Preharvest Sprouting of Winter Wheat. II. Amino Acid Composition and Functionality of Flour and Flour Fractions

K. LORENZ, P. ROEWE-SMITH,[1] K. KULP,[2] and L. BATES[3]

ABSTRACT

Cereal Chem. 60(5):360-366

Preharvest field sprouting of wheats reduces the baking potential of flours because α-amylase and protease in wheat increase. Baking experiments with flours milled from wheats of varied degrees of sprouting and with gluten-starch systems from the same flours demonstrated that excessive α-amylase causes stickiness of doughs and poor handling and machining properties, and that a high level of protease affects the gluten properties, producing an expended loaf volume of poor internal quality. Soft wheat flour applications and thickening powers of starches are also adversely affected by sprouting.

Flour milled from sprouted wheat has a deleterious effect on the quality of bread. Kozmin (1933) reported that bread baked from wheat that was sprouted in the laboratory was sticky, had an inelastic crumb, and appeared to be high in moisture. She showed that the defective crumb was a result of the excessive degradation of starch to sugars and dextrins. The crumb was wet and sticky, not because of excessive water, but because of the impaired gel formation of the damaged starch.

In a study conducted by Tipples et al (1966) on the effect of malt and sprouted wheat, the use of heavily sprouted wheat flour necessitated a reduction in baking absorption and produced bread with large holes.

Huang and Bushuk (1973) reported that doughs prepared from wheats highly sprouted under laboratory conditions were so sticky that they could not be made into bread.

Ranhotra et al (1977) showed that the addition of laboratory-sprouted wheat flour at a 5% level to sound flour improved the volume without adversely affecting other bread characteristics. However, as the level of addition increased, bread volume decreased and a general deterioration of bread quality occurred. Apparently, the low amylolytic activity at the 5% level provided additional but not excessive fermentable sugars, resulting in increased bread volume.

Ibrahim and D'Appolonia in 1979, and D'Appolonia in 1981, studied the effect of field sprouting of hard red spring wheat on bread quality. They reported inferior grain and texture and grayer crumb color but no detrimental effect on loaf volume. The stickiness of the dough and decrease in absorption and dough development time shown by previous investigators was also noted.

Finney et al (1980) evaluated the performance of field-sprouted soft white wheat flour in a variety of leavened and unleavened international breads. Seven of the nine breads were considered acceptable, even when baked from highly sprouted flour.

Comparison of these studies indicated that researchers are in general agreement regarding the effects of sprouting on dough preparation and handling, and on characteristics of the baked bread. The purpose of this study was to investigate the effect of preharvest sprouting on the baking functionality of flour and on its two major components, the starch and the gluten.

MATERIALS AND METHODS

Sample Identification

The three varieties of winter wheat used in this study were Newton, a sprouting-resistant hard red winter wheat; Centurk, a sprouting-susceptible hard red winter wheat; and KS73256, a sprouting-susceptible hard white winter wheat. The agronomic conditions under which they were grown and pertinent analytical data were described previously (Bhatt et al 1981, Kulp et al 1983). The grains were milled into flour using a Miag Multomat mill.

Fractionation of Flours into Gluten and Starch

Five hundred grams of flour and 200 ml of water were mixed into a stiff dough through the use of a laboratory mixer. The gluten was hand-washed from the dough. The gluten for bread-baking experiments was frozen immediately and kept in frozen storage until needed for baking. Gluten samples for amino acid determinations were frozen and then lyophilized. The method of starch isolation was described previously (Kulp et al 1983).

Amino Acid Analyses

Samples of flour and gluten containing approximately 10–15 mg of protein were weighed directly in 16 × 150-mm glass culture tubes. Exactly 10 ml of 3*N* *p*-toluenesulfonic acid (Liu and Chang 1971) containing norleucine as an internal standard was added, and the tubes were capped with polypropylene caps. The tubes were placed in an enclosed boiling water bath for 31 hr of hydrolysis. Each sample was cooled, transferred to a 25-ml volumetric flask, neutralized with NaOH, diluted with pH 2.2 buffer, and frozen until analyzed.

Each sample was thawed and ultrafiltered through a 0.2-nm cellulose acetate membrane immediately before application to the ion-exchange column. Samples (185 μl) were applied to the long and short columns of a Beckman 120C automatic amino acid analyzer and eluted according to the Beckman 2-hr hydrolyzate procedure.

Recoveries of amino acids were corrected for mechanical losses with norleucine (Walsh and Brown 1962) and calculated to 100% on a protein basis. The Beckman automatic amino acid analyzer reproducibility is ±3.0%.

Bread-Baking Experiments

Breads were baked from each flour by straight and sponge/dough procedures using the following formulation: flour, 100%; sugar, 6%; nonfat dry milk, 4%; shortening, 3%; yeast, 2.5%; salt, 2%; and yeast food, 0.5%.

A good-quality commercial flour (Minnesota Girl) served as a control for each method. Absorptions were determined by farinograph (Kulp et al 1983).

Straight doughs were mixed in a McDuffy mixer to optimum development, fermented 1.5 hr at 88° F and 80% rh, divided into 200-g pup loaves, rounded, and allowed to rest on the bench for 10 min. They were then molded, proofed (100° F, 90% rh) to 1 in. above the pan, and baked at 425° F for 18 min.

