

Milling and Baking Quality of Soft White Wheat Genotypes Subjected to Preharvest Sprouting¹

M. E. SORRELLS,² A. H. PATERSON,² and P. L. FINNEY³

ABSTRACT

Cereal Chem. 66(5):407-410

Damage due to preharvest sprouting can cause major economic losses in regions where precipitation occurs frequently at harvest time. This research was conducted to evaluate the effects of preharvest sprouting on milling and baking characteristics of resistant and susceptible soft white wheat genotypes subjected to conditions inducing preharvest sprouting. Three sprinkler irrigation treatments were applied for durations of 5 hr on each of two consecutive days (5/5 hr), 10 hr on one day, or for 10 hr on each of two consecutive days (10/10 hr). Percent germination and α -amylase activity in the 5/5- and 10-hr treatments were not significantly different from the control. Under conditions inducing severe preharvest sprouting (10/10-hr treatment), preharvest-sprouting resistant genotypes had lower germination, lower α -amylase activity, higher grain yield, higher test weight, and higher alkaline water retention capacity

than susceptible genotypes. Relative to the control, the 10/10-hr treatment reduced flour yield of resistant genotypes more than that of susceptible cultivars. Flour protein, sugar-snap cookie diameter, ash content, kernel hardness, and top grain were not affected by any of the treatments. The effects of preharvest sprouting on the tested soft wheat milling and baking characteristics were relatively minor, even with high levels of sprouting damage. Two of the resistant genotypes provided protection from preharvest sprouting damage with lower germination and lower α -amylase activity. The resistance to preharvest sprouting in two of these genotypes should benefit farmers by extending the duration of the wetting period before visible damage is incurred and benefit processors by reducing hydrolytic breakdown of starch.

Preharvest sprouting is a major economic problem in wheat (*Triticum aestivum* L. em Thell) production, especially where white-kernelled cultivars are grown and precipitation occurs frequently at harvest time. Preharvest-sprouting damage includes harvest losses, reduced test weight, loss of seed viability, and reduced flour quality due to synthesis and activation of hydrolytic enzymes such as α -amylase, proteases, etc. (Belderok 1968, Bhatt et al 1981, Derera 1979, Gordon et al 1977).

Studies show that doughs prepared from sprouted bread wheat exhibit stickiness, decreased absorption, and decreased development time (Ibrahim and D'Appolonia 1979, Lorenz et al 1983). These investigators also reported that breads exhibit inferior crumb grain, coarse texture, and grayer color, but that bread loaf volume is not negatively affected. Kulp et al (1983) found that mixogram curves were higher and area under the curve increased in sprouted samples, suggesting potential increases in loaf volume. The mixogram also peaked sooner and declined more rapidly, indicating possible damage to the gluten.

Finney et al (1980) compared baking quality of nine international bread formulae originating in five different countries using sprouted and sound soft white wheat from the Pacific Northwest. Seven of the nine bread types were judged suitable even when produced with highly sprouted wheat characterized by 15–19% sprouted kernels and a falling number of 62–70. The highly field-sprouted wheat flours were not deleterious to those seven bread types because of the high oven temperatures, short bake times, and relatively thin dough pieces that allowed quick heat penetration and enzyme inactivation of the dough, unlike traditional U.S. type pan or hearth breads. The breads that were unacceptable had crusts that were too white, sticky crumb, coarse texture, and excessively large air pockets.

Using soft white winter wheat, Finney et al (1981) investigated the effects of field sprouting on sponge cake quality. They found that cake volume increased with low levels of sprouting, but at higher levels of sprouting (more than 0.35 dextrose units g^{-1} of α -amylase activity) volume rapidly decreased and the cake grain became more open and coarse. Different results were obtained when unsprouted wheat flour was supplemented with highly sprouted wheat or barley malt than with field-sprouted samples. They concluded that researchers should not assume that adding equal amounts of α -amylase from lightly and highly sprouted grains will have the same effects on functional properties. Using soft white wheat, Lorenz and Valvano (1981) examined the effects of one, two, and four days of sprouting in the laboratory on functionality of flour for cookies and cakes. They reported that cookie spreads increased and cookie top grain score improved as sprouting increased, but the crust color of the cookies darkened. Sprouting of the grain for more than one day reduced cake volume and increased the coarseness of the grain. They also found that

¹Research supported in part by a grant from Nabisco Brands, Inc., and Hatch project 418. Contribution from the Cornell Agricultural Experiment Station, Cornell University, Ithaca, NY. Paper no. 753.

