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Properties of Starch as Related to the Characteristics of Starch-Structured Breads

Marie Rodgers Walt and Andrea C. Mackey

ABSTRACT

Starch-structured breads were prepared with five starches—corn, wheat, potato, arrowroot, and waxy maize—used as granular starch with and without addition of 5 percent freshly prepared or retrograded pastes. Highest average scores were for breads made with wheat starch containing retrograded paste and potato starch containing fresh paste. Analysis of variance and correlation coefficients were calculated for the starch properties (amylose content, swelling capacity, and viscosity) and bread characteristics (shape of loaf, grain, chewiness, springiness, and compressibility). The behavior of the various starches differed for all characteristics studied. The differences due to starch were significant at the 1 percent level, and differences due to treatment were significant at the 5 percent level for viscosity at 95° C of the granular and retrograded starch pastes. Bread characteristics were different due to the kind of starch used and the treatment. This work is especially important for people who have food allergies, or who cannot absorb or properly metabolize gluten of wheat flour.

Some work has been reported on starch-structured breads, but no studies have been made which attempt to relate the characteristics of such breads to the chemical composition of the starch or to the performance of the starch when heated in water. Some of these relationships were investigated in this study.

Starch has been found to be an indispensable component of bread structure. Rotsch (as cited by Herz, 1965) made a protein-free bread with good grain and texture from starch and carbohydrate adhesives. Sandstedt (1961) demonstrated the essentiality of starch rather than gluten in bread structure by baking loaves made with 12 percent wheat gluten and 88 percent starch or glass beads. The loaves made with the starches were fairly normal. The differences in gas retention of the starch-gluten loaves was dependent on the type of starch, not on the gluten. When glass beads were substituted for the starch, the exterior appeared normal but the interior exhibited ruptured and collapsed cells. The cell structure developed in fermentation was lost during baking. Both of these authors pointed out that this was probably due to the fact that water was not removed from the gluten, as no adjacent starch granules were present for gelatinization.

These studies suggested the possibility of making gluten-free breads. According to Kim and DeRuiter (1968), a stable starch-water suspension to be used as a bread dough lacks coherence and therefore is unable to effectively retain gas. The gas escapes early or is trapped in irregular cells. Jongh (1961) prepared a wheat starch dough from wheat starch and water in normal bread dough proportions, plus sodium chloride, yeast, and sugar. The dough had a more fluid character than wheat flour doughs. The baked bread had a coarse and irregular structure with thick cell walls. Photomicrographs revealed that the starch-structured bread crumb had cell walls in which starch granules completely adhered to each other on all sides during baking, thus accounting for the extreme hardness of the crumb upon cooling.

Glyceryl monostearate (GMS) was found to be one of the most satisfactory emulsifiers for improving starch bread characteristics, both by Jongh (1961) and Kim and DeRuiter (1968). Emulsifiers increase resiliency and smoothness of the crumb, decrease the firmness, and restrict the swelling of the starch. In addition, they regulate the moisture distribution. Coating the granules with GMS should decrease the contact between them. Microscopic examination of the cell walls in starch bread made with increasing amounts of GMS showed a decreased amount of contact between starch granules, producing a finer crumb structure (Jongh, 1961).

EXPERIMENTAL PROCEDURE

Five commercially available starches were selected to represent grain starches, both regular and waxy, and tuber and root starches. They were corn, waxy maize, wheat, potato, and arrowroot starch.

The percentage of amylose in each starch was determined, and the performance characteristics of the starches were tested using raw starch or a retrograded starch paste as starting material. The performance tests were (1) swelling capacity of the raw starch and the retrograded starch paste, and (2) the apparent viscosity of the starch suspension and of the retrograded starch paste during heating to 96° C.

In addition, formulas were developed for bread-like products in which starch was responsible for the structure. The five starches, used as granular starch alone, as the freshly prepared 5 percent paste plus granular starch, or as the retrograded 5 percent paste plus granular starch, were made into starch-structured breads.

Retrogradation of the starch

Retrogradation of the starch paste was always induced in the same way. The starch was weighed and distilled water added. The suspension was stirred while heating until it began to boil. The starch paste was removed from the heat, cooled, and placed under refrigeration at 4° C for two days, then frozen at –20° C until needed. The retrograded starch was thawed overnight before being used.

Tests on the Starches

Swelling capacity

Portions of starch (0.25 gram) plus 40 ml of distilled water were placed in 50-ml centrifuge tubes. One of the tubes remained at room temperature, and the others were heated while stirring in a boiling water bath to 65°, 75°, 85°, and 95° C. The tubes were immediately centrifuged at 4500 rpm for 10 minutes. The supernatant liquid was removed with an aspirator and the weight of the remaining paste was determined. The swelling capacity of the starch at each temperature was expressed as grams of swollen starch per gram of dry starch. One-gram aliquots of the centrifuged pastes were dried under 10 inches of vacuum at 50° C for 12 hours and then weighed. The procedure was repeated with retrograded starch pastes.

