Interactions Between Starches, Sugars, and Emulsifiers in High-Ratio Cake Model Systems[1]

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Cereal Chem. 69(2):206–212

ABSTRACT

The cake flour in a high-ratio cake model system was replaced by a blend of commercial wheat starch, vital gluten, and a lipid mixture of lecithin and ethoxylated mono-diglycerides. Then the wheat starch in the control formula was replaced with corn or potato starch. Lactose or dextrose (glucose) replaced 50% of the sucrose, and additional emulsifier, sucrose ester F-160, or polysorbate 60 also was used. Potato starch produced acceptable cakes, whereas corn starch did not. A 50% dextrose replacement for sucrose improved the cake volume and grain structure with corn starch. The potato starch, lactose, and polysorbate 60 combination produced a significant increase in batter viscosity, but this was not true for corn starch batters containing lactose. The increased batter viscosity tended to aid in air incorporation. Both additional emulsifiers improved all cake volumes. The addition of polysorbate 60 to the wheat starch batter containing lactose produced the highest cake volume with the best grain structure. Dextrose tended to retain more cake crumb moisture. Partial flour replacement by commercial starches might be beneficial in high-ratio cake baking, if proper combinations of starch, sugar, water, and emulsifier are used.

Complex cake batters contain a large number of highly reactive components that can interact with other components. For cakes containing high levels of sugar and water, an increase in batter viscosity and an improvement in batter stability are important in obtaining a noncollapsing, porous cake structure. This generally has been accomplished by treating wheat flour with chlorine, which produces reduced crumb stickiness, a whiter crumb color, and finer grain texture.

Heat treatment and/or aging (Johnson and Hoseney 1980) of wheat flour has been proposed as an alternative to chlorination. Johnson and Hoseney (1980) concluded that the better cake-baking quality resulting from storing defatted flour for two months at room temperature was partly due to changes in the starch. Some of the benefits from heat-treated or aged flour might be obtained from various commercial starches, which differ in water absorption behavior as well as in gelatinization and pasting properties, if the setting point of the cake is controlled by other means.

When unmodified starches replaced flour, variations occurred in cake-baking performance related to their gelatinization temperatures (Howard et al 1968, Kulp and Lorenz 1981, Glover et al 1986).

Generally, the sugar in high-ratio cake formulas plays an important role in delaying starch gelatinization during cake baking so that the air bubbles can be properly expanded by carbon dioxide and water vapor before the cake sets (Yamazaki and Kissell 1978). Thus, the resulting cake structure is highly aerated and has a higher volume. Bean and Osman (1959) found that disaccharides retard swelling more than monosaccharides. Therefore, Glover et al (1986) improved the volume of cakes in which wheat starch had been replaced with sorghum starch by substituting dextrose for sucrose, thus lowering the gelatinization temperature. Bean and Yamazaki (1973) found that when the starch was allowed to gelatinize in a range between 87.5 and 92°C, successful cakes could be produced from glucose or fructose with changes in the sugar-water ratio. Therefore, the deleterious effects of other sources of starch might be compensated for by using different types of sugars and changing their concentrations to get a proper gelatinization pattern and a satisfactory cake structure.

The objectives of this study were to develop a high-ratio cake model system and to determine the effects of various starches, sugars, additional emulsifiers, and their interactions on cake batter viscosity and cake quality.

[1]Contribution 91-23-J from the Kansas Agricultural Experiment Stations. Presented in part at the 74th Annual Meeting, American Association of Cereal Chemists, Washington, DC, October 29–November 2, 1989.

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MATERIALS AND METHODS

Wheat starch was provided by Manildra Milling Corp., Minneapolis, MN; corn (maize) starch was obtained from National Starch and Chemical Corp., Bridgewater, NJ; and potato starch was purchased from Raisio Inc., Berwick, PA.

Vital wheat gluten was a gift from Midwest Grain Products, Atchinson, KS.

Lecithin (unbleached) was obtained from ADM/Arkady Products, Olathe, KS. Ethoxylated monodiglycerides (EMG-20) was donated by Breddo Food Products, Kansas City, KS. Polysorbate 60 (PS), with a hydrophile-lipophile balance of 14.7, was provided by Humko Chemical Division, Witco Corp., Memphis, TN. Sucrose ester F-160 (SE) was obtained from Dai-Ichi Kogyo Seiyaku Co., Kyoto, Japan. This emulsifier is a mixture of the stearic and palmitic acid esters of sucrose (Walker 1984). It contains approximately 70% monoester and 30% di-tri-poly ester, and the hydrophile-lipophile balance is approximately 15.

Food-grade sugars were used in all studies. Fine granulated sucrose was donated by the American Crystal Sugar Co., Moorhead, MN. Dextrose monohydrate (commercial-grade glucose prepared from maize starch) was obtained from Corn Products, CPC International Inc., Englewood Cliffs, NJ, and hydrated lactose was purchased from Land O'Lakes Inc., Arden Hills, MN.

Formulation of Model System

For the model system of a high-ratio cake batter, 100% cake flour was replaced by 89.3% commercial wheat starch, 10% vital gluten, and 0.7% lipid mixture of lecithin (0.5%) and EMG-20 (0.2%).

