

HIGH FRUCTOSE CORN SYRUP IN SHORTENED CAKES

WITH MODIFIED CORN STARCH ADDITIVES

by

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(ABSTRACT)

Cakes were prepared with high fructose corn syrup (HFCS) at 0, 50, and 75% replacement for sucrose by weight of sugar and pregelatinized cross-bonded waxy corn starch added at 0, 0.5, and 1% by weight of flour. The water was adjusted to allow for the moisture content (literature value) of the syrup. Cakes were tested freshly baked, after 3 days of room temperature storage, and after 14 and 45 days of frozen storage (-16°C).

The pH, specific gravity, and sugar composition by HPLC were determined for the cake batters. Baked cakes were evaluated for moisture content, volume, and crust and crumb color. Photographs were taken to record the overall appearance. Sensory evaluation of crust and crumb color, moistness, tenderness, flavor, and overall acceptability were completed on all variations after each storage time.

The HFCS level and storage time were significant variables. The addition of starch had no effect on the quality of the cakes. Acceptable cakes were made at all levels of HFCS replacement for sucrose. Crust and crumb color were significantly ($P < 0.0001$) darker and volume was significantly ($P < 0.0001$) lower for cakes containing HFCS, however, there was little difference in cakes made with the two

levels of HFCS (50 and 75%). Storage did lower the overall quality of the cakes, but not significantly in all cases. Moisture content of the cakes stored for 14 days was equal to that of freshly baked cakes. Crust and crumb color continued to darken slightly with storage. A satisfactory cake suitable for frozen storage may be prepared using HFCS.

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INTRODUCTION

Corn syrups are defined in the United States as "purified concentrated solutions of nutritive saccharides obtained from corn starch and having a dextrose equivalent of 20 or more" (Wardrip, 1971). High fructose corn syrups (HFCS) undergo a further enzymatic reaction and contain upwards of 10% fructose (Wardrip, 1971). Corn syrup manufactured before World War II and as early as 1812 was produced by acid hydrolysis followed by a further enzymatic hydrolysis. The process was a "shredding" of the starch molecule to dextrans, maltose, and eventually, glucose which was then "reformed" to create fructose syrups (Casey, 1978). In 1967 Clinton Corn Processing¹ manufactured the first high fructose syrup. The glucose in high conversion corn syrups (91-95 dextrose equivalents) was converted to fructose by the immobilized enzyme glucose isomerase (Volpe and Meres, 1976; Anonymous, 1977). Glucose was reported to be approximately 75% as sweet as sucrose while fructose was 1870% as sweet (Shallenberger, 1963). The increased sweetness of HFCS over regular corn syrups reversed the direction of wet corn milling economics (Casey, 1978). Corn syrup produced from corn starch, a by-product of wet corn milling (Young, 1981), were previously sold on the basis of their functional properties, but HFCS now compete with cane and beet sugar on the basis of sweetness (Casey, 1978).

Young mentioned several positive functional properties of HFCS other than increased sweetness. These included high osmotic pressure

¹Clinton, Iowa.

which rendered systems microbiologically stable, fermentability which made HFCS useful in the wine and baked goods industries, hygroscopicity which increased the tendency of the system to pick up and hold moisture, and other characteristics which made storage and handling easier. Young (1981) also noted that HFCS participated in non-enzymatic browning or the Malliard reaction.

REVIEW OF LITERATURE

High Fructose Corn Syrup's Production and Use

Since 1967, syrups containing between 15-90% fructose have been produced. Currently, first generation HFCS is 42% fructose and second generation syrups 55 or 90% fructose. The uses for the first generation syrups include soft drinks, jams, jellies, frozen desserts, some yeast-raised baked goods, and salad dressings. Second generation syrups are added to table syrups, wine, low-calorie frozen yogurts, and desserts (Inglett, 1981).

The basic production process employed by industry in the making of HFCS is shown in Figure 1.

During the years since 1970, the use of high fructose corn syrup (HFCS) in foods steadily increased. Coleman and Harbers (1983) attributed the increased consumption of HFCS to the fact that during the same years the price of sucrose increased. For example, in 1981 HFCS was 50% cheaper than sucrose on an equal solids basis (Inglett, 1981). Coleman and Harbers (1983) stated that HFCS had the equivalent sweetness of sucrose because the fructose and glucose were present in similar proportions.

The advantages for HFCS use in beverages, both carbonated and still were reported by Crocco (1976). The syrup was stable and did not invert during storage in acidic food and beverage mediums. Clinton Corn Processing Co. recommended the replacement of sucrose by HFCS at the 55-60% level in beverages. Crocco (1976) reported acceptable results when sucrose was replaced with up to 75% HFCS.

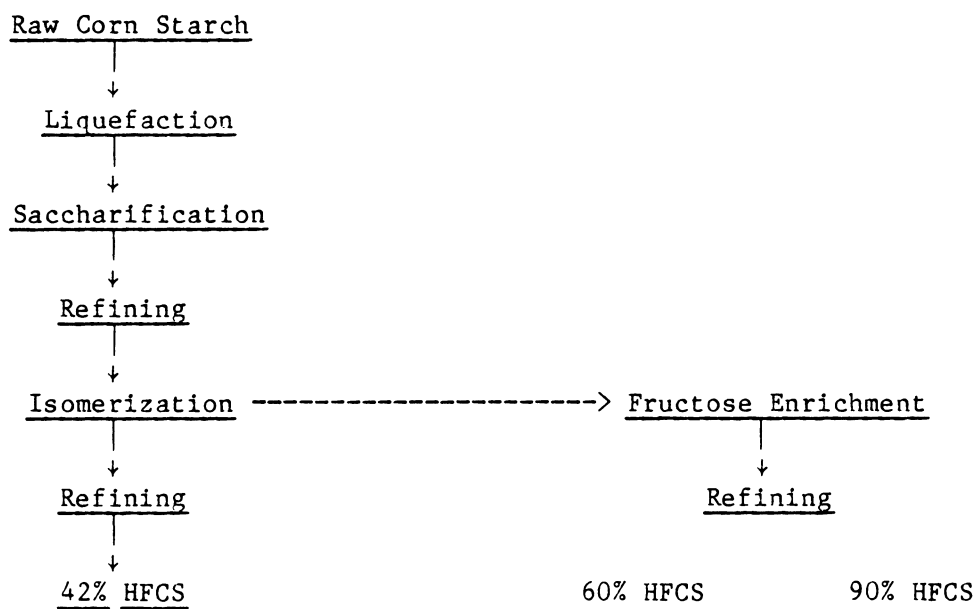


Figure 1: Manufacturing Process for High Fructose Corn Syrups
Reprinted from "Immobilized Enzyme Technology Produces
High-Fructose Corn Syrup" in Food Technology, 1977,
p. 56.

Isosweet 5500² was tested in beverages, jams, jellies, and preserves. HFCS inhibited crystal formation in the jams, jellies, and preserves. As the sucrose content was reduced and the HFCS content increased, the formation of crystals was reduced (Crocco, 1976). Paul (1972) stated that fructose does not crystallize as readily as sucrose. Fruit pie fillings, apple sauces, cordials, and canned fruits also included HFCS as an ingredient (Crocco, 1976).

The producers of HFCS reported that the clean taste and ease of storage and handling are additional advantages for use of the syrup. HFCS is liquid at ambient temperatures of 29-32°C. Therefore, little energy expenditure is needed to process the syrup through existing equipment. Glucose is added to food products in a liquid form, but must be heated to reach that state (Henry, 1976). Storage temperatures of 54°C are common. The clean taste of HFCS makes it a useful mask for saccharin in artificially sweetened beverages and may, in many cases, reduce the amount of saccharin used (Crocco, 1976).

Clinton Corn Processing Co. indicated several nonfood uses for HFCS which utilize the humectant properties, such as chewing tobacco, cough syrup and other pharmaceuticals (Crocco, 1976).

Finally, successful use of HFCS as a replacement for sucrose was made in bakery products such as yeast-leavened breads and sweet doughs. The replacement of sucrose with HFCS at the 100% level was satisfactory in both cases (Saussele et al., 1976). However, sweet doughs contain only a maximum of 20% sucrose by total weight of formula. The

²A.E. Staley Manufacturing Co.

fermentation characteristics, proof time and finished product quality of breads made with HFCS were equivalent to those made with sucrose. Based on this, Saussele et al. (1976) noted that high fructose corn syrups are not only less expensive than sucrose but possess equal functional properties. HFCS was also used in cookies with favorable results although the humectant quality of the syrup made only soft cookies suitable (Saussele et al., 1976).

Coleman and Harbers (1983) prepared cakes with HFCS as a replacement for sucrose and had several problems in the successful use of the syrup. Off flavors, lower volume, coarse texture, and excessive browning were characteristic of cakes made with HFCS as the sweetener. Saussele et al. (1976) used HFCS in several angel food and sponge cake formulations and concluded that specific gravity of batter and sweetness of cake did not change with the substitution of HFCS, but crumb color was not satisfactory at replacement levels of 25% and above. Only dark colored devil's food cakes were satisfactory at all levels of replacement. These authors suggested that spice cakes with naturally dark crumbs might also be suitable for HFCS as a replacement for sucrose, but that levels should be limited in yellow cakes and even more so in white cakes (Saussele et al., 1976).

Flour Mixtures/Sugar and Cakes

The five basic ingredients of cakes are flour, sugar, eggs, milk, and shortening. Each ingredient contributes to the appearance, taste, and overall quality of the product. Lawson (1970) categorized the ingredients into one or more of the following groups: "structure

builders or tougheners, tenderizers, moisteners, dryers, and flavorers." Flour was classed as a structure builder or toughener as well as a drying agent. Campbell et al. (1979) defined cake flour as a soft wheat flour having about 7.5% protein and 79.4% total carbohydrates (starch). Howard et al. (1968) reported starch as the major component of the structure of cake. Other starches have been substituted for wheat starch with varying results. Corn starch gave adequate, but not good results (Sollars and Rubenthaler, 1971).

Eggs were structure builders and moisteners by the classification of Lawson (1970). The protein content of the egg white and to a lesser extent the yolk contributed to the structure of the cake. The fat contained in the yolk also had a tenderizing effect and added the yellow color.

Milk or milk solids added structure to cakes and were classed as tougheners, as well as dryers and flavorers (Lawson, 1970). Milk also participated in carbonyl-amine reactions resulting in crust browning (Campbell et al., 1979).

Hunter et al. (1950) attributed tenderness and flavor of the cake to sugar. When incorporated as a syrup, sugar acted as a moistener (Lawson, 1970). The nonreducing sugar, sucrose, did not contribute to crust browning as did the reducing sugars glucose and fructose (Saussele et al., 1976).

