containing samples (4%) had a significantly higher viscosity (47). Changing the ingredients while maintaining the taste is the main challenge of the food industry in reformulation of different food products. Wittinger et al. investigated the effect of replacement of 50% (17% total) of sucrose with HFCS. These researchers reported no significant difference in the sweetness or vanilla taste of ice cream (48).

The use of HFCS is common approach in dairy science; however, to our knowledge, researchers have not treated this issue in much detail. So, little is published on the functional properties of different concentrations of HFCS in dairy products. It is recommended that further research be undertaken in this field.

[DOI: 10.18869/acadpub.nfsr.3.4.3]

Economic aspects and market potential of HFCS: HFCS has gained rapid commercial acceptance since its introduction. It substitutes directly for cane or beet sugar in many manufactured products. The pricing of HFCS relative to sugar has been an important factor in the growth in use of it. The net cost of production of HFCS is considerably less than that of domestic cane or beet sugar (49, 50). As a result, HFCS has been priced below sugar with the amount of differential being a direct function of the price of sugar. The very competitive pricing can be attributed to the favorable price situation for corn byproducts and the existence of excess processing capacity. 25 kg of corn yields in the wet milling process about 0.75 kg of corn oil, 6.3 kg of corn gluten feed, 1.2 kg of corn gluten meal and 14 kg of HFCS 55 (on a dry basis). Ordinarily, based on the mass balance shown in Table 4, the production costs are calculated for HFCS 55 (70-86% dry solids). The costs vary depending on parameters related to the actual production plant, country and production year; however, they can be used as an illustration of the various costs of the different operation steps involved (51, 52).

Table 4. Estimated mass balance of the corn wet milling and HFCS process (51)

Products and fractions	Mass (kg)
Corn (90% dry solids)	100
Corn oil	3.0
Corn gluten feed	25.2
Corn gluten meal	8.4
HFCS (78% dry solid)	73.0

The demand for HFCS is clearly derived from the demand for sugar and other sweeteners for industrial application. HFCS competes directly with sugar from beets and cane and with other corn sweeteners in the total caloric sweetener market. The market share captured by HFCS will depend on the suitability of HFCS in various product uses, the ratio of HFCS prices to sugar prices, the rate of acceptance of HFCS, and other factors such as the availability of handling facilities for liquid sweeteners (49).

Continued acceptance and market penetration of HFCS has economic implications for diverse groups, including domestic beet and cane sugar producers and processors, sweetener users, consumers, corn producers, and trading partners. In many foods, HFCS substitutes for sugar on a one-to-one basis, implying nearly linear production isoquants. Production theory shows that this condition will result in full specialization with less expensive input.

The economic impact on consumers and food manufacturers will depend on numerous factors such as the price differential between sugar and HFCS, the amount of sweetener used and its relative importance in various products, the competitive structure in the food-manufacturing industry, marketing margins, and the price elasticity of demand for products using HFCS. Under competitive conditions, decreased manufacturing costs due to the use of HFCS should be passed onto consumers in lower retail prices. This price decrease would be a percentage of total prices for most HFCS products. However, HFCS' economic impact on various groups can be an important consideration in investment planning and policy development (49, 50).

Conclusion

Taste has a pivotal role in sensory acceptance of food products. Adjustment of sweet taste in a food matrix could be performed using nutritive and non-nutritive sweeteners. Historically, sucrose (table sugar) was primarily added to processed foods and beverages as the sweetening agent. The interest for finding alternative sweeteners has greatly increased in food industries over the past three decades, and HFCS has largely replaced sucrose as the major sweetener used in different sugar sweetened food products. HFCS has more stability, and particularly works well in acidic beverages, is available in liquid form, which makes it easier to transport, handle, and mix better than granulated sucrose. Since, fructose is sweeter than glucose, the overall sweetness of the syrup increased resulting in more cost-effective use over sugar in food processing. In addition, it has strong effect on the tenderness, flavor and color of different cereal and confectionary products and the crystallization rate of ice in dairy products.

Financial disclosure

The authors declared no financial interest.

