Physicochemical Properties of Starches of Wheats and Flours[1]

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ABSTRACT

The properties of mature wheat starch granules and the effects of milling were investigated. Starches were separated from three hard winter-, three hard spring-, and two soft wheat flours, and from their parent wheats. Those from wheats were obtained under conditions designed to provide minimum changes in the granules. The native granules from different wheats varied only slightly in physicochemical properties except that those of the soft-wheat group were more soluble and yielded hot pastes of lower stabilities than those derived from hard wheats. The breadmaking potential of winter-wheat starches was highest, followed by spring- and soft-wheat starches. Differences between the parent wheat and flour starches reflected the effects of milling. As compared with the parent-wheat starch, the flour-starch differed little in swelling power and gelatinization-temperature ranges, but had lower Brabender consistencies, slightly higher solubilities, and greater susceptibility to enzymolysis and a higher water-hydration capacity. The baking potential of flour starch was less than that of the parent-wheat starch, indicating that native granules are desirable for the optimum starch performance, provided sufficient fermentable carbohydrates are used in the bread formula. Of the flour starches, best results were obtained with spring flour starches, followed in order by the soft flour- and then winter flour starches.

Starch is a major constituent of flours. It appears, therefore, likely that its characteristics and condition may contribute to the baking properties of flours.

There is no uniform opinion about the relative importance of starch to quality of flours, although its necessity in the formation of bread is well documented. Rotsch (1) made breads without gluten using starch and various hydrophilic colloids. Similarly, Jongh (2) produced products with breadlike structure using starch-emulsifier systems. Further, it is recognized that wheat starch performs in bread systems better than all other starches except those from rye and barley, which also appear to be functional and similar to wheat starch (3). The data vary on the baking quality of wheat starch itself. The underlying cause of discrepancy may be that, generally, starches modified by milling were investigated. Medcalf and Gilles (4) studied the physicochemical properties of native starches after defatting, which also might have altered their functionality. Recently, D'Appolonia and Gilles (5) studied a series of wheat starches isolated from flours milled from commercial blends and pure wheat varieties. Only small variations in baking properties of these starches were found in the absence of flour water-solubles; they became more pronounced, however, when water-solubles were used, indicating an interaction between starch and certain water-soluble components.

The purpose of the present study was to learn the fundamental and baking properties of native wheat starches and to determine the effects of milling on these characteristics. Physicochemical indices were determined for starches isolated from flours and their parent wheats. Then, the same starches were tested in actual

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baking, using a gluten-starch model system in an attempt to correlate the objective data with baking performance.

MATERIALS AND METHODS

Wheats and Flours

The starches were isolated from eight pairs of wheat and flour samples; the flours in each pair were of straight grade, totally untreated, and commercially milled from the respective wheats by the conventional process. This sample selection was made to permit an estimation of the effects of milling on the starch component of typical flours. The pertinent analytical data of these samples are given in Table I. All samples were refrigerated prior to use.

Isolation of Starches from Wheats and Flours

Starches were isolated from wheats under conditions of minimum damage, as suggested by Schoch[2]. Wheats were washed and steeped overnight under toluene at 50°C., and the softened grain was wet-milled in a Waring Blendor. The magma was screened through a bolting cloth, and the starch recovered from the filtrate by centrifugation. Only the prime-starch portion was used. The starch was thoroughly washed repeatedly by resuspending in distilled water and centrifuging. Starches from flours were prepared by the dough procedure (6).

The pH values of the starches were 5.9 to 6.0; protein content of starches was 0.23 to 0.30% (N × 5.7) on a moisture-free basis.

Pasting Characteristics

The starch-paste consistencies were studied by means of Brabender Visco/Amylograph (7). Nine parts of starch solids per 100 parts (420 ml.) of water were heated from 25° to 95°C., kept at this temperature for 60 min., then cooled to 35°C. and held at 35°C. for 60 min. The following reference consistencies (B.U.) are reported: peak (95°); 60 min. after peak; at 35°C.; and 60 min. after reaching 35°C.