The modifications to the formula and mixing procedure, which did not deviate substantially from Method 10-90 (AACC 1983), were made to obtain optimization and sensitivity to the effect of each treatment. Modifications were done with one variable at a time. Cake flour was used, initially, to provide the basis for optimizing the model system.

In preliminary trials, the use of an all-purpose or commercial emulsified shortening (Anderson Clayton/Humko Product Inc, Memphis, TN), containing only α-monoglyceride (2.75%), made an unsatisfactory cake batter emulsion with a severely curdled appearance. The addition of either lecithin or EMG-20 alone to the shortenings did not produce a proper emulsion either, resulting in cakes that were not porous, but gummy and collapsed. However, when the commercial emulsified shortening was combined with a mixture of lecithin and EMG-20, it produced a smooth batter emulsion and thus was used in the base formula. Lecithin and EMG-20 were first mixed and dispersed carefully into the emulsified shortening at room temperature.

The levels of double-acting baking powder (Red Star, Universal Food Corp., Milwaukee, WI) and water were adjusted. Optimum baking absorption was determined by baking cakes at several liquid levels and observing their contours and volumes. The final high-ratio cake model system formula is shown in Table I.

A modified mixing procedure was as follows: Combine all dry ingredients and sift well, put dry ingredients into mixing bowl, add shortening-emulsifier mixture and 60% of the water, mix at low speed for 30 sec, scrape down, mix at medium speed for 4 min, add remaining water, mix at low speed for 30 sec, scrape down, mix at medium speed for 2 min, scrape down, and mix at low speed for 1 min.

Cake batter (375 g) was transferred to an 8-in. (20.3 cm) diameter steel cake pan and baked in an electric reel oven at 375° F (190° C) for 25 min.

Effects of Ingredient Variables on Cake Quality

For the starch variable, the wheat starch in the control formula was replaced with corn or potato starch on a 14% moisture basis. Lactose or dextrose replaced 50% of the sucrose. For each starch and sugar combination, the water levels and baking times were checked for optimization. The criteria for the accepted standard cake were a slightly rounded top surface (or at least a flat, not sunken, surface for the corn starch cakes), a uniform cell size, and a moderately open crumb structure.

For the lipid variable, SE or PS was added to the formula. Three concentrations were chosen for each added lipid: 0.25, 0.5, and 0.75% for SE and 0.1, 0.3, and 0.6% for PS, based on total weight of starch, gluten, lecithin, and EMG-20.

All starch cake batters were mixed and baked in the manner described. After the cakes were removed from the oven, they were placed on a wire rack for 1 hr to cool to room temperature, wrapped in plastic bags, and evaluated later on the same day.

A control model-formula cake made with wheat starch and sucrose, but without added SE or PS, was baked each day. A minimum of two replicates was baked.

Batter Specific Gravity

Specific gravity of cake batter was calculated by dividing the weight of a standard cup of the batter by the weight of an equal volume of water. Batter temperature was controlled at 71 ± 1° F (22.7 ± 0.6° C).

Cake Batter Viscosity

Cake batter viscosity was determined by a Brabender Visco-amylograph (C.W. Brabender Instruments, Inc., Hackensack, NJ) with variable speed control and by a Brookfield Synchro-Lectric Viscometer, model LVT (Brookfield Engineering Laboratories, Inc., Stoughton, MA), to compare the two methods.

Cake batters were made as previously described, except the double-acting baking powder was omitted to eliminate the variation resulting from carbon dioxide evolution during analysis. Although pH and viscosity may be different from the batters as baked, this was the only way to get reproducible measurements. Water absorptions for all cake batters were fixed at 150%, based on flour weight.

Cake batter (250 g) was poured into the amylograph bowl, temperature was set at 25° C, and rotational speed was adjusted to 20 rpm. Viscosity was read after 10 min and expressed in Brabender units.

To measure viscosity by the Brookfield viscometer, the same volume of cake batter was placed in a 100-ml beaker each time, and the spindle speed was fixed at 6 rpm. Spindles no. 3 for wheat and corn and no. 4 for potato starch cake batters were used. With lactose, spindle no. 4 was used regardless of the starch source. Room temperature was held at 78–79° F (25.6–26.1° C). Batter temperature was controlled at 71 ± 1° F (22.7 ± 0.6° C) by adjusting water temperature.

Cake Measurements

Cake volume, symmetry (contour), uniformity, and shrinkage were determined by the AACC template method (AACC 1983). The volume index used here was based on the sum of five points, instead of the usual three cake heights. Crumb grain quality was evaluated for fineness and crumb cell distribution uniformity.

Cake crumb firmness was measured using a Voland-Stevens texture analyzer (Voland Corp., Hawthorne, NY). A crosshead speed of 0.2 mm/sec and a chart speed of 20 cm/min were used to compress the cake samples by 40% of their original heights. Firmness was determined at 25% compressibility, calculated as described in Method 74-09 (AACC 1983). A 2-cm-diameter cylindrical indenter was used for the wheat and potato starch cakes. A smaller, 1.5-cm indenter was used for the corn starch cakes because of their much smaller profile. A piece 1 in. (2.54 cm) thick was removed 2 cm from each side of the center of the cake for two measurements per cake.

Moisture Content

A piece of cake was taken from the same location in the cake as was used for the firmness measurements. The top and bottom portions of the cake were removed, and the inside cake crumb was used to determine moisture content by the two-stage air-oven Method 44-15A (AACC 1983).

