Heat-Moisture Treatment of Starches.
II. Functional Properties and Baking Potential[1]

K. LORENZ[2] and K. KULP[3]

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ABSTRACT

Samples of wheat and potato starch were adjusted to 18, 21, 24, and 27% moisture, respectively, and heated at 100°C for 16 hr. After the treatment, all starches were dried to a uniform moisture content (7.5%) and their bread and cake-baking potential and thickening power were evaluated. Bread-baking quality of wheat starch decreased with heat-moisture treatment. Bread volumes were lower and the grain more open. Bread-baking potential of the potato starch improved, however. Bread grain and texture were considerably better; volume improved somewhat. Cake-baking potential of heat-moisture treated wheat starch decreased, whereas that of treated potato starch improved. Cakes baked with treated potato starch were higher in volume and had a less compact and more uniform grain than did those baked with untreated potato starch. The overall quality of cakes baked with treated potato starch was always lower, however, than that of cakes with untreated wheat starch. Both treated starches had less thickening power in pie fillings than did untreated starch samples.

Heat-moisture treatment of starch changes the properties of root starches (Sair 1967). Gelatinization temperature, swelling behavior, and paste translucency of root starches approach those of cereal starches. The X-ray diffraction patterns of the root starches change to those of cereal starches.

Heat-moisture treatment of wheat starch also affects physicochemical properties (Kulp and Lorenz 1981). Gelatinization temperature, water-binding capacity, and enzyme susceptibility increase because of the treatments. Viscograph consistencies and swelling powers decrease with increasing moisture content during heat treatment.

Modification of wheat and potato starches by heat-moisture treatments also affects their functional characteristics and baking potential. These effects, which have not previously been studied, are reported in this article.

MATERIALS AND METHODS

Sample Identification and Preparation

Wheat starch from hard red spring wheat (Waldron) and potato starch from white potatoes were prepared as described previously (Kulp and Lorenz 1981).

The method of heat-moisture treatment was that of Sair (1964). The moisture contents of a series of wheat and potato starch samples was brought to 18, 21, 24, and 27%. The samples were sealed in glass jars and heated for 16 hr at 100°C in an air oven. After the heat treatment, all starch samples were air dried to a uniform moisture content (about 7.5%) before evaluation of their functional characteristics and baking potential.

Functional and Baking Potential of Treated Starches

The remix procedure (Irvine and McMullan 1960) was adapted for baking of starch-gluten breads. The bread formula for each pup loaf consisted of: 50 g of wet gluten (63.4% moisture), 85 g of starch, 10 g of sucrose, 1.5 g of salt, 3.0 g of shortening, 3.0 g of yeast, 4.0 g of nonfat dry milk, 0.5 g of mineral yeast food, and water as required. 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.

Fermentation time was 1.5 hr at 30°C and 85% rh. The loaves were mechanically molded, proofed to height at 35°C and 95% rh, and baked at 218°C for 18 min.

Specific loaf volume was measured by rapeseed displacement. The breads were scored as follows with the maximum number of possible points indicated for each bread characteristic: crust color, 7; symmetry, 7; break and shred, 6; crumb color, 10; volume, 15; flavor, 15; grain, 20; and texture, 20.

For softness determinations, loaves were sealed in moisture-proof bags and stored at room temperature for one, three, and six days. The softness of five bread slices was measured on each of those days with a Baker Compressimeter (AACC 1976).

For evaluation of starches in cakes, a high-ratio yellow cake formulation by Cauvain and Gough (1975) was used (Table I). The formulation had to be adjusted slightly because of the altitude of our laboratory (5,000 ft).

Cake volume was measured with a volume meter developed by the Pillsbury Company. The cakes were scored as follows with the maximum number of possible points indicated for each cake characteristic: volume, 14; crust color, 5; symmetry, 10; crust character, 5; grain, 15; crumb color, 10; aroma, 10; taste, 20; and texture, 10.

