Gelatinization of Starch during Bread-Baking[1]

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ABSTRACT

The amylograph was used to study the pasting characteristics of starch in baked bread. A slurry was prepared by dispersing the crumb in distilled water with a Waring Blendor. Crumb amylograms were characterized by a positive initial viscosity and one or, under some conditions, two viscosity peaks. The appearance of a peak in the amylogram was taken as evidence that the starch was only partly gelatinized during baking. The degree of gelatinization depends mainly on moisture but also on temperature during baking. Within a loaf, the starch in outer layers of crumb was gelatinized to a greater degree than the starch in the center. Peak viscosity (PV) of crumb decreased continuously during post-baking storage of bread and was also decreased by additions of malt to the bread formula. The extent of starch damage in flour was important in relation to the condition of starch in the baked loaf. Shortening showed little effect in fresh crumb but delayed the decrease in PV with storage. Glyceryl monostearate produced an increase in gelatinization temperature, increased PV, and slowed down the drop in PV with storage. On the basis of changes in hydration capacity of crumb, the effects investigated can be divided into two categories: those that decrease PV by increasing the extent of gelatinization (e.g., baking absorption) and thereby increase hydration capacity, and those that decrease PV by degrading the starch (e.g., malt) and thereby decrease the hydration capacity.

The role of starch in bread-baking has been one of the major areas of investigation for cereal chemists for many years. Studies of the properties of gelatinized starch in bread crumb have been one approach to this problem. Sandstedt *et al.* (1) examined microscopically the state of starch granules in crumb, and reported that the granules retain some identity and are separated from each other by a continuous protein phase. They indicated that this separation of the granules is an important factor in formation of the fine grain of bread. Attempts to improve crumb grain by modifying the gelatinization characteristics of starch have been made by several workers. Rubenthaler *et al.* (2) examined the effect of various alpha-amylases on loaf properties. Miller and Trimbo (3) investigated the relation of gelatinization temperature and hydration of starch to the quality of cake. Ulmann (4) examined the effect of baking on the size of starch molecules by chromatography on alumina columns. Several additives which modify the pasting characteristics of starch have been investigated for their improving effect on the grain (5,6,7) of bread crumb.

Starch also plays an important role in the staling of bread. The extent of gelatinization is particularly important because of its role in determining the distribution of moisture in the baked loaf. Numerous papers have been published on this problem. In these reports, several different methods have been used for estimating or characterizing the properties of gelatinized starch. For example, X-ray diffraction (8,9,10), swelling capacity (11), content of soluble material (11), and rate and extent of beta-amylolysis (12,13) have

[1]Joint contribution of the Board of Grain Commissioners for Canada, Grain Research Laboratory, Winnipeg 2, Manitoba (Paper No. 270), and the Food Research Institute, Tokyo, Japan.
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all been used to estimate the extent of gelatinization during baking and post-baking retrogradation.

From the foregoing brief summary, it is apparent that starch plays a major role in the physical properties of freshly baked bread and also in the changes that occur after baking. Major questions that have not been answered adequately relate to the extent of starch gelatinization during baking and the factors that control this change. Results of a study designed to answer these questions are reported in this paper.

MATERIALS AND METHODS

A straight-grade flour milled from Canadian hard red spring wheat on the experimental Buhler mill was used. Its ash content was 0.44% and protein 13.5%. It had no treatment or additives.

Except where noted otherwise, all bread was baked by the GRL Remix method (14) with 100 g. flour.

A number of procedures for preparing a slurry of bread crumb for the amylograph test were examined; these are discussed in a later section. The method finally selected for this study is as follows: a weight of crumb equivalent to 60 g. flour (14% m.b.) is soaked in 300 ml. of distilled water at room temperature for 1 hr. and thereafter dispersed in a Waring Blendor (15 sec. at low and 60 sec. at high speed) to form a smooth slurry. The slurry is transferred to the amylograph bowl and a further 150 ml. of distilled water is added. The amylogram is then determined, with the 350 cm.-g. cartridge and normal heating cycle.

