Effect of Bread Ingredients on Starch-Gelatinization Properties as Measured by the Amylograph[1]

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ABSTRACT

The Brabender Amylograph was used to study the gelatinization properties of starch in the presence of ingredients commonly used in bread production. Effects of the addition of sugar (sucrose); salt (sodium chloride); nonfat dry skim milk; shortening; oxidizing agents; reducing agents; and a mold inhibitor, sodium propionate, on the pasting properties of starch at different concentrations were studied. The inclusion of sucrose during starch gelatinization resulted in an increase in peak height as the concentration of sugar was increased. Concomitantly, the initial temperature of pasting and peak temperature increased at high sucrose concentrations, while the set-back decreased. Initial temperature of pasting and peak height increased in the presence of sodium chloride up to the 4% level. Beyond this concentration of salt, no distinct peak was obtained. The addition of shortening decreased peak height slightly but increased the set-back. Concentrations of nonfat dry skim milk resulted in higher peak viscosities; however, an irregular type curve was produced. The addition of oxidizing agents such as potassium bromate ($KBrO_3$) or potassium iodate (KIO_3) at levels commonly used in bread did not affect pasting properties. At high concentrations the peak height increased in the presence of both oxidizing agents. However, with the $KBrO_3$ the set-back was sharply reduced, whereas it was not greatly affected with the KIO_3. Ascorbic acid had a similar effect to the $KBrO_3$ on the set-back property. No effect was observed on pasting properties of the starch with low levels of sodium bisulfite, but with higher concentrations the peak height was increased. The effect of the same ingredients on starch pasting properties also was studied utilizing the incorporation of carboxymethyl cellulose. In addition to the amylograph, the temperature of gelatinization of starch in the presence of the baking ingredients was measured by the Kofler microscope hot-stage technique, with loss of birefringence used as a criterion of starch gelatinization.

Several reports appear in the literature regarding the effect of different additives on the pasting properties of wheat starch. The effect of baking ingredients commonly used in bread production on starch pasting properties has not been fully examined. The effects of particular ingredients, however, including sucrose and sodium chloride (NaCl), have been looked into by a few workers.

As early as 1931, Woodruff and Nicoli (1) studied the effect of sucrose upon starch gels. These workers found that in the presence of 60% sugar, a viscous, syrupy mass resulted, but no gel. Hester et al. (2) reported that in the presence of sucrose the hydration of starch granules was decreased. Data in support of the above statement were the increase in temperature of the initial rise in paste viscosity and the fact that the maximum viscosity of the starch pastes was lower or not reached at 95°C. Campbell and Briant (3) studied the effects of citric acid and of sucrose on the properties of the pastes and gels of wheat starch. A slight increase in maximum hot-paste viscosity was obtained during gelatinization with concentrations of sugar up to 10 or 20%, but a decrease with higher concentrations

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was found by Bean and Osman (4). Hirai et al. (5) recently reported that wheat-starch pastes or wheat-starch-shortening pastes containing whey proteins, lactose, lactose-plus-proteins, or dried whole whey had higher viscosities than control pastes.

The effect of different salts on gelatinization properties of starch has been investigated by different workers, including Medcalf and Gilles (6). These workers found a significant increase in the peak height of wheat starch in the presence of NaCl. Ganz (7) also reported a marked increase in peak viscosity of starch with the inclusion of 3.5% NaCl.

The effect of fats and emulsifying agents on starch pasting properties also has been examined. Included here would be the work of Osman and Dix (8). These workers found that viscosity increased in a 6% corn-starch paste at a progressively lower temperature as fat was added.

The present study was undertaken to investigate the effect on starch pasting properties of a wide range of baking ingredients commonly used in bread production. The Brabender Amylograph was chosen for this purpose. Starch gelatinization as measured by such an instrument is quite different than the gelatinization that takes place during bread-baking. In one instance gelatinization of the starch is measured in a dilute slurry, whereas in baking, gelatinization takes place in a limited amount of water.

The information obtained in this study, therefore, is applicable only to the conditions specified—namely, gelatinization in a dilute slurry—and not to gelatinization in bread-baking. Future work based on the results of this study will be directed towards establishing the effect of the same ingredients on starch gelatinization in a bread-dough system.

MATERIALS AND METHODS

Starch Source

A commercial sample of wheat starch obtained from Hercules, Inc., Harbor Beach, Mich., was used throughout the study.