Apparent viscosity upon heating

The Brabender VISCO-amylo-GRAPH[1] was used to continuously plot the changes in apparent viscosity of the starch versus the time and temperature

[1] C. W. Brabender Instruments, Inc., South Hackensack, New Jersey.

during the pasting procedure. The concentration of the suspension necessary to obtain a satisfactory curve varies with the type of starch used. Forty grams each of corn, waxy maize, wheat, and arrowroot and 20 grams of potato starch were used, together with 417 ml of distilled water.

The instrument charted the viscosity of the paste in Brabender units (BU) as the starch suspension was heating. Two replications were carried out with each of the five starches. The lesser amount of potato starch was necessary because of the high viscosity of the paste. The viscosity of the retrograded pastes was tested in the same way, using 500 grams of retrograded 5 percent starch gel.

Determination of amylose content

The percent amylose in each starch was determined following the method of McCready and Hassid (1943, p. 1156). By this method, the starch is first wetted with dilute ethanol solution, then dissolved with heating in a dilute aqueous sodium hydroxide solution. An aliquot is diluted and acidified. Iodine solution is added and the absorbance read at a wavelength of 680 millimicrons. The percent amylose in each of the starches was then determined from a calibration curve. The percentages of amylose to amylopectin were: 0, 5, 10, 20, 30, and 50.

Starch-Structured Breads

Formula

A formula developed by Jongh (1961) was the basis for the starch-structured breads. However, it was necessary to vary the amount of water depending on the kind of starch used. The basic formula was as follows:

300 grams starch
6 grams sodium chloride
12 grams sucrose
18 grams active dry yeast
3 grams glyceryl monostearate as a 1:9 water emulsion
200 to 300 milliliters distilled water

The quantity of water used with each type of starch is listed in Table 1.

Table 1. Quantity of distilled water used in starch-structured breads[1]

Starch	Milliliters water[2]	Water as percent of starch
Corn starch	270	90
Wheat starch	300	100
Potato starch	210	70
Arrowroot starch	225	75
Waxy maize starch	270	90

[1] Basis of 300 grams of starch.

[2] This figure includes 27 milliliters of water which were combined with the glyceryl monostearate.

Procedure

Each of the five starches was used in the formula as (1) granular starch only, (2) 5 percent starch paste, freshly prepared, plus the remainder as granular starch; and (3) 5 percent paste, retrograded, plus the remainder as granular starch. The pastes were prepared by using all the water (minus that mixed with the glyceryl monostearate) plus starch equal to 5 percent of the weight of the water, bringing to a boil, and then cooling to room temperature. For use when freshly prepared, the cooled paste was combined with the remaining starch and other ingredients and the dough was mixed. For use as the retrograded paste, retrogradation was carried out as previously described. The retrograded paste was thawed and allowed to come to room temperature. It was then combined with the remaining starch and other ingredients and the dough was mixed.

All ingredients were at room temperature when combined in the mixing bowl of a KitchenAid Mixer.[2] The wire whisk of the KitchenAid was used to mix the dough. The mixer was turned on and off quickly several times to blend the ingredients. Then the dough was mixed at speed No. 6 for two minutes. The dough in the bowl and on the whisk was scraped down and mixing was continued for another three minutes. The dough was allowed to rise for 15 minutes and was then stirred down.

Two portions of 180 grams each were weighed into small loaf pans, 6 x 3⅜ x 2¼ inches, and two 50-gram portions were weighed into 150-ml beakers. The dough was proofed at 30° C. It was allowed to rise in the bread pans until the top of the loaves reached the top of the pan, and in the beakers until double in bulk. The bread was baked at 475° F, the loaves for 20 minutes and the beakers for 12 minutes.

The bread was removed from the oven and allowed to cool for 10 minutes before it was turned out onto cooling racks. One hour after removal from the oven, the bread was cut and prepared for testing.

Tests

Compression test. A slice two centimeters thick from each cylinder of bread baked in the beakers was used for the compression test. The millimeters of compression at 25 grams of force under the disc of the Baker Compressimeter[3] was read and recorded.

[2] Hobart Manufacturing Co., Troy, Ohio.
[3] Wallace and Tierman Company, Inc., Newark, New Jersey.

Sensory evaluation. Slices from each of the breads were presented to five judges. They were asked to score the bread for (1) grain, (2) shape of loaf, (3) texture in regard to chewiness, and (4) texture in regard to springiness. The characteristics were scored from one to five, with five being the best score.

RESULTS AND DISCUSSION

Bread Characteristics as Affected by Starch and Treatment

Very satisfactory breads were made with some of the starches and treatments. The best breads were those having a resilient, chewy, soft texture; a fine, even grain; and a good loaf shape reminiscent of white bread made from wheat flour. The judges noted a combination of these characteristics in wheat starch bread made with the retrograded paste and in potato starch bread made with the fresh paste.

