

Behavior of Hinoat Oat Starch in Sucrose, Salt, and Acid Solutions¹

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ABSTRACT

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The behavior of starch from the oat variety Hinoat was studied in the presence of sucrose, mild acid, salts, and sucrose-acid combinations. The unusually high solution torque developed by this starch when a hot paste was cooled to 75–80°C was abolished in the presence of acetic acid at pH 3.0. Salts at 0.1*N* concentration reduced the magnitude of this cool torque value. In the presence of increasing sucrose concentrations, this cool torque

value was progressively reduced; however, in citric acid solution, sucrose's greatest effect was in minimizing hot paste breakdown. The lytic action of the acid cannot be completely reversed by sucrose. The behavior of this oat starch, and of wheat starch by comparison, in the presence of sucrose and acid/sucrose mixtures is dependent upon the heat transfer conditions employed during the testing.

Many food ingredients are known to affect the gelatinization and pasting properties of starches. An excellent review on this subject has been published by Osman (1967). In general, salts can either increase or decrease the birefringence end point temperature (Ruggeberg 1953, Sandstedt et al 1960). The peak viscosity is also increased, as is the setback viscosity. Mild acids slightly increase the peak viscosity and slightly decrease the temperature at which this occurs (Campbell and Briant 1957). Acid solutions also result in a rapid breakdown or thinning of cooked starch pastes.

Sucrose, when present in amounts up to 20% of the starch slurry weight, retards starch granule swelling and slightly increases the peak

viscosity value. Higher sucrose concentrations result in greater retardation of the temperature of granule swelling and a reduction in peak viscosity (Bean and Osman 1959). The strength of these sucrose/starch gels also decreases as the sucrose content increases. The effects of sucrose, fructose, and glucose on wheat starch gelatinization have recently been reported by Bean and Yamazaki (1978) and by Bean et al (1978), with specific reference to the behavior and function of these sugars in layer cake systems.

Some of the physical and chemical properties of oat starch isolated from the Canadian high protein cultivar, Hinoat, have previously been described (Paton 1977). One purpose of the present article is to report the effects of sucrose, salts, and acids upon the paste viscosity characteristics of this oat starch. A further objective is to report such effects under short time-rapid heat transfer conditions. These seem to have been neglected but have been recognized by Osman (1967) as being of interest and practical significance. The present study uses the Ottawa Starch Viscometer

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(OSV), which offers short time-high heat transfer conditions and is more representative of actual commercial starch cooking operations (Voisey et al 1977) than is the Brabender amylograph, which has traditionally been used in studies of starch paste characteristics.

MATERIALS AND METHODS

Oat starch was isolated and purified from the Canadian cultivar, Hinoat, as previously described by Paton (1977). Wheat starch was a commercial sample from Industrial Grain Products Ltd., Montreal, Quebec, Canada. All starch pasting properties were determined in the OSV as 9% (w/w, db) slurries in distilled water at pH 6.8 (Voisey et al 1977). The unit of force used for calibration was

TABLE I
Comparison of Brabender Amylograph and Ottawa Starch Viscometer (OSV) in the Cooking of Hinoat Oat Starch^a

pH Level ^b	Torque (cm · N × 10 ²)			Ratios		
	Peak	Hold	Cool (68° C)	Peak/ Hold	Peak/ Cool	Hold/ Cool
Amylograph ^c						
3.0	455	85	245	5.35	1.85	0.34
6.8	543	372	1,065 ^d	1.46	<0.51	<0.35
OSV ^e						
3.0	138	68	160	2.03	0.86	0.42
6.8	176	108	430	1.64	0.41	0.25

^a Starch slurry concentrations, 9% (db). Total slurry weight for Amylograph and OSV, 500 and 70 g, respectively.

^b Dilute acetic acid used to adjust pH of slurries.

^c Holding time at 97° C, 30 min.

^d Off scale at 75° C.

^e Holding time at 97° C, 3 min.