The thickening power of each starch was determined in a simulated pie filling which consisted of 90 g of water, 50 g of sugar, 0.4 g of salt, and 9 g of starch. The starches were suspended in 15 ml of water while 65 ml of water containing the salt was brought to

TABLE I
Normal and Modified Formulation for High Ratio Yellow Cakes

	Percent of Flour Weight[a]	
Ingredients	**Normal**	**Modified**
Ingredients A		
Cake flour	100	···
Starch	···	99
Sugar	120	120
High-ratio shortening	75	75
Baking powder	4	4
Salt	2.5	2.5
Skim-milk powder	···	7.8
Ingredients B		
Milk[b]	55.5	···
CMC[c]	···	52
Water	···	10
Ingredients C		
Milk[b]	40	···
CMC[c]	···	37
Whole egg	75	75

[a]The formula, based on 100 g of flour or 99 g of starch, was used for a single cake.
[b]Skim milk powder/water, 1:10.
[c]Carboxymethyl cellulose aqueous solutions (1.3%) substituted for milk.
Procedure. Ingredients A were mixed alone (45 sec) in a Hobart N-50 mixer, then mixed with Ingredients B (5 min), and finally with Ingredients C (5 min). Portions of batter (400 g) were baked at 375° in a reel oven for 23 min.

[1]Presented at the 64th Annual Meeting, Washington, DC, October 1979.
[2]Department of Food Science and Nutrition, Colorado State University, Fort Collins 80523.
[3]American Institute of Baking, Manhattan, KS 66502.

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boil. The starch suspensions were then added with stirring to the boiling water. The remaining 10 ml of water was used to rinse the beaker containing the starch suspensions. The sugar was stirred into the filling as soon as the starch was fully gelatinized. Any water lost by evaporation during preparation of the filling was then replaced to assure that all fillings had identical water contents. The beakers containing the fillings were covered with aluminum foil to prevent moisture loss and allowed to cool to room temperature (22° C) and, in a second series of experiments, to refrigeration temperature (10° C). The consistency of the fillings was recorded with a Brookfield viscosimeter (model RVF, spindle No. 6 for starches treated at 18 and 21% moisture and No. 3 for those at 24 and 27% moisture) on the day of preparation and after one, three, and six days of storage at the respective temperatures.

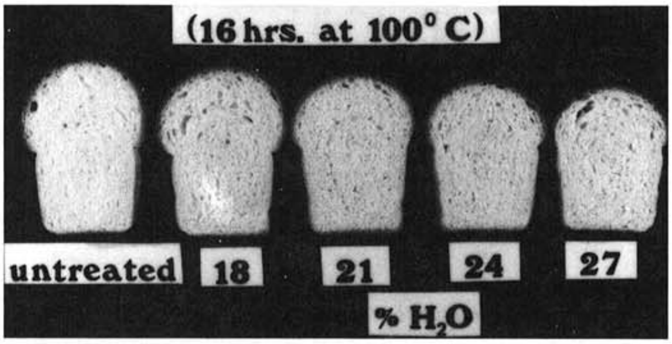

Fig. 1. Breads baked with heat-moisture treated wheat starch.

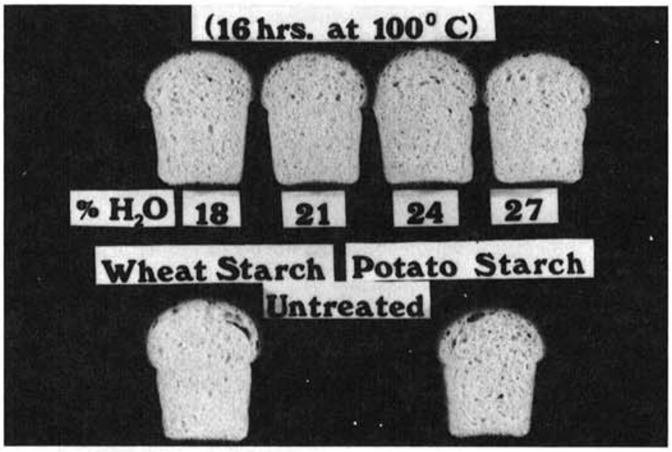

Fig. 2. Breads baked with heat-moisture treated potato starch.