All bread characteristics were different due to starch and treatment at the 1 percent level of significance, except for grain which was different due to treatment at the 5 percent level.

Shape of loaf

The preferred loaf shape was that resembling bread made with wheat flour. Thus, a rounded top was preferred to a flat top. The best shaped loaves were made with wheat granular starch and potato starch made with the fresh paste. Wheat starch bread made with the retrograded paste was scored nearly as high, but the top of this loaf was flat rather than rounded.

Scores for the shape of the loaves are given in Table 2. The shape of the loaves may also be seen in Figure 1.

Grain

A fine grain, uniformly sized cells, and a light, fluffy appearance are valued characteristics of bread made with wheat flour. According to the judges, the starch breads having a grain most closely resembling that of wheat flour bread were the ones made with potato starch containing fresh paste and the loaves made with granular wheat starch. Although not quite as uniform or light-appearing, a quite satisfactory grain was noted for corn, wheat, and arrowroot starch breads made with retrograded pastes.

The grain of the starch-structured breads can be seen in Figure 1. The desirability of the grain as scored by the judges is given in Table 2.

Chewiness

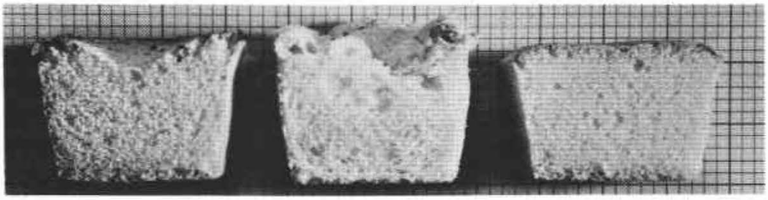
Although good loaf shape and evenness of grain were important factors, the acceptability of the starch breads depended mostly upon their chewy and springy characteristics. The judges expressed a preference for the breads whose chewiness and springiness resembled those of bread made with wheat flour.

With the exception of the products made with waxy maize, which had no resemblance to bread, the use of starch solely in its granular form resulted in breads having a powdery, pasty feel when chewed. The use of pastes in the formula, both freshly prepared and retrograded, improved the chewy quality of

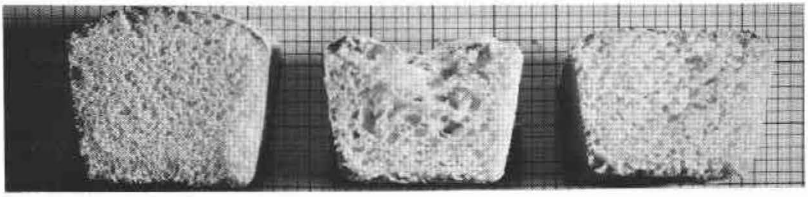
Table 2. Scores for starch-structured bread loaves[1]

Characteristics	Starch	Starch treatment: Granular	Fresh paste	Retrograded paste
Shape	Corn	2.6	3.0	3.9
	Wheat	4.7	2.8	4.3
	Waxy maize	1.0	1.0	1.0
	Arrowroot	3.3	1.1	3.1
	Potato	3.8	4.6	2.8
Grain	Corn	3.3	3.5	3.8
	Wheat	4.1	2.7	3.9
	Waxy maize	1.0	1.0	1.0
	Arrowroot	3.4	2.5	3.9
	Potato	3.7	4.2	3.6
Chewiness	Corn	1.8	4.8	2.5
	Wheat	3.0	4.2	4.3
	Waxy maize	4.4	4.4	4.4
	Arrowroot	1.3	3.2	2.4
	Potato	1.7	3.5	2.0
Springiness	Corn	2.1	4.7	3.2
	Wheat	3.7	4.5	4.6
	Waxy maize	1.1	1.1	1.1
	Arrowroot	2.0	2.0	3.0
	Potato	3.0	4.3	3.1

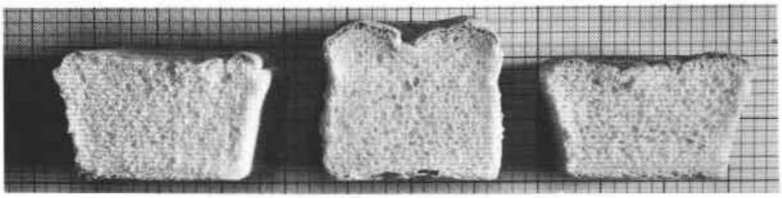
[1] Each figure is the average of 10 scores; scoring range: 1 (low) to 5 (high).