²Associate professor and former graduate student, Dept. of Plant Breeding and Biometry, Cornell University, Ithaca, NY 14853.

³Research food technologist in charge, USDA-ARS Soft Wheat Quality Laboratory, Ohio Agricultural Research and Development Center, Wooster 44691.

thickening power of starches was lower and consistency decreased more rapidly for sprout-damaged flours.

In a study of genotypic and nitrogen effects on sprouting, Bhatt et al (1981) reported that resistant hard red and hard white wheat genotypes exhibited lower α -amylase activity, lower protease activity, and higher falling numbers than susceptible genotypes. Nitrogen fertilization treatments had no effect on sprouting. They concluded that α -amylase activity would be the best criterion for screening genotypes for sprouting resistance. Because their study was conducted using seed sprouted from natural precipitation, there were no unsprouted samples for comparison to determine relative changes in damage due to preharvest sprouting for resistant and susceptible genotypes.

The primary objectives of this research were to evaluate the effect of preharvest sprouting on soft white wheat milling and baking quality when wheat plants in the field were subjected to controlled sprout-inducing conditions and compare changes in milling and baking characteristics of resistant and susceptible genotypes due to different levels of preharvest sprouting.

MATERIALS AND METHODS

Field Trial Methods

Six soft white winter wheat genotypes, three of which were known to have varied levels of resistance to preharvest sprouting, were planted on the McGowan Farm of the Cornell Agricultural Experiment Station near Ithaca, NY, on 20 September 1984. The three genotypes previously shown to be resistant to preharvest sprouting were NY6432-3, NY6432-18, and NY6708-18 (Sorrells and Paterson 1986, Paterson 1986), and the susceptible cultivars were Houser, Fredrick, and Geneva. Houser, Geneva, and the NY experimental lines were developed by the Cornell Agricultural Experiment Station. Fredrick was obtained from D. Sampson, Agriculture Canada, Ottawa, Ontario. Different levels of preharvest sprouting damage were induced using a sprinkle irrigation system to apply water for different times. The experimental design was a split-plot, with water treatments as main plots and genotypes as subplots. Within each main plot, genotypes were planted in four replicates of 12-row plots, 8 m long, with 0.2 m between rows. Seed was drilled at 148 kg ha⁻¹, and plots were fertilized with 336 kg ha⁻¹ 10-20-20 (10% elemental N, 20% P₂O₅, and 20% K₂O by weight) in the fall and 112 kg ha⁻¹ ammonium nitrate in the spring.

The date of physiological maturity for each plot was estimated as the day when 50% of the spikes in a plot had lost green color (Hanft and Wych 1982). All genotypes in this experiment reached physiological maturity within one day of 11 July 1985; sprinkler irrigation treatments (94 ml m⁻² min⁻¹) began 16 July. The treatments were 10 hr on each of two consecutive days from 8 a.m. to 6 p.m. (10/10 hr), 10 hr on 16 July only (10 hr), 5 hr of irrigation on each of two consecutive days from 10 a.m. to 3 p.m. (5/5 hr), and no irrigation (0 hr). Random samples of five individual spikes were collected from each plot at harvest ripeness (for comparison with bulk samples), and the remainder were harvested by plot combine on 24 July 1985. Germination percentages of the bulk samples and the individual spike samples were nearly identical. Thus, all subsequent analyses were conducted on germination percentage determined from the bulk samples. Wheats were dried to a uniform moisture, and plot weight and test weight (0.25-L container) were determined.