Sponge doughs were prepared by mixing a sponge composed of 70% of total flour, yeast, yeast food, and necessary water. The sponge was mixed in a National mixer for 3 min and fermented for 3 hr at 88° F and 80% rh. The sponge and the remaining dough ingredients were then mixed to optimal development in a McDuffy bowl. After a 20-min intermediate proof (88° F, 80% rh), the doughs were divided into 200-g pup loaves, rested for 10 min,

[1]Dept. of Food Science and Nutrition, Colorado State University, Fort Collins 80523.
[2]American Institute of Baking, Manhattan, KS 66502.
[3]LSB Products, 1568 Hayes Drive, Manhattan, KS 66502.

molded, proofed at 90° F and 100% rh to 1 in. above the pan, and baked at 425° F for 18 min.

Breads were cooled on wire racks for 2 hr before specific volumes were measured by rapeseed displacement. The external and internal loaf characteristics were evaluated after overnight storage. To score the breads, a maximum number of points was given to each bread characteristic: crust color, 7; symmetry, 7; break and shred, 6; crumb color, 10; volume, 15; flavor, 15; grain, 20; and texture, 20.

Recombination Studies

The starch and gluten fractions were recombined for bread baking such that each sprout-damaged fraction was combined with the control fraction isolated from Minnesota Girl flour and with the varietal control flour.

Starch-gluten breads were baked by the remix procedure and formulation of Irvine and McMullan (1960). Doughs were mixed to optimum development in a National mixer and allowed to ferment (88° F, 80% rh) for 75 min after mixing. Doughs were rounded and bench-rested for 10 min before they were molded, proofed (100° F, 90% rh) to 1 in. above the pan, and baked at 425° F for 18 min. The specific volume and bread scores were determined by procedures described previously for the straight and sponge doughs.

Bread Softness Determinations

The effect of field sprouting on bread softness was evaluated with pound loaves of breads baked by the straight dough procedure. Flour samples used included Newton, 0 and 2% field sprouting; Centurk, 0, 17, and 40% field sprouting; KS73256, 0 and 75% field sprouting; and a good-quality control flour (Minnesota Girl). Freshly baked and cooled loaves were wrapped in plastic bags and stored under ambient conditions. After one, three, and five days, loaves were cut into eight 0.5-in.-thick slices, and two softness measurements were taken on each slice. Softness, expressed as grams of force per 0.5-mm compression, was measured with a Baker Compressimeter.

Pasting Characteristics of Bread Crumb

Pasting properties of the bread crumb were evaluated with the amylograph according to the procedure of Kim and D'Appolonia (1977). Samples studies included Newton, 0 and 2% field sprouting; Centurk, 0, 17, 30, and 40% field sprouting; and KS73256, 0, 75, 78, and 80% field sprouting. The crumb of breads baked by the straight dough procedure was removed from the bread and allowed to air dry.

A 55-g crumb sample was suspended in 350 ml of distilled water by agitation at low speed in a Waring Blendor for 1 min. The suspension was poured into the amylograph bowl along with 100 ml of distilled water, which was used to rinse the blender. The suspension was heated from 30–92° C at a controlled rate of 1.5° C/min, held at 92° C for 15 min, and cooled to 35° C at a rate of 1.5° C/min. Consistency was recorded in Brabender units at 92° C, after 15 min at 92° C, and after cooling to 35° C.

Measurements of Functional Characteristics

For evaluation of the starches in cakes, a high-ratio yellow cake formulation by Cauvin and Gough (1975), as modified by Lorenz and Kulp (1981), was used.

The cakes were scored as follows: volume, 15; crust color, 5; symmetry, 10; crust character, 5; grain, 15; crumb color, 10; aroma, 10; taste, 20; and texture, 10. The maximum number of possible points was indicated after each cake characteristic.

The thickening power of all starches was determined in a simulated pie filling following the procedure of Lorenz and Kulp (1981). The formulation consisted of 90 g of water, 50 g of sugar, 0.4 g of salt, and 9 g of starch. The consistency of the fillings was measured with a Brookfield viscometer at 20 rpm. The consistencies were recorded on the day of preparation and one, two, and five days after preparation and storage at 10 and 22° C, respectively.

RESULTS AND DISCUSSION

Amino Acid Compositions of Flours and Gluten Samples

Changes in amino acid composition of cereal grains sprouted in the laboratory have been studied by several investigators. Dalby and Tsai (1976) reported on the effects of germination of mature seeds of wheat, barley, triticale, oats, rice, and rye, which were surface-sterilized before sprouting at 28° C in the dark for up to 5 days. In all grains, increases in lysine and tryptophan were observed. Not all changes were equally striking quantitatively, however. The extent of the increases appeared to be inversely related to the amount of prolamine present and its metabolism during germination. Wheat produced the largest increase in lysine (about 40%) during five days of germination and oats the lowest.

Miller (1978) reported increases in wheat lysine content of 15–27% after seven days of sprouting, with the greater increase in low-protein wheats and the least increase in high-protein varieties. The wheat seeds in this study were rinsed briefly with water before being placed into sprouting jars. Miller (1978) did not provide a good description of the varieties of wheat used and how they were grown, which might explain the differences in lysine increase in his study compared to the data of Nielsen et al (1978), who did not show greater lysine increases with higher protein wheats.

No data in the literature show differences in amino acid composition of flours milled from field-sprouted wheat.

Table I shows the amino acid composition of the flours used in this study. No definite trends are apparent comparing the amino acid compositions of the flours from the four genotypes. However, the flours from the sprout-susceptible wheat varieties (Centurk and KS73256), which had relatively high field-sprouting percentages, had a few noticeable trends. Comparing the KS-0 N with KD-90 N and Centurk-0 N with Centurk-90 N decreases in aspartic acid, threonine, histidine, and lysine, and increases in glutamic acid are apparent with higher field sprouting. The flour from sprout-resistant wheat varieties (Newton and Clark's Cream) showed no such trends.

