QUALITY AND BROWNING AND THE EFFECTS OF pH ADJUSTMENT ON CAKES PREPARED WITH HIGH FRUCTOSE CORN SYRUP

by

James Richard Raville

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APPROVED:

J. M. Johnson, Chairman

W. Barbeau

R. Young

J. Phillips

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Committee Chairman: Janet M. Johnson
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(ABSTRACT)

Cakes were prepared with high fructose corn syrup as the total sweetening agent in a moisture adjusted formulation which allowed for the moisture content of the syrup. Three treatments were produced by adding glucose-delta-lactone and cream of tartar (high acid), cream of tartar (medium acid), or no addition (low acid). Cakes were baked and immediately tested under controlled conditions.

The pH and specific gravity were determined for cake batters. Baked cakes were evaluated for pH, standing height as an index to volume, moisture, deformation, crust color, and crust and crumb browning.

Volume, color and browning were all significantly affected by pH adjustment. As acidity increased, cakes had less volume and a gummy, pudding-like texture. Color decreased and browning decreased at higher levels of acidity. Thus, it was concluded that increasing acidity decreased the over-development of color and browning, but altered the texture. The high fructose corn syrup sweetened

cakes that were moderately acidified by the addition of cream of tartar alone were less brown but lighter in texture than the other treatments.

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INTRODUCTION

Corn syrup is produced by the acid hydrolysis of corn starch. In the United States, corn syrups are defined as "purified concentrated solutions of nutritive saccharides obtained from corn starch and having a dextrose equivalent (D.E.) of 20 or more." (Wardrip, 1971) This simple corn syrup may be further treated with various techniques to produce products of unique composition, properties and intended usages. Examples include syrups of various D.E.'s, high maltose syrup, invert syrup and high fructose corn syrup (HFCS) (Wardrip, 1971).

HFCS is produced by the isomerization of part of the glucose, normally present in corn syrup, to fructose. The enzymatic conversion results in a sweeter product, that may be used in many foods (Anon, 1977). Depending on the extent of glucose conversion and subsequent manipulation, production of HFCS with as much as 90% fructose is possible (Crocco, 1976). Blends of HFCS containing a range of fructose content, up to 55-60%, are available (Crocco, 1976).

HFCS is useful as a partial or total sucrose replacement in products such as carbonated beverages, syrups, salad dressings, pickles, yeast-raised baked goods and desserts (Anon., 1977). The economy, ease of handling and storage advantages of HFCS, when compared to sucrose, have helped the syrup achieve widespread industry acceptance.

While a given HFCS blend may be equal to sucrose in perceived sweetness, it differs from sucrose in that it is more hygroscopic, less readily crystallizable and more fermentable (Sausselle, 1983). Depending on the intended usage these differences may or may not be advantageous. For example, in baked goods, HFCS is an excellent yeast energy source for yeast-raised breads, but may contribute to excess browning in light-colored cakes (Sausselle, 1983). Enthusiastic claims by industry about HFCS usage must be weighed against experimental evidence which is at times less encouraging.

Purpose

The present project was designed to study the limitation of excessive browning while maintaining other quality attributes in cakes prepared using HFCS as a 100% replacement for sucrose. pH manipulation was the means of limiting browning. The pH was altered by adding an acidulant (cream of tartar) or substituting a more acidic leavener (glocono delta lactone and soda) with the addition of cream of tartar.

REVIEW OF LITERATURE

History and Production of High Fructose Corn Syrup

Corn syrups are manufactured by the acid hydrolysis of corn starch (Wardrip, 1971). In the process the corn starch molecule is broken into smaller units which include dextrins, maltose and glucose (McCullough, 1985). While somewhat sweet, these simple corn syrups are used more for their functional properties than their sweetening power (Casey, 1978). Casey (1978) described several technological developments of the postwar period which resulted in the development of modified syrups with a range of functional properties, as well as increased sweetness. These developments included better syrup refining methods utilizing ion exchange and carbon filtration systems, improved chromatographic separation techniques and advances in enzyme technology. With these developments, corn syrup usage gradually increased.

Without question, improved enzyme technology was the most important factor in increased corn syrup usage. In 1964, American Corn Processing Company obtained the U.S. rights for the production of a fructose containing corn syrup by using a microbial enzyme which isomerized glucose to fructose. By 1968 a high fructose corn syrup (HFCS) of 42% fructose was commercially available. Initial HFCS production utilized a batch process in which soluble enzyme (glucose isomerase) converted glucose to fructose. This technique was slow, requiring two days per batch of HFCS produced.

In 1972 a continuous system utilizing immobilized glucose isomerase was developed. The continuous system reduced contact time from two days to two hours with a consequent less expensive production of HFCS (Anon, 1977). Henry (1976) attributed the wide availability and a 10-20% lower price than sucrose as contributing to increased HFCS usage (Henry, 1976).

Food Technology described a simple overview of the production of HFCS as follows: "The process involves liquefying raw cornstarch, saccharifying to dextrose, refining, isomerizing the dextrose to fructose, refining again, and concentrating the refined high fructose corn syrup" (Anon., 1977). The endproduct was a 42% fructose syrup approximately equal to sucrose in sweetness (Anon., 1977).

