Performance of Wheat and Other Starches in Reconstituted Flours[1]

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ABSTRACT

Reconstituted flours with starches from rye, barley, corn, rice, and potatoes substituted for wheat starch were subjected to cookie-baking, cake-baking, and MacMichael viscosity tests. For cake-baking, the starches were used untreated and treated with chlorine at three levels. Reconstituted flours with rye and barley starches proved very good for cakes and cookies and had viscosities close to those of flours with wheat starch. Corn and potato starches generally gave fair-quality cakes and cookies and intermediate viscosity values. Rice starch gave very poor cakes and cookies and low viscosities. These results indicate that starch must have certain physical and chemical properties for satisfactory performance. Wheat starch was not unique, since rye starch in particular was virtually the equal of wheat starch.

The part each flour constituent plays in wheat-flour quality has long concerned cereal chemists. Today most interest is focused on gluten, the water-soluble proteins, starch, pentosans, and lipids. Of these, gluten and starch make up the major part of flour, and the relative roles of these two have commanded most attention. Probably even today most chemists agree that the unique viscoelastic properties of dough and the excellent bread-baking properties of wheat flour are due primarily to the gluten (1,2,3). Furthermore, only wheat and, to a lesser extent, rye possess these valuable proteins (4).

Over 70% of flour is starch, and several workers have studied the role of starch. Stamberg (5) added wheat, corn, rice, and potato starches to flour to study the absorption properties of these mixtures. Sandstedt et al. (6) baked bread from reconstituted gluten-starch doughs with various wheat and durum starches. Harris and Sibbitt (7) used wheat and emmer starches in reconstituted gluten-starch doughs in a bread-baking study. Sandstedt (8) substituted starches from corn, waxy corn, rice, and potatoes for wheat starch in reconstituted flours and baked bread from these flours. Only the flours reconstituted with wheat starch gave good bread. Yasunaga et al. (9) pointed out the importance of granular starch in gelatinizing and absorbing water during bread-baking. Medcalf and Gilles (10) studied the mixing properties of gluten-wheat starch and gluten-corn starch mixtures. Today perhaps the view prevails that most, if not all, flour constituents are necessary for

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acceptable bread, and that starch plays an important role in the breadmaking process (1,3).

The role of starch in soft wheat flour uses has been investigated. Miller and Trimbo (11) substituted potato and waxy corn starches for up to 30% of cake flour to show the importance of early gelatinization to cake quality. Howard and co-workers (12) demonstrated the essentiality of intact granular starch to layer-cake structure. The improvement in cake-flour quality effected by chlorine treatment of flour has been shown to be due primarily to the action of chlorine on starch (13). The present paper reports the role of starch in three soft wheat flour tests studied through the use of reconstituted flours.

MATERIALS AND METHODS

Flours

For cookie-baking and MacMichael viscosity experiments, hard common wheat (Itana), soft common wheat (Gaines), and club wheat (Omar) varieties were selected to cover a wide range in quality. Composites of each variety were made and milled on a Buhler[R] laboratory mill.[3] The flours were typical and conformed to the varietal ratings established in this laboratory (14). A commercial, unbleached cake flour was used for the cake-baking experiments.

Flour Fractions

Flours were fractionated into water-solubles, gluten, tailings, and starch (15). It was possible but difficult to fractionate the very soft and weak Omar and unbleached cake flours by kneading. Partial disintegration of the doughball occurred, but the gluten particles could be recovered from the screen. The fractions from these flours, however, corresponded closely in yield and protein content to those from the other flours. The wheat starches were thus obtained by essentially neutral procedures and were air-dried.

Other Starches

Rye starch was prepared by milling No. 1 market-grade rye grain to a flour on a Buhler mill and applying an acetic acid extraction procedure to the flour (16). Attempts to form a doughball from rye flour and separate starch by kneading were unsuccessful.