Baking Ingredients

The baking ingredients in this investigation included: sucrose; nonfat dry skim milk powder; liquid shortening (Crisco®); salt (NaCl); the oxidizing agents potassium bromate ($KBrO_3$), potassium iodate (KIO_3), and ascorbic acid; the reducing agent sodium bisulfite ($NaHSO_3$); and the mold inhibitor sodium propionate.

Starch Gelatinization Study

The Brabender Visco-amylograph was used to study the gelatinization properties of starch in the absence and presence of the different ingredients.

Also, the pasting properties were examined with the various ingredients using the incorporation of carboxymethyl cellulose (CMC). The CMC technique has been used previously to study starch-gelatinization properties (9).

Investigation of Starch-Gelatinization Properties without CMC

The starch pasting properties were examined using a starch concentration of 9% (dry basis, d.b.) in 450 ml. of distilled water as a control.

The sugar (sucrose), nonfat dry skim milk, shortening, salt (NaCl), and sodium propionate were ingredients commonly used in a commercial bakery. These were added on a percentage basis (weight per 100 ml. water). The sucrose, nonfat dry skim milk, NaCl, and sodium propionate were dissolved in 350 ml. distilled water. The starch was added to the above solution by agitation with a Waring Blendor at low speed for 1.5 min. The slurry was transferred quantitatively to the bowl of the amylograph, the Blendor jar rinsed with the remaining 100 ml. of distilled water, and this also transferred to the amylograph bowl. The shortening was melted first and then added by agitation with a Waring Blendor to 350 ml. of distilled water. The $KBrO_3$, KIO_3, $NaHSO_3$, and ascorbic acid were reagent-grade chemicals. They were added either as parts per million or as a molar concentration.

Starch suspensions with and without the different additives were heated uniformly from 25°C. to 95°C., held at 95°C. for 15 min., and then cooled under ambient conditions for 30 min. The temperature after this period was 68°C. The measurements obtained were pasting temperature, peak height, peak temperature, 15-min. height, and set-back. Definition of these terms was the same as has been reported previously (6), with the exception of set-back. In this instance, set-back was the difference in Brabender units (B.U.) between the 15-min. height and viscosity after cooling for 30 min. to 68°C.

Investigation of Starch-Gelatinization Properties with Incorporation of CMC

The same ingredients mentioned previously were utilized to study their effects on starch-gelatinization properties in the presence of CMC. The CMC-amylograph technique has been used to show the two steps of gelatinization characteristic of wheat starch (9). The principal reason for utilizing this technique also was to ascertain if the baking ingredients would affect the early stage of starch gelatinization or the steps in the gelatinization. Normal amylograms of most grain starches fail to show the above starch characteristics.

In this case, starch (20 g., d.b.) was suspended in 350 ml. distilled water, or in the solution containing the baking ingredients being studied, by means of a Waring Blendor. CMC (3.6 g.) was added with gentle stirring and then poured into the amylograph bowl. The Blendor was rinsed with 100 ml. of additional water. The amylograph was then operated as without the use of CMC.

Corrections were made for the use of the CMC by subtracting the values for a blank curve using only CMC from the CMC-starch curve. This served as the starch control curve. In the case of the addition of a particular bread ingredient, values for the CMC-bread ingredient curve were subtracted from the starch-CMC-bread ingredient curve to give the corrected starch curve.

Measurements obtained by the CMC-amylograph technique included pasting temperature, peak height, 15-min. height, and height after cooling for 30 min. under ambient temperature which resulted in a final temperature of 68°C.

Microscopic Examination of Starches

The Kofler hot stage was used to determine the gelatinization temperature of starch when suspended in water or in solutions containing the different baking ingredients. The procedure utilized has been described previously (10). Three temperatures were recorded. These were when 10, 50, and 98% of the granules, respectively, had lost their birefringence.

RESULTS AND DISCUSSION

Effect of Bread Ingredients on Starch-Gelatinization Properties: Sucrose

Table I shows the effect of different sucrose concentrations on starch pasting properties. The pasting temperature remained the same as the starch control until the sucrose concentration reached 16%. Beyond this level, there was an increase in the pasting temperature of the starch. Likewise, an increase in peak temperature at the higher sucrose concentrations was noted. There was a continual increase in peak height as the sucrose concentration was increased to 30%. Beyond this level the peak viscosity decreased, and with 40 or 50% sucrose, no definite peak was obtained. Also observable in Table I is the sharp reduction in the set-back when the sucrose concentration increased above 16%. The pasting curves obtained for the starch control and with the addition of four different sucrose concentrations are shown in Fig. 1.

