# Effects of High-Fructose Corn Syrup Replacement for Sucrose on Browning, Starch Gelatinization, and Sensory Characteristics of Cakes

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**ABSTRACT**

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White layer cakes were prepared replacing sucrose with 0, 50, 75, and 100% high-fructose corn syrup (HFCS) with and without an acidulant to control browning. Cakes were evaluated for pH changes, total browning, 5-hydroxymethylfurfural content (HMF), onset of starch gelatinization of cake batters, and sensory characteristics. Total browning and HMF results indicated that the addition of an acidulant to the HFCS cake batters controlled excessive browning. Increased levels of HFCS lowered the onset temperature for starch gelatinization and resulted in a lower volume cake. Sensory analysis of cakes prepared with varying levels of HFCS and an acidulant did not show significant differences from the control (100% sucrose) cake for color, tenderness, or flavor.

High-fructose corn syrup (HFCS) is an important alternative sweetener for sucrose in numerous food products. However, researchers have encountered problems that limit the frequency and quantity of HFCS used in baked products (Volpe and Meres 1976, Coleman and Harbers 1983). Excessive browning of the crust and crumb of cakes containing HFCS was attributed to the Maillard browning reactivity of monosaccharides in the HFCS. Volpe and Meres (1976) controlled the browning with a high-acid leavening system but the cakes scored poorly for flavor. Lower volume and reduced tenderness was attributed to premature gelatinization of the starch during baking when the replacement of sucrose with HFCS exceeded 25% in baked products (Koepsel and Hoseney 1980).

The objective of the study was to monitor the browning and chemical characteristics of cakes prepared with HFCS. The measurement of total browning, pH changes in crumb and crust, and HMF were used to determine the extent of browning reactivity of the monosaccharides with varying levels of HFCS. Sensory characteristics were evaluated and correlated with the chemical and physical data to determine organoleptic changes between treatments. Differential scanning calorimetry was used to explain the transitions of the cake batters during baking and to demonstrate the effect of increasing levels of HFCS on starch gelatinization.

## MATERIALS AND METHODS

### Preparation of Cakes

Yellow shortened cakes were prepared from a formulation adapted from the work of Volpe and Meres (1976). Cakes were prepared with 108 g of shortening, 82.8 g of egg white, 57.2 g of egg yolk, 200 g of flour, 10 g of baking powder, 20 g of nonfat dried milk, and varied levels of sucrose, HFCS, and water. Cakes contained 0, 50, 75, and 100% HFCS as a sucrose replacement. Each level was prepared with and without 3 g of an acidulant—potassium acid tartrate or cream of tartar. The HFCS was first generation syrup (Isosweet 100, A.E. Staley Manufacturing Co.) and by high-performance liquid chromatographic (HPLC) analysis was 44% fructose, 51% glucose, and 5% oligosaccharides. Water was adjusted to allow for moisture content of the syrup. Ingredients were prepared by a common lot number except for eggs, which were purchased fresh daily.

Cakes were prepared by a two-stage mixing procedure: eggs were separated and the whites were whipped to a foam and added as the last step. Ingredients were combined in a Kitchen-Aid mixer (model K5SS, Hobart Co.) fitted with a paddle attachment and linked through an automatic timer to the power source. Batter (630 g) was poured into a 20 × 20 × 5 cm pan and baked in a household type oven for 30 min at 175° C. The accuracy of the oven temperature was tested by a Leeds and Northup Speedomax W Potentiometer with a type J thermocouple (North Wales, PA) and found to be 175 ± 5° C throughout the oven. Batter pH was determined before baking. Baked cakes were evaluated after a 45-min cooling period for pH of the crumb and crust, total browning of crust, HMF content, and sensory attributes.

### pH and Index to Volume

The pH values of the batter, crumb, and crust were determined by direct measurement of the batter or a slurry containing 1 g of the crust or crumb in 10 ml of distilled water. A Fisher Accumet pH meter with pencil combination electrode was used to make the pH measurements. The pH electrode was cleaned daily in a solution of pepsin in 0.1 *N* HCl to remove any protein, which would interfere with pH measurements. An index to volume of the baked cakes was determined by averaging the standing height of the four corners one inch from each edge and the center.