Shortening, the fifth basic ingredient was categorized as a tenderizer and also an agent for improving keeping quality, fineness of grain and moistness (Lawson, 1970). Leavening agents produced gases

which increased the volume of the finished product and thus were as tenderizers by the lightening effect.

Matz's (1960) recommendation for the formulation of a high ratio cake or one in which the weight of the sugar is greater than the weight of the flour was as follows:

The weight of sugar equal to 1.1-1.8 times the weight of flour.

The weight of egg equal to or greater than the weight of shortening.

The weight of shortening equal to 30-70% the weight of flour.

The weight of liquid (eggs, milk, and water) greater than weight of sugar by 25-35%.

Based on consumer acceptability Lawson (1970) recommended the following ratios:

<u>Ingredients</u>	<u>Ratio</u>
Sugar:Flour	1.25:1
Eggs:Shortening	>1:1
Liquid:Sugar	>1:1

If eggs are expensive, then whole egg:shortening, 1:1 and egg white:shortening, >1:1.

If liquid shortening is used instead of plastic shortening, then more liquid is used.

Lawson (1970) also stated that the higher proportion of sugar, shortening, and especially liquids increased the shelf life, moistness, tenderness, and consumer acceptability. These high ratio formulations also limited the amount of chemical leavening needed as air was more readily incorporated in mixing (Matz, 1960).

Baking of the cake depended on several factors to produce the best cake possible. These included the size and shape of the pan, the amount of batter used, the material from which the pan was made and the oven temperature (Campbell et al., 1979). Charley (1952) reported that cake quality was more acceptable if heat penetration occurred rapidly. A shallow pan made of dark colored metal, correctly filled and placed in a moderate oven produced a cake with high volume, tender crumb, fewer peaks, and of an even golden brown color (Campbell et al., 1979).

Leavening Agents and pH Control

The reactions of leavening which made baked products light through expansion of carbon dioxide in the dough or batter during mixing and baking were outlined by Kichline and Conn (1970). The three reactions are:

1. Fermentation = Sugar + Yeast -----> Alcohol + CO₂

2. Decomposition = Ammonium bicarbonate heat→ Ammonia + Water + CO₂

$$\text{NH}_4\text{HCO}_3 \qquad \qquad \qquad \text{NH}_3 \qquad \qquad \qquad \text{H}_2\text{O}$$

$$= \text{Acetonedicarboxylic acid} \text{ heat→ } 2\text{CO}_2 + \text{Acetone}$$

$$\text{HOOCCH}_2\text{COCH}_2\text{COOH} \qquad \qquad \qquad \text{CH}_3\text{COO}$$

3. Acid salts + Sodium bicarbonate

$$\text{HX} + \text{NaHCO}_3 \text{ moisture→ } \text{NaX} + \text{N}_2\text{O} + \text{CO}_2$$

$$\text{acidic salt} + \text{soda} \text{ heat→ } \text{neutral salt}$$

The latter is the most commonly used for baked products such as cakes. The combination of the reaction by the leavening agent, air incorporated during mixing, and water evaporated as steam during baking served to give

cakes their desired volume (Ash and Colmey, 1973). The amount of leavening used in a cake formulation was the most rapid manner in which to change the pH and in turn affect certain qualities in the finished product (Ash and Colmey, 1973). The qualities of taste, crumb and crust color, volume, and overall texture were affected by a pH which was too high or too low (Ash and Colmey, 1973). A cake with an acidic pH had a sour taste. Ingredients which contributed to acidic batters include corn syrup, invert syrup, cake flour, milk, dextrose, and acid leavenings such as cream of tartar (Ash and Colmey, 1973). Conversely, alkaline cakes were reported to have a soapy or soda taste caused by additions of cocoa, eggs, soda, and in some areas of the country, water. An elevated pH also caused darkening of crust and crumb in white and yellow cakes, reddening of chocolate cakes, and darkening of molasses containing products such as gingerbread (Ash and Colmey, 1973). Although an increased volume may be achieved with increased pH, the crumb becomes coarse and heavy according to Ash and Colmey (1973). The pH levels between 6.5-7.5 were found in cake formulation with a good balance of ingredients and leavening agents (Ash and Colmey, 1973).

The type of cake determined the desired pH level in the finished product within the range of 6.5-7.5. Ash and Colmey (1973) reported that citrus flavors were best at a slightly acidic pH, chocolate at a slightly alkaline pH and vanilla flavors peaked at the neutral pH. Color was also aided by slight changes in hydrogen ion concentration. The carbonyl-amine reaction and sugar caramelization were slowed in acidic batters (Campbell et al., 1979).

This accounted for the bright white color of a white cake at less than neutral pH (Ash and Colmey, 1973; Kichline and Conn, 1970). Ash and Colmey

(1973) stated that other advantages of a lower batter pH was increased keeping qualities and more stability.

HFCS Replacement in Baked Goods/Problems

Researchers have encountered several problems which limit the frequency and quantity of HFCS use. Volpe and Meres (1976) stated that the most severe problem was browning of the crust and crumb when HFCS was incorporated into cakes. Coleman (1983) noted that browning, flavor, volume, and texture of cakes were affected by both the type and amount of sweetener used. Maillard browning appeared to be the major source of the problem caused by the presence of the monosaccharides fructose and glucose in the HFCS. The non-reducing sugar sucrose had only a limited action in the Maillard reaction (Volpe and Meres, 1976). Stickler (1981) noted that with the use of HFCS not only did the crust brown excessively, but in both white and yellow cakes the crust was thick and the crumb color was uneven. HFCS was acidified with lactic acid to alleviate the color problems, and successful small and layer cake formulations were made with up to 80% replacement of sucrose with HFCS. Other researchers have noted excessive browning at 50% replacement (Koepsel and Hosney, 1980) and 15-25% replacement (Saussel et al., 1976). Volpe and Meres (1976) suggested incorporating the syrup into dark colored or small sized cakes with shorter baking times. Saussel et al. (1976) also suggested the use of chocolate or spices to mask the color changes. The flavor of HFCS cakes was acceptable, although some differences were noted. Volpe and Meres (1976) reported a sour taste in HFCS cakes leavened with glucono-delta-lactone (GDL), or

sodium aluminum phosphate-monocalcium phosphate, monohydrate (SAP-MCP, MH), but acceptable results were achieved with the use of sodium acid pyrophosphate (SAPP). These workers suggested improvement in the flavoring system to mask the undesirable acidic taste incurred with the use of high acid leavening systems. Coleman and Harbers (1983) reported lower scores for sweetness of angel food cakes made with 50 and 100% substitution of HFCS for sucrose and that two-thirds of the panelists noted a bitter taste in some of the cakes. Sweetness scores for 25% HFCS replacement of sucrose in cakes were equal to scores for the controls and the panelists commented that the cakes made with that level of HFCS substitution were quite acceptable.

Volume and texture will be discussed together as they contribute to the overall appearance of the cake. Strickler (1981) stated that significant decreases in cake volume occurred with the use of HFCS. Further, the cake crumb was overly moist and dense, and these cakes required extended baking times. The exact percentage of replacement was not noted. Saussele et al. (1976) made cakes with 25% replacement of sucrose and reported no textural changes found, and these volume changes were attributed to mixing variables instead of the type of sweetener used.

In an exploration of the nature of the problem of HFCS replacement for sucrose in layer cakes, Koepsel and Hosney (1980) substituted HFCS at the 50 and 100% levels. Volume was equally poor in both cases with an open grain for the cakes made with 50% sucrose and 50% HFCS. A coarse grain was reported for the cakes made with total substitution of

HFCS for sucrose. Volpe and Meres (1976) reported on a variety of parameters including grain, texture, and symmetry of the cake. All substitution of HFCS for sucrose was at the 60% level, but a variety of acid leavenings were tested. Sensory scores for all the cakes made with HFCS were good for the grain, two out of three of the cakes made with HFCS were scored above the cakes made with all sucrose for texture, and symmetry of all cakes was scored as highly acceptable.

Coleman and Harbers (1983) prepared angel food cake with HFCS and evaluated these for volume and texture. Volumes for cakes made with 25% replacement of sucrose with HFCS were comparable to volumes of cakes made with all sucrose, however, cakes made with 50, 75, and 100% replacement of sucrose with HFCS had decreasing volumes with increasing levels of HFCS. This was attributed to premature gelatinization of starch incurred by the increased use of HFCS as previously reported by Bean (1978) and Koepsel and Hosney (1980). Sensory evaluations for tenderness and moistness indicated that the 25% substitutions for these characteristics were satisfactory. The angel food cakes prepared with 50, 75, and 100% HFCS replacement of sucrose were firmer than those made with less syrup.

Waxy Corn Starch and Corn Starch Additives

Hahn and Hood (1980) stated that processed food quality can be enhanced by the addition of modified starches. Katzbeck (1972) added pregelatinized starches and particularly pregelatinized waxy starches to dilute and weaken gel structures. The dilution was effective as the waxy starches contained only amylopectin or the branched portion of the

starch which did not leach out of the granule. Increased viscosity was possible without the problem of retrogradation. Waxy starches were also reported to have a high water binding capacity and to resist gel formation with increased apparent moisture retention and improved shelf life (Schoch, 1965; Osman, 1972). Cross bonding of waxy starches, in particular corn starch, eliminated undesirable characteristics and improved the products by increasing the viscosity, improving tolerance to acidity, and strengthening the granule (Lineback and Ingelett, 1982).

Mousseri et al. (1974) concluded that both pregelatinized waxy corn starch and phosphated waxy sorghum (hydrophilic) starch had greater water binding capacity than did ordinary corn starch. Schoch (1965) indicated that properties of waxy sorghum and waxy corn may be considered interchangeable, therefore, reinforcing the claim of increased apparent moisture retention in baked products made with added cross bonded waxy corn starch.

Freeze-thaw Behavior of Baked Goods

Pence and Heid (1960) reported that cakes stored frozen for one month were superior to day-old non-frozen cakes. These authors further indicated that texture deteriorated before flavor did. When stored at -12°C cakes became crumbly with a harsh crumb, but below -12°C cakes were soft and gummy in texture.

Bamford (1975) recommended blast freezing at -40°C in single unit boxes with plastic overwrap for the best preservation of cakes. Formulation changes that included oil rather than solid shortenings helped to preserve tenderness of the product. Bamford (1975) concluded

that the addition of freeze-thaw stable starches, colloids, and gums aided in the prevention of moisture rearrangement, particularly in puddings and pie fillings.

MATERIALS AND METHODS

Pilot study and Experimental Design

Cake formulations for use in this study were established by a pilot study during the Summer of 1984.

The experimental design shown in Table 1 was based on the results of the pilot work. Three levels of pregelatinized cross-bonded waxy corn starch, 0, 0.5, and 1% by weight of flour, and three levels of high fructose corn syrup (HFCS), 0, 50, and 75% by weight of sugar were used. The water was adjusted to allow for the moisture content (literature value) of the syrup.

