EFFECTS OF CERTAIN SUGARS AND SUGAR ALCOHOLS ON THE SWELLING OF CORNSTARCH GRANULES

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ABSTRACT

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The effects of the swelling of cornstarch granules exerted by glucose, galactose, fructose, maltose, sucrose, lactose, sorbitol, and mannitol at levels of 5, 20, and 50% of the weight of water in the slurry were studied by means of the Brabender Visco/amylo/Graph®; swelling power determinations at 75, 85, and 95°C water bath temperatures; and photomicrography. Increasing sugar concentrations increasingly delayed viscosity development in the amylograph, with the 50% sugars also causing a pronounced increase in the temperature of maximum viscosity. All pastes had essentially the same rate of viscosity increase, but the maximum viscosity varied with the sugar concentration. Decrease in viscosity from maximum during holding at 96°C was least rapid at 50% sugar levels, although 20% levels of the disaccharides sucrose and lactose also exerted a marked inhibition on breakdown of the pastes. Sugars at 5 and 20% levels generally showed little effect on swelling power, especially at 75 and 85°C. Sugars at the 50% level, however, inhibited granular swelling, with the various sugars yielding a greater variation in effect at 75 and 95°C than they did at 85°C. Photomicrographs made from pastes containing 50% sugars indicated agreement with the results of the other methods, judged on size of granules and relative number of birefringent granules. In all aspects of the study, disaccharides in general showed a markedly greater effect than did monosaccharides, with sugar alcohols intermediate. Maltose, however, exhibited an anomalous behavior, usually between that of the monosaccharides and other disaccharides.

As increasing numbers of carbohydrate sweeteners such as high-fructose corn syrup, lactose, and hydrolyzed lactose become available to the food industry, a better understanding of the differences in their effects on the properties of foods in which they are used and the cause of these differences is important.

In the past 50 years, numerous investigators (1–7) have shown that increasing concentrations of sucrose cause increasing inhibition in the thickening of starch pastes and decreasing firmness of gels formed when the pastes are cooled. Bean and Osman (4) showed that although various monosaccharides, disaccharides, and mixtures such as corn syrups have the same qualitative effect on cornstarch pastes, they differ in the degree of effect. Weight-for-weight substitution of monosaccharides for disaccharides was found to cause far less inhibition of the starch swelling, although the molarity of the solutions was nearly doubled. Similar observations were made with wheat starch (7,8). Gelatinization of potato starch has also been reported to be inhibited by sucrose, glucose, maltose, and sorbitol (5).

Miller and Trimbo (9) showed that the temperature at which starch in cake batter gelatinizes is an important factor in determining cake quality. Bean and Yamazaki (7) later showed that with a given cake formula, substitution of glucose or fructose for sucrose yields a cake of good contour, volume, and grain if the ratio of sugar to water in the batter is adjusted to provide a medium in which

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the gelatinization temperature of the starch remains essentially unchanged.

The present study represents a comparison of the effects of several previously studied sugars, plus galactose and mannitol, on the swelling of cornstarch as determined by the Brabender Visco/amylo/Graph®, photomicrography, and swelling power.

MATERIALS AND METHODS

Materials

Commercially prepared food-grade cornstarch was used. Food-grade samples of sucrose and anhydrous D-glucose (Cerelose) were used. The other sugars—galactose, fructose, maltose, and lactose—were of chemically pure quality. The two sugar alcohols, sorbitol and mannitol, were pure crystalline products.

Dry weights of sugars used were 5, 20, or 50% of the weight of water in the starch slurry. The sugar was dissolved in distilled water before being mixed with the starch.

Amylographs

The method used was essentially that which Smith (10) described, with the following modifications. When sugar solutions were used in place of water, the quantities were adjusted so that the final volume of approximately 500 ml contained the same proportion of starch to water as the 7% (dry substance) cornstarch-water control. Enough water was replaced by a 0.1*N* sodium hydroxide solution to produce a cooked paste with a pH of 6.6. Samples were heated from 50 to 96°C and held at 96°C for 15 min.

