Effects of Acidulants in Controlling Browning in Cakes Prepared with 100% High-Fructose Corn Syrup or Sucrose

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ABSTRACT

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Replacing sucrose in cakes with high-fructose corn syrup (HFCS) affects browning, volume, and sensory characteristics. In this study, cakes were prepared with 100% HFCS or 100% sucrose and two different acid leavening systems to control browning, cream of tartar, an acid salt, or glucono-delta-lactose. Cakes were evaluated for total browning, 5-hydroxymethylfurfural, volume, moisture, color, loss of lysine, and sensory characteristics. The use of acidulants and consequent lowering of the batter pH significantly reduced the total browning and hydroxymethylfurfural content of the cake crusts. Glucono-delta-lactose was more effective in controlling browning than cream of tartar. Lysine loss was reduced by the addition of either acidulant. Sensory analysis determined that the cakes containing 100% HFCS and acidulants were significantly different from control cakes containing 100% sucrose and acidulants in crust and crumb color, moistness, tenderness, and aftertaste.

High-fructose corn syrup (HFCS) is rapidly replacing sucrose as a sweetener in beverages, soups, and cookies. HFCS is manufactured from corn starch that is converted by α-amylase to a hydrolysate with a glucose content of 94–96%. The glucose is isomerized by immobilized enzymes to produce a syrup with a fructose content of 42, 55, or 90% (Inglett 1981). The low cost, price stability, and availability of the corn-based sweetener makes the syrup a popular replacement for sucrose.

The major use of HFCS is in soft drinks, salad dressings, frozen desserts, jams, jellies, and fruit preservation. Hannigan (1982) stated that the future growth of the HFCS industry will come from baking and preservation of foods. However, researchers have encountered several problems that limit the frequency and quantity of HFCS used in baked products. The most severe problems—excessive browning of the crust and crumb, lower volume, loss of tenderness, and bitter taste—made HFCS an unsatisfactory replacement for sucrose in baked goods (Koepsel and Hoseney 1980, Coleman and Harbers 1983). Volpe and Meres (1976) reported that the replacement of more than 25% of the sucrose with HFCS did not produce an optimum quality white shortened cake. In more recent studies, up to 75–100% HFCS as a replacement for sucrose in cakes was used with an acidulant, cream of tartar, which lowered the pH of the batter and controlled excessive browning. Cake flour was used in place of all-purpose flour to improve the cake volume (Harris and Johnson 1988; McCullough et al 1986; Johnson, *unpublished*).

The purpose of this study was to test two different acid leavening systems containing cream of tartar (COT), an acid salt, and glucono-delta-lactone (GDL) to control browning in cakes prepared with 100% HFCS and to determine the optimum formulation by objective and sensory measurements compared with a control containing 100% sucrose.

MATERIALS AND METHODS

Cake Samples

Yellow shortened cakes were prepared from a formulation adapted from the work of Volpe and Meres (1976). Cakes were prepared with sucrose or 100% HFCS. The cake ingredients are listed in Table I. The HFCS was Isosweet 100 (A.E. Staley Manufacturing Co., Decatur, IL) that was found by high performance liquid chromatography (HPLC) analysis to contain 44% fructose, 51% glucose, and 5% higher saccharides. Water was adjusted to allow for moisture content of the syrup. Batters were prepared without and with an acidulant, COT or GDL. Ingredients were purchased by a common lot number, except for eggs which were purchased fresh daily.

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Cake Baking

Cakes were prepared by a two-stage mixing procedure in which the egg whites were whipped to a foam and added as the last step. Mixing was done with a Kitchen-Aid mixer (model K5SS, Hobart Co., Troy, OH) 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 Speedmax W Potentiometer with a type J thermocouple (North Wales, PA) and found to be 175° C ± 5° C throughout the oven. The specific gravity and pH of the batter were measured. After a 45-min cooling period, the cakes were evaluated for crust pH, total browning of crust, 5-hydroxymethylfurfural (HMF) content, standing height, ΔE, loss of lysine, and sensory analysis.

pH Measurements

The pH of the batter and crust were measured by direct measurement of the batter or of a slurry containing 1 g of the crust in 10 ml of distilled water. A Fisher Accumet pH meter (model 600, Lexington, MA) with pencil combination electrode was used. The pH electrode was cleaned daily in a solution of pepsin in 0.1*N* HCl.