### Total Browning

Total browning of the cake crusts was determined by the modified method of Saltmarch (1980). Samples containing approximately 62.5 mg of protein were placed in a 25-ml polyethylene test tube with lid. Deionized water (10 ml) was added to the samples and equilibrated at 37° C for 30 min. The pH was adjusted to 7.5, and 1 ml of an enzyme solution containing 6 mg/ml of protease from bovine pancreas (Sigma Chemical Co., St. Louis, MO) was added. Incubation continued at 37° C for 30 min. Samples were then removed from the water bath and 2 ml of 50% trichloroacetic acid was added to stop the digestion and precipitate the protein. The samples were filtered and the absorbance of the supernatant read at 420 nm against a reagent blank on a Bausch & Lomb Spectronic 2000 (Rochester, NY). To calculate absorbance units per 100 g of solid the following equation was used:

$$\text{Units per 100 g of solid} = A/B \times 100$$

where A = the absorbance at 420 nm divided by the weight of the sample in grams, and B = 100 minus the percent moisture determined by a Brabender moisture tester (model SAS, C. W. Brabender Instruments, Hackensack, NJ).

### HPLC Analysis of 5-Hydroxymethylfurfural

The 5-hydroxymethylfurfural (HMF) content was determined by HPLC from the adapted procedure of Jeuring and Kuppers (1980). A Lichrosorb RP-18, 225 × 0.46 cm, with a mean particulate diameter of 10 μm (Alltech Associates, Deerfield, IL) was used to separate the compound. The mobile phase consisted of HPLC grade methanol/water (10:90) at a flow rate of 1 ml/min at 800 psi. The ultraviolet detector was an Isco model 228 (Lincoln, NE) set at 280 nm. The peaks were eluted isocratically with a Perkin-Elmer series 10 HPLC pump (Norwalk, CT), and the peak heights and areas were calculated with a Hewlett-Packard 3390A

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integrator (Avondale, PA). Quantification was achieved using a pure HMF standard obtained from Aldrich Chemical Co., Milwaukee, WI).

Samples were prepared for HMF analysis by placing 1 g of cake crust in 9 ml of HPLC grade water to bring the total volume to 10 ml. Samples were homogenized and held for 30 min in the dark to allow for complete extraction, vortexed, and filtered through a 0.45-$\mu$m nylon filter; 10 $\mu$l was injected into the chromatograph.

### Thermal Analysis of Cake Batter

The gelatinization temperature of the starch in the cakes was measured by differential scanning calorimetry (DSC). Cake batters for this analysis were prepared without leavening agent to prevent possible expansion of the sample capsule and breaking the seal, which would release volatiles into the DSC system.

The thermal analysis method of Abboud and Hoseney (1984) for cookie dough was adapted for this study. The system used was a Perkin-Elmer system 4 with microprocessor controller and data handling (Norwalk, CT). Samples were weighed on a Perkin Elmer AD-6 computerized microbalance accurate to 2 mg $\pm$ 0.1 $\mu$g. DSC experiments with 15–20 mg portions of cake batter were weighed into large volume stainless steel capsules and sealed to prevent vaporization and volatiles from entering the system. Indium was used as a standard for calibrating temperatures and enthalpy measurements. The sample was heated from 30 to 140° C at a scan rate of 10° C/min. The sensitivity was set at 5 mcal/sec and then rescaled to 1.5 mcal/sec. The reference material was an empty pan.

### Sensory Evaluation

Sensory evaluation was conducted for all cake treatments. The panel consisted of one male and five female judges, 21–24 years old. Panel members were selected for their ability to discriminate among cake attributes and previous experience in evaluating cakes. Panelists were trained before testing to familiarize them with sensory attributes and to confirm scale differences on the score card. Cakes were evaluated for crust and crumb color, moistness, tenderness, and flavor by a modified quantitative descriptive analysis method using a nonnumerical, unstructured horizontal line of 8 cm with descriptive anchors (Stone et al 1974). The panelists were situated in individual booths with incandescent lighting to minimize distractions and assure independent scoring. Each panelist was provided with room temperature water to clear the mouth between samples so residual flavors did not interfere with scoring. The determination of sample presentation was done by superimposed Latin square arrangements. The samples were coded with three random letters and presented to tasters in 4 × 4 cm portions with top and bottom crust.

### Statistical Analysis

A two-way analysis of variance test followed by Duncan's multiple range test were used to determine differences among means. Means were considered different if the probability of such a difference was 0.05 or less (SAS Institute 1982).

## RESULTS AND DISCUSSION

The results for batter, crumb, and crust pH, total browning, and HMF are listed in Table I.

