Germination of Soft White Wheat and Its Effect on Flour Fractions, Breadbaking, and Crumb Firmness[1]

M. M. MORAD[2] and G. L. RUBENTHALER[3]

ABSTRACT

Cereal Chem. 60(6):413-417

The pasting properties of bread crumb flour were modified by 20 and 36 hr of germination and were related to the degree of crumb firmness measured over a 96-hr storage period. Data indicated that insufficient or excess amylase activity increased crumb firmness and staling rate of bread. The amounts of soluble starch, amylose, and amylopectin increased with germination time and decreased in the crumb as the bread aged. Interchanging fractions of germinated and ungerminated material suggests simultaneous amylolytic and proteolytic activities. Thrity-six hours of germination modified the gluten fraction enough to prevent normal baking quality. Gluten from sound flour slightly improved loaf volume of the starch and water-solubles of the material germinated for 36 hr. Germination for 20 hr improved bread-baking quality.

It is well known that sprouting of cereal grains causes increased enzyme activity, a loss of total dry matter, an increase in total protein, a change in amino acid composition, a decrease in starch, increases in sugars, a slight increase in crude fat and crude fiber, and slightly higher amounts of certain vitamins and minerals. Finney et al (1980) studied sprouted soft white wheat grown in the Pacific Northwest in nine leavened and unleavened international breads. They found seven of the breads acceptable, and concluded that highly sprouted flour may be suitable for specific types of yeast-fermented breads. Ranhotra et al (1977) stated that fully acceptable bread with a good volume and crumb texture can be prepared by blending sprouted wheat flour with sound flour.

Numerous investigators (Finney et al 1980, Ibrahim and D'Appolonia 1979, Kozmin 1933, Ranhotra et al 1977) have found that sprouted hard red wheat is not well suited for breadbaking. They reported that sprouting causes a dark crumb, an inferior grain, and texture that is sticky and gummy. The latter is thought to be due to the breakdown of the starch.

Hwang and Bushuk (1973), Finney et al (1977), and Magoffin et al (1977) agreed that an excessively high concentration of α-amylase in sprouted wheat has a negative effect on the loaf volume and other internal and external properties of white pan bread. Finney et al (1981) stated that sponge cake volume, percent of sprouted wheat, amylograph viscosity, falling number, and gas production were all functions of the α-amylase activity of wheat or flour.

Beck et al (1957), Bechtel (1959), Miller et al (1953), Waldt and Mahoney (1967), and Dragsdorf and Varriano-Marston (1980) have indicated that the addition of amylase from plant sources to bread formulations reduces the firming of stored bread. The reduction in bread firmness has been attributed to the enzymatic breakdown of starch (Miller et al 1953). Schultz et al (1952) suggested that the dextrin fragments that form interfere with the crystallization of starch. Dragsdorf and Varriano-Marston (1980), however, indicated a decreasing degree of starch crystallinity in bread when bacterial α-amylase, cereal α-amylase, fungal α-

[1]Scientific paper no. 6362, College of Agriculture Res. Ctr., Washington State University, Pullman, WA 99164.

[2]Cereal Quality Lab., Dept. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843.

[3]Research Food Technologist in Charge, USDA, ARS, Western Wheat Quality Laboratory, Washington State University, Pullman, WA 99164.

Mention of firm names or trade products does not constitute endorsement by the USDA over others not mentioned.

amylase, and unsupplemented bread were used, respectively. Lorenz and Valvano (1981) found that sprouting of the wheat for longer than one day resulted in flours of poor cake-baking quality. Morad and D'Appolonia (1980a) found that soluble starch and its amylose content were decreased in the bread crumb as the bread aged; the decrease was greatest during the first 24 hr of storage.

Banecki (1972) and Morad and D'Appolonia (1980b) reported staling studied with the amylograph, showing that the decrease in peak viscosity of starch isolated from bread crumb was greatest during the first day but less pronounced thereafter. Miller et al (1973), Allen et al (1977), and Lai and Varriano-Marston (1979) indicated that the presence of soluble starch leached from the starch granules upon heating caused an effect on the Brabender viscosity pattern of the starches.

