

Effect of Laboratory Sprouting and Storage on Physicochemical and Breadmaking Properties of Hard Red Spring Wheat¹

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ABSTRACT

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The effect of storage on physicochemical and functional (breadmaking) properties of both newly harvested hard red spring wheats (control samples) and the same wheats sprouted in the laboratory for 12 hr (lightly) and 40 hr (heavily) were examined. Control samples generally showed an increase in milling extraction and flour protein content, a decrease in proteolytic activity, and an improvement in baking quality during eight months of grain storage. Sprouted samples showed an increase in milling extraction, flour protein content, and α -amylase activity and a decrease in proteolytic activity. The heavily sprouted samples, however, showed smaller changes than the lightly sprouted samples during storage. Unlike

the control samples, storage did not improve but rather reduced the baking quality of the sprouted samples. Results from the Osborne solubility fractionation of both control and sprouted samples showed an increase in globulin protein distribution during storage. No significant changes were observed in distribution of other protein fractions. Storage seemed to affect the sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) patterns of albumin, glutenin, and residue fractions of both control and sprouted samples. However, storage did not affect the PAGE patterns of albumin and globulin, and the SDS-PAGE patterns of globulin and gliadin fractions.

Sprout damage of hard red spring wheat is sometimes a serious problem for farmers, millers, bakers, traders, and consumers. The detrimental effect of sprouting on baking is attributed to high levels of α -amylase activity in sprouted wheats. Kozmin (1933) reported that an increase in diastatic activity, sugar content, and water-soluble substances during fermentation and baking were observed in sprouted wheat. Tipples et al (1966) reported that a decrease in baking absorption and bread yield was observed when sprouted wheat flour was added. Ibrahim and D'Appolonia (1979) observed a decrease in mixing time, sticky dough, and inferior grain and texture in field-sprouted wheats.

Sprouted wheat also has high levels of proteolytic activity (Mounfield 1936). Hanford (1967) reported that gluten softening was due to endoproteolytic activity. Hwang and Bushuk (1973) studied sprouted wheat protein using modified Osborne fractionation. They reported a decrease in residue proteins and an increase in acetic acid soluble proteins during sprouting.

Hwang and Bushuk (1973) also studied the sprouted wheat proteins by polyacrylamide gel electrophoresis (PAGE). They reported small changes in PAGE patterns in albumin and globulin fractions, and no changes in gliadin patterns. Lukow and Bushuk (1984b) applied sodium dodecyl sulfate (SDS)-PAGE to the sprouted wheat proteins fractionated by the modified Osborne procedure. They found no changes in reduced glutenin and some changes in unreduced gliadin, reduced gliadin, and unreduced glutenin.

Newly harvested wheats, however, showed an improvement in milling extraction and baking characteristics during several months of grain storage (Shellenberger 1939). Rao et al (1978), using gel filtration chromatography, observed a gradual shift in the molecular weight of the proteins to higher values during storage of newly harvested wheat. Posner and Deyoe (1986) reported that newly harvested wheats increased in flour protein, ash, and water absorption during storage.

Because newly harvested wheat improved in breadmaking quality upon storage, it was of interest to see whether sprouted wheat would also improve its quality upon storage. The purpose of this study, therefore, was to investigate the effect of storage on the physicochemical (such as protein fractionation and gel electrophoresis) and functional (breadmaking) properties of newly

harvested wheat and the same wheat sprouted under laboratory conditions.

MATERIALS AND METHODS

Wheat Samples

Two varieties of hard red spring wheat, Len and Olaf, were used for this study. Both were harvested in August, 1987, in North Dakota. Approximately 8 kg of each variety was used as controls, and 16 kg of each was used for the sprouted samples.

Sprouted Wheat Samples

Sprouted wheat samples were prepared in October, 1987, two months after harvest, according to a partial modification of the procedure of Lukow and Bushuk (1984a). Each variety was surface sterilized by soaking in a solution of 2.0% aqueous sodium hypochlorite for 15 min at room temperature and rinsed for 20 min with several changes of distilled water. Samples were then soaked in distilled water at 20°C for several hours until the grain obtained 40% moisture. After rinsing with distilled water, samples were placed in a germination cabinet set at 25°C and 100% relative humidity. Lightly and heavily sprouted samples were obtained by germinating for 12 and 40 hr, respectively.

