HIGH FRUCTOSE CORN SYRUP: REPLACEMENT FOR SUCROSE IN ANGEL CAKE

by

PHILIP EDWARD COLEMAN

B.M.E., Friends University, 1972

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

Approved by:

Carole A. Z. Harbers

TABLE OF CONTENTS

Page

INTRODUCTION

Sucrose prices have risen considerably during the past several years. Commercial use of corn syrup, dextrose and high fructose corn syrup (HFCS) has increased dramatically since 1970, primarily because corn sweeteners are less expensive than sucrose (Robinson, 1975). The major reason for the increased usage of corn sweeteners was the development in 1967 of first-generation HFCS containing 42% fructose, 52% glucose and 6% higher saccharides (Vuilleumier, 1980). Although other functional properties may differ, HFCS theoretically is equivalent to sucrose in sweetness because it contains glucose and fructose in a proportion similar to that of sucrose. HFCS has found wide application as a less expensive alternative to sucrose in food products such as soft drinks, yeast-leavened baked goods and canned fruits, where the main function of the sugar is to provide sweetness (Inglett, 1981).

One of the most difficult applications of HFCS is in cakes, because the amount and type of sugar present greatly affect the flavor, volume, texture and browning of the product. A manufacturer of HFCS, the Clinton Corn Processing Company (1980), has proposed the replacement of sucrose with HFCS in angel cakes. Substitution of HFCS for sucrose in angel cakes could result in a reduction in ingredient cost.

No research studies were found concerning the use of HFCS in angel cakes. This study was undertaken to investigate selected physical and sensory characteristics of angel cakes with 25, 50, 75 or 100% of the sucrose replaced with first-generation HFCS.

REVIEW OF LITERATURE

Physical properties of HFCS

A typical first-generation HFCS contains 29% water and 71% solids consisting of 52% glucose, 42% fructose and 6% higher saccharides (Vuilleumier, 1980). HFCS has haze-free clarity, a "water-like" color and no overriding flavors or odors to mask other ingredients (Robinson, 1975; Wardrip, 1971). The sugars in HFCS are fully fermentable (Henry, 1976), but the high osmotic pressure in HFCS resists microbial growth during storage (Wardrip, 1971).

Second-generation HFCS containing 55 to 90% fructose have been available since 1976. The major uses of 55% HFCS are in soft drinks, frozen desserts, jams, jellies and breakfast cereals (Inglett, 1981). Under some conditions, a smaller quantity of 90% HFCS than sucrose can be used to achieve the same sweetness as sucrose, resulting in calorie reduction. Uses of 90% HFCS include "light" foods and beverages, salad dressings, table syrups, wines and low-calorie frozen yogurts (Inglett, 1981).

Relative sweetness of HFCS

All sugars in solution change in sweetness under varying conditions of temperature, pH and concentration (Hodge and Osman, 1976). The relative sweetness of glucose is fairly stable under varying conditions (Shallenberger and Birch, 1975a). The wider shifts in sweetness by fructose under comparable conditions have been attributed to changes in the equilibration of anomeric forms and ring isomers (Hodge and Osman, 1976).

HFCS has been reported to be as sweet or slightly sweeter than sucrose at 15, 30 and 55% concentrations in distilled water (Wardrip, 1971). However, the sweetness of HFCS must be assessed in each application because of the variability in sweetness of the fructose component (Saussele et al., 1976).

Relative sweetness of fructose

D-fructose decreases in sweetness with increasing temperature at a faster rate than do other reducing sugars, including D-galactose, D-glucose and L-sorbose (Hodge and Osman, 1976). At 4°C, fructose-sweetened lemonade was judged sweeter than sucrose-sweetened lemonade (Hardy et al., 1979). Cardello et al. (1979) compared the relative sweetness of fructose and sucrose in a lemonade-flavored beverage (pH 2.35) and at six concentrations ranging from 1.4 to 14.3% in distilled water at 24°C. Fructose was rated 1.8 to 1.9 times sweeter than sucrose at the lower sugar concentrations, but that advantage was lost with increasing sugar concentration. At room temperature, there was no advantage of fructose over sucrose at any concentration.

No reports were found in the literature of an advantage of fructose over sucrose as a sweetener in baked products containing a high sugar concentration. Vanilla layer cakes prepared with sucrose or fructose were rated equal in sweetness, although the moderately strong vanilla flavor of the cakes may have masked differences in sweetness (Cardello et al., 1979). Sugar cookies made with sucrose were rated sweeter ($P < 0.01$) than sugar cookies made with fructose (Hardy et al., 1979). White cake and vanilla pudding made with fructose were rated slightly less sweet than the same products made with sucrose. From sensory work with lemonade, vanilla pudding, white cake and sugar cookies, an inverse relationship between browning and sweetness was suggested in products containing fructose (Hardy et al., 1979).

Effect of sugars on wheat starch gelatinization

Wheat starch is the principal ingredient of the crumb and structure of baked products (Campbell, 1972). Because all sugars at any concentration raise the gelatinization temperature of starch, the amount and type of sugar in a cake formula have a profound effect on the volume, grain, texture and crumb of the finished cake. Bean and Yamazaki (1978) found that the major effect of sucrose in wheat starch-water slurries was to delay the onset of swelling of starch granules during heating. At a 50% sucrose concentration, typical of the concentration in shortened cakes, starch granule swelling was delayed to 85°C, as compared to 60°C when no sucrose was present. That model system may explain how starch gelatinization is delayed during baking until maximum volume is achieved by leavening action (Bean and Yamazaki, 1978).

Glucose and fructose do not raise the gelatinization temperature of starch to the same extent as does sucrose. In a study of cake flour-sugar slurries, 50% concentrations of sucrose, glucose or fructose raised the gelatinization temperature of cake flour starch to 85, 81 or 77°C, respectively (Bean et al., 1978). In the same study, plain layer cakes were prepared with sucrose, glucose or fructose to determine the effects of gelatinization temperature on cake quality. Glucose and fructose cakes had poor volume, flat contour and coarse grain. Volume and contour were improved if water in the formula was reduced to 85% of normal in glucose cakes and to 65% of normal in fructose cakes. The starch gelatinization temperatures of the cakes were: sucrose, 89°C (100% water level); glucose, 87.5°C (85% water level); fructose, 88.5°C (65% water level). Thus, high-volume, rounded cakes were produced using glucose or fructose if the water content was adjusted to obtain a sugar solution concentration that induced a starch gelatinization temperature similar to that induced by sucrose.

Replacement of sucrose with HFCS in shortened cakes

Thompson et al. (1980) studied the flavor acceptance and taste perception of butter cakes prepared with sucrose, fructose, glucose, equal parts fructose and glucose, or HFCS. A sensory panel scored the flavor of the crusts of all cakes as delicately sweet and caramelized; however, some panelists detected a sharp but acceptable flavor in the crusts of the monosaccharide and HFCS cakes. The flavor of the crumb of the HFCS cakes was as acceptable as that of the sucrose cakes. Volpe and Meres (1976) noted an undesirable sourness in the crumb of white layer cakes in which 60% of the sucrose was replaced with HFCS. They attributed the sour flavor to the high-acid leavening system used to prevent excessive exterior browning, and they believed that the sourness might be masked by a flavoring system different from the vanilla that was used.

Fructose and glucose, as reducing sugars, participate readily in aldose-amine nonenzymatic browning reactions (Hodge and Osman, 1976). Koepsel and Hoseney (1980) found that layer cakes made with HFCS had excessive browning, which was minimized in white layer cakes having 60% of the sucrose replaced with HFCS by a leavening system that acidified the cake batter to below pH 6.0. At the lowered pH, Maillard browning was reduced to an acceptable level.

Thompson et al. (1980) reported that available lysine in crust and crumb of HFCS butter cakes indicated both the occurrence and intensity of the Maillard reaction. A decrease in available lysine in crust and crumb was accompanied by an increase in crust browning and development of yellowish or greenish colors in the interior of the cake. No correlation occurred between available lysine and acceptability of flavor.

Thompson et al. (1980) also reported that although volume of butter cakes with HFCS was lower than that of sucrose cakes, the cakes were equal in tenderness. Koepsel and Hoseney (1980) found that replacement of 100% of the sucrose in high-ratio white layer cakes resulted in greatly decreased volume and open grain. In glucose cakes they observed that reductions of up to 30% of the formula water improved volume and grain, but cake contours were flat and crusts were wet. White layer cakes in which 60% of the sucrose was replaced with HFCS had slightly greater volume than 100% sucrose cakes (Volpe and Meres, 1976).

Angel cake

Angel cake is one of the simplest cake formulas. A typical formula consists of 42% each of egg white and sugar, 15% flour, and minor amounts (less than 1%) of cream of tartar, salt and flavorings (Pyler, 1973). Mixing the cake involves making an egg white foam and then carefully folding in the other ingredients. When the foam is subjected to heat, the air trapped within the bubbles of the foam expands, increasing the volume of the foam. The structure and volume of the cake are set when gas release and bubble expansion cease during heating as starch gelatinizes and proteins coagulate (Mizukoshi et al., 1980).

A primary function of sucrose in angel cake is to raise the gelatinization temperature range of starch and the denaturation temperature range of protein, so that gelatinization of starch occurs simultaneously with denaturation of the protein in the egg white and flour (Donovan, 1977). Flour in angel cake acts as a binder, provides starch that gelatinizes during baking and supplements egg protein in forming the structure of the cake (Palmer, 1972).

The important role of starch in the thermal setting of cake batter is well recognized (Miller and Trimbo, 1965; Hoseney et al., 1978; Lineback and Wongsrikasen, 1980; Mizukoshi et al., 1980). Several studies have shown the degree of starch gelatinization is greater in angel cake than in shortened cakes. Starch gelatinization in angel cake is nearly complete at the end of baking, whether measured as loss of birefringence, enzymatically or by examining scanning electron micrographs (Hoseney et al., 1977; Hoseney et al., 1978; Lineback and Wongsrikasen, 1980). Hoseney et al. (1978) suggested that the starch in angel cake undergoes the greatest change of all products they investigated because of the high moisture content present during baking.

Acid is necessary to adjust the pH of the egg white in angel cake for foam stability (Barmore, 1934; Bernard et al., 1948; Seideman et al., 1963; Palmer, 1972). Barmore (1934) found that increased foam stability allowed heat to penetrate the foam and coagulate the proteins before the foam collapsed, thus preventing shrinkage of the cake during the last stage of baking and during cooling. Grewe and Child (1930) reported that angel cakes made with potassium acid tartrate were white and fine-grained, whereas angel cakes without the acid were yellow and coarse-grained. More recently, monocalcium phosphate monohydrate was used because it performed the same functions as potassium acid tartrate, but resulted in a more plastic foam permitting less destruction during folding in of flour (Kissell and Bean, 1978).

Sodium lauryl sulfate (SLS) is an anionic surfactant which improves the foaming of egg white. Electrophoretic studies showed that SLS complexes with lysozyme in addition to lowering surface energy (Gardner, 1960). The addition of small quantities of SLS to egg whites used in making angel cake resulted in increased volume.

MATERIALS AND METHODS

Ingredients and formula

The AACC Method 10-95 for testing baking quality of angel cake flour (Kissell and Bean, 1978) was modified by the addition of clear imitation vanilla flavoring; HFCS was used to replace 25, 50, 75 or 100% of the sucrose (Table 1). In the cakes containing HFCS, the 71% sugar solids content of the HFCS was included in the sugar solids total, and the 29% water content of the HFCS was subtracted from the formula water; thus, all cakes contained 314 g sugar solids and 295 ml water.

Mixing procedure

In the AACC Method 10-95 for angel cake (Kissell and Bean, 1978), reconstituted egg albumen is whipped with a sifted mixture of acid salt, sodium chloride and half the sucrose to a specific gravity of 0.14 to 0.13. The remaining sucrose is sifted with the flour

Table 1 - Formulas for angel cakes at five HFCS levels

	Percentage of HFCS				
Ingredient	0	25	50	75	100
Bleached cake flour[a], g	110	110	110	110	110
Dried egg albumen[b], g	40	40	40	40	40
Acid salt[c], g	1.5	1.5	1.5	1.5	1.5
Sodium chloride, g	3.0	3.0	3.0	3.0	3.0
Clear imitation vanilla flavoring, ml	7.5	7.5	7.5	7.5	7.5
Extra fine granulated sucrose[d], g	314	236	157	79	---
HFCS[e], g	---	111	222	333	444
Distilled water, ml	295	263	231	199	167

[a]Softasilk, General Mills
[b]Type P-20, Henningsen; includes approximately 0.1% sodium lauryl sulfate added to dried egg solids by processor
[c]Monocalcium phosphate monohydrate, Regent 12XXX, Stauffer Chemical
[d]C & H, Californian and Hawaiian
[e]Isomerose 100, Clinton Corn Processing; contains 42% fructose, 52% glucose and 6% higher saccharides

and folded into the egg white foam. In preliminary work, cakes prepared by this method had optimum volume and grain at a specific gravity of 0.15 ± 0.01 for the egg white foam.