There are no data in the literature showing differences in amino acid composition of gluten samples isolated from sprout-damaged flours. Table II shows the amino acid composition of the gluten samples used in this study. No definite trends are apparent comparing the amino acid compositions of glutens from the different flours even though differences in gluten characteristics were observed during isolation. Gluten samples from highly sprout-damaged flours were very difficult to isolate. They had very little cohesion and elasticity. There seemed to be a relationship between the physical condition of the isolated gluten sample and the protease activity of the grain as determined by Bhatt et al (1981).

Bread-Baking Experiments

Photographs of breads prepared by the straight and sponge dough procedures are shown in Figs. 1 and 2, respectively. Results were similar in both procedures, but the effects of sprouting were amplified by the sponge/dough procedure because of the longer fermentation time. As observed previously by other researchers (D'Appolonia 1981, Huang and Bushuk 1973, Ibrahim and D'Appolonia 1979, Kozmin 1933), the doughs prepared from the highly sprouted samples were stickier and more difficult to handle than the controls.

The quality of the baked loaf was affected by the use of flour from sprouted wheat. Sprouting caused higher volumes as shown by the specific volume data presented in Table III. A more open grain and grayer crumb were observed in breads baked from more highly sprouted samples. The increased amounts of fermentable sugars resulted from starch degradation that had been enhanced by the presence of high levels of α-amylase. This reaction caused a concomitant increase in gas production, and thus, more open grain and higher loaf volume.

Bread Softness Determination

The softness measurements taken with a Baker Compressimeter one, three, and five days after baking are presented in Table IV.

TABLE I
Amino Acid Composition of Flour[a]

	KS Control	KS 0 N	KS 45 N	KS 90 N	Clarks Cream 0 N	Clarks Cream 45 N	Clarks Cream 90 N	Newton Control	Newton 0 N	Newton 45 N	Newton 90 N	Centurk Control	Centurk 0 N	Centurk 45 N	Centurk 90 N
Aspartic acid	4.81	4.77	4.67	4.51	4.38	4.31	4.15	4.54	4.59	4.43	4.58	4.68	4.74	4.64	4.35
Threonine	3.07	2.92	3.06	2.76	2.70	2.73	2.57	2.72	2.72	2.72	2.78	2.73	2.89	2.85	2.57
Serine	5.01	5.31	5.07	5.13	5.11	5.03	5.10	5.44	5.67	5.28	5.46	5.44	5.49	5.55	5.34
Glutamic acid	29.96	32.58	32.64	33.11	33.92	34.48	32.70	33.13	32.48	30.73	32.49	29.98	29.96	31.87	31.54
Proline	10.92	12.17	11.84	12.05	12.20	12.42	11.53	11.33	10.95	10.54	11.25	10.53	11.30	10.94	10.61
Glycine	4.07	4.11	4.15	4.01	3.94	3.75	3.65	3.94	4.11	3.87	3.95	3.93	3.83	3.93	3.76
Alanine	3.87	3.84	3.65	3.75	3.63	3.68	3.45	3.52	3.51	3.52	3.47	3.71	3.76	3.63	3.68
Half cystine	2.13	1.81	1.95	1.88	1.93	1.90	1.86	1.86	1.92	1.96	1.83	1.86	1.97	1.81	1.88
Valine	3.42	3.04	3.18	3.15	3.15	3.14	3.24	3.12	3.22	3.39	3.09	3.29	3.37	3.28	3.40
Methionine	1.97	1.49	1.63	1.64	1.61	1.55	1.83	1.67	1.74	1.94	1.69	1.85	2.03	1.80	2.01
Isoleucine	2.66	2.29	2.37	2.42	2.49	2.54	2.67	2.53	2.56	2.71	2.42	2.58	2.79	2.65	2.85
Leucine	6.67	6.70	6.67	6.71	6.65	6.75	6.60	6.83	6.95	6.85	6.83	6.70	6.79	7.04	6.75
Tyrosine	3.67	3.36	3.62	3.50	3.45	3.45	4.08	3.53	3.67	4.10	3.47	3.67	3.88	3.54	4.01
Phenylalanine	5.74	4.96	5.55	5.63	5.67	5.64	6.66	5.30	5.14	6.07	5.21	5.34	5.28	5.14	6.00
Histidine	2.52	2.32	2.26	2.26	1.64	1.11	1.53	2.76	2.03	3.56	3.32	4.30	2.69	2.54	2.37
Lysine	2.29	1.94	1.81	1.68	1.61	2.00	1.97	2.09	2.58	1.79	2.06	2.45	2.35	2.13	2.12
Ammonia	1.14	1.17	1.06	0.92	1.00	1.03	1.13	0.96	1.11	1.16	1.07	1.30	1.31	1.22	1.14
Arginine	6.08	5.22	4.83	4.88	4.94	4.46	5.28	4.73	5.07	5.38	5.03	5.66	5.59	5.45	5.64
Rec. norleucine, %	111.67	99.25	100.77	101.90	107.86	86.74	101.75	91.08	96.85	92.97	94.15	103.80	90.45	101.28	112.08
Rec. protein, %	96.49	107.07	113.89	123.49	120.02	122.34	136.79	156.58	117.57	126.04	127.93	97.73	98.35	111.21	113.02
Nitrogen, %	1.32	1.45	1.51	1.63	1.57	1.59	1.81	2.08	1.57	1.72	1.73	1.37	1.35	1.51	1.53

[a] Grams of amino acids per 100 grams of protein corrected to 100% recovery, protein basis.