Swelling Power

In this method, cornstarch is heated with excess water to allow the granules to swell to the maximum extent while exerting as little shear force as possible to minimize the rupture of the swollen granules. The method of Schoch (11) was used with the heating time in the 75, 85, or 95°C water bath extended to 1 hr, which preliminary experiments had shown was necessary with some of the sugar solutions to reach an essentially constant value. Correction for soluble starch was not made in the calculation of the swelling power values because of the presence of relatively large amounts of sugar in the supernatant. For a more accurate comparison of the sugar-containing samples with the control, however, the calculated weight of sugar in the sediment was subtracted before the calculation of swelling power was made.

Photomicrography

Before centrifugation of samples containing 50% concentrations of sugar during the determination of swelling power, one drop was removed for photographing under normal and polarized light. A representative field with regard to size and shape of granules and amount of birefringence was chosen.

RESULTS AND DISCUSSION

Amylographs

The amylograph curves obtained in this study showed many of the same general effects that Bean and Osman (4) found with the Corn Industries

TABLE I
Effect of Various Sugars on Hot-Paste Viscosity of 7% Cornstarch Slurry[a]

Sugar	Sugar Concentration (% Water Weight)											
	5				20				50			
	Initial Rise (°C)[b]	Maximum Viscosity (°C)	Maximum Viscosity (BU)	Final Viscosity (BU)[c]	Initial Rise (°C)[b]	Maximum Viscosity (°C)	Maximum Viscosity (BU)	Final Viscosity (BU)[c]	Initial Rise (°C)[b]	Maximum Viscosity (°C)	Maximum Viscosity (BU)	Final Viscosity (BU)[c]
Fructose	72.5	89.5	490	295	74.0	90.0	510	310	77.0	93.0	460	350
Glucose	73.5	90.5	490	305	73.5	91.0	500	320	79.5	94.5	415	360
Galactose	73.5	90.0	485	305	74.5	90.5	515	325	81.0	94.5	450	390
Sorbitol	73.5	90.5	500	305	73.5	90.5	520	335	79.5	95.5	440	390
Mannitol	73.5	91.0	490	305	74.0	91.0	520	335	80.5	96.0 (0.5 min)[d]	440	395
Maltose	74.5	91.5	485	310	75.0	91.5	510	340	82.0	96.0 (1.5 min)[d]	450	435
Lactose	73.5	90.0	485	310	75.5	92.5	465	340	82.5	96.0 (1.5 min)[d]	400	390
Sucrose	73.0	90.0	485	310	75.5	92.5	485	365	83.0	96.0 (2.5 min)[d]	420[e]	420

	Initial rise (°C)[b]	Maximum viscosity (°C)	Maximum viscosity (BU)	Final viscosity (BU)[c]
Cornstarch (no sugar control)	72.5	90.0	460	295

[a] Average of two determinations.
[b] Temperature of initial rise in viscosity to 20 BU.
[c] After holding at 96.0°C for 15 min.
[d] Time in parentheses is number of minutes after temperature first reached 96.0°C.
[e] No maximum reached; leveled off at this value.

Viscometer (e.g., increasing retardation in viscosity development with increasing sugar concentrations, with disaccharides showing a markedly greater effect than did monosaccharides in solutions of the same concentration by weight). As before, maltose showed anomalous behavior, having a greater effect than did the monosaccharides but generally less than that of the other disaccharides—sucrose and lactose.

Although the concentration of starch used in the present study was 7% compared with 5% in the previous one, and the stirring mechanism was different, the most important difference was the rate of heating. In the amylograph, the temperature of the sample mixture heated by an air bath rises steadily at 1.5°C per min, whereas that of the sample mixture in the Corn Industries Viscometer, which was heated in a water or water-glycol bath maintained at constant temperature (100°C in the study cited), rises rapidly to about 90°C after which the rate becomes progressivley slower. This difference in heating enables determination of the values shown in Table I with greater precision with the amylograph.

Only 50% concentrations of sugar caused pronounced increases in the temperatures at which increases in viscosity were recorded and maximum viscosities were reached. The heights of the viscosity curves, which were raised slightly by all sugars at 5% concentration, were raised appreciably by 20% levels; at 50%, however, levels were no higher or slightly lower than that of the control. Although one might postulate that these effects were caused in all cases by inhibited swelling of the starch granules (with the increased viscosity at 20% sugar levels resulting from fewer granules becoming sufficiently swollen and fragile to be fragmented and cause the viscosity to decrease), subsequent studies of granular swelling, to be discussed later, indicate that this is not the case.

