Preharvest Sprouting of Winter Wheat. I. Rheological Properties of Flours and Physicochemical Characteristics of Starches

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ABSTRACT

The objective of this study was to determine the effect of field sprouting on breadbaking and other functional properties of flours and their gluten and starch components. Compositional characteristics (visual sprouting, protein, ash, and falling number) of flours used are reported. Rheological evaluations showed gradual weakening of doughs (mixograph) with little effect on mixing time and absorptions. Amylograph peak viscosities decreased with decreasing falling number values. Physicochemical characteristics of wheat starches isolated from flours derived from field-sprouted and sound wheat were determined. To eliminate the effect of α-amylase on these measurements, the starches were subjected to enzyme-inactivation treatment. Solubility, swelling powers, viscogram indices, and gelatinization temperature ranges were virtually unaffected by sprouting; water-binding capacity was slightly higher for samples from sprouted wheats than for controls. Scanning electron microscopy and X-ray diffraction studies failed to show changes attributable to in situ damage of the granules during sprouting.

The extent of sprouting is an important criterion in grading of wheat and other cereal grains because sprouted grain is inferior (USDA 1970).

The problem of grain sprouting in the field is not confined to one specific area in the world. It has been reported in northern and western Europe, South America (Chile and Argentina), western Canada, New Zealand, and Australia, as well as in many areas of the United States (MacKey 1976, Moss et al 1972, Weilenmann 1976). Sprouted wheat in the northern Great Plains of the United States continues to be a serious marketing problem and a threat to established hard red spring wheat export markets (Ibrahim and D'Appolonia 1979). Economic losses from decreased grain quality caused by sprouting can be substantial (Weilenmann 1976).

Flours milled from sprouted hard red wheats are ill suited for breadbaking. The use of 100% flour from extensively sprouted hard wheat yields breads with very poor characteristics; crumb color is darker, and crumb grain quality and texture are inferior. Flours from extensively sprouted wheat impart undesirable stickiness and gumminess to the crumb because the starch breaks down excessively (Ibrahim and D'Appolonia 1979, Kozmin 1933).

The starch in kernels of cereal grains during laboratory sprouting is gradually degraded, and values for free sugars increase as this process progresses, due to the activity of amylases (Dronzek et al 1972).

The extent of starch degradation depends on the length of sprouting time. The water-binding capacities of starches from sprouted grains decreased initially and then increased again with longer sprouting times. Swelling powers decreased while solubilities and enzyme susceptibilities of the starches increased with sprouting. Starches from sprouted grains gelatinized at a lower temperature and over a narrower temperature range than starch from ungerminated grains. Falling number values and amylograph viscosities decreased due to sprouting of grains before starch isolation (Lorenz and Kulp 1981).

All alterations in the composition and properties of the carbohydrate components have been studied, with cereal grains sprouted under laboratory conditions. There are no reports in the literature of changes in starch properties as cereal grains sprouted in the field.

The effects of preharvest sprouting of winter wheats on rheological properties and on the physicochemical and functional characteristics of starches from those wheats are discussed.

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MATERIALS AND METHODS

Wheat Genotypes

The four genotypes used were Newton, which is the most popular hard red winter sprouting-resistant wheat cultivar in Kansas; Centurk, another popular hard red winter wheat, which is sprouting-susceptible; Clark's Cream, a sprouting-resistant hard white winter wheat cultivar; and KS73256, a sprouting-susceptible hard white winter wheat experimental line. These samples were the same as the ones used by Bhatt et al (1981).

Heavy rainfall (13.4 cm) between harvest maturity in early July and actual harvest on July 27 caused differential sprouting. Percentage of sprouting was assessed visually by counting the grains in which the radicle and/or the scutelum had penetrated the pericarp on 10 spikes on 10 randomly chosen plants in each plot in one replication (Bhatt et al 1981).

Milling of Samples and Proximate Analyses

Grain composites from the three replications of each experimental variable were milled into flours using a Miag Multomat mill. The flours were analyzed for moisture, ash, nitrogen, and falling number using AACC approved methods (AACC 1969).