Total Browning

Total browning of 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, pH 7.5, was added for digestion of protein. Incubation was 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 read at 420 nm against a reagent blank on a Bausch and 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.

HPLC Analysis of HMF

HMF content was determined by HPLC using the procedure of Jeuring and Kuppers (1980). A Lichrosorb RP-18, 225 cm × 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 integrator (Avondale, PA). Quantification was achieved using a pure HMF standard obtained from Aldrich Chemical Co. (Milwaukee, WI).

Samples were prepared for analysis of HMF by placing cake crust (1 g) 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 μm nylon filter; 10 μl were injected into the HPLC.

Specific Gravity, Volume, Moisture and Color Analysis

Specific gravity of each batter was determined by dividing the weight of 50 ml of cake batter by the weight of 50 ml of water. An index of volume of the baked cakes was determined by averaging the standing height of the four corners, one inch from each edge and the center. Cake crumb (10 g) was dried to a constant weight at 155° C in a moisture tester (Brabender, South Hackensack, NJ) to determine the percent moisture. Crust color was measured by a Hunter color difference meter (Hunter Labs, Reston, VA) and the *L*, *a*, and *b* values were used to calculate the ΔE.

Available Lysine

Reactive lysine content of proteins in the cake batter, crumb, and crust was obtained by measuring the decrease in moles of dye bound to lysine when the available lysine epsilon amino groups were blocked before reacting with acid orange 12 dye (1-phenylazo-2-sulfonic acid) (Hurrell and Carpenter 1976). Samples for A and B were weighed into 50-ml polypropylene sample bottles obtained from the Udy Corporation (Fort Collins, CO). Sample A should contain approximately 40% protein and sample B approximately 2.2 times that of the weight of A to compensate for the blocked lysine after propionylation. To both A and B was added 1 ml of isopropanol, which acts as a wetting agent, and the mixture was gently swirled to wet all particles. Propionic anhydride (0.5 ml) was added to sample B followed by 2 ml of 5% sodium acetate buffer and 2.5 ml of 5% sodium acetate buffer was added to sample A. The samples were vortexed and shaken vigorously for 15 min on a laboratory shaker. Udy reagent dye (20 ml) (Udy Corp.) was added to each bottle and shaken for an additional 60 min. Samples were then filtered and diluted 1:100 with deionized-distilled water. The color intensity was read at 480 nm on a Bausch & Lomb Spectronic 2000 (Rochester, NY) against a reagent blank. Stock solutions of the Udy reference dye were prepared at concentrations of 1.2, 1.3, 1.4, 1.5, 1.6, and 1.7 mmol/L. Working standards were prepared fresh daily by diluting the stock solutions 1:100 with deionized-distilled water. Results in millimoles per liter of residual dye were obtained from a linear regression curve of the working standards. Final results were calculated using the following formulations:

$$\text{Lysine (g) per 16 g N} = [(A - B) \times 146.3/1{,}000] \times 16/(5.70 \times \% \text{ protein})$$

where A = 3.77 − [(mmol/L of sample A)/(g of sample A)] = mmol/L of dye bound per gram of sample, and B = 3.77 − [(mmol/L of sample B)/(g of sample B)] = mmol/L of dye bound per gram of sample, 5.70 = Kjeldahl nitrogen factor of flour, % protein = decimal percent of protein as determined by Kjeldahl analysis, and 146.3 = molecular weight of lysine.

Sensory Evaluation

The 100% sucrose and 100% HFCS cakes with and without the acidulants were evaluated by a trained sensory panel. Six panelists, female, 21–24 years of age, were trained prior to the study to acquaint and enable them to evaluate each of the attributes and to confirm scale differences on the scorecard. The panelists were in individual booths with incandescent lighting to minimize distraction and assure independent scoring. Tap water was used between samples to cleanse the palate. A Latin square design was used for presentation of samples, and each sample was coded with random letters. Cakes were evaluated for crust and crumb color, sweetness, moistness, tenderness, and aftertaste by a modified quantitative descriptive analysis method using a nonnumerical unstructured horizontal line of 8 cm with descriptive anchors (Stone et al 1974).

Statistical Analysis

A two-way analysis of variance followed by Duncan's multiple range test were used to determine differences among means. Means were considered different from each other if the probability of such a difference was 0.05 or less (SAS Institute 1983).