The purposes of this study were: 1) to determine the effect of germination on the chemical composition, dough rheological properties, and baking quality of bread made from soft white wheat grown in the Pacific Northwest and suitable for breadmaking; and 2) to determine the effect of germinated wheat on the staling rate of bread crumb. The study involved the fractionation of sound and germinated samples into gluten, starch, and water-solubles. The sound and germinated fractions were interchanged during reconstitution. Doughs were prepared and baked, and the staling properties of the bread were tested by measuring their firmness. Rheological properties as measured by a mixograph of the reconstituted flours and the Brabender amylograph viscosity of the bread crumb flour were also used to evaluate the effect of germination on the various flour fractions.

MATERIALS AND METHODS

Wheat Samples

Equal amounts of five soft white winter wheat varieties grown in 1977 through 1980 in experimental plots at Lind and Pullman, WA, were blended into a composite. The sample was subdivided into three parts. The first part was milled and used as a sound flour. The second part was germinated for 20 hr, air-dried, and milled. The third part was germinated for 36 hr, air-dried, and milled. A laboratory Buhler mill was used for milling the three samples at an extraction rate of 72%.

Analytical Procedures

Moisture and protein contents were determined by AACC (1962) approved methods 44-15A, and 46-11, respectively. α-Amylase activity (dextrinizing units [DU] per gram) was determined by the method of Mathewson and Pomeranz (1979). Soluble starch content was determined according to the procedure of Schoch and French (1947), as modified by Morad and D'Appolonia (1980a). Amylose and amylopectin contents in the water-soluble starch were determined according to the procedure of Williams et al (1970).

Rheological Properties

Mixograms (10 g) were prepared as described by Finney and Shogren (1972). Samples of bread crumb were collected 0.17, 1, 3, 6, 24, 48, 72, and 96 hr after removal from the oven. Pasting properties of the bread crumb flour were determined using the Brabender amylograph. Preparation of the samples, determination of pasting properties by the Brabender amylograph, and interpretation of the amylograph curves were performed as reported by Morad and D'Appolonia (1980b). Falling number was determined according to AACC (1962) approved method 56-81B.

Breadbaking

Breads were baked from sound, germinated, and reconstituted samples (moisture and protein contents shown in Table I) according to the following formula: 100 g flour (14% mb), 3 g vegetable shortening (Crisco), 1.5 g salt, 6 g sugar, and 5.25 g fresh bakers' yeast (Fleishmann's standard brand). Baking absorption, mixing time, and oxidation (ascorbic acid) were optimized for each formulation. The dough was fermented for 90 min at 30°C and proofed to optimum (35–40 min). Doughs were degassed after 26 and 60 min and immediately before panning. Breads were baked at 425°F for 24 min and weighed. Loaf volume was determined by rapeseed displacement immediately after removal from the oven. Breads were sliced (2 cm) after 1 hr and kept in plastic bags at room temperature until they were used for determination of texture and pasting properties.

Bread Crumb Firmness

Crumb firmness was determined at 1, 3, 6, 24, 48, 72, and 96 hr after bread was removed from the oven by use of a Fudoh rheometer (model NRM-20002JD) fitted with a 1-cm plunger accessory. An average of six replicates was reported for crumb firmness.