Barley starch came from two sources. One lot was prepared by a modified batter process (17) from Betzes barley at Montana State University and was not subjected to either alkali or acid washing; thus it was obtained by a neutral process. The other lot was prepared by milling a mixture of equal parts Gem and Unitan barley grain to a flour on a Buhler mill and by applying the acetic acid extraction procedure (16) to the flour. Corn and potato starches were furnished by commercial producers.

The Rice Experiment Station, Beaumont, Texas, supplied milled Belle Patna rice of 5.7% protein content. Rice starch was first prepared by a screening process (18) adapted to milled rice.[4] This somewhat tedious method yielded 62% starch with 3% protein content.

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[3]This is a trademark of The Buhler Corporation, Minneapolis, Minn. 55426.

[4]Personal communication from Joseph T. Hogan, Southern Utilization Research and Development Division, New Orleans, La. 70119.

Application of the acetic acid extraction procedure (16) to ground milled rice was then found feasible. Centrifugation of the acid suspension left a two-layer residue of crude starch similar to that from wheat flour. The upper, rather thin, nearly-white layer was separated almost entirely by feel (with wheat-flour tailings, color is also an important indicator for separation) and discarded. The lower, dense, pure-white layer was resuspended, neutralized, and air-dried. This method yielded 78% starch of 1.3% protein and 3.2% damaged-starch contents.

Publication by Schoch and Maywald (19) of improved procedures for separating legume starches from fiber and insoluble protein provided a means of preparing relatively pure rice starch. Method B (19) was used with slight modifications. The suspension obtained by steeping and grinding milled rice was screened through 100- and 200-mesh screens. No tabling equipment was available; therefore the crude starch was suspended in 0.2% sodium hydroxide for 30 min. and then centrifuged for 10 min. at 2,000 r.c.f. A light-yellow, soft upper layer similar to wheat-flour tailings was scraped off and discarded, leaving a firm, white lower layer. The alkaline suspension and centrifugation were repeated once for a total of two alkaline suspensions after preliminary trials showed that three alkaline suspensions gave no lower lipid content and only slightly lower protein content than two alkaline suspensions. Total contact time with alkali was 4 to 6 hr. The starch was resuspended in water, neutralized, and air-dried. This procedure gave 63% yields of rice starch with 0.3% protein and 0.6% damaged starch. Table I gives data for all the starches.

Chlorine Treatment of Starches

Starches were treated with chlorine for 5 min. with agitation in a laboratory bleaching apparatus (20). Earlier studies (21) had shown that a relatively small

TABLE I. ANALYTICAL DATA FOR STARCHES

Starch	Yield of Parent Flour %	Moisture %	Protein %	Lipid %	Damaged Starch %	pH
Wheat						
Itana	60	10.4	0.2	0.48	1.6	6.0
Gaines	63	10.1	0.2	0.44	0.3	6.2
Omar	67	10.4	0.2	0.53	0.5	6.2
Cake flour	66	10.7	0.2	0.43	0.3	6.1
Rye	56	12.2	0.1	0.19	0.8	6.2
Barley						
Acid process	66	11.4	0.3	0.62	0.7	6.5
Batter process	Purchased	9.0	0.1	0.88	0.3	6.8
Corn	Commercial	10.3	0.2	0.59	1.1	6.7
Rice[a]						
Acid process	78	11.4	1.3	0.66	3.2	6.8
Alkaline process	63	11.1	0.3	0.67	0.6	7.0
Potato	Commercial	12.0	0.0	0.01	0.0	7.1

[a]Yield of rice starch is based on milled rice.

amount of chlorine applied for as little as 1 min. produced optimum improvement of wheat starch for cake-baking; generally this amount was about one-fourth that required for optimum improvement of the entire flour. However, each starch was treated at three levels to uncover any potential for cake-baking: at the optimum for wheat starch, and at three times and ten times this amount. Moisture contents of the starches ranged from 10.0 to 12.2% except for the batter-process barley starch at 9.0%. The unbleached cake flour was also treated in the laboratory apparatus as a check on the effectiveness of the procedures.