Statistical Analysis

All statistical analysis was performed in an MS-DOS operating system personal computer using the Number Cruncher Statistical System package (Hintze 1987).

RESULTS AND DISCUSSION

Batter Specific Gravity

The amount of air incorporated into a batter can be determined by measuring the batter's specific gravity. The effects of starches, sugars, and emulsifiers on the specific gravities of the cake batters are shown in Figures 1 and 2.

Lactose lowered the specific gravities of the wheat and potato starch batters, aiding air incorporation. For corn starch batters, specific gravities with the three sugars were the same, although water absorptions were decreased by 10% for dextrose and lactose replacements.

Generally, additional emulsifiers decreased the specific gravity as concentrations increased. PS decreased batter-specific gravity more than SE.

Cake Batter Viscosity

A sufficiently high batter viscosity might keep the air bubbles from rising out of the batter, providing increased batter stability at room temperature. It is generally known that specific gravity

TABLE I
Formulation for High-Ratio Layer Cakes

AACC Method 10-90		Model Cake System	
Ingredients	Flour Basis (%)	Ingredients	Flour Substitute Basis[a] (%)
Flour (14% mb)	100.0	Starch	89.3
		Gluten	10.0
		Lecithin	0.5
		Ethoxylated monodiglycerides	0.2
		(Total flour substitute	100.0)
Sugar	140.0		140.0
Shortening (emulsified)	50.0		50.0
Nonfat dried milk	12.0		12.0
Dried egg white	9.0		9.0
Salt	3.0		3.0
Baking powder	5.3		4.4
Water[b] (distilled)	150.0		145.0

[a] Percentage of ingredients was based on the combined weights of starch, gluten, lecithin, and EMG-20 (flour substitute basis).
[b] Amount of water variable, depending on starch source.

is related to the batter's viscosity. To examine the effects of starches, sugars, and emulsifiers on batter viscosity, results from the Brookfield viscometer and the viscoamylograph were compared. Correlations between the two methods for the three starch cake batters are shown in Figure 3. Their correlations were greatest with corn starch batter ($R^2 = 0.90$), followed by wheat ($R^2 = 0.76$) and potato starch ($R^2 = 0.73$), coinciding with the order of increasing starch granule size. The smaller the starch granule size, the better the correlation between the two methods. These results indicate that suspended particle size can be an important factor affecting apparent viscosity, depending on the methods used.

The standard deviations of the Brookfield viscometer batter viscosities (8.8%) were higher than those obtained by the viscoamylograph (7.2%), especially for very thick samples such as potato starch batter with lactose. Small day-by-day differences in room temperature may have partly accounted for the increased standard deviations, because the Brookfield viscometer is known to be very sensitive to temperature changes. When very thick samples were tested by the rotating Brookfield viscometer spindle, the whole sample mass did not turn, but only a thin film remained close to the spindle. Therefore, the resulting viscosity reading may not represent the whole mass viscosity and may have been lower than it should have been.

Viscosity measurements by the viscoamylograph were more reproducible. This may have been because, at the constant batter temperature (25°C) controlled by the machine, the whole sample mass was subject to rotation, producing a more uniform torque to be recorded. Therefore, this method seemed more applicable for differentiating ingredient effects on batter viscosity. The interactions between starch and emulsifier or sugar and emulsifier that significantly ($P < 0.05$) affected batter viscosity were detected on the viscoamylogram but not by the Brookfield viscometer (Table II).

When the amounts of water (150%) used were constant, potato starch exhibited a greater effect on increasing batter viscosity than did wheat and corn starch. The wheat and corn starch batter viscosities were very close.

The low solubility of lactose contributed to a significant increase in batter viscosity with high solids concentration at room