RESULTS

Breads

The results of baking breads with heat-moisture treated wheat and potato starches are given in Table II. The baking absorption for the dough mixed with the untreated wheat starch sample was similar to that reported by others for reconstituted flours (Hoseney et al 1978). The absorption increased for starches heated at a moisture content of 24 and 27%, respectively. Increased water-binding of starches after such treatments have been reported (Kulp and Lorenz 1981).

Proof times of the loaves decreased as the percent of moisture in the wheat starch sample during heating increased. A certain increase of starch susceptibility to enzymes occurred during heat-moisture treatment (Kulp and Lorenz 1981), which would provide more fermentable carbohydrates.

The breads are shown in Fig. 1. Bread volume decreased; the grain became more open; and crumb color darkened from heat-moisture treatment of wheat starch. With the higher absorptions, the breads had a fairly moist, but not silky, texture. The flavor of the breads was not affected by the treatment. The total bread scores indicate the detrimental effects of heat-moisture treatment on overall bread quality.

All breads became firmer with time of storage, but softness determinations on these loaves one, three, and six days after baking indicated essentially no differences for breads that had the same baking absorption of 65.1%. Breads baked with starches heated after adjustment of the moisture content to 24 and 27% were slightly firmer the day after baking than were the breads baked with untreated starch, presumably because of lower bread volumes. Three and six days after baking, these breads appeared to be softer, however, because of higher crumb moisture resulting from the higher baking absorptions.

Baking absorptions of doughs with heat-moisture treated potato starch were increased by the treatments. The higher the moisture content of the starch during heating, the higher the absorption required to mix a dough to optimum consistency. Mixing times were rather long because the treated potato starch samples did not combine readily with gluten to form a dough. Precise mixing times could not be established because of the constant need to scrape the mixing bowl during mixing.

The proof times of the loaves decreased as the percent moisture of the starch during heat treatment increased, presumably from a certain amount of starch degradation during heat-moisture treatment.

TABLE II
Bread-Baking Data

Starch	Treatment Moisture Level[a] (%)	Baking Absorption[b] (%)	Proof Time (min)	Bread Specific Volume (cc/g)	Total Bread Score[c]	Bread Crumb[d]	Bread Softness (gram force)[e] at Days After Baking		
							1	3	6
Wheat	Control	65.1	43	4.44	90	S	9.8	23.4	24.7
	18	65.1	44	4.21	84	S	9.3	17.3	22.5
	21	65.1	42	4.24	84	S	8.4	17.5	19.1
	24	66.7	40	4.06	77	S	11.7	13.0	19.0
	27	73.0	35	3.46	71	S-Q	11.0	12.9	17.2
Potato	Control	74.6	50	3.17	62	U	...	...	...
	18	76.2	49	3.26	67	S-Q	...	...	...
	21	77.8	47	3.39	70	S	...	...	...
	24	78.7	41	3.28	71	S	...	...	...
	27	81.3	41	3.25	74	S	...	...	...

[a] At all treatment moisture levels, starch was heated for 16 hr at 100° C.
[b] Based on dry weight of gluten-starch blend.
[c] Based on 100 possible points.
[d] S = satisfactory, Q = questionable, U = unsatisfactory.
[e] For 0.5-mm compression of slice 1.0-cm thick. Averages of five determinations.