The formulations, mixing and baking procedures for each of the variations is shown in Appendix A.

Procurement and Storage of Ingredients

Two 25-gallon drums of IsoSweet 100 High Fructose Corn Syrup, Lot 4H1X4 were obtained from A.E. Staley Manufacturing Co.¹

One 25-pound bag of Amaizo Instant 721-A pregelatinized phosphate cross-bonded waxy corn starch was obtained from American Maize-Products Company.²

Two 50-pound bags of all purpose, enriched, bleached flour were obtained from Roanoke City Mills³ and milled from the same lot of wheat.

Other cake ingredients were obtained from a local grocery.

¹Decatur, Illinois.

²Harmond, Indiana.

³Roanoke, Virginia.

TABLE 1
Experimental Design

Cross-bonded waxy corn starch ²	HFCS ¹		
	0%	50%	75%
0%	1	4	7
0.5%	2	5	8
1%	3	6	9

¹Percentage based on weight of sucrose and moisture content of HFCS.

²Percentage based on weight of flour.

All ingredients, except the eggs, were stored at ambient temperatures in a non-air-conditioned laboratory out of direct light. Both the flour and waxy corn starch were stored in plastic bags placed inside air-tight plastic containers with close fitting lids. The HFCS was stored in the original 25-gallon drums. Eggs were stored in a refrigerator compartment of a Frigidaire Frost Proof refrigerator, Model FP CL-170T. All ingredients except the HFCS, waxy corn starch and flour were purchased as needed, approximately two days prior to use.

Preliminary Objective Measures

Flour moisture was determined by a Brabender Moisture Tester, Model SAS-692. Duplicate ten gram samples were dried for one hour at 110°C.

Sugar composition of the HFCS was determined by HPLC using a Perkin-Elmer, Model LC 25 RI Detector and the following conditions:

column: 300 mm HPX87C

temperature: 85°C

flow rate: 0.6ml/minute

solvent: degassed filtered HPLC grade water

pressure: 400psi

The pH of the HFCS and of the cake batters were measured using a Fisher Accumet pH Meter, Model 600. Specific gravity of each batter variation was determined using the following formula:

$$\text{specific gravity} = \frac{\text{weight of 50ml of cake batter}}{\text{weight of 50ml of water}}$$

The volume of the baked cakes was determined by averaging the standing height at the four corners, one centimetre from each edge, and the geometric center as measured by vernier calipers.

Baking and Evaluation Schedule

Four storage times and conditions were chosen with three replications of each as follows:

<u>Storage of cakes</u>	<u>Baking dates</u>	<u>Evaluation dates</u>
45 days, frozen	October 13, 14, 15	November 26, 27, 28
14 days, frozen	October 29, 30, 31	November 12, 13, 14
3 days, room temperature	November 2, 3, 4	November 5, 6, 7
0 days, freshly baked	October 22, 23, 24	October 22, 23, 24

One of each of the nine variations were baked on each of the 12 baking days. Cakes were removed from the oven, left in the pan, and placed on cooling racks until all of the cakes were baked. Thus, the first two cakes baked were left in the pan for about 3 hours and the last cake taken from the oven was left in the pan about 30 minutes before being turned out onto a cooling rack. Freshly baked cakes were evaluated when cooled to room temperature. The cakes that were stored for 3 days were removed from the pans and wrapped in plastic wrap prior to room temperature storage. Cakes stored for 14 to 45 days were wrapped in freezer paper and sealed with freezer tape prior to being stored in the freezer section of the Frigidaire Frost Proof refrigerator, Model FP CL-170T at -16°C . Frozen cakes were thawed at room temperature prior to evaluation.

Objective Measures

Objective evaluations performed on each cake included, moisture determination by a Brabender Moisture Tester, Model SAS-692. A ten gram sample was dried for 1 1/2 hours at 110°C. Color differences were determined on both crust and crumb using a Hunter Lab Model D25 Color and Color Difference Meter, Serial No. 683. The instrument was standardized using a white tile, standard number C20-1651; $L_1 = 91.97$, $a_1 = -0.8$, $b_1 = -1.0$. Crumb and crust samples were pressed into the bottom of Agron sample cups to minimize surface variations. Two readings of each sample were recorded. Overall appearance was objectively recorded using photography.

Sensory Evaluation

Sensory evaluation was done by an experienced taste panel composed of four members from the faculty and students in the Department of Human Nutrition and Foods at Virginia Polytechnic Institute and State University. Each panelist tasted each of the nine variations once for each of the four storage times (Appendix B). Tasters received three 4cm×4cm×4cm samples of cake randomly labeled with a two letter code at each of twelve tasting sessions. Panelists were asked to refrain from eating, drinking, smoking or chewing gum for thirty minutes before each tasting session. They were also instructed to rinse the mouth with distilled water between each sample. Cakes were evaluated for crust and crumb color, flavor, moistness, tenderness, and overall acceptability. A sample sensory score sheet is shown in Appendix C. All tasters sat at

individual sensory booths, with neutral gray walls and individual florescent lights.

The location of each cake sample within the cake that was used for objective and sensory evaluation is shown in Appendix D.

Statistical Analysis

Statistical analysis consisted of a two-way analysis of variance for the objective data and an incomplete split plot design (Robinson, 1967) for the sensory data. Duncan's Multiple Range Test was used to determine differences among means.

RESULTS

The purpose of this study was to determine suitable levels of high fructose corn syrup (HFCS) replacement for sucrose in shortened cakes, and the effect of the addition of pregelatinized cross-bonded waxy corn starch on improved cake quality. Throughout this discussion the cakes will be identified by their percentage of HFCS for replacement of sucrose because it was found that the amount of starch added made no difference in quality of cake. The storage times will be identified by the number of days held before testing. Freshly baked cakes were evaluated after baking and cooling; 3 day cakes were held at room temperature for 3 days prior to evaluation; 14 day cakes were frozen for 14 days and thawed before evaluation; 45 day cakes were frozen for 45 days and thawed prior to evaluation.

Objective Measurements/HFCS

The amount of HFCS used had a significant effect on the pH and specific gravity of the batters as shown in Table 2. The pH of the batter made with 75% HFCS was significantly ($P < 0.0001$) lower than the pH for all other batters. The acidity of the HFCS (pH 3.2) contributed, in part to this lower pH for the batters made with the higher level of HFCS. The specific gravity increased with increasing amounts of HFCS substitution.

Mean volume and moisture values for the three tested levels of sucrose:HFCS are given in Table 3. The replacement of sucrose with HFCS significantly ($P < 0.0001$) lowered the volume of the baked cake. The moisture content was significantly ($P < 0.0001$) different for cakes

TABLE 2

Mean¹ pH and Specific Gravity Values for Cake Batters Made with
0, 50, and 75% HFCS as a Replacement for Sucrose

HFCS	pH		Specific Gravity	
	Mean	Range	Mean	Range
0	7.02a ²	6.7-7.5	0.93a	0.85-1.01
50	7.00a	6.7-7.5	0.97b	0.9-1.02
75	6.90b	6.7-7.4	1.03c	0.98-1.11

¹Mean values from 36 replications.

²Values in the same vertical row bearing the same letters are not significantly different ($P < 0.0001$), determined by ANOVA.

TABLE 3

Mean¹ Standing Height as an Index to Volume and Moisture Content
for Baked Cakes Made with 0, 50, and 75% HFCS as a
Replacement for Sucrose

HFCS	Index to Volume (cm)		Moisture Content (%)	
	Mean	Range	Mean	Range
0	3.54a ²	3.39-3.79	29.39a	26.4-30.9
50	3.00b	2.36-3.28	30.33b	26.7-32.1
75	2.99b	2.66-3.34	27.72c	24.5-29.2

¹Mean values from 36 replications.

²Values in the same vertical row bearing the same letters are not significantly different ($P < 0.0001$), determined by ANOVA.

made with all levels of HFCS. The cakes made with 50% HFCS had the highest moisture content.

When compared to a standard white tile, Hunter Color Meter ΔE values are shown in Table 4. Calculated cake crust and crumb colors were significantly ($P < 0.0001$) different for all treatments. The crust of the cake made with 50% HFCS was the palest and although significantly ($P < 0.0001$) darker, the crust of the cake made with 75% HFCS was acceptable. The crumb color was darker with increasing levels of HFCS.

Photographs of the cakes which were taken to objectively record the overall appearance are shown in Figures 2-7. The cake in Figure 2 was made with 100% sucrose and 0% starch. Cake variations 2 and 3, shown in Figure 3, contained 100% sucrose and 0.5 and 1% starch, respectively. Cake variation 4, pictured in Figure 4, contained 50% sucrose, 50% HFCS, and 0% starch. Figure 5 displays cake variations 5 and 6 made with 50% sucrose, 50% HFCS, and 0.5 and 1% starch, respectively. The cake in Figure 6 was made with 25% sucrose, 75% HFCS, and 0% starch. Cake variations 8 and 9, pictured in Figure 7, were made with 25% sucrose, 75% HFCS, and 0.5 and 1% starch, respectively.

Objective Measurements/Storage Time

Results of the moisture content (Table 5) and color difference measurements (Table 6) were determined after each of the four storage times. Cakes stored for 3 days were evaluated to determine the effects of storage at ambient temperatures. The cakes stored frozen for 14 and 45 days were studied to assay the effects of freezing/thawing and of frozen storage. The moisture content of freshly baked cakes and cakes stored for 14 days was significantly ($P < 0.0001$) different from cakes.

TABLE 4

Mean¹ ΔE Values² as Determined by the Hunter Color Meter of Crust
and Crumb Color for Baked Cakes Made with 0, 50, and 75%
HFCS as a Replacement for Sucrose

HFCS	Crust		Crumb	
	Mean	Range	Mean	Range
0	58.13a ³	50.2-64.0	21.08a	19.9-23.2
50	55.48b	47.0-65.0	22.48b	21.0-25.7
75	61.48c	54.1-68.7	24.80c	22.2-26.4

¹Mean values from 36 replications.

² ΔE is calculated by duplicate readings as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

³Values in the same vertical row bearing the same letters are not significantly different (P < 0.0001), determined by ANOVA.