After germination, sprouted wheats were placed in a kilning chamber, where they were dried at 30°C for approximately 22 hr. When the samples were dried down to 10-11% moisture content, the drying process was terminated. Both controls and sprouted wheat samples were placed in sealed plastic containers and stored at room temperature until ready for use.

Milling

Controls were milled at one, three, five, and eight months after harvest. Sprouted samples were milled at three, five, and eight months after harvest.

Wheat samples were tempered to 15.5% moisture content and milled into straight grade flour on a Buhler laboratory mill according to AACC approved method 26-21A (1983). A reference grain sample was routinely milled to evaluate milling efficiency which was approximately $\pm 1.0\%$.

Analyses of Flour Samples

Moisture content of flour samples was determined by the loss of sample weight in the Brabender air oven at 130°C for 1 hr. A 10-g sample of flour was used.

The ash content of flour samples was determined according to AACC method 08-01 (1983).

The protein content ($N \times 5.75$) of flour samples was determined by the Kjeldahl method (method 46-11, AACC 1983) according

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to the procedure of Williams (1973), who used titanium dioxide catalyst instead of mercury catalyst.

Falling number of the flour samples was determined with the Falling Number 1600 apparatus according to method 56-81b (AACC 1983).

Enzyme Analyses

α -Amylase activity of the flour samples was measured by the Perkin-Elmer model 191 α -amylase analyzer according to method 22-07 (AACC 1983).

Endoproteolytic activity of flour samples was measured according to Kruger (1971). A 250-mg sample on a 14.0% moisture basis of flour in sodium phosphate buffer was reacted with azocasein substrate at 37°C for 3 hr. A 0.01 change of absorbance at 440 nm was reported as 1 unit of activity.

Protein Fractionation and Gel Electrophoresis

A modified Osborne fractionation procedure reported by Chen and Bushuk (1970) was applied. A 10-g flour sample (dry basis) was extracted with 0.5M sodium chloride, 70% aqueous ethanol, and 0.05M acetic acid solutions to give four protein fractions as follows: salt-soluble (albumin and globulin), ethanol-soluble (gliadin), acetic acid soluble (soluble glutenin), and insoluble residue (insoluble glutenin). The salt-soluble fraction was dialyzed against distilled water for 48 hr at 5°C, then centrifuged to separate the water-soluble albumin (supernatant) from the salt-soluble globulin (pellet) fraction. The ethanol-soluble fraction was dialyzed against distilled water under the same conditions as the salt-soluble fraction to remove ethanol. All fractions were freeze-dried. Freeze-dried samples were weighed and ground to obtain uniform samples.

The protein content of all fractions was measured by the micro-Kjeldahl method according to method 46-13 (AACC 1983).

Polyacrylamide gel electrophoresis of albumin, globulin, and gliadin fractions was carried out according to Khan et al (1985). A 20-mg protein sample per 1 ml was prepared, and 5 μ l of this sample was applied to the gel.

SDS-PAGE of albumin, globulin, gliadin, glutenin, and residue fractions was examined according to a modified Laemmli (1970) procedure. A 12% (w/v) acrylamide with 0.1% (w/v) bisacrylamide gel was used. A sample of 20-mg of protein per milliliter was prepared, and 5 μ l of this sample was applied to the gel.

Physical Dough and Baking Analyses

Physical dough characteristics of flour samples were tested with

the farinograph according to method 54-21 (AACC 1983).

Baking properties of flour samples were tested by the straight-dough baking method according to the Cereal Science and Food Technology Department, North Dakota State University. This was a partial modification of the method of D'Appolonia et al (1970). Fermentation time was 180 min with two punches, and 100 g of flour samples on a 14.0% moisture basis was employed. The baking formula was as follows: flour 100 g, yeast 2%, sugar 5%, salt 2%, ammonium phosphate 0.1%, and variable amounts of water. No malt or bromate were added to this formula.

Baking absorption was determined as 1.5% less than the farinogram absorption. Loaves were weighed, and volume was determined by rapeseed displacement at 30 min after removal from the oven. Loaves were stored overnight, then crust color, shape, grain and texture, and crumb color were judged by visual comparison with a standard.

Statistical Analysis

All analyses were done in duplicate, except for flour milling. Data were analyzed statistically using SAS programs (SAS 1986). Complete randomized design was employed, and Duncan's multiple range test was applied to compare mean values.