In this study, one modification of the AACC Method 10-95 was made because HFCS was used. Acid salt, sodium chloride, flavoring and all sugar (sucrose and/or HFCS) were whipped with the reconstituted egg albumen. The specific gravity of the foam was adjusted to 0.19 ± 0.01 because all formula sugar was added to the foam (Appendix, p. 67). In preliminary work, cakes in which 0 or 20% of the sucrose was replaced with HFCS and that were prepared by this method were not noticeably different in observed quality characteristics from cakes prepared by the AACC Method 10-95.

The preparation procedure used for test cakes is as follows:

1. Approximately 18 hours before baking, add 40 g dried egg albumen to 167 ml distilled water in 5-quart stainless steel mixer bowl of KitchenAid mixer (model K5-A, Hobart Co., Troy, OH). Mix with whip at Speed 1 (60 rpm) for five minutes, stopping twice to scrape bowl and whip. Transfer product to a covered glass container and store at 2°C until needed.
2. When ready to bake cake, place reconstituted egg albumen in 5-quart mixer bowl. Bring albumen to 24°C.
3. Add remaining formula water, if any; sucrose and/or HFCS; acid salt; sodium chloride and flavoring. Mix at Speed 1 for one minute.
4. At Speed 6 (180 rpm), whip to specific gravity of 0.19 ± 0.01.
5. At Speed 1, gradually add flour over a 20-second period. Remove bowl and whip from mixer. Fold in residual flour by dipping whip into batter and bringing up side of bowl. Rotate bowl one-quarter turn. Repeat for 10 folds.
6. Transfer 650 g batter to a 10" aluminum tube pan with removable bottom using a rubber spatula. Eliminate large air voids by pulling metal spatula through batter.
7. Bake for 35 minutes at 190°C in the center of the lower oven of household type double oven range (model RFE950PW, Whirlpool Corp., Benton Harbor, MI).

8. Invert cake on center tube for cooling; after one hour, ring with metal spatula and tap cake out of pan.
9. Place cake upright on cardboard cake circle and place in a plastic bag. Fold open side of the bag several times and tape shut. Store cake at ambient temperature (22 to 26°C) until used for further evaluation.

Physical measurements

Foam and batter specific gravity were determined by the method outlined by Kissell and Bean (1978). Beating time was recorded for each foam. Batter pH was read directly from an approximately 10 g sample using a pH meter (model 5998-10, Horizon Ecology Co., Chicago, IL).

An estimate of volume was determined immediately after the cakes were taken out of the pan using the method described by Kissell and Bean (1978), Appendix, p. 68. Immediately after the cakes were taken out of the pan, the investigator recorded descriptive statements of symmetry including smoothness of side and bottom crusts, presence of cracks in the top crust and presence of "dips" or other irregularities in the top surfaces of the cakes.

The sampling diagram for other physical measurements is shown in Figure 7, Appendix, p. 65. Percentage moisture in the cake interior was determined from 10 g samples of crumbs dried in a Brabender Semi-Automatic Rapid Moisture Tester (C. W. Brabender Instruments, Inc., South Hackensack, NJ) for two hours at 120°C. Two samples per cake were taken and means recorded.

Crust and crumb color were evaluated using a Hunterlab Spectrophotometer (model D54, Hunter Associates Laboratory, Inc., Reston, VA). A 4 x 4 x 1.5-cm sample of the crumb or a 4 x 4 x 1.5-cm sample including top crust was placed in an optically clear cup, 6 cm in diameter. Three readings per sample of L (lightness), a (redness) and b (yellowness) were taken. The cup was rotated 90^{o} after each reading, and the means of three readings recorded.

An Instron Universal Testing Machine (IUTM) (model 1122, Instron Corp., Canton, MA) was used to evaluate firmness and elasticity of the cake crumb. The 50-cm^2 compression anvil model A372-17 was used with the 500 kg load cell (Figure 1). Three 2.5-cm cubes taken from the midsection of each cake were compressed to 1.0 cm using a 0.2 kg load. Two force curves were recorded using crosshead and chart speeds of 200 mm/min. The peak height of the first curve, converted to kg units, represented the resistance of the crumb to compression, or firmness. The distance (in cm) to the peak of the second curve expressed as a ratio of the distance to the peak of the first curve was an indication of elasticity of the crumb (Neukom and Rutz, 1980). A diagram of typical compression curves is shown in Figure 2.

An extra series of cakes was baked for photography. After photography, those cakes were tested for firmness using the IUTM on days one, three and five after baking. Three readings per cake were taken and means recorded. With the exception of IUTM measurements on days three and five, all physical measurements were completed within 24 hours of baking.

Sensory evaluation

Sensory evaluation of angel cakes was completed within 22 hours of baking by a 10-member panel of faculty and graduate students from the Department of Foods and Nutrition and graduate students

THIS BOOK CONTAINS NUMEROUS PAGES THAT WERE BOUND WITHOUT PAGE NUMBERS.

THIS IS AS RECEIVED FROM CUSTOMER.

Fig. 1 - Instron Universal Testing Machine

A. 50 cm^2 compression anvil

B. 2.5 cm^3 angel cake sample

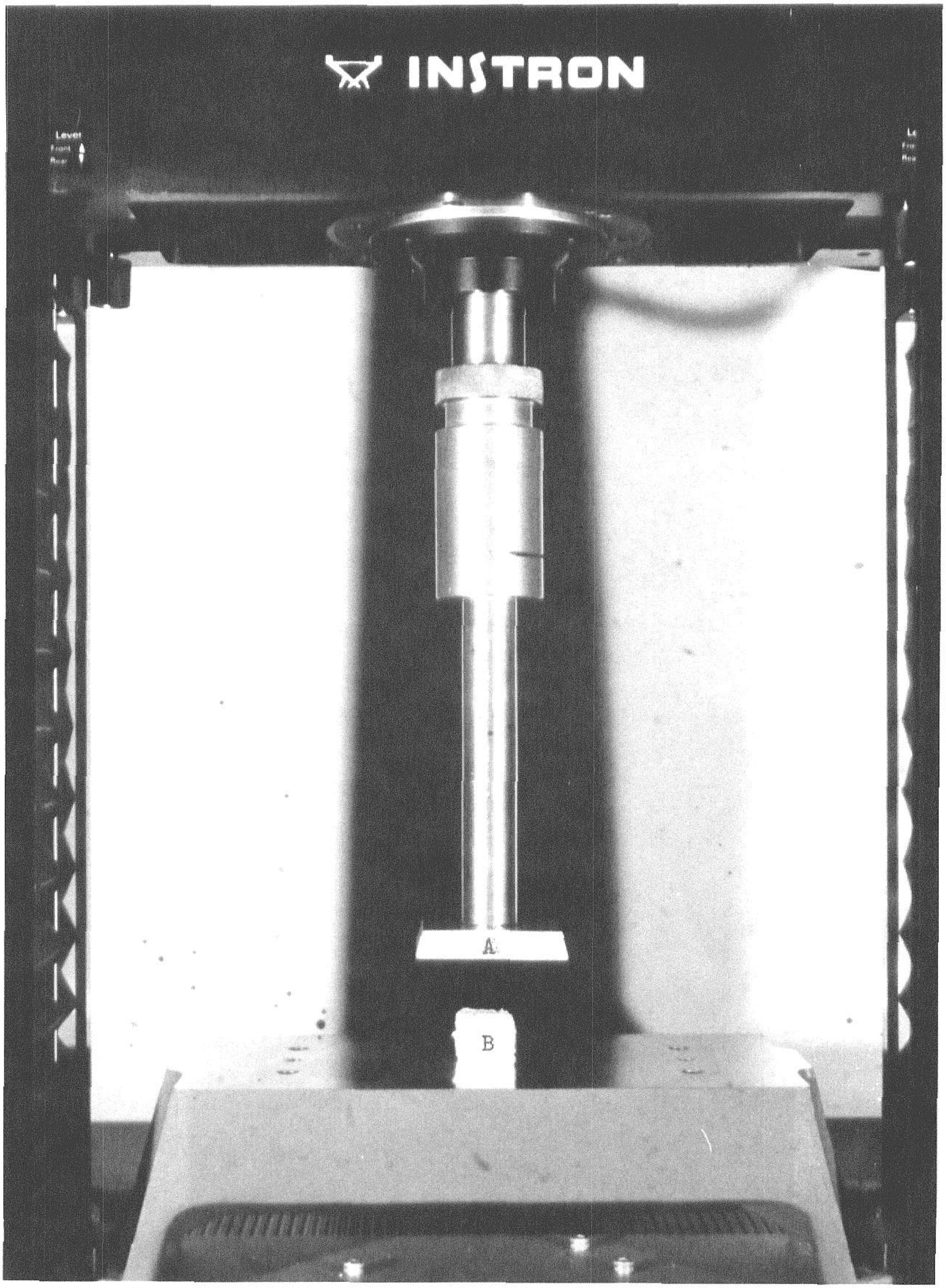
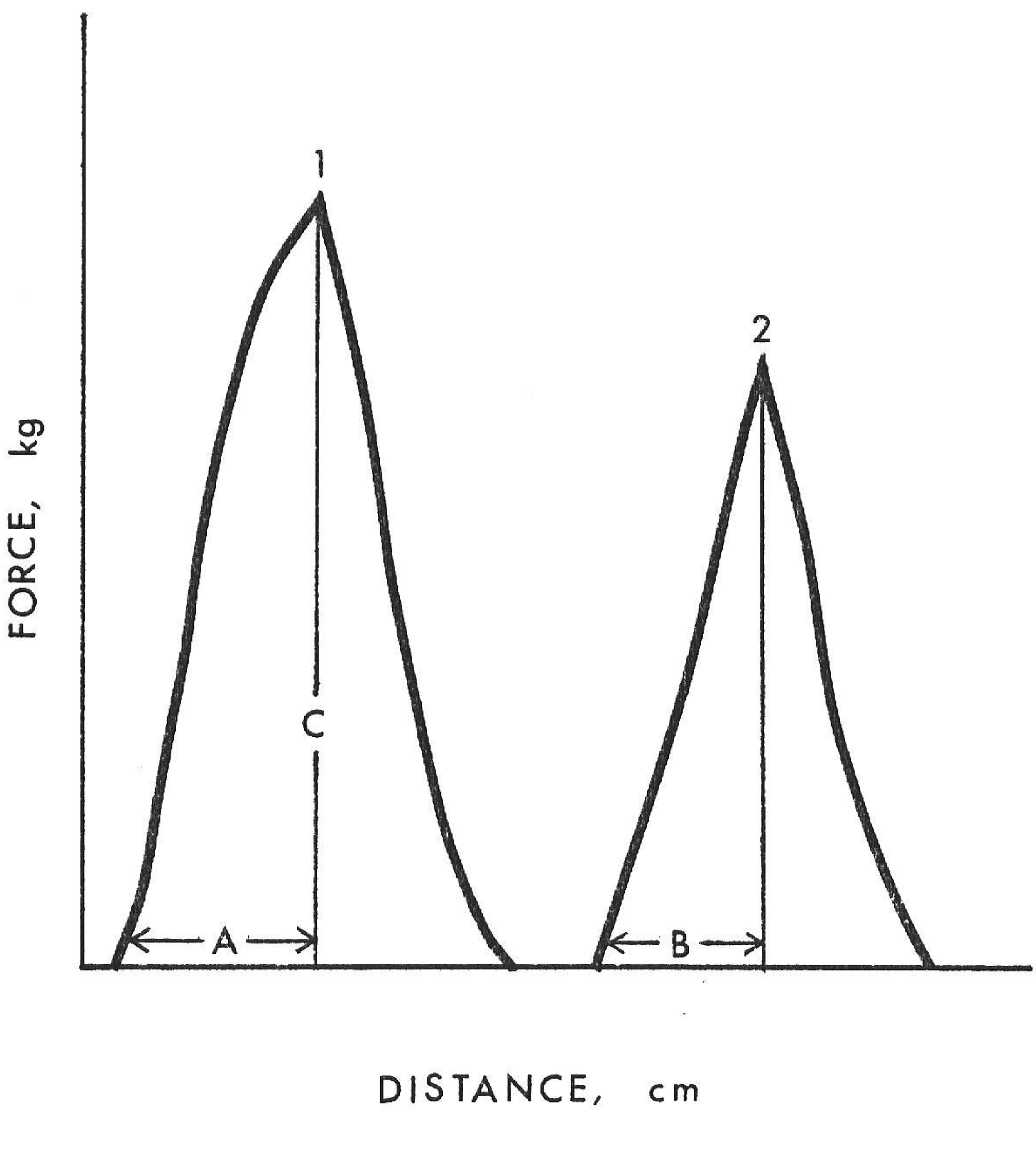

INSTRON
A
B

Fig. 2 - Typical compression curves obtained from the IUTM for determining firmness and elasticity of angel cake

firmness = C

elasticity = B/A x 100


FORCE, kg
1
2
C
A
B
DISTANCE, cm

from the Department of Grain Science. During two preliminary sessions, the panel evaluated three samples for tenderness, moistness, sweetness, thickness of cell walls, grain, crust color and crumb color. The three samples were 0 and 100% HFCS cakes and a commercial angel cake. Five-point category scales were provided for each characteristic, and panelists were instructed to use whole numbers only. After the preliminary sessions, some of the scales were modified to better reflect the panel's perception of the cakes. The score sheet used in the main study is shown in Figure 8, Appendix, p. 66.