Hydration capacity, used to characterize some samples, was determined by the following procedure: 36 g. of slurry prepared as described above was held for 30 min. at 22°C. and then centrifuged for 10 min. at 1,000 × *g*. The supernatant layer was decanted and drained by holding the centrifuge tube in an inverted position for 5 min. Excess water was wiped from the walls of the tube, and the tube, with the hydrated crumb, was weighed. Hydration capacity is defined here as the uptake of water per g. of dry solids. The supernatant was used for determining the amount removed as solubles (required in calculating hydration capacity) and Blue Value with iodine. Blue Value, which indicates the amount of soluble starch, was expressed as absorbance at 660 mμ of 2 ml. supernatant extract in 100 ml. of 0.004% iodine solution.

RESULTS AND DISCUSSION

Procedures for Preparation of Crumb Slurries

Since swollen or partly gelatinized starch granules are readily broken by mechanical action, it was necessary to examine the effect of various procedures used for preparing the slurry from bread crumb on the amylogram. Figure 1 shows the effect of 30- and 90-sec. dispersing times at high speed in the Waring Blendor, after initial blending for 15 sec. at low speed. The crumb from fresh bread showed slightly higher initial viscosity for the shorter dispersing time; 1-day-old crumb had the same initial viscosity for both dispersing times. Longer dispersing time produced a slightly higher peak viscosity in fresh and 1-day crumb. Table I gives the hydration capacities and the Blue Values as a function of dispersing time for the two types of crumb (Fig. 1). Longer dispersion times produced slightly higher hydration capacities. For all subsequent experiments, 60-sec. dispersion time was adopted.

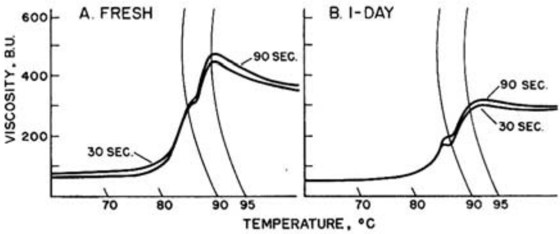


Fig. 1. Effect of dispersion time on crumb amylograms for fresh and 1-day-old bread.

TABLE I

EFFECT OF DISPERSING TIME ON PROPERTIES OF CRUMB SLURRIES

Fresh Crumb			1-Day Crumb		
Dispersion Time	Hydration Capacity	Blue Value	Dispersion Time	Hydration Capacity	Blue Value
sec.	%		*sec.*	%	
30	355	0.254	30	240	0.116
60	360	0.260	60	246	0.122
90	358	0.264	90	253	0.127

The reproducibility of the adopted procedure was examined; crumb from two loaves from each of three replicate bakes was used. Over-all replicability of ± 15 B.U. at a peak viscosity of 330 B.U. was obtained and was considered satisfactory.

Shape of the Crumb Amylogram

Amylograms for crumb slurries have two characteristics that are different from those of flour and starch amylograms. First, the crumb slurry shows a measurable initial viscosity at room temperature. Second, a minor, additional peak, is observed that is not normally present in flour or starch amylograms. This minor peak appears at a lower temperature than the major peak, and is particularly prominent when the over-all increase in viscosity is relatively low.

It is assumed that the difference between the initial viscosity and the major peak viscosity is inversely related to the degree of gelatinization during baking. The early portion of the amylograms (25°–60°C.), although recorded in each test, is not shown in any of the figures. Initial viscosity therefore refers to viscosity at 60°C. The initial and major peak viscosities of crumb amylograms will be considered in examining the effects of various factors related to breadmaking; the minor peak will not be considered.

Effect of Bread Storage Conditions

Storage of bread in sealed polyethylene bags (to prevent moisture loss) produces significant changes in the crumb amylogram. Both initial and peak viscosities decrease progressively with longer storage time (Fig. 2), and this change is more extensive at 4° than at 22°C. These observations suggest that it might be possible to use the amylograph in measuring the extent of staling.