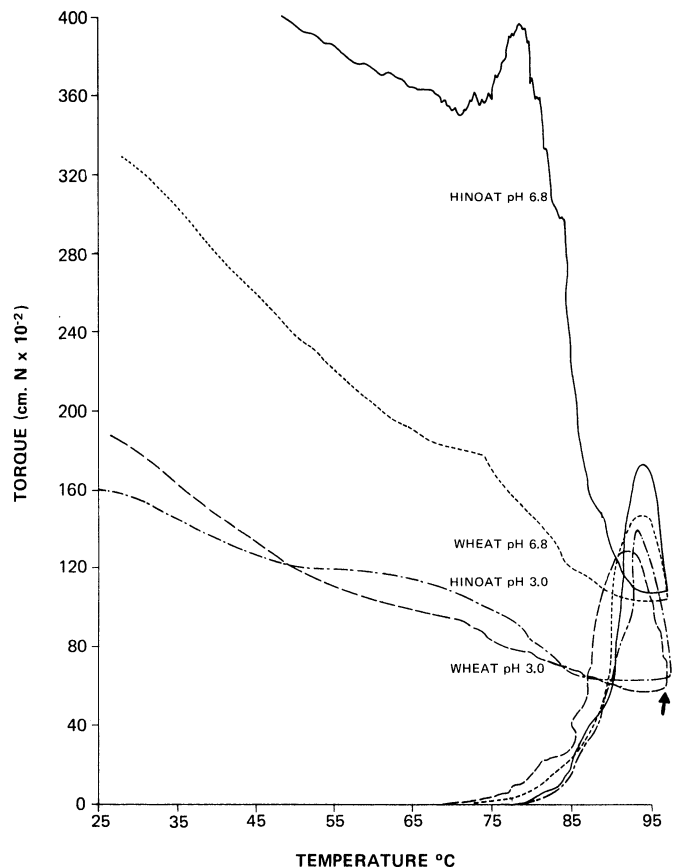


Fig. 1. The effect of dilute acetic acid in the pasting curves of Hinoat and wheat starches. Arrow = start of cooling period.

the Newton (N), where 1 N = 0.102 kg. Because the water bath temperature was thermostated at 97° C, the sample temperature could never exceed this value. Thus when sample and bath achieved equilibrium at 97° C, a holding period could be initiated at constant temperature. At this point, the heaters were shut off, and the hot bath water was rapidly drained and replaced by cold running tap water. Samples were then cooled until they reached 25° C, at which point the pen was raised from the chart paper. The torque values C_1 and C_2 , reached on cooling the hot paste to 80 and 68° C, respectively, were noted, and setback ratios C_1/H and C_2/H were calculated, using H, the torque value after the hot paste was held at 97° C for 3 min. For acidic solutions, acetic acid was used to adjust the pH to 3.0. When citric acid was the acidulant, it was employed at the 0.5% level (based upon the weight of starch plus water), the acidity level typical of fruit pie fillings. All acidic solutions were unbuffered.

Salts were added to the water, as required, such that the final salt concentration was 0.1N.

For test runs using sucrose, different levels (10–40%, based upon the weight of starch plus water) were employed. When citric acid and sucrose were present together, the acid level was fixed at 0.5% and the sucrose content was in the 10–40% range. Gel strengths of stored, cooked starch pastes were determined, using the penetrometer method described by Voisey and Emmons (1966).

RESULTS AND DISCUSSION

The effect of cooking wheat and Hinoat starches in water (pH 6.8) and water adjusted to pH 3.0 with acetic acid is shown in Fig. 1. For wheat starch, the temperature of initial torque rise was lowered by 3–4° C and the peak (P) viscosity temperature by 3° C; the peak itself was broader and reduced slightly in magnitude at pH 3.0. Hinoat starch, in contrast, exhibited no change in the temperature of initial torque rise nor in the peak torque temperature; only the peak torque magnitude was reduced in size. The most notable change occurred on cooling the hot starch pastes. Acid had the greatest effect upon Hinoat starch, almost eliminating the very unusual cooling peak located at approximately 80° C.

