Effect of Various Starches in Baking[1]

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ABSTRACT

Starch was isolated from 12 different varieties of hard red spring (HRS) wheat flour; 3 HRS composite flours which had yielded loaves of good, intermediate, and poor baking quality; 2 durum semolinas; 2 club wheat flours; and a soft white wheat flour. In addition, an isolated starch was fractionated into a large- and small-granule fraction. One commercial sample each of corn starch and wheat starch also were included in the study. The temperature of initial pasting and the peak height ranged from 55° to 59°C. and 540 to 865 B.U., respectively, for the different wheat starches. Absolute density, water-binding capacity, and starch-damage values ranged from 1.466 to 1.496, 81.5 to 100.0%, and 2.3 to 12.2 Farrand Units Equivalent, respectively, for the wheat starches. Farinogram measurements indicated that mixing time and stability ranged from 1.5 to 4 min., and 3 to 6 min., respectively, for the gluten-starch blends containing the different wheat starches. The same gluten-starch blends when baked into bread showed a range in loaf volume of from 137 to 161 cc. The addition of a common lot of water-solubles to the gluten-starch blends showed greater variations in loaf volume. This would suggest a possible different type and degree of interaction between certain water-soluble components and the various starches.

Alsberg (1), as early as 1935, stated that variations in the properties of starches of different flours materially influence their baking qualities. Sandstedt et al. (2) showed that certain undesirable baking characteristics of some starches isolated from hard wheat originated from damage to the starch in milling. Harris and Sibbitt (3) concluded that the marked differences in those properties that influence baking quality were inherent in starches from different wheat varieties. The authors further

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stated that the differences may have been due to starch-granule damage during milling. In a later paper, Harris and Sibbitt (4) concluded that both the starches and gluten isolated from hard red spring (HRS) wheats vary in baking quality as a result of both inherited and environmental factors. Starches isolated from rice, corn, waxy corn, and potato have been shown to lack the baking quality of wheat starch (5,6). Pence et al. (7) reported that protein, starch, and protein-starch interaction effects are all significant factors governing flour quality. Rotsch (8) showed that bread could be produced from doughs in which the gluten was replaced by other gel-forming substances. He did not, however, find a suitable substitute for starch. Similar results have been reported by Jongh (9). Jongh et al. (10) stated that addition of glyceryl monostearate to starch bread results in its being adsorbed onto the surface of the starch, bringing about aggregate formation with the resulting coherent network formed by the starch granules. The function of starch in dough has been reviewed recently (11,12). Pomeranz (13) has stated that although the loaves baked by Rotsch (8) and those by Jongh (9) were better than those baked from starch alone, none were comparable to commercially acceptable white pan bread in the U.S., Canada, or England. The author further states that, in his opinion, bread without gluten is basically bread without bread.

The present study was undertaken primarily to study the effect of different starches in baking. To relate any differences that might be observed in the baking to certain properties of the starches, this study included an investigation of the physical dough characteristics using a gluten-starch system, of gelatinization properties as measured by the amylograph, and of certain physical properties of the starches, which included absolute density, water-binding capacity, and starch damage.

Properties of a number of new wheat varieties not perviously described are cited. In particular, owing to current interest in semi-dwarf wheats, information is provided on three such varieties: an unnamed sample, Red River 68, and Tobari.

MATERIALS AND METHODS

Samples

The following samples were used as sources of starch:

a) Flour from 12 varieties of HRS wheat which were composites of samples grown at different locations.
b) Semolina from two varieties of durum.
c) Flour from two varieties of club wheat.
d) Flour of one variety of soft white wheat.
e) Three HRS wheat composite flours of good, intermediate, and poor baking qualities.
f) Large- and small-granule starch fractions isolated from a composite of HRS wheat flour.
g) A commercial sample of corn starch supplied by Clinton Corn Processing Co., Clinton, Iowa, and a commercial sample of wheat starch supplied by Hercules, Inc., Harbor Beach, Mich.