Flour Fractionation and Reconstitution

Flours from sound and 20- and 36-hr germinated wheat samples were fractionated into crude gluten, starch, and water-solubles. Each flour (100 g) was first mixed with distilled water to optimum consistency. The dough was divided into two equal portions. Each portion was manually washed with gentle squeezing with approximately 2,000 ml of distilled water until the wash water was clear and the crude gluten was obtained. The wash liquid was collected and centrifuged (2,500 $\times g$) for 20 min. The supernatant (water-soluble) was freeze-dried. The precipitate (starch fraction) was air-dried at room temperature (25°C) for approximately 24 hr and ground on a Udy cyclone mill to pass a 60-mesh sieve (250 μm). The crude gluten was immediately freeze-dried and also ground on the Udy mill to pass through a 60-mesh sieve. Total recovery of flour fractions was 95, 98.06, and 95.14% for sound, 20-hr germinated and 36-hr germinated flours, respectively. Fractions were then interchanged in all combinations. The fractions from sound wheat flour were interchanged with their matches of 20- or 36-hr germinated wheat flour. The fractions of the sound wheat flour were reconstituted and considered as a control. The same procedure was repeated with both the 20- and 36-hr germinated wheat flour, using the sound flour fractions for their reconstitution. The fractions of wheat flour from both 20- and 36-hr germinated wheat flour were reconstituted and used as a control.

All reconstituted flours were prepared on a 14% moisture basis.

TABLE I
Physical, Chemical, Mixograph, and Baking Properties of Sound and Sprouted Wheat Flour[a]

	Physical, Chemical Analysis[b]				Mixograph Characteristics[c]			Baking Properties[c]		
Sample Description	Moisture (%)	Protein (%)	Falling Number (sec)	α-Amylase Activity (DU[d]/g)	Mixing Time (min)	Center of Curve at Peak (units)	Water Absorption (%)	Mixing Time (min)	Water Absorption (%)	Loaf Volume (cc)
Sound	11.3	10.1	388	0.023	2:45	5.5	58	2:30	58	780
Sound with malt	11.3	10.1	223	0.100	2:45	5.5	58	2:30	58	809
20-hr germinated wheat	12.3	9.3	181	0.256	2:40	5.0	55	2:15	55	860
36-hr germinated wheat	12.4	9.4	61	1.245	1:40	5.5	50	1:40	50	710

[a] Data based on 14% moisture basis.
[b] Average of three replicates.
[c] Average of two replicates.
[d] DU = Dextrinizing units.

Mixographs were determined for the reconstituted samples, and the samples were baked as previously described. Firmness was also determined using the rheometer, for breads from reconstituted flours. The Brabender amylograph was used to determine maximum viscosity of the bread crumb flour after 96 hr of storage.

TABLE II
Amylograph Characteristics of Bread Crumb Flour Made from a Blend of Soft White Wheat[a,b]

Blend	Time (hr)	Initial Pasting	Maximum Viscosity (BU)	Height at 95°C After 15 Min (BU)	Height at 50°C (BU)
Sound	0.17	82.75 b	180 a	195 de	370 bcd
	1	78.60 e	180 a	207 bcd	390 bc
	3	79.37 cde	185 a	210 bc	385 bc
	6	76.00 f	175 a	190 ef	350 cde
	24	58.00 j	180 a	200 cde	380 bc
	48	52.00 lm	185 a	250 a	460 a
	72	52.00 lm	170 ab	220 b	400 b
	96	51.00 m	175 a	208 bcd	380 bc
Sound with malt					
	0.17	85.00 a	65 i	55 l	160 ij
	1	80.50 cd	85 gh	65 kl	140 j
	3	80.00 cde	100 ef	80 k	195 hi
	6	81.00 c	80 h	65 l	135 j
	24	70.00 h	95 efg	80 k	155 j
	48	64.00 i	120 d	120 j	225 h
	72	69.00 h	90 fgh	80 k	155 j
	96	58.00 j	90 fgh	80 k	165 ij
20-hr germination					
	0.17	83.50 ab	160 b	180 fg	330 ef
	1	83.00 b	160 b	175 gh	350 cde
	3	79.00 de	145 c	175 gh	330 ef
	6	73.00 g	140 c	160	290 g
	24	58.00 j	145 c	160 i	305 fg
	48	55.00 k	140 c	180 fg	335 def
	72	53.50 kl	135 c	165 hi	305 fg
	96	53.50 kl	105 e	110 j	225 g
36-hr germination					
	0.17	83.00 b	25 g	15 m	60 k
	1	85.00 a	20 g	10 m	40 k
	3	83.00 b	25 g	10 m	35 k
	6	83.50 ab	25 g	15 m	40 k
	24	83.00 b	20 g	8 m	25 k
	48	83.00 b	20 g	8 m	25 k
	72	85.00 a	10 gk	5 m	25 k
	96	83.00 b	5 k	0 m	25 k
Standard deviation		0.765	6.533	6.583	17.500

[a] Average of two replicates on 14% moisture basis.
[b] Values in each column followed by the same letter are not significantly different by Duncan's multiple range test ($P<0.01$).