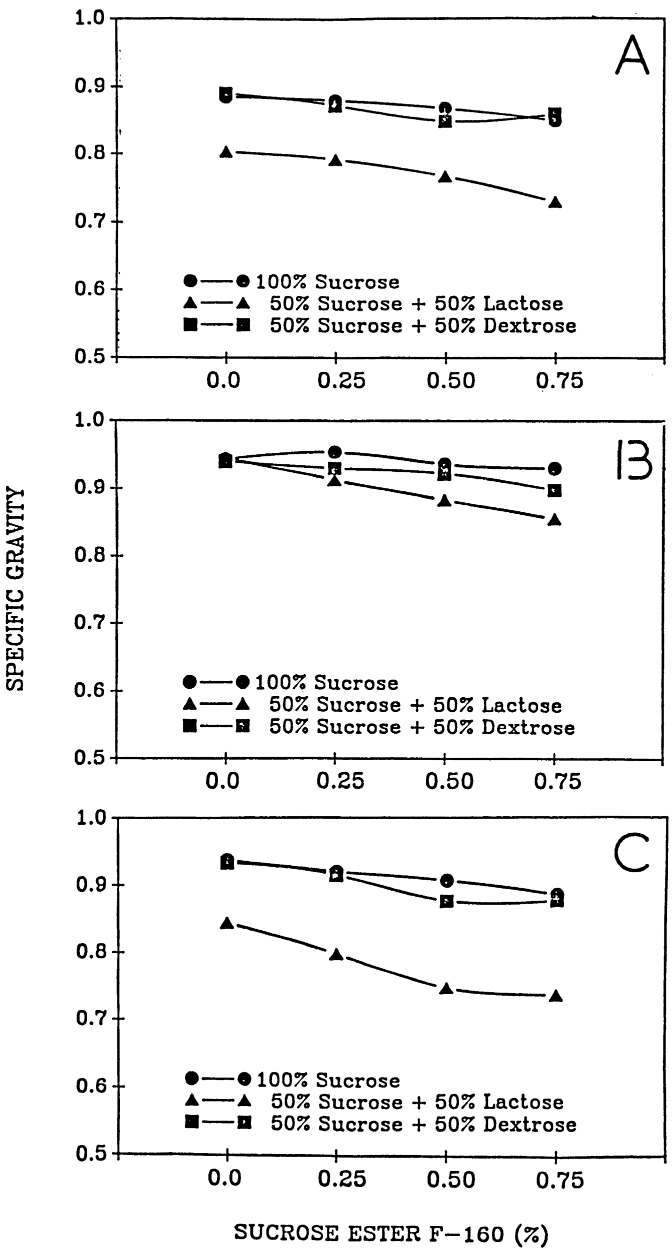

Fig. 1. The effect of sucrose ester F-160 on the specific gravities of starch cake batters made with various sugars. **A,** Wheat starch; **B,** corn starch; **C,** potato starch.

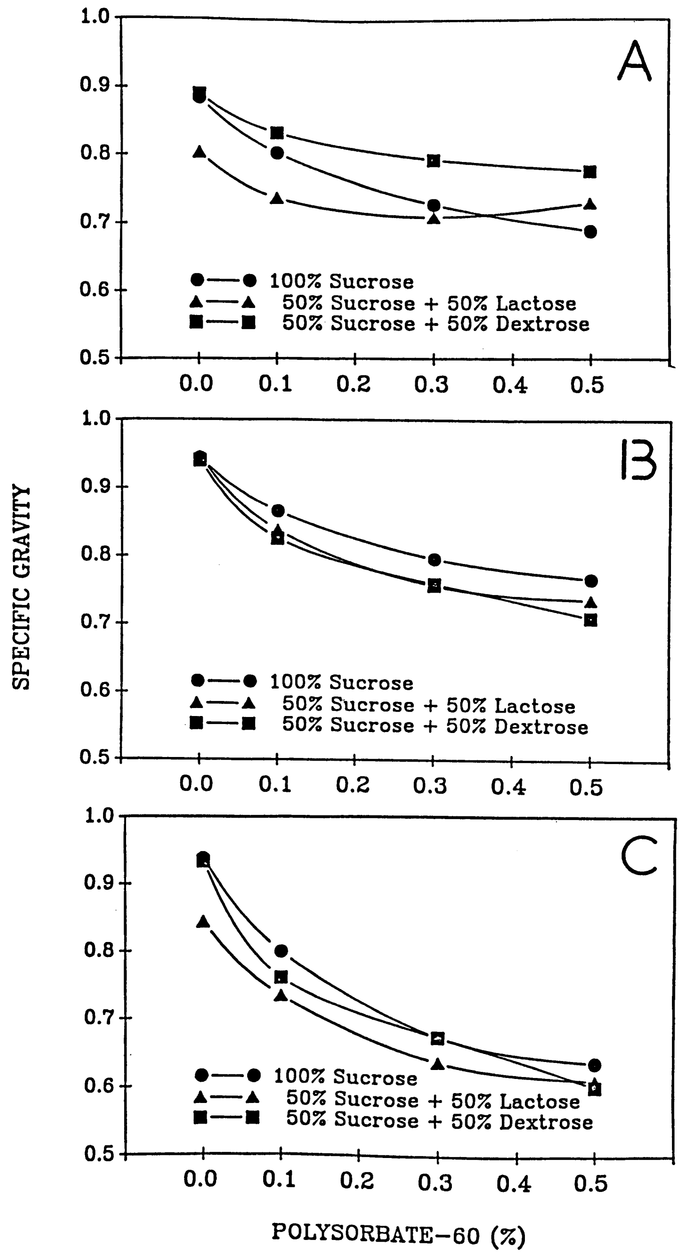

Fig. 2. The effect of polysorbate 60 on the specific gravities of starch cake batters made with various sugars. **A,** Wheat starch; **B,** corn starch; **C,** potato starch.

temperature. Sucrose and dextrose produced similar effects on the batter viscosity for all three starch cake batters.

PS increased batter viscosity more than SE did. This may have been caused by more air bubbles being incorporated or a more viscous continuous phase interacting with water. For whatever reason, its effect was exaggerated with potato starch.

Effect of Starch Replacement on Cake Quality

When cake batters were prepared with corn and potato starches at the same water absorption (145%) as the wheat starch batter (control), the cakes collapsed completely. The corn starch batter might not have reached its setting temperature within the standard baking time (25 min). The cake's center was gummy and had an uncooked appearance. This was apparently due to incomplete gelatinization. Similar results also were observed in previous studies (Howard et al 1968, Glover et al 1986) with sorghum, corn, and rice starches.

Wilson and Donelson (1963) described a satisfactory cake as one that had sufficient but not excessive starch gelatinization. The water amount, by itself, can control the starch gelatinization temperature and affect the degree of gelatinization (Derby et al 1975). Miller and Trimbo (1965) suggested that increasing the batter water content lowered the temperature of its initial increase in consistency and caused a much higher consistency to be developed at lower temperatures. Therefore, an attempt was made to control the setting points by changing the water contents as well as the baking times for corn and potato starch cakes. No gummy layers or sunken contours were observed after water and baking time adjustments.