RESULTS AND DISCUSSION

Milling

The milling extraction data from the Buhler laboratory mill are shown in Table I. A gradual decrease in milling extraction was evident as sprouting progressed. These results agree with those of Hwang and Bushuk (1973). Both control and sprouted samples showed a tendency to increase in milling extraction during storage. Control samples showed the highest increase (3.2–4.6%). The increase shown by the controls was slightly higher than the data reported by Shellenberger (1939). These small increases during storage may not be significant due to variation in the milling procedure itself (approximately \pm 1.0%). As sprouting progressed, the increase in milling extraction during storage declined (light 2.6–2.0%, heavy 0.2–1.8%). It should be noted that the control samples were available after one month of storage, whereas the laboratory-sprouted samples were only available after three months due to the time required to prepare them.

Hwang and Bushuk (1973), and Lukow and Bushuk (1984a) observed a high break flour yield for sprouted wheat samples. From the milling results of this study, controls showed almost the same break flour yield as sprouted samples (data not shown). The different milling characteristics of grain in the two previous studies might be due to different wheat varieties or to freeze-drying of the sprouted samples in those studies instead of air-drying after the germination process as was done in the present study.

Physico-Chemical Characteristics of Flour Samples

The ash and protein contents of flour samples (Tables II and III, respectively) showed a similar trend with sprouting and storage. Controls showed higher values than sprouted samples, and heavily sprouted samples showed slightly lower values than lightly sprouted samples. These results were quite similar to those of Hwang and Bushuk (1973).

TABLE I
Milling Extraction of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	67.2	...	...	67.7	...	...
3	71.2	66.7	66.0	70.1	65.4	63.0
5	70.9	69.6	65.3	70.8	66.1	64.4
8	71.8	69.7	66.2	70.9	68.0	64.8

^a Values are expressed as percent on a 14.0% moisture basis.

^b Samples sprouted for 12 (light) and 40 hr (heavy), respectively.

TABLE II
Duncan's Multiple Range Test on Ash Content of Flour of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	0.40 cd	...	...	0.38 ef	...	...
3	0.41 b	0.37 fg	0.36 g	0.39 de	0.32 ij	0.31 j
5	0.42 a	0.38 ef	0.35 h	0.39 cd	0.33 i	0.32 ij
8	0.43 a	0.39 cd	0.37 g	0.40 bc	0.35 h	0.31 j

^a Mean values are expressed as percent on a 14.0% moisture basis. Any two means followed by different letters differ significantly ($\alpha = 0.05$).

^b Samples sprouted for 12 (light) and 40 hr (heavy), respectively.

TABLE III
Duncan's Multiple Range Test on Protein Content of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	14.0 c	...	...	13.7 e	...	...
3	14.5 b	13.7 e	13.5 f	13.9 cd	13.3 g	13.0 h
5	14.7 a	13.9 d	13.6 f	13.9 cd	13.5 f	13.2 g
8	14.5 b	14.0 cd	13.6 ef	13.9 cd	13.8 f	13.1 h

^a Mean values are expressed as percent on a 14.0% moisture basis. Any two means followed by different letters differ significantly ($\alpha = 0.05$).

^b Samples sprouted for 12 (light) and 40 hr (heavy), respectively.

Both ash and protein contents increased during storage for both control and lightly sprouted samples, however, heavily sprouted samples did not show any significant increase. Results for the controls agree with those of Posner and Deyoe (1986). Generally, there is a close relationship between milling extraction and flour ash content (Pelshenke et al 1966). The increase in ash content, therefore, might be due to the increase in milling extraction (Table I). The aleurone layer and subaleurone endosperm cells are higher in protein content than the inner endosperm cells (Pomeranz and Shellenberger 1961). An increase in flour protein content during storage may, therefore, be due to an increase in milling extraction observed during storage (Table I).

The falling number values of flour samples are shown in Table IV. As expected, control samples showed the highest values, and the values decreased with increased sprouting. All heavily sprouted samples showed a falling number value of 62 sec, which is not meaningful. This low value can be explained as follows: After 60-sec of stirring a flour suspension, the falling number value is measured as the period of time (in seconds) it takes the spindle to drop to the bottom of the test tube. In the case of the heavily sprouted samples, the flour suspension had too low a viscosity to hold the spindle just after stirring began because of extremely high amylase activity in the samples. Therefore, the values of heavily sprouted samples are very low. No significant trends were observed during storage of control and sprouted samples. The value of Len control decreased during storage, but the value of Olaf control increased. The differences may be due to varietal differences or, perhaps, to sampling variability.