Properties of High Fructose Corn Syrup

Henry (1976) and Sausselle (1983) compared the properties of HFCS and sucrose. HFCS (42% fructose; 71% solids) was reported to be approximately as sweet as sucrose and was easily used as a sucrose replacement when sweetness was the only concern (Henry, 1976).

The physical form differed from a liquid for HFCS to crystalline for sucrose. HFCS required a fluid adjustment of 29% in formulas utilizing HFCS as a sucrose replacement. In fermented products, the monosaccharides of HFCS were more readily fermented than the disaccharides which compose sucrose. The greater humectancy of fructose and glucose allowed for more moisture retention in products in which HFCS was substituted for sucrose.

HFCS was less crystallizable than sucrose due to its composition of different types of sugar molecules. This property may be good or bad depending on the desired characteristics of the product (Sausselle, 1983). Compared to other liquid sweeteners Wardrip (1971) reported that the solids content of HFCS provided better resistance to microbial growth during storage and handling (Wardrip, 1971). He further reported HFCS was more effective than sucrose as a synergistic sweetener with sacharine.

HFCS In Baked Products

The present study examined baked goods, specifically white layer cake. Therefore, aspects of HFCS usage in these products will be addressed. The limitations to utilization of HFCS as a replacement for sucrose were related to the variety and type of sugar molecules HFCS contained. Specifically, the fructose and glucose in HFCS increased browning and caused decreased volume and poor texture of the cakes (Coleman and Harbers, 1983).

Bean, Yamazaki and Donelson (1978) studied wheat starch gelatinization in cakes as affected by simple sugars. They noted similar concentration solutions of fructose, glucose or sucrose yielded very different cake products. Cakes made using monosaccharides appeared flat and shrunken, and had smaller volumes. Other researchers noted a similar effect (Koepsel and Hoseney, 1980; Coleman and Harbers, 1983; Beery, 1982; Strickler, 1981). The phenomenon was attributed to the presence of the monosaccharides fructose and glucose, which were responsible for premature gelatinization of the starch during baking. Thus, cakes made with monosaccharides had inadequate structural development manifested by poor texture and decreased volume (Bean et al, 1978).

Glucose and fructose are reducing sugars which are more reactive than sucrose in Maillard or carbonyl-amine browning (Campbell, 1979). The glucose and fructose content of HFCS accounted for excessive browning of baked products prepared with HFCS as a replacement for sucrose. The excess browning was reported by most researchers as the major drawback to HFCS utilization in baked goods (Coleman and Harbers, 1983; Volpe and Meres, 1976; Koepsel and Hoseney, 1980, Strickler, 1981).

Layer Cakes - General Formulation Considerations

A brief overview of cake ingredient functions and overall formulation considerations are presented here as a background to better understand this project. Each ingredient in a cake formulation performs specific functions. Substitution of any ingredient can result in altered product characteristics making formulation adjustments necessary.

Lawson (1970), in an in-depth consideration of cake ingredients and their functions in the final product, categorized all cake ingredients into one or more of five functional groups: structure builders, tenderizers, moisteners, dryers, and flavorers.

Flour was classified a structure builder and drying agent. Sugar was reported to tenderize and give flavor. Shortening was also reported to tenderize as well as moisten. It was found that the amount and type of shortening used affected cake keeping qualities. Shortening with added emulsifiers (i.e., monoglycerides) emulsified more liquid in a batter and thereby performed a shortening function more effectively. Shortening also entrapped minute air bubbles during batter mixing which served as nucleation sites for leavening. The more completely and uniformly the shortening was dispersed in a batter, the more effectively it served in its air cell nucleation function. Emulsifiers added to the shortening further enhanced this function.

Milk solids added richness, structure and flavor. Milk solids also increased crust browning. Eggs contributed to moistness and structure. The lipid portion of yolks also tenderized and emulsified. Leavening agents contributed volume and lightness to a cake. (Lauson, 1971)

Lauson (1971) determined a weight ratio of cake ingredients to establish a balanced formula: (1) a sugar:flour ratio of at least 125:100; (2) weight of shortening not greater than weight of eggs; (3) weight of liquids (including milk, water and liquid egg) should equal or exceed the weight of the sugar.

pH - Role in Baked Products

The expression, pH, is a measure of a solution's hydrogen ion concentration. Defined: pH equals the negative log of hydrogen ion concentration per liter. (-log[H+]) (Campbell, 1979). Ash and Colmey (1973) studied the effect of pH on baked products. Flavor was altered towards sourness with acidity and soapiness with alkalinity. The color of crust and crumb was lighter at a more acidic pH and darker at a more alkaline pH. (Kichline and Conn, 1970)

Cake texture, volume, and grain was influenced by pH. As the pH increased beyond the optimum point the grain of the crumb became coarse and volume increased. As pH decreased the grain became fine and compact with decreased volume (Ash and Colmey, 1973).