Flour Reconstitution

For cookie-baking, the liquid concentrate of water-solubles was warmed to room temperature, and appropriate amounts were mixed with gluten, tailings, and starch in the proportions obtained in fractionation. Amounts of fractions corresponding to 50.0 g. flour, plus additional water if necessary, were mixed in a 100-g. dough mixer to doughs of optimum consistency. Doughs were lyophilized and ground. The resulting flours were rehydrated to 14% moisture and used for cookie-baking.

For viscosity experiments, gluten, tailings, and starch in the proportions obtained in fractionation were blended and mixed with distilled water in the 100-g. dough mixer. These doughs were lyophilized and ground but not rehydrated (15).

For cookie-baking and MacMichael viscosity studies, preliminary trials were made to determine the optimum conditions for reconstituting each flour. Duplicate reconstitutions in different weeks were then made for each flour for each test. Each reconstitution study contained all six starches tested.

For cake-baking, amounts of fractions corresponding to 75.0 g. flour (plus water if necessary) were mixed to doughs of optimum consistency. These doughs were introduced directly into the cake-baking test (22,23).

The lean-formula cake test used (24) is sensitive to water level. Each flour and each blend of fractions used was baked over a wide range of water levels to determine the optimum level. Duplicate reconstitutions of the entire series of starches at the optimum water level for each blend were then made in different weeks for the unbleached starches and for each of the three levels of chlorine treatment.

Baking Methods

A modified Kissell lean-formula white layer cake test (24) was used. Direct introduction of reconstituted doughs with 55% or more water into this test does not permit the use of liquid sucrose solution. Doughs (75.0 g. flour equivalent and 41 to 52 ml. water) were added to 97.5 g. sugar, 21.0 g. shortening, and 3.5 g. baking powder and mixed for 0.5 min. at low speed and 2.5 min. at medium speed. Water (varying amounts) was added, and the batter was mixed 0.5 min. at low speed and 1.5 min. at medium speed. One cake was baked as in the original method (24) and scoring was according to the original method.

Cakes to serve as standards were baked from the untreated and treated commercial cake flour by this method. Flour (75.0 g.) and 45 ml. water were added to the dry ingredients and the above procedure followed.

Cookies were baked by the micro method of Finney et al. (25).

MacMichael Viscosity

Viscosity was determined by a slight modification of the official method (26). Mechanical shaking was used, the digestion time was omitted, one addition of 7 ml. 1N lactic acid was made, and the reading was taken within 15 to 30 sec. after the bob was resuspended.

Analytical Methods

Protein and pH were determined by conventional methods (26). Damaged starch was determined by a recent modification (27) of the original Donelson and Yamazaki method (28). Lipids were determined by acid hydrolysis (29).

RESULTS AND DISCUSSION

The results reported here were obtained with wheat, barley, corn, and potato starches prepared by neutral methods and with rye and rice starches from the acid-extraction procedure. Preliminary trials showed that the alkaline process rice starch gave poorer results (to be discussed later) in baking tests than did the acid process rice starch. Barley starch was prepared by the acid-extraction procedure after the batter process barley starch showed some anomalies.

Table II lists the diameters for cookies from flours reconstituted with wheat starch and with other starches substituted for wheat starch. Figure 1 shows the cookies from one complete reconstitution series.

In the Gaines series, rye, barley, and potato starches gave cookies that were almost equal in diameter to the wheat-starch cookie. The rye- and barley-starch cookies were equal in quality (color, top grain, and general appearance) to the wheat-starch cookie. The potato-starch cookie frequently was of poorer quality (darker colored and lumpy). Corn starch produced a smaller, thicker cookie although one of pleasing appearance. Rice starch caused the cookie to be very small and thick, similar to cookies from hard wheat flours.