The effect of sucrose on starch pasting properties with the CMC technique was also studied. In this instance, the gelatinization temperature remained essentially the same as the starch control (55°C.) until the sucrose concentration was increased beyond the 18% level. The peak temperature, likewise, increased as the sucrose concentration was raised. The progressive increase in peak height observed without the incorporation of CMC and increased sugar levels was not as evident utilizing the CMC technique. Values for peak height were higher than the control with the inclusion of sucrose, but varied somewhat.

Table II shows the effect of sucrose on gelatinization temperature by measurement of the loss of birefringence. Values are reported for the starch control and for the different sucrose concentrations when 10, 50, and 98% of the granules had lost their polarization crosses. The results in this table confirm the results obtained by the amylograph. Up to a sucrose concentration of 16%, there was little effect on the gelatinization temperature; however, beyond this level, the gelatinization temperature showed a more pronounced change. The data obtained indicate that sucrose, when present in concentrations greater than 16%, results in an

TABLE I. EFFECT OF SUCROSE ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
Sucrose					
2%	83.5	515	94.0	340	160
4%	83.5	535	95.0	360	165
8%	83.5	560	95.0	365	175
12%	83.5	610	95.0	370	170
16%	83.5	650	95.0 (1 min.)	450	150
20%	84.5	670	95.0 (2 min.)	500	90
25%	85.0	670	95.0 (2 min.)	540	40
30%	86.5	705	95.0 (2.5 min.)	600	−50
35%	88.0	690	95.0 (3 min.)	620	−80
40%	89.5	No peak	...	510	−90
50%	90.0	No peak	...	330	−45

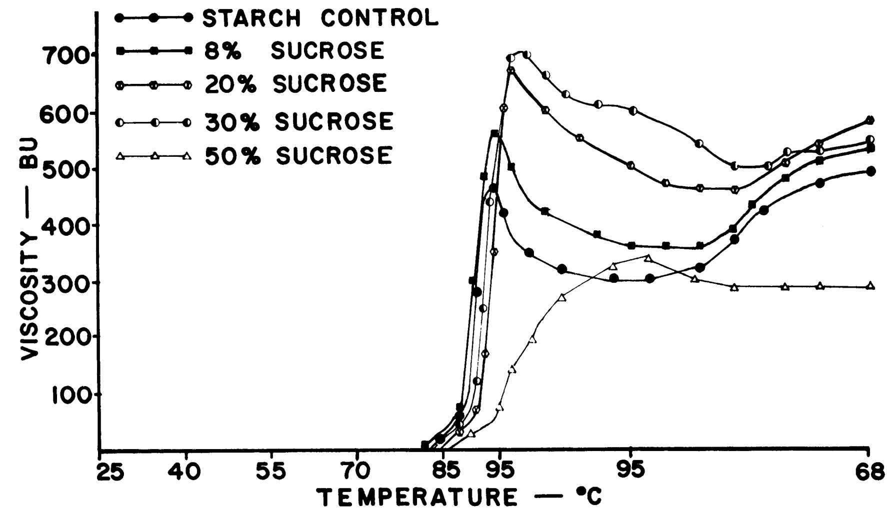


Fig. 1. Effect of sucrose on starch pasting properties.

TABLE II. EFFECT OF SUCROSE ON GELATINIZATION TEMPERATURE BY MEASUREMENT OF LOSS IN BIREFRINGENCE

	Percentage Loss in Polarization Crosses		
	10%	50%	98%
Starch			
(control)	54	57	60
Sucrose			
4%	54	57	60
8%	55	57	61
12%	56	59	61
16%	56	60	63
20%	60	62	65
24%	62	66	69
32%	63	67	70
40%	66	71	76
50%	70	73	77
60%	72	75	79
80%	77	80	84

inhibition of the hydration of the starch granules. The inhibition of hydration is indicated by the higher pasting temperature or gelatinization temperature and the higher peak temperature.