Ash and Colmey (1973) stated: "In general, a baked product in which the proper balance of soda and leavening acid have been used will have a cake crumb in the neutral range of pH 6.5-7.5." Other ingredients of a cake formula were reported to contribute to the final pH. Ingredients considered weak bases raised pH. These included cocoa, eggs, soda and in some cases water. Ingredients which lowered final pH were weak acids. These included corn syrup, invert syrup, cake flour, milk, buttermilk, dextrose, fruit juices, fruits, emulsifiers and leavening acids such as cream of tartar (COT), sodium acid pyrophosphate (SAPP) and monocalcium phosphate (MCP). Ingredients not affecting cake pH included sugar, shortening, salt and good-quality baking powder. Ingredients of variable pH exerted differing pH influences on the final product (Ash and Colmey, 1973).

Ash and Colmey (1973) reported that for optimum quality batters should have a neutral pH. However, a pH adjustment was reported to be beneficial in some baked products. Variables affected by small pH changes were crust and crumb color, grain, volume and texture. The amount and type of leavening agent (composed of acid and alkaline salts) was adjusted to produce small changes in the cakes' pH.

Leaveners

As may be concluded from the preceding discussion, researchers have shown the type and source of a cake's leavening affect the quality of the baked product. Volume, grain, texture and flavor of cakes were altered with variation of chemical leavening agents.

Leavening systems which produce the carbon dioxide (CO_2) to leaven a cake involve the reaction between an acidic salt and sodium bicarbonate (baking soda). In aqueous solution, with heat application the substances react to produce a neutral salt, and water with the concurrent evolution of CO_2

$$\underset{\text{(acidic salt)}}{HX} + \underset{\text{(soda)}}{NaHCO_3} \xrightarrow[\text{heat}]{\text{moisture}} \underset{\text{(neutral salt)}}{NAX+H_2O+CO_2}$$

(Kichline and Conn, 1970).

Kichline and Conn (1970) reported the acidic salt used in a baking powder determined its leavening characteristics. The chemical form (anhydrous) of the acidic salt altered the baking powder's properties including rate, timing and amount of CO_2 evolution.

Kichline and Conn (1970) compiled a list of the most commonly used leavening salts, their reaction speed and best application. Potassium acid tartrate upon hydration reacted very quickly. Monocalcium phosphate monohydrate was quick to react and proved valuable used in conjunction with a slower reacting acid. In its coated anhydrous form, monocalcium phosphate's leavening reaction was slowed enough to be useful in small batches of baked goods (i.e., household use). Sodium aluminum pyrophosphates (SAPP) released most of its CO_2 in one quick puff, upon reaction with water and heat application. Thus SAPP applications were limited to items such as small cakes and doughnuts. Sodium aluminum sulfate (SAS) also reacted with heat and moisture, but much slower than SAPP, making SAS more practical for household use. Like SAS, sodium aluminum phosphate (SAP) evenly released CO_2 as a leavening acid. SAP was recommended for use in household baking powders over SAS because it had a less astringent aftertaste and did not accelerate rancidity. Dicalcium phosphate dihydrate (DPD) evolved CO_2 slowly upon the application of moisture and heat. DPD prevented dipped or fallen cakes when used in conjunction with other leavening salts. Glucono delta lactone (GDL) reacts slowly, but at an even constant rate. GDL's even reaction rate and good CO_2 evolution give it great potential for use as an alternative leavener.

Kichline and Conn (1970) reported that the selection of leavening acid used in a formulation was based on consideration of mixing time, bench holding time and baking time. Leavening agents may be combined to achieve a combination of properties for an optimum quality baked product.

Whether or not the correct leavener(s) was used in a baked product is evidenced by the cake's internal structure. Kichline and Conn (1970) stated that "The thin cell wall structure of doughs and particularly of batters is dependent on leavening rate. This includes the early nucleation state and the optimum rate of inflation during baking." Ash and Colmey (1973) reported that "control of leavening reactions is of utmost importance in determining the ultimate volume of the cake." Low volume resulted from quick CO_2 release, which was lost before the cake structure had time to set. A slow CO_2 release caused the cakes to lose structure due to CO_2 release after structure was set. This was manifested by cakes with small volumes and large holes throughout the structure. Household baking powders generally contain both fast and slow reacting leavening acids to accommodate home baking requirements. Commercial bakers generally select a leavening blend which best accommodates their particular needs (Kichline and Conn, 1970).

Browning Reactions

A browned exterior and crumb and a pleasant nutty flavor and aroma are positive by-products of browning reactions which occur in the baking process. However, browning reactions are not always desirable (Campbell, 1979). Browning reactions can be divided into enzymatic or nonenzymatic. Enzymatic browning occurs only on the cut surfaces of certain fruits and vegetables. These reactions do not occur in baked goods and will not be considered here.

Nonenzymatic browning contributes greatly to the appearance of baked goods. while much work has been directed towards determining the exact mechanism of nonenzymatic browning, much remains uncertain (Campbell, 1979). Several different reactions contribute to the browning, each of which has unique requirements of substrate and reaction conditions. For example, reactions may require sugars, amines, or specific amino acids and may be affected by heat, moisture or pH. Even within a specific browning reaction there may exist several pathways, mechanisms and subreactions (Campbell, 1979).