Table I shows a comparison of two different methods of cooking Hinoat starch. The fundamental difference between the

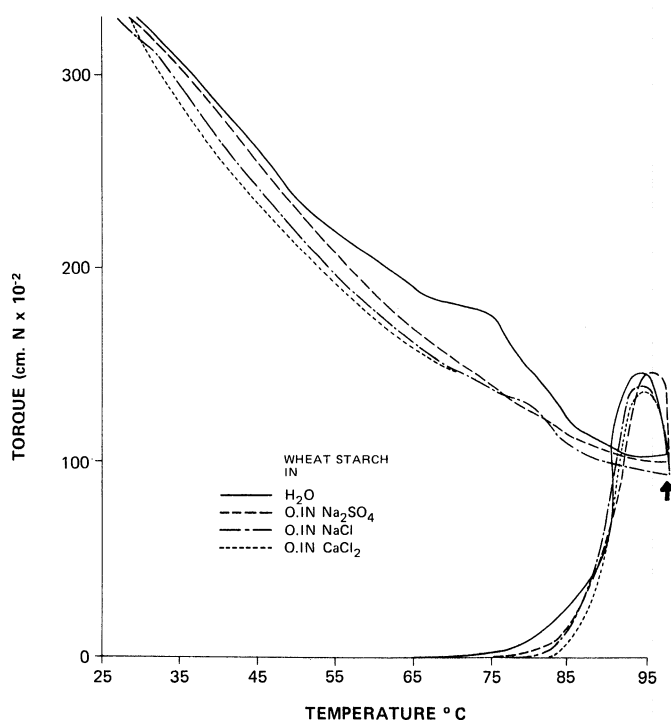


Fig. 2. The effect of salts on the pasting curves of wheat starch. Arrow = start of cooling period.

instruments was the nature of the heat transfer; the amylograph, programmed with a small incremental temperature rise (1.5° C/min), had a much slower heat transfer rate, and thus the sample was exposed to the operating conditions for a much longer period.

As previously (Paton 1977), these torque results were expressed in terms of ratios rather than as absolutes, to account for instrumental design differences and to compare samples in relative terms. A similar approach has also been suggested by Bhattacharya and Sowbhagya (1978). At pH 6.8, only a small difference was found in the P/H ratios of both instruments. However, cooking the starch in the presence of dilute acid resulted in very marked differences; in the amylograph this ratio was increased almost four times over that obtained at pH 6.8. Acid cooking of Hinoat starch in the OSV resulted in a 0.3 ratio increase over the control. The large ratio increase shown by the amylograph was considered to result from the lengthy exposure of the sample to acid. Relative breakdown (P/H) also occurred in the OSV but to a much smaller extent. Thus even with a rapid heat transfer system, in which the total cooking time to the end of the Hold stage was 7 min, the lytic action of dilute acid was quite evident. The ratio C_2/H magnified to an even greater extent the effect of prolonged exposure of starch to acid conditions. An absolute value for C_2 in the amylograph was impossible to obtain because of insufficient full-scale calibration during the test and the lack of sufficient sample to repeat it. Further, in studies in this laboratory the cooling function of the amylograph has generally not been effective. Only that area in the immediate vicinity of the cooling coil and thermoregulator reach the indicated temperature; bowl areas further removed from the thermoregulator are at a considerably higher temperature.

When wheat and Hinoat starches were cooked in the presence of salts (Figs. 2 and 3), the influence of salt on starch pasting curves depended on the starch type. Wheat starch was not markedly affected; retardation of the temperature of initial torque rise, peak height, and temperature variations were all in accordance with previous observations (Sandstedt et al 1960). Salts influenced the cooling curve of wheat starch by slightly lowering the torque profile within a narrow range compared to that of the control. For Hinoat starch, the effect of salts on the temperature of initial torque rise, peak torque temperature, and cooling curve were much more pronounced. $CaCl_2$ lowered the peak torque temperature, and Na_2SO_4 increased it. The effect of salts on the cooling curve was very evident.