Tables III and IV show the cake volume indices and grain scores for the three starches. The performance extremes were shown by the corn starch cake, which was not acceptable because it had a very low volume and coarse grain structure (Tables III and IV, Fig. 4). This may have been due to a cake setting temperature that was still high, even with increased water content and baking time. Most of the air bubble sites for evolved CO_2 and water vapor expansion were lost from the thin (low viscosity) cake batter before the setting temperature had been reached. Potato starch produced lower cake volumes than wheat starch. Potato starch granules may swell at a faster rate. Thus, batter viscosity increased rapidly during initial baking and might have reached the thermal setting point too early, but not because of early gelatinization. The potato starch cake expanded well initially, but it collapsed while still inside the oven. A weak gel structure, which was not able to withstand the gas pressure built

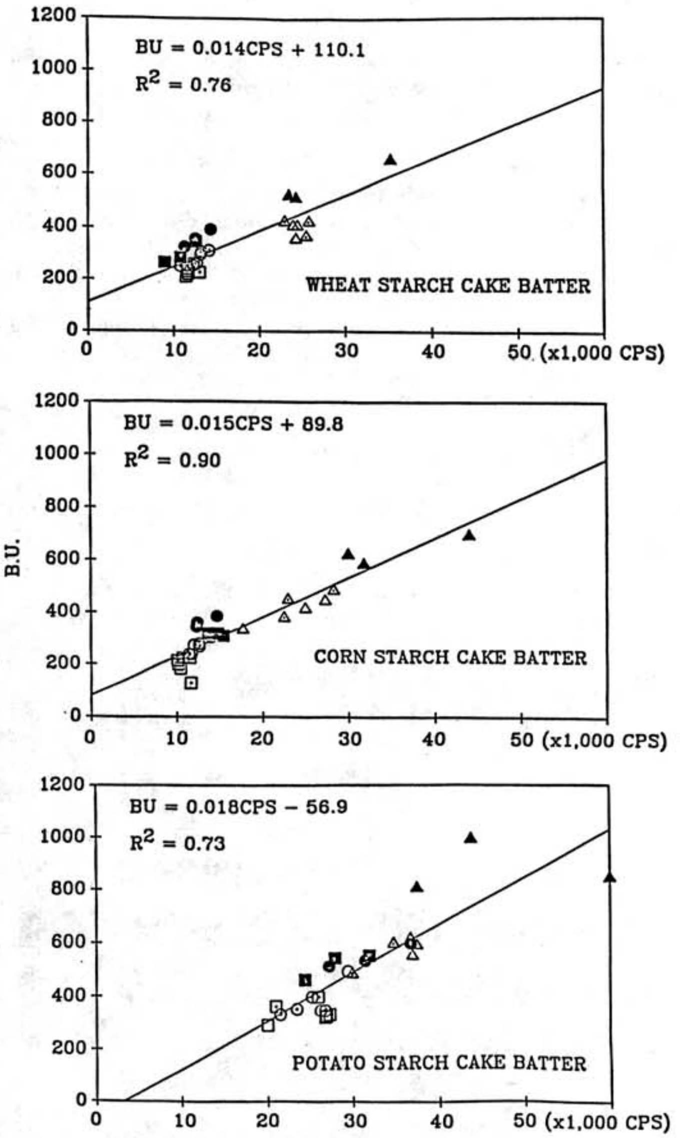

Fig. 3. Correlation between amylogram (BU; Y-axis) and viscometry (CPS; X-axis) measurements for starch batters made with various emulsifiers and sugars. ○ = No sucrose, ● = polysorbate 60 (sucrose), ⊙= sucrose ester 160 (sucrose), △ = no lactose, ▲ = polysorbate 60 (sucrose), ⚠= sucrose ester 160 (lactose), □ = no dextrose, ■ = polysorbate 60 (dextrose), ⊡= sucrose ester 160 (dextrose).

TABLE II
Interactions of Variables in Cake Batter Viscosity Measured by Amylograph and Brookfield Viscometer

Source	Significance of *F*-Value from Analysis of Variance[a] Amylograph	Brookfield Viscometer
Starch[b]	S	S
Sugar[c]	S	S
Emulsifier[d]	S	S
Starch × sugar	NS	NS
Starch × emulsifier	S	NS
Sugar × emulsifier	S	NS
Starch × sugar × emulsifier	NS	NS

[a]S = Significant at the 5% level if probability less than 0.05. NS = Not significant at the 5% level if probability larger than 0.05.
[b]Wheat, corn, and potato starches were used.
[c]100% sucrose, a mixture of sucrose and lactose (1:1), and a mixture of sucrose and dextrose (1:1) were used.
[d]Sucrose ester F-160 and polysorbate 60 were added to cake batter at 0.5% based on flour weight.