TABLE II
Amino Acid Composition of Gluten Samples[a]

	Newton 0 N	Newton 90 N	Centurk Control	Centurk 0 N	Centurk 90 N	KS Control	KS 0 N	KS 90 N
Aspartic acid	4.15	4.54	4.59	4.43	4.58	4.09	3.95	3.91
Threonine	2.57	2.72	2.72	2.72	2.78	2.92	2.87	2.84
Serine	5.10	5.44	5.67	5.28	5.46	5.67	5.74	5.82
Glutamic acid	32.70	33.13	32.48	30.73	32.49	34.11	32.73	33.81
Proline	11.53	11.33	10.95	10.54	11.25	11.38	11.28	11.35
Glycine	3.65	3.94	4.11	3.87	3.95	4.12	4.45	4.62
Alanine	3.45	3.52	3.51	3.52	3.47	3.29	3.37	3.31
Half cystine	1.86	1.86	1.92	1.96	1.83	2.01	2.05	2.06
Valine	3.24	3.12	3.22	3.39	3.09	3.29	3.48	3.45
Methionine	1.83	1.67	1.74	1.94	1.69	1.76	1.83	1.80
Isoleucine	2.67	2.53	2.56	2.71	2.42	2.51	2.70	2.71
Leucine	6.60	6.83	6.95	6.85	6.83	6.99	7.20	7.20
Tyrosine	4.08	3.53	3.67	4.10	3.47	3.70	3.83	3.93
Phenylalanine	6.66	5.30	5.14	6.07	5.21	5.26	5.71	5.87
Histidine	1.53	2.76	2.03	3.56	3.32	1.64	0.81	1.33
Lysine	1.97	2.09	2.58	1.79	2.06	2.25	3.56	1.34
Ammonia	1.13	0.96	1.11	1.16	1.07	0.81	0.70	0.69
Arginine	5.28	4.73	5.07	5.38	5.03	4.20	3.75	3.95
Rec. norleucine, %	100.55	90.01	95.71	91.88	93.04	109.95	122.03	134.03
Rec. protein, %	106.74	104.14	113.31	97.21	106.99	153.59	133.31	151.68
Nitrogen, %	7.06	6.91	7.59	6.63	7.23	9.89	8.47	9.59

[a] Grams of amino acids per 100 grams of protein corrected to 100% recovery, protein basis.

TABLE III
Straight Dough and Sponge Dough Bread Scores

		Straight Doughs					Sponge Doughs				
Flour	Grain Field Sprouting (%)	Specific Volume (cc/g)	Grain[a]	Texture[a]	Crumb Color[b]	Total Score[c]	Specific Volume (cc/g)	Grain[a]	Texture[a]	Crumb Color[b]	Total Score[c]
Minnesota Girl	0	4.79	19	19	10	88	...	...	...	...	...
Newton	0	5.30	15	18.5	8.5	88	4.91	15	16	8.5	83
	2	5.01	17	18	8	87	4.64	16	16	8	80.5
Centurk	0	4.86	17	16	8	83	4.38	16	16	9	84
	17	5.16	15	18	9	87	5.01	12	17	7	81
	30	5.40	13	18	9	86	5.26	12	17	7	82
	40	5.97	13	19	9	86	5.24	12	17	7	82
KS-73256	0	4.94	16	16	9	86	4.56	19	17	9	87
	75	5.86	12	17	7	79	5.52	10	16	7	78
	78	5.39	14	17	7	84	5.34	11	16	7	78
	80	5.59	10	17	7	80	5.24	8	16	7	78

[a] 20 possible points.
[b] 10 possible points.
[c] 100 possible points.

Lower values indicate softer breads. These data showed a general increase in bread softness with sprouting. This could be explained by the more open grain of the breads baked from the more highly sprouted samples. The larger air cells provided less resistance to the applied force. Comparison of the measurements taken for each sample on days one, three, and five showed no significant differences in the rate of staling with increased sprout damage.

Pasting Characteristics of the Bread Crumb

Results of the amylograph study of the pasting characteristics of the bread crumb are presented in Table V. Consistency measurements were recorded at the three reference points: 92°C, after 15 min at 92°C, and at 35°C. Viscosity decreased with increased sprout damage at each of these points. The lower values reflect the enzymatic breakdown of the starch by the amylases during bread preparation.

Recombination Studies (Starch-Gluten Breads)

The breads pictured in Fig. 3 were baked by combining starch isolated from Minnesota Girl, a good-quality bread flour, and gluten from the experimental flour as indicated. Doughs from glutens with low sprouting levels were dry and extensible. The doughs prepared with glutens from highly damaged samples were dry and inelastic. Thus, the sprouting process affected the gluten in a manner that caused it to be less extensible during mixing.

As sprouting increased, the grain became more open and the crumb became grayer in color in comparison with breads from sound flours (Table VI). These results were amplified more in the starch-gluten breads than in the breads prepared from the intact flour. Scores of breads for the control flours have been included in the table. Mixing times between control flours and starch-gluten breads cannot be compared because relatively long mixing times are always required when gluten and starch are mixed into a dough.

Breads shown in Fig. 4 were prepared by combining gluten isolated from a sound flour (Minnesota Girl) with starch fractions from experimental flours as indicated. As the sprouting damage

TABLE IV
Bread Softness[a]

Flour	Grain Field Sprouting (%)	Softness[b] Day 1	Day 3	Day 5
Minnesota Girl	0	6.2 ± 0.3	9.5 ± 1.1	13.4 ± 1.2
Newton	0	7.8 ± 0.5	12.2 ± 1.0	21.8 ± 2.0
	2	7.1 ± 0.4	10.3 ± 1.2	19.2 ± 2.1
Centurk	0	9.8 ± 1.2	15.1 ± 1.6	24.5 ± 2.1
	17	8.1 ± 1.0	16.7 ± 1.4	20.7 ± 1.9
	40	8.9 ± 0.9	15.7 ± 1.2	22.4 ± 1.8
KS-73256	0	8.4 ± 1.1	11.3 ± 0.9	20.5 ± 2.0
	75	5.7 ± 0.4	12.4 ± 0.9	18.3 ± 0.9

[a] Averages ± standard deviation.
[b] Grams of force per 0.5 mm compression.