Enzyme Analyses

Values for α -amylase activity are shown in Table V. Activity was not detectable in the controls by this procedure. The activity increased substantially as sprouting progressed. Control samples showed no changes during storage, however, heavily sprouted samples showed significant increase in enzyme activity during storage. Lightly sprouted samples increased significantly in milling extraction (Table I), flour ash (Table II), and protein content (Table III). Therefore, the increase in α -amylase activity might be due to increase in flour extraction. Heavily sprouted samples, however, did not show a significant increase in flour extraction, flour ash, and protein content. Nevertheless, α -amylase activity increased significantly in the heavily sprouted samples. Because the α -amylase activity of sprouted grain is particularly high near the aleurone layer, a very slight increase in milling extraction,

TABLE IV
Duncan's Multiple Range Test on Falling Number
of Flour of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	426 f	...	...	502 d	...	...
3	397 g	159 hi	62 k	539 c	134 j	62 k
5	398 g	155 hi	62 k	561 b	133 j	62 k
8	443 e	164 h	62 k	700 a	142 ij	62 k

^aMean values are expressed in seconds. Any two means followed by different letters differ significantly ($\alpha = 0.05$).

^bSamples sprouted for 12 (light) and 40 hr (heavy), respectively.

TABLE V
Duncan's Multiple Range Test on α -Amylase Activity
of Flour of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	0 h	...	...	0 h	...	...
3	0 h	1,190 gh	22,439 f	0 h	2,065 g	39,250 c
5	0 h	1,295 gh	25,875 e	0 h	2,165 g	41,125 b
8	0 h	1,435 g	28,863 d	0 h	2,210 g	45,125 a

^aMean values are expressed as percent on a 14.0% moisture basis. Any two means followed by different letters differ significantly ($\alpha = 0.05$).

^bSamples sprouted for 12 (light) and 40 hr (heavy), respectively.

which might not result in significant increases in ash and protein contents, could certainly result in an increase in α -amylase activity of the flour. Also, there would have been migration of α -amylase into the endosperm during the 40-hr germination period of the heavily sprouted samples.

Endoprotease activity of flour samples is shown in Table VI. Control samples showed the lowest values, and the activity increased two- to threefold as sprouting progressed. These results were about half of the values reported by Lukow and Bushuk (1984a), who applied the same procedure as the present study. These differences might be due to different wheat varieties, extractability of the enzyme, or age of the samples after harvest (which might affect the ability of the grains to germinate). Control and lightly sprouted samples showed a significant decrease in proteolytic activity during storage. However, heavily sprouted samples showed only a slight decrease. These results, therefore, indicate that proteolytic activity decreases during grain storage at room temperature. Rohrich and Thomas (1967) also reported a decrease in proteolytic activity of grain during storage at room temperature.

Flour Protein Composition Analyses

Protein distribution was obtained from the modified Osborne solubility fractionation procedure of Chen and Bushuk (1970). Protein recovery (percentage of protein recovered compared with total flour protein) was 82–92%. The distribution of the various fractions is shown in Figure 1.

As sprouting progressed, the albumin and glutenin fractions increased while the globulin and residue protein fractions decreased. The gliadin fraction remained relatively constant. These fractionation results showed almost the same trend as that reported by Hwang and Bushuk (1973). Lukow and Bushuk (1984b)