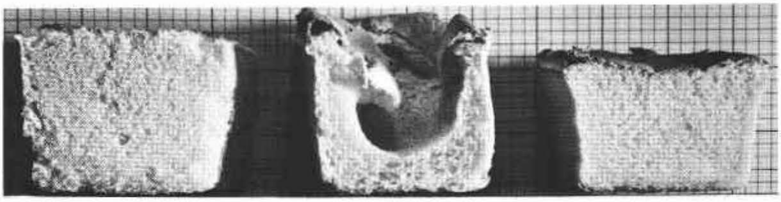
CORN STARCH



WHEAT STARCH



POTATO STARCH



ARROWROOT STARCH

WAXY MAIZE STARCH

Figure 1. Starch-structured breads made from granular starch only (left); 5 percent fresh starch paste and the remainder as granular starch (center); 5 percent retrograded starch paste and the remainder as granular starch (right).

all the breads except for those made with waxy maize, whose scores remained the same regardless of starch treatment. Corn starch breads showed an especially marked improvement when made with the fresh paste, the scores being 1.8 for loaves made with granular starch and 4.8 when made with the fresh paste. Arrowroot and potato starch loaves made with the fresh paste also showed improvement. The wheat starch breads had a relatively high score of 3.0 for those made with granular starch. However, the characteristic of chewiness was improved by the use of the fresh paste. These loaves received a score of 4.2.

The use of retrograded pastes in the formula appeared to improve the chewiness of the bread as compared with loaves made with granular starch, but not to the same extent as the fresh pastes did.

Waxy maize loaves received high scores for chewiness, but this was because of the gummy gel which formed. It was chewy when manipulated in the mouth, but not in the same sense as the chewiness of a normal bread crumb.

Springiness

Scores for springiness were low for breads made with the granular starches except for potato and wheat which had scores of 3.0 and 3.7 respectively. As was noted for chewiness, use of the fresh paste improved the springiness of the corn, wheat, and potato starch breads. The use of retrograded pastes as compared with granular starch alone improved the springiness of breads made with corn, wheat, and arrowroot starches. This corn starch bread was not as springy as the one made with the fresh paste.

The wheat starch bread made with the retrograded paste rated a score of 4.6, higher than for the bread made with the fresh paste and considerably improved over the granular starch loaf. Arrowroot starch loaves improved from 2.0 for both the loaf made with granular starch and the loaf made with the fresh paste to 3.0 for the loaf made with the retrograded paste. The potato starch bread made with the retrograded paste was about the same as that made with granular starch. Waxy maize again remained the same throughout all the starch treatments at a low score of 1.1.

Compressibility

Compressibility of bread slices as determined on the Baker Compressimeter are given in Table 3. The results shown are averages for four slices: two slices per batch, each slice from a separate cylinder of bread. No test was made on the waxy maize bread since no crumb structure was formed and the gelatinous substance of the crust could not be cut into suitable slices for this measurement.

Figures for bread compressibility, when analyzed by the analysis of variance, revealed a difference among starches at the 1 percent level, but treatments (the use of granular starch, fresh paste, or retrograded paste) did not result in significant differences. This is because the breads did not react in the same way to the different treatments. For example, improvements in compressibility in the wheat starch series brought about by using the retrograded paste were counteracted in the analysis by a loss of quality for this treatment in the potato starch series. It would be expected that the bread characteristics of springiness and chewiness would be related to the compressibility. This was true, but the correlation was somewhat lower than expected.

Correlation coefficients were significant at the 5 percent level for judges'

Table 3. Compressibility of starch-structured bread slices (millimeters compression per 25 grams force)[1]

Starch	Starch treatment		
	Granular	Fresh paste	Retrograded paste
Corn	0.41	0.70	0.55
Wheat	0.60	0.78	0.86
Waxy maize	......	......	......
Arrowroot	0.45	0.35	0.41
Potato	0.39	0.43	0.36

[1]Four slices.

Table 4. Correlation coefficients at three levels of significance[1]

	Starch treatment[2]		
	Granular	Fresh paste	Retrograded paste
Springiness versus compressibility	.93**	.92**	.95**
Springiness versus shape	.98***	.89**	.95**
Chewiness versus shape	.92**	ns	.94**
Chewiness versus compressibility	.94**	.94**	.99***
Amylose versus grain	.97***	.84*	.92**
Amylose versus shape	.97***	ns	.81*
Amylose versus springiness	.97***	.81*	.94**
Amylose versus temperature at maximum viscosity (BU)	.95**	.95**	......
Amylose versus viscosity of retrograded pastes at 25° C (BU)	......	......	.90**
Viscosity of retrograded pastes at 25° C (BU) versus shape	......	......	.89**
Viscosity of retrograded pastes at 25° C (BU) versus springiness	......	......	.90**
Viscosity of retrograded pastes at 25° (BU) versus average score	......	......	.93**

[1]At 10%, 5%, or 1% level; three degrees of freedom: 10% level r = .805, 5% level r = .878, 1% level r = .959.

[2] * = significant at 10% level, ** = significant at 5% level, *** = significant at 1% level.

scores for chewiness of the bread versus compressibility (as measured with the Baker Compressimeter) and for springiness versus compressibility. As shown in Table 4, r was significant at the 1 percent level for chewiness of breads made with retrograded pastes versus compressibility.