Milling Methods

Samples of cleaned grain were prepared for quality analyses by tempering 250 g to 14% moisture overnight. The sample was milled on a modified Quadrumat Junior mill with the rolls preheated. The ground wheat was then transferred to a 10-in. square Great Western sifter assembly containing a 54-mesh screen and a 94-mesh screen and sieved for 1½ min. The overs of both sieves were weighed and then the overs of the 94-mesh sieve were combined with the throughs of the 94-mesh sieve and saved for further milling. Flour yield percent was calculated as (250 - overs of 54)/250 × 100. Softness equivalence was estimated as follows:

[(250 - overs of 54) - (overs of 94)]/(250 - overs of 54) × 100. Higher values of softness equivalence indicate softer kernel texture and greater break flour yield. The flour was then milled on a third break stand to further reduce particle size and sieved on a 105-mesh sieve for 1½ min. The recovered flour was blended for analysis.

Analytical Methods

Flour moisture, protein, and ash contents, and α -amylase activity of wheats or flours were determined by AACC approved methods 44-15A, 46-11, 08-01, and 22-06, respectively. Absorbance data for α -amylase were converted to standard dextrose activity units (DU) per milligram at 20°C. Alkaline water retention capacity (AWRC) was determined as described by Yamazaki et al (1968). Cookies were baked using the sugar-snap method described by Finney et al (1950).

Statistical Analyses

Data were analyzed using SAS (SAS Institute 1982) PROC GLM procedures. An arcsine square-root transformation (Snedecor and Cochran 1980) was applied directly to germination percent and considerably reduced error heterogeneity. Germination data are presented as untransformed data, but significance values are based on the transformation. A separate analysis of variance for each treatment was then performed to evaluate genotypic effects within a treatment. Untransformed data for all variables except germination percentage were used in an analysis of variance to evaluate treatment effects where replicates were confounded with treatments, and the replicates-within-treatments mean square was used to test for significance. Because only the 10/10-hr treatment was significantly different from the control for both germination and α -amylase activity, further analyses of variance were conducted on milling and baking characteristics in that treatment. Statistical comparison of relative changes between genotypes in the sprout-inducing treatment compared with the untreated control were accomplished by dividing the 10/10-hr treatment data by the mean of the four replications in the control treatment for each genotype. Relative changes in each variable were compared for resistant and susceptible genotypes using single-degree-of-freedom comparisons. Genotype means were compared within treatments using Duncan's multiple range test.

RESULTS AND DISCUSSION

Environmental Conditions

Temperatures 2.0°C cooler than the normal temperature of 19.0°C during seed maturation resulted in good expression of dormancy in the resistant lines in this study. A low germination percentage for the susceptible cultivars, Houser and Fredrick, was observed in the control treatment (Fig. 1). This resulted from

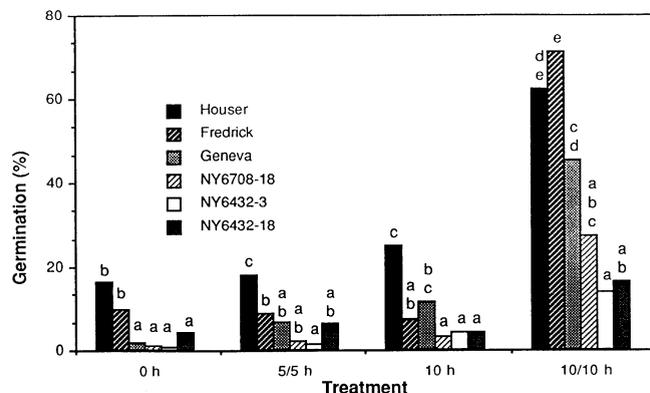


Fig. 1. Germination percentage of six genotypes subjected to sprinkler irrigation treatments five days after physiological maturity. The genotype mean squares and the resistant versus susceptible genotype contrasts were highly significant within each of the treatments. Genotype means with the same letter within treatments are not significantly different at the 0.05 level of probability.

natural precipitation of 1.5 cm on 10 July and 2.5 cm on 13 July. Because most of the plants had not yet reached physiological maturity, the precipitation on 10 July probably caused little sprout damage, and most of the germination in the control was a result of the 2.5 cm of precipitation on 13 July. Since the 5/5- and 10-hr treatment effects on germination were not significantly different from the control, it was concluded that the small amount of damage from natural precipitation did not have a major effect on quality.