The rate of viscosity increase was approximately the same for all pastes.

TABLE II
Decrease in Viscosity From Maximum to Final Viscosity After 15 Min Holding at 96°C

	Sugar Concentration (% Water Weight)					
	5		**20**		**50**	
Sugar	**(BU)**	(%)[a]	**(BU)**	(%)[a]	**(BU)**	(%)[a]
Fructose	195	39.8	200	39.2	110	23.9
Glucose	185	37.8	180	36.0	55	13.3
Galactose	180	37.1	190	36.9	60	13.3
Sorbitol	195	39.0	185	35.6	50	11.4
Mannitol	185	37.8	185	35.6	45	10.2
Maltose	175	36.1	170	33.3	15	3.3
Lactose	175	36.1	125	26.9	10	2.5
Sucrose	175	36.1	120	24.7	0	0.0
			(BU)	(%)[a]		
Cornstarch (no sugar control)			165	35.9		

[a] $\% = \dfrac{\text{maximum viscosity} - \text{final viscosity}}{\text{maximum viscosity}}$

TABLE III
Swelling Power Values of Cornstarch[a] Showing Effect of Three Concentrations of Various Sugars at Three Water Bath Temperatures

	Sugar Concentration (% Water Weight)								
	5			20			50		
	Water Bath Temperature								
Sugar	75°C	85°C	95°C	75°C	85°C	95°C	75°C	85°C	95°C
Fructose	8.8	10.8[b]	17.6[b]	9.5	11.6	18.0	8.1[b]	10.5[b]	17.7[b]
Glucose	9.2	10.8	17.6[b]	8.7[b]	10.9	18.0	6.5[b]	10.0[b]	15.1[b]
Galactose	8.7	11.2[b]	17.9	9.4[b]	11.2	19.2	6.2	9.8	15.2[b]
Sorbitol	9.1	10.7	17.9[b]	9.0	11.3[b]	17.8[b]	5.9	9.4[b]	13.5
Mannitol	8.8	10.4	17.1	8.9	11.0	16.6[b]	5.2	9.7	12.7[b]
Maltose	9.0	10.0	17.8	8.6[b]	11.4[b]	20.3[b]	3.8	10.7	16.6
Lactose	8.7[b]	11.0	16.9	8.3[b]	10.6[b]	17.4[b]	2.6	9.2	11.8
Sucrose	8.8	10.8[b]	18.5	8.4	10.5[b]	16.0[b]	2.8[b]	9.0	10.8[b]
				75°C	85°C	95°C			
Cornstarch (no sugar control)[b]				8.8	10.6	17.7			

[a] Swelling power = $\frac{\text{Weight of sedimented paste} - \text{weight of sugar in paste}}{\text{Weight of starch (dry substance)}}$

[b] Average of three determinations; other values, average of two determinations.

Temperatures at maximum viscosity reflected the effect of the sugar on the temperature at which the initial rise in viscosity was observed. This is in contrast to the slower viscosity increase with higher sugar concentrations that Bean and Osman (4) reported and probably reflects the difference in the rates of heating between the amylograph and Corn Industries Viscometer. This difference may also be the cause of the increase in maximum viscosity observed with monosaccharides at 50% concentration in the previous study but not in this one.

Decrease in viscosity from the maximum to that after a holding period of 15 min at 96°C varied with both concentration and sugar. If this decrease is calculated as percentage of maximum viscosity (Table II), the relative amounts of paste breakdown can be compared. All sugars at 50% concentration, and at least sucrose and lactose at 20%, apparently were effective in reducing the fragility of the granule and resulted in less loss of viscosity on prolonged cooking of the cornstarch paste. Disaccharides, including maltose, were much more effective in this respect than were the monosaccharides or sugar alcohols.

Swelling Power

Sugars at 5% concentration had little effect on the swelling of cornstarch (Table III). At 20% concentration, differences among the various sugars began to appear, especially in the samples heated at 95°C. In general, swelling in the presence of monosaccharides was slightly greater than that of the control, while those with disaccharides and sugar alcohols were nearly the same or lower than the control. The striking exception was the sample containing maltose, in which swelling at 95°C was greater than in any of those containing monosaccharides.