Rheological Properties of Flours

Mixograph characteristics of the flours were determined using 35 g of flours (14% moisture basis) with the absorptions established in farinograph studies. Maximum curve height, length of curve to maximum height, time to maximum height, and the area under the curve were recorded.

Amylograph characteristics were determined using the AACC approved method (AACC 1969).

Starch Isolation

Starch was isolated from flours of the four wheat varieties as outlined by Lorenz and Kulp (1981). The starch from each of the flours was divided into two subsamples. The first of these subsamples received no further treatment. The second subsample received an amylase inactivation treatment as described by Meredith (1970). Starch (1,500 g) was suspended at room temperature in 3,000 ml of 0.1*N* HCl and stirred for 20 min. Then, 3,000 ml of 0.1*N* NaOH was gradually added to neutralize the starch suspension, which then was centrifuged. The starch was air-dried.

Starch samples were analyzed for moisture, nitrogen, and crude fat (AACC 1969).

Measurements of Physicochemical Properties

Water-binding capacity was measured through the method of Medcalf and Gilles (1965). Swelling power and solubility determinations were estimated for the temperature range of 60–90° C by the procedure of Leach et al (1959). Gelatinization temperature ranges were determined through the use of a polarizing microscope equipped with a Kofler hot stage as described by Schoch and Maywald (1956). Pasting properties were established by means of the Brabender Visco/Amylograph. Forty grams (dry basis) of starch and 420 ml of distilled water were heated from 30 to 95° C, kept at this temperature for 30 min, then cooled to 35° C and held at 35° C for 30 min. Enzyme susceptibility of the starches was determined by a procedure of Leach and Schoch (1961). Starch (5 g) was suspended in distilled water (20 ml), the pH adjusted to 4.7 and 1% (starch basis) of a commercial amylase (Doh-Tone, fungal α-amylase, 5,000 SKB units per gram) added. The starch was incubated with agitation for 24 hr at 30° C; then the amount of the insoluble residue was determined. Blank determinations were run with all assays.

Scanning Electron Microscopy (SEM) and X-Ray Diffraction

Samples of the starches isolated from sprouted grains were sprinkled onto a copper tape glued to circular specimen stubs and coated with 400 Å of gold palladium. The samples were viewed and photographed using a Hitachi HHS-2R scanning electron microscope.

X-ray diffractometer traces were obtained using the following experimental conditions: CuK_a radiation, voltage 35 kV, current 18 mA, scanning speed 1°2θ per inch of chart. Values of intensities were read from the curves over the angular range 10–29°, which includes most of the crystalline peaks. Percent crystallinity was determined by an integral method. The results depend only on the intensities of the peak.

TABLE I
Protein, Ash, and Falling Numbers of Flours

Flour Sample	Sprouting (%)	Flour		
		Protein (%)	Ash (%)	Falling No. (sec)
KS73256				
Control	0	9.3	0.43	190
0 N[a]	78	10.9	0.39	65
45 N	75	11.3	0.39	63
90 N	80	11.8	0.40	62
Centurk				
Control	0	9.0	0.42	440
0 N	17	10.1	0.46	100
45 N	30	10.3	0.38	87
90 N	40	11.1	0.35	74
Newton				
Control	0	13.1	0.42	449
0 N	2	10.2	0.38	277
45 N	2	10.4	0.38	272
90 N	0	11.1	0.38	288
Clark's Cream				
0 N	3	11.6	0.41	155
45 N	20	12.0	0.38	183
90 N	17	12.7	0.36	185

[a] N = Level of nitrogen applied (pounds per acre).