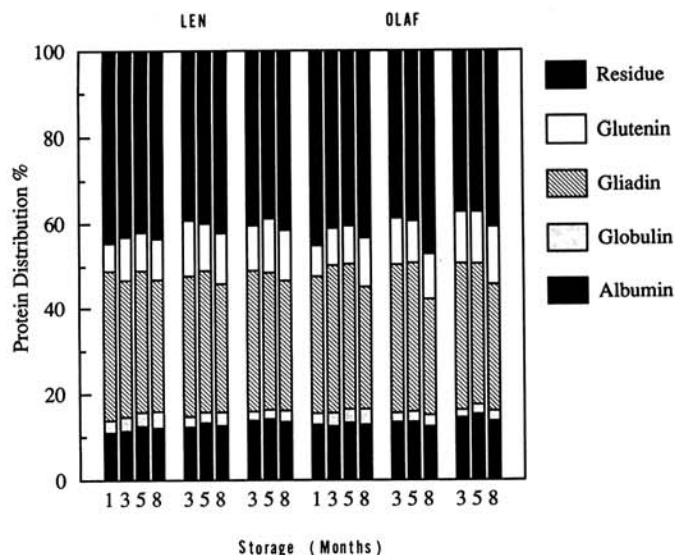


Fig. 1. Histograms of protein distribution from the modified Osborne fractionation procedure of nonsprouted (controls) and sprouted (light and heavy) hard red spring wheats Len and Olaf.

TABLE VI
Duncan's Multiple Range Test on Endoprotease Activity
of Flour of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	1.873 bc	...	...	1.240 ef	...	...
3	1.866 bc	2.113 b	3.033 a	1.010 f	1.783 bc	2.843 a
5	1.286 ef	1.706 bcd	2.836 a	1.006 f	1.723 bcd	2.993 a
9	1.100 ef	1.330 def	2.803 a	0.943 f	1.500 cde	2.786 a

^aMean values expressed in units: 1 unit indicates 0.01 change of absorbance at 440 nm. Any two means followed by different letters differ significantly ($\alpha = 0.05$).

^bSamples sprouted for 12 (light) and 40 hr (heavy), respectively.

however, observed an increase in gliadin content with sprouting. The data in the present study do not agree with their results. The different results may be due to differences in varieties or sprouting procedures.

The globulin fraction of both controls and sprouted samples increased upon storage; however, other fractions did not show any particular trends. Rao et al (1978) reported that gel filtration patterns of wheat protein dissolved in a dissociating solvent changed with grain aging. They observed a gradual shift from the gliadin fraction to the glutenin fraction. However, the results of the present study do not show a similar trend, perhaps because of differences in fractionation methods, varieties, and environments.

PAGE and SDS-PAGE of Solubility Fractions

For the PAGE and SDS-PAGE studies, the samples on each gel were compared on an equal protein basis. This was done so that observed differences among patterns on the same gel would be due to real compositional differences rather than to unequal protein application among the samples.

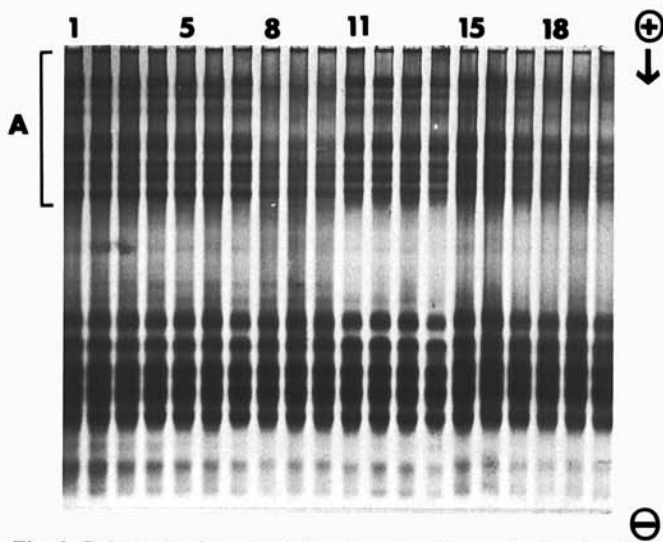


Fig. 2. Polyacrylamide gel electrophoresis patterns of albumin of non-sprouted (controls) and sprouted (light and heavy) hard red spring wheats: Len (patterns 1-10) and Olaf (patterns 11-20), respectively; 1-4 and 11-14, control samples stored for one, three, five, and eight months; 5-7 and 15-17, lightly sprouted samples stored for three, five, and eight months; 8-10 and 18-20, heavily sprouted samples stored for three, five, and eight months.