Solubility and Swelling Power

By the procedure of Leach et al. (8) these properties were tested for the

TABLE I. ANALYSES[a] OF WHEAT AND FLOUR SAMPLES

Series		Protein (N × 5.7)		Ash	
		Wheat %	Flour %	Wheat %	Flour %
Spring wheat					
A	Montana-N. Dakota	13.4	12.8	1.69	0.48
B	Montana-N. Dakota	13.4	12.7	1.70	0.48
C	N. Dakota	14.8	13.5	1.76	0.48
Winter wheat					
D	Kansas-Nebraska	14.6	11.5	1.86	0.48
E	Montana	14.5	11.2	1.47	0.48
F	Kansas-Nebraska	11.6	11.3	1.60	0.44
Soft wheat					
G	Indiana, red	11.0	10.6	1.71	0.46
H	Michigan, white	10.3	7.6	1.60	0.40

[a]All data are given at 14% m.b.

[2]Thomas J. Schoch, personal communication (1967).

temperature range from 60° to 95°C., with 5°C. intervals. The swelling powers were corrected for the solubility of the starch.

Gelatinization Temperatures

These measurements were made microscopically with a Kofler hot stage according to Schoch and Maywald (9).

Enzymic Susceptibility

The procedures of Schoch (10) were followed. Starch (25 g.) was suspended in water (100 ml.), the pH adjusted to 4.7, and 1% (starch basis) of a commercial amylase (Rhozyme 33) added. The starch was incubated with agitation for 24 hr. at 30°C. (Dubnoff Shaker); then the amount of the insoluble residue was determined. Blank determinations were run with all the assays.

Water-Binding Capacity

Water-binding capacity was determined according to Medcalf and Gilles (4).

Baking Tests

The remix procedure (11) was adapted for preparation of pup loaves from fractions. Gluten-starch blends were used instead of flours. Gluten isolated by the dough process was frozen and stored at −20°C. prior to use. The bread formula consisted of: 100 g. starch-gluten mixture, 10 g. sucrose, 1.5 g. salt, 0.5 g. mineral yeast food, 3.0 g. lard, 3.0 g. yeast, 4.0 g. nonfat dry milk solids, and water as required. Gluten was added to produce 12.5% protein (N X 5.7) of the starch-gluten mixture, dry basis. A single gluten preparation was used with each starch sample. Water in the formula was adjusted with each starch to provide doughs of optimum consistency.

Other Methods

General analytical determinations were made according to AACC procedures (12).

RESULTS AND DISCUSSION

The results of the physicochemical measurements and of the baking tests of the starches are presented individually and then the possible correlations are discussed.

Pasting Properties of Starches

Typical viscograms of starches derived from hard- and soft-wheat samples (flours and parent wheats) are shown in Figs. 1 and 2, respectively; detailed viscogram indices of the individual samples are reported in Table II. These data characterize the pasting patterns of starches, reflecting the physicochemical makeup of the granules.

Only nominal variations were observed among starches derived from hard wheats; there were significant differences between starches from soft and hard wheats, as evident from comparison of Figs. 1 and 2, and also from data in Table II. Although values of hot- and cold-paste consistencies from both wheat groups were similar, the stabilities of hot pastes of starches from soft wheat (Fig. 2) were below those from hard wheats (Fig. 1). The starch-consistency maxima from hard wheats were reached only during the holding period subsequent to the peak