TABLE V
Amylograph Characteristics of Bread Crumb[a]

Flour	Grain Field Sprouting (%)	Consistency (BU)[b] After 15 Min at 92°C	92°C	35°C
Newton	0	155	250	340
	2	170	230	335
Centurk	0	155	225	415
	17	40	50	110
	30	35	35	100
	40	20	20	50
KS-73256	0	90	105	110
	75	50	55	110
	78	50	60	120
	80	40	50	95

[a] Reproducibility = ±10 BU.
[b] BU = Brabender units.

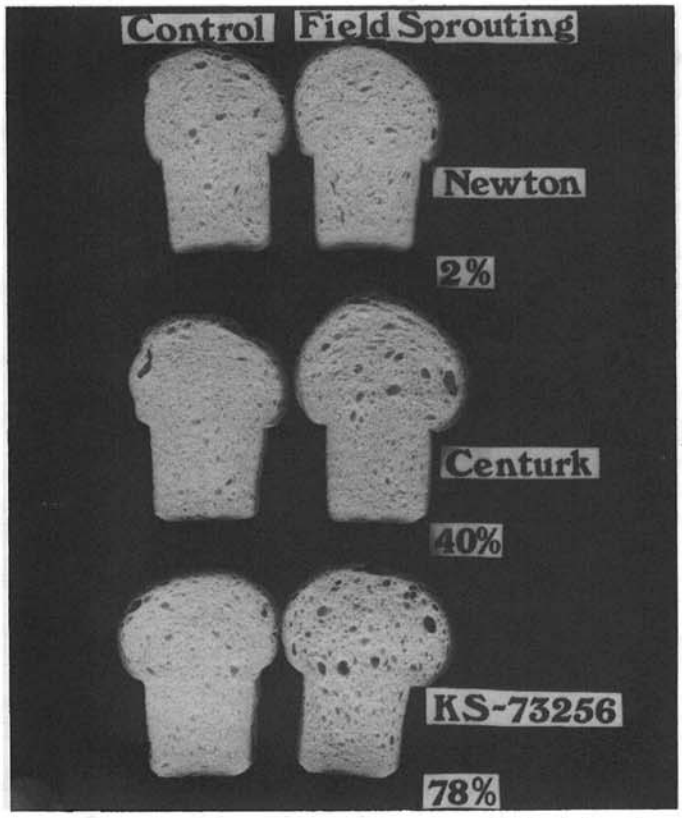

Fig. 1. Breads baked by straight dough procedure with flours from three different wheat varieties varying in percent field sprouting (percent field sprouting given under each variety name).

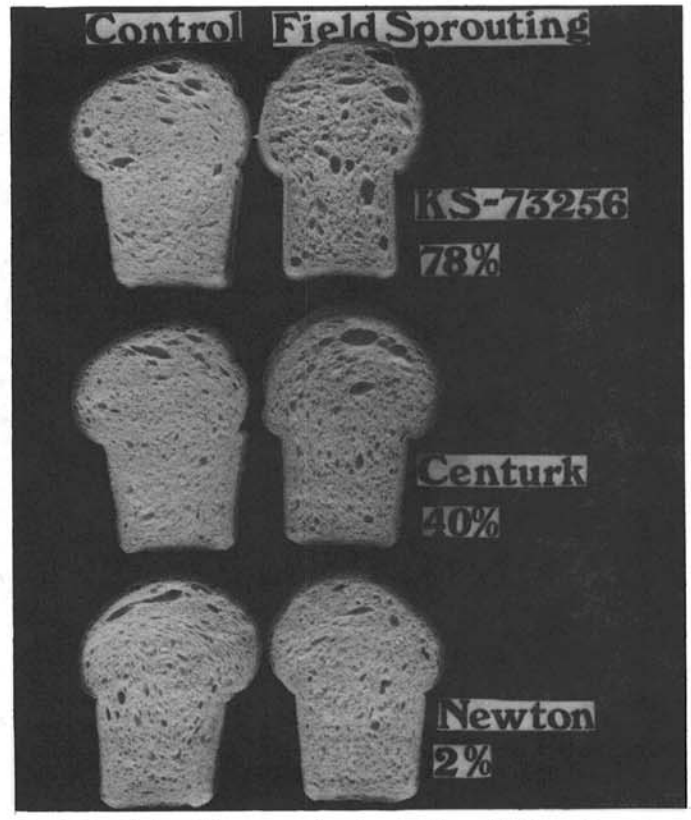

Fig. 2. Breads baked by sponge dough procedure with flours from three different wheat varieties varying in percent field sprouting (percent field sprouting given under each variety name).

increased, less mixing time was required to develop doughs to their optimal consistencies, indicating a quicker interaction between gluten and starches from sprouted than sound samples (Table VI). Their dough structure was of good quality until the fermentation stage when doughs became extremely soft, sticky, and nearly impossible to handle. Resulting breads from these doughs were also of poor quality and reduced volumes (Table VI, Fig. 4). These results are unexpected in view of the performance of parent flours (no volume losses were observed) and of the physicochemical characteristics for starches that failed to show appreciable alterations in starches by sprouting (Kulp et al 1983). This effect cannot be attributed to excessive enzymic activities in the dough since any residual α-amylase in starches was inactivated. The