Data in Table II also indicate that the loss of birefringence corresponds to the pasting temperature obtained with the starch-CMC amylograph technique. As already mentioned, without the incorporation of CMC, the first stage in starch gelatinization is not always evident.

Salt (NaCl)

The effect of NaCl at concentrations between 1 and 4% on the pasting properties of starch is shown in Table III. A significant increase in peak height of the starch was observed as the NaCl concentration increased from 1 to 3.5%. Beyond 3.5%, no distinct peak was obtained, as shown in Fig. 2. The peak temperature also increased as the concentration of NaCl increased. At concentrations above 3%, the set-back decreased considerably over the control. These data would indicate that the NaCl causes the starch granule to remain intact for a longer period of time before fragmentation takes place. Figure 3 shows the starch-CMC control as well as the addition of 2 and 3% NaCl on the starch pasting properties. From this figure, it is evident that NaCl apparently has an effect on the CMC. Whereas without the incorporation of the CMC, the peak viscosity increased as the salt concentration increased up to 3.5%, with the CMC the peak viscosity of

TABLE III. EFFECT OF SALT (NaCl) ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
Salt					
1%	85.0	590	95.0	395	195
2%	85.0	665	95.0 (0.5 min.)	480	150
3%	88.0	720	95.0 (1.5 min.)	590	170
3.5%	88.0	720	95.0 (5 min.)	670	90
4%	88.0	No peak	...	600	−80

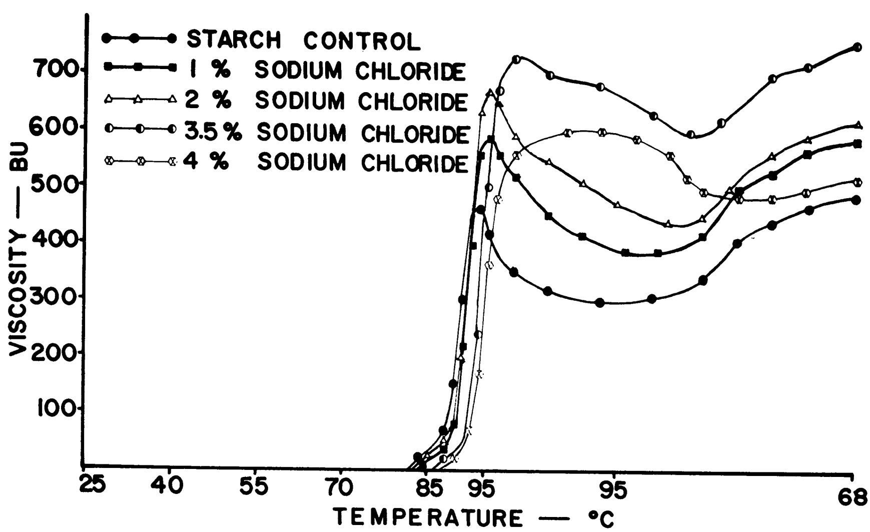


Fig. 2. Effect of NaCl on starch pasting properties.

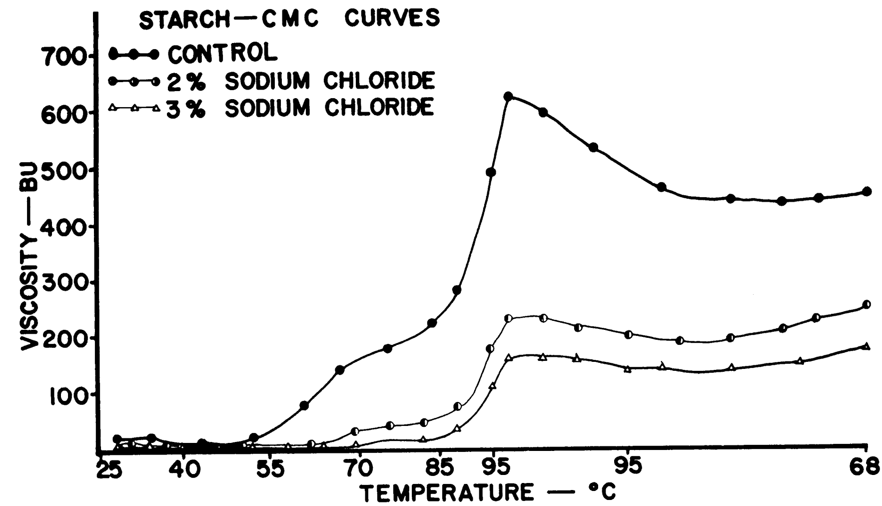


Fig. 3. Effect of NaCl on starch pasting properties utilizing CMC.

the starch in the presence of 2% salt was higher than in the presence of 3% salt. The gelatinization-temperature ranges for starch increased in the presence of salt as measured by loss of birefringence.