Gluten Isolation

Gluten, used in the physical dough-testing experiments and in the baking study, was isolated from a composite of HRS wheat flour by the dough-kneading procedure (14). The protein content of the extracted gluten was 74.2% on a dry basis.

Isolation of Water-Solubles

The water-solubles used in the baking study were isolated from a composite lot of HRS wheat flour. Flour was extracted with distilled water in a 1:2 ratio at low speed in a Waring Blendor. After centrifugation, the supernatant was decanted, shell frozen, and freeze-dried. Protein content of the water-solubles was 23.4% on a dry basis.

Starch Isolation

Starch was isolated from the different flours and semolinas by the dough-kneading procedure (14). A dough ball was made with the flour or semolina and distilled water and washed by hand until free of starch. The starch slurry was centrifuged and the prime starch recovered. The starch was allowed to air dry, and was then sieved on a No. 70-mesh sieve.

Large- and Small-Granule Fractionation

A composite lot of HRS wheat flour was used to obtain a large and a small starch-granule fraction. The procedure utilized was as follows: The starch and "sludge" (tailings), which were removed by the dough-kneading procedure mentioned above, were reslurried in distilled water and centrifuged at exactly 2,000 r.p.m. for 15 min. The "sludge" top layer was removed and saved for the isolation of the small-granule fraction. The prime-starch layer was removed, reslurried in water, and centrifuged at 2,000 r.p.m. for 15 min. The "sludge" layer in this instance was removed and discarded. The prime starch was collected and represented the large-granule fraction. The "sludge" material obtained from centrifugation of the first slurry was reslurried in water and centrifuged at exactly 4,500 r.p.m. for 15 min. The top "sludge" layer was removed and discarded. The bottom "starch" layer was removed, air dried, and sieved. This material represented the small-granule fraction. Figure 1 shows a photograph of the large- and small-granule fractions obtained.

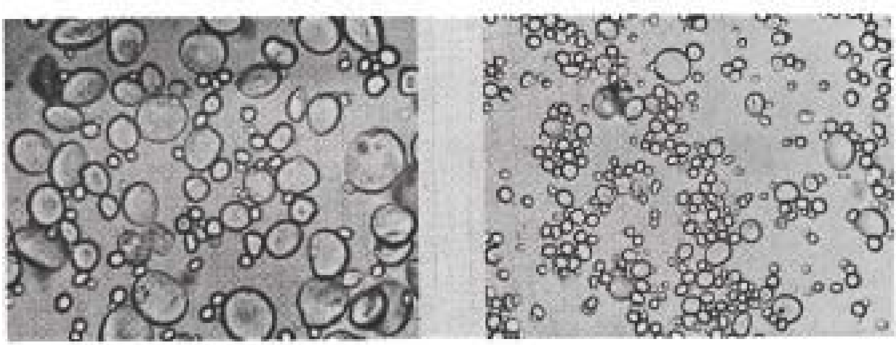

Fig. 1. Photomicrographs of large- and small-granule fractions of HRS wheat starch. Magnification (X 470). Left: large granule fraction. Right: small granule fraction.

Starch Determination in Flour and in Isolated Starch

The amount of starch present in the different flour samples as well as in the isolated starches was determined by the polarimetric procedure (15).

Nitrogen Determination

Nitrogen content in the various starches was measured by the micro-Kjeldahl procedure (15).

Gelatinization Curves

The gelatinization properties of the different starches were investigated with the Brabender amylograph by the carboxymethyl cellulose technique as described by Sandstedt and Abbott (16) and by Medcalf and Gilles (17). The properties examined were temperature of initial pasting, peak height, 15-min. height, and height after coding for 30-min. at room temperature, which resulted in a gel temperature of between 67°–69°C.