Present standards for cookie baking quality require the flour to yield a large diameter cookie with attractive top grain and color. Under these standards the rye- and barley-starch cookies would be acceptable. The potato-starch cookie would be questionable because of its appearance. The corn-starch cookie would be borderline

TABLE II. COOKIE DIAMETERS FOR FLOURS RECONSTITUTED WITH VARIOUS STARCHES

	Standard[a] cm.	Wheat Starch cm.	Rye Starch cm.	Barley Starch cm.	Corn Starch cm.	Rice Starch cm.	Potato Starch cm.
Gaines[b]	8.77	8.70	8.59	8.44	8.16	7.52	8.87
Omar	8.86	8.75	8.79	8.62	8.44	7.67	8.32
Itana	7.67	7.69	7.52	7.45	7.32	6.98	7.50

[a]Cookie from normal, unfractionated flour of the indicated variety.

[b]Each reconstituted flour in this line contained water-solubles, gluten, and tailings from Gaines flour plus the indicated starch; likewise for Omar and Itana.

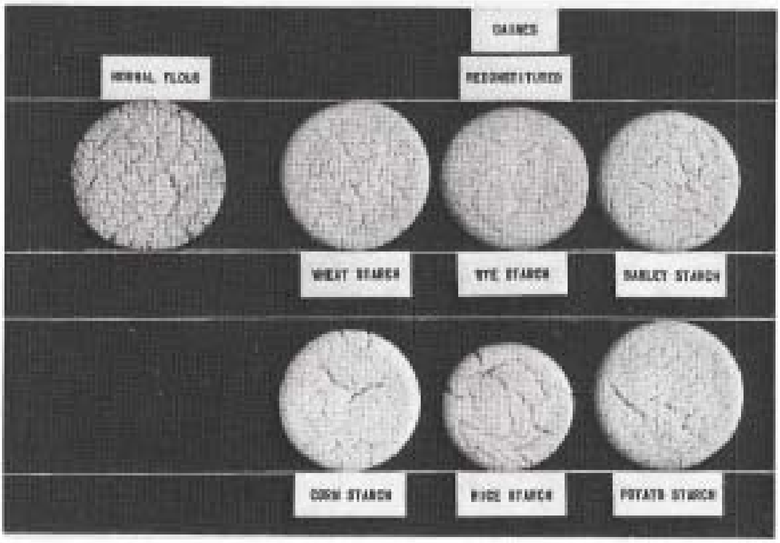


Fig. 1. Cookies baked from reconstituted flours with various starches plus Gaines water-solubles, gluten, and tailings.

because of small diameter, and the rice-starch cookie would be completely unacceptable.

Results with Omar, the club wheat flour, were similar to those with Gaines flour, and the same comments would apply.

Duplicate reconstitutions were made with Itana flour fractions with the various starches substituted for wheat starch (Table II). Itana has good hard-wheat but poor soft-wheat quality. Again, rye, barley, and potato starches produced cookies nearly equal in diameter to the wheat-starch cookie, and potato starch gave an occasional dark, lumpy cookie. Corn starch gave smaller, and rice starch very small, cookies compared with the other starches. This experiment showed that even at the relatively poor quality level of the Itana cookie, the type of starch made a difference.

Lean-Formula Cakes from Normal Flours

Cakes were baked from the normal flours by the original lean-formula method using liquid sucrose solution (24) and by the modified method using dry sugar and water (23). The modified method in this laboratory gave slightly lower quality cakes than the original method.

Cake-baking Results with Untreated Starches

Because untreated wheat starch has poor cake-baking quality but is capable of a large response to chlorine treatment, the cake-baking qualities of the other untreated starches were determined. Table III gives the average results of duplicate runs, while Fig. 2 shows the cakes from one run.

Untreated rye starch gave a surprisingly good-quality cake of fair volume. Untreated barley and potato starches gave cakes somewhat better than the untreated wheat-starch cake, which in Fig. 2 was better than the average of

TABLE III. CAKES FROM FLOURS RECONSTITUTED WITH VARIOUS UNBLEACHED STARCHES

	Standard[a]		Reconstituted[b]													
			Wheat starch		Rye starch		Barley starch		Corn starch		Rice starch		Potato starch	
	I ml.	II ml.	I ml.	II ml.	I ml.	II ml.	I ml.	II ml.	I ml.	II ml.	I ml.	II ml.	I ml.	II ml.
Volume	365	375	360	370	425	440	395	425	350	355	350	340	380	375
Score	3	3	2	2	7	7	4	5	1	1	0	0	5	4

[a]Normal, unfractionated, unbleached cake flour.