RESULTS AND DISCUSSION

Falling Number, Alpha-Amylase, Mixograph, and Baking Properties

The falling number, as indicated in Table I was decreased by germination. Germination for 20 and 36 hr increased α-amylase activity 11- and 54-fold, respectively.

The effects of germination on the Mixograph characteristics are shown in Table I. Twenty hours of germination slightly decreased mixing time and water absorption, whereas the decrease in both mixing time and water absorption was more pronounced with 36 hr of germination. Both lack of α-amylase activity and high activity produced lower loaf volume from sound and 36-hr germinated wheat flour. The 20-hr germinated samples produced good-quality bread with good loaf volume (Table I). This indicates that with a short period of germination, quality bread can be produced without the necessity of using malt as an exogenous source of α-amylase. The sound flour, when baked in a formula containing malt (0.25 g of barley malt per 100 g of flour, with 52 DU per gram of α-amylase activity), produced bread with a loaf volume of 809 cm^2. This malt level has been used to produce optimum baking performance (Bruinsma and Finney 1981, Finney et al 1982).

Effect of Germination on Bread Crumb Flour Pasting Properties

Table II shows that the initial pasting temperatures of fresh bread crumb flour from sound wheat flour, sound wheat flour with malt added, and from wheat flour germinated for 20 and 36 hr were relatively high. These values significantly decreased with time, except for wheat flour germinated for 36 hr, in which the value remained unchanged. The greatest decrease occurred during the first 24 hr of storage. No clear trend was observed with bread storage time in the initial pasting temperature of bread crumb flour

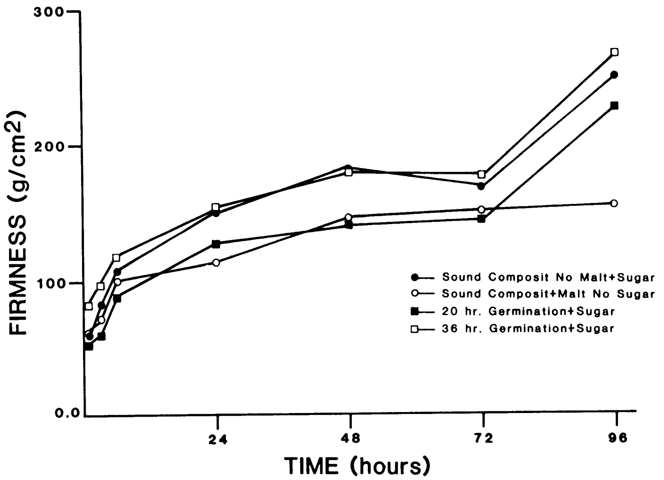

Fig. 1. Firming of bread crumb (g/cm^2) prepared from sound, 20-, and 36-hr germinated wheat flours.

TABLE III
Soluble Starch, Amylose, and Amylopectin Content in Bread Crumb Flour[a,b]