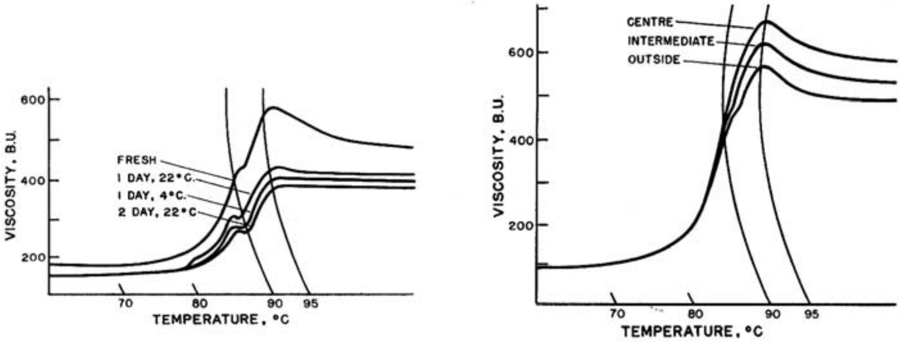


Fig. 2 (left). Effect of storage on amylograms of crumb.

Fig. 3 (right). Amylograms for crumb from various parts of the loaf.

Effect of Position in the Loaf

The outside of the loaf of bread is subjected to higher temperature than the interior, and this could lead to a gradient in the degree of starch gelatinization within a loaf. This in turn could affect the distribution of moisture. To examine this factor experimentally, the crumb of 1-lb. loaves was separated into three parts: the outside layer, representing the 1-cm. layer immediately beneath the crust; the intermediate layer, representing the next 1-cm. layer; and the center portion. Figure 3 shows crumb amylograms for these three portions of the loaf. Peak viscosity was highest for the center portion and lowest for the outside layer. This suggests that the starch in the outer parts of the loaf is gelatinized to a greater extent than in the inner parts. Hydration capacities for the outside, intermediate, and center portions were 378, 374, and 365 respectively, indicating the same trend in the degree of gelatinization as in the amylogram. Peak viscosity decreased on storage, but the relative positions of each of the three samples were maintained (results not shown).

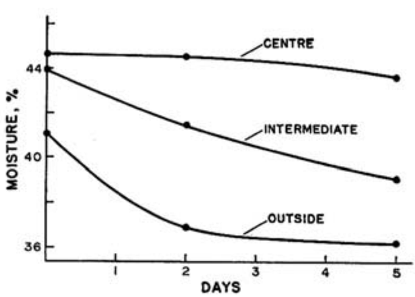
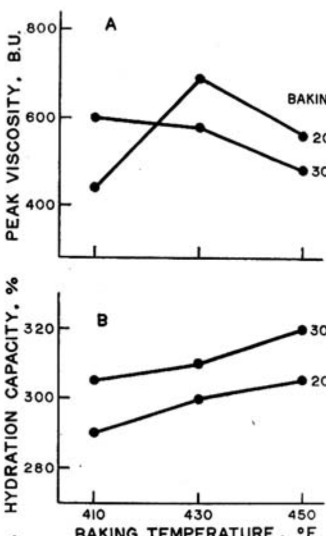


Fig. 4. Effect of storage time on moisture content of crumb in three parts of the loaf.

The moisture content of the center part was found to be significantly higher than that of the outside part (Fig. 4). Furthermore, during storage in moisture-tight bags this difference increased, indicating a transfer of moisture from the outside and intermediate portion to the crust. The progressive decrease in peak viscosity with storage was essentially the same for the three parts of the loaf. Accordingly, it would seem that the postbaking movement of moisture is not an important factor in the observed changes in the pasting characteristics. Differences in the extent of gelatinization within a single loaf must be due to differences in temperature during baking for the three portions examined.

Effect of Baking Time and Temperature

Bread was baked at three temperatures, 410°, 430°, and 450°F., and two baking times, 20 and 30 min. The trend, with one exception, was for the peak viscosity to decrease with longer baking time and higher temperature (Fig. 5, A). The exception is the 20-min. bake at 410°F., which gave a lower peak viscosity than the 30-min. bake at the same temperature. It is quite possible that a 20-min. baking period at the low temperature is not sufficient to inactivate the malt amylases which are included in the bread formula and which would be active in the amylograph test. The hydration capacity of the crumb increased with time and temperature (Fig. 5, B). With the exception already noted, results of Fig. 5, A, indicate that the extent of starch gelatinization is greater with baking time and temperature. As expected, hydration capacity also follows this trend.