References

1. Kuhn C, Meyerhof W. Chapter 13 - Oligomerization of Sweet and Bitter Taste Receptors. In: Conn PM, editor. Methods in Cell Biology. Volume 117: Academic Press; 2013. p. 229-42.
2. Zhang Y, Venkitasamy C, Pan Z, Wang W. Recent developments on umami ingredients of edible mushrooms – A review. Trends in Food Science & Technology. 2013 10//;33(2):78-92.
3. Haschke F, Prescott S. Preventive Aspects of Early Nutrition: Karger; 2016.
4. Low JY, Lacy KE, McBride R, Keast RS. The Association between Sweet Taste Function, Anthropometry, and Dietary Intake in Adults. Nutrients. 2016;8(4):241.
5. Birch GG, Parker KJ. Sugar, science and technology. Applied Sciences Publishers, Ltd. London 1979.
6. DuBois GE, Prakash I. Non-caloric sweeteners, sweetness modulators, and sweetener enhancers. Annual review of food science and technology. 2012;3:353-80.
7. Rippe JM. Fructose, high fructose corn syrup, sucrose and health: Springer; 2014.
8. Gallagher C, Keogh JB, Pedersen E, Clifton PM. Fructose acute effects on glucose, insulin, and triglyceride after a solid meal compared with sucralose and sucrose in a randomized crossover study. American Journal of Clinical Nutrition. 2016;103(6):1453-7.
9. Bucke C. There is more to sweeteners than sweetness. Trends in Biotechnology. 1983;1(3):67-9.
10. Scaman C. Corn Sweeteners: Enzyme Use. Endo. 2011;3:1.69.
11. Nabors L, Gelardi R. Alternative sweeteners: An overview. Alternative sweeteners. 2001;2:1-10.
12. Moeller SM, Fryhofer SA, Osbahr III AJ, Robinowitz CB. The effects of high fructose syrup. Journal of the American College of Nutrition. 2009;28(6):619-26.
13. www.persistencemarketresearch.com/market-research/high-fructose-corn-syrup-hfcs-market.asp
14. O'Brien-Nabors L. Alternative sweeteners: CRC Press; 2016.
15. Hull P. Glucose syrups: technology and applications: John Wiley & Sons; UK. 2010.
16. Hanover LM, White JS. Manufacturing, composition, and applications of fructose. The American journal of clinical nutrition. 1993;58(5):724S-32S.
17. Hall KL, Denda CE, Yeung H. Dietary vitamin D intake among elderly residents in a Veterans' Centre. Canadian Journal of Dietetic Practice and Research. 2010 Feb 16;71(1):49-52.
18. Thor P, Carman H. High fructose corn syrup: An important new sugar substitute. California Agriculture. 1979;33(7):13-5.
19. Matz SA, Matz TD. Cookie and cracker technology: AVI Publishing Company, Inc.; 1978.
20. Manohar RS, Rao PH. Effect of sugars on the rheological characteristics of biscuit dough and quality of biscuits. Journal of the Science of Food and Agriculture. 1997;75(3):383-90.
21. Doescher L, Hoseney R. of Sugar-Snap Cookies1. Cereal Chem. 1985;62(4):263-6.
22. Curley LP. Effects of corn sweeteners on cookie quality: Kansas State University; 1983.
23. Doescher LC, Hoseney R, Milliken G, Rubenthaler G. Effect of sugars and flours on cookie spread evaluated by time-lapse photography. Cereal Chem. 1987;64(3):163-7.
24. Coleman PE, Harbers CA. High fructose corn syrup: Replacement for sucrose in angel cake. Journal of Food Science. 1983;48(2):452-6.
25. Doescher LC, Hoseney R, Milliken G. A mechanism for cookie dough setting. Cereal Chemistry (USA). 1987.
26. Marx JT, Marx BD, Johnson JM. High fructose corn syrup cakes made with all purpose flour or cake flour. Cereal Chemistry. 1990;67(5):502-4.
27. Koepsel K, Hoseney R. Effects of corn syrups in layer cakes [Food quality]. Cereal Chemistry (USA). 1980.
28. Conforti FD, Nee P, Archilla L. The synergistic effects of maltodextrin and high-fructose corn sweetener 90 in a fat-reduced muffin. International Journal of Consumer Studies. 2001;25(1):3-8.
29. Johnson J, Harris C, Barbeau W. Effects of high-fructose corn syrup replacement for sucrose on browning, starch gelatinization, and sensory characteristics of cakes. Cereal Chemistry (USA). 1989.
30. Murano P, Johnson J. Volume and sensory properties of yellow cakes as affected by high fructose corn syrup and corn oil. Journal of Food Science-Chicago. 1998;63:1088-92.
31. Ahmad FB, Williams PA. Effect of sugars on the thermal and rheological properties of sago starch. Biopolymers. 1999;50(4):401-12.
32. McCullough M, Johnson J, Phillips J. High fructose corn syrup replacement for sucrose in shortened cakes. Journal of Food Science. 1986;51(2):536-7.
33. Volpe T, Meres C. Use of high fructose syrups in white layer cake. Bakers Digest. 1976.
34. Hartnett DI. Cake compositions containing high fructose corn syrup. Google Patents; 1981.