Treatment Effects

Using the replicates-within-treatments mean square to test for treatment effects, analyses of variance indicated that percent germination and α -amylase activity in the 5/5- and the 10-hr treatments were not significantly different from the control (Figs. 1 and 2). Both percent germination and α -amylase activity in the 10/10-hr treatment were significantly higher than in the control; therefore, further analyses and interpretation focused on genotypic differences for quality characteristics of sprouted grain in the 10/10-hr treatment. Mean germination and α -amylase activity for the 10/10-hr treatment were 37.9% and 333 DU mg^{-1} , compared with control values of 5.5% and 89 DU mg^{-1} , respectively.

Genotype Effects

Within each treatment, all genotype effects for germination percentage and α -amylase activity were highly significant (Fig. 1). Furthermore, the planned contrasts between resistant and susceptible genotypes were highly significant within each of the treatments for these variables.

Increased sprouting relative to the control became apparent in the 10-hr treatment; however, only Houser exceeded 20% germination (Fig. 1). The level of sprouting for Houser in the 10-hr treatment was comparable to the highly sprouted samples evaluated by Finney et al (1980), whereas the level of sprouting in the Geneva and Fredrick samples was similar to the medium and low sprouting samples in their study, respectively. Germination percentage increased significantly when a second 10-hr irrigation treatment was applied; more than 50% of Houser and Fredrick kernels sprouted in the 10/10-hr treatment. None of the resistant genotypes exceeded 30% germination, and less than 20% of kernels of the two NY6432 lines germinated.

The 10/10-hr treatment increased α -amylase activity, with susceptible genotypes producing nearly three times the activity of the two resistant NY6432 lines (Fig. 2, Table I). α -Amylase activity and preharvest sprouting are highly correlated (Derera et al 1976); however, endosperm degradation may have occurred concomitant with the increases in α -amylase activity (Gordon et al 1977). Although NY6708-18 germinated less than Fredrick in the 10/10-hr treatment, α -amylase activity was higher,

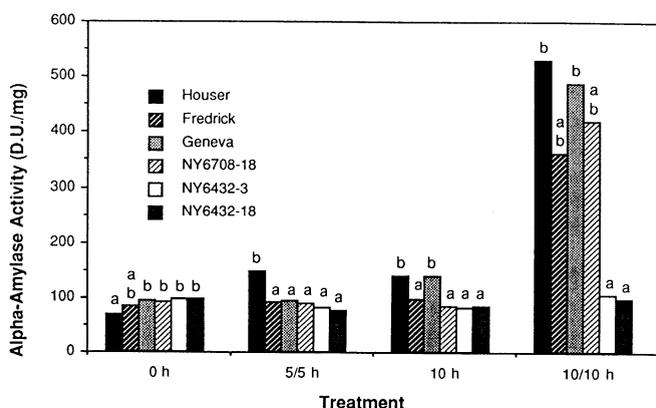


Fig. 2. α -Amylase activity of grain harvested from six genotypes subjected to sprinkler irrigation treatments five days after physiological maturity. The genotype mean squares and the resistant versus susceptible genotype contrasts were highly significant within each of the treatments. Genotype means with the same letter within treatments are not significantly different at the 0.05 level of probability.

illustrating the potential for misclassification when using only germination percentage to determine preharvest sprouting damage or resistance of a genotype. Hagemann and Ciha (1984) concluded that germination tests were preferred for predicting sprouting susceptibility, whereas enzymatic tests were better for quantifying actual degree of field sprouting.

Each quality characteristic was analyzed for the 10/10-hr treatment, and significant genotype effects were further examined in planned comparisons between the 10/10-hr treatment and the control and between resistant and susceptible genotypes (Table I). Analysis of variance of quality characteristics conducted on the 10/10-hr treatment indicated that resistant genotypes exhibited higher grain yield, test weight, and AWRC than susceptible genotypes. Percent flour yield of resistant genotypes was significantly reduced compared with the control, whereas susceptible cultivars were not different. Although the resistant genotypes still showed higher flour yield, the statistical contrast of the relative changes was highly significant, showing that the resistant cultivars were more adversely affected by the treatment. Thus, sprouting resistance appears not to be beneficial for this trait, under these conditions. Cookie diameter, flour protein, ash content, softness equivalence, and top grain were not affected by any of the treatments. Lorenz and Valvano (1981) found that wheat that had been sprouted in the laboratory for two or four days had slightly higher ash and protein contents, but Finney et al (1981) observed no effect of field sprouting on these traits.