Granule Density

Absolute densities of the different starches used in the baking study were determined by the xylene-displacement method described by Schoch and Leach (18). The starches were all pre-dried by heating for 4 hr. in a vacuum oven at 120°C. prior to the determination. Densities were determined at 30°C., with an average of duplicate determinations reported in all cases.

Water-Binding Capacity

Water-binding capacity of the different starches was determined according to the procedure described by Medcalf and Gilles (17).

Starch Damage

Starch damage in the different starches was determined according to a colorimetric procedure of Williams and Fegol, except that a 5-g. starch sample (dry basis) was used.

Physical Dough-Testing Experiments

The mixograph and the farinograph were used to study the effect of the different starches on physical dough properties. A common lot of gluten was used throughout. The gluten-starch blends were prepared so that the protein content of each blend was 15.0% on a dry basis.

A 25-g. sample of the gluten-starch blend was used for the mixograph with a fixed amount of water.

A 50-g. sample (dry basis) was used for the farinograph determinations, with the curve centered on the 500-B.U. line. In certain cases, if there was insufficient sample, it was necessary to estimate the absorption from previous trials in order to have the curve center on the 500-B.U. line.

Baking Study

The different starches were baked by two basic systems: a gluten-starch and a gluten-starch-water-soluble baking procedure. A common sample of gluten and water-solubles was used throughout the baking study. The gluten-starch loaves were made from blends containing 20% gluten and 80% starch. The gluten-starch-water-soluble loaves were made from the above blends, but in which 3.2% of the blend was replaced by water-solubles. The protein contents of the gluten-starch blends and gluten-starch-water-soluble blends on a dry basis were 15.0 and 15.3%, respectively.

A lean-type baking formula was used in which 25 g. pup loaves were baked. The baking procedure has been described previously (14). The amount of water was determined by an examination of the dough during mixing and also from the feel of the dough of previous bakes at punching and panning. Mixing was performed in a National mixer (National Mfg. Co., Lincoln, Nebr.). The mixing time varied for the different starches and was determined by physical examination of the dough. The volumes were measured by rapeseed displacement 30 min. after removal from the oven. Crust color, crumb grain and texture, and crumb color of the different gluten-starch loaves were noted.

RESULTS AND DISCUSSION

The protein and starch contents of the HRS wheat samples used for the starch isolation are shown in Table I, together with starch yield and nitrogen content. Data in this table are reported only for the HRS wheat samples, since the procedure utilized for the starch isolation resulted in a certain loss of material in the case of durum and soft wheat samples owing to the very unelastic type of gluten they produced. The protein content of the HRS wheat flours ranged from 13.4 to 16.2%, while the starch yield ranged from 47.7 to 58.8%. Of the 15 HRS wheat flours used for starch isolation, the 3 semidwarfs, Tobari, Red River 68, and an unnamed semidwarf variety, and the conventional variety, Manitou, contained the highest amounts of starch.

The nitrogen content of the starches isolated from the durum semolina samples

TABLE I. PERTINENT DATA ON HRS WHEAT FLOUR STARCHES

Flour Source	Flour Protein[a] %	Flour Starch[b] %	Starch Yield[a] %	Starch Nitrogen[a] %
Thatcher	15.8	63.9	47.7	.06
Selkirk	14.9	63.2	52.3	.05
Justin	16.2	63.4	52.8	.06
Chris	16.2	62.9	53.3	.08
Manitou	16.0	65.2	54.6	.04
Waldron	16.0	62.3	51.8	.06
Valley	15.3	63.2	54.6	.06
Tobari	14.5	65.9	54.1	.05
Fortuna	14.8	64.1	55.9	.06
Red River 68	13.4	67.5	58.8	.08
Semidwarf	15.5	65.1	50.1	.05
Polk	15.2	63.3	52.3	.08
Good-quality baking flour	17.3	...	50.9	.05
Intermediate-quality baking flour	14.9	64.0	50.5	.04
Poor-quality baking flour	12.9	60.0	51.7	.03

[a]Expressed on a dry basis.