After preliminary sessions, the most frequently given score (mode score) for each characteristic of each treatment was determined. Panelists were ranked according to the number of mode scores they recorded. Panel I consisted of those five panelists who most frequently recorded mode scores, and Panel II consisted of those five panelists who least frequently recorded mode scores. The panelists were not aware of their assignment to Panel I or Panel II, and they were not treated differently in any way because of their designation. The designations Panel I and Panel II were used only in statistical analyses to detect possible differences between the panels' evaluations.

Samples from each of the five treatments were evaluated by each panelist during each session of the main study. The sampling diagram is shown in Figure 7, Appendix, p. 65. Samples (4 x 4 x 1.5 cm) from the midsection of the cakes were placed on white plates and evaluated for tenderness, moistness and sweetness under red light to eliminate possible color influences. Crumb color, grain and thickness of cell walls were evaluated under a Super Skylight (Macbeth Daylighting Corp., Newburgh, NY) on daylight setting using similar samples displayed on white plates. Crust color was evaluated under the Super Skylight using 4 x 4 x 1.5-cm samples including a 4 x 4-cm section of top crust.

Random codes were assigned to samples so that codes for samples evaluated for tenderness, moistness and sweetness were different from codes for samples evaluated for crust color, which were in turn different from codes assigned to samples evaluated for crumb color, grain and cell wall thickness. The random codes for each replication and treatment were chosen from Roscoe (1975) and are listed in Table 7, Appendix, p. 53.

Experimental design and analyses of data

Analysis of variance for a randomized complete block design (Snedecor and Cochran, 1967) was used to study treatment effects of HFCS on selected physical and sensory characteristics of the angel cakes. Data for physical measurements from five replications and sensory characteristics from four replications were analyzed. Sensory data from Panel I and Panel II were compared to determine possible differences between the panels' evaluations. Least square means were compared to determine treatment effects. When F-values were significant for sensory data, least significant differences were calculated at the 5% level to determine significance of differences between means. Linear correlation coefficients were calculated overall and within each treatment for four replications of physical and sensory data.

The analysis of variance (AOV) for physical measurement data was:

Source of variation	df
Treatments	4

Replications	3
Error	16
Total	23

The AOV for sensory characteristic data was:

Source of variation	df
Treatments	4
Replications	3
Error (Treatment x Replications)	12
Panel Type	1
Treatments x Panel Type	4
Error (Panelists within Panel Type)	8
Total	32

RESULTS AND DISCUSSION

Physical measurements

Data for differences among cakes made with 0, 25, 50, 75 or 100% HFCS were analyzed by AOV. F-values and levels of significance for physical measurements are shown in Table 2. When F-values indicated significant differences among treatments, probabilities of greater F-values were calculated to determine significant differences between specific means (Table 3).

Beating time and foam specific gravity. As egg white is whipped, stiffness and volume of the foam increase and specific gravity decreases as air is incorporated into the foam (Palmer, 1972). Foams containing 50, 75 or 100% HFCS were beaten a shorter time ($P < 0.001$) than foams containing 0 or 25% HFCS before reaching the desired specific gravity range (Table 3). Foams containing 0 or 25% HFCS were beaten

Table 2 - F-values from AOV for physical measurements of angel cakes made with five levels of HFCS

Physical measurement	Treatment df=4	Replication df=4
Beating time	76.95***	2.07
Specific gravity		
Foam	4.74*	4.29*
Batter	5.54**	6.44**
Estimate of volume	65.13***	4.22*
Batter pH	1.40	2.10
Percentage moisture	1.74	2.07
Hunterlab values		
Crust		
L	37.66***	2.27
a	24.64***	1.53
b	10.94***	3.60*
Crumb		
L	2.31	2.24
a	2.18	0.75
b	123.55***	2.93
Instron values		
Elasticity	1.21	1.17
Firmness	7.72**	2.06

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Table 3 - Least square means for physical measurements of angel cakes made with five levels of HFCS

	Percentage of HFCS				
Physical measurement	0	25	50	75	100
Beating time, seconds	180a	186a	138b	114c	54d
Specific gravity					
Foam	0.191abd	0.193ab	0.182cd	0.183acd	0.180cd
Batter	0.237a	0.238a	0.254a	0.253a	0.272b
Estimate of volume, cc	2933a	2878a	2648b	2566c	2494d
Batter pH	5.42a	5.42a	5.42a	5.36a	5.35a
Percentage moisture	39.06a	39.89a	40.07a	39.70a	40.50a
Hunterlab values					
Crust					
L	57.01a	48.57a	47.63a	46.49b	43.50c
a	7.86a	7.83a	8.41b	8.82c	9.23d
b	17.20a	15.24b	15.39b	14.39b	12.88c
Crumb					
L	84.01a	84.23a	84.03a	83.51a	82.46a
a	-3.04a	-2.87a	-2.94a	-2.80a	-2.68a
b	9.72a	10.98b	12.31c	12.85d	14.04e

Table 3 - (concluded)

	Percentage of HFCS				
	0	25	50	75	100
Instron values					
Elasticity[f]	88.70a	90.53a	91.50a	91.08a	88.72a
Firmness, kg	0.247a	0.234a	0.367b	0.394b	0.466b

[abcde]Means bearing different letters within the same row differ significantly ($P < 0.05$)

[f]B/A x 100

approximately 180 seconds, foams containing 50 or 75% HFCS approximately 125 seconds and foams with 100% HFCS approximately 55 seconds. Despite less beating time, foams containing 50, 75 or 100% HFCS had slightly but significantly ($P < 0.05$) lower specific gravities than 0 or 25% HFCS foams.

Differences ($P < 0.05$) occurred among foam specific gravities because of HFCS (Table 3). Those differences may have little practical importance, because the range of means (0.180 to 0.193) was narrow and within the desired range of 0.19 ± 0.01. In general, the higher the level of HFCS, the lower the foam specific gravity (foams with 0% HFCS had a mean specific gravity of 0.191, and 100% HFCS foams had a mean specific gravity of 0.180).

Although mean specific gravities were lower, foams containing any level of HFCS were less "stiff" than foams containing only sucrose. Sucrose foams held a stiff, slightly bending peak at a specific gravity of approximately 0.19 (Figure 2); foams containing HFCS only barely mounded at a specific gravity of approximately 0.18 (Figure 3). Foams containing 25% HFCS were similar in appearance to sucrose-containing foams. Foams with 50 or 75% HFCS had peak stiffness characteristics intermediate to the 0 and 100% HFCS foams. Because egg white stiffens with increased beating time (Palmer, 1972), the differences in peak stiffness between 0 and 100% HFCS foams could be attributable to differences in beating time, although specific gravities were comparable. Whether or not decreased stiffness of foams containing HFCS indicated less air incorporated into the foams is not known.

<u>Batter specific gravity.</u> Batters containing 100% HFCS had

Fig. 2 - Typical peak formed by all sucrose egg white foam (specific gravity = 0.193)

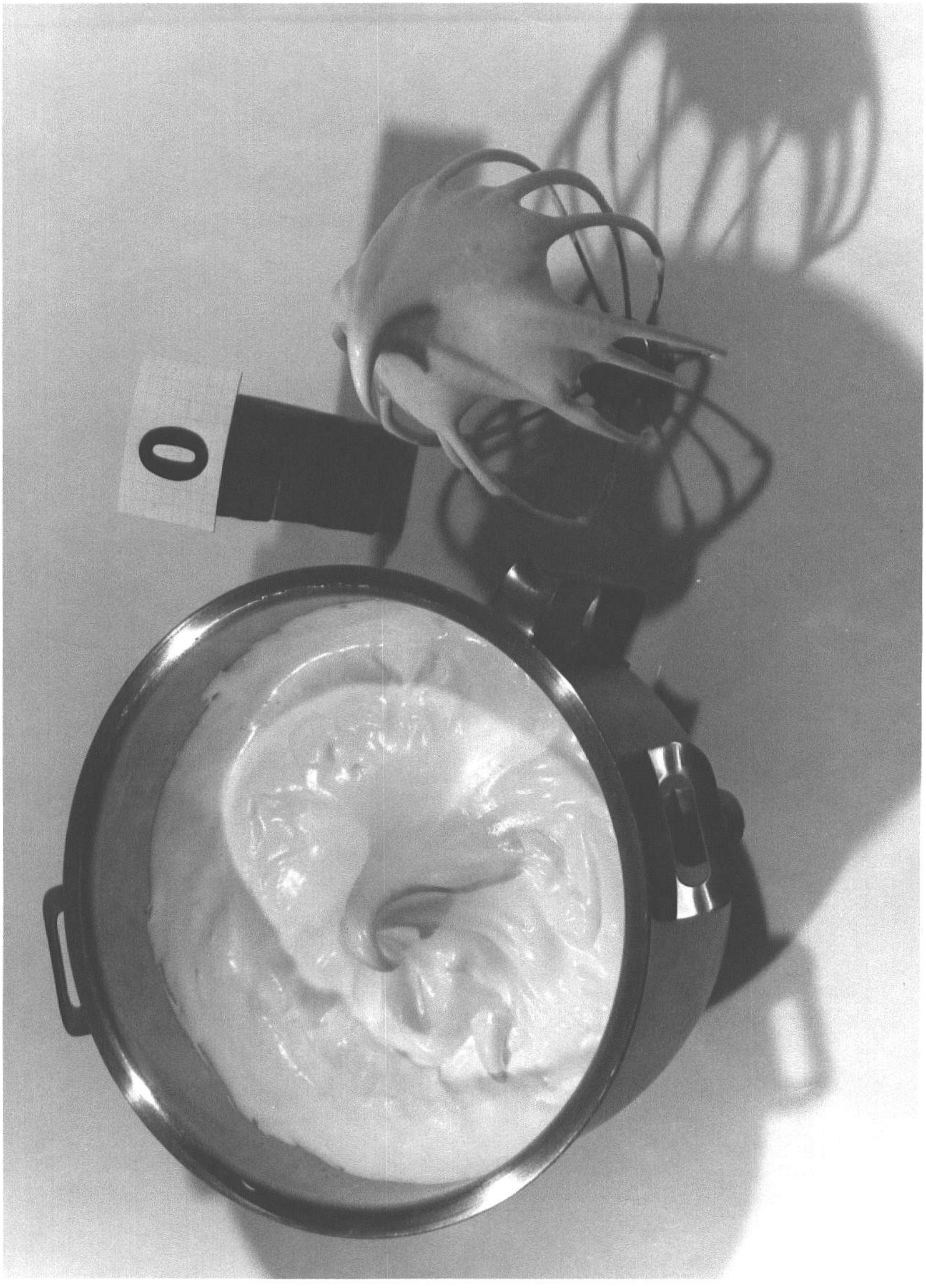
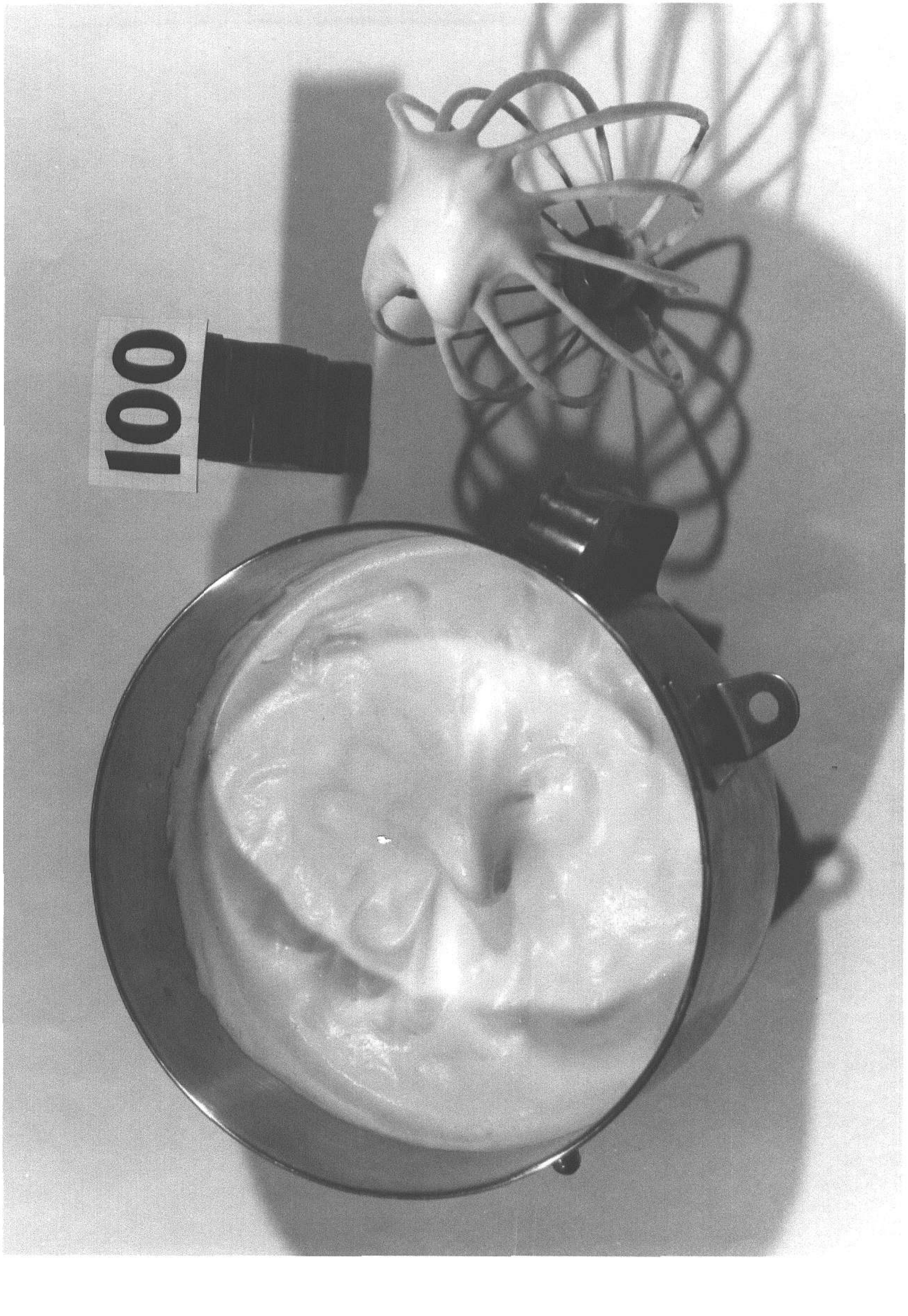

