WHEAT STARCH GELATINIZATION IN SUGAR SOLUTIONS. II. FRUCTOSE, GLUCOSE, AND SUCROSE: CAKE PERFORMANCE[1]

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ABSTRACT

Solutions of the monosaccharides glucose and fructose raised the initial gelatinization temperature of wheat starch, but to a lesser extent than did sucrose. Comparisons of the temperatures for loss of birefringence at several solution concentrations showed sucrose >glucose>fructose. The differences among the three sugars increased with concentration. Layer cakes baked with the Wooster research formula, substituting either of the monosaccharides for sucrose, demonstrated the need for high glucose and even higher fructose levels or lower batter absorptions compared with sucrose to obtain cakes with optimum contour and volume. Successful cakes were obtained if the sugar/water ratio in the batter would permit a starch gelatinization temperature of approximately 90° C.

In the first part of this study (1), we showed that the initial swelling of starch granules coinciding with the loss of birefringence occurs at 85 and 95° C when wheat starch is heated in 50 and 60% sucrose solutions, respectively. These solution concentrations represent the approximate sugar/water ratio in layer cake batters before water evaporation during baking has occurred. Viscosity curves at these high sucrose concentrations suggested only first-stage gelatinization before boiling temperature was reached.

The monosaccharides glucose and fructose have been shown to raise the temperature of the viscosity increase of cornstarch pastes (2), but to a lesser extent than the same weight concentration of sucrose. Miller and Trimbo (3) showed earlier viscosity increases (lower "apparent" temperature of initial gelatinization) during heating of layer cake batters or flour-water slurries containing glucose or invert sugar in place of sucrose.

A useful study appeared to be developing direct microscopic evidence of the effects of glucose and fructose on starch gelatinization properties and relating such evidence to sucrose effects and to layer cake studies with the same three sugars. This article reports such a comparison.

MATERIALS AND METHODS

Commercial cane sugar (sucrose) was used in the study. Glucose and fructose were reagent-grade compounds. Thorne flour was a laboratory-milled

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unbleached first-break flour stream of Thorne soft red winter (SRW) wheat variety. The cake flour was a bleached patent commercially milled from SRW wheat.

Starch granule diameter changes were determined as described before (1). Gelatinization temperatures at 2, 50, and 98% loss of birefringence were determined using Schoch and Maywald's (4) method. Cakes were baked by Kissell's (5) Wooster research formula with sugar and liquid level adjustments as indicated for each experiment. Sugars were dissolved in distilled water and concentrations verified with an Abbé refractometer. Sugar solution concentrations are expressed in terms of weight of sugar per total weight of solution (% w/w). All other ingredients are expressed in bakers' percentages (parts per 100 parts of flour).

RESULTS AND DISCUSSION

Microscopic Observations

Observations of heating starch slurries on a microscope hot stage provides direct evidence for the onset of starch gelatinization. Increases in granule diameters are readily measured during heating as birefringence is lost. Figure 1 shows the rate of diameter increase in starch granules during heating of Thorne flour in water and 50% solutions of glucose, fructose, and sucrose. All three sugars raised the temperature at which starch began to swell. This temperature increase was greatest for sucrose, about 25° C above the initial temperature in

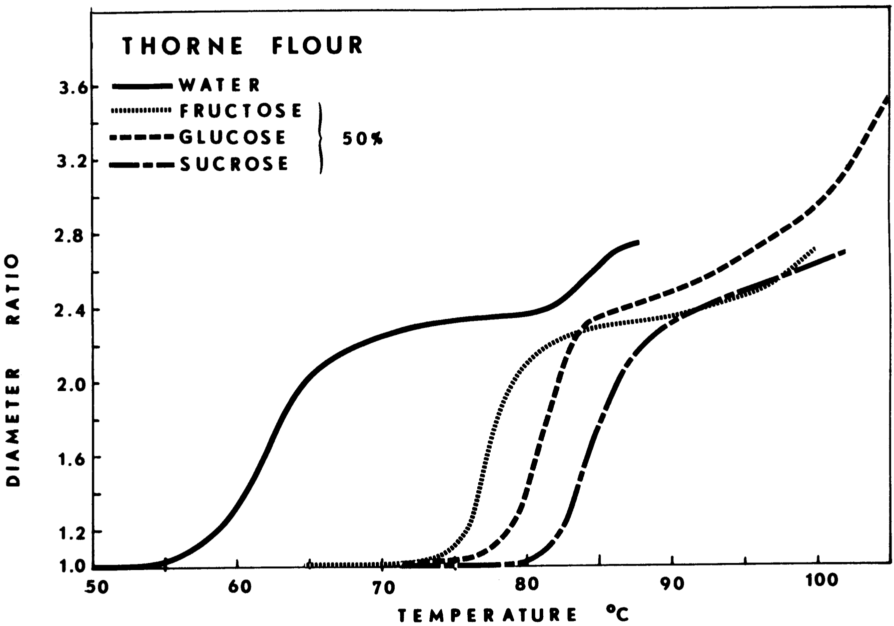


Fig. 1. Granule diameter changes in starch in flour heated in water and 50% sugar solutions.

water, about 4°C less for glucose, and an additional 4°C less for fructose, but still 17°C above the initial swelling temperature in water. The relative effects of the three sugars on starch swelling is the same as that reported in viscosity studies (2,3).