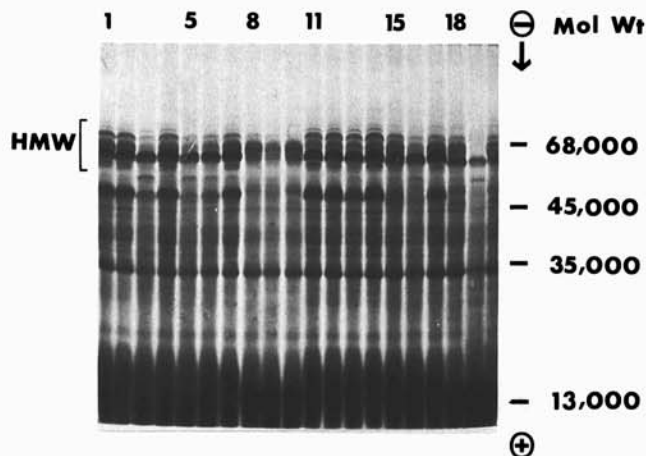


Fig. 3. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of reduced albumin of nonsprouted (controls) and sprouted (light and heavy) hard red spring wheats: Len (patterns 1-10) and Olaf (patterns 11-20), respectively; 1-4 and 11-14, control samples stored for one, three, five, and eight months; 5-7 and 15-17, lightly sprouted samples stored for three, five, and eight months; 8-10 and 18-20, heavily sprouted samples stored for three, five, and eight months.

Sprouting affected the PAGE patterns of albumins (Fig. 2), which showed a decrease in intensity of some of the low mobility bands (A in Fig. 2) and the disappearance of some of these bands in the heavily sprouted samples. Hwang and Bushuk (1973) reported that two minor bands appeared due to sprouting; however, in the present study, this was not observed. This difference could be due to their disc gel electrophoresis procedure, different pH and buffer conditions, and to different wheat varieties. Storage did not affect the PAGE patterns of both control and sprouted samples.

The SDS-PAGE patterns of reduced albumins (Fig. 3) showed that some bands in the higher molecular weight region were fainter in the heavily sprouted samples. No significant effect of storage was found, except for the samples stored for five months, which showed much fainter bands in the highest molecular weight region.

PAGE patterns of globulins (not shown) showed a similar sprouting effect as observed for albumin, that is, a decrease in intensity of low-mobility bands, with some bands missing in the heavily sprouted samples and an increase in intensity of some high mobility bands. These results agree with those of Hwang and Bushuk (1973). Storage did not affect the PAGE patterns of globulin.

SDS-PAGE patterns of reduced globulins (patterns not shown) did not show any qualitative or quantitative differences. Although the PAGE patterns of globulins showed differences, and the quantitative fractionation data (Fig. 1) showed that globulin decreased with sprouting and increased with storage, SDS-PAGE does not seem to show compositional changes of globulin proteins with sprouting and storage.

There were no particular differences in SDS-PAGE patterns (not shown) of unreduced gliadins and reduced gliadins (patterns not shown). Lukow and Bushuk (1984b) reported that the bands of 118,000, 92,000, and 69,000 daltons of reduced gliadin increased in intensity with sprouting. However, the results of this study did not show any changes in the SDS-PAGE patterns of the reduced gliadin fractions.

The SDS-PAGE patterns of reduced glutenins (Fig. 4) showed no obvious qualitative changes in protein bands with sprouting. However, there were various quantitative differences in band intensities in the sprouted samples compared with the controls. These results do not agree with those of Lukow and Bushuk (1984b), who found no qualitative or quantitative changes during germination. Also, there were changes in the patterns of the samples stored eight months, which showed fainter bands in the high molecular weight region and more intensely stained bands in the lower molecular weight region.

The SDS-PAGE patterns of reduced residue proteins (Fig. 5)

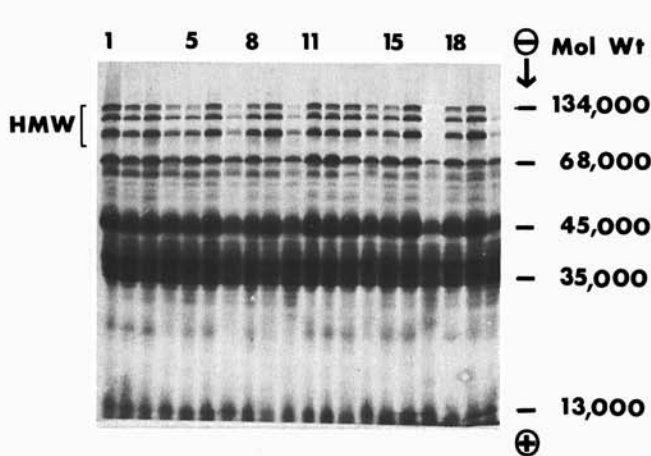


Fig. 4. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of reduced glutenin of nonsprouted (controls) and sprouted (light and heavy) hard red spring wheats: Len (patterns 1-10) and Olaf (patterns 11-20), respectively; 1-4 and 11-14, control samples stored for one, three, five, and eight months; 5-7 and 15-17, lightly sprouted samples stored for three, five, and eight months; 8-10 and 18-20, heavily sprouted samples stored for three, five, and eight months.