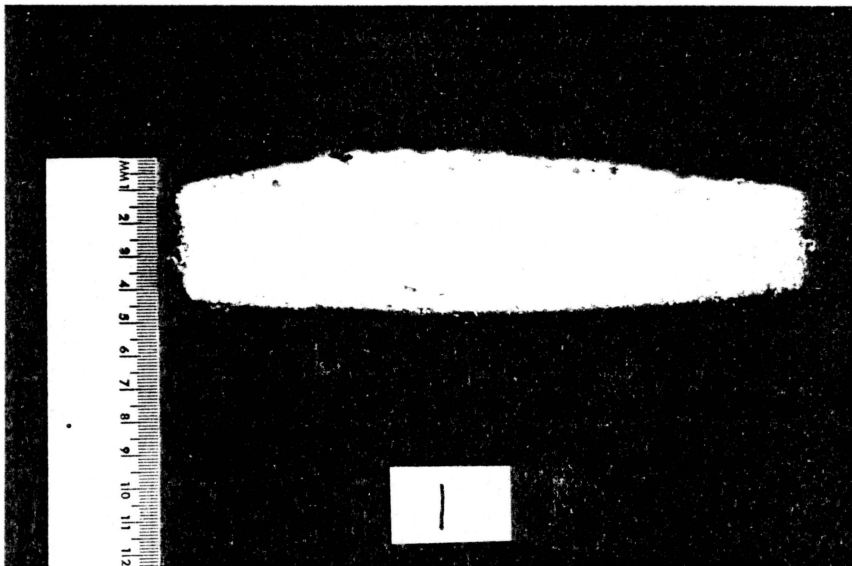


Figure 2: Photograph of Cake Variation 1 Made With 100% Sucrose and 0% starch

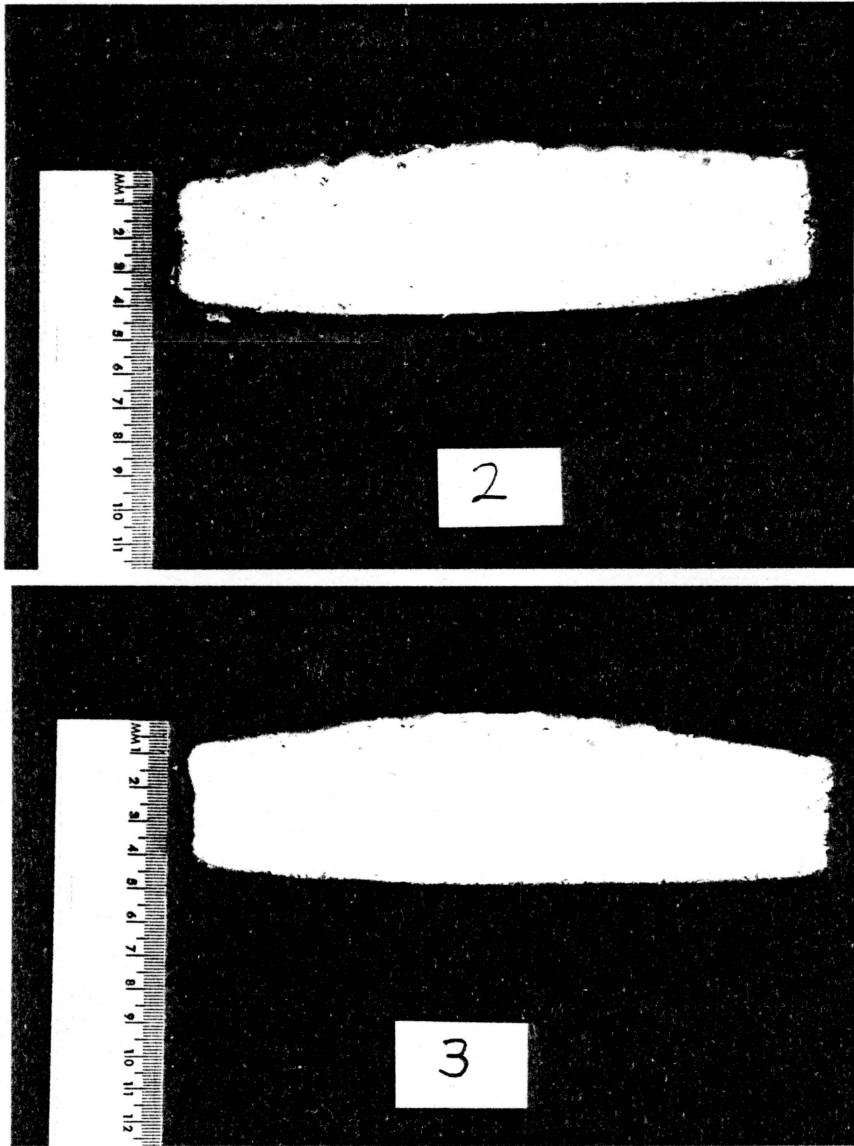


Figure 3: Photographs of Cake Variations 2 and 3 Made with 100% Sucrose and 0.5 and 1% Starch, Respectively

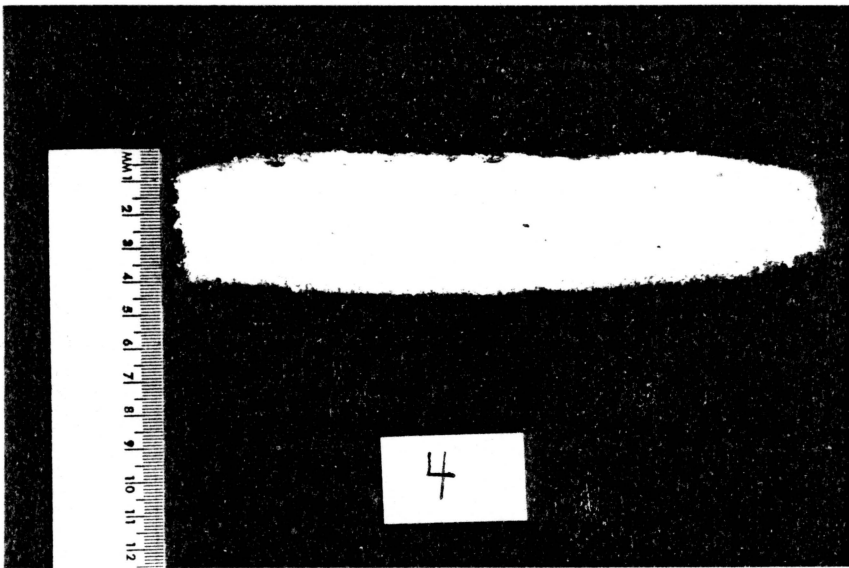


Figure 4: Photograph of Cake Variation 4 Made with 50% Sucrose, 50% HFCS, and 0% Starch

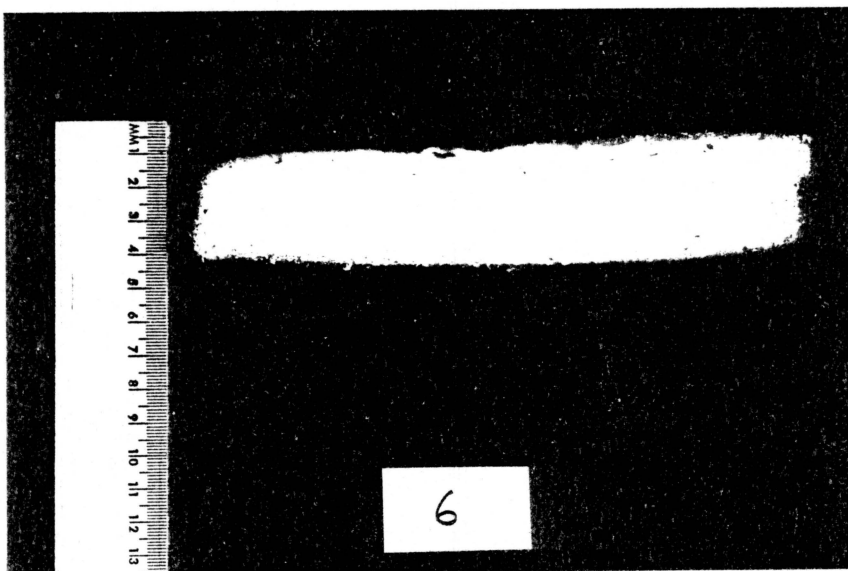
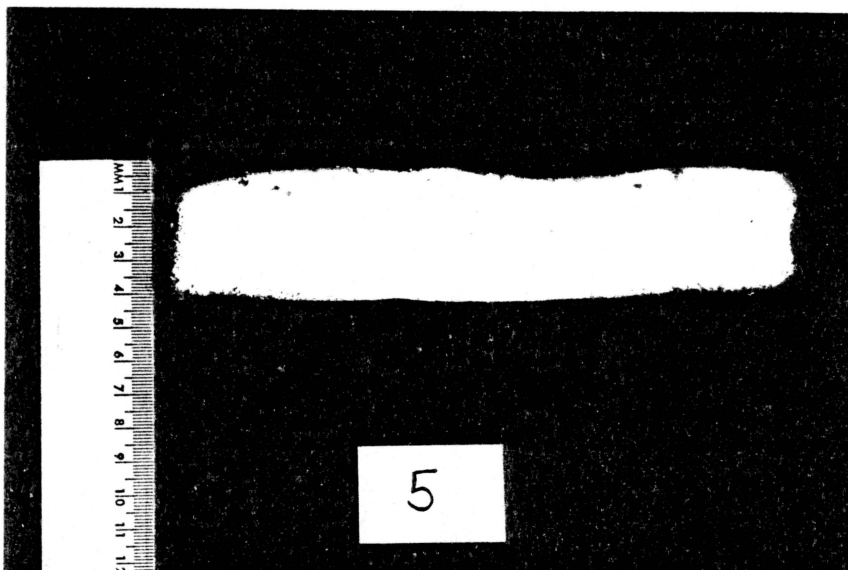


Figure 5: Photographs of Cake Variations 5 and 6 Made with 50% Sucrose, 50% HFCS, and 0.5 and 1% Starch, Respectively

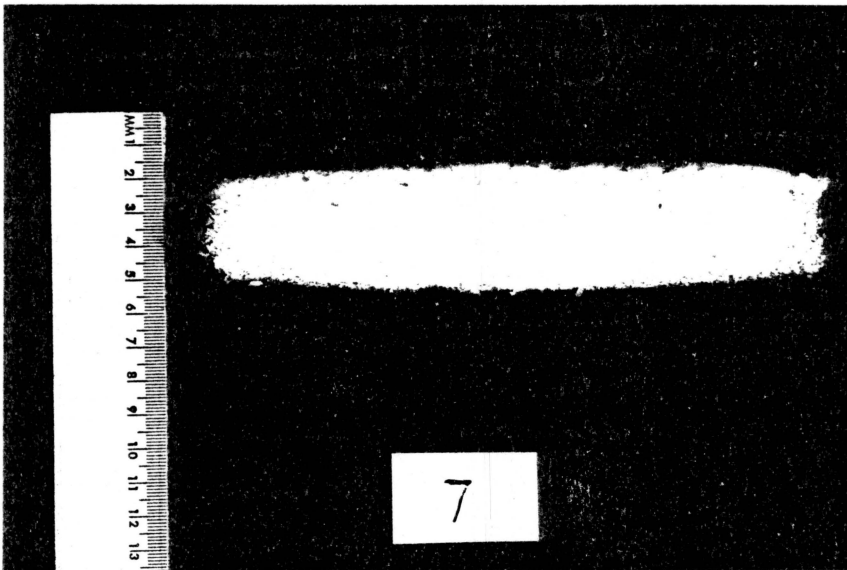


Figure 6: Photograph of Cake Variation 7 Made with 25% Sucrose, 75% HFCS, and 0% Starch