Diameter measurements of granules were possible at temperatures high enough to note a plateau and then a second increase before distortion and collapse of granules made the measurements meaningless. The granules were beginning to wrinkle during the last few degrees recorded for each curve so that the actual value at the highest temperatures reached may be questionable. Nevertheless, the extended curves help to illustrate that the characteristic second stage of gelatinization of wheat starch might be occurring.

Because of the measurable differences noted with these 50% solutions, it becomes of interest to determine the gelatinization temperature range at several solution concentrations of these three sugars. For this experiment, the commercial cake flour was used so that results could be related to layer cake performance with the same flour. Instead of diameter changes, the temperature range for loss of birefringence was determined (Table I). The midpoint of the range was plotted in Fig. 2. Sugar concentrations up to 80% for fructose were feasible. Temperature differences due to sugar type were slight at low concentrations, but increased markedly with increasing sugar levels so that in 60% solutions, the difference was almost 12°C.

Cake Performance

In balancing cake formulations, many ingredients have been shown to affect the final quality and often to be interdependent. Sugar/water ratios are among the more important as shown by Kissell (6,7) in optimizing lean and full cake formulas and by Miller and Trimbo (3) while making formula adjustments to accommodate different flours.

TABLE I
Temperature Range for Loss of Birefringence by Starch in Bleached Commercial Cake Flour in Several Sugar Solutions

	Sugar and % Loss of Birefringence								
	Sucrose			Glucose			Fructose		
Sugar Solution (% w/w)	2% (°C)	50% (°C)	98% (°C)	2% (°C)	50% (°C)	98% (°C)	2% (°C)	50% (°C)	98% (°C)
None	55	58.5	62.5	55	58.5	62.5	55	58.5	62.5
10	58	61	65	58.5	61	64.5			
20	59	63.5	69.5	61	64	67.5	59	63	67
30	66	70	74	66	68	72			
40	73	76	79	68.5	73	76	67	71	74
50	82	84	87	77	79	83			
57	90	91.5	94	82	84	86.5	78	80	83
60	93.5	94.5	96.5	85	86.5	90.0	81	83	85
62				88	89.5	91.5	84	86	88.5
65	98	101	104	90	91.5	94	85	87	90
70	104.5	106	Boiled	95	97.5	100.5	89	91	94.5
73							91.5	94.5	97
80							99	103	105

From the reports of these workers and the microscopic study results shown here, one might consider that sugar/water ratios were affecting cake quality through their effects on starch gelatinization temperature. The differing effects of

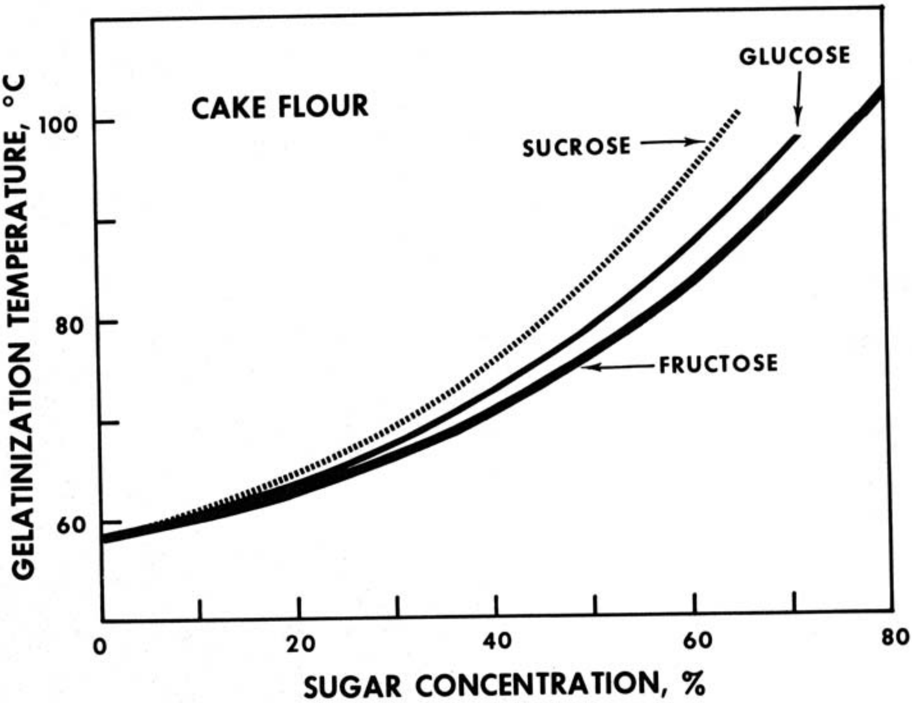


Fig. 2. Gelatinization temperature of wheat starch in bleached cake flour in several sugar solutions. Temperatures are 50% loss of birefringence from Table I.