### pH of Batter, Crumb, and Crust

In all treatments, the pHs of the batter and crumb were significantly lower when acidulant was added. The crust pH of cakes was significantly lower when cakes were prepared with sucrose and 50 or 75% HFCS replacement for sucrose with an acidulant. The crust pH of cakes prepared with 100% HFCS without an acidulant was not significantly different from the 100% HFCS cake with an acidulant added. The possible explanation for these findings is that increased browning with additional HFCS caused an increase in acidity that negated the effect of the acidulant (Dworshak 1980).

### Total Browning

The total browning of the crusts of cakes prepared with different levels of HFCS was significantly less when an acidulant was added to the batter. These results were supported by the taste panel's evaluation of crust color (Table II). Increasing the amount of HFCS increased the amount of total browning.

### HMF

The HMF content was significantly less in cakes with added acidulant whether prepared with HFCS or sucrose. The sucrose cakes prepared without an acidulant were not significantly different from the 50% HFCS cake with an acidulant. The HMF content of all cakes increased as total browning increased.

### Starch Gelatinization

The gelatinization of starch during baking was investigated using DSC. As the amount of HFCS replacement for sucrose in the cakes was increased, the onset temperature of gelatinization decreased (Fig. 1). This supports earlier work indicating that the monosaccharides in HFCS lower the gelatinization temperature causing the structure to set too early during the baking process and restricting the volume (Fig. 2) (Koepsel and Hoseney 1980).

### Sensory Evaluation

The sensory evaluation results are shown in Table II. With the exception of the crumb in cakes prepared with 75% HFCS and the crust in sucrose cakes, the color of acidulated cakes was rated significantly lighter than cakes without acidulant. The crusts of cakes prepared with an acidulant were not significantly different in color from the sucrose cakes. Sensory judges found no significant differences in moistness, tenderness, or flavor of cakes prepared with or without an acidulant.

## CONCLUSIONS

The addition of the acidulant controlled the excessive browning of the cakes prepared with up to 100% HFCS as a sucrose replace-

**TABLE I**
**Results of pH of Batter, Crumb, and Crust, Total Browning, and 5-Hydroxymethylfurfural (HMF) Content in the Crust[a,b]**

| Cake | pH Batter | pH Crumb | pH Crust | Total Browning (absorbance units/ 100 g of solid) | HMF (mg/100 g) |
|---|---|---|---|---|---|
| 0% HFCS, with acidulant[c] | 7.133 c | 7.033 d | 6.300 c | 23.15 f | 1.93 f |
| 0% HFCS, no acidulant | 7.933 a | 8.100 a | 6.800 a | 33.84 ef | 3.969 e |
| 50% HFCS, with acidulant | 6.900 d | 7.000 d | 6.300 c | 41.51 e | 4.235 e |
| 50% HFCS, no acidulant | 7.366 b | 7.833 b | 6.466 b | 76.33 c | 6.268 d |
| 75% HFCS, with acidulant | 6.900 d | 7.000 d | 6.133 d | 56.66 d | 7.923 c |
| 75% HFCS, no acidulant | 7.366 b | 7.900 b | 6.500 b | 93.99 b | 18.250 b |
| 100% HFCS, with acidulant | 6.800 d | 7.033 d | 6.166 d | 60.55 d | 8.749 c |
| 100% HFCS, no acidulant | 7.400 b | 7.633 c | 6.200 d | 114.86 a | 30.140 a |

[a] Mean values of three replicates.
[b] Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).
[c] Contains 100% sucrose. HFCS = high-fructose corn syrup.

**TABLE II**
**Sensory Results for Color of Crust and Crumb, Moisture, Tenderness, and Flavor[a,b]**

| Cake | Color of Crust[c] | Color of Crumb[b] | Moistness[e] | Tenderness[f] | Flavor[g] |
|---|---|---|---|---|---|
| 0% HFCS, with acidulant[h] | 3.4000 b | 2.937 bc | 2.0895 bc | 3.7421 a | 3.7421 a |
| 0% HFCS, no acidulant | 3.9125 b | 3.2062 b | 2.7312 c | 4.1312 a | 3.6562 a |
| 50% HFCS, with acidulant | 4.0444 b | 2.2278 c | 4.0389 ab | 3.5889 a | 3.6500 a |
| 50% HFCS, no acidulant | 5.2471 a | 3.6294 b | 3.8176 abc | 3.2647 a | 4.1253 a |
| 75% HFCS, with acidulant | 3.7533 b | 2.2067 c | 4.8467 a | 3.7667 a | 4.4667 a |
| 75% HFCS, no acidulant | 6.1200 a | 2.8800 bc | 4.0667 ab | 3.2733 a | 4.1400 a |
| 100% HFCS, with acidulant | 3.3278 b | 3.3167 b | 3.5389 bc | 3.9000 a | 3.6167 a |
| 100% HFCS, no acidulant | 5.5278 a | 4.6611 a | 2.7389 c | 3.7944 a | 3.7824 a |