0

Fig. 3 - Typical peak formed by all HFCS egg white foam (specific gravity = 0.183)


100

a higher ($P < 0.01$) mean specific gravity than any of the other batters. Although HFCS egg white foams had lower mean specific gravities than sucrose egg white foams before flour was folded in, batters containing any amount of HFCS had higher mean specific gravities than batters containing only sucrose. Those results suggest that foams containing HFCS are less able to retain air than sucrose foams as flour is folded in during the last stage of the mixing process. The differences ($P < 0.01$) among replications may be attributed to human imprecision and/or the lesser ability of foams containing higher levels of HFCS to withstand mechanical handling.

Estimate of volume. There was no significant difference between the mean volume estimates for 0 and 25% HFCS cakes (Table 3). The mean volume estimates for 50, 75 and 100% HFCS cakes were lower ($P < 0.001$) than those for 0 and 25% HFCS cakes, and were different ($P < 0.05$) from each other. The higher the level of HFCS, the lower the estimated volume. The lower volume of cakes containing HFCS could be affected by premature starch gelatinization caused by the monosaccharides in HFCS (Bean et al., 1978; Koepsel and Hoseney, 1980) or by decreased stiffness of foams containing HFCS (Palmer, 1972).

Batter pH. The mean batter pH values for the five cakes were not significantly different (Table 2). The mean range of batter pH was from 5.35 to 5.42 (Table 3), well within the optimum range of 5.0 to 6.5 recommended by Pyler (1973) for angel cake.

Percentage moisture. Thompson et al. (1980) reported that layer cakes made with HFCS were moister than sucrose cakes. In this study, mean percentage moisture readings from the five treatments were not significantly different (Table 2). Those results do not agree with the suggestion made by Henry (1976) and Saussele et al.

(1976) that HFCS may contribute to moisture retention in baked products to a greater extent than does sucrose.

Crust color. Crust color was affected greatly ($P < 0.001$) by the replacement of sucrose with HFCS (Table 2). In general, as the HFCS increased, the crust color became darker, more red and less yellow, as measured by the Hunterlab Spectrophotometer (Table 3). Those results agree with previous studies in which the substitution of HFCS for sucrose in layer cakes resulted in much browner exteriors (Koepsel and Hoseney, 1980; Thompson et al., 1980). The b-values (yellowness) for 25, 50 and 75% HFCS cakes were not significantly different, whereas b-values for 0 and 100% HFCS cakes were different ($P < 0.001$) from each other and from all other treatments ($P < 0.05$). The crusts of the 0% HFCS cakes were yellower ($P < 0.01$) than the crusts of all other cakes. The crusts of 100% HFCS cakes were darker ($P < 0.05$) and less yellow ($P < 0.05$) than all other cakes. Crust a-values (redness) were not significantly different for 0 and 25% HFCS cakes. Crust a-values for 50, 75 and 100% HFCS cakes were different ($P < 0.05$) from each other and from those of 0 and 25% HFCS cakes.

Crumb color. Crumb L-values (lightness) and a-values (greenness) were not significantly different at any HFCS level (Table 2). Crumb b-values (yellowness) were different ($P < 0.05$) at each HFCS level (Table 3). As the level of HFCS increased, the b-values increased, indicating a yellower crumb at the higher HFCS levels. Those results agree with results of shortened cakes in which the use of HFCS caused the development of uncharacteristic yellowish or greenish interior colors attributed to Maillard reactions (Thompson, 1980; Volpe and Meres, 1976).

Elasticity and firmness. There were no significant differences in elasticity among the five treatments (Table 2). Firmness measurements (kg force) were not significantly different for 0 and 25% HFCS cakes (Table 3). Firmness measurements for 50, 75 and 100% HFCS cakes were not significantly different from each other, but were higher ($P < 0.05$) than those for 0 and 25% HFCS cakes. The increased firmness measurements of 50, 75 and 100% HFCS cakes possibly could be attributed to the decreased stiffness of the foams.

Changes in firmness over time. In a brief study, firmness measurements were recorded for one series of cakes on days one, three and five after baking. Because of mechanical failure of the IUTM, data for 75% HFCS cakes are not reported. Results from 0, 25 50 and 100% HFCS cakes suggest that angel cakes made entirely with HFCS became firmer at a faster rate than did other cakes (Figure 4). Cakes with 0 and 100% HFCS had greater increases in firmness between days one and three than between days three and five; 25 and 50% cakes had greater increases between days three and five than between days one and three.

Surface symmetry. The bottom crusts of all cakes were smooth. The side crusts of 75 and 100% HFCS cakes were occasionally ragged because those cakes tended to stick to the pan. The top crusts of the 0 and 25% HFCS cakes always had pronounced cracks and splits that are characteristic of angel cake. Cracks were less apparent or not present in the surfaces of 50, 75 and 100% HFCS cakes (Figure 5). The top surfaces of 0 and 25% HFCS cakes tended to be even, whereas the top surfaces of 50, 75 and 100% HFCS cakes frequently had one or two small, shallow "dips."

Fig. 4 - Changes in firmness of 0, 25, 50 and 100% HFCS cakes as a function of time