also showed quantitative differences in band intensities, both in the high and low molecular weight regions upon sprouting. Also the samples stored eight months showed fainter high molecular weight bands but more intensely stained bands in the low molecular weight regions.

Farinogram Data

Effects of sprouting were evident in the farinograph patterns (not shown). Control samples showed strong patterns; however, the patterns became weaker as sprouting progressed. The weaker patterns are probably due to protein modification from proteolytic activity (Table VI). No significant trends, however, were found in other farinograph parameters during storage except the mixing tolerance index (MTI) of the controls. The MTI values decreased with storage.

Breadmaking Quality

There were no technical problems during the baking process. Loaf volume values are shown in Table VII. Sprouted samples had significantly higher loaf volume than controls because of higher α -amylase activity.

Loaf volume of controls increased with storage. The samples stored one month had the lowest loaf volumes. Len showed the highest volume at five months and Olaf at three months, after which loaf volume decreased slightly. These results agree with those of Shellenberger (1939). Many factors may affect changes in loaf volume during storage, such as maturation and an increase in flour extraction, flour protein, and flour ash contents, and also a decrease in proteolytic activity. However, it is difficult to explain the decrease in loaf volume at the later stages of storage. One cause could be an increase in free fatty acids, which were reported by Zeleny and Coleman (1938) to increase during storage. Sorger-Domenigg et al (1955) reported that wheat having high

fat acidity had poor baking quality.

Sprouted samples, however, showed a significant decrease in loaf volume during storage. Lightly sprouted samples showed larger decreases (about 140–200 cm³) than heavily sprouted samples (40 cm³). Both the lightly and heavily sprouted samples had higher volumes than control samples after eight months of storage.

The increase in milling extraction (Table I) might explain the decrease in loaf volume for the lightly sprouted samples. In general, synthesis of hydrolytic enzymes and modification of protein and starch occur at the embryo and the aleurone layer close to the embryo during germination (MacGregor 1983). During storage of sprouted samples, an increase in milling extraction resulted in an increase in flour protein content and α -amylase activity. However, the flour proteins that might come from near the aleurone layer had already been modified during germination. An increase in milling extraction, therefore, resulted in a negative effect of those modified proteins on loaf volume. Because heavily sprouted samples showed a lower increase in milling extraction than the lightly sprouted samples, the negative effect on loaf volume was smaller for the heavily sprouted than the lightly sprouted samples.

Crust color values became darker with sprouting due to high α -amylase activity in the sprouted samples. Control samples showed a slight improvement in crust color during storage; however, sprouted samples remained relatively constant.

Crumb color values were acceptable except that heavily sprouted samples showed a yellowish crumb color. Controls showed a slight deterioration in crumb color during storage. This might be due to an increase in flour ash content. Crumb color of sprouted samples remained relatively constant throughout storage.

Grain and texture of loaves of controls were uniform. A decrease in grain uniformity and an increase in the number of large cells with sprouting was seen for the Len samples. Heavily sprouted Olaf also had poor grain; however, lightly sprouted Olaf showed a slightly better grain and texture than controls. Lukow and Bushuk (1984a) mentioned that the protein from very strong mixing varieties could have acceptable baking characteristics when the wheat was germinated slightly. The gluten of Olaf, a strong mixing variety, seems to tolerate light sprouting conditions. The proteins of Len, however, seem to have been modified to a greater extent than Olaf's under equivalent sprouting conditions. Grain and texture remained relatively constant during storage of both control and sprouted samples.

TABLE VII
Duncan's Multiple Range Test on Loaf Volume
of Flour of Two Hard Red Spring Wheats and Their Sprouted Samples^a

Months Stored	Len			Olaf		
	Control	Light ^b	Heavy ^b	Control	Light ^b	Heavy ^b
1	785 h	...	...	770 h	...	...
3	810 gh	1,043 a	958 bc	813 gh	978 b	923 bcd
5	880 def	963 bc	910 cde	793 gh	850 efg	893 de
8	828 fgh	883 def	925 bcd	768 h	783 h	878 def

^aMean values are expressed in cubic centimeters. Any two means followed by different letters differ significantly ($\alpha = 0.05$).