Two browning mechanisms found important in baked products are carbonyl-amine browning (the Maillard reaction) and caramelization (sugar browning). The results of studies indicate that for carbonyl-amine browning several components are required. First, a reducing sugar was necessary to contribute a reactive carbonyl group. Particularly reactive reducing sugars included glucose fructose and lactose. Sucrose, a nonreducing sugar, did not participate since the reducing groups were tied up in a glycosidic linkage. A free amine group, generally provided by amino acids, was needed to react with the reducing sugar (Campbell, 1979). Lysine was particularly reactive. The reaction was due to the condensation of carbonyl and amine groups to ultimately form brown colored pigments termed melanoidins. Increasing pH and/or temperature caused the reaction to increase. The reaction was prevalent at intermediate moisture levels. (Campbell, 1979). Caramelization browning required only that sugars and heat be present. Variables which affected carbonyl amine browning affected caramelization similarly. Both reactions increased in cakes made with HFCS as a consequence of the sugar profile, moisture level and pH.

HFCS - Use in Cakes

The properties of HFCS such as humectancy, resistance to crystallization, ease of fermentation and sweetness were advantageous in the use of HFCS (Henry, 1976; Sausselle, 1983). HFCS was found to be a valuable sucrose substitute in many products such as soft drinks, sauces, condiments and breads (Crocco, 1976). However, the utilization of HFCS as a sucrose replacement in baked goods at levels above 25% was limited due to excessive browning and volume loss. (Sausselle, 1983) Investigators using HFCS as a replacement for sucrose in several types of cakes found that formulation and mixing modifications were needed to utilize HFCS (Coleman and Harbers, 1983; Beery, et al, 1982; Strickler, 1981).

Volpe and Meres (1976) attempted substitution of HFCS for 60% of the sucrose used in making standardized white layer cakes. Several leavening salts were used to lower pH of the cake and thus limit browning. The most severe problem in cakes prepared with HFCS was excessive browning. Cakes made using the more acidic leaveners were less browned, but had a disagreeable tart flavor. some of the acidic leaveners produced cakes comparable to the sucrose control in color and volume. The authors concluded that for successful HFCS use in white layer cakes the leavening acid should be GDL or a SAPP-MCP blend. They also recommended further flavor system modifications to compensate for the excessive acidity and tart flavor of these leaveners. (Volpe and Meres, 1976)

Koepsel and Hoseney (1980) studied the effects of substituting several different types of corn syrups in layer cakes. None of the syrups performed as well as sucrose at the 50% replacement level. The HFCS variation was noted to have a much lower volume, open grain and dark brown exterior. Formulation moisture adjustment improved volume and grain, but did not limit excess browning (Koepsel and Hoseney, 1980).

Strickler (1981) reported several drawbacks using HFCS as sucrose replacement in small and layer cakes. HFCS cakes had excessively thick bottom crusts, excessive browning, decreased volume and poor texture. Strickler (1981) also noted the top crust became thick and dark with an uneven color, and the crumb was overly moist and dense. Some of these undesirable characteristics were overcome by formulation adjustments which included changing the leavening agent and substituting bread flour for cake flour. These alterations improved volume and crumb structure but did not lessen browning. Adjustments were more effective in small cakes than in layer cakes. Acidifying the batters for layer cakes by adding lactic acid improved volume and texture of the baked cake and decreased browning. By making appropriate formulation changes, Strickler concluded that up to 80% HFCS substitution for sucrose was possible (Strickler, 1981).

Beery (1982) noted darkened crumb, decreased volume, excess tenderness and reduced shelf life in HFCS-sweetened cakes. In order to produce acceptable products, several factors were altered. He noted that lowering pH improved several cake quality attributes including volume, color, and texture. The use of SAP or GDL as the leavening acid produced an HFCS substituted cake superior to HFCS substituted cakes using more conventional leaveners (Beery, 1982).

Coleman and Harbers (1983) replaced 25, 50, 75 or 100% of the sucrose in angel food cake with HFCS. They noted that crust color became progressively darker and crumb color more yellow with increasing HFCS substitution. Volume and tenderness decreased with increasing HFCS substitution. The authors concluded that HFCS substitution for sucrose above 25% resulted in angel food cake of unacceptable quality (Coleman and Harbers, 1983).

McCullough (1985) baked white layer cakes using 0, 50 and 75% HFCS replacements for sucrose. It was found that with increasing levels of HFCS substitution cake volume decreased and crust and crumb color became darkened (McCullough, 1985).

Studies performed by corn syrup industry-affiliated authors also indicated HFCS has disadvantages as a sweetener for bakers. Henry (1976), affiliated with Corn Sweeteners, Inc., did not mention any quality detriments as a by-product of HFCS used in baked products. Henry did not, however, recommend HFCS replacement for sucrose in baked products at more than low levels. Sausselle, et al (1976), affiliated with Anhueser Busch, Inc., reported that sucrose replacement with more than 25% HFCS caused excess browning.

To briefly summarize, HFCS was reported to possess several disadvantages when used as a sucrose substitute in baked goods. These included excess browning of crust and crumb, decreased volume and tenderness and poor texture. Some researchers produced acceptable products in adjusted formulations at partial sucrose replacement levels between 15% to 75%.