Time (hr)	Sound, No Malt: Soluble Starch (%)	Amylose (%)	Amylopectin (%)	Sound + Malt: Soluble Starch (%)	Amylose (%)	Amylopectin (%)	20-Hr Germination: Soluble Starch (%)	Amylose (%)	Amylopectin (%)	36-Hr Germination: Soluble Starch (%)	Amylose (%)	Amylopectin (%)
0.17	3.24 n	2.10 m	1.14 jk	6.64 f	4.50 f	2.14 g	4.40 k	3.22 i	1.18 jk	16.96 a	12.87 a	4.09 a
1	2.94 o	1.79 o	1.15 jk	6.30 g	4.16 g	2.14 g	4.10 l	3.00 j	1.10 k	16.36 b	12.41 b	3.95 b
3	2.52 pq	1.39 p	1.13 k	5.94 i	4.08 g	1.86 h	3.86 m	2.85 k	1.01 l	13.82 c	10.31 c	3.51 c
6	1.84 s	0.99 r	0.85 mn	5.10 j	3.55 h	1.45 i	3.32 n	2.32 l	1.00 l	10.80 d	7.55 d	3.25 de
24	1.68 s	0.87 s	0.81 mnop	4.14 l	2.92 jk	1.22 j	3.36 n	1.41 p	0.95 l	8.98 e	5.70 e	3.28 d
48	1.46 t	0.70 t	0.76 op	2.98 o	2.15 m	0.83 mno	2.06 r	1.20 q	0.86 m	6.12 h	2.94 jk	3.18 e
72	1.44 t	0.67 t	0.77 nop	2.68 p	1.95 n	0.73 p	2.06 r	1.08 r	0.98 l	5.84 i	2.84 k	3.00 f
96	1.42 t	0.67 t	0.75 op	2.40 q	1.74 o	0.76 op	1.04 u	0.46 u	0.58 q	1.28 t	0.33 v	0.95 l

[a] Average of three replicates on 14% moisture basis.
[b] Values in each column followed by the same letter are not significantly different by Duncan's multiple range test ($P<0.01$).

from 36-hr germinated wheat. Maximum viscosity, 15-min viscosity at 95° C, and viscosity at 50° C for both sound and 20-hr germinated samples were similar to each other, indicating little change within the starch up to 20 hr of germination. Viscosities of both flours were higher than equivalent viscosities of the 36-hr and sound flours with added malt. The maximum viscosity, the 15-min viscosity at 95° C, and viscosity at 50° C were low, especially for 36-hr germinated wheat flour. The effect of α-amylase on the starch granules may have decreased the resistance of such granules to swelling when heated and may have shortened their chain length.

Effect of Germination on Bread Crumb Firmness

Bread crumb firmness is shown in Fig. 1. A substantial increase in crumb firmness occurred after 72 hr of storage. The greatest increase in crumb firmness occurred during the first 24 hr for all samples. The sound sample with malt added was similar to the 20-hr germinated sample in firmness values for the first 72 hr of storage. This sample was softer than the 36-hr germinated samples and the sound samples. The data indicate that either excess or insufficient amylase activity increases crumb firming.

TABLE IV
Mixogram Characteristics, Loaf Volume, and Crumb Viscosity of Doughs and Bread from Reconstituted Flours from Sound and from Germinated Wheats[a]

		Mixogram[c]				Amylograph
Type	Samples[b]	Mixing Time (min)	Peak Height (unit)	Water Absorption (%)	Loaf Volume[c] (cc)	Maximum Viscosity[c] (BU)[d]
A	Sound reconstituted[e]	2:15 b	5.00 b	54 a	500 d	295 a[e]
	Sound G, S + 20-hr WS	2:10 c	5.50 a	54 a	470 e	290 a
	Sound G, S + 36-hr WS	1:40 e	5.50 a	50 c	490 de	65 f
	Sound S, WS + 20-hr G	2:30 a	5.00 b	54 a	400 g	240 cd
	Sound S, WS + 36-hr G	0:50 h	4.50 e	51 bc	400 g	220 d
	Sound G, WS + 20-hr S	2:10 c	5.50 a	52 b	510 d	250 c
	Sound G, WS + 36-hr S	2:10 c	5.00 b	52 b	675 b	70 ef
B	20-hr germinated, reconstituted[e]	2:00 d	4.60 d	52 b	540 c	240 cd
	20-hr G, S + sound WS	1:30 f	4.50 e	52 b	430 f	280 ab
	20-hr G, WS + sound S	1:30 f	5.00 b	52 b	510 d	285 ab
	20-hr S, WS + sound G	2:00 d	5.00 b	52 b	745 a	260 bc
C	36-hr germinated, reconstituted[e]	1:15 g	4.50 e	50 c	475 e	50 f
	36-hr G, S + sound WS	2:30 a	5.50 a	52 b	400 g	50 f
	36-hr G, WS + sound S	1:30 f	5.50 a	48 d	400 g	90 e
	36-hr S, WS + sound G	1:30 f	4.70 c	50 c	500 d	60 f