TABLE II
Mixograph Data of Flours

Variety	Field Sprouting (%)	Absorption[a] (%)	Maximum Curve Height (cm)	Length of Curve to Maximum Height (cm)	Time to Reach Maximum Height (min)	Area Under Curve (cm^2)
Newton	0	55.8	5.4	6.8	5.4	54.9
	2[b]	52.9	5.6	6.6	5.2	54.3
Centurk	0	51.3	4.9	7.5	6.0	47.7
	17	52.6	4.8	7.4	5.8	47.3
	30	52.0	5.1	7.2	5.6	49.9
	40	53.6	5.3	6.6	5.2	52.8
KS-73256	0	53.0	5.3	7.1	6.0	48.0
	75	52.2	6.0	5.8	4.6	52.8
	78	52.8	5.5	6.4	5.0	50.0
	80	53.0	6.2	5.5	4.5	57.6

[a] Absorption as determined by the farinograph.
[b] Nitrogen = 45 pounds per acre.

RESULTS AND DISCUSSION

Composition and Rheological Properties of Flours

Bhatt et al (1981) reported that nitrogen fertilizers increased grain protein percentages of the varieties used in this study. The flours milled from these grains showed the same trend of higher protein content with higher level of fertilizer (Table I). Falling number values of flours from sprouting-susceptible varieties (Centurk and KS73256) were as expected from visual assessment of field sprouting and from grain α-amylase activities determined by Bhatt et al (1981). Falling number values of flours from sprouting-resistant varieties (Newton and Clark's Cream), which showed comparatively low α-amylase activities, did not follow the activity trend.

Data summarizing the effects of field sprouting on mixogram characteristics are given in Table II. Johnson et al (1943) have positively correlated the maximum height of the mixogram and the area under the curve with the protein content of the flour and the volume of the baked loaf. In this study, both the height of the curve and the area under the curve increased with sprouting, indicating potential increases in bread volume.

The extent of field sprouting affected the length of the curve from the starting point to the maximum height and the time required to reach that point. Both values decreased with increased sprouting, indicating a reduction in the mix time required to reach optimal dough development.

The magnitude of the weakening angle has been positively correlated to the sensitivity of the dough to overmixing (Johnson et al 1943). As sprout damage increased, the weakening angle declined more sharply, which indicated a decrease in the stability of the dough after reaching optimum development. This decrease in weakening angle is illustrated in Fig. 1. Dough stability during prolonged mixing has commonly been considered to be a factor of gluten quality. Thus, damage to the gluten during field sprouting is a probable explanation for the increased weakening angle.

The amylograph data from the various flours are given in Table III. Peak viscosities decreased with decreasing flour falling number values. There was no relationship between peak temperature of a flour and its amylase activity as measured by falling number. The temperature of initial viscosity rise did not vary significantly as the result of differences in α-amylase activity of the flours.

Proximate Composition and Physicochemical Properties of Starches, Swelling Power, Solubility, and Water Binding

Proximate analyses of the starch samples showed values of crude fat and protein typical of those of wheat starches isolated in the laboratory by the procedure used (Adkins and Greenwood 1966).

Swelling powers and solubilities of the starches are presented in Table IV. Swelling power values increased with temperature, as expected, but did not show any differences between starch samples isolated from grains of different field sprouting percentages and α-amylase activities (Bhatt et al 1981). Values obtained with the enzyme-inactivated starches were comparable to those determined with the untreated starch samples. On the other hand, laboratory sprouting of cereal grains (triticale, barley, corn) produced decreased swelling powers of the starches due to extensive hydrolysis of the starch caused by α-amylase activity (Lorenz and Kulp 1981). These differences between laboratory and field-sprouted samples are really not surprising considering that conditions for germination and sprouting (temperature and moisture) in the field are not as ideal as those generally provided during sprouting in the laboratory. The data indicate that a substantial degree of sprouting is required before the swelling powers are altered.

Solubilities of enzyme-inactivated starch samples (Table IV) increased with temperature. There were no differences due to different field-sprouting percentages. The starch samples, to which the enzyme inactivation step was not applied, showed considerable increases in solubility with higher field-sprouting. This trend is similar to that reported for solubilities of starches from laboratory-sprouted grains (Lorenz and Kulp 1981). Residual α-amylase activity on surfaces of isolated starch granules would cause some hydrolysis when samples are gelatinized and incubated at temperatures ideal for enzyme activity during the course of the assays. The decreased solubilities at 90°C are due to more rapid inactivation during heating than at lower temperatures.