[b]Calculated by a polarimetric procedure.

and the club and soft wheat flours was similar to the HRS wheat starches shown in Table I. The protein content of the semolina and flour of these samples was lower than that shown for the HRS wheat flours, whereas their starch content was higher.

Table II lists the amylograph data for the different starches investigated in the baking study. The initial temperature of pasting for the HRS wheat-flour starches varied from 55°to 59°C. The peak height for these starches did show considerable variation. The highest peak height was obtained with Selkirk starch and the lowest from the starch obtained from the blended flour having good baking quality. The initial temperature of gelatinization of the soft wheat and club wheat starches was similar to the HRS wheat starches. The starches isolated from the durum wheat had slightly lower initial temperatures of gelatinization, as reported previously (17). The corn starch had the highest initial temperature of gelatinization of the starches investigated and also the highest peak height. No significant correlation was obtained between the different amylograph measurements and the loaf volume of the gluten-starch loaves.

Table III lists some of the physical properties of the isolated starches as well as the amount of starch present measured polarimetrically. The absolute density of the wheat starches was similar and showed little variation, with Manitou starch

TABLE II. SUMMARY OF STARCH AMYLOGRAMS

Starch Source	Temperature of Initial Pasting °C.	Peak Height B.U.	15-Min. Height B.U.	30-Min.[a] Height B.U.
HRS				
Thatcher	59	775	715	690
Selkirk	58	865	790	750
Justin	56	765	700	685
Chris	58	750	715	665
Manitou	58	740	675	620
Waldron	58	705	670	615
Valley	58	755	715	660
Tobari	56	640	600	595
Fortuna	58	640	600	575
Red River 68	56	770	710	685
Semidwarf	59	800	735	705
Polk	59	755	715	675
Commercial	56	620	505	450
Good-quality baking flour	57	580	560	585
Intermediate-quality baking flour	57	615	575	590
Poor-quality baking flour	56	590	560	570
Small-granule fraction	57	630	590	595
Large-granule fraction	57	580	555	565
Durum wheat				
Mindum	55	610	590	590
Leeds	55	520	510	510
Soft wheat				
Nugaines	57	575	555	590
Club wheat				
Omar	57	575	560	580
Moro	57	540	540	580
Corn starch	64	900	785	830

[a]Height after cooling for 30-min. at room temperature which resulted in a gel temperature of between 67°–69°C.

TABLE III. SUMMARY OF PHYSICAL PROPERTIES OF STARCHES

Starch Source	Starch in Isolated Starch %	Absolute Density	Water-Binding Capacity %	Starch Damage Farrand Units Equivalent
HRS				
Thatcher	81.6	1.494	84.0	4.5
Selkirk	82.6	1.484	84.5	4.3
Justin	84.0	1.489	83.5	3.6
Chris	82.0	1.493	85.5	3.2
Manitou	81.2	1.466	83.5	3.1
Waldron	83.8	1.488	85.0	4.1
Valley	82.0	1.480	85.5	5.5
Tobari	83.0	1.483	82.5	3.5
Fortuna	82.8	1.496	84.5	4.9
Red River 68	80.0	1.484	85.0	3.3
Semidwarf	81.4	1.494	85.0	3.3
Polk	83.4	1.490	81.5	4.5
Commercial	86.4	...	90.0	9.5
Good-quality baking flour	84.0	1.480	86.0	4.1
Intermediate-quality baking flour	82.4	1.490	85.5	3.2
Poor-quality baking flour	84.6	1.480	88.0	3.9
Small-granule fraction	88.0	1.488	100.0	12.2
Large-granule fraction	84.0	1.486	82.5	2.5
Durum Wheat				
Mindum	83.6	1.480	81.0	3.3
Leeds	82.0	1.492	88.5	2.3
Soft wheat				
Nugaines	80.0	1.493	93.5	3.1
Club wheat				
Omar	84.8	1.494	87.0	2.3
Moro	80.8	1.492	88.0	2.3
Corn starch	87.2	1.721	98.0	2.8