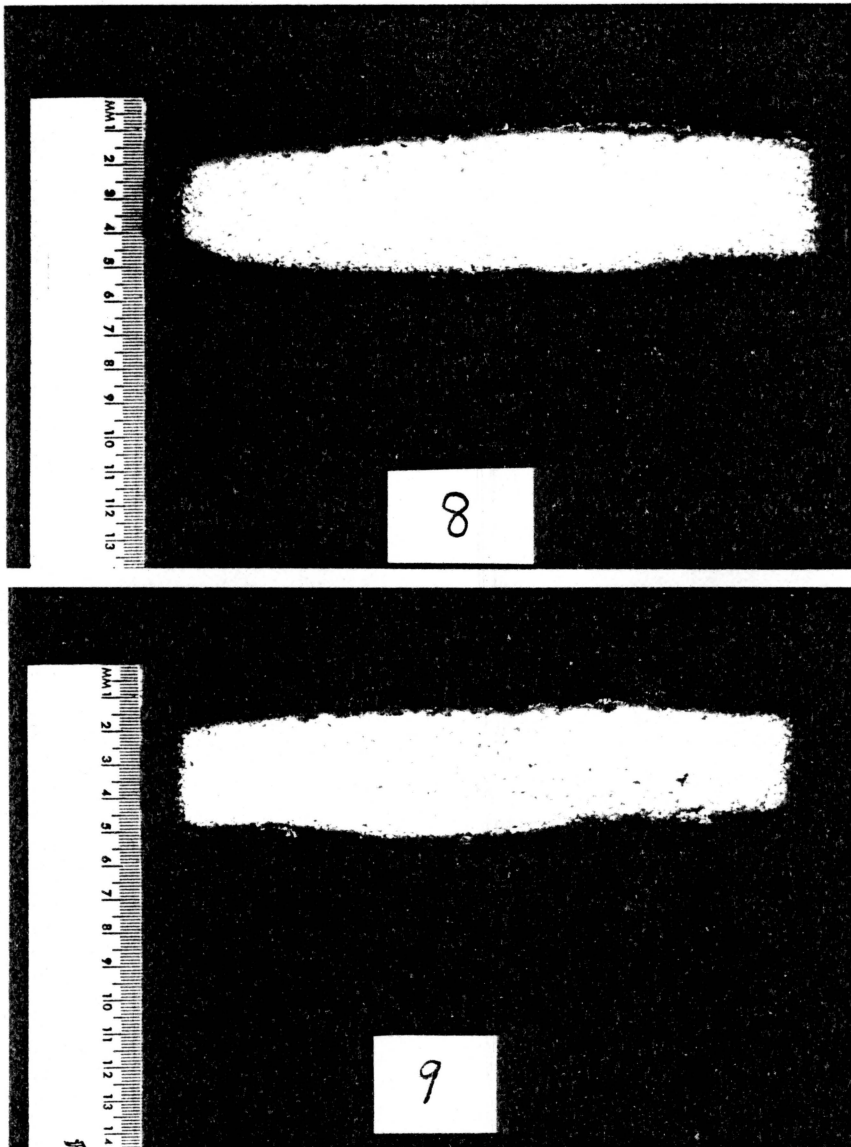


Figure 7: Photographs of Cake Variations 8 and 9 Made with 25% Sucrose, 75% HFCS, and 0.5 and 1% Starch, Respectively

TABLE 5

Mean¹ Moisture Content Values for Four Storage Times of Baked Cakes

Storage Time	Moisture Content (%)	
	Mean	Range
Freshly baked	30.00a ²	28.1-32.1
3 days	28.32b	26.4-30.8
14 days	29.61a	26.9-31.4
45 days	28.65b	25.5-31.4

¹Mean values from 27 replications.

²Values in the same vertical row bearing the same letters are not significantly different ($P < 0.0001$), determined by ANOVA.

TABLE 6

Mean¹ ΔE Values² as Determined by the Hunter Color Meter of Crust
and Crumb Color for Four Storage Times of Baked Cakes

Storage Time	Crust		Crumb	
	Mean	Range	Mean	Range
Freshly baked	56.54a ³	51.7-63.2	22.69a	20.3-25.7
3 days	57.69a	50.2-64.7	22.26b	19.9-25.4
14 days	58.15a	50.7-65.0	23.19c	20.6-25.8
45 days	61.07b	54.8-66.9	22.99a,c	20.5-26.4

¹Mean values from 27 replications.

² ΔE is calculated by duplicate readings as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.0001$), determined by ANOVA.

stored for 3 and 45 days. The moisture content was lower after 3 and 45 days of storage (Table 5).

The ΔE values calculated for crust and crumb color of cakes are shown in Table 6. After 45 days of frozen storage the crust color of cakes was significantly ($P < 0.0001$) darker than that of the crust of cakes at all other storage times. The color measurement of the fresh cake crumb was consistent with the values for crumb of cakes stored for 45 days, but significantly ($P < 0.0001$) different from values for crumb of cakes stored for 3 and 14 days. The crumb color of the cakes was the lightest after storage for 3 days and was significantly ($P < 0.0001$) darker after 14 and 45 days of storage.

Sensory Scores/HFCS

The results of sensory evaluation are shown in Tables 7-9. The crust color differed significantly ($P < 0.0001$) among treatments with cakes made with 50% HFCS being the lightest and cakes made with 75% HFCS being the darkest. This parallels the objective measure with the Hunter Color Meter. Unlike the differences perceived by the sensitive Hunter Color Meter in crumb color, the taste panel found no significant differences among crumb colors.

Sensory scores for flavor and moistness are shown in Table 8. Cakes made with 75% HFCS were significantly ($P < 0.01$) sweeter than cakes made with 0 or 50% HFCS. Cakes made with all sucrose and no HFCS were significantly ($P < 0.05$) less moist than either cakes made with 50 or 75% HFCS. This is a reflection of the hygroscopic properties of fructose. Tenderness and overall acceptability as rated by the taste panel are

TABLE 7

Mean¹ Sensory Scores² for Crust and Crumb Color of Baked Cakes
Made with 0, 50, and 75% HFCS as a Replacement for Sucrose

HFCS	Crust		Crumb	
	Mean	Range	Mean	Range
0	3.63a ³	1.0-7.5	0.74a	0-1.5
50	3.03b	1.0-6.25	0.88a	0-2.5
75	4.59c	1.0-7.75	0.94a	0-2.5

¹Mean values from 36 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = light brown, 8 = dark brown for crust and 0 = light brown (pale for a white cake), 8 = dark brown.

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.0001$ for crust; $P < 0.05$ for crumb), determined by ANOVA.

TABLE 8

Mean¹ Sensory Scores² for Flavor and Moistness of Baked Cakes
 Made with 0, 50, and 75% HFCS as a Replacement for Sucrose

HFCS	Flavor		Moistness	
	Mean	Range	Mean	Range
0	4.03a ³	1.5-6.25	3.97a	0.75-6.5
50	3.85a	0.5-7.0	4.52b	1.0-7.25
75	4.59b	1.5-7.5	4.45b	2.0-7.25

¹Mean values from 36 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = bland, 8 = sickly sweet for flavor and 0 = dry, 8 = wet for moistness.

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.01$ for flavor; $P < 0.05$ for moistness), determined by ANOVA.

TABLE 9

Mean¹ Sensory Scores² for Tenderness and Overall Acceptability of Baked Cakes Made with 0, 50, and 75% HFCS as a Replacement for Sucrose

HFCS	Tenderness		Overall Acceptability	
	Mean	Range	Mean	Range
0	4.25a ³	1.5-7.25	4.36a	2.5-7.5
50	3.11b	0.5-6.01	3.16b	0.75-6.0
75	4.02a	1.0-6.75	3.44b	1.5-5.25

¹Mean values from 36 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = tough, 8 = crumbly for tenderness and 0 = not acceptable, 8 = very acceptable.

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.001$ for tenderness; $P < 0.0001$ for overall acceptability); determined by ANOVA.

HFCS. This is a reflection of the hygroscopic properties of fructose. Tenderness and overall acceptability as rated by the taste panel are shown in Table 9. Cakes made with 50% HFCS were recorded as significantly ($P < 0.001$) less tender than cakes made with 0 or 75% HFCS. Although the cake made with all sucrose and no HFCS was significantly ($P < 0.0001$) more acceptable than either the cake made with 50 or 75% HFCS, the cake made with 75% HFCS was more acceptable than the cake made with 50% HFCS.

Sensory Scores/Storage Time

The sensory scores after the four storage times are presented in Tables 10-12. These data indicated that storage time had no effect on the crust color, but the crumb color was significantly ($P < 0.01$) darker after 3 days of storage.

Cakes stored for 14 days were rated significantly ($P < 0.05$) different in flavor (sweetness) from the cakes stored for 45 days (Table 11). Cakes stored for 14 days were the least sweet and cakes stored for 45 days were the sweetest. The sugar composition of HFCS is shown in Table 13.

Scores for the sensory evaluation of tenderness and overall acceptability are shown in Table 12. Cakes stored for 3 days were rated significantly ($P < 0.05$) more crumbly than freshly baked cakes or cakes stored for 14 or 45 days. All freshly baked cakes were significantly ($P < 0.01$) more acceptable than stored cakes. The amount of HFCS used had no effect on acceptability after storage.

TABLE 10

Mean¹ Sensory Scores² for Crust and Crumb Color for Four Storage Times of Baked Cakes

Storage Time	Crust		Crumb	
	Mean	Range	Mean	Range
Freshly baked	3.87a ³	1.25-7.75	0.74a	0.25-2.5
3 days	3.89a	1.0-6.5	1.13b	0-2.5
14 days	3.27a	0.75-6.25	0.82a	0-2.25
45 days	3.96a	1.0-6.25	0.72a	0-1.75

¹Mean values from 27 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = light brown, 8 = dark brown for crust and 0 = light brown (pale for a white cake), 8 = dark brown.

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.05$ for crust; $P < 0.01$ for crumb), determined by ANOVA.

TABLE 11

Mean¹ Sensory Scores² for Flavor for Four Storage
Times of Baked Cakes

Storage Time	Flavor	
	Mean	Range
Freshly baked	4.12a,b ³	1.0-7.0
3 days	4.33a,b	1.25-7.0
14 days	3.78a	0.5-7.0
45 days	4.40b	1.25-7.5

¹Mean values from 27 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = bland, 8 = sickly sweet for flavor.