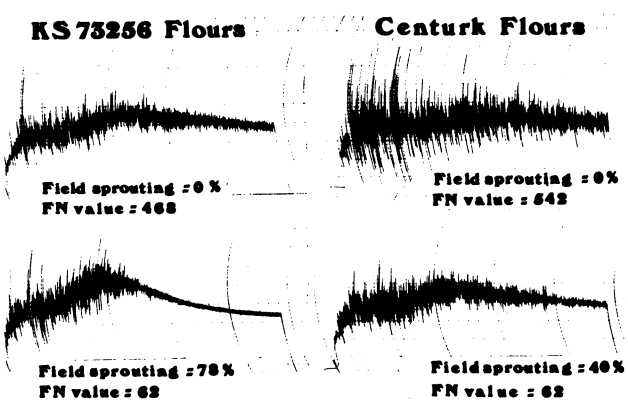

Fig. 1. Effect of degree of sprouting on mixograms of wheat flour.

TABLE III
Viscograph Data[a] of Various Flours from Sprouted Wheat

Sample[b]	Peak Viscosity (BU)	Peak Temp. (°C)	Temperature of Initial Viscosity Rise (°C)
KS control	460	74.5	64.0
KS 0 N	90	70.1	65.5
KS 45 N	80	71.5	66.3
KS 90 N	70	71.5	67.0
Centurk Control	>2,500	>87.5	62.5
Centurk 0 N	160	71.5	65.5
Centurk 45 N	130	70.8	65.5
Centurk 90 N	110	70.8	65.5
Newton Control	>2,500	>87.5	63.3
Newton 0 N	935	87.3	63.3
Newton 45 N	1,060	87.3	62.5
Newton 90 N	1,570	88.8	63.3
Clark's Cream 0 N	300	73.8	64.8
Clark's Cream 45 N	450	74.5	64.4
Clark's Cream 90 N	470	73.8	64.0

[a] Reproducibility = ±10 BU.
[b] All samples are 100 g (14% m.b.)/460-ml buffer solution.

TABLE IV
Swelling Power and Solubility Data[a]

Variety	Field Sprouting	Swelling Power[b] 60°C	70°C	90°C	Solubility (%)[c] 60°C	70°C	90°C
		Enzyme-Inactivated Samples					
Newton	0	3.84	5.99	8.10	1.28	2.81	3.61
	2	3.82	5.92	7.92	1.22	2.48	4.22
Centurk	0	3.88	5.99	7.63	1.49	3.11	4.34
	17	3.89	5.92	8.27	1.32	2.76	3.40
	40	3.66	5.78	8.59	1.43	3.14	3.47
KS-73256	0	3.04	6.00	8.40	0.86	2.88	3.18
	78	3.69	5.98	7.88	1.38	2.81	3.37
	80	3.77	6.11	8.56	1.46	2.95	3.50
		Untreated Samples					
Newton	0	3.94	6.07	8.10	2.02	3.82	3.81
	2	4.01	5.93	7.69	1.87	3.55	3.48
Centurk	0	3.95	6.05	7.98	1.39	3.11	3.83
	17	3.44	6.15	9.75	16.80	24.41	3.61
	40	3.16	5.40	9.73	23.24	30.93	4.70

[a] Mean value of 10 replications.
[b] Standard deviation = ±0.13.
[c] Standard deviation = ±0.11.

Water-binding capacities (Table V) show a slight increase with higher field-sprouting percentage. The differences are small but suggest an incipient enzymic attack. There were no differences between the enzyme-inactivated and the untreated starch samples. Water-binding capacities of starches from laboratory-sprouted triticale, barley, and corn decreased initially due to sprouting of the grains, but then increased again with longer periods of sprouting (Lorenz and Kulp 1981). The initial decrease in water binding was probably due to the action of α- and β-amylase on the amorphous regions of the granules while the crystalline areas remain intact. Higher degrees of sprouting also affect the crystalline regions, which become more hygroscopic. This causes the water-binding capacity to increase again.