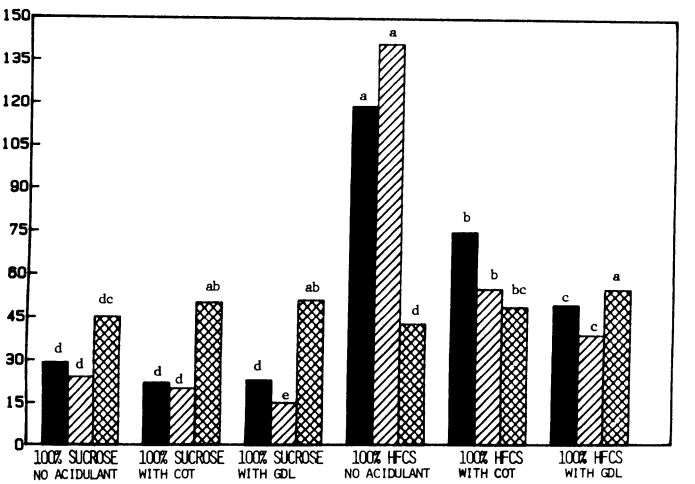

Fig. 1. Mean results of total browning in absorbance units per 100 g of solid (■), 5-hydroxymethylfurfural (HMF) content in milligrams per liter (▨), and ΔE (▩) for cake crusts. Columns with the same letter within the same measurement are not significantly different at $P \leq 0.05$.

TABLE I
Cake Formula for Cakes Prepared with High-Fructose Corn Syrup (HFCS) or Sucrose[a]

	0% HFCS			100% HFCS		
Ingredient	**No Acidulant**	**With COT**	**With GDL**	**No Acidulant**	**With COT**	**With GDL**
Shortening	108.0	108.0	108.0	108.0	108.0	108.0
Egg white	82.8	82.8	82.8	82.8	82.8	82.8
Egg yolk	57.2	57.2	57.2	57.2	57.2	57.2
Flour	200.0	200.0	200.0	200.0	200.0	200.0
Baking powder	10.0	10.0	5.0	10.0	10.0	5.0
Cream of tartar (COT)	0.0	3.0	0.0	0.0	3.0	0.0
Glucono-delta-lactone (GDL)	0.0	0.0	3.7	0.0	0.0	3.7
Soda	0.0	0.0	1.3	0.0	0.0	1.3
Nonfat dry milk	20.0	20.0	20.0	20.0	20.0	20.0
Sucrose	240.0	240.0	240.0	0.0	0.0	0.0
HFCS	0.0	0.0	0.0	338.0	338.0	338.0
Water[b]	138.0	148.0	148.0	50.0	50.0	50.0

[a] Ingredient amounts in grams.
[b] Water was adjusted to allow for the moisture content of the syrup.

TABLE II
Results for Batter pH, Crust pH, Standing Height, Specific Gravity of Batter, Moisture, and Lysine[a]

Cake	Batter pH	Crust pH	Volume Index	Specific Gravity	Moisture	Lysine (g)/16 g of Nitrogen		
						Batter	Crumb	Crust
100% Sucrose								
No acidulant	7.46 a	6.50 a	5.1360 a	0.890 a	34.33 a	5.63 a	4.43 a	1.51 bc
+ Cream of tartar	6.90 b	6.34 b	4.9520 a	0.785 a	34.33 a	5.66 a	4.49 a	2.08 a
+ Glucono-δ-lactone	6.76 c	6.36 b	5.1520 a	0.757 a	34.00 a	5.89 a	4.59 a	1.99 ab
100% High-fructose corn syrup								
No acidulant	7.34 a	6.00 c	4.5760 b	0.813 a	38.00 b	5.79 a	3.62 b	0.70 d
+ Cream of tartar	6.70 c	6.04 c	4.1600 c	0.780 a	38.00 b	5.81 a	3.99 ab	1.27 c
+ Glucono-δ-lactone	6.70 c	6.08 c	4.1920 c	0.757 a	38.33 b	5.94 a	4.16 ab	1.41 cd

[a] Mean value of three replicates. Means with the same letter in the same column are not significantly different ($P \leq 0.05$).