having the lowest value at 1.466; and Fortuna, the highest value at 1.496. The values reported for the absolute density were higher than those reported in the literature (17), since the determination was performed on undefatted starch. Corn starch had the highest absolute density. A correlation coefficient of −0.48 was obtained between absolute density of the starches vs. loaf volume of the gluten-starch loaves, which was significant at the 5% level. Water-binding capacity of the starches varied little except for the commercial sample and the small-granule starch fraction. The high water-binding capacity value obtained for these starches was due in part to the relatively high amount of damaged starch granules. The large fraction, on the other hand, exhibited the lowest starch-damage value. The pentosan content in the large- and small-granule fractions was similar. The Leeds variety of durum starch and the soft and club wheat starches had higher water-binding capacity values than HRS wheat starches. At the same time, the starch-damage values for these starches was lower than for HRS wheat starches, indicating that the higher water-binding capacity for these starches was not owing to an excess of damaged starch. The corn starch also had a high water-binding capacity and a low starch-damage value. With the exception of the commercial starch and the small-granule starch fraction, the starch-damage values among the HRS wheat starches revealed only small differences. No significant correlation was obtained between either water-binding capacity or starch damage and loaf volume.

Table IV shows pertinent data obtained from the farinograph for the gluten-starch blends in which a common lot of gluten and the different starches were utilized. In general, absorptions for the gluten-starch blends containing HRS wheat starches were similar except for the commercial starch and small-granule starch fraction, which had higher absorptions. Only small differences were noted in the mixing time of the gluten-starch blends using the different HRS wheat starches. The gluten-starch blend having the small-granule starch fraction had the longest mixing time. This result has been suggested previously (11). In general, absorptions of the gluten-starch blends containing the durum, soft, and club wheat starches were higher than those containing the HRS wheat starches. This result was indicated by the higher water-binding capacity of these starches. A shorter arrival time also was noted for the blends containing these starches as compared to the

TABLE IV. FARINOGRAPH DATA ON GLUTEN-STARCH BLENDS

Starch Source	Absorption %	Mixing time min.	Stability min.
HRS			
Thatcher	55.0	2.5	5.0
Selkirk	53.6	3.5	5.5
Justin	53.4	3.0	6.0
Chris	55.0	2.5	5.0
Manitou	54.2	2.5	4.0
Waldron	54.4	2.5	4.5
Valley	54.4	3.0	5.0
Tobari	53.9	1.5	4.0
Fortuna	55.0	2.75	4.0
Red River 68	54.6	2.25	5.5
Semidwarf	54.6	3.0	4.5
Polk	53.6	2.0	4.5
Commercial	60.0	2.5	3.0
Good-quality baking flour	55.0	2.5	5.0
Intermediate-quality baking flour	56.0	2.5	5.0
Poor-quality baking flour	56.0	3.0	5.0
Small-granule fraction	68.8	4.0	3.5
Large-granule fraction	55.0	2.5	3.5
Durum wheat			
Mindum	57.1	1.5	3.0
Leeds	58.6	2.0	3.0
Soft wheat			
Nugaines	57.8	2.5	4.0
Club wheat			
Omar	56.2	3.0	4.0
Moro	56.8	3.0	4.0
Corn starch	67.0	1.25	1.5

blends containing the HRS wheat starches. This would indicate a faster uptake of water by these starches. The gluten-starch blend containing the corn starch showed a very short arrival time, a short mixing time, and a very low range of stability.

The mixograph also was used to study the physical dough properties of the different gluten-starch blends but with this instrument it was difficult to observe differences.