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.05$), determined by ANOVA.

TABLE 12

Mean¹ Sensory Scores² for Tenderness and Overall Acceptability
for Four Storage Times of Baked Cakes

Storage Time	Tenderness		Overall Acceptability	
	Mean	Range	Mean	Range
Freshly baked	4.00a, b ³	0.75-7.25	4.36a	2.0-7.5
3 days	4.35a	1.5-7.0	3.40b	1.25-5.75
14 days	3.37b	0.5-5.5	3.39b	0.75-7.25
45 days	3.45b	0.5-7.25	3.45b	0.75-5.75

¹Mean values from 27 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = tough, 8 = crumbly for tenderness and 0 = not acceptable, 8 = very acceptable for overall acceptability.

³Values in the same vertical row bearing the same letters are not significantly different ($P < 0.05$ for tenderness; $P < 0.01$ overall acceptability), determined by ANOVA.

TABLE 13

Sugar Composition of HFCS by HPLC

Sugar	# of Carbon Atoms	mg/ml of carbohydrate
Glucose Oligomer	6	0.1250
Sucrose	12	0.4320
Glucose	6	7.2819
Fructose	6	6.2318
Psicose	6	0.1900

DISCUSSION

Three levels of high fructose corn syrup (HFCS) as a replacement for sucrose (0, 50, 75%) in cakes were explored with pregelatinized cross-bonded waxy corn starch substitution for a small percentage of the flour (0, 0.5, 1%). The cakes were evaluated immediately after baking and cooling, after 3 days storage at ambient temperatures and after 14 and 45 days storage frozen to compare the qualities after staling, freeze-thawing, and frozen storage with the qualities of freshly baked cakes.

Objective Measurements/HFCS

The pH of the HFCS (pH 3.2) contributed to lowering the pH of the batter which decreased the browning characteristics of cakes made with HFCS. This concurs with the work of Ash and Colmey (1973) and Kichline and Con (1970).

Specific gravity of the batter was significantly different for all three levels of substituted HFCS. Specific gravity was increased with increased levels of substituted HFCS. This was attributed to the specific gravity of the syrup and decreased air incorporation during the mixing due to use of syrup rather than crystalline sugar.

During visual observations of the batters it was noted that as the amount of crystalline sugar was reduced, the viscosity was decreased and the color of the batter had a grayish tint.

Cake volume was highest for the cakes made with 100% sucrose. Although cakes made with HFCS were significantly lower in volume they were still of an acceptable height. There was no difference in volume

between cakes made with 50 and 75% HFCS. Koepsel and Hoseney (1980) and Strickler (1981) both reported a decreased volume that was unacceptable in cakes made with HFCS. The lower volume was attributed to decreased air incorporation during mixing. The pregelatinized cross-bonded waxy corn starch had no effect on volume.

Moisture content for cakes made with each level of HFCS was significantly ($P < 0.0001$) different from one another. The cakes made with 50% HFCS were the most moist and cakes made with 75% HFCS the least. The nature of the mathematical computations used resulted in formulations whereby the total gram weight of the batters were different. The batter made with 50% HFCS weighed the least and the batter made with 75% HFCS weighed the most. Even though a consistent amount of batter was baked for each variation, the overall moisture content was different.

Hunter Color Meter readings for cakes at each of the three HFCS levels were significantly ($P < 0.0001$) different. Cakes made with 75% HFCS had the darkest crust color and the darkest crumb color. This is consistent with the reaction of fructose in carbonyl-amine browning reactions. A comparison of the moisture content (Table 3) and the crust color (Table 4) indicated that increased levels of moisture were associated with decreased browning. Campbell et al. (1979) stated that "Browning rate generally is higher at low to intermediate moisture levels than at very high or very low levels." The crumb color of cakes were darker with increased amount of HFCS which is attributed to the pale amber color of the HFCS and the increased carbonyl-amine browning resulting from the presence of glucose and fructose in the syrup.

Objective Measurements/Storage Time

Storage times were varied to observe changes during ambient temperature storage, from freeze-thaw, and cakes stored frozen. The moisture content (Table 5) was similar between freshly baked cakes and cakes stored 14 days and between cakes stored for 3 and 45 days. However, there were significant ($P < 0.0001$) differences between the two groups. Evaporation may account for moisture loss from cakes stored for 3 days and sublimation for cakes stored for 45 days. Cakes stored for 14 days retained a moisture content similar to the freshly baked cakes.

The measurements made by the Hunter Color Meter for browning after storage are shown in Table 6. The cakes stored for 45 days were significantly ($P < 0.0001$) darker than cakes stored for 3 days. Although freezer temperatures inhibit carbonyl-amine browning they do not prevent this mechanism. A gradual increase in crumb darkening is attributed to the slowing, but not stopping of the carbonyl-amine browning. Crust and crumb color of cakes stored for 14 and 45 days were darker than crust and crumb of cakes freshly baked or stored for 3 days. The significantly ($P < 0.0001$) lighter color of the crumb in cakes stored for 3 days may be attributed to attraction of water to the protein contained in the crumb. This attraction made the protein unavailable for participation in the Malliard reaction.

Sensory Scores/HFCS

Sensory evaluation of crust color of cakes baked with the three levels of HFCS concurred with the Hunter Color Meter readings. All three cakes were significantly ($P < 0.0001$) different with cakes prepared with

50% HFCS being the palest and cakes prepared with 75% HFCS identified as the darkest by both Hunter Color Meter and sensory values. The explanation of increased moisture content delaying the carbonyl-amine browning applies here. The taste panelists were unable to detect any differences in crumb color for the sample. Samples given to the taste panel had not been manually compressed as had those used with the Hunter Color Meter, thus the color was not as concentrated and differences not as noticeable to the human eye.

Members of the taste panel evaluated flavor (Table 8) as defined by sweetness and determined that cakes made with 75% HFCS were significantly ($P < 0.01$) sweeter than cakes made with 0 or 50% HFCS. This may be attributed to the fructose content of the syrup (Table 13) and the flavor concentration due to decreased moisture content (Table 13). This suggests that a change in formulation would be an appropriate topic for future research.

There were significant ($P < 0.05$) differences between cakes containing HFCS and those made with all sucrose in scores for sensory moistness (Table 8). The moisture holding capacity of the fructose in the syrup contributed to the increased moistness of the cakes made with HFCS.

Significant ($P < 0.001$) differences in tenderness were detected by the sensory panel members. Cakes made with 50% HFCS were less tender than cakes made with either 0 or 75% HFCS. Curley and Hosney (1984) reported that a higher replacement of HFCS in cookies caused more sucrose to be dissolved during the mixing than during the baking process. The

recrystallization of sugars in the cookies after baking was slower when more had been dissolved on mixing. This may explain the increased moistness and may have decreased tenderness of the cakes containing 50% HFCS. As the cakes containing 50% HFCS were made with less syrup than the cakes containing 75% HFCS, more sucrose may have dissolved during the baking process than during the mixing. If so, then more recrystallization of sugar may have occurred after baking in the cakes made with 50% HFCS. The recrystallization frees water to contribute to moistness and lower the apparent tenderness of the cakes made with 50% HFCS.

Cakes made with all sucrose were scored significantly ($P < 0.0001$) higher for overall acceptability than the cakes containing HFCS. However, cakes made with 75% HFCS were rated slightly higher than cakes containing only 50% HFCS. This final viable added to all the previous evidence against the success of the 50% HFCS variation points to a needed formulation change.

Sensory Scores/Storage Times

Storage times also affected the sensory scores. Crust colors were scored as similar by the panel, but a significant ($P < 0.01$) difference was noted in the crumb color of cakes stored for 3 days (Table 10). The darkening of the crumb does not support the findings of the Hunter Color Meter (Table 6). Necessary compression of the crumb for the evaluation by Hunter Color Meter may have concentrated the color whereas the taste panel observed the sample without manual compression.

Cakes stored for 14 days were significantly ($P < 0.05$) different in flavor from cakes stored for 45 days. The moisture loss (Table 5) upon storage of the samples for 3 and 45 days may have concentrated the flavor to a point detectable by the taste panel. The sensory panel indicated that cakes stored for 14 and 45 days were significantly ($P < 0.05$) less tender than cakes stored for 3 days. This may have been due to poor handling and overcrowding in the freezer resulting in some manual compression of the cakes prior to sensory evaluation. Cakes stored for 3 days were rated significantly ($P < 0.05$) more crumbly than other variations. This is attributable to the process of starch retrogradation (Campbell et al., 1979).

Overall acceptability was scored significantly ($P < 0.01$) higher for freshly baked cakes than for stored cakes. This was expected as fresh cakes have not yet had time for the starch to retrograde noticeably with the concomitant moisture loss or flavor change. The substitution of the HFCS made no difference in the acceptability of the cakes after frozen storage.

An acceptable product may be produced with the use of HFCS as a sucrose substitution, however, some formulation changes may improve overall acceptability. The use of HFCS did extend the keeping qualities of the cakes during frozen storage.

CONCLUSIONS

Acceptable cakes were made at all levels of high fructose corn syrup (HFCS) substitution and all the cakes remained acceptable after all storage times used in this study. Starch substitution did not affect the quality of the cakes. There was little difference between cakes made with 50 or 75% HFCS, although cakes made with 75% HFCS were scored slightly higher by the taste panel. Increased browning and lowered volumes were evident in cakes containing HFCS, but the adverse effects on sensory qualities were slight. Storage at room and freezer temperatures did lower the product quality, however, the effect was not pronounced. Moisture content of cakes stored for 14 days was not significantly different from the freshly baked cakes due to the humectant qualities of the fructose in the syrup. Sensory score for tenderness and flavor also showed little change with storage, albeit there was some flavor concentration due to slight moisture losses in cakes stored for 3 and 45 days.

Recommendations for further research include, reformulation to decrease the moisture content of the cakes containing 50% HFCS, a formulation to include 100% HFCS as the sweetener, the addition of a flavoring system to the formulations (vanilla, salt, etc.) and the use of HFCS in combination with aspartame (Nutra Sweet) in reduced calorie products such as table syrups and candies.

SUMMARY

Cakes were prepared containing 0, 50, and 75% high fructose corn syrup (HFCS) as a replacement for sucrose and pregelatinized cross-bonded waxy corn starch at 0, 0.5, and 1% weight of flour. The cakes were evaluated freshly baked, after 3 days storage at room temperature, and 14 and 45 days frozen. Three replications of each treatment were done, but the substitutions of starch had no effect, thus there were 9 replications of each sweetener combination.

Objective measures of pH, specific gravity and sugar composition by HPLC were determined for each cake batter. Moisture content, crust and crumb color, and volume measurements were made on baked cakes. The finished products were photographed to determine overall appearance. Other measurements included moisture content of the flour (12%), sugar composition of the HFCS and the cakes by HPLC, and pH of the HFCS (pH 3.2).