Wheat starch cooked in varying concentrations of sucrose solutions exhibited a progressive retardation of the temperature of initial torque rise and a slight shift to higher values of the peak torque temperature. The torque curves (not shown) were similar in the heating cycle to those reported by others (Bean and Osman 1959). D'Appolonia (1972) reported a progressive loss of any definite peak for wheat starch as sucrose content increased, with high sucrose

concentrations (40–50%) resulting in a plateau. This behavior was also shown by Savage and Osman (1978).

D'Appolonia also reported that as sucrose content increased, the amount of setback (defined as torque at 68° C minus the hold torque) of a cooked wheat starch paste decreased. The results shown in Table II are not in accord with these observations. All wheat starch-sucrose pastes exhibited a peak, although at 40% sucrose concentration the hot paste had to be held at 97° C for 15 min for this to occur. The hold values also increased, and although this could result from a slightly reduced swelling that would cause the granules to be more resistant to shear thinning, this explanation seems unlikely when the ratios C_1/H and C_2/H are considered. One

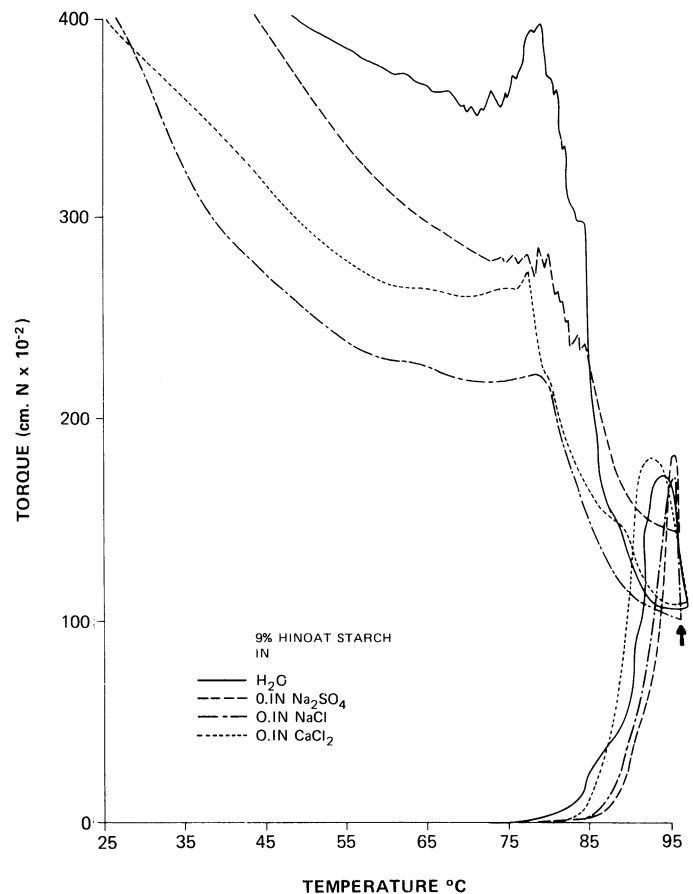


Fig. 3. The effect of salts on the pasting curve of Hinoat starch. Arrow = start of cooling period.

TABLE II
Behavior of Wheat and Hinoat Oat Starch in the Presence of Sucrose

Starch	Torque		Breakdown Ratio P/H	Torque		Setback Ratios	
	Peak (P)	Hold (H) ^a		C_1 (80° C)	C_2 (68° C)	C_1/H	C_2/H
Wheat							
H ₂ O	148	104	1.42	148	184	1.42	1.77
Added sucrose, %							
10	166	112	1.48	184	210	1.64	1.87
20	178	120	1.48	200	226	1.67	1.88
30	192	128	1.50	204	240	1.60	1.88
40	184	136 ^b	1.35	226	256	1.65	1.88
Hinoat Oat							
H ₂ O	176	108	1.63	396	362	3.67	3.35
Added sucrose, %							
10	182	104	1.75	384	350	3.69	3.36
20	192	116	1.66	352	334	3.04	2.88
30	212	176	1.20	258	294	1.47	1.67
40	214	184 ^b	1.15	208	244	1.13	1.33

^a Holding time at 97° C, 3 min except where noted.