[b]Water-solubles, gluten, and tailings were from unbleached cake flour.

untreated wheat starch. Corn starch gave a poor cake, and the rice-starch cake was very poor.

Chlorine Treatment of Starches

The pH responses of the starches to chlorine treatment are shown in Table IV. Barley starch had very little drop in pH with increasing amounts of chlorine. Rye and rice starches gave moderate drops in pH values. Wheat, corn, and potato starches exhibited more decided drops in pH with increasing amounts of chlorine. There appeared to be no relation between starch lipid content and the amount of chlorine required to effect the pH drop.

Cake-baking Results with Treated Starches

The wheat and other starches treated with chlorine at three levels were reconstituted with the other three untreated fractions into doughs and baked into cakes. The effect of different amounts of chlorine on cake volume is shown in Fig. 3. Wheat starch, as previously reported (21), gave maximum volume at the lowest level of treatment used in this study. Four of the other starches also gave maximum volume at the lowest treatment level. Barley starch gave a different response; volume of barley-starch cakes was improved almost to maximum by the lowest treatment and remained about the same through the highest treatment.

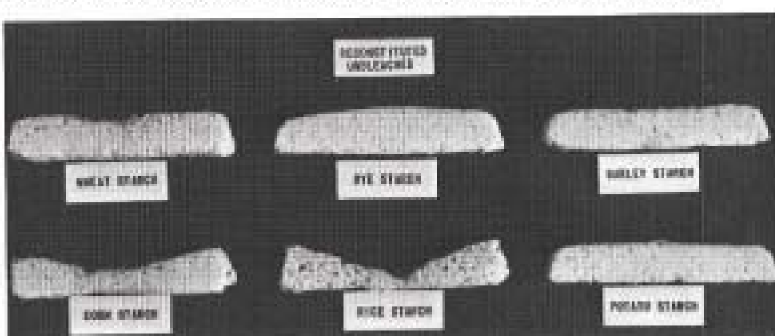


Fig. 2. Lean-formula cakes from reconstituted doughs with various untreated starches plus cake flour water-solubles, gluten, and tailings.

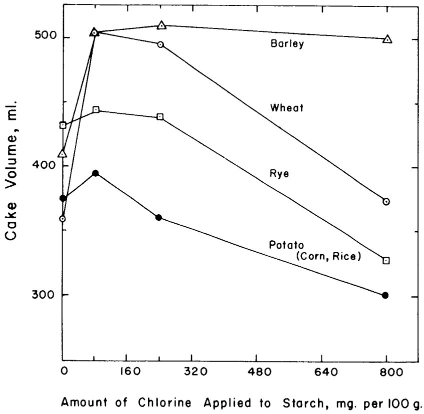
TABLE IV. THE EFFECT OF CHLORINE ON STARCH pH

Amount Chlorine per 100 g. Starch mg.	Wheat starch pH	Rye starch pH	Barley starch pH	Corn starch pH	Rice starch pH	Potato starch pH
0	6.2	6.3	6.7	6.5	6.6	7.1
80	4.1	5.2	6.5	4.3	5.7	5.2
240	3.8	4.9	6.4	3.9	5.0	4.1
800	3.5	4.5	6.2	3.3	4.5	3.9

Optimum cake score also occured with the lowest level of treatment for all starches (Fig. 4). Rye starch (not shown) improved from a score of 7 when untreated to 9 at the lowest treatment and then closely followed the wheat-starch behavior. Potato starch, which gave a fair cake untreated, was improved slightly by chlorine (score increased from 4.5 to 6), and this was in the absence of any lipid. Corn starch was more improved by treatment (score going from 1 to 5), but it still yielded only a fair cake at optimum treatment. Rice starch remained poor under any treatment.