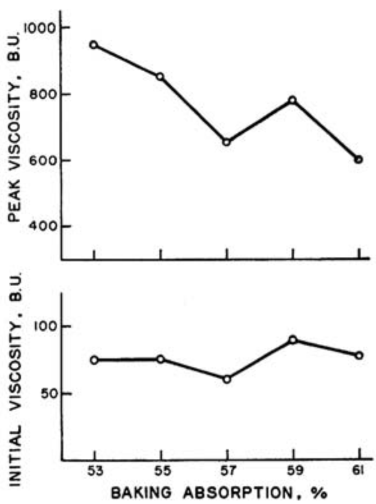


Fig. 5 (left). Effect of baking temperature and baking time on peak viscosity and hydration capacity of the crumb.

Fig. 6 (right). Effect of baking absorption on peak and initial viscosities of fresh crumb.

Effect of Baking Absorption

The effect of baking absorption on the peak and the initial viscosities for fresh crumb was examined; five absorption levels were used.

The initial viscosity increases slightly, and peak viscosity decreases, with increasing absorption (Fig. 6). From this it appears that the extent of starch gelatinization during baking increases in direct relation to moisture content of the dough, over this absorption range.

Table II gives moisture contents and hydration capacities of fresh crumb at the five levels. The data on hydration capacity confirm that gelatinization increases with increasing absorption.

TABLE II
EFFECT OF BAKING ABSORPTION ON CRUMB MOISTURE AND HYDRATION CAPACITY OF FRESH CRUMB

BAKING ABSORPTION	CRUMB MOISTURE	HYDRATION CAPACITY
%	%	%
53	37.5	317
55	39.0	330
57	39.4	325
59	40.4	340
61	40.6	345

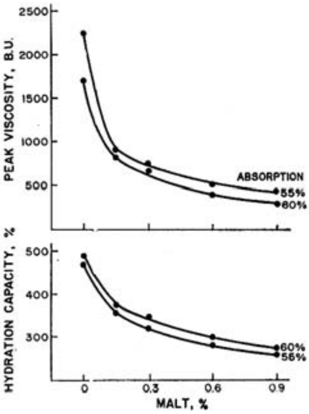
Effect of Malt

The effect of adding malt syrup to the baking formula, on the crumb amylogram, was examined at two baking absorptions. Additions of malt were made at three levels, 0.3, 0.6, and 0.9% (0.3% is normal). All levels produced a marked decrease in initial viscosity (not shown), peak viscosity, and hydration capacity (Fig. 7.) In the presence of higher-than-normal levels of malt, the change in hydration capacity follows the change in peak viscosity, whereas at normal malt levels, hydration capacity of bread crumb is inversely related to peak viscosity (see Fig. 5 and Table II). At 60% absorption, the peak viscosity was lower and hydration capacity was higher than at 55% absorption for all levels of malt addition; however, the differences were not large.

Effect of Starch Damage

Since damaged starch is readily attacked by amylases, it would be expected that the extent of damage would have an effect on the gelatinization of the starch during baking. This was examined to a limited extent by comparing the results for a normal flour with those for a flour in which the degree of starch damage was increased by milling with reduced roll clearance. The diastatic activity (mg. maltose) and gassing power (mm.) values were 191 and 279, and 345 and 455, for the control and damaged flours respectively. For this experiment the bread was baked with 0, 0.1, and 0.3% malt syrup.

Amylograms for the crumb from the flour with high starch damage had lower initial and peak viscosities (Table III) when there was no added malt. At the highest malt level used (0.3%), the crumb amylograms were essentially the same, irrespective of the level of damaged starch.



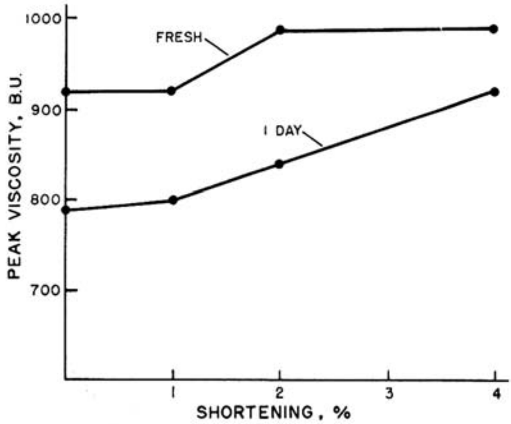


Fig. 7 (left). Effect of malt at two absorption levels on peak viscosity and hydration capacity of crumb.