Nonfat Dry Skim Milk

The addition of nonfat dry skim milk at different levels to a starch slurry and its effect on pasting properties are shown in Table IV. It was very difficult to arrive at any definite conclusions on the effect of this ingredient owing to the irregular type of curve produced, in particular with milk concentrations above 2%. As observed in Table IV, with the presence of 2 or 4% milk during starch gelatinization, little difference in peak height took place. As the milk concentration was increased to 6%, the peak height increased, and even more so with 8%; however, with the latter concentration, the curve characteristics were very irregular. The pasting temperature appeared to decrease as the concentration of milk was increased; however, with loss of birefringence as a criterion of gelatinization temperature, this

TABLE IV. EFFECT OF NONFAT DRY SKIM MILK ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
Milk					
2%	83.5	480	94.0	400 (Irr. curve)	60
4%	82.0	480	92.5	380 (Irr. curve)	80
6%	80.5	590	94.5	500 (Irr. curve)	30
8%	Very irregular curve				

TABLE V. EFFECT OF SHORTENING ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
Shortening					
2%	83.5	440	94.5	295	205
4%	83.5	425	94.5	280	230
6%	83.5	430	94.5	290	260
8%	84.5	430	95.0	290	260
10%	85.0	440	95.0	320	300
12%	85.0	400	95.0	280	320
14%	86.5	No sharp peak	95.0	300	300
16%	86.5	No sharp peak	95.0	290	320

effect was not noted and, in general, the gelatinization temperature remained the same as that of the starch control for the same milk concentrations used in the amylograph.

Shortening

The results to starch-gelatinization properties of incorporating different levels of shortening are shown in Table V. The pasting temperature of starch increased slightly in the presence of shortening concentrations above 6%. The peak height or maximum viscosity remained essentially unchanged with the shortening addition and, if anything, a decrease was noted. With shortening levels of 14 and 16%, the peak on the amylogram was irregular. The addition of shortening during starch gelatinization did, however, appear to affect set-back. Set-back increased in the presence of shortening, and whereas the 15-min. height was essentially the same for the control without shortening and with the different levels of shortening, the set-back showed a progressive increase as the concentration of shortening was increased to 10%. Beyond this level, the set-back did not increase further. From the data, it would appear that the shortening is involved in maintaining the gel properties of the starch upon cooling.

Likewise, in the case of starch gelatinization utilizing the incorporation of CMC, the peak height after the 30-min. cooling period to 68°C. was higher with the inclusion of 2 or 4% shortening during starch gelatinization as compared to the control. With the CMC-starch procedure, effects of higher shortening concentrations on starch-gelatinization properties were not investigated.

Oxidizing Agents ($KBrO_3$, KIO_3, Ascorbic Acid)

$KBrO_3$ and KIO_3 are two of the common oxidizing agents used by bakers in bread production. KIO_3 is a much stronger and faster oxidizing agent than the bromate and has been used to a large extent in the continuous-type bread process. Ascorbic acid, another oxidizing agent, actually has a different mechanism depending on the type of bread production. In conventional baking it acts as an oxidizing agent, whereas in continuous baking its principal role is as a reducing agent.

The effects of these three ingredients on starch-gelatinization properties are shown in Tables VI, VII, and VIII.

