Gelatinization of Wheat Starch. IV. Amylograph Viscosity[1]

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ABSTRACT

Surfactants (monoglyceride and sodium stearoyl lactylate) reduced the first-stage viscosity of wheat starch and delayed the second-stage increase. The delay in the increase of second-stage viscosity apparently stems from the fact that the surfactant complexed with amylose and reduced its solubility. Wheat-starch solubility at 95° C was inhibited by monoglyceride but not by sodium stearoyl lactylate; however, both surfactants affected amylograph viscosity equally. Thus, amylograph viscosity does not depend entirely on starch solubility. Viscosity of solubilized starch was lower than that of heated, granular starch. Calculations based on swelling power and starch solubility indicate that much of the available water is absorbed by the starch granules. As more water is bound, the concentration of soluble starch in the remaining free water increases, giving the sharply increased viscosities.

When starch granules are heated in aqueous suspensions, they swell, and solubles leach from the granules into the surrounding aqueous phase to produce a viscous paste. That is the most important practical property of starch. A common belief is that the increased viscosity of a cooked starch paste results from the granules imbibing increasing amounts of free water as they swell, thus making contact among them more likely (Collison 1968, Schoch 1965). Reports have also stated that the increase in viscosity is a measure of the work required to move the granules past each other as they continue to swell.

Miller and co-workers (1973), however, concluded that granule swelling does not account for the rapid rise in viscosity of a wheat starch suspension heated in excess water, but that the exudate principally causes the large increase in viscosity at higher temperatures. Pretreatment of starch suspension with sodium stearoyl fumarate, chlorine, or α-amylase gave normal granule swelling but low viscosities and little or no exudate. Thus, Miller et al (1973) concluded that a correlation between starch-paste viscosity and granule size was almost nonexistent.

Ghiasi et al (1982a) showed that sodium stearoyl lactylate (SSL) and monoglyceride (MG) inhibited swelling and solubility of wheat starch at temperatures below 85°C. At higher temperatures, SSL did not affect solubility, but MG did. They also showed that the surfactants effectively stopped the leaching of amylose at temperatures below 95°C. Ghiasi et al (1982b), using X-ray

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diffraction patterns, also showed that surfactants enter the starch granule and complex with amylose and that the SSL-amylose complex dissociates at temperatures higher than 85°C. Because the two surfactants act differently at higher temperatures, we hoped to determine the effect of starch solubility and swelling on amylograph viscosity.

MATERIALS AND METHODS

Starch

Prime starch was isolated from hard wheat flour (cv. Cloud) milled on a Buhler experimental mill by the dough-kneading procedure (Wolf 1964).

Swelling and Solubility

Starch swelling was determined by the method of Leach et al (1959). The level of soluble starch was determined by suspending 5 g of starch in 180 ml of water, placing the sample in a water bath adjusted to the desired temperature, and mechanically stirring. The samples were then heated to 120°C in a pressure cooker. When the starch was to be characterized chemically, the sample was purged with nitrogen and held at the desired temperature for 30 min. After centrifuging (1,000 × *g*), the soluble carbohydrate was determined by the phenol-sulfuric acid method (Dubois et al 1956). Preliminary work showed that the 2% levels (based on starch) of SSL and MG used gave a maximum effect in an amylograph. The surfactants were dispersed in the buffer immediately before the starch was added.

Viscosity

To show the two stages of starch swelling, we added carboxymethyl cellulose (CMC, 1.5%, w/v) to a 5% wheat starch suspension (Crossland and Favor 1948) and heated it in an amylograph. The amylograph was also run with 40 g of starch in 460 ml of buffer instead of with CMC. All other measurements were made without CMC.

RESULTS AND DISCUSSION

Effect of SSL and MG on Pasting Properties of Wheat Starch

The amylograph was used to study the effect of SSL and MG on the pasting properties of wheat starch (Fig. 1). CMC was used so that the two stages of wheat starch swelling could be seen (Crossland and Favor 1948). Without CMC, only the second stage of viscosity increase was seen; however, the effect of surfactants on viscosity was the same as with CMC, which indicates that CMC does not affect the interaction of surfactants with starch. The amylograph viscosity obtained in the first stage presumably resulted from granule swelling. Bean and Yamazaki (1978) showed that granule diameter increases between 58 and 70°C (first-stage swelling of wheat starch), which corresponds to the onset of viscosity of wheat starch-CMC amylograph curves. Starch treated with SSL and MG gave slightly lower first-stage viscosities. In addition, those surfactants delayed the second-stage increase in viscosity. The gradual increase in amylograph viscosity obtained with the control sample below 85°C apparently resulted from amylose solubilization (Fig. 2). This is consistent with the data of Miller et al (1973). Both SSL and MG form complexes with amylose and reduce its solubilization at temperatures below 85°C (Ghiasi et al 1982a, Schoch 1965).