Barley starch was again different in that cake score did not deteriorate through the highest level of chlorine used. Barley starch pH did not drop appreciably with heavy chlorine treatment, and this may be related to the stability of the volumes and scores of the treated barley-starch cakes.

The best cake from each treated starch is shown in Fig. 5. This was, of course, the cake with the starch from the lowest level of treatment. The best reconstituted cakes were those with the treated rye and barley starches; these were judged equal in quality to cakes from the bleached normal cake flour. Treated wheat-starch cakes were almost as good.



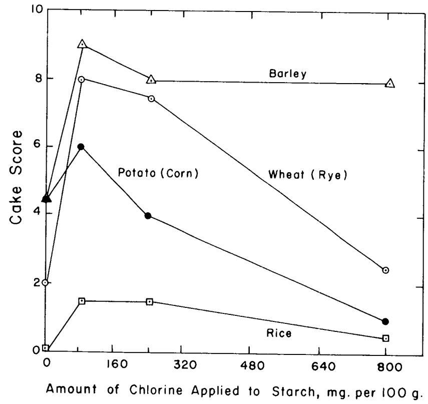


Fig. 3 (left). The effect of different amounts of chlorine on the volume of cakes from doughs reconstituted with various starches.

Fig. 4 (right). The effect of different amounts of chlorine on the score of cakes from doughs reconstituted with various starches.

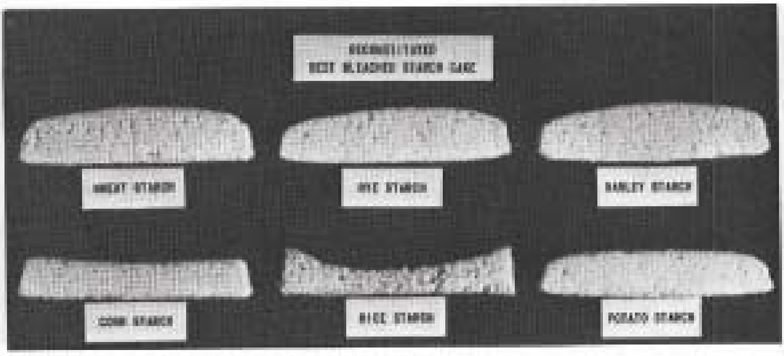


Fig. 5. The best reconstituted cake from each starch.

MacMichael Viscosities with Various Starches

An important physical test in soft wheat flour evaluation is the MacMichael viscosity test. It has long been known that if the water-soluble material were extracted from flour, leaving what is here termed residues, the MacMichael viscosity would rise sharply. Recently it was shown that gluten, tailings, and starch could be reconstituted to residues whose viscosities matched closely those of the corresponding water-extracted flours (15).

The starches were reconstituted with gluten and tailings of the varietal flours into residues and subjected to the viscosity test. Table V lists the results. For reconstituted residues from the two common wheat flours, rye starch gave lower and barley starch higher viscosities than did wheat starch. Corn, rice, and potato starches caused viscosity to be much lower than wheat starch, with rice starch giving decidedly low viscosities.

With club-wheat flour residues, rye, barley, and potato starch residues gave higher viscosities than the wheat-starch residue. Corn- and rice-starch residues had lower viscosities than wheat-starch residues.

Liquid Requirements for Dough Reconstitution

Yamazaki (30) was the first to show that it was necessary to form a dough from the fractions prior to cookie-baking. Succeeding investigators have confirmed this

TABLE V. MacMICHAEL VISCOSITIES OF RESIDUES RECONSTITUTED WITH VARIOUS STARCHES

	Standard[a]	Wheat starch	Rye starch	Barley starch	Corn starch	Rice starch	Potato starch
				Degrees MacMichael			
Itana[b]	318	323	272	345	220	158	243
Gaines	145	139	102	168	90	61	102
Omar	54	53	58	68	37	36	69

[a]A water-extracted but not further fractionated flour residue.

[b]All residues in this line contained Itana gluten and tailings plus the indicated starch; likewise for Gaines and Omar.