TRT 1, 0% HFCS

TRT 2, 25% HFCS

TRT 3, 50% HFCS

TRT 4, 100% HFCS

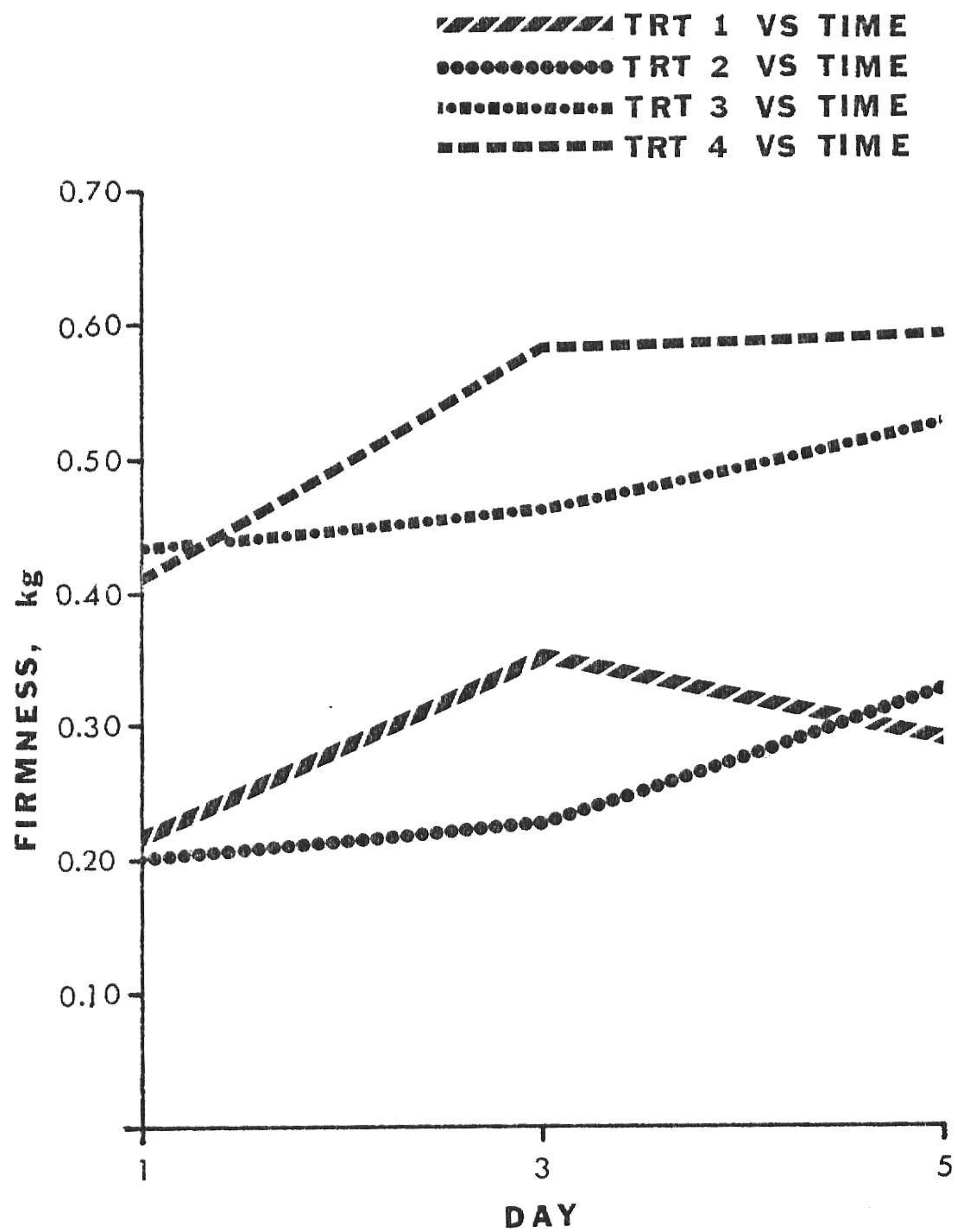

TRT 1 VS TIME
TRT 2 VS TIME
TRT 3 VS TIME
TRT 4 VS TIME
0.70
0.60
0.50
0.40
0.30
0.20
0.10
FIRMNESS, kg
1
3
5
DAY

Fig. 5 - Top surfaces of angel cakes at five HFCS levels

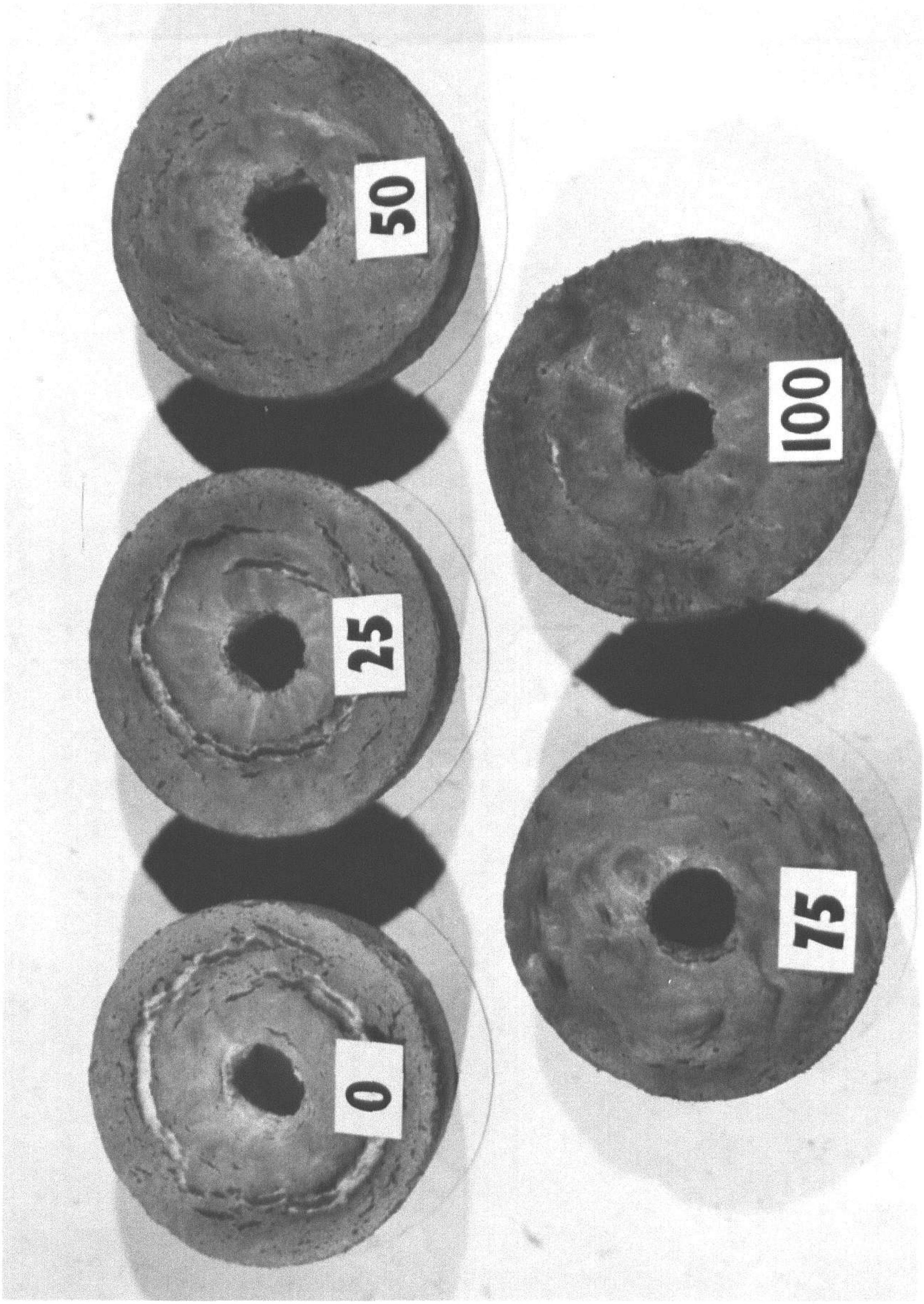
0, 0% HFCS

25, 25% HFCS

50, 50% HFCS

75, 75% HFCS

100, 100% HFCS


50
100
25
75
0

Sensory evaluation

Statistical analyses comparing the sensory data of Panel I and Panel II showed there were no significant differences between the panels' scores for any sensory characteristic (Table 8, Appendix, p. 54). Therefore, data from all ten panelists were pooled and analyzed by AOV (Table 4).

Tenderness. Mean tenderness scores were not significantly different for 0 and 25% HFCS cakes or for 25 and 50% HFCS cakes (Table 5). Mean tenderness scores for 50, 75 and 100% HFCS cakes were not significantly different from each other, but were lower ($P < 0.05$) than those for 0 and 25% HFCS cakes. Those results are in general agreement with firmness values obtained with the IUTM in which 50, 75 and 100% HFCS cakes were firmer ($P < 0.05$) than 0 and 25% HFCS cakes (Table 3).

Moistness. There were no significant differences among moistness scores (Table 4). That agrees with percentage moisture measurements, among which no significant differences were found (Table 2). Results from this study differ from findings by Thompson et al. (1974), in which frozen and thawed layer cakes made with HFCS were judged moister than sucrose cakes.

Sweetness. Cakes with 25% HFCS had the highest mean sweetness scores, but their scores were not significantly higher than those for 0% HFCS cakes (Table 5). Mean sweetness scores for 0 and 75% HFCS cakes were not significantly different. The 50 and 100% HFCS cakes were not significantly different from each other in sweetness, but were less sweet ($P < 0.05$) than all other cakes.

During preliminary sessions, some panelists detected a slight

Table 4 - F-values from AOV of sensory scores for selected characteristics of angel cakes made with five levels of HFCS

Sensory characteristic	Treatment df=4	Replication df=3
Tenderness	5.11*	0.55
Moistness	2.09	1.90
Sweetness	11.11***	1.89
Grain	3.23*	0.18
Cell walls	2.74	2.96
Crumb color	85.66***	2.40
Crust color	86.70***	0.59

*, $P < 0.05$; ***, $P < 0.001$

Table 5 - Least square means of sensory scores for selected characteristics of angel cakes made with five levels of HFCS

Sensory characteristic	Percentage of HFCS				
	0	25	50	75	100
Tenderness[f]	4.34a	3.95ab	3.29bc	3.03c	3.18c
Moistness[g]	3.97a	3.74a	3.29a	3.47a	3.47a
Sweetness[h]	3.26ab	3.55a	2.74c	3.16b	2.79c
Grain[i]	2.61a	3.45bc	3.76b	3.32abc	2.76ac
Cell walls[j]	2.97a	3.34a	3.13a	2.89a	2.61a
Crumb color[k]	4.37a	3.66b	2.97c	2.29d	1.84e
Crust color[l]	3.89a	2.79b	2.34c	1.84d	1.21e

[abcde]Means bearing different letters within the same row differ significantly ($P < 0.05$)
[f]Tenderness: 5 = tender and 1 = tough
[g]Moistness: 5 = moist, does not require much saliva and 1 = dry, requires much saliva
[h]Sweetness: 5 = strongly sweet and 1 = moderately sweet, slightly bitter
[i]Grain: 5 = many uniform, small cells, a few larger cells and 1 = large, irregular cells
[j]Cell walls: 5 = thin cell walls and 1 = extremely thick cell walls
[k]Crumb color: 5 = intensely white and 1 = light yellow
[l]Crust color: 5 = light beige and 1 = dark golden brown

bitterness in some cakes. The sweetness scale was modified to include the bitter taste (Figure 8, Appendix, p. 66). During the main study, six of ten panelists recorded sweetness scores of 1 or 2 on at least one occasion, indicating they detected bitterness in some cakes. Four of ten panelists recorded scores of 3, 4 or 5 for all cakes, indicating that they did not detect bitterness. Those four panelists (40%) may reflect the insensitivity to bitter taste occurring in 28 to 40% of Caucasian Americans when tasting solutions of phenylthiocarbamate (Amerine et al., 1965). Consequently, the lower mean sweetness scores for cakes containing 50% or greater levels of HFCS may not reflect the full extent of the bitterness present.

Desirable and undesirable flavor compounds can be produced by caramelization of sugars or by other ingredients of cake as well as by aldose-amine reactions (Hodge and Osman, 1976). Monosaccharides such as glucose and fructose in HFCS undergo those reactions more readily than does sucrose because they are reducing sugars (Hodge and Osman, 1976). Data for 50, 75 and 100% HFCS cakes suggest that sweetness decreases and bitterness increases if HFCS replaces 50% or more of the sucrose in angel cakes. A different reaction may have occurred in the 25% HFCS cakes, which received the highest mean sweetness scores. Some glucose syrups, when mixed with sucrose syrup, give greater sweetness than predicted from the separate sweetnesses of the component sugars (Hodge and Osman, 1976).

Grain and cell walls. Mean scores for grain were higher ($P < 0.05$) for 25 and 50% cakes than for all other treatments (Table 5). The higher the mean scores, the smaller the cells and the more uniform the grain (Figure 8, Appendix, p. 66). Cakes with 0 and 100% HFCS were not significantly different in grain from each other, but received lower ($P < 0.05$) scores than did 25 or 50% HFCS cakes. Mean grain scores for 75% HFCS cakes were intermediate and not significantly different from the mean scores for any other treatment. Those results agree with studies of shortened cakes in which 60 or 100% replacement of sucrose with HFCS resulted in cakes with an acceptable grain which was similar to that of sucrose (Volpe and Meres, 1976; Thompson et al., 1974). In contrast, Koepsel and Hoseney (1980) found HFCS high-ratio white layer cakes had open grain. Typical slices illustrating grain at each HFCS level are shown in Figure 6.

There were no significant differences among scores for cell wall thickness (Table 4). Several panelists indicated cell wall thickness was difficult to evaluate without magnification under the conditions of this study.

Crumb color. Mean scores for crumb color decreased ($P < 0.05$) as the level of HFCS increased (Table 5). Mean scores for the crumb of 0 and 25% HFCS cakes indicated that they appeared white; the crumb of 50% HFCS cakes was judged off white, and that of 75 and 100% HFCS cakes was judged creamy (Table 5). Panel scores for crumb color agree with b-values measured by the Hunterlab Spectrophotometer, which indicated a yellower crumb ($P < 0.05$) as the level of HFCS increased.

Reducing monosaccharides such as glucose and fructose in HFCS participate in nonenzymatic browning reactions more readily than does sucrose (Shallenberger and Birch, 1975b). Volpe and Meres (1976) prevented yellowing of the crumb in high-ratio white layer cakes