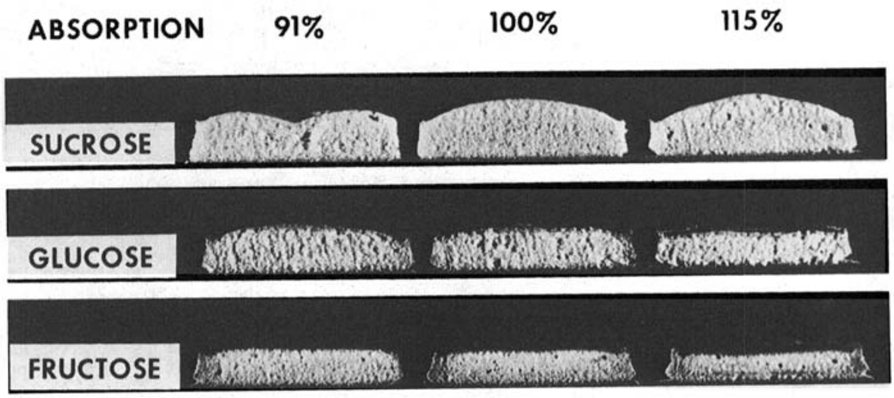


Fig. 3. Lean-formula cakes containing 130% sucrose, glucose, or fructose baked at three absorption levels.

the three sugars provide a system for assessing these factors. Cakes were made using the Wooster research formula, which omits milk and eggs. Thus flour supplied the only structural ingredient. The sugar level was 130% (flour basis).

Figure 3 shows cakes baked at three absorption levels chosen to represent too little, optimum, and too much water for sucrose-containing cakes. While 100% absorption gave the best sucrose cake of this series, the lower absorption (91%) gave improved results for both monosaccharides. Baking at still lower absorptions further improved the volumes and contours of the glucose and fructose cakes (Fig. 4). Also shown are cakes obtained at low absorption and having the sunken contour typical of too little water. When too much water is present, both monosaccharides caused cakes to have flat tops instead of the typical peaked contour obtained with sucrose cakes (Fig. 3).

Figure 5 shows the best cakes obtained with each sugar along with pertinent information related to starch gelatinization behavior. The sugar solution percentages shown were calculated from the absorption level indicated for each cake and the 130% sugar in the formula. The gelatinization temperature indicated was obtained for each sugar solution from the appropriate curve in Fig. 2. It indicates the 50% loss of birefringence or the onset of swelling of the granules. These temperatures were similar, all within a 1.5°C range (89°C for sucrose, 87.5°C for glucose, and 88.5°C for fructose).

Thus, large differences in absorption (65–109%) were necessary to produce high-volume, well-rounded cakes using different sugars. The respective water levels appeared to be necessary to obtain a sugar solution concentration in the batter that would foster the same starch gelatinization temperature, regardless of the sugar used.

Cakes baked with the commercial flour were of good volume over a range in absorption. For example, the sucrose cake in Fig. 5 was baked at a higher absorption (109%) than the optimum cake in Fig. 3 (100%). This flour

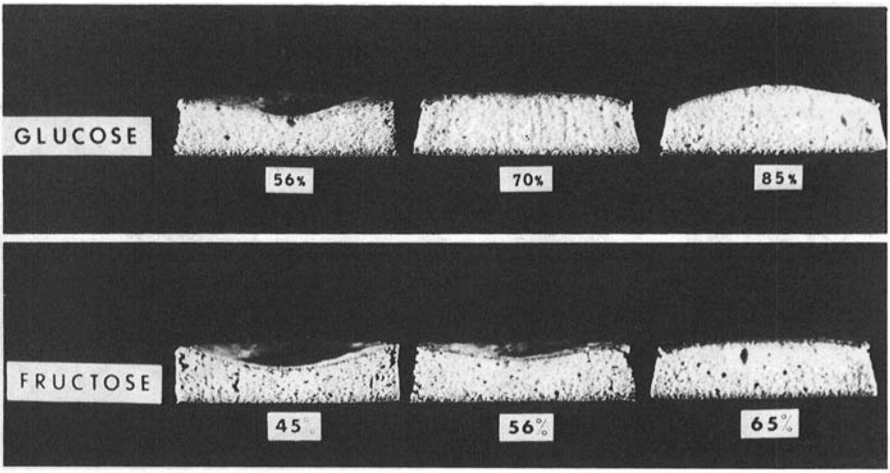
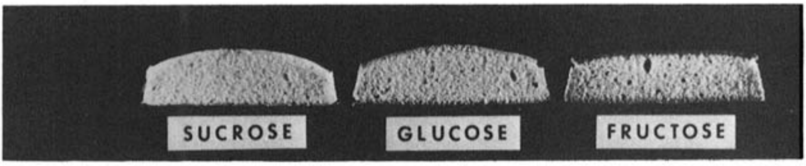