Table V shows the baking data for the gluten-starch and the gluten-starch-water-soluble blends in which the various starches were substituted. Except in a limited number of cases, no extreme differences in mixing time were noted for the different starches. The gluten-starch blends containing the commercial sample of starch or the corn starch had short mixing times. The baking absorptions for the gluten-starch and gluten-starch-water-soluble blends containing the HRS wheat starches were constant except for blends containing the commercial starch and the small- and large-granule fraction starches. The commercial and small-granule fraction starches required a higher baking absorption. Because of the

TABLE V. EFFECT OF DIFFERENT STARCHES IN BAKING

Starch Source	Gluten-Starch Blend			Gluten-Starch-Water-Soluble Blend		
	Mixing time min.	Absorption %	Loaf volume cc.	Mixing time min.	Absorption %	Loaf volume cc.
HRS						
Thatcher	3.5	74.0	147	3.0	72.0	190
Selkirk	3.0	74.0	152	3.0	72.0	189
Justin	4.0	74.0	143	2.75	72.0	193
Chris	4.5	74.0	140	3.0	72.0	184
Manitou	4.25	74.0	140	3.0	72.0	199
Waldron	3.75	74.0	148	3.0	72.0	171
Valley	3.5	74.0	149	2.75	72.0	189
Tobari	3.5	74.0	156	2.75	72.0	204
Fortuna	4.5	74.0	146	3.0	72.0	192
Red River 68	3.5	74.0	149	2.75	72.0	166
Semidwarf	3.25	74.0	160	2.75	72.0	184
Polk	3.25	74.0	149	2.75	72.0	203
Commercial	2.0	80.0	149	1.5	72.0	167
Good-quality baking flour	3.5	74.0	154	2.75	72.0	197
Intermediate-quality baking flour	4.0	74.0	137	2.75	72.0	178
Poor-quality baking flour	4.5	74.0	143	2.75	72.0	181
Small-granule fraction	3.25	84.0	140	2.5	80.0	147
Large-granule fraction	3.75	74.0	138	2.75	68.0	209
Durum wheat						
Mindum	3.25	76.0	155	2.5	72.0	219
Leeds	3.25	80.0	147	2.25	76.0	168
Soft wheat						
Nugaines	3.25	74.0	142	2.75	72.0	168
Club wheat						
Omar	3.25	74.0	160	2.75	72.0	181
Moro	3.25	74.0	161	2.5	72.0	190
Corn starch	2.5	88.0	128	2.25	84.0	145

lower water-binding capacity, a slightly lower absorption was used for the gluten-starch-water-soluble blend containing the large-granule fraction starch. The gluten-starch blends containing the durum starch required a higher absorption, whereas the absorptions used for the blends containing the soft wheat and club wheat starches were the same as that used for the blends containing the HRS wheat starches. The soft wheat, club wheat, and corn starches hydrated faster than the HRS wheat starches. This same observation was noted with the short arrival time obtained with the gluten-corn starch blend. The addition of a fixed amount of water-solubles resulted in a reduction in the mixing time and a reduction in absorption.

The standard deviation for 16 gluten-starch loaves baked in duplicate was 5 cc. From Table V, the average loaf volume of the gluten-starch loaves containing the unmodified HRS wheat starches was 147.5 cc. As seen in this table, 6 of the gluten-starch loaves containing HRS wheat starches had a volume with a deviation from the average greater than 5 cc. The gluten-starch loaves containing the small-granule starch fraction, large-granule starch fraction, as well as Mindum, Nugaines, Omar, Moro, and corn starch, also showed a deviation greater than 5 cc. from the average of HRS wheat starches. The highest loaf volume was obtained with the gluten-starch loaves containing the club wheat starches, and the lowest loaf volume with the corn starch. The loaves containing the corn starch also had an inferior crust color.