Schoch (1965) believed that the addition of a starch paste to a bread dough may interfere with the rigid amylose gel network that would form in an ordinary bread, this network giving structure to the bread. Evidence of this effect of the pastes can be seen in the greater compression possible for the corn and wheat starch breads and the improved chewiness and springiness of breads made with fresh or retrograded paste over breads made with all granular starch.

Starch Characteristics Versus Bread Quality

The composition and behavior of each starch and the relationship of these factors to the performance of the starch in the breads is a complex interaction of many factors.

Amylose content of starch

The characteristic of the starches that appears to be most closely related to their performance in breads is the amylose content. The effective contribution of amylose to bread structure becomes immediately evident when loaf characteristics are examined. The loaf made with waxy maize, of zero amylose content, had no cell structure and no loaf structure. It formed only a gel. Because of the concentration and rigidity of the batter, the loaf rose, but when placed in a hot oven the edges set and the entire interior of the loaf collapsed.

Amylose holds the starch granules intact as they swell and gelatinize. Crystalline areas of the starch are partially dependent on the amylose, which reinforces the granule network. Amylose apparently gives structure to the bread so it can retain gas satisfactorily, expand, and form a bread structure with desirable shape and uniform porous grain. Amylose also affects the texture of the bread. For bread made with the granular starches, correlation coefficients for amylose content versus the bread characteristics of grain, shape of loaf, and springiness were significant at the 1 percent level, and amylose versus chewiness was significant at the 5 percent level. For breads made with retrograded pastes, correlation coefficients were significant at the 5 percent level for amylose content versus bread scores for grain and springiness and at the 10 percent level for amylose versus shape and chewiness. Amylose versus scores for grain, chewiness, and springiness gave r values significant at the 10 percent level for breads made with the fresh pastes.

Table 5. Absorbance at 680 millimicrons and percentage amylose[1] for five starches

Starch	Absorbance	Amylose
		%
Corn	0.088	14.0
Wheat	0.106	23.0
Waxy maize	0.009	0.0
Arrowroot	0.093	17.5
Potato	0.103	21.5

[1] Percentage determined by reference to a calibration curve.

The absorbance values for the pure samples of amylose and amylopectin used to prepare the calibration curve lay in a straight line, the absorbance in mu increasing as the percentage of amylose increased. The percent of amylose in the starches may be read by plotting their absorbance values on this curve.

The percentage of amylose for the starches tested in this experiment was somewhat lower than the values reported in the literature, especially that of corn starch. Scheick (1966) found corn to contain 27 percent amylose as compared to the 14 percent amylose of the corn starch used in this experiment. Greenwood (1966) reported wheat starch at 26 percent amylose and potato starch at 23 percent amylose. Figures in this experiment were 23 and 21.5 percent amylose respectively. Arrowroot starch, reported to contain 20.5 percent amylose (Anderson, Greenwood, and Hirst, 1955) was found to contain 17.5 percent amylose in this experiment. Waxy maize starch was reported to contain less than 1 percent amylose by Greenwood (1966), and in this experiment waxy maize starch was so low in amylose that the absorbance value did not fall on the calibration curve, indicating very little or no amylose.

The particular starch samples used in this experiment may have been very low in amylose, the amylose may not have been completely solubilized, or since the starch was not defatted before use, some of the amylose may have been in the form of a fatty acid complex which was unable to complex with the iodine to develop the blue color.

Performance tests of starch

The behavior of the starches differed from each other as shown by the analysis of variance for all characteristics studied. Differences were significant at the 1 percent level for swelling capacity of native starch and retrograded pastes, and for starch remaining after drying one gram of retrograded paste. Differences were significant at the 5 percent level for grams of starch remaining after drying one gram of paste prepared from the native starches and for the viscosity of the different starches at 95° C.

In spite of these differences, the measurements on the starches correlated but slightly with the scores for bread characteristics. Amylose content of the starches correlated with the temperature at maximum viscosity of the fresh pastes, r being significant at the 5 percent level.

Swelling Capacity of Starches

Granular starch. The swelling capacity of each native starch was studied from two viewpoints—the weight of the swollen granules after heating in water to various temperatures and centrifuging, and the weight of dry starch remaining from one gram of swollen granules. Although these figures are inversely related, the correlation is far from −1.0 because of the difference in swelling capacity of the different starches at each temperature. A correlation coefficient calculated for all starches was $r = -0.48$, significant at the 5 percent level.

The grams of dry starch from one gram of swollen granules indicates the proportion of starch to water at each temperature. The decrease in the grams of dry starch per gram of paste also shows the temperature range in which the starch gelatinizes. The smallest quantity of dry starch remaining from one gram of paste would be expected at 95° C with the maximum swelling of the starch occurring at that temperature. Swelling capacity of each starch is shown in Table 6. Dry starch from one gram of swollen starch paste is shown in Table 7. The values given are averages of two replications.