Compared with controls, grain yield was unaffected, and test weight was reduced 1.5 kg hl^{-1} for sprout-resistant genotypes by the irrigation treatments; however, both grain yield and test weight (4 kg hl^{-1}) were significantly reduced for the susceptible genotypes (Table I). Because the sprinkler irrigation was not applied until five days after physiological maturity, reduced grain yield probably resulted from harvest losses due to grain shattering, partially germinated broken kernels, and embryos separating from the endosperm (Belderok 1968, Derera 1979). Belderok (1968) reported up to 10% yield loss due to preharvest sprouting. Reduced

TABLE I
Grain Yield and Milling and Baking Characteristics
of Preharvest-Sprouting Resistant and Susceptible Genotypes

Character/ Genotype	Treatment ^a	
	Control	10/10-hr
Germination (%)		
Resistant	1.9	19.2** ^b
Susceptible	9.1	59.6**
Contrast	-7.2**	-40.4**
α -Amylase (DU mg^{-1}) ^c		
Resistant	96	207*
Susceptible	82	459*
Contrast	14**	-252**
Grain yield (kg ha^{-1})		
Resistant	4,670	4,790
Susceptible	5,070	4,670*
Contrast	-400**	115**
Test weight (kg hl^{-1})		
Resistant	79.2	77.7*
Susceptible	78.8	74.8**
Contrast	0.43*	2.90**
Flour yield (%)		
Resistant	73.0	72.2*
Susceptible	72.1	71.8
Contrast	0.90**	0.34**
AWRC ^d (%)		
Resistant	52.9	55.3**
Susceptible	52.5	54.7**
Contrast	0.46	1.05*

^aControl = no irrigation; 10/10-hr = 10 hr of irrigation on two consecutive days. Single-degree-of-freedom contrasts for 10/10-hr treatment are based on relative change from control values, but untransformed data are presented.

^b*, ** Significant at the 0.05 and 0.01 levels of probability, respectively, based on single-degree-of-freedom comparisons.

^cDU = Dextrinizing units.

test weight probably resulted from poor packing efficiency of sprouted and weathered grain.

Milling and Baking

Among the milling and baking quality traits studied, flour protein, ash, cookie diameter, ash content, softness equivalence, and top grain were not affected by any treatment, and resistant and susceptible genotypes were not significantly different. The lack of an effect on cookie quality contrasts with the results of Lorenz and Valvano (1981), who observed increased cookie diameter and improved top grain score in response to sprout damage. There may have been a higher level of sprouting in their samples; however, comparison is difficult because they used falling number as a measure of sprout damage, whereas this study used germination percentage and α -amylase activity. Flour yield of resistant genotypes was reduced more than for susceptible lines in the 10/10-hr treatment compared to the control. While there is no clear explanation for the reduced flour yield of the resistant genotypes, one factor that could contribute to maintaining or increasing flour yield of susceptible genotypes would be the loss of embryos, coleoptiles, and radicles of germinated kernels resulting in a higher percentage of endosperm relative to grain weight in the sample. In addition, endosperm of weathered grain may separate more easily from the seed coat during the milling process after partial digestion of the protein, starch, or β -glucan layer adjacent to the aleurone layer. Finney et al (1981) observed no effect of field sprouting on flour yield in samples with up to 36% sprouting. The softness equivalence was different for different genotypes; however, it was unaffected by treatment.