Fig. 6 - Typical slices from angel cakes made with five levels of HFCS

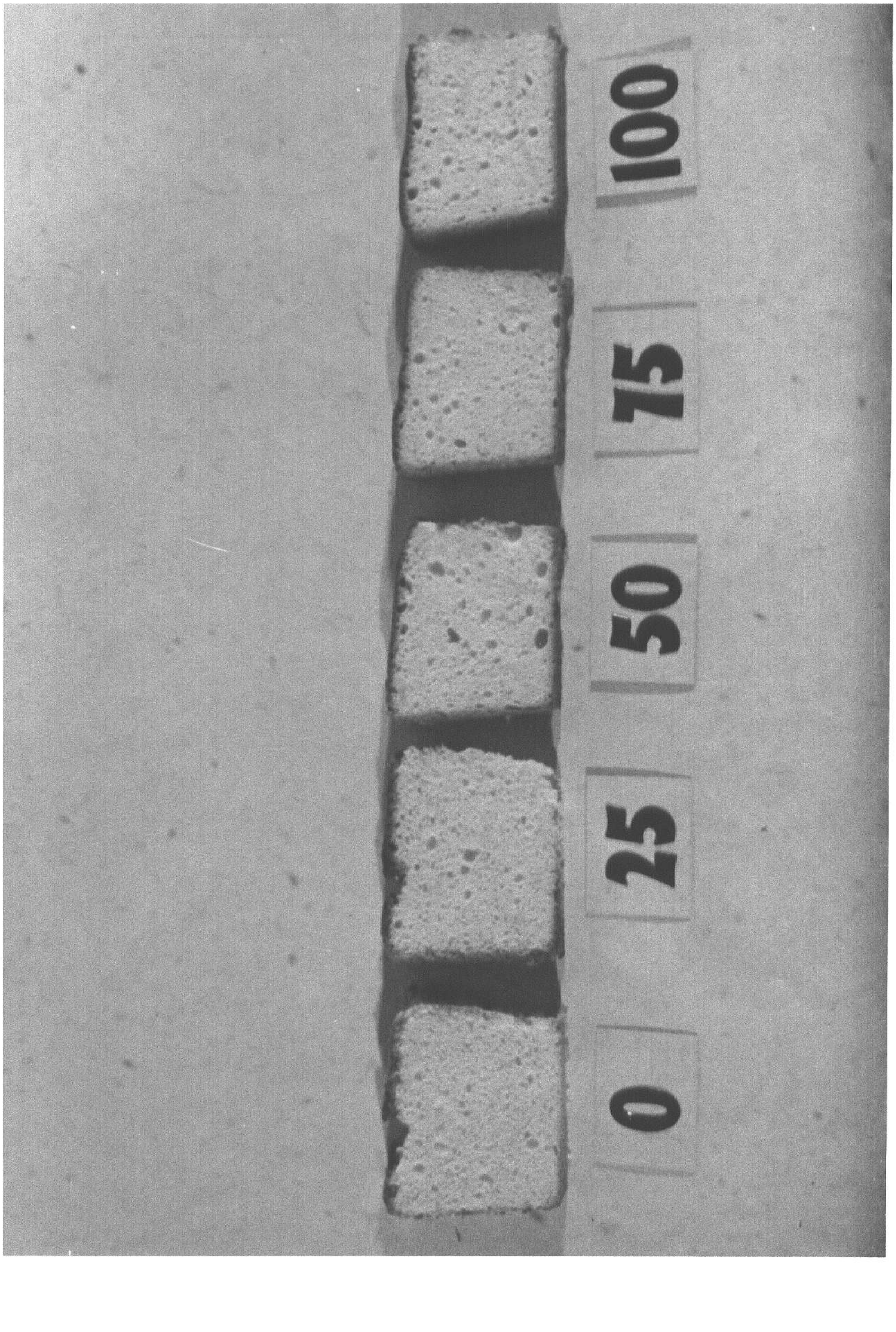
0, 0% HFCS

25, 25% HFCS

50, 50% HFCS

75, 75% HFCS

100, 100% HFCS


0
25
50
75
100

containing 60% HFCS by using a high-acid leavening system that resulted in a cake batter pH of 6.3. The crumb color of the HFCS-containing cakes made with high-acid leavening was not significantly different from the crumb color of sucrose cakes. At pH 6.3, Maillard browning reactions were minimized. The mean pH of angel cake batters in this study ranged from 5.35 to 5.42 (Table 3). At that pH range, Maillard browning reactions are not as prominent as caramelization (Shallenberger and Birch, 1975b). The off white or creamy color observed in 50, 75 and 100% HFCS cakes may be attributable more to caramelization than to Maillard browning reactions.

Crust color. Mean scores for crust color decreased ($P < 0.05$) as the level of HFCS increased (Table 5). The crusts of 0% HFCS cakes were scored light yellowish brown; crusts of 25, 50 and 75% HFCS cakes were scored golden brown, and those of 100% HFCS cakes were scored dark golden brown (Table 5). Panel scores agree with Hunterlab L (lightness), a (redness) and b (yellowness) values, which indicated that the crust of cakes became darker, redder and less yellow as the level of HFCS increased (Table 3).

Excessive exterior browning in HFCS-containing cakes has been attributed to Maillard browning reactions of monosaccharides (Koepsel and Hoseney, 1980; Thompson et al., 1980). The low pH of cake batters in this study may have favored crust caramelization rather than Maillard browning in cakes containing HFCS.

Correlation coefficients

Shindell (1964) stated that a correlation between 0.39 and 0.80 was moderate. The correlation between volume and firmness was moderately negative ($P < 0.05$), as was the correlation between

Table 6 - Correlation coefficients for selected physical vs physical, physical vs sensory and sensory vs sensory data for angel cakes at five HFCS levels

Variates	all treatments df=18[a]	Percentage of HFCS 0	25	50 df=2[b]	75	100
Volume vs firmness	-0.74*	-0.40	-0.14	-0.25	0.01	-0.68
Firmness vs tenderness scores	-0.67*	-0.31	-0.16	-0.85	-0.33	-0.59
Volume vs tenderness scores	0.79*	0.47	0.45	0.53	-0.52	0.88
Crust L-values vs crust color scores	0.92*	0.18	-0. 6	0.01	-0.52	0.93
Crumb L-values vs crumb color scores	0.51*	0.71	-0.09	0.10	-0.07	-0.97*
Crumb b-values vs crumb color scores	-0.93*	0.85	-0.27	-0.02	0.13	-0.16
Tenderness scores vs moistness scores	0.54*	0.71	0.39	0.24	0.54	0.72
Crust color scores vs crumb color scores	0.65*	-0.02	-0.17	-0.21	0.23	0.23

*, $P < 0.05$;
[a] $r = 0.444$
[b] $r = 0.950$

tenderness scores and firmness ($P < 0.05$), Table 6. The correlation between tenderness and volume was moderately positive ($P < 0.05$). These results agree with previous studies indicating higher volume angel cakes are more tender than angel cakes of lower volume (Palmer, 1972; Franks et al., 1969). Crust L-values (lightness) and crumb L-values were correlated to their respective sensory scores ($P < 0.05$). Generally, b-values were negatively correlated to crumb color scores, indicating cakes with greater yellowness scores tended to be judged more yellow. The correlation between crust color scores and crumb color scores was moderately positive ($P < 0.05$), indicating cakes with darker exteriors had more yellow interiors. The correlation between tenderness scores and moistness scores was moderately positive ($P < 0.05$), and in agreement with findings by Franks et al. (1969).

Cost of ingredients

A cost comparison of angel cakes made with sucrose or HFCS is shown in Table 15, Appendix, p. 63. Using February, 1981 wholesale prices, a 25 to 100% replacement of sucrose with HFCS could result in a 4.5 to 18% reduction in ingredient cost of angel cakes.

SUMMARY

HFCS was used to replace 25, 50, 75 or 100% of the sucrose in angel cakes. Less water was used in cakes containing HFCS so that all cakes contained 314 g sugar solids and 295 ml water. Acid salt, salt, flavoring, reconstituted albumen and all sugar (sucrose and/or HFCS) were beaten to a specific gravity of 0.19 ± 0.01 before flour was folded in.

Physical measurements, completed before or within 24 hours of baking, were: beating time; foam specific gravity; batter specific gravity; batter pH; estimate of volume; percentage moisture; elasticity; firmness; and, for crust and crumb, Hunterlab L (lightness), a (redness) and b (yellowness). Sensory evaluation of tenderness, moistness, sweetness, grain, cell wall thickness, crust color and crumb color was completed within 22 hours of baking.

Data were analyzed by AOV. When F-values indicated significant differences, least significant differences among means were calculated for sensory data.

Replacement of sucrose with HFCS resulted in no significant differences among treatments in batter pH, percentage moisture, crumb L-values and a-values, elasticity, moistness scores and cell wall thickness scores. Foams containing HFCS were beaten a shorter time, were less stiff and had slightly lower specific gravities than sucrose foams. Cakes containing HFCS had significantly darker crusts and yellower interiors than all sucrose cakes. Cakes containing 25, 50 or 75% HFCS had more uniform grain than did 0 or 100% HFCS cakes. Cakes containing 50, 75 or 100% HFCS had greatly

decreased volume, were less sweet, less tender, had fewer cracks and more "dips" in the top surfaces than 0 or 25% HFCS cakes.

HFCS at the 25% level did not greatly affect any physical measurement or sensory characteristic studied. Cakes containing 25% HFCS were slightly sweeter, slightly more uniform in grain, had more golden crusts and slightly less white crumb than sucrose cakes. All other physical and sensory characteristics of 25% HFCS cakes were not significantly different from those of sucrose cakes.

CONCLUSIONS

Under the conditions of this study, it was concluded that:

1) Egg white foams containing HFCS are less stiff than egg white foams containing only sucrose at comparable specific gravities.

2) Replacement with HFCS of 50, 75 or 100% of sucrose in angel cake results in foams with lower specific gravities; decreased foam beating time; decreased volume of cakes; browner crusts; yellower crumb; firmer texture; and decreased sweetness.

3) Replacement with HFCS of 25% of the sucrose in angel cakes does not greatly affect the physical measurements or sensory characteristics studied, and may result in savings in cost of ingredients.

REFERENCES

Amerine, M.A., Pangborn, R.M. and Roessler, E.B. 1965. The sense of taste. In "Principles of Sensory Evaluation of Food," p. 108. Academic Press, New York, NY.

Baldwin, R.E. 1973. Functional properties in foods. In "Egg Science and Technology," p. 241, edited by Stadelman, W.J. and Cotterill, O.J. Avi Publishing Co., Westport, CT.

Barmore, M.A. 1934. The influence of chemical and physical factors on egg white foams. Tech. Bull. 9, Colo. Agric. Exper. Stat., Fort Collins, CO.

Bean, M.M. and Yamazaki, W.T. 1978. Wheat starch gelatinization in sugar solutions. I. Sucrose: microscopy and viscosity effects. Cereal Chem. 55: 936.

Bean, M.M., Yamazaki, W.T. and Donelson, D.H. 1978. Wheat starch gelatinization in sugar solutions. II. Fructose, glucose, and sucrose. Cake performance. Cereal Chem. 55: 945.

Bernard, C., Slosberg, H., Lowe, B. and Stewart, G.F. 1948. Factors influencing performance of egg white in angel cakes. Poultry Sci. 27: 653.

Campbell, A.M. 1972. Flour mixtures. In "Food Theory and Applications," p. 677, edited by Paul, P.C. and Palmer, H.H. John Wiley and Sons, Inc., New York, NY.

Cardello, A.V., Hunt, D. and Mann, B. 1979. Relative sweetness of fructose and sucrose in model solutions, lemon beverages and white cake. J. Food Sci. 44: 748.

Clinton Corn Processing Company. 1980. Private communication. Clinton, IA.

Donovan, J.W. 1977. A study of the baking process by differential scanning calorimetry. J. Sci. Food Agric. 28: 571.

Franks, A.J., Zabik, M.E. and Funk, K. 1969. Angel cakes using frozen, foam-spray-dried, freeze-dried, and spray-dried albumen. Cereal Chem. 46: 349.

Gardner, F.A. 1960. The role of chemical additives in altering the functional properties of egg white. Ph.D. thesis, University of Missouri, Columbia, MO.

Grewe, E. and Child, A.M. 1930. The effect of potassium acid tartrate as an ingredient in angel cake. Cereal Chem. 7: 245.

Hardy, S.L., Brennand, C.P. and Wyse, B.W. 1979. Fructose: comparison with sucrose as sweetener in four products. J. Am. Dietet. Assoc. 74: 41.

Henry, R.E. 1976. High fructose corn syrup: new sweetener for the baker. Bakers Dig. 50(2): 25.

Hodge, J.E. and Osman, E.M. 1976. Carbohydrates. In "Principles of Food Science," Vol 4, p. 94, edited by Fennema, O.R. Marcel Dekker, Inc., New York, NY.

Hoseney, R.C., Atwell, W.A. and Lineback, D.R. 1977. Scanning electron microscopy of starch isolated from baked products. Cereal Foods World 22(2): 56.

Hoseney, R.C., Lineback, D.R. and Seib, P.A. 1978. Role of starch in baked foods. Bakers Dig. 52(4): 11.

Inglett, G.E. 1981. Sweeteners--a review. Food Technol. 35(3): 37.

Kissell, L.T. and Bean, M.M. 1978. AACC technical committee report: development of a method for angel food cake. Cereal Foods World 23(3): 136.

Koepsel, K.M. and Hoseney, R.C. 1980. Effects of corn syrups in layer cakes. Cereal Chem. 57: 49.

Lineback, D.R. and Wongsrikasen, E. 1980. Gelatinization of starch in baked products. J. Food Sci. 45: 71.

Miller, B.W. and Trimbo, H.B. 1965. Gelatinization of starch and white layer cake quality. Food Technol. 19: 640.

Mizukoshi, M., Maeda, H. and Amano, H. 1980. Model studies of cake baking. II. Expansion and heat set of cake batter during baking. Cereal Chem. 57: 352.

Neukom, H. and Rutz, W. 1980. Observations on starch retrogradation and bread staling. Presented at the 65th Annual Meeting of the American Association of Cereal Chemists, Chicago, IL, Sept. 21-25.

Palmer, H.H. 1972. Eggs. In "Food Theory and Applications," p. 527, edited by Paul, P.C. and Palmer, H.H. John Wiley and Sons, Inc., New York, NY.