TABLE VI. EFFECT OF $KBrO_3$ ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
$KBrO_3$					
10 p.p.m.	83.5	460	93.5	310	180
50 p.p.m.	83.5	460	93.5	310	180
100 p.p.m.	83.5	480	93.5	310	180
0.05M	83.5	650	95.0	420	50
0.10M	83.5	660	95.0	340	−50
0.20M	84.0	630	95.0	190	−80
0.25M	83.5	650	95.0	160	−80
0.40M	82.0	710	95.0	70	−30

TABLE VII. EFFECT OF KIO_3 ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
KIO_3					
10 p.p.m.	83.5	455	93.5	290	185
50 p.p.m.	83.5	470	93.5	300	205
100 p.p.m.	83.5	465	93.5	300	190
0.05M	85.0	640	95.0	450	200
0.10M	84.0	670	95.0 (0.5 min.)	460	210
0.25M	85.0	760	95.0	490	200
0.40M	84.0	910	95.0	630	170

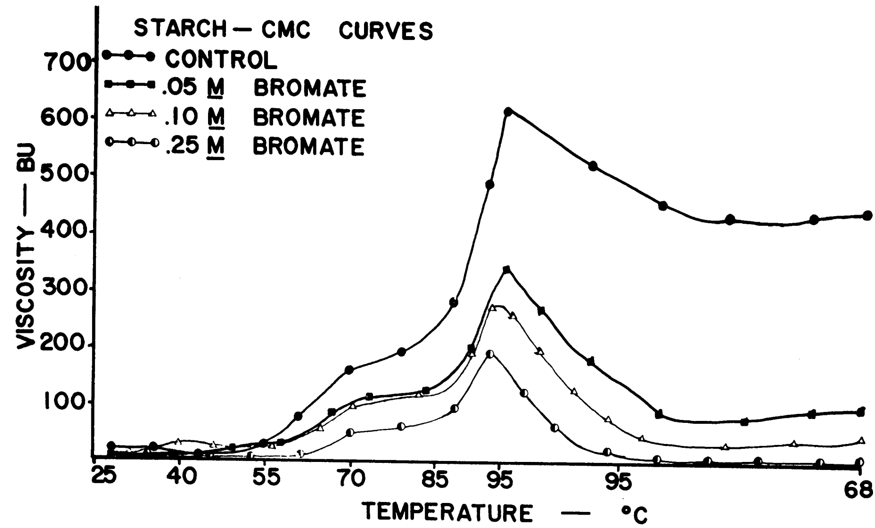
TABLE VIII. EFFECT OF ASCORBIC ACID ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
Ascorbic acid					
0.001M	83.5	550	95.0	300	170
0.002M	83.5	570	94.0	240	150
0.005M	83.5	570	94.0	170	90
0.010M	82.5	550	93.5	110	60
0.050M	82.0	450	91.0	30	10
0.0625M	80.5	455	90.0	20	10
0.1000M	80.5	410	89.5	10	0

No appreciable differences were noted in the pasting properties of the starch in the presence of $KBrO_3$ or KIO_3 at the 10-, 50-, or 100-p.p.m. levels.

However, starch-gelatinization properties in the presence of 0.05M to 0.40M solutions of $KBrO_3$ or KIO_3 did show differences over the control. In the case of the $KBrO_3$, the most pronounced differences were the increase in peak height and the reduced set-back. Likewise, in the case of the presence of KIO_3, the peak height or viscosity increased; and at the 0.40M level, the peak height was 200 B.U. higher with KIO_3 than with $KBrO_3$. The interesting difference between the bromate and iodate was the fact that with the KIO_3 there was not the sharp decrease in set-back that was noted with the $KBrO_3$.

The use of the CMC-amylograph technique utilizing various molar concentrations of KIO_3 or $KBrO_3$ also was investigated. Some of the results are shown in Figs. 4 and 5. With both $KBrO_3$ and KIO_3 there was a reduction in the peak height, which was opposite to the results obtained without incorporation of