^b Holding time at 97° C, 15 min.

might expect setback values to decrease as granule swelling is decreased; however, the values of C_1 and C_2 do not bear this out.

Hinoat oat starch, on the other hand, does not behave in the same manner as wheat starch in the presence of sucrose. Breakdown and setback ratios were substantially reduced. Because Hinoat starch in water exhibits an unusually high cooling curve (Fig. 1), one possible explanation for the behavior in sucrose might be that sucrose competes with the starch for the available water in the system, thereby reducing the magnitude of the high torque attained on cooling the slurry. Because paste breakdown is quite evident in sucrose pastes of both wheat and Hinoat starch, the design features of the OSV possibly lead to higher shear factors than are normally encountered with an amylograph.

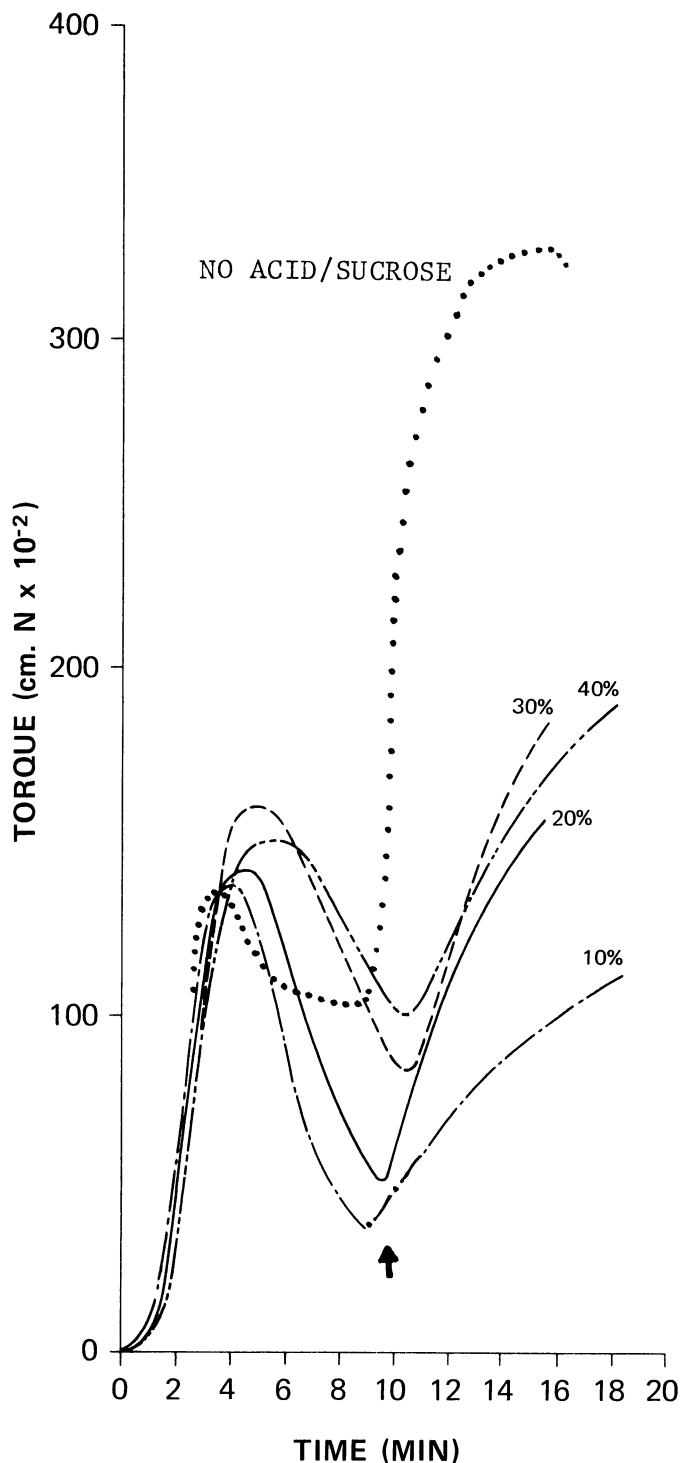


Fig. 4. The effect of sucrose concentration on the pasting curve of wheat starch in the presence of citric acid. Arrow = start of cooling period.