A four member taste panel evaluated the cakes for crust and crumb color, flavor, moistness, tenderness, and overall acceptability. An unstructured scale (0 to 8) with anchors was used.

Amount of HFCS used and length of storage time had significant effects on cake quality. The interaction of HFCS and storage time had no effect. All cake variations were acceptable, although cakes made with all sucrose and no HFCS were scored significantly higher for sensory ratings.

Specific gravity of the batters increased significantly ($P < 0.0001$) with increasing amounts of HFCS used. The volume of cakes containing any

level of HFCS was significantly ($P < 0.0001$) lower than that of the cakes made with all sucrose and no HFCS, however, it was not unacceptably low. Crumb and crust color were significantly ($P < 0.0001$) darker in cakes containing 75% HFCS compared to cakes containing 0 to 50% HFCS. The cakes made with 50% HFCS were significantly lighter which was attributed to the higher moisture content.

Storage at room temperature and freezer temperature affected the cake quality adversely, but did not lower it below acceptable levels. Cakes stored for 14 days were not significantly different in moisture content than freshly baked cakes. Crust and crumb continued to brown during storage.

Taste panel members were able to detect differences in crust color, flavor, moistness, tenderness and overall acceptability among cake variations. Crumb color differences were not evident. Increased crust browning during storage was not detected by panelists, however, significant ($P < 0.05$) flavor changes were noted between cakes stored for 14 and 45 days. Overall acceptability was significantly ($P < 0.01$) lower with added storage time, but not to unacceptable levels.

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APPENDIX A
CAKE FORMULATIONS, MIXING AND BAKING INSTRUCTIONS

Cake Formulations, Mixing and Baking Instructions

Ingredient	Sucrose (g)	50% HFCS (g)	75% HFCS (g)
Hydrogenated vegetable shortening (Crisco)	108	108	108
Sugar system			
Sucrose (Domino)	240	120	60
HFCS	-	128	317
Egg whites (Kroger)	140	140	140
All purpose flour*	200	200	200
Double acting baking powder (Hearth Club)	10	10	10
Cream of tartar (Kroger)	3	3	3
NFDM (Kroger)	20	20	20
Water (deionized, distilled)	148	111	56

Mixing and baking

Cream shortening one minute at speed 2 in a Hobart Kitchen Aid electric mixer, Model K5SS, Listed 775A. Add sugar system and cream two minutes at speed 2. Add egg whites and beat two additional minutes at speed 2. Add remaining ingredients and mix one minute at speed 1. Scrape bowl with rubber spatula and mix four minutes at speed 4. Pour 630 grams of batter into an 8"x8"x2" Wear Ever metal baking pan that has been sprayed with Mazola No Stick on the bottom only. Bake at 350°F for 25 minutes in a GE oven, Model #J 336B1DC, Louisville, Kentucky. Remove from oven and cool in pan on rack until cold.

*Variations 2, 5, and 8 contained 199 g of all purpose flour and 1 g of pregelatinized cross-bonded waxy corn starch. Variations 3, 6, and 9 contained 198 g of all purpose flour and 2 g of pregelatinized cross-bonded waxy corn starch.

APPENDIX B
SENSORY EVALUTION SCHEDULE

Taster #1

	Fresh	3 Days	14 Days	45 Days
Day 1	1) *2-MD** 2) 6-LH 3) 7-CG	1) 4-FS 2) 8-DQ 3) 3-TS	1) 7-FT 2) 2-MQ 3) 6-VG	1) 4-PH 2) 3-TA 3) 8-TM
Day 2	1) 9-HJ 2) 5-HQ 3) 1-NK	1) 9-MR 2) 1-YZ 3) 5-XS	1) 1-UW 2) 5-RO 3) 9-GN	1) 7-NI 2) 2-BW 3) 6-HR
Day 3	1) 3-ON 2) 4-VI 3) 8-OW	1) 6-HV 2) 7-FM 3) 2-NB	1) 4-TX 2) 8-IP 3) 3-EK	1) 1-CK 2) 9-JL 3) 5-VO

Taster #2

	Fresh	3 Days	14 Days	45 Days
Day 1	1) 1-UT 2) 9-CJ 3) 5-TD	1) 7-NZ 2) 2-AO 3) 6-NC	1) 3-FE 2) 8-SF 3) 4-HN	1) 4-RH 2) 8-TS 3) 3-XF
Day 2	1) 3-DO 2) 8-AI 3) 4-GV	1) 9-BV 2) 5-MY 3) 1-FN	1) 6-GH 2) 7-AG 3) 2-OT	1) 9-GC 2) 1-MI 3) 5-JV
Day 3	1) 6-VA 2) 7-DV 3) 2-FB	1) 4-IP 2) 3-KH 3) 8-KU	1) 5-ME 2) 9-JQ 3) 1-FT	1) 7-PD 2) 6-WH 3) 2-JA

*Cake variation: 1, 2, and 3 contained 100% sucrose and 0, 0.5, 1% pregelatinized cross-bonded waxy corn starch, respectively. 4, 5, and 6 contained 50% sucrose and 50% HFCS and 0, 0.5, 1% pregelatinized cross-bonded waxy corn starch, respectively. 7, 8, and 9 contained 25% sucrose and 75% HFCS and 0, 0.5, 1% pregelatinized cross-bonded waxy corn starch, respectively.

**Randomized two-letter code.

Taster #3

	Fresh	3 Days	14 Days	45 Days
Day 1	1) 4-JM 2) 9-AT 3) 2-KT	1) 9-QI 2) 2-MV 3) 4-CO	1) 6-DE 2) 8-MJ 3) 1-WL	1) 9-NM 2) 2-CQ 3) 4-IG
Day 2	1) 5-LF 2) 3-RF 3) 7-DT	1) 1-PQ 2) 8-MG 3) 6-GJ	1) 4-CJ 2) 9-HO 3) 2-WU	1) 8-WG 2) 1-EO 3) 6-CM
Day 3	1) 1-IZ 2) 8-ZR 3) 6-WJ	1) 5-NV 2) 3-MJ 3) 7-VX	1) 5-DG 2) 3-IG 3) 7-UW	1) 7-KV 2) 3-AV 3) 5-HG

Taster #4

	Fresh	3 Days	14 Days	45 Days
Day 1	1) 6-IK 2) 8-BP 3) 1-HU	1) 2-QW 2) 4-LA 3) 9-DW	1) 5-QT 2) 7-UO 3) 3-NH	1) 4-NK 2) 2-MN 3) 9-XB
Day 2	1) 7-JP 2) 5-KL 3) 3-VJ	1) 5-OM 2) 3-HE 3) 7-FU	1) 8-MO 2) 6-VM 3) 1-GL	1) 8-QK 2) 6-GQ 3) 1-CO
Day 3	1) 2-CW 2) 9-PP 3) 4-QU	1) 1-HB 2) 8-UL 3) 6-YK	1) 2-MY 2) 4-ML 3) 9-UG	1) 7-QS 2) 3-UR 3) 5-UI

APPENDIX C
SAMPLE SENSORY SCORE SHEET

Sample Sensory Score Sheet

The lines below are labeled from left to right, least to most. Place a vertical slash through the line at the point that best describes the sample.

Taster _____
Sample _____

Least Most

- | | | | |
|--------------------------|----------------|-------|------------------|
| 1. Crust Color | Lt. Brown | _____ | Dk. Brown |
| 2. Crumb Color | Lt. Brown | _____ | Dk. Brown |
| 3. Flavor | (Bland) Sweet | _____ | Sweet (Sickly) |
| 4. Moistness | (Dry) Moist | _____ | Moist (Wet) |
| 5. Tenderness | (Tough) Tender | _____ | Tender (Crumbly) |
| 6. Overall Acceptability | Desirable | _____ | Desirable |

Sample _____

Least Most

- | | | | |
|--------------------------|----------------|-------|------------------|
| 1. Crust Color | Lt. Brown | _____ | Dk. Brown |
| 2. Crumb Color | Lt. Brown | _____ | Dk. Brown |
| 3. Flavor | (Bland) Sweet | _____ | Sweet (Sickly) |
| 4. Moistness | (Dry) Moist | _____ | Moist (Wet) |
| 5. Tenderness | (Tough) Tender | _____ | Tender (Crumbly) |
| 6. Overall Acceptability | Desirable | _____ | Desirable |

Sample _____

Least Most

- | | | | |
|--------------------------|----------------|-------|------------------|
| 1. Crust Color | Lt. Brown | _____ | Dk. Brown |
| 2. Crumb Color | Lt. Brown | _____ | Dk. Brown |
| 3. Flavor | (Bland) Sweet | _____ | Sweet (Sickly) |
| 4. Moistness | (Dry) Moist | _____ | Moist (Wet) |
| 5. Tenderness | (Tough) Tender | _____ | Tender (Crumbly) |
| 6. Overall Acceptability | Desirable | _____ | Desirable |