The fact that starches perform differently from each other when pasted can be seen by referring to Figure 2, which illustrates the swelling capacity of granular starch. The corn and wheat starches behaved in a fashion typical of cereal starches. Both showed limited swelling capacity. The swelling power of arrowroot starch was greater than that of the cereal starches. The swelling capacity of the potato starch greatly exceeded that of any of the other starches tested, at all temperatures above 25° C. The waxy maize starch was difficult to work with, as a line did not form between the paste and the excess water when centrifuged. The figures in this research represent the amount of starch

Table 6. Swelling capacity of raw starch (grams swollen starch per gram of dry starch)

Starch	Temperature, degrees C				
	25	65	75	85	95
Corn	2.345	4.520	9.775	12.190	15.430
Wheat	2.300	7.270	7.840	10.020	13.400
Waxy maize	2.686	5.008	11.100	8.328	5.416
Arrowroot	2.370	3.695	22.530	27.465	33.585
Potato	1.950	19.090	44.525	79.550	99.725

Table 7. Swelling capacity of raw starch (grams of starch remaining after drying one gram of centrifuged starch paste)

Starch	Temperature, degrees C				
	25	65	75	85	95
Corn	0.484	0.256	0.098	0.075	0.051
Wheat	0.447	0.129	0.115	0.090	0.051
Waxy maize	0.369	0.177	0.018	0.016	0.020
Arrowroot	0.432	0.325	0.036	0.028	0.020
Potato	0.510	0.038	0.018	0.008	0.010

in the dense layer in the bottom of the centrifuge tube. As the temperature increased above 75° C, this dense layer became smaller, with greater solubility and dispersibility of some of the starch into the upper aqueous layer. This starch was discarded during aspiration of the aqueous layer.

Retrograded starch pastes. Identical quantities of starch and water were used in this test, as for the test of swelling capacity of the granular starches. However, the mixture of starch and water was heated to boiling before the retrogradation was induced. Upon thawing, the swelling capacity was investigated in two ways—determining the grams of swollen starch after heating the paste to the various temperatures and determining the grams of dry starch per gram of swollen paste.

Retrogradation, defined as increasing crystallinity and the loss of water-holding capacity, would be expected to result in decreased swelling capacity of the starch. However, some retrogradation is overcome at temperatures between 50 to 60° C, so the loss in swelling capacity of the retrograded pastes at room temperature may be somewhat reversed upon heating the paste.

The swelling capacity of the retrograded starches and the starch remaining after drying one gram of paste were different at the 1 percent level of significance for starches and temperatures, as shown by the analysis of variance.

The results of the swelling capacity tests on the retrograded starch pastes are given in Tables 8 and 9, and in Figure 2.

The swelling capacity of the retrograded cereal starch pastes remained essentially the same as temperatures were increased. The appearance and behavior of the retrograded waxy maize was similar to the native starch when heated to

Table 8. Swelling capacity of retrograded starch pastes (grams starch paste per gram of dry starch)

Starch	Temperature, degrees C				
	25	65	75	85	95
Corn	14.695	13.695	13.745	13.850	13.893
Wheat	13.170	15.020	15.290	14.350	14.785
Waxy maize	6.035	4.460	3.830	4.130	4.870
Arrowroot	17.630	22.170	24.530	25.270	26.510
Potato	17.909	67.210	79.300	95.875	92.625

Table 9. Swelling capacity of retrograded starch pastes (grams of starch remaining after drying one gram of centrifuged paste)

Starch	Temperature, degrees C				
	25	65	75	85	95
Corn	0.070	0.066	0.065	0.074	0.065
Wheat	0.065	0.060	0.063	0.060	0.056
Waxy maize	0.106	0.038	0.030	0.032	0.028
Arrowroot	0.050	0.038	0.030	0.032	0.028
Potato	0.056	0.012	0.008	0.008	0.006

95° C. The root and tuber starches had a low swelling capacity at room temperature, but upon heating the retrograded pastes were able to swell again and approach the swelling capacity of the fresh pastes at 95° C.

Swelling capacity of the retrograded potato starch increased rapidly with increased temperatures, reaching a maximum at 85° C and falling slightly at 95° C. The swelling capacity of the retrograded potato starch was similar to the swelling capacity of the native starch which occurred at 95° C. The retrograded paste took on behavior and appearance of the fresh paste as heat was applied.

All the starches had increased paste clarity and became more shiny and translucent when heated. The dull opaque finish of the retrograded paste disappeared. This was especially noticeable with arrowroot and potato starch pastes.