Osman (1967) reported that wheat starch pastes rapidly break down in the presence of citric acid but that sucrose slowed down this lytic action by its tendency to inhibit starch granule swelling. Figures 4 and 5 show the combined effects of 0.5% citric acid and increasing sucrose concentrations on the torque (viscosity)-time curves for wheat and Hinoat starches. Time was chosen as the X axis in preference to temperature in this case, in order to better display the region at which the peak viscosity occurs. The holding time at 97°C was 5 min for all samples. As was observed for wheat starch in the presence of sucrose alone, the starch-sucrose-acid system showed a delay in the temperature of initial torque rise and an increase in the time taken to the peak, in its magnitude, and in the magnitude of the final cooled torque (25°C). Paste breakdown was less for increasing sucrose content, as was the total setback. In contrast, much greater shifts were seen for Hinoat oat starch (Fig. 5).

Under the viscometer conditions used here, exposure to acid for

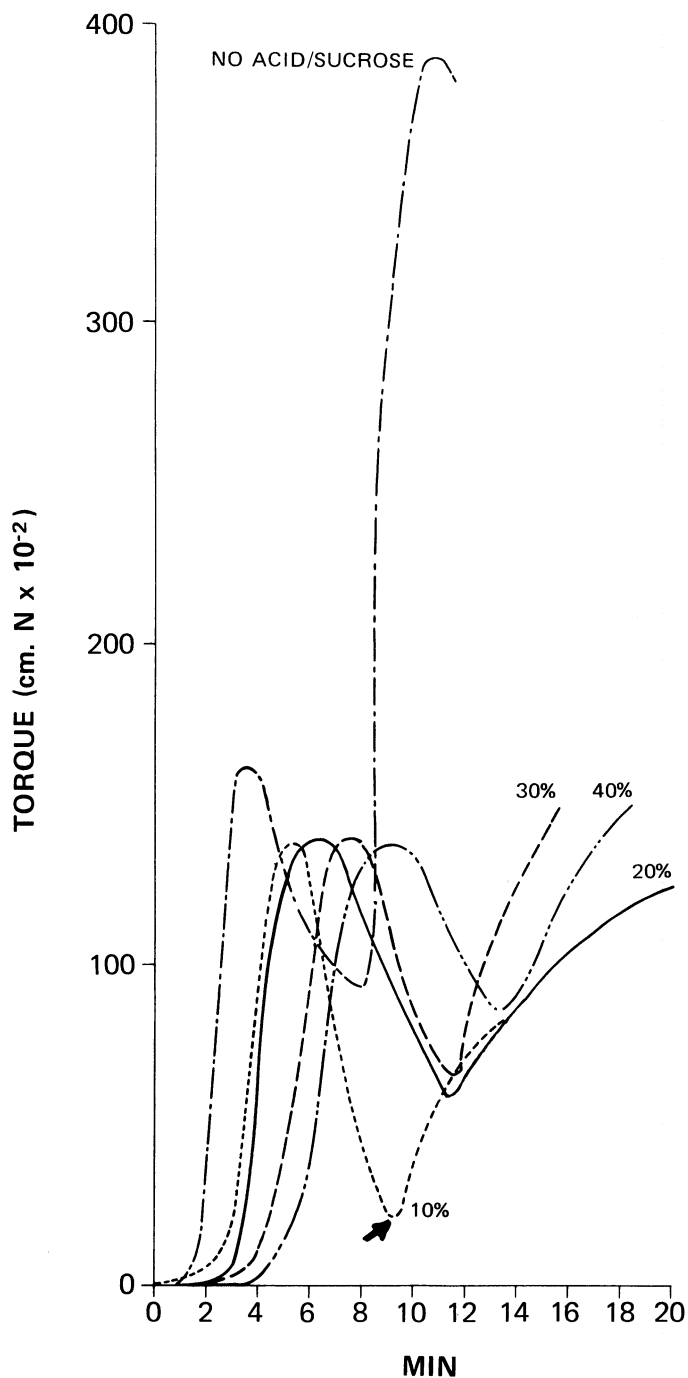


Fig. 5. The effect of sucrose concentration on the pasting curve of Hinoat starch in the presence of citric acid. Arrow = start of cooling period.