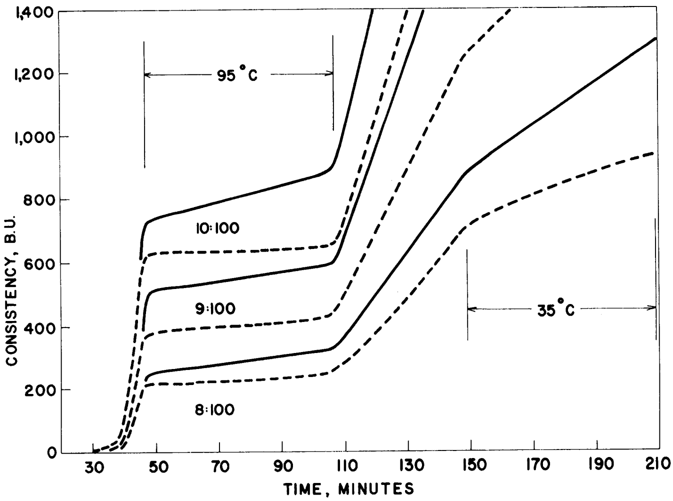

Fig. 1. Viscograms of hard-wheat starch (solid lines) and of the corresponding flour starch (broken lines) at different concentrations (10, 9, 8 parts of starch solids per 100 parts of water).

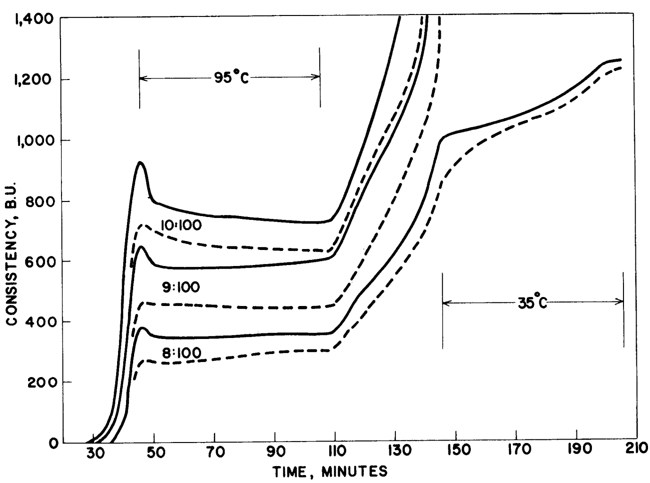

Fig. 2. Viscograms of soft-wheat starch (solid lines) and of the corresponding flour starch (broken lines) at different concentrations (10, 9, 8 parts of starch solids per 100 parts of water).

temperature; those of soft-wheat starches, however, occurred with the attainments of peak temperature, and then a setback was observed. Since differences in the pasting characteristics of starches reflect the strength of associative forces in the granules, it can be postulated that the hard-wheat starches are more closely associated than those from soft wheats.

TABLE II. VISCOGRAPHIC INDICES OF STARCHES

Starch from[a]	Consistency, B.U.			
	Peak	After 60 min. at peak temp.	At 35° C.	After 60 min. at 35° C.
Spring wheat series:				
Wheat A	470	600	1,800	2,200
Flour A	395	520	1,290	2,130
Wheat B	440	630	1,730	2,340
Flour B	380	410	1,510	2,130
Wheat C	580	500	1,330	1,670
Flour C	485	450	1,160	1,670
Av. wheat	497	567	1,620	2,070
Av. flour	420	460	1,320	1,977
Winter wheat series:				
Wheat D	500	620	1,705	2,080
Flour D	360	430	1,590	1,910
Wheat E	510	590	1,780	2,230
Flour E	380	430	1,260	1,840
Wheat F	580	570	1,530	1,910
Flour F	400	420	1,330	1,710
Av. wheat	530	593	1,672	2,073
Av. flour	380	427	1,393	1,820
Soft wheat series:				
Wheat G	650	590	1,690	2,170
Flour G	460	420	1,320	1,700
Wheat H	700	540	1,560	2,010
Flour H	425	410	1,180	1,600
Av. wheat	675	565	1,625	2,090
Av. flour	443	415	1,250	1,650
Av. all wheats	554	580	1,641	2,076
Av. all flours	411	436	1,330	1,836

[a]Nine parts of starch solids per 100 parts of water.

A comparison of indices of starches from wheats with those from the corresponding flours shows clearly lower consistencies of the flour starches at all the reference points. These differences, caused by conversion of wheat to flour, were observed with all of the sample pairs regardless of the type of wheat, but varied in the degree because of differences in the inherent fragility of the granules and in the severity of the milling process. The soft-wheat starches appeared to be more altered than those from the hard wheats. Of the hard-wheat group, winter-wheat starches were more affected than those from spring wheats. This is rather surprising since it is a general milling experience that more power input is required for milling of spring and soft than of winter wheats. These effects point out the inherent differences among the starch granules of the wheat groups.