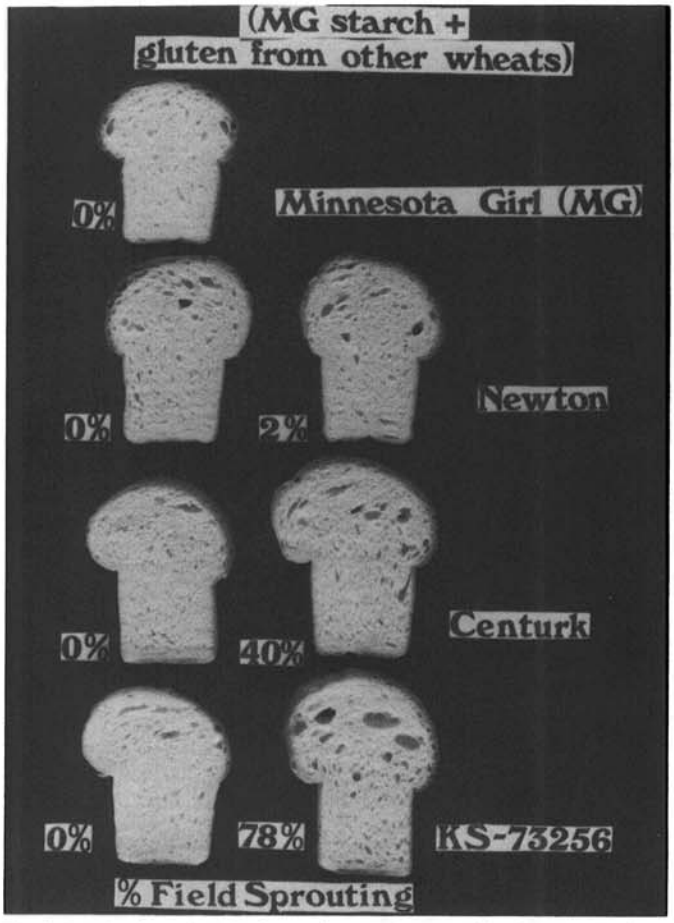

Fig. 3. Starch-gluten breads. Starch from Minnesota Girl flour; gluten from other wheat flours (percent field sprouting of grain given next to each variety name).

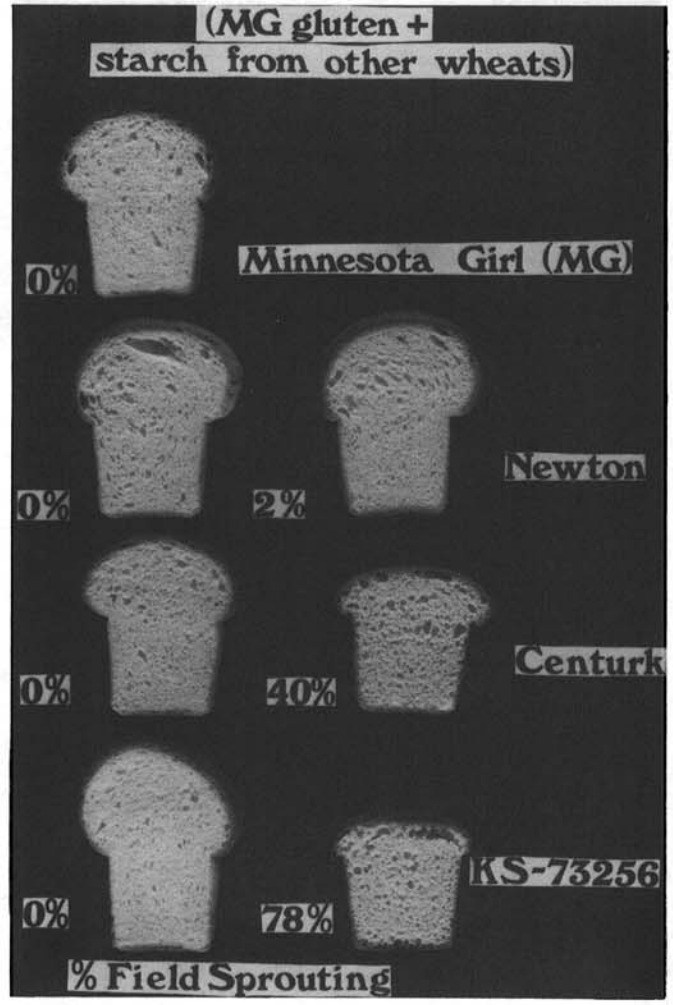

Fig. 4. Starch-gluten breads. Gluten from Minnesota Girl flour; starch from other wheat flours (percent field sprouting of grain given next to each variety name).