Pyler, E.J. 1973. Cake ingredients. In "Baking Science and Technology," Vol 2, p. 898. Siebel Publishing Co., Chicago, IL.

Robinson, J.W. 1975. Will high fructose corn syrup sweeten your future? Food Eng. 47(5): 57.

Roscoe, J.T. 1975. Random number table. In "Fundamental Research Statistics for the Behavioral Sciences," p. 459. Holt, Rinehart & Winston, Inc., New York, NY.

Saussele, H., Ziegler, H.F. and Weideman, J.H. 1976. High fructose corn syrup for bakery applications. Bakers Dig. 50(1): 32.

Seideman, W.E., Cotterill, O.J. and Funk, E.M. 1963. Factors affecting heat coagulation of egg white. Poultry Sci. 42: 406.

Shallenberger, R.S. and Birch, G.G. 1975a. Role of sugars in food and medicine. In "Sugar Chemistry," p. 155. Avi Publishing Co., Westport, CT.

Shallenberger, R.S. and Birch, G.G. 1975b. Nonenzymatic browning reactions. In "Sugar Chemistry," p. 188. Avi Publishing Co., Westport, CT.

Shindell, S. 1964. "Statistics, Science, and Sense," University of Pittsburgh Press, Pittsburgh, PA.

Snedecor, G.W. and Cochran, W.G. 1967. Analysis of variance. In "Statistical Methods," 6th edition, p. 255. Iowa State University Press, Ames, IA.

Thompson, C.M., Funk, K., Schimmel, R. and Mickelsen, O. 1974. Dental caries: possible sugar substitutes for sucrose. Ecol. of Food Nutr. 3: 231.

Thompson, C.M., Mickelsen, O., Schimmel, R., Funk, K. and Kakade, M.L. 1980. Taste perception and flavor acceptance of cakes prepared with monosaccharides. Nutr. Reports Inter. 21: 913.

Volpe, T. and Meres, C. 1976. Use of high fructose syrups in white layer cake. Bakers Dig. 50(2): 38.

Vuilleumier, S. 1980. Corn sweetener outlook. Presented at the 1981 Agricultural Outlook Conference, Washington, D.C., Nov. 17-20.

Wardrip, E.K. 1971. High fructose corn syrup. Food Technol. 25(5): 46.

ACKNOWLEDGMENTS

The author expresses sincere appreciation to Dr. Carole A. Z. Harbers, Assistant Professor of Foods and Nutrition and Major Professor, for encouragement and belief in the writer's capabilities throughout graduate study and for guidance in the preparation of this manuscript. The author wishes to thank the following who helped during the course of this study: Dr. Dorothy L. Harrison, Professor, Department of Foods and Nutrition, and Dr. Paul A. Seib, Professor, Department of Grain Science, for technical advice and for serving on the writer's committee; and Dr. Arthur D. Dayton, Professor and Head, Department of Statistics, for the experimental design and analysis of the data. The author thanks the Clinton Corn Processing Company, Clinton, IA, for HFCS used in preliminary work and in the main study.

Special thanks are extended to Dona R. Coleman, wife of the author, for love, patience and encouragement throughout graduate study and the course of this study.

VITA

Philip Edward Coleman was born in Wichita, Kansas, on July 8, 1949. He received his Bachelor of Music Education degree, with honors, from Friends University, Wichita, Kansas, in 1972. Following several years' employment as a computer programmer and systems analyst, he attended Kansas State University, Manhattan, Kansas, where he pursued the Master of Science degree in Foods and Nutrition. During that time he held a graduate teaching assistantship and a graduate research assistantship.

The author is a member of Phi Upsilon Omicron, and is professionally affiliated with the Institute of Food Technologists and the American Home Economics Association.

He is married to Dona R. Coleman.

APPENDIX

Table 7 - Random codes for sensory evaluation

Replication	Treatment[a]	Tenderness, moistness, sweetness	Crumb color, grain, cell walls	Crust color
1	0	420	925	520
	25	982	318	473
	50	249	764	179
	75	399	635	603
	100	202	138	344
2	0	112	038	877
	25	789	485	116
	50	249	652	422
	75	364	753	608
	100	500	316	268
3	0	576	751	374
	25	067	553	794
	50	991	019	400
	75	724	498	814
	100	195	642	308
4	0	941	262	917
	25	461	844	158
	50	744	648	878
	75	872	441	585
	100	622	598	361

[a]0, 0% HFCS; 25, 25% HFCS; 50, 50% HFCS; 75, 75% HFCS; 100, 100% HFCS

Table 8 - Means and F-values for nonsignificant panel x panel-type interactions

Sensory characteristic	Treatment	Mean scores		F-value
		Panel I	Panel II	
Tenderness[a]				1.32
	0	4.40	4.28	
	25	3.80	4.11	
	50	3.05	3.56	
	75	2.95	3.11	
	100	3.00	3.39	
Moistness[b]				0.18
	0	3.95	4.00	
	25	3.65	3.83	
	50	3.25	3.33	
	75	3.55	3.39	
	100	3.50	3.44	
Sweetness[c]				1.34
	0	3.30	3.22	
	25	3.65	3.44	
	50	2.85	2.61	
	75	3.45	2.83	
	100	2.85	2.72	
Grain[d]				0.56
	0	2.45	2.78	
	25	3.35	3.56	
	50	3.75	3.78	
	75	3.10	3.56	
	100	2.75	2.78	

Table 8 - (concluded)

Sensory characteristic	Treatment	Mean scores Panel I	Mean scores Panel II	F-value
Cell walls[e]				0.09
	0	2.90	3.06	
	25	3.45	3.22	
	50	3.05	3.22	
	75	3.05	2.72	
	100	2.55	2.67	
Crumb color[f]				1.47
	0	4.15	4.61	
	25	3.50	3.83	
	50	2.90	3.06	
	75	2.15	2.44	
	100	1.80	1.89	
Crust color[g]				0.02
	0	3.90	3.89	
	25	2.80	2.78	
	50	2.40	2.28	
	75	1.75	1.95	
	100	1.30	1.11	

[a]Tenderness: 5 = tender and 1 = tough
[b]Moistness: 5 = moist, does not require much saliva and 1 = dry, requires much saliva
[c]Sweetness: 5 = strongly sweet and 1 = moderately sweet, slightly bitter
[d]Grain: 5 = many uniform, small cells, a few larger cells and 1 = large, irregular cells
[e]Cell walls: 5 = thin cell walls and 1 = extremely thick cell walls
[f]Crumb color: 5 = intensely white and 1 = light yellow
[g]Crust color: 5 = light beige and 1 = dark golden brown

Table 9 - Raw data for foam specific gravity, batter specific gravity and batter pH

	Percentage of HFCS				
Measurement	0	25	50	75	100
Foam specific gravity	0.190	0.189	0.171	0.183	0.172
	0.201	0.194	0.194	0.189	0.179
	0.193	0.202	0.181	0.185	0.184
	0.195	0.189	0.184	0.184	0.192
	0.175	0.191	0.182	0.176	0.171
Mean	0.191	0.193	0.182	0.183	0.180
Batter specific gravity	0.256	0.228	0.276	0.268	0.280
	0.239	0.251	0.262	0.267	0.276
	0.234	0.247	0.266	0.249	0.298
	0.236	0.227	0.249	0.256	0.284
	0.220	0.236	0.216	0.225	0.223
Mean	0.237	0.238	0.254	0.253	0.272
Batter pH	5.41	5.39	5.38	5.32	5.25
	5.25	5.39	5.45	5.35	5.30
	5.35	5.45	5.38	5.40	5.38
	5.53	5.38	5.50	5.35	5.39
	5.55	5.47	5.37	5.39	5.41
Mean	5.42	5.42	5.42	5.36	5.35

Table 10 - Raw data for beating time, volume and and percentage moisture

	Percentage of HFCS				
Measurement	0	25	50	75	100
Beating time, seconds	180	150	120	90	60
	180	210	150	120	60
	180	180	150	120	45
	180	180	150	120	45
	180	210	120	120	60
Mean	180	186	138	114	54
Volume, cc	2870	2836	2552	2506	2497
	3014	2824	2583	2585	2509
	2959	2812	2647	2537	2475
	2841	2872	2709	2534	2467
	2979	3018	2748	2666	2521
Mean	2933	2878	2648	2566	2494
Percentage moisture	39.65	40.20	41.85	40.00	40.80
	39.15	40.80	38.80	38.55	40.50
	36.70	38.05	40.30	40.20	39.75
	39.75	40.30	39.55	39.95	40.80
	40.05	40.10	39.85	39.80	40.65
Mean	39.06	39.89	40.07	39.70	40.50

Table 11 - Raw data for crust L-values, crust a -values and crust b -values[a]

	Percentage of HFCS				
Measurement	0	25	50	75	100
Hunterlab values					
Crust L	62.16	48.78	48.10	46.88	43.03
	56.60	50.08	49.75	47.03	46.34
	58.19	48.97	46.15	44.75	42.50
	56.32	48.60	47.19	47.21	42.25
	51.79	46.40	46.98	46.58	43.19
Mean	57.01	48.57	47.63	46.49	43.50
Crust a	8.17	7.98	8.85	8.92	9.13
	7.44	7.87	8.12	8.92	9.71
	7.98	7.69	8.30	8.58	8.74
	8.22	8.00	8.54	8.94	9.09
	7.50	7.61	8.24	8.76	9.47
Mean	7.86	7.83	8.41	8.82	9.23
Crust b	18.61	16.94	16.69	15.17	12.72
	16.97	16.16	16.41	14.82	14.93
	17.28	14.74	13.76	12.61	11.17
	17.50	14.77	14.14	14.74	11.33
	15.65	13.59	15.97	14.63	14.27
Mean	17.20	15.24	15.39	14.39	12.88

[a]Hunterlab Spectrophotometer

Table 12 - Raw data for crumb L-values, crumb a -values and crumb b -values[a]

	Percentage of HFCS				
Measurement	0	25	50	75	100
Hunterlab values					
Crumb L	83.22	84.99	85.01	84.41	82.68
	83.01	83.46	82.36	83.25	82.30
	85.85	85.29	84.59	82.62	82.30
	85.24	84.06	85.40	82.62	84.08
	82.71	83.34	82.80	84.64	80.96
Mean	84.01	84.23	84.03	83.51	82.46
Crumb a	-3.03	-2.91	-2.67	-2.73	-2.88
	-2.94	-3.15	-2.80	-3.07	-2.83
	-3.08	-2.95	-2.93	-2.45	-2.55
	-3.04	-2.77	-3.22	-3.11	-2.59
	-3.13	-2.57	-3.07	-2.65	-2.56
Mean	-3.04	-2.87	-2.94	-2.80	-2.68
Crumb b	9.19	11.37	12.43	12.04	13.66
	9.36	10.50	11.98	12.93	13.86
	10.03	11.47	12.28	13.54	14.20
	9.89	10.63	12.48	12.81	13.99
	10.11	10.94	12.38	12.95	14.49
Mean	9.72	10.98	12.21	12.85	14.04

[a]Hunterlab Spectrophotometer

Table 13 - Means of three measurements of elasticity and firmness[a]

	Percentage of HFCS				
	0	25	50	75	100
Elasticity[b]	83.35	89.80	90.52	91.92	88.00
	93.10	87.83	94.50	91.84	87.25
	92.05	94.32	92.22	88.89	89.89
	91.67	90.91	89.72	90.82	90.48
	83.35	89.80	90.52	91.92	88.00
Mean	88.70	90.53	91.50	91.08	88.72
Firmness, kg	0.225	0.206	0.427	0.343	0.406
	0.271	0.343	0.401	0.503	0.385
	0.193	0.143	0.279	0.365	0.411
	0.321	0.271	0.301	0.415	0.724
	0.225	0.206	0.427	0.343	0.406
Mean	0.247	0.234	0.367	0.394	0.466