[a]Mean value of 36 replicates.
[b]Means in the same column followed by the same letter are not significantly different ($P \leqslant 0.05$).
[c]0 = light, 8 = dark.
[d]0 = white, 8 = yellow.
[e]0 = less moist, 8 = very moist.
[f]0 = less tender, firm; 8 = more tender, fragile.
[g]0 = less sweet, 8 = more sweet.
[h]Contains 100% sucrose. HFCS = high-fructose corn syrup.

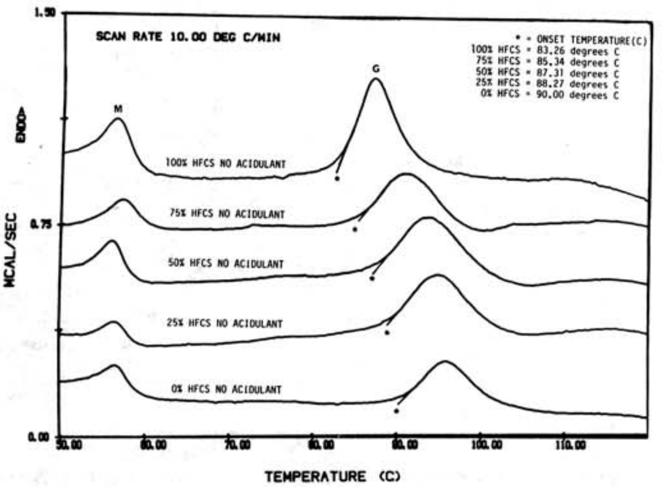


**Fig. 1.** Effect of increasing levels of high-fructose corn syrup on gelatinization temperature of starch in cake batters. Endotherms of (**M**) shortening melting and (**G**) starch gelatinization.

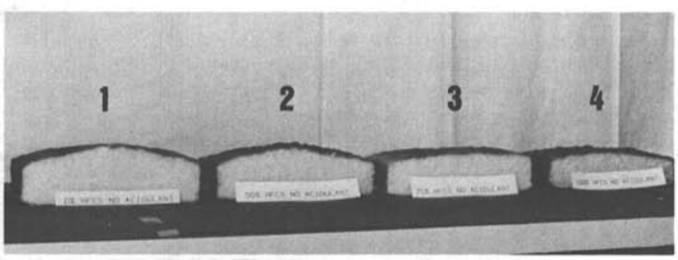


**Fig. 2.** Index of volume for cakes prepared with high-fructose corn syrup (HFCS) and no acidulant: 0% HFCS (6.351 $cm^3$) (**1**), 50% HFCS (5.653 $cm^3$) (**2**), 75% HFCS (5.403 $cm^3$) (**3**), and 100% HFCS (4.538 $cm^3$) (**4**). There was not significant difference at the 95% level between mean volumes for the 50 and 75% HFCS cakes.

ment. The total browning and HMF content of the crust and crumb was altered as the amount of HFCS replacement increased indicating the acidulant reduces the browning reactivity of monosaccharides by lowering the pH of the batter prior to baking. The pH of the crust was not altered by the addition of an acidulant when sucrose was replaced with 100% HFCS. Increased amounts of HFCS lowered the onset of gelatinization during baking, altering the consistency of the cake batter and the quality of the product. Increasing the level of HFCS lowered the standing height used as an index of volume. Results of the total browning and HMF content were supported by sensory evaluation of color of crust and crumb, demonstrating the effect of Maillard browning when increasing levels of HFCS were incorporated in the cake formula. High accumulations of HMF in HFCS cakes prepared without an acidulant indicated that the Maillard type reaction was one of the potential sources of browning when increasing amounts of HFCS were used as a sucrose replacement.

Sensory panelists found no significant differences in moistness, flavor, or tenderness with an acidulant added when HFCS replaced sucrose. Under the conditions of this study, browning of cake crust was controlled when an acidulant was added to cake batters with high levels of HFCS as a sucrose replacement.

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