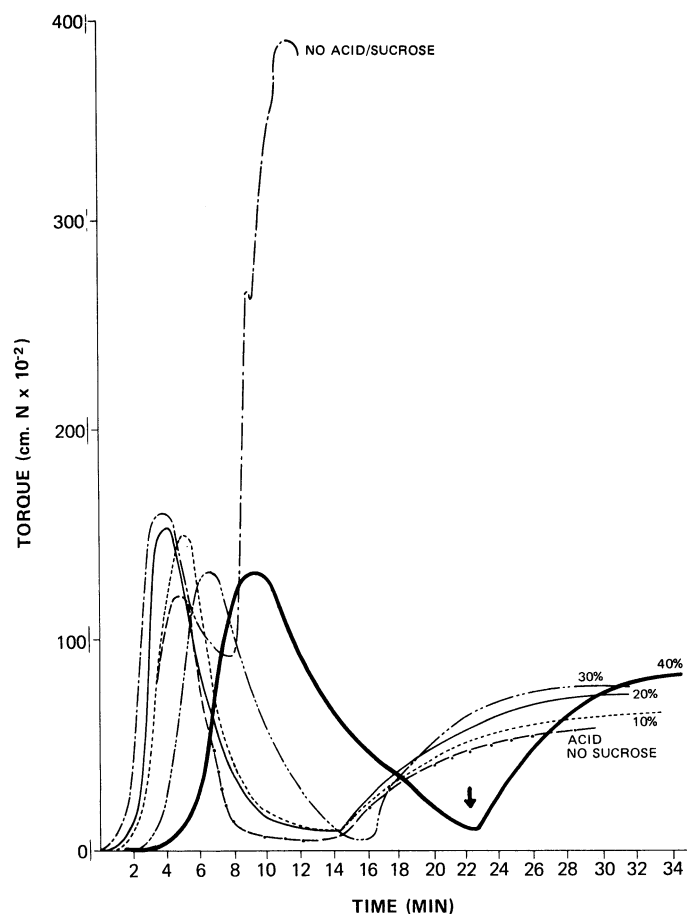


Fig. 6. The effect of extending the hot paste holding time on the pasting curve of Hinoat starch in the presence of citric acid and sucrose. Arrow = start of cooling period.

as short a time as 12 min, even in the presence of high concentrations of sucrose, was sufficient to abolish the very high cooling peak of the control. Figure 6 illustrates the effect of allowing all starch-sugar-acid pastes to thin to a limit before each was cooled to 25°C. Holding times at 97°C were obviously not constant in this case. Sucrose could not effectively overcome the lytic action of the acid, and all solutions cooled back to approximately the same torque value. No consistent relationship could be identified between final cooled torque values of acid-sucrose-starch pastes and the strength of their gels measured 24 and 48 hr after pasting. No explanation can be offered at this time, but Figs. 5 and 6 suggest that both the length of exposure of samples to acid and the high shear effects play important roles.

Hinoat oat starch, when cooked in the presence of acid, salts, sucrose, and sucrose-acid combinations, exhibited pasting curve behavior vastly different from that of an aqueous control and fundamentally different from those of wheat starch pastes similarly treated. Although the fine structure of this oat starch is still under investigation and has yet to be established, separate data accumulated to date suggest that Hinoat starch is unusual in its solution behavior during the cooling portion of the starch pasting cycle. Gel permeation chromatography and iodine absorption of the fractions suggest that this oat starch contains species of molecular weight between amylose and amylopectin and that the amylose is of slightly lower molecular weight (Paton 1979). The presence of these species in the oat starch granule may result in a rapid rate of change in solution torque as the hot paste is cooled from 95°C. The presence of salts, sucrose, and acid hinder, inhibit, or reduce some form of steric rearrangement of these starch species, giving rise to this unusual behavior.

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