TABLE III
Effect of Replacing Sugars on Cake Volume Index (cm)

Starch	Sucrose 100%	Lactose + Sucrose	Dextrose + Sucrose
Wheat	164.5 ± 6.3	170.5 ± 6.2	147.8 ± 3.1
Corn	119.5 ± 1.1	109.3 ± 3.5	131.0 ± 4.2
Potato	140.0 ± 5.7	145.3 ± 6.2	129.0 ± 6.4

TABLE IV
Effects of Sugar and Emulsifier on Crumb Grain[a]

Starch	Sugar[b]	No Emulsifier	Sucrose Ester F-160, % 0.25	0.50	0.75	Polysorbate 60, % 0.10	0.30	0.50
Wheat	S 100	24.5	20.0	19.0	17.5	24.5	25.0	22.5
	L + S	25.3	22.0	20.8	20.0	28.0	27.8	25.5
	D + S	27.0	23.0	23.5	22.5	25.5	19.0	18.0
Corn	S 100	20.0	20.0	23.0	22.0	25.0	23.0	23.0
	L + S	25.3	25.5	25.0	24.0	25.5	25.0	24.5
	D + S	22.5	24.0	23.5	22.8	25.0	24.5	25.0
Potato	S 100	27.0	26.8	26.5	25.7	26.0	24.0	22.0
	L + S	25.3	25.0	24.3	23.7	24.0	23.0	22.3
	D + S	23.8	23.5	19.8	17.7	21.0	21.2	21.5

[a]Based on a possible score of 30. Averages are for a minimum of two replicates.
[b]S 100 = Sucrose 100%; S = sucrose 50%; L = lactose 50%; D = dextrose 50%.

up inside the cells, may have formed during baking. Potato starch cakes also shrank more from the sides of the pan. Potato starch produced cakes with the whitest crumb and a more uniform cell distribution, showing a higher grain score than wheat starch cakes. Thus, partial replacement of wheat starch by potato starch may improve cake quality by stabilizing the cake batter with sufficient viscosity at mixing and early baking stages.

When the gelation temperature of starch in sucrose and water, as measured by the DSC, was related to cake-baking performance (Kim 1990), it appeared that a melting temperature of the wheat starch crystals (endotherm peak, T_p) of around 89°C permitted a satisfactory cake to be made with wheat starch and sucrose. Most potato starch crystals melted at 89.5°C, almost the same temperature as wheat starch, but the initial onset gelatinization temperature (82.8°C) was higher than that of wheat starch (80°C). On the other hand, most corn starch crystals melted at a much higher temperature (97.3°C) than the other two starches. Bean and co-workers (1978) suggested that a gelatinization temperature around 90°C, as measured by loss of birefringence under a polarized hot stage microscope, produced successful cakes. This coincides with the 89°C crystal melting temperature in the wheat starch-sucrose-water mixture (1:1.5:1.5).

Effect of Sugar Replacement on Cake Quality

When cakes were prepared with lactose or dextrose replacing 50% of the sucrose, adjustments in the water absorptions and baking times were necessary. Only the lactose and dextrose replacements in corn starch batters required a decrease in water absorption from 165 to 155%.

The monosaccharide (dextrose) and disaccharides (sucrose and lactose) appeared to influence cake volumes differently, depending on the starch source, as shown in Table III and Figures 4–6.

Lactose replacement for 50% of the sucrose apparently improved the cake volume and grain structure for potato and wheat starch cakes. Lactose appeared to exert an emulsifying function in potato and wheat starch cake batters by increasing the viscosity, thus helping air incorporation and resulting in a lower specific gravity. Therefore, crumb grains of wheat starch cakes improved, with a more uniform small cell distribution. On the other hand, the very stiff potato starch batter containing lactose, with an early cake setting, did not appear to hold the gases properly, resulting in many large gas holes in the cake. Lactose produced a wrinkled, crusty cake surface (Fig. 5). Brack and Brerschneider (1985) noted that lactose can replace 30% of the sucrose to reduce fat in a formula without hurting the cake quality. Holmes and Lopez (1977) reported that a significant improvement in volume, appearance, and shelf life was obtained by reducing both sucrose and shortening levels and by adding lactose to the formula.

According to the DSC data, lactose seemed to have less effect on decreasing the gelatinization temperature. However, it is difficult to relate the volume index data of lactose-containing cakes to the gelatinization temperatures. Lactose solubility, which is highly temperature dependent, will vary with the different heating rates in a baking oven and the DSC. Thus, the resulting gelatinization pattern may occur differently. Corn starch cakes containing lactose had lower volume indices than those with sucrose.

Dextrose functioned to decrease cake volumes with wheat and potato starches, whereas it increased cake volume with corn starch (Table III and Fig. 6). The improved corn starch cake volume was attributed to lowering the cake setting point by controlling gelatinization temperature, in conjunction with the pronounced batter viscosity increase during early baking, as assessed by the Rapid Visco Analyser (Foss Food Technology, Eden Prairie, MN) (pasting data not shown) (Kim 1990). Dextrose replacement for 50% of the sucrose significantly ($P < 0.05$) improved the grain structure of corn starch cakes, giving a uniform cell distribution and texture as well as better volumes. These results suggest that optimum starch gelatinization coincides with a uniform cell size and the largest cake volume. Wheat starch cakes containing dextrose shrank compared with other cakes.

Emulsifier's Effects on Cake Quality

Batter appearance became smoother and more glossy with PS, but not with SE. However, a slightly curdled appearance of batters containing SE appeared to be reduced by lactose or potato starch replacements.