The breads are shown in Fig. 2. Untreated potato starch does not produce a satisfactory loaf of bread. The volume is low, the grain very open, the texture rather harsh, and the crumb color dark. Heat-moisture treatment of potato starch improved bread volume somewhat. Grain, texture, and crumb color were considerably improved. Moisture adjustment of potato starch to 27% before heating produced a bread that was quite satisfactory except for volume (Fig. 2 and Table II). The grain was rather uniform and the crumb color considerably lighter than that of the bread baked with the untreated potato starch. The flavor of these potato starch breads was satisfactory; it was different from that of breads baked with wheat starch but not objectionable.

Sair (1967) mentioned a change in potato starch characteristics in the direction of those of wheat starch. Our bread baking results have shown that heat-moisture treated potato starches show improvement in bread baking potential over that of untreated potato starch. However, in no instance did the potato starch characteristics increase to the extent of being comparable to an acceptable wheat starch.

Cakes

The results of baking cakes with heat-moisture treated wheat starch and potato starch are given in Table III, as are results from control cakes prepared with a test cake flour (chlorinated). According to Cauvain and Gough (1975), the formula requires chlorinated flour, but no collapse is observed when starch from unchlorinated flour is used. Consequently, this formula permitted us to evaluate the heat-moisture treatment of starches without the interfering effect of chlorination.

Moisture adjustment of the wheat starch to 18 or 21% before heating did not affect the cake-baking potential of the starch. The cakes with starch at this treatment level were actually slightly higher in volume than those prepared with untreated wheat starch. More severe treatments (starch moistened to 24 or 27% before heating) had detrimental effects on batter and cake quality.

Gas retention capabilities of the batters were reduced. The cakes had a dip in the center. Cake volumes were low, the grain open, and the crumb color rather dark. Typical cakes are shown in Fig. 3. Total cake scores indicate the overall detrimental effect of heat-treatment of wheat starch at moisture contents of 24 or 27%.

Untreated potato starch did not produce a cake of satisfactory quality (Fig. 4). Cake volume was low, and the grain very compact and dense. Adjustment of the moisture in potato starch to 18 or 21% before heat treatment improved the cake-baking potential of the starch somewhat. Cake volumes were slightly higher and the grain less compact. Cake-baking potential further improved when the moisture of the potato starch was adjusted to 27% before heating. Cake volume was considerably higher but still not as high as that of untreated wheat starch cakes, although their textures were equal. The grain was as expected for a yellow layer cake.

Heat-moisture treatment of potato starch did indeed change the cake-baking functional characteristics of potato starch in the direction of those of wheat starch.

Thickening Power of Starches

The thickening power of untreated and heat-moisture treated wheat starches in fillings stored at room temperature and in a refrigerator at 10° C is indicated in Table IV. Fillings prepared with untreated wheat starch and stored at room temperature showed no change in consistency for up to six days. However, storage at 10° C produced a considerably higher initial consistency, which decreased with time of storage.

Heat-moisture treatment caused a significant reduction in thickening power of the wheat starch. The higher the moisture content of the starch before heat treatment, the lower the initial consistency of the filling prepared with the starch. Consistency of the fillings made with heat-moisture treated starches was slightly higher on the day after preparation than it was on the day fillings were cooked. However, consistencies generally decreased upon room temperature storage and decreased drastically upon 10° C storage. Moisture adjustment of the wheat starch to 27% before heating produced the lowest filling consistencies. These fillings showed signs of syneresis after three and six days of storage in the refrigerator or at room temperature.

TABLE III
Cake-Baking Data[a]

Starch	Treatment Moisture Level[b] (%)	Batter Specific Gravity	Cake Volume (cc)	Grain[c]	Texture[d]	Total Cake Score[e]
Wheat	Control	0.89	1,120	15	9	89
	18	0.93	1,200	13	8	87
	21	0.93	1,200	14	9	87
	24	0.86	900	8	7	74
	27	0.86	920	7	6	70
Potato	Control	0.82	630	9	7	68
	18	0.89	680	12	8	73
	21	0.95	660	12	8	74
	24	0.92	860	13	8	81
	27	0.96	950	14	9	85
Cake flour control		0.85	1,250	14	9	90

[a] Results of duplicate baking experiments.
[b] At all treatment moisture levels, starch was heated for 16 hr at 100° C.
[c] Based on 15 possible points.
[d] Based on 10 possible points.
[e] Based on 100 possible points.