[a]Instron Universal Testing Machine

[b]B/A x 100

Table 14 - Means of sensory evaluation scores of ten panelists

	Percentage of HFCS				
Measurement	0	25	50	75	100
Tenderness[a]	4.75	3.63	3.25	3.00	3.75
	4.80	3.50	3.00	2.60	3.50
	3.70	4.00	3.70	2.90	2.80
	3.80	4.60	3.30	3.60	2.80
Mean	4.34	3.95	3.29	3.03	3.18
Moistness[b]	4.00	3.88	3.63	3.75	3.75
	4.40	3.70	2.90	3.20	3.70
	3.90	3.50	3.80	3.20	3.00
	3.60	3.90	2.90	3.80	3.50
Mean	3.97	3.74	3.29	3.47	3.47
Sweetness[c]	3.38	3.88	3.00	3.25	2.75
	3.40	3.70	2.60	3.30	3.00
	3.30	3.10	2.70	3.10	2.40
	3.00	3.60	2.70	3.00	3.00
Mean	3.26	3.55	2.74	3.16	2.79
Grain[d]	2.88	3.00	3.38	2.88	3.00
	2.20	3.40	4.10	3.20	3.10
	2.60	3.30	3.40	3.30	3.10
	2.80	4.00	4.10	4.00	1.80
Mean	2.61	3.45	3.76	3.32	2.76

Table 14 - (concluded)

	Percentage of HFCS				
Measurement	0	25	50	75	100
Cell walls[e]	2.63	3.00	2.50	2.38	2.75
	2.60	3.20	3.50	2.70	2.50
	3.50	3.60	2.90	3.00	2.70
	3.10	3.50	3.50	3.40	2.50
Mean	2.97	3.34	3.13	2.89	2.61
Crumb color[f]	3.88	3.25	2.63	2.38	1.88
	4.40	3.50	2.90	2.00	2.00
	4.60	3.80	3.20	2.50	1.90
	4.50	4.00	3.10	2.30	1.60
Mean	4.37	3.66	2.97	2.29	1.84
Crust color[g]	4.00	2.88	2.63	1.88	1.25
	3.90	2.60	2.20	1.30	1.50
	3.70	2.90	2.20	2.10	1.00
	3.90	2.80	2.40	2.20	1.10
Mean	3.89	2.79	2.34	1.84	1.21

[a]Tenderness: 5 = tender and 1 = tough
[b]Moistness: 5 = moist, does not require much saliva and 1 = dry, requires much saliva
[c]Sweetness: 5 = strongly sweet and 1 = moderately sweet, slightly bitter
[d]Grain: 5 = many uniform, small cells, a few larger cells and 1 = large, irregular cells
[e]Cell walls: 5 = thin cell walls and 1 = extremely thick cell walls
[f]Crumb color: 5 = intensely white and 1 = light yellow
[g]Crust color: 5 = light beige and 1 = dark golden brown

Table 15 - Cost comparison of angel cakes made with sucrose or HFCS[a]

Ingredient	Unit cost, dollars	Amount for one cake		Cost for one cake, cents	
		100% suc.	100% HFCS	100% suc.	100% HFCS
Bleached cake flour	15.10/100 lb	110 g	110 g	4	4
Dried egg albumen	2.95/lb	40 g	40 g	26	26
Acid salt[b]	44.65/100 lb	1.5 g	1.5 g	0.15	0.15
Sodium chloride	2.22/25 lb	3.0 g	3.0 g	0.02	0.02
Distilled water	---	295 ml	167 ml	---	---
Extra fine granulated sucrose	36.90/100 lb	314 g	---	26	---
HFCS	16.00/100 lb	---	444 g	---	16
	Total cost of ingredients			56.17	46.17
	Per cent savings with 100% HFCS			18.0	
	Per cent savings with 25% HFCS			4.5	

[a]February 1981 wholesale prices
[b]Monocalcium phosphate monohydrate, food grade

Fig. 7 - Sampling diagram for physical measurements and sensory evaluation of angel cakes made with five levels of HFCS

A, sensory evaluation

B, crust color (Hunterlab and sensory evaluation)

C, percentage moisture

D, elasticity and firmness (IUTM)

TOP VIEW

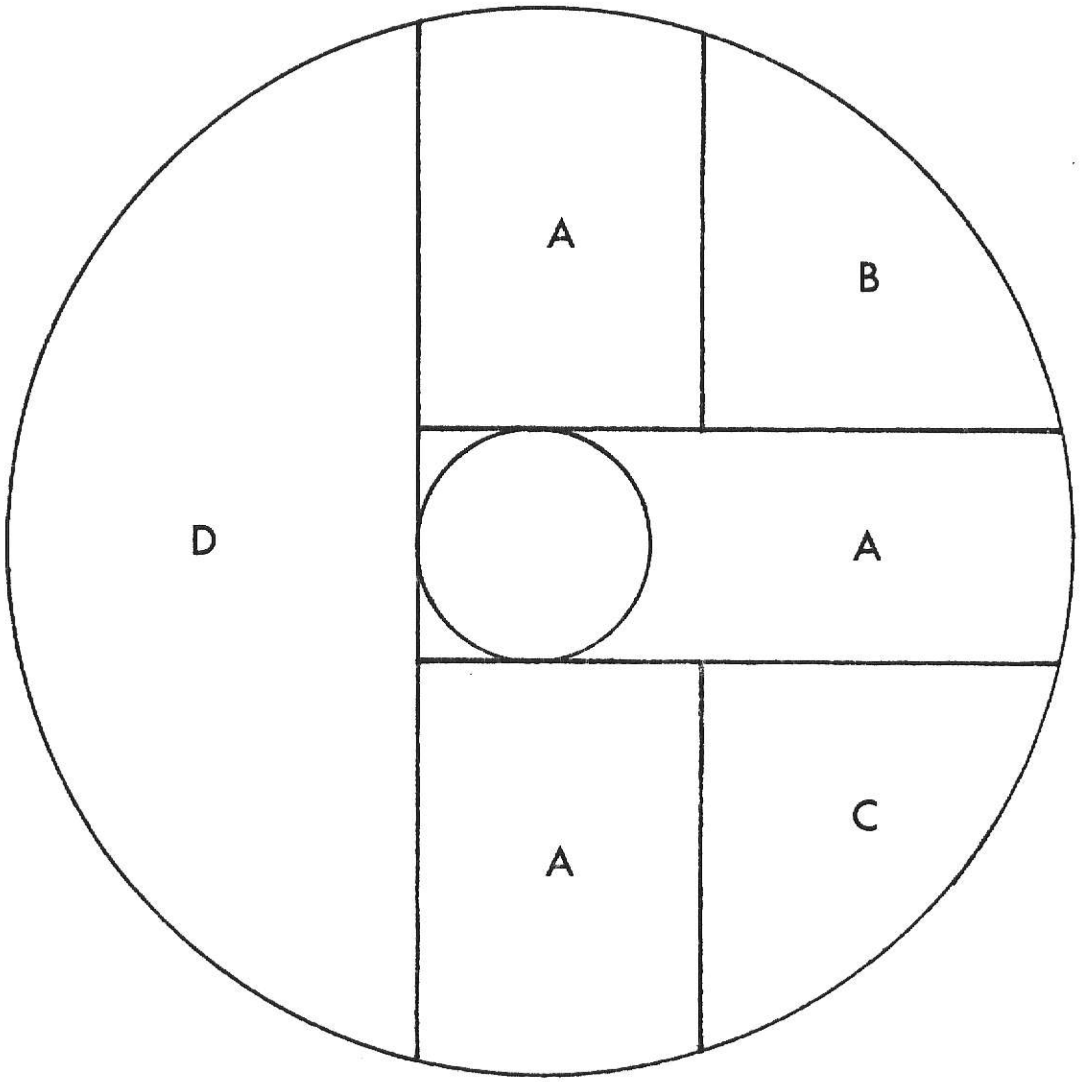


Fig. 8 - Score sheet for evaluation of angel cakes

Directions: Use the scales below to evaluate the angel cake samples. Please use whole numbers only.

Sample No.	Tenderness	Moistness	Sweetness

Tenderness

1 tough
2 slightly tough
3 slightly tender
4 moderately tender
5 tender

Moistness

1 dry; requires much saliva
2 slightly dry
3 neither moist nor dry
4 slightly moist
5 moist; does not require much saliva

Sweetness

1 moderately sweet, slightly bitter
2 sweet, slightly bitter
3 moderately sweet
4 sweet
5 strongly sweet

Sample No.	Crumb Color	Grain	Cell Walls

Sample No.	Crust Color

Crust Color

1 dark golden brown
2 golden brown
3 light golden brown
4 light yellowish brown
5 light beige

Crumb Color

1 light yellow
2 creamy
3 off white
4 white
5 intensely white

Cell Walls

1 extremely thick cell walls
2 thick cell walls
3 medium cell walls
4 slightly thin cell walls
5 thin cell walls

Grain

1 large, irregular cells
2 many large, irregular cells; a few smaller cells
3 many medium cells; a few smaller cells; a few larger cells
4 many uniform, medium cells; a few larger cells
5 many uniform, small cells; a few larger cells

Additional comments:

CALCULATION FOR ADJUSTMENT OF SPECIFIC GRAVITY OF EGG WHITE FOAMS FROM 0.15 TO 0.19

Total weight of foam ingredients except sucrose, g = Total weight of dried egg albumen, water, acid salt, sodium chloride, flavoring

$$= 40 + 295 + 1.5 + 3.0 + 7.5$$

$$= 347$$

Specific gravity when half the sucrose (157 g) is included in the foam

$$= \frac{347 + 157}{347 + 157 + 2856}$$

$$= 0.15$$

Specific gravity when all the sucrose (314 g) is included in the foam

$$= \frac{347 + 314}{347 + 314 + 2856}$$

$$= 0.19$$

CALCULATION OF ESTIMATE OF VOLUME OF ANGEL CAKES

1. Measure and record cake height (h) after depanning at center of hole using 30 cm scale as a straightedge and 30 cm scale as depth gauge. Hold crossed scales together firmly and remove for reading. Repeat measurement four times, rotating the straightedge 45° for each reading.
2. Measure outside diameters at the top (D_T) and bottom (D_B), and corresponding hole diameters (d_b and d_t).
3. Consider the cake as a geometric volume, ignoring local shrinkage and imperfections. From mean diameters ($\bar{D}$ and $\bar{d}$) and mean height ($\bar{h}$), compute a ring volume (V):

$$V = \pi \bar{h} \left(\frac{\bar{D}^2 - \bar{d}^2}{4} \right)$$

(Kissell and Bean, 1978)

HIGH FRUCTOSE CORN SYRUP: REPLACEMENT FOR SUCROSE IN ANGEL CAKE

by

PHILIP EDWARD COLEMAN

B.M.E., Friends University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

ABSTRACT

Sucrose prices have risen dramatically in recent years. As a result commercial food processors are using high fructose corn syrup (HFCS) as a less expensive alternative to sucrose. A syrup composed of monosaccharides, HFCS has some functional properties that make its replacement of sucrose difficult in certain food products, including shortened cakes. This study was designed to investigate the effects of HFCS on selected physical measurements and sensory characteristics of angel cakes as a possible means of reducing ingredient costs through the substitution of HFCS for all or a portion of the sucrose.

HFCS was used to replace 25, 50, 75 or 100% of the sucrose in angel cakes. Less water was used in cakes containing HFCS so that all cakes contained 314 g sugar solids and 295 ml water. Acid salt, salt, flavoring, reconstituted albumen and all sugar (sucrose and/or HFCS) were beaten to a specific gravity of 0.19 ± 0.01 before flour was folded in.

Physical measurements, completed before or within 24 hours of baking, were: beating time; foam specific gravity; batter specific gravity; batter pH; estimate of volume; percentage moisture; elasticity; firmness; and, for crust and crumb, Hunterlab L (lightness), a (redness) and b (yellowness). Sensory evaluation of tenderness, moistness, sweetness, grain, cell wall thickness, crust color and crumb color was completed within 22 hours of baking.

Data were analyzed by AOV. When F-values indicated significant differences, least significant differences among means were calculated for sensory data.

Replacement of sucrose with HFCS resulted in no significant differences among treatments in batter pH, percentage moisture, crumb L-values and a-values, elasticity, moistness scores and cell wall thickness scores. Foams containing HFCS were beaten a shorter time, were less stiff and had slightly lower specific gravities than sucrose foams. Cakes containing HFCS had significantly darker crusts and yellower interiors than all sucrose cakes. Cakes containing 25, 50 or 75% HFCS had more uniform grain than did 0 or 100% HFCS cakes. Cakes containing 50, 75 or 100% HFCS had greatly decreased volume, were less sweet, less tender, had fewer cracks and more "dips" in the top surfaces than 0 or 25% HFCS cakes.

HFCS at the 25% level did not greatly affect any physical measurement or sensory characteristic studied. Cakes containing 25% HFCS were slightly sweeter, slightly more uniform in grain, had more golden crusts and slightly less white crumb than sucrose cakes. All other physical and sensory characteristics of 25% HFCS cakes were not significantly different from those of sucrose cakes.