Explanations as to exactly why HFCS produced less satisfactory cakes than sucrose were offered by many researchers. Most attributed problems to the sugar composition found in HFCS. Problems with texture, volume and grain were attributed to the fact that the monosaccharides glucose and fructose did not raise the temperature of gelatinization of wheat starch as did the disaccharide sucrose. Thus, the cakes set too early during baking, causing reduced volume, poor grain, and heavy texture (Bean, et al, 1978).

Researchers reduced the water content in HFCS sweetened cakes to compensate for the monosaccharides in the syrup. This raised starch gelatinization temperatures and therefore increased starch granule protection. By making moisture adjustments, sufficient delay of starch granule gelatinization was afforded to give HFCS substituted cakes good volume, grain and texture (Bean, et al, 1978).

Excessive browning often observed in HFCS cakes was attributed to the sugar composition of HFCS. The reducing sugars glucose and fructose participated in carbonyl-amine browning to produce dark color pigments (Campbell, 1979). Glucose and fructose were more susceptible than sucrose to a second browning reaction, caramelization. Thus, the increased browning in HFCS cakes was attributed to both these reactions (Beery, 1982; McCullough, 1985).

The rate and extent of the two browning reactions depend on similar variables. These include temperature, pH and moisture level (Campbell, et al, 1979). Several attempts were made to limit browning by manipulating these variables. The greatest success was by pH adjustment. Since both browning reactions decrease with a decreased pH, cake acidification was proven successful as a means of reducing browning (Berry, 1982; Strickler, 1981; Volpe and Meres, 1976). Various methods of acidification have been used. These included the use of a more acidic leavener (Volpe and Meres, 1976), adding an acidulant (Beery, 1982; Strickler, 1981) or decreasing the pH of egg white in the batter (Strickler, 1981).

MATERIALS AND METHODS

Experimental Design

Cake formulations used in this study were developed by McCullough (1985) and modified for use with 100% HFCS sweetening. Formula water content was decreased to compensate for the higher moisture content of the HFCS. The amount of cream of tartar (an acidulant) and the appropriate amount and type of acidic leavener, GDL, were determined in exploratory baking trials conducted spring and summer, 1986. Formulations and baking instructions are shown in Appendix A.

The Experimental design (shown in table 1) provided for the production of three variations. Variations were identical except for pH level which was adjusted by adding cream of tartar, using a more acidic leavener (GDL) or both. Thus highly, moderately and non-acidified 100% HFCS sweetened variations were baked.

Table 1

Experimental Design for 100% HFCS
Sweetened Cakes with pH Adjustment

Treatment	Description
Highly Acidified (High Acid)	-Use of GDL as a portion of leavener -Addition of COT as an acidulant
Moderately Acidified (Medium Acid)	-Addition of COT as an acidulant
Non-Acidified (Low Acid)	-

Ingredients

The HFCS used was Isosweet 100 (A.E. Staley Manufacturing Co., Decatur, Illinois) with a content of 42% fructose and 71% soluble solids. All other ingredients were obtained from a local supermarket. The type and brand of each ingredient was identical throughout the study.

Ingredients were purchased in one lot, stored at ambient conditions, and used within seven days with the exception of eggs. Eggs were purchased no more than two days prior to use and stored at $5^{o}C$. Other ingredients were kept from exposure to direct sunlight, heat and moisture. HFCS was stored in the original 25-gallon drum. Cake flour was stored in its original container, placed inside a tightly-sealed plastic bucket.

Objective Measures

Objective measurement of the latter included pH (Fisher Accumet pH meter, model 600) and specific gravity using the method of McCullough (McCullough, 1985). Tests performed on the baked cake included crust and crumb pH, which was measured as a preliminary step in the total browning test. pH measurement involved weighing out 1.14g of composite sample which was dissolved into 10ml of deionized water in a large (30ml) screw-topped test tube using a vortex mixer. pH meter electrobe was then placed into the hydrated sample and pH read directly. Also standing height as an index to volume using the method of McCullough (McCullough, 1985), moisture analysis by gas chrometography using the method of Saltmarch (Saltmarch, 1983), texture was evaluated by deformation using the method of Bourne et al (Bourne et al, 1982). Color was measured by Hunter colorimeter (Hunter lab model #D25, serial #683) standardized using a white tile, Standard # 20-1651; L. = 9192, a = -.8, b = -1.0) and total browning using the single enzyme method of Saltmarch (Saltmarch, 1980).

Statistical Analysis

Statistical analysis consisted of Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) to determine significant differences among the variations means.

RESULTS

The purpose of this study was to compare the quality of cakes prepared with HFCS as a replacement for 100% of the sucrose when the pH of the cake batters was adjusted to limit excessive browning. Cake variations were highly acidified with GDL and COT (referred to as high acid), moderately acidified with COT (referred to as medium acid), and not acidified (referred to as low acid). Results and discussion will consider each variation's three-day mean score as the indicator for each variable. Results are shown in Table 2.

pH as Affected by Formulation

Formulation differences resulted in significantly different pH for the crumb of the baked cakes and for the batter ($p < .001$). The pH of the high acid crumb was different than either the low or moderate variations, while all three variations pH for the batter were different from each other as determined by DMRT.