TABLE VI
Starch-Gluten Breads

Gluten Fraction	Starch Fraction	Mixing Time (min)	Spec Volume (cc/g)	Symmetry (7 pts max)	Break (6 pts max)	Crumb Color (10 pts max)	Grain (20 pts max)	Texture (20 pts max)	Total Score
Minnesota Girl	Minnesota Girl	9.5	4.33	6	6	8	18	15	83
Minnesota Girl	Newton 0% FS[a]	11	4.75	7	6	9	18	18	90
Minnesota Girl	Newton 2% FS	12	4.93	7	6	9	18	17	90
Minnesota Girl	Centurk 0% FS	9	4.11	4	4	7	15	12	71
Minnesota Girl	Centurk 17% FS	8	3.06	2	1	4	5	5	40
Minnesota Girl	Centurk 40% FS	8	3.59	3	2	4	5	5	44
Minnesota Girl	KS-73256 0% FS	12	4.65	7	6	10	18	18	91
Minnesota Girl	KS-73256 78% FS	9.5	3.08	2	1	4	5	5	41
Minnesota Girl	KS-73256 80% FS	9.5	3.30	2	1	4	5	5	42
Newton 0% FS	Minnesota Girl	10	4.66	7	6	9	18	17	89
Newton 2% FS	Minnesota Girl	11.5	4.20	7	6	8	16	16	83
Centurk 0% FS	Minnesota Girl	11.5	5.01	7	6	9	17	17	90
Centurk 17% FS	Minnesota Girl	10.5	5.16	7	6	8	16	16	87
Centurk 40% FS	Minnesota Girl	10	5.15	7	5	8	16	15	82
KS-73256 0% FS	Minnesota Girl	10	4.45	7	6	10	18	17	89
KS-73256 78% FS	Minnesota Girl	11	5.06	7	6	9	14	15	85
KS-73256 80% FS	Minnesota Girl	10	5.66	7	5	7	7	18	80
Minesota Girl flour		...	4.79	6	6	10	19	19	88

[a] FS = Field sprouting percentage of grain.

suggested explanation is that the surface of starch granules is altered by sprouting and fails to interact normally with gluten to produce a stable dough structure. Similar difficulty was reported by Sandstedt et al (1939) in reconstitution studies with commercial wheat starches, which also did not perform unless pretreated with cereal amylases. Possibly these changes may not be apparent in sprouted flours where abundant amylases are present but become critical in the starch gluten systems where the level of enzymes is drastically reduced. Alternatively, one may speculate that the incipient damage to the granules is augmented by the isolation step and causes poor performance of starch.

Functional Characteristics (Cakes and Pie Fillings)

Results of baking cakes with starches isolated from field-sprouted wheats are given in Table VII. There were no differences in batter specific gravity. Cake volumes increased and the grain of the cakes became a little more open and coarse, but texture actually became slightly smoother and softer with an increase in field sprouting. Untreated starch samples of the Centurk series, which would have a residual amylase activity, produced higher cake volumes than the enzyme-inactivated samples.

A beneficial effect of low levels of sprouting of soft wheat on sponge cake volume has been demonstrated by Finney et al (1981). Volume decreased rapidly, however, and the grain became more open at high levels of sprout damage.

Generally, laboratory sprouting of soft white wheat had an adverse effect on the functionality of flours in soft wheat applications. Sprouting of the grain for longer than one day resulted in flours of poor cake-baking quality. The cakes were low in volume, had a dip in the center, a coarse grain, and a firm texture. Cookie spreads increased, and cookie top grain score improved with longer times of sprouting of the grain, but the crust color of the cookies darkened (Lorenz and Valvano 1981).

Thickening-power data (Table VIII) show that fillings stored in the refrigerator had a higher consistency than those stored at room temperature. This was previously reported (Lorenz and Kulp 1981, Lorenz and Valvano 1981). Initial consistency increased with higher field sprouting of the grains from which the starches were isolated. Consistencies decreased after two and five days of storage at 10 and 22°C. There was a greater decrease in consistency percentage with higher field sprouting. All fillings showed signs of syneresis after five days of storage at each of the two temperatures.

Laboratory-sprouted soft wheat produced flours that had decreased thickening powers as time of sprouting increased (Lorenz and Valvano 1981). The difference in extent of damage caused during sprouting explains the difference in the data.

CONCLUSIONS

The baking experiments along with other data presented in the two papers of this series suggest that the sprouting damage that affects functionality of flours is caused by a combination of

TABLE VII
Cake-Baking Data

Starch	Grain Field Sprouting (%)	Starch Treatment	Batter Specific Gravity	Cake Volume (cc)	Grain[a]	Texture[b]	Total Cake Score[c]
Newton	0	enz.-inact.	0.78	1,465	14	9	90
Newton	2	enz.-inact.	0.77	1,515	12	9	87
KS-73256	80	enz.-inact.	0.78	1,520	10	10	85
Centurk	0	enz.-inact.	0.76	1,395	14	8	86
Centurk	17	enz.-inact.	0.75	1,475	12	10	91
Centurk	40	enz.-inact.	0.74	1,440	11	9	89
Centurk	0	none	0.74	1,495	14	8	89
Centurk	17	none	0.74	1,515	14	9	92
Centurk	40	none	0.78	1,520	12	10	91
Minnesota Girl	0	none	0.77	1,505	14	7	87

[a] Based on 15 possible points.
[b] Based on 10 possible points.
[c] Based on 100 possible points.

TABLE VIII
Thickening Power of Starches (cP)

Starch from Wheat Variety	Grain Field Sprouting (%)	Starch Treatment	Filling Storage Temp. (°C)	Consistency (cP) at Day After Preparation			
				0	1	2	5
Newton	0	enz.-inact.	22	15,150	21,750	13,925	12,150
Newton	2	enz.-inact.	22	30,950	23,950	25,450	16,125
KS-73256	78	enz.-inact.	22	17,600	17,000	18,700	14,425
KS-73256	80	enz.-inact.	22	19,450	22,825	16,150	15,850
Centurk	0	enz.-inact.	22	22,875	19,550	21,325	13,200
Centurk	17	enz.-inact.	22	24,950	23,600	26,000	13,850
Centurk	40	enz.-inact.	22	26,375	25,725	20,675	17,775
Centurk	0	none	22	26,900	26,725	24,200	18,450
Centurk	17	none	22	36,075	29,400	23,450	15,525
Centurk	40	none	22	37,150	25,275	24,950	13,900
Newton	0	enz.-inact.	10	29,825	24,975	23,025	21,525
Newton	2	enz.-inact.	10	29,375	24,375	21,650	17,125
KS-73256	78	enz.-inact.	10	19,810	19,900	19,350	16,875
KS-73256	80	enz.-inact.	10	32,400	31,525	27,200	17,450
Centurk	0	enz.-inact.	10	17,550	18,925	18,300	16,875
Centurk	17	enz.-inact.	10	19,150	26,375	17,475	16,400
Centurk	40	enz.-inact.	10	28,950	28,350	21,125	20,275
Centurk	0	none	10	30,475	30,725	19,625	18,025
Centurk	17	none	10	31,950	29,750	18,050	15,675
Centurk	40	none	10	31,900	26,375	25,625	8,440