[a] Average of two replicates on 14% moisture basis.
[b] G = Gluten, S = starch, WS = water-soluble fraction.
[c] Values in each column followed by the same letter are not significantly different by Duncan's multiple range test ($P < 0.01$).
[d] BU = Brabender units.
[e] Control.

TABLE V
Alpha-Amylase Activity in Fractions from Germinated Wheats[a,b]

	Alpha-Amylase Activity (DU/g)		
Wheat	Starch	Gluten	Water-Solubles
Sound composite	0.064 a	0.121 a	0.590 a
20-hr germination	0.099 b	0.272 b	1.206 b
36-hr germination	0.130 c	0.561 c	1.600 c

[a] Average of three replicates on 14% moisture basis.
[b] Values in each column followed by the same letter are not significantly different by Duncan's multiple range test ($P < 0.01$).

Effect of Germination on Soluble Starches, Amylose, and Amylopectin Leached from Bread Crumb

The amounts of total soluble starch, amylose, and amylopectin extracted after increasing storage times for bread crumb made from sound or germinated wheat flours are shown in Table III. The amount of soluble starch, amylose, and amylopectin was highest in the 36-hr germinated sample, followed in order by the sound flour with malt added, the 20-hr germinated wheat flour, and the sound flour. The amount of amylose, amylopectin, and soluble starch decreased as the bread aged. The decrease was most pronounced in bread made from 36-hr germinated wheat flour. The data indicate that α-amylase activity was the cause of the increase in the amount of soluble starch. Retrogradation of amylose and amylopectin appears to have occurred during storage and caused bread firmness to increase.

Effect of Sound and Germinated Flour Fractions on Mixograph Properties, Loaf Volume, and Maximum Viscosity of Bread Crumb Flour

Replacing the water solubles of sound flour with those from the 36-hr germinated wheat flour significantly decreased mixing time, water absorption, and amylograph maximum viscosity. Replacing sound water solubles with water solubles from the 20-hr germinated wheat decreased mixing time and loaf volume (Table IV, A).

Replacing the gluten of sound flour with those from either 20-hr or 36-hr germinated wheat flour significantly decreased loaf volume and maximum viscosity. Water absorption and peak height