Table 2

pH and Specific Gravity of Batters of 100% HFCS Sweetened Cakes with pH Adjustment 1/ 2/

Treatment	Batter pH	Batter Specific Gravity
Low Acid	7.38a	.82a
Medium Acid	6.93b	.82a
High Acid	6.68c	.81a

1/ Mean of three replications.

2/ Values in the same verticle column bearing different letters differ significantly, as determined by ANOVA and DMRT ($\alpha = .05$).

Specific Gravity, Moisture Content

Batter S.G. and cake moisture content were not significantly different among the three variations.

Index to Volume

The index to volume as measured by average standing height decreased with increasing acidity. Standing height of the low acid cake was significantly higher ($\alpha = .05$) than the high acid cake.

Deformation

Cake tenderness as measured by deformation was not significantly different among the three variations.

Table 3

Physical Characteristics of 100% HFCS Sweetened Cakes with pH Adjustment 1/ 2/

Treatment	Crumb pH	Standing H+ (cm)	Defamation (mm)	Moisture (percent)
Low Acid	6.52a	3.79a	25.6a	37.93a
Medium Acid	6.40a	3.65ab	21.2a	37.51a
High Acid	5.76b	3.49b	18.7a	36.33a

1/ Mean of three replications.

2/ Values in the same vertical column bearing different letters differ significantly, as determined by ANOVA and DMRT ($\alpha = .05$).

Color, Browning

Hunter colorimeter E values increased as cake acidity increased, indicating greater browning at lower acidity. These differences were significant at $p < .01$.

Browning, measured by the enzymatic digestion and spectrophotometric measurement of browning compounds indicated significantly different browning scores ($p < .001$) with the high acid variation different from both the lower acid variations ($\rho < .01$). Thus tests for both color and browning confirmed observations that the high acid variation was lighter than the lower acid cakes.

Table 4

Color Measurement of 100% HFCS Sweetened Cakes with pH Adjustment 1/ 2/

	Color 3/ (ΔE) 5/	Total Browning 4/ (Optical Density Units)
Low Acid	67.25a	0.48a
Medium Acid	63.96a	0.26b
High Acid	54.62b	0.14c

1/ Mean of three replications.

2/ Values in the same vertical column bearing different letters differ significantly, as determined by ANOVA and DMRT ($\alpha = .05$).

3/ Measured by Hunter Colorimeter.

4/ Saltmarch, 1980.

5/ $E = L^2 + a^2 + b^2$

DISCUSSION

Three adjustments of the acidity of cakes prepared with 100% HFCS replacement for sucrose were prepared to determine how acidification altered the characteristics of the cakes. Cakes of similar formulation with different levels of acidulant were baked and objectively evaluated. Batter measurements included pH and S.G. Measurements of the baked cakes included pH, percent moisture, index to volume, deformation color and browning.

Specific Gravity

The average specific gravity of the batter for all three variations was in the range of .805-.821. These S.G.'s for HFCS sweetened cakes are lower than values reported for HFCS replacement for sucrose levels of 50% (.97) (McCullough, 1985), 60% (.82-.90) (Coleman and Harbers, 1983) and 75% (1.03) (McCullough, 1985). The batter viscosity decreased with greater levels of HFCS. (Coleman and Harbers, 1983) This may have allowed for greater ease in mixing and increased air incorporation in the batter, since lower S.G. is an indication of increased air incorporation. The present study utilized longer batter mixing and whipping times as well as using the egg whites as a whipped foam to incorporate air in the batter.

Batter pH

The degree of acidification used in the present study was chosen to provide a large contrast between the high and low acid variations. The pH of the batters were similar to other research when similar formulations were used. Coleman and Harbers (1983) produced a batter of 60% HFCS replacement for sucrose, with added COT and leavened with SAPP which had a pH of 6.5. McCullough (1985) reported a batter pH of 6.9 using a similar formulation. These formulations approximated the medium acid formulation of this study with a pH of 6.93. Coleman and Harbers (1983) reported a batter pH of 6.4 for a 60% HFCS sweetened cake with added COT and using GDL and baking soda as leavener. The high-acid variation of this study, with GDL added to the batter, had the lowest pH of 6.67. The fact that Coleman and Harbers' cake was entirely GDL-soda leavened, while the present study used a GDL/SAPP/soda blend accounted for the present study's higher pH. The low acid variation contained no acidulant and was leavened using SAPP only, resulting in a batter pH of 7.38.

Crumb pH

Volpe and Meres (1976) reported a cake formulation of 1g COT and 60% HFCS had a crumb pH of 7.1 when leavened with SAPP and 5.7 when leavened with GDL. The results of this study for the low, moderate and high acid variations were consistent with the results of Volpe and Meres. The difference of a crumb pH of 7.1 in the study by Volpe and Meres with the present study's crumb pH of 6.4 was attributable to a higher COT and HFCS content in the formulation. HFCS acted as an acidulant due to its pH of 3.2 (McCullough, 1985).

In baking, generally only enough leavening acid to balance with the alkaline salt of the formula is used. Excessive leavening acid in a cake batter will lower crumb pH. Volpe and Meres (1976) noted a drop from pH 6.4 in the batter to 5.7 in the crumb of their GDL/soda leavened cake. This drop was attributed to the use of excessive leavening acid (Volpe and Meres, 1976). The pH drop from 6.68 (batter) to 5.76 (crumb) noted in the high acid formulation of this study is possibly due to the use of excess leavening acid, as well as simple moisture loss during baking, as noted by Volpe and Meres.