[a] cP = centipoise. Brookfield viscometer, 20 rpm.

amylolytic and proteolytic activities. The ill effects attributable to α-amylase are: stickiness of doughs, poor handling and machining properties, and stickiness of the bread crumb. These defects are due to the excessive amylase activity during dough processing rather than the in situ damage of starches. The in situ damage is limited and demonstrable in reconstituted doughs in the absence of amylases only.

The gluten component is altered in situ and also during the bread-making process, and it is responsible for the expanded loaf and the low quality of the internal characteristics of breads. The changes in the protein components and gluten appear to be limited to the peptide and disulfite linkages and have not progressed to biochemical transformation of the amino acids, since no changes in amino acid profiles attributable to sprouting were detected. This shows that incipient changes at the protein level effect conformational changes and functionality of protein. They appear to occur in situ in the wheat kernel and are responsible for the expanded loaf volume and poor internal quality.

LITERATURE CITED

BHATT, G. M., PAULSEN, G. M., KULP, K. and HEYNE, E. G. 1981. Preharvest sprouting in hard winter wheats: Assessment of methods to detect genotypic and nitrogen effects and interactions. Cereal Chem. 58(4):300.

CAUVAIN, S. P., and GOUGH, B. M. 1975. High ratio yellow cake. The starch cake as a model system for response to chlorine. J. Sci. Food Agric. 26:1861.

DALBY, A., and TSAI, C. Y. 1976. Lysine and tryptophan increases during germination of cereal grains. Cereal Chem. 53:222.

D'APPOLONIA, B. L. 1981. 1980 hard red spring wheat quality and sprout damage studies. 1981 Wheat Quality Conference Report, pp. 7-11.

FINNEY, K. F., NATSUAKI, O., BOLTE, L. C., MATHEWSON, P. R., and POMERANZ, Y. 1981. Alpha-amylase in field-sprouted wheats: Its distribution and effect on Japanese-type sponge cake and related physical and chemical tests. Cereal Chem. 58:355.

FINNEY, P. L., MORAD, M.M., PATZEL, K., CHAUDHRY, S. M., GHIASI, K., RANHOTRA, G., SEITZ, L. M., and SEBRI, S. 1980. Nine international breads from sound and highly field sprouted Pacific Northwest soft white wheat. Bakers Dig. 54(3):22.

HUANG, P., and BUSHUK, W. 1973. Some changes in the endosperm proteins of wheat. Bakers Dig. 53(5):17.

IBRAHIM, Y., and D'APPOLONIA, B. L. 1979. Sprouting of hard red spring wheat. Bakers Dig. 53(5):17.

IRVINE, G. N., and McMULLAN, M. E. 1960. The remix baking test. Cereal Chem. 45:329.

KIM, S. K., and D'APPOLONIA, B. L. 1977. Bread staling studies. I. Effect of protein content on staling rate and bread crumb pasting properties. Cereal Chem. 54:207.

KOZMIN, N. 1933. Biochemical characteristics of dough and bread from sprouted grain. Cereal Chem. 10:420.

KULP, K., ROEWE-SMITH, P., and LORENZ, K. 1983. Preharvest sprouting of winter wheat. I. Rheological properties of flours and physicochemical characteristics of starches. Cereal Chem. 60:355.

LIU, T. Y., and CHANG, Y. H. 1971. Hydrolysis of proteins with *p*-toluenesulfonic acid. J. Biol. Chem. 246:2842.

LORENZ, K., and KULP, K. 1981. Sprouting of cereal grains. Effects on starch characteristics. Staerke 33:183.

LORENZ, K., and VALVANO, R. 1981. Functional characteristics of sprout-damaged soft white wheat flours. J. Food Sci. 46:1018.

MILLER, B. F. 1978. Effects of sprouting on nutritional value of wheat, in Proc. 10th Natl. Conf. Wheat Utilization Research, November 16–18, 1977, 144; ARM-W-4/August. Tucson, AZ.

NIELSEN, M. T., MEADE, R. E., PAULSEN, G. M., and HOSENEY, R. C. 1978. Improvement of wheat protein quality by germination, in Proc. 10th Nat. Conf. Wheat Utilization Research, November 16–18, 1977, 24; ARM-W-4/August. Tucson, AZ.

RANHOTRA, G. S., LOEWE, R. J., and LEHMANN, T. A. 1977. Bread-baking quality and nutritive value of sprouted wheat. J. Food Sci. 42(5):1373.

SANDSTEDT, R. M., JOLITZ, C. E., and BLISH, M. J. 1939. Starch in relation to some baking properties of flour. Cereal Chem. 16:780.

TIPPLES, K. H., KILBORN, R. H., and BUSHUK, W. 1966. Effect of malt and sprouted wheat. Cereal Sci. Today 11(9):362.

WALSH, K. A., and BROWN, J. R. 1962. Internal standards for amino acid analyses. Biochim. Biophys. Acta 58:596.

[Received October 25, 1982. Accepted April 11, 1983]