Both of the additional emulsifiers, SE and PS, improved all of the starch cake volumes at different optimum concentrations, depending on cake ingredients, and showed some synergistic effects in combinations with lecithin, EMG-20, and monoglyceride (Table V and Figs. 4–6). Both SE and PS noticeably improved the corn starch cake volumes. PS functioned better in the corn

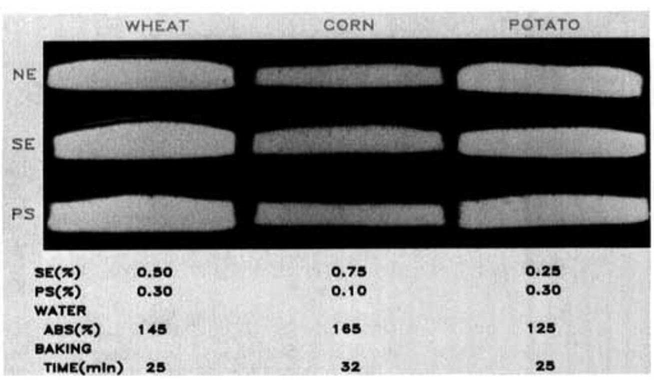

Fig. 4. Cake cross sections for the starch-sucrose-emulsifier system, showing combined effects. NE = No emulsifier, SE = sucrose ester F-160, PS = polysorbate 60.

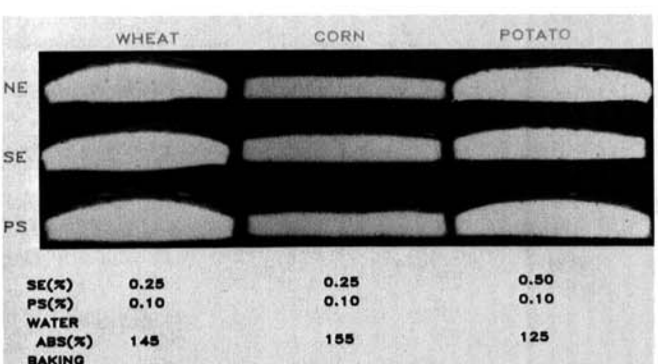

Fig. 5. Cake cross sections for the system using starch, emulsifier, and lactose plus sucrose (1:1), showing combined effects. NE = No emulsifier, SE = sucrose ester F-160, PS = polysorbate 60.

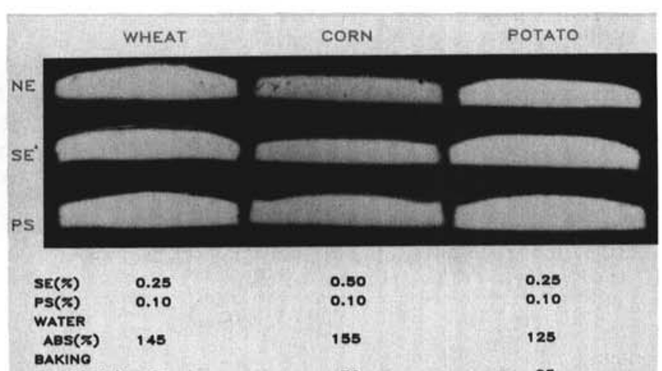

Fig. 6. Cake cross sections for the system using starch, emulsifier, and dextrose plus sucrose (1:1), showing combined effects. NE = No emulsifier, SE = sucrose ester F-160, PS = polysorbate 60.

TABLE V
Effects of Sugars and Emulsifiers on Starch Cake Volume[a]

Starch	Sugar[c]	No Emulsifier	Sucrose Ester F-160, %[b] 0.25	0.50	0.75	Polysorbate 60, %[b] 0.10	0.30	0.50
Wheat	S 100	164.5 ± 6.3	173.5 ± 3.2	177.0 ± 1.2	169.0 ± 3.5	178.0 ± 2.5	180.0 ± 3.3	175.0 ± 7.3
	L + S	170.5 ± 6.2	185.8 ± 1.3	184.0 ± 2.7	179.8 ± 3.5	190.3 ± 4.3	188.8 ± 3.8	173.0 ± 7.2
	D + S	147.8 ± 3.1	153.5 ± 2.7	147.5 ± 2.7	143.3 ± 3.0	147.8 ± 5.0	139.8 ± 6.8	140.0 ± 6.6
Corn	S 100	119.5 ± 1.1	138.3 ± 2.5	137.5 ± 4.6	141.3 ± 2.2	133.8 ± 3.3	135.2 ± 2.5	134.3 ± 2.2
	L + S	109.3 ± 3.5	137.0 ± 2.5	139.3 ± 3.8	134.8 ± 0.4	134.3 ± 1.8	136.0 ± 3.1	128.0 ± 4.3
	D + S	131.0 ± 4.2	143.5 ± 4.0	143.0 ± 3.1	135.8 ± 0.4	148.8 ± 1.1	148.8 ± 3.1	147.0 ± 4.1
Potato	S 100	140.0 ± 5.7	149.8 ± 5.9	142.8 ± 4.6	141.2 ± 2.5	147.0 ± 5.6	155.5 ± 5.3	152.2 ± 3.5
	L + S	145.3 ± 6.2	147.7 ± 10.5	147.7 ± 7.2	152.3 ± 6.4	151.7 ± 13.0	152.7 ± 5.8	143.0 ± 3.7
	D + S	129.0 ± 6.4	131.8 ± 4.2	123.7 ± 6.4	124.3 ± 6.2	150.0 ± 11.8	147.0 ± 9.8	146.2 ± 7.2

[a]Volume index obtained from five points of cake height.
[b]Percentage based on flour weight basis.
[c]S 100 = Sucrose 100%; S = sucrose 50%; L = lactose 50%; D = dextrose 50%.

starch batter containing dextrose. However, SE appeared to exert less effect on increasing the volumes of the wheat and potato starch cake containing dextrose. The addition of PS (0.1%) to the wheat starch batter containing lactose produced the highest cake volume with the best grain structure among all the treatments (Fig. 5). This cake did not shrink away from the pan sides.