APPENDIX D
CAKE SAMPLE PLACEMENT

Cake Sample Placement

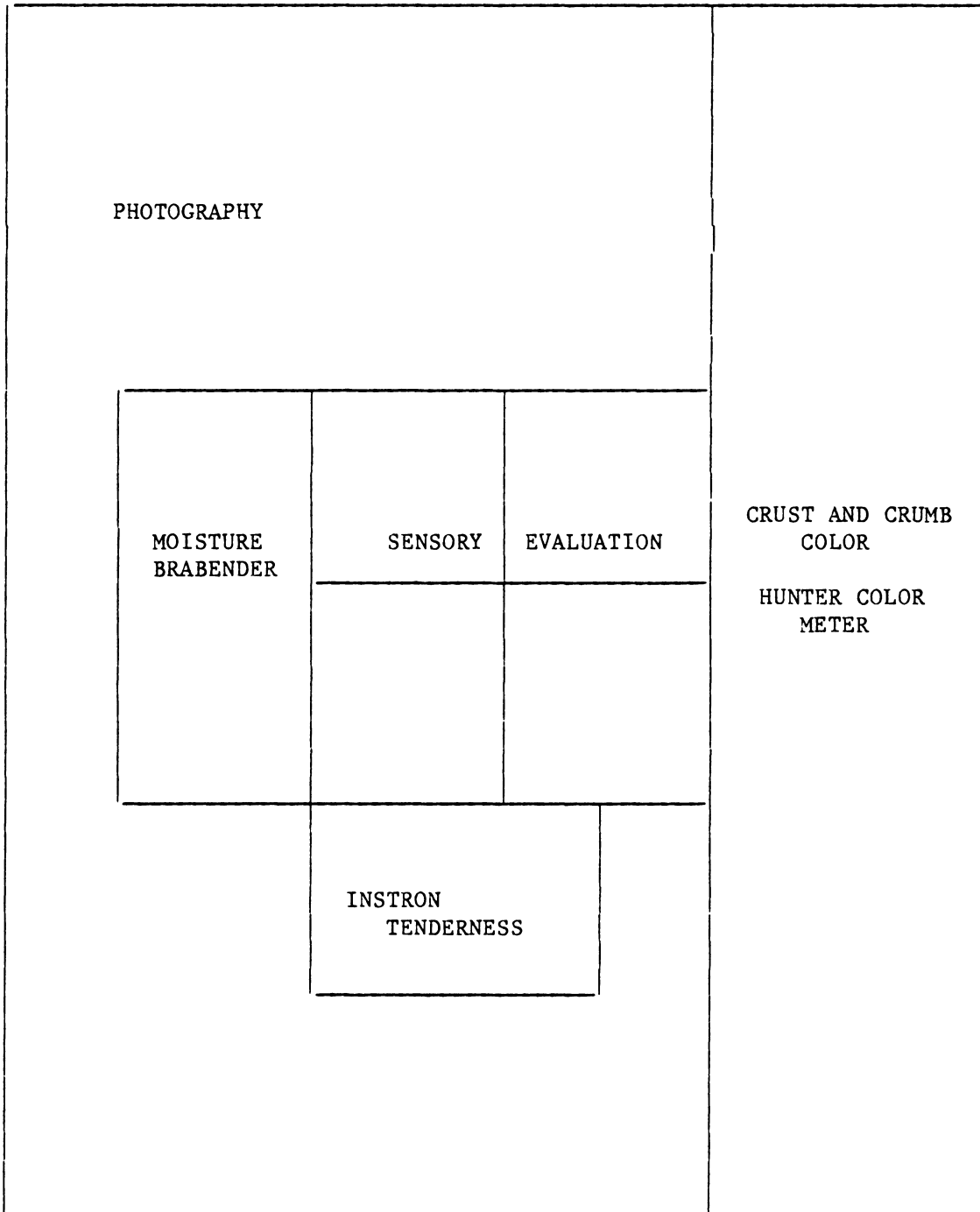


TABLE 14

Mean¹ pH and Specific Gravity Values for Cake Batters

	Cake ²	pH	Specific Gravity
Fresh	1	6.95	0.94
	2	7.00	0.92
	3	7.05	0.95
	4	6.97	0.99
	5	6.90	1.00
	6	6.90	0.96
	7	6.77	1.04
	8	6.80	1.05
	9	6.88	1.07
3 Days	1	6.83	0.91
	2	6.90	0.93
	3	6.90	0.93
	4	6.95	0.98
	5	6.90	0.97
	6	6.90	0.97
	7	6.80	1.04
	8	6.78	1.03
	9	6.80	1.04
14 Days	1	6.87	0.91
	2	6.90	0.91
	3	6.87	0.92
	4	6.95	0.98
	5	6.83	0.96
	6	6.87	0.96
	7	6.73	1.00
	8	6.83	1.02
	9	6.87	1.03
45 Days	1	7.33	0.93
	2	7.30	0.97
	3	7.37	0.94
	4	7.25	0.98
	5	7.37	0.96
	6	7.30	0.96
	7	7.18	1.04
	8	7.23	1.03
	9	7.17	1.03

¹Mean values from 3 replications.

²Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS and 0, 0.5, and 1% starch, respectively.

TABLE 15

Mean¹ Standing Height² as an Index to Volume for Baked Cakes

Cake	Fresh	3 Days	14 Days	45 Days
1	3.47	3.53	3.50	3.60
2	3.55	3.50	3.56	3.51
3	3.59	3.55	3.56	3.58
4	3.04	3.05	3.07	2.94
5	3.01	2.99	3.03	2.87
6	2.95	2.99	3.04	3.02
7	2.87	3.25	2.96	2.85
8	2.95	3.03	2.98	3.04
9	2.98	3.08	2.96	3.00

¹Mean values from 3 replications.

²Centimeters.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 16

Mean¹ Percent Moisture of Fresh and Stored Cakes

Cake ²	Fresh	3 Days	14 Days	45 Days
1	30.1	28.3	29.3	25.6
2	30.4	28.4	30.0	30.0
3	30.0	28.6	29.7	29.2
4	30.9	29.5	30.6	30.3
5	31.3	29.8	30.9	30.2
6	31.3	29.0	31.0	29.0
7	28.4	27.5	28.1	26.1
8	28.6	26.8	28.2	27.7
9	29.0	27.0	28.3	26.8

¹Mean values from 3 replications.

²Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 17

Mean¹ Hunter Color ΔE Values² for Crust of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	56.6	57.2	58.7	59.9
2	55.6	57.0	59.7	60.9
3	57.8	56.3	58.6	59.2
4	52.7	56.2	54.3	56.9
5	53.0	54.0	55.7	58.1
6	54.5	55.2	53.5	61.5
7	57.5	62.7	61.7	64.5
8	61.0	60.4	59.0	64.9
9	60.2	60.1	62.2	63.6

¹Mean values from 3 replications.

² ΔE calculated by duplicate readings as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 18

Mean¹ Hunter Color ΔE Values² for Crumb of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	20.7	20.4	21.6	21.4
2	20.8	20.3	22.4	21.4
3	20.7	20.9	21.2	21.2
4	22.3	21.9	22.5	22.4
5	22.5	21.8	22.6	23.1
6	22.6	22.0	23.3	22.7
7	24.8	24.3	24.9	24.2
8	24.8	24.6	25.4	25.1
9	25.0	24.1	24.8	25.1

¹Mean values from 3 replications.

² ΔE calculated by duplicate readings as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 19

Mean¹ Sensory Values for Crust Color² of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	3.56	4.50	2.94	3.81
2	4.38	3.25	3.75	3.50
3	4.56	3.38	3.13	3.81
4	2.81	2.31	2.19	4.13
5	2.50	3.31	2.38	3.31
6	3.00	3.56	3.31	3.50
7	5.00	5.31	4.44	4.81
8	5.25	4.56	4.06	4.38
9	4.75	4.88	3.25	4.38

¹Mean values from 3 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = light brown, 8 = dark brown.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 20

Mean¹ Sensory Values for Crumb Color² of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	0.58	0.92	0.50	0.67
2	0.42	0.83	0.67	0.33
3	0.83	1.00	0.58	0.67
4	0.33	1.17	0.83	1.00
5	0.75	1.08	0.58	0.50
6	1.17	1.50	0.92	0.50
7	0.67	1.08	0.92	0.75
8	1.83	1.42	0.67	0.50
9	0.42	1.25	0.92	0.83

¹Mean values from 3 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = light brown (very pale for a white cake), 8 = dark brown.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 21

Mean¹ Sensory Values for Flavor² of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	4.38	4.19	3.75	4.00
2	3.88	4.56	3.75	4.25
3	4.13	4.25	2.88	4.38
4	3.75	3.69	3.44	4.69
5	4.38	3.94	3.50	4.06
6	3.19	4.31	3.63	3.63
7	4.00	4.56	5.06	4.44
8	5.00	4.31	3.75	5.25
9	4.38	5.13	4.25	4.94

¹Mean values from 3 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = bland, 8 = sickly sweet.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 22

Mean¹ Sensory Values for Moistness² of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	3.56	3.81	3.56	4.25
2	4.50	5.50	3.88	3.50
3	4.06	4.19	3.69	4.13
4	3.81	4.31	4.38	3.44
5	5.63	4.19	4.00	5.69
6	4.94	4.44	4.69	4.75
7	4.19	3.63	3.88	4.63
8	4.50	4.44	3.81	4.75
9	4.25	5.58	4.50	5.25

¹Mean values from 3 replications.

²Scores derived from an unstructures scale of 0-8 with 0 = dry, 8 = wet.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 23

Mean¹ Sensory Values for Tenderness² of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	4.50	4.00	3.50	4.69
2	4.19	5.00	4.19	3.81
3	4.75	4.75	3.63	4.00
4	3.13	3.31	3.06	2.06
5	3.56	3.63	2.56	3.38
6	3.19	3.88	3.75	1.88
7	4.38	4.63	2.88	3.38
8	4.19	4.94	3.50	4.13
9	4.13	5.06	3.25	3.75

¹Mean values from 3 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = tough, 8 = crumbly.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 24

Mean¹ Sensory Values for Overall Acceptability² of Fresh and Stored Cakes

Cake ³	Fresh	3 Days	14 Days	45 Days
1	4.56	4.13	4.63	4.44
2	5.06	4.50	4.13	3.75
3	5.63	3.31	4.06	4.13
4	4.19	2.94	3.44	3.25
5	4.19	3.44	2.06	3.13
6	3.50	2.94	2.63	1.94
7	4.06	3.25	3.13	3.13
8	3.88	2.88	3.44	3.38
9	4.19	3.25	3.06	3.69

¹Mean values from 3 replications.

²Scores derived from an unstructured scale of 0-8 with 0 = not acceptable, 8 = very acceptable.

³Cakes 1, 2, and 3 contain 100% sucrose and 0, 0.5, and 1% starch, respectively. Cakes 4, 5, and 6 contain 50% sucrose, 50% HFCS, and 0, 0.5, and 1% starch, respectively. Cakes 7, 8, and 9 contain 25% sucrose, 75% HFCS, and 0, 0.5, and 1% starch, respectively.

TABLE 25

Sugar Analysis¹ of Cake Batters by HPLC

Cake	Glucose Oligomer	Sucrose	Glucose	Fructose	Psicose	Maltotriose
1	0.367	12.10	0	0	0.497	0
2	0.561	10.72	0	0	0.510	0
3	0.697	11.44	0	0	0.351	0
4	0.281	6.99	2.09	1.79	0.478	0
5	0.789	6.58	2.11	1.77	0.345	0
6	0.733	6.97	2.05	1.87	0.537	0
7	0.320	3.36	4.89	4.17	0.386	0
8	0.419	3.24	4.53	3.85	0.576	0
9	0.443	3.34	5.24	3.40	0.556	0

¹Milligrams per ml of carbohydrate.

TABLE 26
Sugar Analysis¹ of Baked Cakes by HPLC

Cake	Glucose Oligomer	Sucrose	Glucose	Fructose	Psicose	Maltotriose
1	0.256	11.24	0	0	0.134	0
2	0.283	11.98	0	0	0.134	0
3	0.315	11.88	0	0	0.175	0
4	0.286	5.59	1.83	1.61	0.123	0
5	0.361	6.57	1.85	1.72	0.147	0
6	0.247	5.55	1.79	1.53	0.136	0
7	0.273	3.30	4.76	4.09	0.172	0
8	0.229	2.59	4.13	4.15	0.137	0
9	0.309	3.16	4.73	4.05	0.136	0

¹Milligrams per ml of carbohydrate.

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