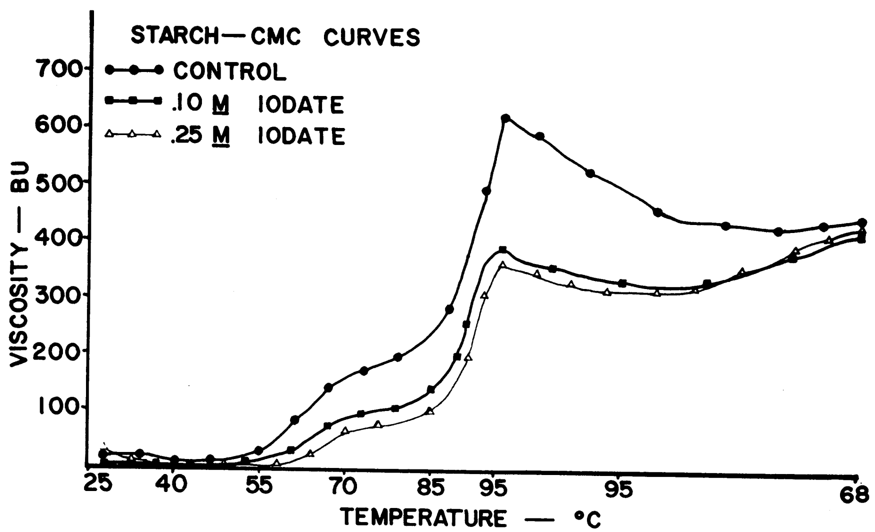


Fig. 4 (top). Effect of $KBrO_3$ on starch pasting properties utilizing CMC.
Fig. 5 (bottom). Effect of KIO_3 on starch pasting properties utilizing CMC.

CMC. This reduction increased as the concentration increased. With the addition of $KBrO_3$ there was a sharp breakdown after it reached its peak viscosity. However, with addition of KIO_3, peak height after the cooling period was similar to that of the control. This same observation was noted with amylograms without incorporation of CMC (Tables VI and VII).

The effects of ascorbic acid on starch pasting properties shown in Table VIII indicate several interesting results. As the amount of ascorbic acid present during the starch gelatinization increased, the pasting temperature decreased. This result was confirmed by measuring loss of birefringence with the Kofler hot-stage method. This technique revealed that, whereas in the starch control 10% of the granules had lost their birefringence at 54°C. and 98% at 60°C., in the presence of ascorbic acid these temperatures decreased. At a 0.40M concentration of ascorbic acid, 10% of the granules had lost their birefringence at 46°C. and 98% at 57°C.

Peak height also increased as the concentration of ascorbic acid reached a certain level, after which the peak height showed a decrease. The peak temperature also decreased as the concentration of ascorbic acid was increased. These results would indicate that in the presence of ascorbic acid the granules are able to swell more readily. Also, as was the case with the $KBrO_3$, ascorbic acid caused a reduction in the set-back.

Sodium Bisulfite

The effects of $NaHSO_3$ on starch-gelatinization properties are shown in Table IX. This material has been used in bread production as a reducing agent. With the inclusion of 10 to 100 p.p.m., no appreciable differences in starch gelatinization over that of the control were noted. However, as the concentration was increased, the peak height also increased. The set-back increased slightly over the control with the higher concentrations.

Sodium Propionate

Sodium propionate is used in bread production to retard mold growth. The effects of this material on starch-gelatinization properties are shown in Table X. The main points to note are the increase in peak height and the decrease in set-back with increasing levels of sodium propionate.

This study has attempted to show some of the effects that ingredients commonly used in bread production have on starch-gelatinization properties using a

TABLE IX. EFFECT OF $NaHSO_3$ ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
$NaHSO_3$					
10 p.p.m.	83.5	455	92.5	290	170
50 p.p.m.	83.5	460	92.5	295	185
100 p.p.m.	83.5	460	92.5	295	155
0.05M	85.0	670	95.0 (0.5 min.)	380	230
0.10M	85.0	680	95.0 (0.5 min.)	380	200
0.25M	85.0	760	95.0 (0.5 min.)	470	180
0.40M	83.5	800	95.0 (1 min.)	510	210

TABLE X. EFFECT OF SODIUM PROPIONATE ON STARCH PASTING PROPERTIES

Addition	Pasting Temperature °C.	Peak Height B.U.	Peak Temperature °C.	15-Min. Height B.U.	Set-Back B.U.
Starch (control)	83.5	460	94.5	310	170
Sodium propionate					
1%	83.5	470	95.0	300	100
3%	83.5	540	95.0	380	60
7%	83.5	630	95.0 (1 min.)	380	40

model type system. The concentrations examined for many of the ingredients would far exceed those used in producing bread. It was felt, however, that useful information would be obtained by examining a wide range of concentrations for each ingredient.

As already mentioned in the introduction, it is not possible to transfer the results obtained in this investigation to what happens during starch gelatinization in the bread-baking process itself. Nevertheless, this study did open the possibilities of several different avenues for future research.

In addition, this study was designed primarily to ascertain the effect of the different baking ingredients on starch-gelatinization properties. No attempts were made to discuss possible mechanisms for some of the effects observed with the different ingredients.

Acknowledgment

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