Fig. 8 (right). Effect of shortening on peak viscosity in fresh and 1-day-old crumb.

TABLE III
EFFECT OF STARCH DAMAGE OF FLOUR ON AMYLOGRAMS OF CRUMB

MALT	INITIAL VISCOSITY		PEAK VISCOSITY	
	Control	Starch Damage	Control	Starch Damage
%	*B.U.*	*B.U.*	*B.U.*	*B.U.*
0	230	130	1,860	1,560
0.1	110	95	940	820
0.3	105	80	465	430

Effect of Shortening and Glyceryl Monostearate

Crumb amylograms were obtained for breads made with 1, 2, and 4% of shortening. The effect of shortening on amylograms of fresh bread crumb was quite small; only a slight increase in peak viscosity with increasing shortening level was observed. However, this difference was more pronounced in bread 1 day old (Fig. 8). It appears that shortening does not affect the gelatinization of the starch during baking but retards the changes that occur during storage.

Glyceryl monostearate (GMS) is used in the baking industry as a bread softener; its effect on the amylograph properties of starch is to raise the gelatinization temperature (15).

Figure 9, A, shows the effect of addition of 0.3% (flour basis) of GMS to the crumb slurry. The effect shown is analogous to the effect of GMS on starch slurries; gelatinization temperature is raised by 3° to 4°C., but peak viscosity is not affected. If GMS is included in the bread formula, its effect is quite different (Fig. 9, B). Again gelatinization is delayed, but peak viscosity increases markedly. This increase in peak viscosity can result from two related phenomena: first is the direct effect, whereby the delay in gelatini-

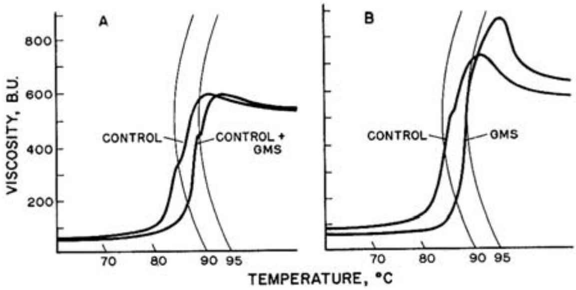


Fig. 9. Effect of 0.3% glyceryl monostearate (GMS) on crumb amylograms: A, added to crumb slurry; B, added to bread formula.

zation temperature decreases the extent of starch gelatinization during baking; and second is the indirect effect, whereby degradation of the starch by amylolytic enzymes is decreased because of greater inactivation of enzymes prior to formation of their substrate (gelatinized starch). Since the hydration capacity of the fresh bread crumb is higher for the control than that for the GMS crumb (see Fig. 10), the direct effect probably predominates under the conditions used in the present study.

The effect of GMS in bread during storage can best be demonstrated by the change in peak amylograph viscosity of the crumb (Fig. 10). As already noted, peak viscosity for crumb decreases with storage time. Figure 10 shows that this decrease is slower in bread which contains GMS. Results for bread containing 2% shortening are parallel to those for bread without shortening. It appears that changes in hydration capacity or peak amylograph viscosity might be directly related to staling; however, further work is necessary to confirm this relationship.

The effect of GMS can also be demonstrated by the change in hydration capacity of crumb during storage. In 3 days, hydration capacity decreases by 160 percentage units for the control and 125 percentage units for the crumb containing 0.3% GMS. Similar results were obtained for crumb with 2% shortening.

GENERAL DISCUSSION

The amylograph was used to study the effect of a number of pertinent factors on the degree of starch gelatinization during the baking process. In some experiments, hydration capacity was used as a secondary index of changes in the starch. It appears that various degrees of starch gelatinization can be obtained during baking. This, in turn, can affect progressive changes in crumb properties as the bread ages.

The main factors that control the degree of gelatinization are baking absorption, temperature, and time. Higher baking absorption, higher baking temperature, and longer baking time each produce more extensive gelatinization. These conclusions are in general agreement with known facts. Other factors and ingredients that affect the starch in dough also affect the degree of gelatinization during baking. Among these are physical damage to starch granules, and the presence of malt, shortening, and monoglycerides in the dough formula.