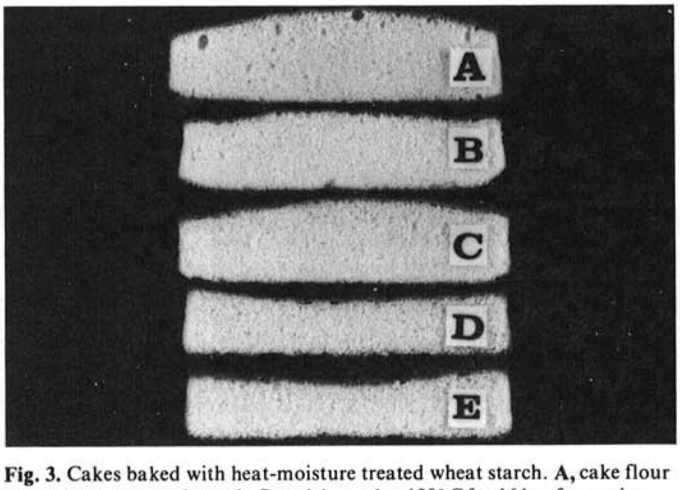

Fig. 3. Cakes baked with heat-moisture treated wheat starch. **A,** cake flour control; **B,** untreated starch. Starch heated at 100° C for 16 hr after moisture adjustment to **C,** 21%; **D,** 24%; **E,** 27%.

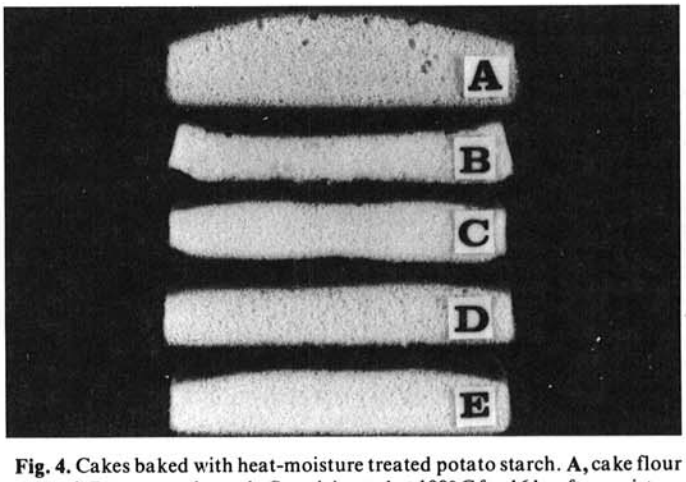

Fig. 4. Cakes baked with heat-moisture treated potato starch. **A,** cake flour control; **B,** untreated starch. Starch heated at 100° C for 16 hr after moisture adjustment to **C,** 21%; **D,** 24%; **E,** 27%.

TABLE IV
Thickening Power[a] of Heat-Moisture Treated Wheat Starches in Fillings Stored at Two Temperatures

Storage Temperature	Treatment Moisture Level[b] (%)	Days After Preparation of Filling			
		0	1	3	6
Room	Control	10,250	10,550	10,600	10,950
	18	9,600	11,375	7,300	7,450
	21	5,700	8,625	6,250	6,400
	24	4,500	8,500	6,050	6,200
	27	1,250	2,875	2,300	2,050
10° C	Control	23,000	14,500	6,125	5,375
	18	16,250	12,000	8,350	8,600
	21	8,100	10,125	3,350	3,300
	24	3,350	3,875	2,950	2,700
	27	3,050	3,000	1,650	1,250

[a] Measured with Brookfield Viscometer at 20 RPM, in Centipoise.
[b] At all treatment moisture levels, starches were heated for 16 hr at 100° C.