TABLE VI. LIQUID REQUIRED TO FORM A DOUGH DURING RECONSTITUTION[a]

	Wheat starch ml.	Rye starch ml.	Barley starch ml.	Corn starch ml.	Rice starch ml.	Potato starch ml.
Cookie-baking,						
Gaines	56	56	57	64	74	58
Cake-baking,						
Untreated	56	57	59	65	76	56
Lowest chlorine treatment	57	59	61	67	76	57
MacMichael viscosity						
Gaines	57	56	60	64	74	57

[a]Expressed as ml. liquid per 100 g. fractions at 14% moisture. For cookie- and cake-baking, this was 50 ml. liquid concentrate of water-solubles from 100 g. flour plus water to give the required consistency. For MacMichael viscosity, this was water.

for cookie-baking (16), cake-baking (13,23), and viscosity test (15). In the present study, the amount of water (or liquid concentrate of water-extract plus water) necessary to form a dough was fairly uniform throughout the three types of reconstitutions (cookie flours, cake doughs, and viscosity residues), and the pattern of responses was uniform among the three types (Table VI).

The amount of liquid necessary did vary with the kind of starch (Table VI). Wheat, rye, and potato starches required the smallest amounts, and there was very little variation in liquid requirements among these three. There was a tendency for barley starch to need more liquid, and corn starch required distinctly higher liquid levels. Rice starch needed an extremely large amount of liquid to form a dough. These requirements have a close, inverse relation to the general performance of the starches in the various tests. Whether there is any significance to this observation is unknown at present.

There was a small but consistent, easily detectable increase in liquid requirement

TABLE VII. COMPARISON OF STARCHES PREPARED BY DIFFERENT PROCEDURES

	Barley Starch		Rice Starch	
Test	Acid process	Batter process	Acid process	Alkaline process
Cookie diameter, cm.				
Gaines	8.25	8.17	7.49	7.96
Cake-baking				
Untreated				
Volume, ml.	405	410	345	310
Score	5	5	0	0
Treated, lowest chlorine level				
Volume, ml.	505	505	375	340
Score	9	9	1	0
Viscosity				
Degrees MacMichael				
Gaines	114	150	54	116

after chlorine treatment. This increase occurred at the lowest level of treatment and stayed the same through the highest level.

The water-solubles appeared to have no role in liquid requirements, since the blends for viscosity tests needed about the same amounts as the blends containing all four fractions.

Barley Starches Prepared by Two Different Methods

Barley starch prepared by the neutral batter process gave higher viscosities (in reconstituted flours) than those obtained with wheat starch, and chlorine treatment of this neutral barley starch resulted in very little change in pH. This suggested preparation of barley starch by the acetic acid extraction procedure for comparison. Some of the results obtained with these two barley starches are shown in Tables VII and VIII.

Cookie-baking and cake-baking results were practically identical for the two barley starches (Table VII). Cookie quality (top grain, shape, and color) was identical, and very good for reconstituted cookies. The batter-process barley starch gave higher viscosities than did the acid-process barley starch, and chlorine had little effect on the pH of the batter-process starch but about the normal effect on acid-starch pH. Chlorine had the same quality-improving effect on both starches, and, interestingly, both barley starches gave cakes of about the same volume and quality at all levels of treatment (Figs. 3 and 4, and Table VII). Barley starch may differ from other starches in its reaction with chlorine.

Rice Starches Prepared by Different Methods

Rice starches from the acetic acid extraction procedure (16) and the screening method (18) had higher protein and damaged-starch contents than the other starches (Table I). Rice starch prepared by the alkaline extraction procedure of Schoch and Maywald (19) was similar in analytical data to the other starches (Table I). Cookie diameter with the alkaline rice starch was somewhat larger than that obtained with the acid rice starch (Table VII), but the cookie was of poorer quality with excessive top grain. Chlorine treatment of alkaline rice starch caused slightly larger drops in pH than with acid rice starch (Table VIII). Cake-baking results (Table VII) were even poorer. The Schoch and Maywald procedure as used here exposed the starch to 0.2% sodium hydroxide (about pH 12) for 4 to 6 hr.; evidently this exposure was somewhat deleterious to baking quality. The alkaline rice starch gave higher viscosities than did the acid rice starch.