35. Caniyilmaz E, Uçarkuş B, Karaman S. Optimization of Formulation Ingredients and Aging Time for Ice Cream Processing Using Combined Design Approach. Journal of Food Processing and Preservation. 2016.

36. Laura O, Pedro DS. High-Pressure Shift Freezing. Handbook of Frozen Food Processing and Packaging, Second Edition. Contemporary Food Engineering: CRC Press; 2011. p. 667-84.

37. Adapa S, Schmidt K, Jeon I, Herald T, Flores R. Mechanisms of ice crystallization and recrystallization in ice cream: a review. Food Reviews International. 2000;16(3):259-71.

38. Miller-Livney T, Hartel RW. Ice recrystallization in ice cream: Interactions between sweeteners and stabilizers. Journal of Dairy Science. 1997;80(3):447-56.

39. Ozdemir C, Arslaner A, Ozdemir S, Allahyari M. The production of ice cream using stevia as a sweetener. J Food Sci Technol. 2015;52(11):7545-8.

40. Smith KE, Bradley R. Effects on freezing point of carbohydrates commonly used in frozen desserts. Journal of Dairy Science. 1983;66(12):2464-7.

41. Hagiwara T, Hartel RW. Effect of sweetener, stabilizer, and storage temperature on ice recrystallization in ice cream. Journal of Dairy Science. 1996;79(5):735-44.

42. Pearson A. Sensory properties of high fructose corn syrup ice cream formulations. Journal of Food Science. 1979;44(3):810-2.

43. Amerinasab A, Labbafi M, Mousavi M, Khodaiyan F. Development of a novel yoghurt based on date liquid sugar: physicochemical and sensory characterization. Journal of food science and technology. 2015;52(10):6583-90.

44. Elizabeth I, Onyinyechi NG. Production and Evaluation of Yoghurt Flavored with Beetroot (Beta vulgaris L.). Journal of Food Science and Engineering. 2012;2(10):583.

45. Lisak K, Lenc M, Jeličić I, Božanić R. Sensory evaluation of the strawberry flavored yoghurt with stevia and sucrose addition. Hrvatski časopis za prehrambenu tehnologiju, biotehnologiju i nutricionizam. 2012;7(SPECIAL ISSUE-7th):39-43.

46. Zargaraan A, Saghafi Z, Hasandokht Firouz M, Fadavi G, Ghorbani Gorji S, Mohammadifar MA. Effect of Rheological Properties on Sensory Acceptance of Two-Model Dysphagia-Oriented Food Products. Journal of Texture Studies. 2015;46(3):219-26.

47. Keating KR, White C. Effect of alternative sweeteners in plain and fruit-flavored yogurts 1, 2, 3. Journal of Dairy Science. 1990;73(1):54-62.

48. Wittinger S, Smith D. Effect of sweeteners and stabilizers on selected sensory attributes and shelf life of ice cream. Journal of Food Science. 1986;51(6):1463-6.

49. Carman HF. A trend projection of high fructose corn syrup substitution for sugar. American Journal of Agricultural Economics. 1982;64(4):625-33.

50. Carman HF, Thor PK. High fructose corn sweeteners: economic aspects of a sugar substitute. Information series-Giannini Foundation of Agricultural Economics, University of California, Division of Agricultural Sciences (USA). 1979.

51. Dziedzic S, Kearsley M. Handbook of starch hydrolysis products and their derivatives: Springer Science & Business Media; 2012.

52. Cubenas GJ, Schrader LF, Ford JD. Cost of producing high-fructose corn syrup: an economic engineering analysis. Station bulletin-Department of Agricultural Economics. Experiment Station, Purdue University, West Lafayette, Indiana. 1979.

[DOI: 10.18869/acadpub.nfsr.3.4.3]