TABLE V
Water-Binding Capacities, Enzyme Susceptibilities, and Relative Crystallinities of Starches from Sprouted Winter Wheats

Sample	Grain Field Sprouting (%)	Starch Treatment	Waterbinding[a] (%)	Enzyme Solubilized (%)	Relative Crystallinity (%)
KS-73256	0	enzyme-inactivated	91.8	1.82	100
	78	enzyme-inactivated	93.4	1.15	100
	0	none	91.4	...	...
	78	none	93.6	...	...
Centurk	0	enzyme-inactivated	89.8	1.68	100
	17	enzyme-inactivated	89.6	1.56	...
	40	enzyme-inactivated	92.2	1.20	103
	0	none	91.1	...	...
	17	none	93.1	...	...
	40	none	97.0	...	...
Newton	0	enzyme-inactivated	90.7	1.26	113
	2	enzyme-inactivated	92.1	1.13	121
	0	none	83.2	...	...
	2	none	90.7	...	

[a]Standard deviation ±1.3%.

TABLE VI
Gelatinization Temperature Ranges of Starches from Sprouted Winter Wheats[a]

Sample	Grain Field Sprouting (%)	Gelatinization Temperature (°C)		
		Initial	Midpoint	Final
KS-73256	78	57	62	66
	80	57	62	66.5
Centurk	0	56	60.5	64
	17	57	62	66
	40	56	61	65
Newton	0	56.5	60.5	64.5
	2	54.5	61	64

[a]Averages of four determinations, enzyme-inactivated starches.

Enzyme Susceptibilities and Gelatinization Temperature Ranges

Enzyme susceptibilities of enzyme-inactivated samples (Table V) decreased with higher grain field sprouting. The plausible explanation for this change is a loss of soluble low molecular amylose during sprouting in the wheat kernel and/or during the isolation process. Since this portion is susceptible to enzymolysis, its loss results in reduction of a readily accessible substrate and causes lower analytical values.

These data are in contrast to observations on starches isolated from laboratory-sprouted wheats (Lorenz and Kulp 1981). The difference is attributed to the retention of active indigenous amylases on the surface of the granules and to a higher erosion of the granules by extensive sprouting evident from scanning electron microscopy.

Field sprouting will not cause change in gelatinization temperature ranges (Table VI). Laboratory sprouting of grains caused the gelatinization temperature range of starches to be narrower and at a lower temperature than those from the respective sound grains (Lorenz and Kulp 1981). Changes in associative forces within the starch granules and a certain degree of degradation were given as possible explanations. Degradation of starch in the present study due to α-amylase activity did not progress to a stage to produce the changes in gelatinization temperature range observed previously with laboratory-sprouted samples.

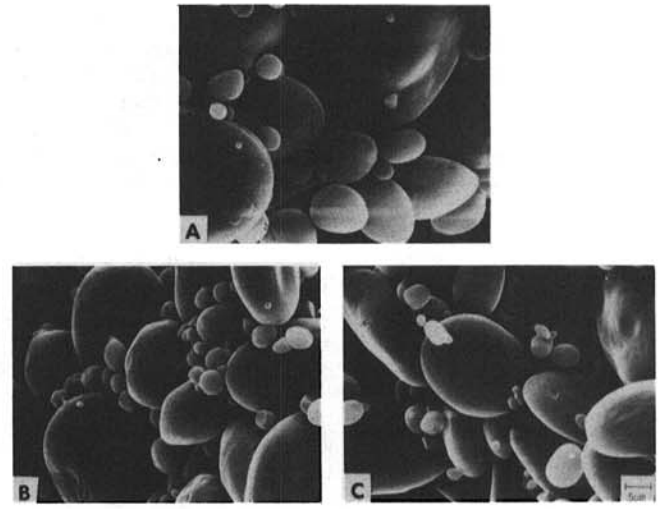

Fig. 2. Scanning electron micrographs of starches from field sprouted wheat. **A**, percent field sprouting = 0; **B**, percent field sprouting = 40; **C**, percent field sprouting = 78.