Fig. 4. Lean-formula cakes containing 130% glucose or fructose baked at absorption levels indicated.

produced satisfactory cakes over an absorption range of 100 to 112% with sucrose. Such a range provided sucrose solution concentrations that allowed the onset of swelling between 87 and 92° C according to the data in Table I and Fig. 2.

From these results, gelatinization temperature of the starch would appear to be an important factor in determining cake structure. Figure 6 further emphasizes this concept. The first two cakes contained the normal 130% sugar and approximately the same absorption, thus giving similar sugar solution concentrations in the batter (55.8% for sucrose and 56.5% for fructose). The starch gelatinization temperatures obtained from Fig. 2 for these solutions were 91° C for sucrose and 80° C for fructose. The sucrose cake was acceptable; the other was not. In the second comparison, the sugar level in the formula was increased to 150% of the flour. The water absorption used gave a fructose solution that would permit starch gelatinization around 89° C. An acceptable



ABSORPTION	109%	85%	65%
SUGAR SOLUTION	54.4%	60.4%	66.7%
GELATINIZATION TEMPERATURE	89°	87.5°	88.5°

Fig. 5. Lean-formula cakes with good volume and contour baked at absorption levels indicated. Sugar solution based on absorption and 130% sugar. Gelatinization temperatures obtained from Fig. 2.

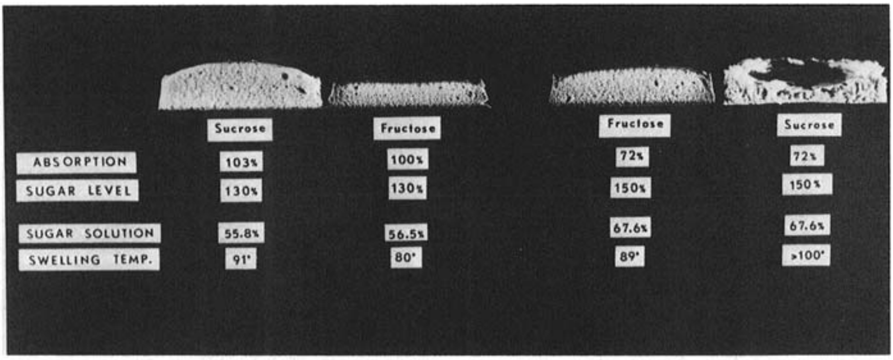


Fig. 6. Lean-formula cakes containing sucrose or fructose. Different sugar and absorption levels give different sugar solutions, resulting in different gelatinization temperatures (from Fig. 2).

cake was baked. Using the same batter formulation with sucrose, a sunken cake resulted. This sucrose solution caused the starch to gelatinize above 100° C, too high to set the structure during baking.

CONCLUSION

The delaying effect of sugars on starch gelatinization appears to be a major factor in determining layer cake volume and contour. Differences in starch gelatinization temperature due to sugar type must be taken into account in formula adjustment. Monosaccharides or disaccharides can be accommodated if the water level is adjusted to allow starch to gelatinize at a temperature that is optimum for the formula. This can be approximated by consideration of the starch gelatinization temperature in the sucrose-water system prevailing in the cake batter.

The reasons for differences in gelatinization temperature due to sugar type were not part of this study. Recent observations, however, are of interest. Water available to the starch as well as the volume that the sugar occupies in solution have been considered. Olkku (8) considered water vapor pressures of sucrose solutions as the determining factor in the temperature of gelatinization of starch in licorice candy systems. Lelievre (9) studied wheat starch in maltose and glucose solutions and considered that the molar volumes of these sugars influenced gelatinization temperature. He used the lattice thermodynamics that Flory (10) developed for polymer solutions to predict starch gelatinization temperatures. His experimental points agreed quite well with the computed points, except at high levels of sugar and starch. His equation considered interactions of the sugar, water, and starch as well as the space in solution that the sugar occupied. Thus, space and water availability may both be important in sugar effects on starch gelatinization.

The work reported here should not be construed as recommending the use of glucose or fructose in place of sucrose in cakes. These sugars serve as models for studying applications of other sugars, including high-fructose corn syrups. Sugar type affects other cake qualities, and these must be assessed before successful substitution of sugars can be accomplished.

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