At 95°C, the viscosity was higher for the control sample than for the surfactant-treated samples (Fig. 1). Wheat starch solubilization at 95°C was inhibited by MG; the SSL-treated and control samples gave nearly equal solubles (Fig. 2). We expected a much lower amylograph viscosity for the MG-treated samples, because Miller et al (1973) suggested that the increase in viscosity obtained in the amylograph resulted mainly from an exudate. The amylogram (Fig. 1), however, shows that MG and SSL affected viscosity equally; thus, amylograph viscosity does not depend entirely on starch solubility.

To study the correlation between solubility and starch-paste viscosity further, we measured the viscosity of a completely solubilized wheat starch. Wheat starch was dissolved in *N* KOH, neutralized with HCl, diluted to 460 ml, and the viscosity measured in the amylograph at 25°C (Fig. 3). Based on solubility data at 95°C (Fig. 2), approximately 35% (14 g) of the starch was soluble. That amount of completely soluble starch gave a viscosity of only 90 BU

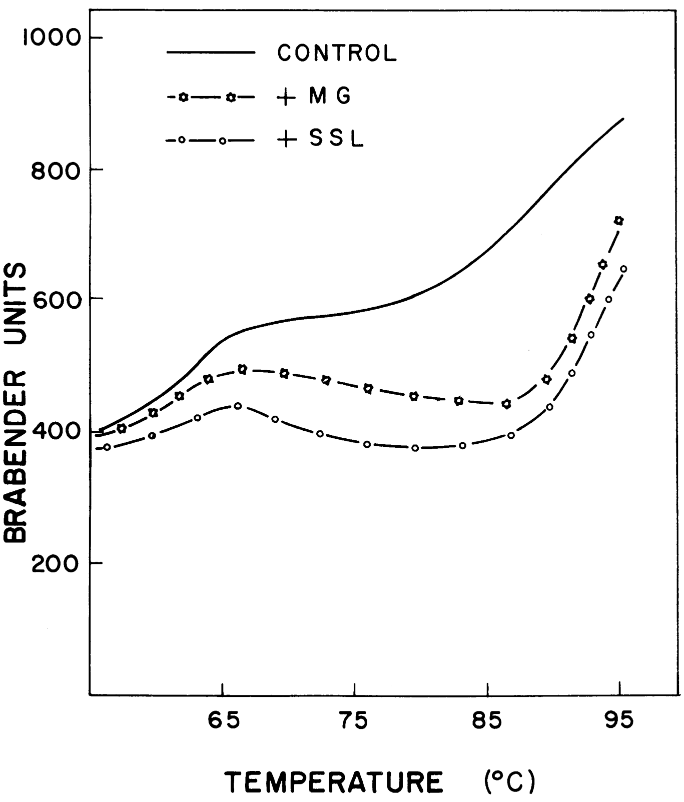

Fig. 1. Effects of 2% monoglyceride (MG) or sodium stearoyl lactylate (SSL) on the Brabender viscosity of wheat starch with carboxymethyl cellulose. The starch solution contained 5% starch and 1.5% carboxymethyl cellulose.