As can be seen readily in Fig. 1, the effect of the presence of 50% sugars varied

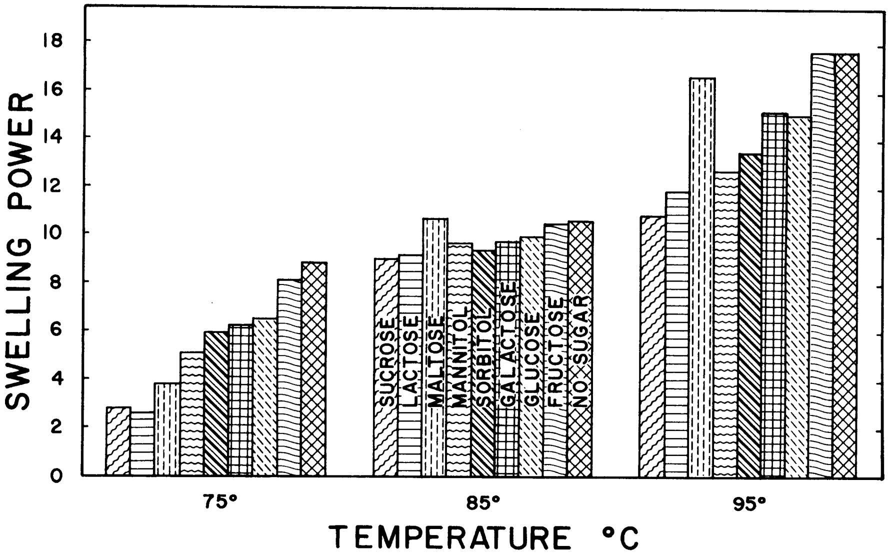

Fig. 1. Effect of 50% concentration of various sugars on swelling power of cornstarch at 75, 85, and 95°C.

greatly among the sugars and at the three temperatures. Fructose and maltose had little if any effect at 85 and 95° C. Fructose differed only slightly from the other monosaccharides, glucose and galactose, which decreased the swelling to only a limited degree. Maltose, however, while resembling other disaccharides in its effect at 75° C, displayed none of their strongly limiting effect at the other temperatures, especially 95° C. As already noted, maltose also showed anomalous effects on amylographs prepared in this study and on Corn Industries Viscometer curves previously reported (4).

While the range of swelling power values among the samples with sugars at 50% concentration was 5.5 at 75° C and 6.9 at 95° C, the range was noticeably smaller (1.7) at 85° C. A possible explanation for this small difference at 85° C may be the two-stage swelling of cornstarch attributed to two sets of bonding forces within the granule that relax at different temperatures (12). An initial rapid swelling before 75° C, a near plateau between 75 and 85° C with only restricted swelling, and a second rapid swelling after 85° C have been reported. In our study, the convergence of values at 85° C might have been due to the fact that the samples with the initially more rapidly swelling granules had reached the plateau and practically ceased their expansion, whereas those with the slower swelling granules had continued swelling until they reached the same plateau. With additional heating to 95° C, the differences in the effects of the sugars on the second stage of swelling were observed. This difference in the effects of the various sugars on the swelling at the three temperatures was not observed with the 5 or 20% sugar concentrations.

Photomicrographs

Photomicrographs of pastes made with 50% sugar concentrations agreed with other observations in showing that the disaccharides had a more pronounced inhibiting effect on the swelling of the granules than did the sugar alcohols or monosaccharides; this was indicated by the size of the granules and the relative number of birefringent granules present at the three temperatures. No birefringent granules were found at any of the three temperatures in the control, but all sugar-containing pastes included many birefringent granules at 75° C. At 85° C, birefringent granules were still in all sugar-containing pastes, with more in the disaccharide samples. Although all birefringence had disappeared from the other samples at 95° C, those containing sucrose or lactose still had some granules that were unswollen and birefringent. The photomicrographs, which were made of drops taken from the samples used to determine swelling power, also confirmed that little rupture of the granules occurred in that determination.

CONCLUSION

The photomicrographs and swelling power determinations support the theory that the major effect of sugars on the viscosity of starch pastes of concentrations in the range used in puddings (7%) can be attributed to their effect on the swelling of the starch granules. In substitution of one sugar for another in food formulations, consideration should be given to the relative effects of the sugars on starch swelling.

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