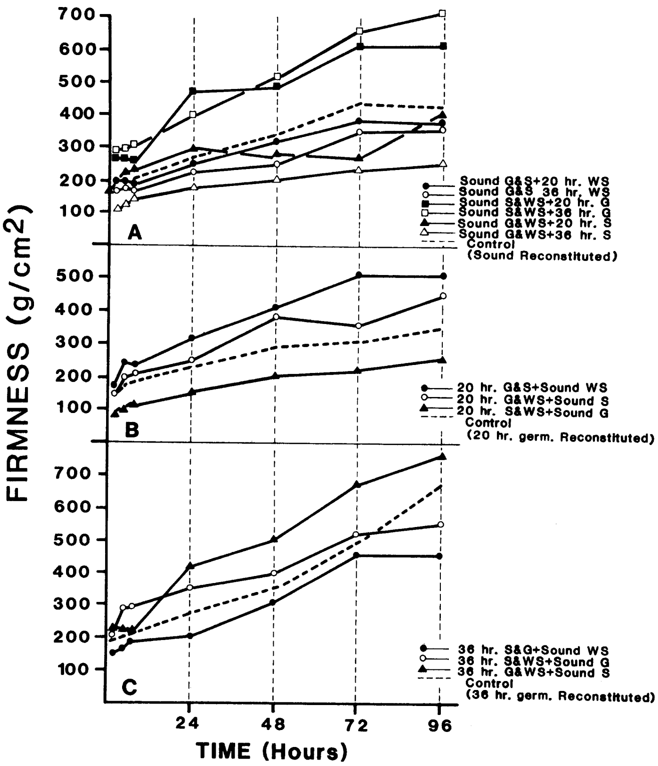

Fig. 2. A, Bread crumb firmness (g/cm²) of the reconstituted flour from sound wheat sample. **B,** Crumb firmness (g/cm²) of bread baked from reconstituted flour of 20-hr germinated wheat sample. **C,** Crumb firmness (g/cm²) of bread baked from reconstituted flour from wheat germinated 36 hr.

decreased significantly when the 36-hr water solubles replaced those of sound wheat flour. These characteristics remained unchanged with substitution of the 20-hr water solubles. Mixing time increased with gluten of 20-hr germinated wheat flour and decreased with those of 36-hr germinated wheat flour (Table IV, A).

Replacing the starch of sound flour with those from either 20-hr or 36-hr germinated wheat flour decreased mixing time, water absorption, and maximum viscosity. A significant increase in loaf volume was obtained with starch of 36-hr germinated wheat (Table IV, A).

Water-solubles of sound flour significantly decreased mixing time and loaf volume and increased maximum viscosity when used to replace those of 20-hr germinated wheat flour. When the gluten of sound wheat flour was used as a replacement, loaf volume and mixogram peak height increased significantly while other characteristics remained unchanged. Starch from sound wheat flour significantly decreased mixing time, loaf volume, and increased maximum viscosity of the 20-hr germinated flour (Table IV, B).

The substitution of sound water-solubles in the 36-hr germinated flour base increased mixogram water absorption, peak height, and mixing time, and decreased loaf volume. Interchanging the sound starch increased mixing time and peak height but decreased water absorption and loaf volume. Replacing the gluten with sound gluten increased mixing time, peak height, and loaf volume. Amylograph maximum viscosity was changed only by the substitution of the sound starch (Table IV, C).

Data presented in Table IV and Fig. 2 indicated that 20-hr germination improved loaf volume and crumb firmness of soft white wheat bread and could be used to replace a malt treatment in baking. Germination also offers nutritional improvements (Finney 1977).

Water solubles contained most of the active α-amylase enzyme (Table V). The excessive activity in the 36-hr germinated wheat flour is responsible for the deterioration in mixing properties, viscosity, and bread quality. Activity in the 20-hr germinated wheat flour appeared to be suitable for bread-baking performance.

Effect of Sound and Germinated Flour Fractions on the Bread Crumb Firmness

Data presented in Fig. 2 show the effect of sound and germinated wheat flour fractions on bread crumb firmness during a storage period of 96 hr. Replacement of gluten from sound wheat flour with either 20- or 36-hr germinated wheat flour gluten increased bread firmness, while starch and water solubles of both 20- and 36-hr decreased it (Fig. 2A). Firmness was also decreased when the gluten from sound wheat flour replaced gluten of 20-hr germinated wheat flour (Fig. 2B). Starch or gluten from sound wheat flour generally increased bread firmness of 36-hr germinated wheat flour when used for replacement, while water-solubles decreased firmness (Fig. 2C). Bread made from water solubles and starch of 20-hr germinated wheat flour in combination with the gluten of sound wheat flour was less firm than any other substitution except the combination of sound gluten and water-solubles plus 36-hr starch (Fig. 2). It is also clear that substitution of water-solubles from the 36-hr germinated wheat flour with their match of sound wheat flour decreased bread firmness of the 36-hr germinated wheat flour. These data indicate that amylolytic activities are important factors affecting bread crumb firmness.

LITERATURE CITED

ALLEN, J. E., HOOD, L. F., and CHABOT, J. F. 1977. Effect of heating on the freeze-etch ultrastucture of hydroxyproply distarch phosphate and unmodified tapioca starches. Cereal Chem. 54:783.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1962. Approved Methods of the AACC. The Association, St. Paul, MN.