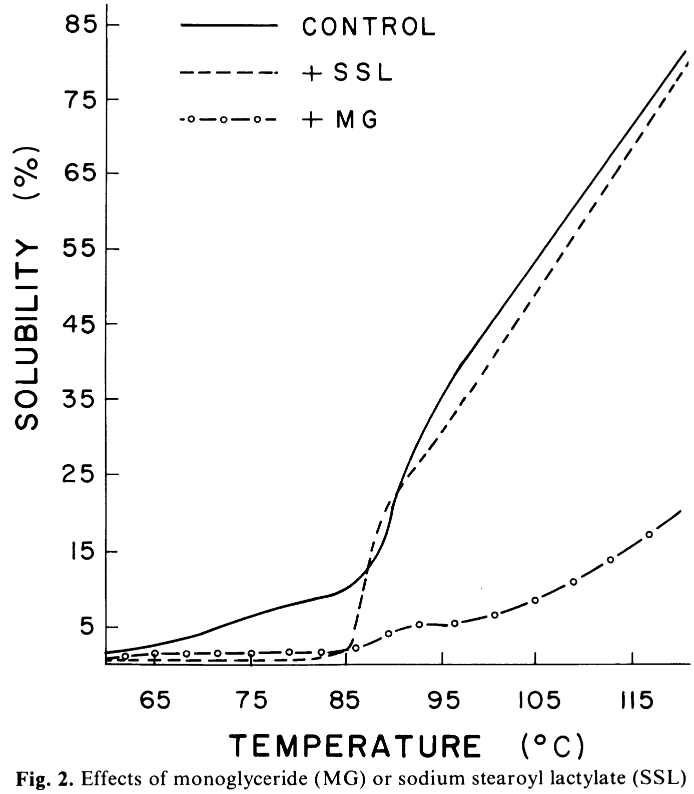

Fig. 2. Effects of monoglyceride (MG) or sodium stearoyl lactylate (SSL) on solubilization pattern of wheat starch.

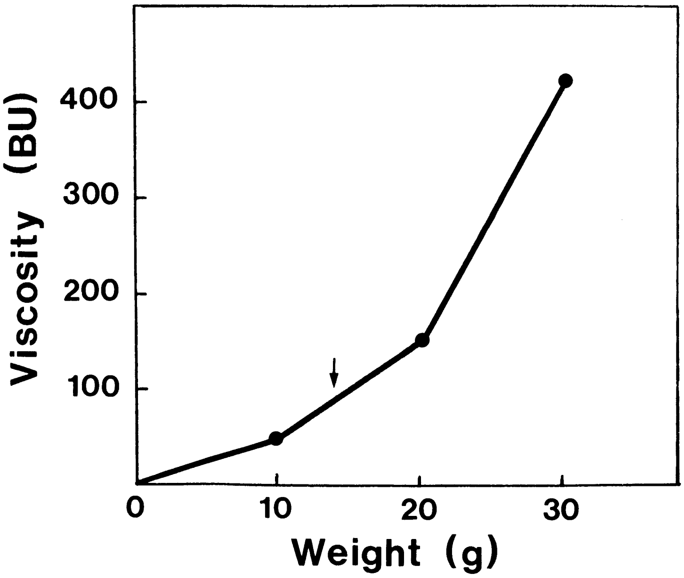

Fig. 3. Relationship between concentration of solubilized starch (g per 460 ml) and amylograph viscosity. Arrow shows the calculated amount of soluble starch (14 g) when 40 g of starch is heated in the amylograph.

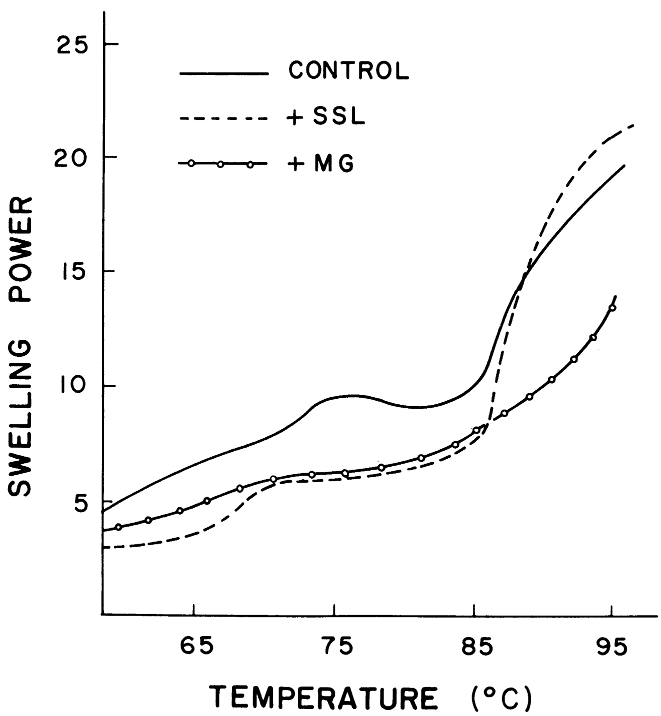

Fig. 4. Effects of monoglyceride (MG) or sodium stearoyl lactylate (SSL) on swelling patterns of wheat starch.

TABLE I
Water Absorbed by Starch During Heating in the Amylograph[a]

Pasting Temperature (°C)	Water Absorbed in Control (g)	MG[b] (g)	SSL[c] (g)
60	126.4	106	102
65	222	149	138
70	247	185	182
75	314	212	201
80	297	216	186
85	324	255	195
90	473	346	488
95	524	486	542

[a] Grams of water per 40 g of starch.
[b] Monoglyceride.
[c] Sodium stearoyl lactylate.