All cakes containing SE tended to rise to the top of the pan during baking but collapsed immediately upon removal from the oven and pulled away from the sides of the pan upon cooling. Still, their volumes remained high, relative to cakes made without emulsifiers.

The reason for cake collapse with the SE emulsifier may be speculated upon as follows. Greater expansion might have occurred during baking because more air bubbles were incorporated, and these could serve as the sites for CO_2 gas and water vapor expansion. Even though a great expansion may have occurred during baking, the resulting starch gel was weaker and could not support the cake when it was removed from the oven. This idea was supported by the Rapid Visco Analyser evidence, which showed that the starch gels with the SE emulsifier had a lower setback viscosity than those with the PS emulsifier.

Moisture Content and Cake Crumb Firmness

The average moisture contents of all of the potato starch cakes (29.5%) was slightly lower than the averages for all of the wheat and corn starch cakes (31.1 and 31.2%, respectively), probably because of the lower initial water absorption used in the former. Partial (50%) replacement of sucrose with dextrose increased the cake crumb moisture content for all three starch cakes by about 2%, but no moisture increase occurred with lactose (Kim 1990).

Firmness measurements (Fig. 7) by the Voland-Stevens texture analyzer showed that the low-volume corn starch cake had the highest firmness value, followed by potato and wheat starch cakes. Generally, all the cakes made with partial replacement of dextrose for sucrose tended to be less firm, regardless of cake volume, possibly due to the increased moisture content of the cake crumb, so that dextrose functions as a tenderizer. The greater effect of dextrose with corn starch on decreasing the cake's crumb firmness may have been caused not only by the increased moisture content but also by the increased cake volume. Lactose produced about the same firmness as sucrose for all three starch cakes, even though volumes increased with wheat and potato starches.

In the presence of emulsifiers (SE and PS), crumb firmness decreased for all cakes. Particularly for corn and potato starch cakes, the tenderizing effect of dextrose apparently became greater in the presence of PS, as compared with cakes containing dextrose and SE. This may have been partly due to an increased volume with the PS emulsifier in addition to the increased moisture content.

Although wheat starch cakes with dextrose exhibited noticeably lower cake volumes than those with sucrose and lactose, a much less firm cake was obtained. This result indicates that even if cakes have lower volumes, they can still be less firm than cakes with higher volumes, depending on the ability of the sugar(s) to retain moisture inside the cake crumb.

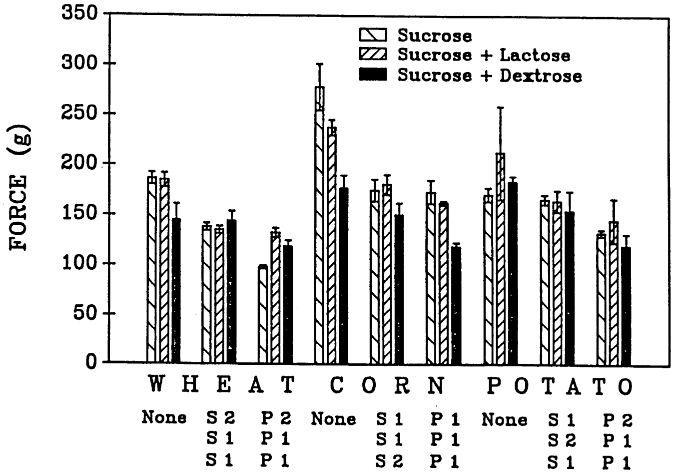

Fig. 7. Effects of sugars and emulsifiers on the crumb firmness of various starch cakes as measured by the Voland-Stevens texture analyzer. None = No addition of sucrose ester F-160 (SE) or polysorbate 60 (PS); S1 = 0.25% SE; S2 = 0.5% SE; P1 = 0.1% PS; P2 = 0.3% PS, based on flour weight.

CONCLUSIONS

A successful high-ratio cake model system was developed. Potato starch, lactose, and PS increased both batter viscosity and air incorporation. Potato starch produced acceptable cakes. A 50% dextrose replacement for sucrose improved the cake volume and grain structure with corn starch. PS resulted in a noncollapsed cake with overall better quality. Dextrose tended to retain more cake crumb moisture. Partial replacement by commercial starches might be beneficial in high-ratio cake making if proper combinations of starch, sugar, water, and emulsifier are used to achieve 1) the appropriate batter viscosity and air incorporation, 2) an optimum cake setting point by gelatinization temperature control, 3) better cake batter stability, retaining sufficient consistency during early baking, and 4) a sufficiently rigid starch gel formation during baking so that the cake does not collapse during cooling.

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[Received September 26, 1990. Received October 4, 1991.]