The addition of water-soluble material to the gluten-starch loaves resulted in an increase in loaf volume in all cases. However, with the gluten-starch-water-soluble

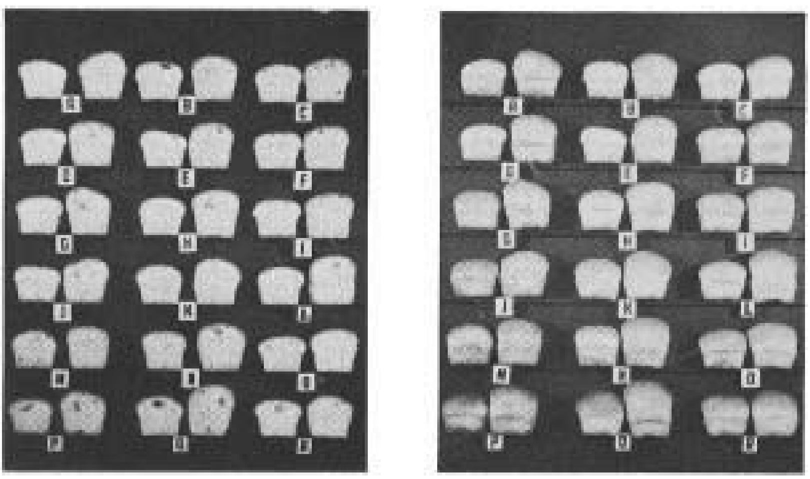

Fig. 2. Photograph showing interior and exterior of gluten-starch and gluten-starch-water soluble loaves. Gluten-starch loaf to the left, gluten-starch-water-soluble loaf to the right, for each pair. Starch source: A. Thatcher, B. Selkirk, C. Justin, D. Chris, E. Manitou, F. Waldron, G. Valley, H. Tobari, I. Fortuna, J. Red River 68, K. Semidwarf, L. Polk, M. commercial, N. good-quality baking flour, O. intermediate-quality baking flour, P. poor-quality baking flour, Q. Mindum, R. Leeds.

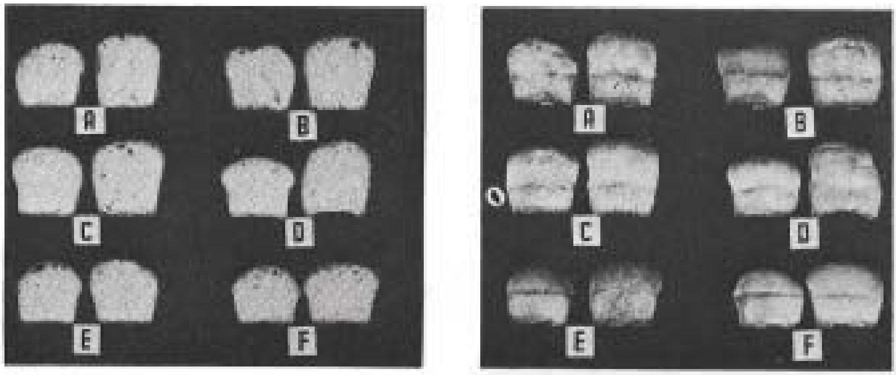

Fig. 3. Photograph showing interior and exterior of gluten-starch and gluten-starch-water-soluble loaves. Gluten-starch loaf to the left, gluten-starch-water-soluble loaf to the right, for each pair. Starch source: A. Nugaines, B. Omar, C. Moro, D. large-granule fraction, E. small-granule fraction, F. corn.

loaves, there was a wider deviation in loaf volume. A range in volume of from 166 to 204 cc. was obtained for loaves containing the HRS wheat starches. The range for the same loaves without the addition of the water-soluble material was 137 to 160 cc. It would appear that addition of the water-soluble material to the gluten-starch blends reacts, or binds, differently with the various starches, thus explaining the wider variation in volume for these loaves. The lack of response with the addition of the water-soluble material was most evident with the loaves containing the small-granule starch fraction.

Figure 2 shows the interior and exterior of the gluten-starch loaves and gluten-starch-water-soluble loaves in which the HRS and durum starches were substituted. In all cases the loaf to the left of each pair is the gluten-starch loaf; the one to the right, the gluten-starch-water-soluble loaf.