(Fig. 3), whereas 40 g of native starch cooked to 95°C gave a viscosity of 650 BU; thus, the swelling of starch granules or their remnants probably have an important effect on amylograph viscosity.

When starch is heated in water, the individual granules absorb water, and their swelling, therefore, indirectly measures the amount of water absorbed by the starch granules. By using swelling and solubility data (Figs. 2 and 4), we calculated the amount of water absorbed by the starch granules at various temperatures and with different treatments. The water absorbed was determined by measuring the difference between the weight of the wet sedimented paste and the weight of the dry starch minus the soluble starch (35%). Using those values, one can calculate the maximum water absorbed by the starch when heated in the amylograph (Table I).

Values were calculated from swelling and solubility data based on 4.5 g of dry starch weight in 180 ml of water (Leach et al 1959), as follows:

$$\text{Swelling power} = \frac{\text{Weight of sedimented paste} \times 100}{\text{Weight of sample (db)} - (100 - \text{percent soluble, db})}$$

$$\begin{array}{c}\text{Absorbed water}\\ \text{(g/4.5 g of starch)}\end{array} = \begin{array}{c}\text{Weight of}\\ \text{sedimented paste}\end{array} - \begin{array}{c}\text{(Dry weight}\\ \text{of starch} - \text{Weight}\\ \text{of solubles)}\end{array}$$

$$\begin{array}{c}\text{Maximum water}\\ \text{absorbed in amylograph}\end{array} = \frac{\begin{array}{c}\text{Absorbed water}\\ \text{(Leach method)}\end{array}}{\text{4.5 (g of dry starch)}} \times \begin{array}{c}\text{40 (starch weight in}\\ \text{amylograph)}\end{array}$$

At temperatures above 90°C, as shown in Table I, the theoretical water absorption exceeds the actual water available to the starch (460 ml); therefore, we cannot directly compare the solubility and swelling data obtained by the method of Leach et al (1959) with data obtained in the amylograph. Because the swelling and solubility data used in these calculations were obtained in a large excess of water, one would expect to obtain maximum swelling power and solubility. The more limited water condition in the amylograph procedure might lead one to expect less swelling and lower solubilities.

For many years, the increase in viscosity of a cooked-starch paste was thought to result from granules absorbing water as they swelled, thus increasing their chances of contacting each other (Collison 1968, Schoch 1965). Miller et al (1973) challenged that concept and presented data suggesting that the exudate was mainly responsible for the increased viscosity. Our data show that several factors are involved in controlling viscosity. Clearly, soluble starch increases viscosity, and the viscosity increases as a function of the soluble-starch concentration (Fig. 3). During starch gelatinization, starch-granule volume also increases; ie, the granules swell as more water is bound (Collison 1968). The bound water can no longer act as a solvent. Thus, as more water becomes bound, the concentration of soluble starch in the remaining free water increases, sharply increasing viscosities.

LITERATURE CITED

BEAN, M. M., and YAMAZAKI, W. T. 1978. Wheat starch gelatinization in sugar solutions. I. Sucrose: Microscopy and viscosity effects. Cereal Chem. 55:936.

COLLISON, R. 1968. Swelling and gelation of starch. Page 168 in: Starch and Its Derivates. J. A. Radley, ed. Chapman and Hall: London.

CROSSLAND, L. B., and FAVOR, H. H. 1948. Starch gelatinization studies. II. A method for showing the stages in swelling of starch during heating in the amylograph. Cereal Chem. 25:215.

DUBOIS, M., GILLES, K. S., HAMILTON, J. K., REBERS, P. A., and SMITH, F. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350.

GHIASI, K., HOSENEY, R. C., and VARRIANO-MARSTON, E. 1982a. Gelatinization of wheat starch. I. Excess water systems. Cereal Chem. 59:81.

GHIASI, K., VARRIANO-MARSTON, E., and HOSENEY, R. C. 1982b. Gelatinization of wheat starch. II. Starch surfactant interaction. Cereal

Chem. 59:86.
LEACH, H. W., McGOWEN, L. D., and SCHOCH, T. J. 1959. Structure of the starch granule. I. Swelling and solubility patterns of various starches. Cereal Chem. 36:534.
MILLER, B. S., DERBY, R. I., and TRIMBO, H. B. 1973. A pictorial explanation for the increase in viscosity of a heated wheat starch-water suspension. Cereal Chem. 50:271.
SCHOCH, T. J. 1965. Starch in bakery products. Bakers Dig. 39(2):48.
WOLF, M. J. 1964. Wheat starch isolation. Methods Carbohydr. Chem. 4:6.

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