Swelling Powers and Solubilities

Swelling powers and solubilities for the temperature range from 60° to 95°C., measured at 5°C. intervals, are given in Tables III (swelling power) and IV (solubilities). The swelling powers were corrected for solubilities, and thus represent

TABLE III. SWELLING POWERS OF STARCHES
(% d.b., corrected for solubles)

Starches from:	Pasting Temperature, °C.							
	60	65	70	75	80	85	90	95
Spring wheat series:								
Wheat A	3.1	5.7	6.3	6.5	7.6	7.8	8.7	10.5
Flour A	4.2	5.3	6.0	6.8	7.1	7.5	9.3	12.2
Wheat B	3.7	5.2	6.0	6.4	6.9	7.6	9.7	13.7
Flour B	4.2	5.5	6.0	6.7	7.2	7.7	10.0	14.1
Wheat C	3.1	5.8	6.4	6.8	7.1	7.8	8.9	12.3
Flour C	3.7	5.5	6.5	7.0	7.3	7.7	8.6	11.9
Av. wheat	3.30	5.57	6.23	6.57	7.20	7.73	9.10	12.27
Av. flour	4.10	5.43	6.17	6.83	7.20	7.63	9.30	12.73
Winter wheat series:								
Wheat D	3.3	5.8	6.2	6.5	7.0	8.0	10.1	14.9
Flour D	4.1	5.4	6.3	6.7	7.2	8.2	10.2	13.5
Wheat E	3.1	5.0	6.0	6.4	7.0	7.0	8.4	11.4
Flour E	4.0	5.7	6.4	6.1	7.0	7.9	8.4	10.4
Wheat F	3.5	5.8	6.4	7.3	8.2	8.6	8.9	10.9
Flour F	4.2	6.3	6.5	6.9	7.4	7.8	9.4	11.8
Av. wheat	3.30	5.53	6.20	6.73	7.40	8.07	9.13	12.40
Av. flour	4.10	5.80	6.40	6.57	7.20	7.97	9.33	11.90
Soft wheat series:								
Wheat G	4.3	6.6	7.5	7.5	8.6	9.1	11.2	14.6
Flour G	4.3	6.0	6.7	7.2	7.4	8.8	10.8	13.8
Wheat H	4.3	6.3	6.9	7.8	8.3	9.2	11.3	17.8
Flour H	4.5	6.1	6.5	7.0	7.4	8.8	11.1	14.1
Av. wheat	4.30	6.45	7.20	7.65	8.45	9.15	11.25	16.17
Av. flour	4.40	6.05	6.60	7.10	7.40	8.80	10.95	13.93
Av. all wheats	3.55	5.78	6.46	6.90	7.59	8.13	9.65	13.26
Av. all flours	4.15	5.72	6.36	6.80	7.25	8.05	9.72	12.72

the swelling power of the insoluble-starch residue. On the average, there was little difference in swelling power between the winter- and spring-wheat starches; on the other hand, the hard-wheat starches had a lower swelling power than those from soft wheats.

The mechanical action of milling, evident from the comparison of respective pairs of wheat and flour starches, had little effect on the swelling powers of the spring- and winter-wheat starches; its effect on soft-wheat starches was to slightly reduce their swelling powers.

Concurrent with the swelling of starch granules, dissolution of shorter linear molecules from the granules occurs. On the average, the solubilities of winter- and spring-wheat starches were similar; those of the soft-wheat starches were higher than those of the hard-wheat starches. A rather great variation was noticed within the wheat- and flour-starch groups.

The milling process increased the solubility of all the starches, as is evident from higher solubility values of the flour starches as compared with those of the starches

TABLE IV. SOLUBILITIES OF STARCHES
(%, d.b.)