A somewhat lower water-holding capacity of the retrograded pastes as compared with the native starch is indicated by a higher weight of dry starch per gram of paste. Since retrogradation was allowed to take place in pastes that had been heated to 95° C, the fresh and retrograded pastes heated to 95° C are compared. Grams of dry starch from one gram of centrifuged paste heated to 95° C were:

	Freshly prepared paste	Retrograded paste
	(*Grams*)	(*Grams*)
Corn	0.051	0.065
Wheat	0.051	0.056
Waxy maize	0.020	0.028
Arrowroot	0.020	0.028
Potato	0.010	0.006

Granular starch. Viscosity of the starch pastes had more relationship to bread characteristics than did swelling ca-

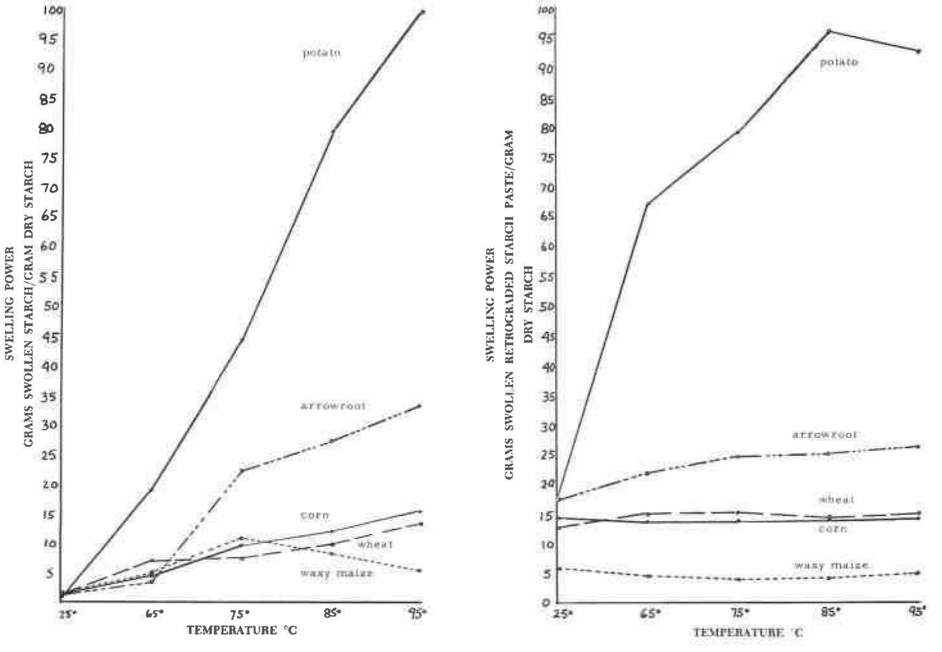


Figure 2. Swelling capacity of raw starch (left) and retrograded starch pastes (right).

pacity of the starches. Viscosity of the retrograded pastes at 25° C showed a correlation at the 5 percent level with bread shape, springiness, and the average score for breads made with the retrograded pastes.

Correlation coefficients showed that amylose versus the temperature at maximum viscosity during pasting was significant at the 5 percent level for pastes made from the native starches. Higher temperatures were needed to reach maximum viscosity for the starches with greater amounts of amylose. Amylose versus viscosity at 25° C was significant at the 5 percent level for the retrograded pastes.

Amylograph curves showed the apparent viscosity during pasting of the different starches throughout the heating cycle. These curves supply important figures—the temperature at which the viscosity begins to rise, the temperature and Brabender units at maximum viscosity, and the viscosity in Brabender units at 95° C. These figures are presented in Table 10.

Each type of starch has a characteristic pattern of granule swelling and development of viscosity. Size of granules and strength of bonding influence the temperature range and rate at which swelling occurs.

Wheat starch had a comparatively low maximum viscosity of 380 BU at 95° C. Corn starch had quite high maximum viscosity (620 BU) at 95° C.

Waxy maize starch had low maximum viscosity (50 BU) at a temperature of 73° C. Slight thinning occurred by the

Table 10. Apparent viscosity of freshly prepared starch pastes

Starch	Conc. g/417 ml	Initial rise in temp., °C	Maximum viscosity Temp., °C	Maximum viscosity BU	Viscosity at 95° C, BU
Corn	40	70	92.5	620	620
Wheat	40	81	95.0	380	380
Waxy maize	40	64	73.0	50	35
Arrowroot	40	74	88.0	690	690
Potato	20	64	95.0	630	630

time the heating cycle was complete. This breakdown in viscosity was probably caused by excessive swelling and agitation which resulted in granule disintegration.

Root and tuber starches characteristically have a higher viscosity than do the cereal starches. Arrowroot starch reached its maximum viscosity at 88° C. The maximum viscosity for arrowroot was greater than for the cereal starches tested. No breakdown occurred and the viscosity was still at its maximum value at 95° C. Potato starch illustrates the behavior of the root and tuber starches very well. Only 20 grams of potato starch were used in the amylograph to obtain a curve which compared well with the 40 grams needed for all the other starches. Forty grams of potato starch would have caused such a high viscosity that it could not have been charted by the amylograph. Even with half the concentration of starch, the viscosity was greater than that of the cereal starch pastes. Potato starch had an early initial rise and the viscosity steadily increased to the maximum value at 95° C.