Volume

Standing height as an index to volume was not significantly different among the three variations as determined by ANOVA, although a trend toward smaller standing height as acidity increased was evident. Differences between the high and low acid variations were different (α = .05) as determined by DMRT. Based on subjective researcher observation, all variations had acceptable volumes.

This study indicated HFCS substitution for sucrose produced cakes of acceptable volume when formulation moisture levels were decreased, which was consistent with the studies of Bean, et al (1978), Koepsel and Hoseney (1980), Strickler (1981), Coleman and Harbers (1983), and Volpe and Meres (1976). The past work of others indicated HFCS substitution for sucrose in nonadjusted formulations produced cakes with smaller, unacceptable volumes. The volumes of cakes prepared with HFCS were increased to acceptable levels by reduction of the moisture content of the formulation. The improvement was attributed to the following: monosaccharides do not protect starch granules from gelatinization as well as sucrose. Therefore, cakes made from these sugars set too early in the baking process to allow for adequate volume development. The reduction of moisture in the formula increased starch granule protection sufficiently to delay cake structure setting and produce a cake of acceptable volume (Bean, et al, 1978; Koepsel and Hoseney, 1980).

Volume was reduced at higher acid levels. This phenomenon was also noted by several researchers (Ash and Colmey, 1973; Strickler, 1983). Ash stated that cake grain became progressively closer as the pH is lowered from the optimum point. Volpe and Meres (1976) obtained small volumes in cakes prepared with HFCS using more acidic leavening salts. Since HFCS is itself acidic, its use in cakes may affect volume. All researchers have obtained smaller volumes when cakes were sweetened with HFCS (Beery, 1983; Koepsel and Hoseney, 1980; Strickler, 1981; Coleman and Harbers, 1983; McCullough, 1985).

Cake Crumb Structure and Quality

Cake crumb structure and quality may be judged by and of a number of attributes. This study considered cake structure, texture and firmness as quality indicators. Collectively these attributes will be referred to as crumb characteristics, and will be dealt with as one subject area to facilitate discussion.

Crumb characteristics are determined by several factors, the most important of which is volume. Any factor affecting volume will, therefore, affect crumb characteristics. By subjective observation of the investigator, the grain became progressively finer and structure less open as acidity increased. The moist and sticky texture of the high acid variation was described by one faculty member as pudding-like. Deformation measurement indicated the more acidic the cake, the firmer its crumb. Crumb was noticeably less elastic and more dense at the higher acid level. Changes in crumb characteristics coincided with loss of volume at the higher level of crumb acidity.

The differences in crumb characteristics between cakes prepared with HFCS and those with sucrose were attributable to gelatinization temperature of the starch in the cake structure, and the sweetener's humectant property. The use of HFCS, which is composed of lower molecular weight sugars, alters the rate of gelatinization of the starch granules. The premature gelatinization caused inadequate volume development during baking. This volume loss phenomenon accounted for the denser crumb, more compact grain and firmer texture usually noted in HFCS cake. The second effect on crumb characteristics is the humectancy of HFCS. Cakes made with HFCS, while not of a greater percent moisture, were perceived to be sticky due to the sugar's affinity for water. Thus HFCS cake crumb is often described as sticky or gummy.

The progressive deterioration of crumb quality with increasing acidity also agreed with existing knowledge. Ash noted: "Cake grain becomes closer and eventually excessively fine as the pH is lowered from the optimum point" (Ash and Colmey, 1973). The use of HFCS decreased cake batter and crumb pH somewhat, since HFCS has a pH of 3.2. Therefore, some of the changes in HFCS substituted cake crumb may be due to acidity of the HFCS.

To summarize; crumb quality indicators were adversely affected by: one, simply using HFCS; or two, acidifying cakes somewhat, whether by using HFCS, adding an acidulant or using more acidic leavener.

Moisture

This study indicated that in a moisture adjusted formula cakes sweetened only using HFCS were of approximately 36-37% moisture. Moisture content was not correlated to acidity. Moistness seemed greater (as subjectively evaluated by the researcher) at the high acid level, but this may be due to the lower volume and therefore denser crumb of the high acid cake.

Results agree with the literature. In formulas adjusted for moisture, HFCS cakes do not differ in moisture content from sucrose cakes or partially substituted HFCS cake (McCullough, 1985; Coleman and Harbers, 1983).

Browning and Color

Hunter colorimeter ΔE values and total browning values indicated that the use of HFCS resulted in greatly increased browning and the acidification of HFCS sweetened cakes limited excessive browning.

Use of HFCS as a sucrose substitute in cakes introduces glucose and fructose. Upon heating, these sugars undergo Maillard browning and caramelization easier, and to a greater extent than sucrose. Thus, use of any HFCS will result in a darker crust and crumb (Strickler, 1981; Koepsel and Hoseney, 1980; Beery, 1982; Henry, 1976; Volpe and Meres, 1976; Sausselle, 1982). Darkening increased proportionately to the amount of HFCS used (Coleman and Harbers, 1976; McCullough, 1985). Cakes prepared using HFCS as the only sweetener were obviously darker, as indicated by both objective and subjective evaluations.