Starch from:	Pasting Temperature, °C.							
	60	65	70	75	80	85	90	95
Spring wheat series:								
Wheat A	0.2	0.8	2.0	2.5	3.3	3.9	5.9	8.8
Flour A	1.1	1.6	2.5	3.5	4.1	4.8	7.5	13.7
Wheat B	0.5	1.0	2.3	2.9	3.7	4.8	10.0	18.3
Flour B	1.5	1.7	3.0	3.8	4.6	5.9	8.8	19.8
Wheat C	0.2	1.0	2.0	2.7	3.5	4.3	5.6	11.4
Flour C	0.6	1.6	2.7	3.1	4.0	4.5	7.0	16.1
Av. wheat	0.30	0.93	2.10	2.70	3.50	4.33	7.17	12.83
Av. flour	1.07	1.63	2.73	3.47	4.23	5.07	7.77	16.53
Winter wheat series:								
Wheat D	0.3	0.9	1.9	2.2	3.1	5.0	6.6	17.3
Flour D	1.4	1.9	3.2	3.8	4.7	6.7	10.5	21.3
Wheat E	0.5	0.8	2.5	3.5	4.1	4.8	6.2	11.3
Flour E	0.6	1.5	2.7	3.2	4.4	5.9	7.5	11.6
Wheat F	0.2	1.3	2.3	2.9	3.8	5.0	6.6	11.1
Flour F	0.6	1.6	2.5	3.2	4.3	5.5	8.1	14.6
Av. wheat	0.33	1.00	2.23	2.87	3.67	4.93	6.47	13.23
Av. flour	0.87	1.67	2.80	3.40	4.47	6.03	8.70	15.83
Soft wheat series:								
Wheat G	0.7	1.9	2.7	3.1	5.0	6.9	10.1	19.6
Flour G	0.9	2.2	3.1	3.7	5.2	7.0	10.4	19.8
Wheat H	0.2	1.6	2.7	3.5	4.8	6.4	9.5	23.6
Flour H	0.6	1.8	3.0	3.6	4.4	6.2	10.2	21.1
Av. wheat	0.45	1.75	2.70	3.30	4.90	6.65	9.80	21.60
Av. flour	0.75	2.00	3.05	3.65	4.80	6.60	10.30	20.45
Av. all wheats	0.35	1.16	2.30	2.91	3.91	5.14	7.56	15.18
Av. all flours	0.91	1.74	2.84	3.49	4.46	5.81	8.71	17.25

from the respective parent wheats. These increases were similar for all hard-wheat- and higher for soft-wheat starches.

Gelatinization Temperature Ranges

Gelatinization temperature (Table V) reflects mainly the range of order of crystallites of the starch polymers in the granules. While the ranges of all native hard-wheat starches were similar, those of the soft-wheat starches were somewhat higher. Microscopically, little damage (less than 0.5%) was observed in the starches derived from wheats. The starches from flours contained 1.5 to 4.0% damaged starch granules which swelled at a low temperature and confused the initial gelatinization point. The gelatinization ranges of flour starches were consistently slightly lower than those of the parent-wheat starches, indicating that the milling process had somewhat disrupted the crystalline order of the structure of the granules.

Enzymic Susceptibility and Water-Binding Capacity

Both of these properties of starches are reported in Table VI. As expected, the

TABLE V. KOFLER GELATINIZATION TEMPERATURES OF STARCHES

Starch from:	Gelatinization Temperature, °C. Initiation	Midpoint	Completion
Spring wheat series:			
Wheat A	58	61	66
Flour A	49	58	63
Wheat B	57	60	65
Flour B	50	58	63
Wheat C	58	62	65
Flour C	53	59	65
Av. wheat	57.7	61.0	65.3
Av. flour	50.7	58.3	63.7
Winter wheat series:			
Wheat D	57	60	64
Flour D	49	58	63
Wheat E	60	63	66
Flour E	53	61	64
Wheat F	58	61	65
Flour F	53	58	64
Av. wheat	58.3	61.3	65.0
Av. flour	51.7	59.0	63.7
Soft wheat series:			
Wheat G	59	62	66
Flour G	55	60	65
Wheat H	59	62	66
Flour H	55	60	64
Av. wheat	59.0	62.0	66.0
Av. flour	55.0	60.0	64.5
Av. all wheat	58.3	61.4	65.4
Av. all flour	52.1	59.0	63.9