TABLE VIII. THE EFFECT OF CHLORINE ON THE pH OF BARLEY AND RICE STARCHES

	Barley Starch		Rice Starch	
Amount Chlorine per 100 g. Starch mg.	Acid process pH	Batter process pH	Acid process pH	Alkaline process pH
0	6.4	6.7	6.6	7.0
80	5.8	6.5	5.7	6.3
240	5.0	6.4	5.0	4.4
800	4.6	6.2	4.5	3.6

GENERAL DISCUSSION

As the standard in reconstitution studies, wheat starch gave the best cookie, produced a poor cake when untreated, was improved greatly by chlorine to give a very good cake, had a high MacMichael viscosity, and had the lowest water requirement. Rye starch gave a very good cookie and a good cake when untreated, was improved slightly by chlorine to give the best-quality cake, and had a viscosity slightly lower than and a water requirement the same as wheat starch. Barley starch gave a good cookie, produced a fair cake untreated, was improved by chlorine to give the best quality reconstituted cake, and had a higher viscosity and slightly higher water requirement. The chief differences between rye and barley starches and wheat starch were in the better cakes from untreated starches and the lesser responses to chlorine. Otherwise, rye starch was virtually the equal of wheat starch, and barley was almost as good. Thus, wheat starch is not unique among starches in possessing good quality, as wheat gluten seems to be among plant proteins.

Corn starch generally gave intermediate results: smaller cookies; some response to chlorine but still smaller, poorer cakes; lower viscosities; and higher water needs. Potato starch was difficult to classify; it gave large cookies and fair cakes, but otherwise, like corn starch, it gave intermediate results.

In all tests, rice starch gave the poorest results. The rice-starch cookies and cakes were the smallest and poorest in quality, there was very little response to chlorine, viscosities were very low, and the water requirements were extremely high.

The literature values for granule size and gelatinization temperature ranges for the starches are listed in Table IX together with overall performance. Perhaps the most obvious fact is that both these properties along with the water requirements varied with the baking and viscosity performance. Rice starch, the poorest performer, had the smallest granule size, the highest gelatinization temperature, and abnormally high water requirements. Wheat starch had exactly the opposite characteristics. Corn and potato starches had intermediate values generally; one anomaly was the extremely large granules in potato starch.

It is tempting to speculate that granule size was a dominating factor in performance. The large granules of wheat, rye, and barley starches might account

TABLE IX. COMPARISON OF STARCH PERFORMANCE WITH LITERATURE VALUES FOR TWO PHYSICAL PROPERTIES

Starch	Performance	Granule Size Range[a] μ	Gelatinization Temperature Range[b] °C.
Wheat	Good	2–10 and 20–35	52–63
Rye	Good	. . .	. . .
Barley	Good	2–6 and 20–35	. . .
Corn	Fair	5–25	62–72
Potato	Fair	15–100	56–66
Rice	Poor	3–8	70–73[c]

[a] Reference 31.

[b] Reference 32.

[c] For Belle Patna variety. Personal communication from B. D. Webb, Crops Research Division, ARS, USDA, Beaumont, Texas 77706.

for the high-quality performance, the small granules of rice starch for its poor performance, and the anomaly of potato starch to the small number of very large granules. However, much the same comments would apply to gelatinization temperatures. Much more evidence will be needed before the behavior of the different starches can be explained.

The present study adds evidence to the work of Sandstedt (8), Miller and Trimbo (11), and Howard and co-workers (12) in showing that starch plays an important role in baking quality. Starch must have certain physical and chemical properties for good performance. Starches not having these properties, such as rice starch, will not give good results. It also seems safe to conclude, as MacMasters did (33), that interaction effects between protein and starch are very important.

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