TABLE VII
Viscograph Data of Starches from Sprouted Winter Wheats[a,b]

Sample	Grain Field Sprouting (%)	Consistency at 95°C (BU)	Consistency After Holding 30 Min at 95°C (BU)	Consistency After Cooling to 35°C (BU)	Consistency After Holding 30 Min at 35°C (BU)
KS-73256	78	350	450	1,430	2,030
	80	530	400	1,720	2,430
Centurk	0	230	350	1,320	1,870
	17	250	375	1,350	1,880
	40	350	410	1,390	2,000
Newton	0	300	400	1,320	1,830
	2	320	440	1,340	1,950

[a]Forty grams d.b./420 ml H_2O enzyme-inactivated starches.
[b]Reproducibility = ±10 BU.

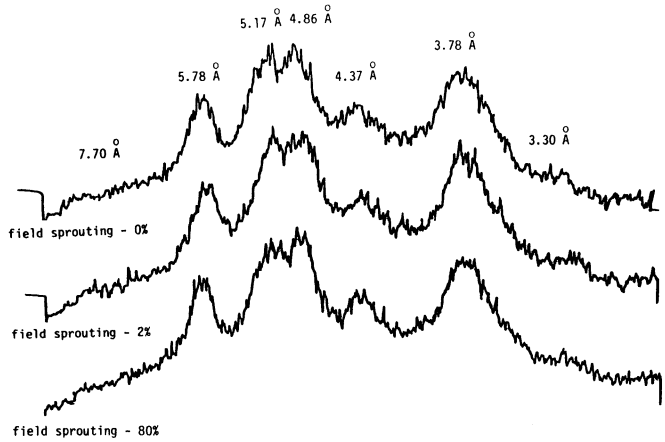

Fig. 3. X-ray diffraction patterns of starches from field-sprouted wheat.

Viscograms of Starches

Little or no relationship is generally observed when swelling power values and Brabender pasting curves are compared. The same was true in this study. Viscogram indices of starches from field-sprouted winter wheats (Table VII) show slight changes in the pasting behavior as compared with the appropriate sound control starches. The only observable differences were increased hot paste consistency peaks and reduced hot paste stability for starches from sprouted samples. This trend indicates some weakening intragranular forces by sprouting.

Laboratory sprouting of grains produced trends considerably different from those in this study. Viscograph consistencies of starches decreased as time of laboratory sprouting of the grain increased, because of degradation of the starch due to high amylase activity during sprouting and also because of the remaining amylase activity on surfaces of starches after isolation (Lorenz and Kulp 1981).

Scanning Electron Microscopy and X-Ray Diffraction

Scanning electron micrographs of starches isolated from wheat with field-sprouting percentages of 0, 40, and 78%, respectively, are shown in Fig. 2. None of the starch granules show any damage as the result of higher amylase activity. Laboratory sprouting of triticale, barley and corn for seven days produced extensive damage to granules of starch due to the increased α-amylase activity during sprouting (Lorenz and Kulp 1981). Extensive damage to wheat starch granules due to laboratory sprouting of the wheat have been shown by Dronzek et al (1972) and Bean et al (1974). Starch degradation takes place much more rapidly in laboratory-sprouted grains than in field-sprouted samples because of the ideal conditions (temperature and moisture) for germination and sprouting provided in the laboratory.

X-ray diffraction patterns of starches from wheat with 0, 2, and 80% field sprouting are shown in Fig. 3. There was no change in the pattern due to field sprouting. Relative crystallinity of the starches (Table V), which is determined by an integral method and depends only on peak intensity, confirms that there are no changes in starch granule crystallinity. Starches from laboratory-sprouted barley and corn showed only minor changes in X-ray pattern. A moderate change in the pattern was observed for triticale starch, which also showed a loss in crystallinity due to sprouting of the grain in the laboratory (Lorenz and Kulp 1981).

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