TABLE V
Thickening Power[a] of Heat-Moisture Treated Potato Starches in Fillings Stored at Two Temperatures

Storage Temperature	Treatment Moisture Level[b] (%)	Days After Preparation of Filling			
		0	1	3	6
Room	Control	93,500	169,000	90,500	30,000
	18	15,875	11,375	8,125	8,250
	21	8,375	5,125	5,250	4,250
	24	538	513	438	288
	27	175	200	200	150
10° C	Control	> 200,000	109,000	25,000	19,000
	18	11,625	5,000	5,375	2,125
	21	7,250	3,375	2,125	3,000
	24	713	388	300	300
	27	350	313	200	250

[a] Measured with Brookfield Viscometer at 20 RPM, in Centipoise.
[b] At each treatment moisture level, starch was heated for 16 hr at 100° C.

Heat-moisture treatment of potato starch produced changes in thickening power similar to those observed with wheat starch (Table V).

Initial consistencies of fillings prepared with untreated potato starch were very much higher than were those of fillings cooked with untreated wheat starch. This was expected. Storage at 10° C produced higher consistencies than did room temperature storage. With time, the consistencies decreased for all fillings and both storage temperatures.

Heat-moisture treatment of potato starch affected thickening power very drastically. Adjustment of moisture to 24 or 27% before heating decreased the consistencies of fillings prepared with these starches to values considerably below those obtained with any of the wheat starch samples. The fillings prepared with these most intensely treated starches exhibited marked syneresis, as previously observed by Sair (1967).

DISCUSSION

Heat-moisture treatment of potato starch alters its physical qualities and crystalline structure in the direction of those of wheat starch (Kulp and Lorenz 1981).

Bread-baking and cake-baking potential of the potato starch showed improvements concomitant with the physical changes produced by the treatment. Although the quality of cakes and breads failed to match that obtained with untreated wheat starch, the trend of improvement as a result of the treatment clearly shows that the changes in physical properties are important in determining the baking performance of starch. All these properties (solubility, swelling power, etc) are interrelated and influenced by the degree and type of granule order, which is related to molecular characteristics of the starch (amylose/amylopectin ratio, molecular size, and conformation of polymers) and to the presence of starch lipids. We were not surprised—in view of the complexity of the situation—that only a gross approximation of potato starch properties to wheat starch properties could be attained by the treatment.

The thickening power, studied in experiments with pie fillings, did not show a simple relationship to the baking performance of starch. The hot paste consistency decreases with severity of heat-moisture treatment and its stability is enhanced, as is evident from viscographic data (Kulp and Lorenz 1981). This behavior suggests that for potato starch, consistency is not an index of starch baking quality. On the other hand, the increased stability of the granules in hot paste, attributable to the treatment, suggests that paste stability is beneficial to baking performance.

The changes in wheat starch effected by the treatment generally harmed its functionality, suggesting that the wheat granules in a native state were more suitable for baking applications than were the treated ones. Thus, certain types of granule damage were produced by the treatment. This concept is in accordance with the investigation of baking properties of wheat starch isolated by wet-milling from wheat and of that derived from flours (Kulp 1972). The latter starch was of lower baking potential because of mechanical damage inflicted by the commercial milling process. The performance of starch in cakes is less affected by the heat-moisture treatment, showing a slight improvement at milder treatment levels but reducing cake-baking potential under more severe conditions. This again is consistent with the view that unaltered wheat starch granules are important for optimal results in cake baking (Howard et al 1968).

In spite of the apparent emphasis on the native condition of the granules, objective granule-level criteria for baking quality of wheat starch are lacking. Possibly, on the basis of this study, attempts could be made to characterize the optimal conditions of wheat starch crystalline order in addition to its physicochemical qualities.

ACKNOWLEDGMENTS

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