BANECKI, H. 1972. Veranderungen der Wahrend des Altbacken werdew des Weizenund Roggenhrotes enzymatisch. Getreide Mehl Brot 26:6.

BECHTEL, W. G. 1959. Staling studies of bread made with flour fractions. V. Effect of a heat-stable amylase and a cross-linked starch. Cereal Chem. 36:368.

BECK, H., JOHNSON, J. A., and MILLER, B. S. 1957. Studies on the soluble dextrin fraction and sugar content of bread baked with alpha-amylase from different sources. Cereal Chem. 34:211.

BRUINSMA, B. L., and FINNEY, K. F. 1981. Functional (breadmaking) properties of a new dry yeast. Cereal Chem. 58:477.

DRAGSDORF, R. D., and VARRIANO-MARSTON, E. 1980. Bread staling: X-ray diffraction studies on bread supplemented with alpha-amylase from different sources. Cereal Chem. 57:310.

FINNEY, K. F., JONES, B. L., and SHOGREN, M. D. 1982. Functional (bread-making) properties of wheat protein fractions obtained by ultracentrifugation. Cereal Chem. 59:449.

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, K. F., and SHOGREN, M. D. 1972. A ten-gram mixograph for determining and predicting functional properties of wheat flours. Bakers Dig. 46:32.

FINNEY, P. L. 1977. Potential for the use of germinated wheat and soybean to enhance human nutrition. Page 681 in: Advances in Experimental Medicine and Biology. M. Friedman, ed. Plenum Press, New York.

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

FINNEY, P. L., RUBENTHALER, G. L., JEFFERS, H. C., and ANDERSON, P. D. 1977. Short-time baking systems. III. Malt interdependence in a sugar-free formula. Cereal Chem. 54:1259.

HWANG, P., and BUSHUK, W. 1973. Some changes in the endosperm proteins during sprouting of wheat. Cereal Chem. 50:147.

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

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

LAI, C. C., and VARRIANO-MARSTON, E. 1979. Studies on the characteristics of black bean starch. J. Food Sci. 44:528.

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

MAGOFFIN, C. D., FINNEY, P. L., and FINNEY, K. F. 1977. Short-time baking systems. II. A 70-min sugar-free formula for conventional and high-protein breads. Cereal Chem. 54:760.

MATHEWSON, P. R., and POMERANZ, Y. 1979. Modified chromogenic alpha-amylase assay for sprouted wheat. J. Assoc. Off. Anal. Chem. 62:198.

MILLER, B. S., DERBY, R. I., and TRIMBO, H. B. 1973. A pictorial explanation for the increase in viscosity of heated wheat starch-water suspension. Cereal Chem. 50:271.

MILLER, B. S., JOHNSON, J. A., and PALMER, D. L. 1953. A comparison of cereal, fungal, and bacterial alpha-amylase as supplements for breadmaking. Food Technol. 7:38.

MORAD, M. M., and D'APPOLONIA, B. L. 1980a. Effect of surfactants and baking procedure on total water-solubles and soluble starch in bread crumb. Cereal Chem. 57:141.

MORAD, M. M., and D'APPOLONIA, B. L. 1980b. Effect of baking procedure and surfactants on the pasting properties of bread crumb. Cereal Chem. 57:239.

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

SCHOCH, T. J., and FRENCH, D. 1947. Studies on bread staling. I. The role of starch. Cereal Chem. 24:231.

SCHULTZ, A. S., SCHOONOVER, F. D., FISHER, R. A., and JACKEL, S. S. 1952. Retardation of crumb starch staling in commercial bread by bacterial alpha-amylase. Cereal Chem. 29:200.

WALDT, L. M., and MAHONEY, R. D. 1967. Antifirming of white bread by application of heat-stable bacterial α-amylase. Cereal Sci. Today 12:358.

WILLIAMS, P. C., KUZINA, F. D., and HLYNKA, I. 1970. A rapid colorimetric procedure for estimating the amylose content of starches and flours. Cereal Chem. 47:411.

[Received October 12, 1982. Accepted May 6, 1983]