Retrograded starch pastes. The starch pastes had set up to gels during retrogradation and were broken into smaller pieces before use in the amylograph as they would be during the mixer action in bread dough. Again, the temperature range was 25° to 96° C, the same range the paste would be subjected to in baking bread. All the retrograded pastes had a maximum viscosity at 25° C and decreased in viscosity upon heating and stirring. This would render the dough more mobile and less viscous as the interior temperature increased during baking as compared with the dough prepared with raw granular starch only. The bread made with the retrograded pastes showed a more open texture, larger air cells, and not as fine a crumb. The decreased viscosity would allow the cells in the dough to expand to a greater extent.

Viscosity of retrograded 5 percent starch pastes from each of the five starches was recorded as the paste was heated from 25° to 96° C. The results of this test are given in Table 11.

The retrograded corn, wheat, and arrowroot pastes rapidly decreased in viscosity as they were heated and stirred.

An unusual pattern was charted for the retrograded waxy maize starch. The maximum viscosity was very low in comparison to the other starches. The viscosity decreased with increase in temperature up to 48° C. A rise in viscosity then ensued up to 52° C, at which time the viscosity proceeded to decrease again until it reached a plateau at 66° C. In contrast to the rapid and pronounced decrease in viscosity of the corn, wheat,

Table 11. Apparent viscosity of retrograded starch pastes

Starch	Viscosity at 25° C, BU	Minimum viscosity		Viscosity at 95° C, BU
		Temp, °C	BU	
Corn	750	85	210	225
Wheat	710	95	200	200
Waxy maize	170	66	10	10
Arrowroot	730	55	260	300
Potato	725	95	525	525

and arrowroot pastes, the viscosity of the retrograded potato paste decreased but slightly. Minimum viscosity was 525 BU, as compared with 210 to 260 BU for the others.

Viscosity of the retrograded pastes at 25° C correlated at the 5 percent level with scores for bread shape, springiness, and the average bread score.

SUMMARY

The amylose content of various starches and their performance when heated in water were studied for the purpose of relating these characteristics to the behavior of the starches in starch-structured breads. Five commercially prepared starches were selected to represent grain starches (both regular and waxy) and root and tuber starches. They were corn, wheat, waxy maize, arrowroot, and potato starch. The performance characteristics tested were the swelling capacity of the raw starches and the apparent viscosity of both the starch suspensions and retrograded starch pastes during heating to 96° C in a Brabender VISCO/amylo/GRAPH. The swelling capacity was studied from two viewpoints: (1) grams of swollen starch from one gram dry starch after centrifugation of the starch paste, and (2) grams of starch remaining after drying one gram of starch paste.

In addition, formulas were developed for bread-like products in which starch was responsible for the structure. The five starches, used as granular starch, as granular starch plus 5 percent freshly prepared paste, or as granular starch plus 5 percent retrograded paste, were made into starch-structured breads. Cross-sections of the breads were photographed. The compressibility of the bread crumb was tested with a Baker Compressimeter. A panel of judges scored the bread for grain, shape of loaf, chewiness, and springiness. Analysis of variance and correlation coefficients were calculated for the starch and bread characteristics. The behavior of the various starches differed for all characteristics studied, as shown by the analysis of variance. The differences were significant at the 1 percent level for swelling capacity of the granular starch and the retrograded pastes, and for starch remaining from one gram of swollen retrograded paste. However, the grams of starch remaining after drying one gram of freshly prepared paste and the viscosity of the different starches at 95° C differed only at the 5 percent level of significance.

Bread characteristics were different due to the kind of starch used and the treatment (use of granular starch only, fresh paste, or retrograded paste). The characteristics of loaf shape, chewiness,

and springiness were different at the 1 percent level of significance for both starch and treatment. The grain of the breads was different due to the kind of starch at the 1 percent level, but treatment caused significant differences only at the 5 percent level. The kind of starch used also affected the compressibility of the breads as determined by the Baker Compressimeter. The differences due to starch were significant at the 1 percent level, but differences due to treatment were not significant.

Correlation coefficients showed that amylose versus the temperature at maximum viscosity during pasting was significant at the 5 percent level for freshly prepared pastes. Amylose versus viscosity at 25° C was significant at the 5 percent level for the retrograded paste.

Correlation coefficients for the percent of amylose in the different starches versus bread characteristics of grain, shape, and springiness were significant at the 1 percent level for breads made with granular starch, and at the 5 percent level for chewiness. For the breads made with retrograded paste, the percent amylose versus grain and versus springiness were significant at the 5 percent level. For these breads, the percent amylose versus bread shape and chewiness were significant at the 10 percent level.

For breads in which freshly prepared pastes were used, percent amylose correlated at the 10 percent level with grain, chewiness, and springiness. A measurement of starch behavior—viscosity of the retrograded pastes at 25° C—showed a correlation at the 5 percent level with bread shape, springiness, and the average score for breads made with the retrograded pastes. Springiness versus compression was significant at the 5 percent level for breads made with all three treatments. Amylose content of the starches correlated at the 5 percent level with the temperature of the freshly prepared pastes at maximum viscosity.

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