TABLE III
Sensory Results of Color of Crust and Crumb, Sweetness, Moistness, Tenderness, and Aftertaste[a]

Cake	Color of Crust[b]	Color of Crumb[c]	Sweetness[d]	Moistness[e]	Tenderness[f]	Aftertaste[g]
100% Sucrose	5.5667 a	2.6566 c	2.5778 b	3.6611 b	4.1278 ab	4.5944 a
100% Sucrose						
+ Cream of tartar	3.5450 c	2.5250 c	3.6400 ab	3.6500 b	3.8250 a	4.6900 a
+ Glucono-δ-lactone	2.9150 c	2.5350 c	2.9000 ab	4.5450 a	4.7900 a	4.7350 a
100% HFCS	5.6421 a	5.0211 a	3.4211 ab	4.1158 ab	3.3474 b	3.6789 b
100% HFCS						
+ Cream of tartar	4.3684 b	4.1368 b	3.7105 a	3.3211 b	3.4368 b	3.5842 b
+ Glucono-δ-lactone	3.2000 c	4.0412 b	3.8176 a	4.5588 a	3.9647 ab	3.3059 b

[a] Mean value of 18 replicates. Means with the same letter in the same column are not significantly different ($P \leq 0.05$).
[b] Crust color: 1 = light, 8 = dark.
[c] Crumb color: 1 = white, 8 = yellow.
[d] Sweetness: 1 = less sweet, 8 = more sweet.
[e] Moistness: 1 = dry, 8 = moist.
[f] Tenderness: 1 = less tender, firm; 8 = more tender, fragile.
[g] Aftertaste: 1 = imperceptible, none; 8 = extremely pronounced.

RESULTS AND DISCUSSION

The results for total browning, HMF content, and ΔE of cake crusts are illustrated in Figure 1. The use of acidulants COT and GDL significantly reduced the HMF level and total browning in cakes prepared with 100% HFCS. The GDL reduced total browning and HMF significantly more than COT in cakes prepared with 100% HFCS. The total browning and HMF content of cakes prepared with sucrose with or without an acidulant was not significantly different but was significantly less than cakes prepared with HFCS. The total browning and HMF content decreased as the browning was reduced and the ΔE increased indicating a lighter crust color.

The results for the batter pH, crust pH, moisture, volume index, batter specific gravity, and loss of lysine in the batter, crumb, and crust are listed in Table II. The pH of the batters was significantly reduced when the acidulants were added, supporting a favorable environment for reduced browning. There were no differences in crust pH for the three treatments of the 100% HFCS cakes. The crust pHs were significantly less in the 100% sucrose cakes prepared with acidulant than in the 100% sucrose cake without acidulant. In cakes prepared with 100% HFCS, the pH appeared to be limited to approximately 6.0 regardless of the amount of browning. The 100% HFCS cakes were significantly more moist than the control cake containing 100% sucrose but had a lower volume index, which is supported by earlier studies (Coleman and Harbers 1983, Koepsel and Hoseney 1980). There were no differences in specific gravities of the batters.

The grams of lysine per 16 g of nitrogen were the same for all the cake batters. The loss of lysine in the cake crumb was the greatest in the 100% HFCS cake with no acidulant where browning was greater. With the addition of acidulants to the 100% HFCS cake batters, the amount of lysine lost in the cake crumb was significantly lower. Loss of lysine in the 100% HFCS cake crust with no acidulant was significantly greater than in any of the other treatments.

The sensory results are listed in Table III. Sensory evaluation of the color of the crust and crumb support the total browning, HMF content, and ΔE values. The panelists noted that the cakes baked with HFCS were significantly sweeter than the 100% sucrose cakes, with the exception of the 100% sucrose cake with COT added. The cakes with 100% HFCS and no acidulant, 100% HFCS with COT, and 100% sucrose with COT were considered less tender than other cakes and were considered to have a more bitter than sweet aftertaste.

CONCLUSION

The addition of the acidulants greatly reduced the HMF and total browning in cakes prepared with 100% HFCS as a replacement for sucrose. GDL was more effective in controlling the browning than COT and also resulted in a more tender and moist cake. Loss of lysine was not as great in the cakes prepared with 100% HFCS when the acidulants were added before baking. As browning proceeded in the cake crusts of the cakes prepared with 100% HFCS, the pH of the system decreased due to acids being formed (Dworshak 1980).

The reduction of browning by the addition of acidulants improved the 100% HFCS cakes in appearance as supported by loss of lysine. However, a lower volume and a bitter flavor or aftertaste was found when using up to 100% HFCS as a sucrose replacement in cakes.

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