Both Maillard browning and caramelization are limited at a lower pH (Campbell et al, 1979). This fact was demonstrated by the greater ΔE and lower T.B. scores as cake acidity was increased. The use of both GDL as a leavener and COT as an acidulant proved more effective at limiting browning than added COT alone. Other studies have used various methods to acidify HFCS sweetened cakes such as: adding lactic acid (Strickler, 1981) using flour of a reduced pH (Beery, 1982), or using more acidic leavening acids (Volpe and Meres, 1976). In all of these cited studies browning was limited by the increased acidity which was in agreement with this study.

CONCLUSIONS

The use of pH adjusted, 100% HFCS sweetened formulations for cake demonstrated limitations of HFCS utilization in baked products and appropriate measures to overcome the limitation. Nonacidified cakes had good volume and texture but were overly browned. The highly acidified cake was much less browned but had a dense crumb and pudding-like texture. The medium acid cake was also much less browned, with only slight volume and texture quality losses. It appears moderate acidification by added acidulant is the best method for improving 100% HFCS sweetened cakes.

Recommendations for further research include: evaluation of alternative acidulants and leavening salts; and the determination of an optimum pH for best product quality.

SUMMARY

Cakes were prepared with HFCS as a replacement for sucrose at three pH's ranging from low acid, to moderate acid, to high acid. Acidification was accomplished using: added COT (moderate acid), added COT and GDL as a partial leavener (high acid) or neither (low acid). Subjective observation and various objective measures were used to determine the type and extent of effects pH differences had on various quality attributes. Tests performed on the latter included pH and specific gravity. Baked cakes were evaluated by pH, measurement of crumb moisture, index to volume (by standing height), deformation, color and browning.

Batter specific gravity ranged from .805-.821 which was lower, but not significantly different from previous studies. Batter pH ranged from 6.67 to 7.38. The range provided adequate pH differences for effects to be seen in the baked cakes.

Crumb pH's ranged from 5.7 to 6.52 and were significantly different. Volumes were acceptable, although slightly decreased at the higher acid level. Crumb characteristics were adversely affected by increased acidity. Grain became fine and less open, texture became gummy and crumb overly firm and dense as acidity increased. The high acid variation was described as pudding-like. Changes in crumb characteristics were due in part to volume

changes. Excessive browning and color development was apparent in the nonacidified cake. As measured by the Hunter colorimeter and the single enzyme digestion method, excessive browning decreased significantly by acidification.

While limiting excessive color and browning, acidification adversely affected other cake crumb characteristics. A moderate acidification using an added acidulant such as COT is recommended to improve 100% HFCS sweetened cake quality.

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Appendix A

Cake Formulations, Mixing, and Baking Instructions

Ingredient	Variation: Low Acid	Medium Acid (g)	High Acid
Shortening (Crisco)	108.0	108.0	108.0
Egg White (Kroger)	82.8	82.8	82.8
Egg Yolk (Kroger)	57.2	57.2	57.2
Cake Flour (Softasilk)	200.0	200.0	200.0
Baking Powder (Hearth Club)	10.0	10.0	5.0
GDL (Eastman Kodak)	-	-	3.7
Baking Soda (Arm and Hammer)	-	-	1.3
NFDM (Kroger)	20.0	20.0	20.0
HFCS (Staley Iso 100)	338.0	338.0	338.0
COT (McCormick)	-	3.0	3.0
Water	50.0	50.0	50.0

Mixing, Baking Instructions

Into mixing bowl; using a paddle board and mixer*

1. Add Crisco; cream for 1 minute at speed 2
2. Add HFCS; mix for 2 minutes at speed 2
3. Add remaining ingredients, except egg white; mix for 1 minute at speed 1; scrape bowl, mix for 4 minutes at speed 4
4. In a different mixing bowl, add egg white; mix for 3 minutes at speed 6, using a wire whip
5. Add whipped egg white to original ingredients; mix for 30 seconds at speed one, scrape bowl
6. Mix for 1 minute at speed 2
7. Into an 8″ x 8″ x 2″ baking pan (sprayed with Pam) pour 630g batter
8. Bake for 30 minutes at 350°F
9. Remove from oven,**

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* Mixer - Kitchen-Aid electric mixer; model k 555,L

** Oven - GE Model # J 336 B10C

Appendix B - Time Table

Each complete replication involved a two-day series of events.

Day 1

9:00 a.m. - 12:00 noon	-Bake cakes -Perform batter pH and S.G. tests on batter
12:00 - 1:00 p.m.	-Cakes allowed to cool
1:00 - 3:00 p.m.	-Hunter Colorimeter -Standing Height -Deformation
3:00 - 5:00 p.m.	-Prepare samples for: Gas Chromatography Total Browning

Day 2

9:00 a.m. - 10:30 a.m.	-Perform Gas Chromatography
10:30 a.m. - 1:00 p.m.	-Perform Total Browning
2:00 - 4:00 p.m.	-Prepare for next replication

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