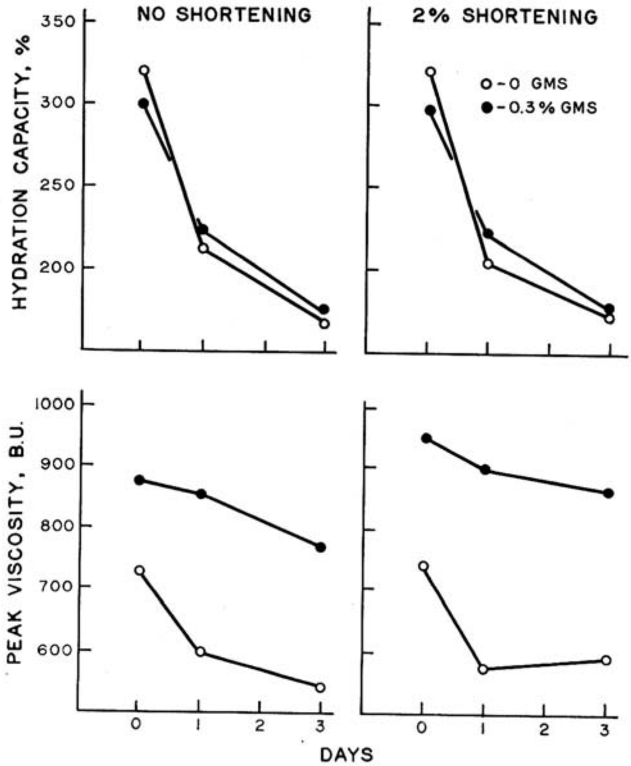


Fig. 10. Effect of storage on hydration capacity and peak viscosity of crumb containing 0 and 0.3% GMS, and 0 and 2% shortening.

Amylograms of crumb slurries show that the changes that occur during storage of bread are reflected in the pasting characteristics of the starch in the crumb. Peak viscosity decreases with storage time, but this change is retarded by the so-called antistaling agents (e.g., shortening and GMS).

More specifically, the results from this study suggest some interesting relations between starch gelatinization in the crumb, its digestion by amylases, its hydration capacity, and the amylogram characteristics. In general, hydration capacity increases with the degree of thermal gelatinization. This effect is analogous to that produced by physical damage of starch granules. The amount of moisture present in dough under normal baking conditions seems to be the main limiting factor in the gelatinization process. Accordingly, an increase in absorption produces an increase in gelatinization. However, if the gelatinization occurs in the presence of large amounts of amylolytic enzymes, then degradation of the gelatinized starch will occur. This leads to a decrease in both the amylograph peak viscosity and the hydration capacity. On the other hand, a decrease in crumb peak viscosity due to more extensive gelatinization in the absence of amylases produces an increase in hydration capacity. This is borne out by the results summarized in Fig. 11. Here the hydration capacity is plotted against amylogram peak viscosity.

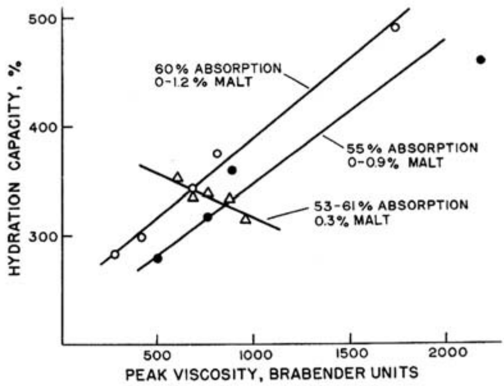


Fig. 11. Relation between hydration capacity and amylogram peak viscosity of crumb.

When the main factor controlling the crumb peak viscosity is the amylase activity in the dough (open and closed circles) the hydration capacity varies directly with peak viscosity. On the other hand, when the peak viscosity depends primarily on the degree of starch gelatinization (as obtained, for example, by varying the absorption), the hydration capacity varies inversely with peak viscosity (triangles). Under practical conditions, both mechanisms probably contribute to the final crumb amylogram, and this must be kept in mind in using the technique discussed in this paper.

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[Received May 10, 1967. Accepted March 1, 1968]