Figure 3 shows the interior and exterior of the gluten-starch and gluten-starch-water-soluble loaves in which the starch from soft wheat, club wheat, large and small starch-granule fractions, and corn were substituted. The main differences observed in this photograph is the lower loaf volume of the loaf containing the corn starch. The lack of volume response with the addition of the water-solubles to the gluten-starch blend containing the small-granule starch fraction and corn starch is also evident.

The results of this study have indicated that certain varieties of starch do respond differently in baking. However, the differences observed using a gluten-starch system were not as great or as variable as when a gluten-starch-water-soluble system was utilized. Of the different starch properties examined, only absolute density showed a significant correlation with loaf volume of the gluten-starch loaves. Starches isolated from a more diverse source may very well show a more pronounced effect on bread properties.

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Literature Cited

1. ALSBERG, C. L. Starch and flour quality. Wheat Stud. Food Res. Inst. (Stanford University) 11: No. 6 (1935).
2. SANDSTEDT, R. M., JOLITZ, C. E., and BLISH, M. J. Starch in relation to some baking properties of flour. Cereal Chem. 16: 780 (1939).
3. HARRIS, R. H., and SIBBITT, L. D. The comparative baking qualities of starches prepared from different wheat varieties. Cereal Chem. 18: 585 (1941).
4. HARRIS, R. H., and SIBBITT, L. D. The comparative baking qualities of hard red spring wheat starches and glutens as prepared by the gluten-starch blend baking method. Cereal Chem. 19: 763 (1942).
5. HARRIS, R. H. The baking quality of gluten and starch prepared from different wheat varieties. Baker's Dig. 16(4): 217 (1942).
6. SANDSTEDT, R. M. The function of starch in the baking of bread. Baker's Dig. 35(3): 36 (1961).
7. PENCE, J. W., EREMIA, KATHRYN M., WEINSTEIN, N. E., and MECHAM, D. K. Studies on the importance of starch and protein systems of individual flours in loaf volume production. Cereal Chem. 36: 199 (1959).
8. ROTSCH, A. Chemische und backtechnische Untersuchungen an künstlichen Teigen. Brot Gebaeck 8: 129 (1954).
9. JONGH, G. The formation of dough and bread structures. I. The ability of starch to form structures, and the improving effect of glyceryl monostearate. Cereal Chem. 38: 140 (1961).
10. JONGH, G., SLIM, T., and GREVE, H. Bread without gluten. Baker's Dig. 42(3): 24 (1968).
11. MEDCALF, D. G., and GILLES, K. A. The function of starch in dough. Cereal Sci. Today 13: 382 (1968).
12. MEDCALF, D. G. Wheat starch properties and their effect on bread baking quality. Baker's Dig. 42(4): 48 (1968).
13. POMERANZ, Y. Bread without bread. Baker's Dig. 43(1): 22 (1969).
14. D'APPOLONIA, B. L., GILLES, K. A., and MEDCALF, D. G. Effect of water-soluble pentosans on gluten-starch loaves. Cereal Chem. 47: 194 (1970).
15. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. AACC Approved methods. The Association: St. Paul, Minn. (1962).
16. SANDSTEDT, R. M., and ABBOTT, R. C. A comparison of methods for studying the course of starch gelatinization. Cereal Sci. Today 9: 13 (1964).
17. MEDCALF, D. G., and GILLES, K. A. Wheat starches I. Comparison of physicochemical properties. Cereal Chem. 42: 558 (1965).
18. SCHOCH, T. J., and LEACH, H. W. Determination of absolute density. In: Methods of carbohydrate chemistry, ed. by R. L. Whistler; Vol. IV. Academic Press: New York (1964).
19. WILLIAMS, P. C., and FEGOL, K. S. W. Colorimetric determination of damaged starch in flour. Cereal Chem. 46: 56 (1969).

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