TABLE VI. ENZYMIC SUSCEPTIBILITIES AND WATER-BINDING CAPACITIES OF STARCHES

Starch from:	Enzyme Solubilized %		Water-Binding Capacity %	
Spring wheat sample:	Wheat	Flour	Wheat	Flour
A	1.0	5.5	85.2	94.1
B	1.6	4.4	80.0	83.3
C	1.5	3.3	81.1	84.6
Average	1.35	4.40	82.1	87.3
Winter wheat sample:				
D	2.4	5.1	81.5	89.1
E	1.8	4.6	82.9	92.0
F	0.10	3.7	77.1	80.6
Average:	1.43	4.47	80.5	87.2
Soft wheat samples:				
G	0.32	1.58	83.6	83.2
H	0.11	0.32	75.3	86.5
Average	0.22	0.95	79.5	84.9
Average of all wheats and flours	1.10	3.56	80.8	86.7

solubilizing effect of amylase was higher for flour- than for wheat starches. The hard-wheat starches were more susceptible than the soft-wheat ones. In general, soft-wheat starches, even those from the flours, were remarkably resistant to amylolysis.

The water-binding capacities of wheat starches were similar and all were increased by milling. The analytical method used does not differentiate between the water sorbed by the granules and that bound intergranularly. Thus, this change caused by milling may be attributed to both a relaxation of the intragranular bonds and to changes of the surface of the granules.

Baking Properties

Breads were prepared using starch-gluten blends while keeping the gluten constant and varying the starch component to show the baking potential of the individual starches. The data of Table VII demonstrate consistent differences in volumes of breads made with wheat- and flour starches. The wheat starches produced breads of higher volume than the comparable flour starches, indicating that milling had an adverse effect on the starch baking quality. Besides the volume reduction there were no apparent differences in the bread quality. The best breads, judging by volume, were obtained with wheat starches, all of which were superior to those obtained with flour starches. Spring-wheat starches were somewhat better than the winter- and soft-wheat starches, which performed similarly. With flour starches, highest volumes were attained with spring-flour starches, followed by soft- and winter flour starches. Obviously, the integrity of starch granules was necessary for an optimum volume and structure of breads in the system used. This conclusion is applicable to modern white-bread systems where sufficient amounts of fermentable sugars are used to meet the yeast fermentation requirements. When low

TABLE VII. BAKING RESULTS

Starch from:	Bread Volume, ml. Wheat	Bread Volume, ml. Flour
Spring wheat samples:		
A	825	733
B	800	700
C	788	775
Average	804	736
Winter wheat samples:		
D	750	650
E	817	725
F	750	692
Average	772	689
Soft wheat samples:		
G	792	742
H	745	697
Average	768	720
Average all wheats	783	...
Average all flours	...	714

sugar levels are used and the fermentation depends on production of fermentable sugars by amylolysis of starch, certain levels of starch damage may be beneficial.

GENERAL CONCLUSIONS

The presented data demonstrate variations in physicochemical and functional properties of the native-wheat starch granules and changes in these properties induced by a conventional milling process.

The parent-wheat starches, isolated in the native state, differed only slightly in pasting properties, swelling powers, solubilities, gelatinization-temperature ranges, amylase susceptibilities, and baking properties. Starches from soft wheats deviated somewhat, having a lower hot-paste stability and a higher solubility than the hard-wheat starches.

Differences between the properties of native-wheat starches and the comparable flour starches showed that the milling process reduced the paste consistencies but increased solubilities, enzymatic susceptibilities, and hydration capacities while not affecting the swelling powers appreciably.

Baking potential of starches was also decreased by milling. Based on these experiments, it can be concluded that the optimum starch for bread formation, provided sufficient fermentable carbohydrates are present in the bread formula, is a starch which contains granules in the native state. The variation attributable to the wheat types was only minor.

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