^bSamples sprouted for 12 (light) and 40 hr (heavy), respectively.

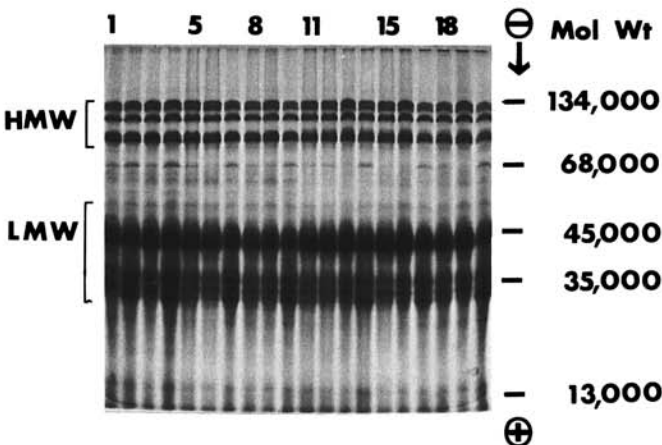


Fig. 5. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of reduced residue of nonsprouted (controls) and sprouted (light and heavy) hard red spring wheats: Len (patterns 1–10) and Olaf (patterns 11–20), respectively; 1–4 and 11–14, control samples stored for one, three, five, and eight months; 5–7 and 15–17, lightly sprouted samples stored for three, five, and eight months; 8–10 and 18–20, heavily sprouted samples stored for three, five, and eight months.

CONCLUSIONS

This study clearly shows that sprouting affected the physicochemical and functional properties of hard red spring wheat flour. Flour extraction, ash and protein content, and falling number decreased while α -amylase and proteolytic activity increased with sprouting. Results from the modified Osborne fractionation study showed a decrease in globulin and residue protein fractions and an increase in albumin and soluble glutenin fractions. The PAGE patterns of the albumin and globulin fractions and the SDS-PAGE patterns of albumins showed both qualitative and quantitative differences, whereas the SDS-PAGE patterns of glutenins and residue proteins showed many quantitative differences. In addition, low farinograph water absorption and weaker farinograph patterns were observed. Due to the high level of α -amylase activity, the bread made from sprouted wheat flour gave higher volume, very dark crust color, inferior grain and texture, and yellowish crumb color particularly for the heavily sprouted samples.

The effect of storage on newly harvested wheat (control samples) was an increase in milling extraction, flour ash, and protein content. However, there were no significant trends in falling number. Proteolytic enzyme activity decreased during storage. MTI index decreased with storage, however, other results from the farinograph data had no significant trends. PAGE patterns of albumin and gliadin and SDS-PAGE patterns of globulins and gliadins

did not change during storage. SDS-PAGE patterns of albumins from samples stored five months and glutenin and residue proteins of the samples stored eight months showed slight differences in staining intensity of certain bands. The baking results showed an improvement during storage, such as an increase in loaf volume and an improvement in crust color.

The effect of storage on sprouted wheat differed depending upon the degree of sprouting. Only the lightly sprouted samples showed a slight increase in milling extraction, flour ash, and protein content. α -Amylase activity increased slightly during storage. Proteolytic enzyme activity decreased. The effect of storage on PAGE and SDS-PAGE patterns of sprouted wheat protein fractions was similar to the results of the control samples, that is, no changes were observed in PAGE patterns of albumin and globulin or SDS-PAGE patterns of globulins and gliadins. Some quantitative changes were observed in SDS-PAGE patterns of albumins from samples stored five months and in glutenin and residue proteins of samples stored eight months. Unlike the results of the control samples, negative storage effects on baking were observed, such as decreased loaf volume.

The overall conclusion, therefore, is that the storage of sprouted grain at room temperature did not improve but rather reduced the breadmaking quality of its flour. Very strong mixing cultivars, such as Olaf in this study, can tolerate a small degree of sprouting and yet produce bread of acceptable quality. Sprouted grain should, therefore, be utilized soon after harvesting so that breadmaking quality will not be further impaired by storage.

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