The 10/10-hr treatment significantly increased AWRC for all genotypes; however, AWRC values of resistant lines increased slightly more than susceptible cultivars for the 10/10-hr treatments, resulting in a significant difference between resistant and susceptible genotypes. Because lower AWRC is usually associated with higher soft wheat quality, these data suggest that quality declined more in resistant than in susceptible genotypes. Despite the higher AWRC, cookie quality was not affected. These results contrast with the lower bread dough water absorption for flour from sprouted grain observed by Finney et al (1980). Because many factors affect AWRC, it is not possible to identify the chemical or physical components effecting the change in this parameter.

This study shows that germination and α -amylase activity can be induced with a relatively short period of wet conditions and that two of the resistant genotypes in this study provided protection from preharvest sprouting damage with lower germination and lower α -amylase activity. These results also support the findings of Finney et al (1980) that moderate amounts of sprouting do not render the flour unacceptable for some end uses. However, wheat flour with essentially no α -amylase activity is required for many soft wheat products, including sponge cakes, noodles, or other products using wheat flour as a thickening agent, because viscosity decreases with increased sprout damage (Lorenz et al 1983). The results of this study also indicated that the sprouting resistance of these genotypes is not associated with factors having adverse effects on milling and baking quality.

The effects of preharvest sprouting on soft wheat milling and cookie baking characteristics were relatively minor even at the

high levels of damage observed in this study, as evidenced by the lack of treatment effect on cookie diameter. Nevertheless, bakers prefer flour with low α -amylase activity because its performance is more predictable during processing. The resistant genotypes tested exhibited reduced harvest losses and stable test weight. Therefore, the resistance to preharvest sprouting in these genotypes is likely to benefit farmers by extending the duration of the wetting period before visible damage is incurred and to benefit processors by reducing hydrolytic breakdown of starch and proteins.

LITERATURE CITED

- BELDEROK, B. 1968. Seed dormancy problems in cereals. *Field Crop Abstr.* 21:203.
- BHATT, G. M., PAULSEN, G. M., KULP, K., and HEYNE, E. G. 1981. Preharvest sprouting in hard red winter wheat: Assessment of methods to detect genotypic and nitrogen effects and interactions. *Cereal Chem.* 58:300.
- DERERA, N. F. 1979. The audit of sprouting. *Cereal Res. Comm.* 8:15.
- DERERA, N. F., McMASTER, G. J., and BALAAM, L. N. 1976. Preharvest sprouting resistance and associated components in 12 wheat cultivars. *Cereal Res. Comm.* 4:173-179.
- FINNEY, K. F., MORRIS, V. H., and YAMAZAKI, W. T. 1950. Micro versus macro cookie baking procedures for evaluating the cookie quality of wheat varieties. *Cereal Chem.* 27:142.
- 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. *Baker's Dig.* 54(3):22.
- FINNEY, K. F., NATSUAKI, O., BOLTE, L. C., MATHEWSON, P. R., and PÖMERANZ, 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.
- GORDON, I. L., DERERA, N. F., and BALAAM, L. N. 1977. Selection against sprouting damage in wheat. I. Germination of unthreshed seed, with a standard wetting procedure. *Aust. J. Agric. Res.* 28:583-596.
- HAGEMANN, M. G., and CIHA, A. J. 1984. Evaluation of methods used in testing winter wheat susceptibility to preharvest sprouting. *Crop Sci.* 24:249.
- HANFT, J. M., and WYCH, R. D. 1982. Visual indicators of physiological maturity in hard red spring wheat. *Crop Sci.* 22:584.
- IBRAHIM, Y., and D'APPOLONIA, B. L. 1979. Sprouting of hard red spring wheat. *Baker's Dig.* 53(5):17.
- 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(5):355.
- LORENZ, K., and VALVANO, R. 1981. Functional characteristics of sprout-damaged soft white wheat flours. *J. Food Sci.* 46:1018.
- LORENZ, K., ROEWE-SMITH, P., KULP, K., and BATES, L. 1983. Preharvest sprouting of winter wheat. II. Amino acid composition and functionality of flour and flour fractions. *Cereal Chem.* 60:360.
- PATERSON, A. H. 1986. Preharvest sprouting resistance and grain dormancy in white-kernelled wheats. M.S. thesis. Plant Breeding, Cornell University, Ithaca, NY.
- SAS INSTITUTE. 1982. SAS Users Guide: Statistics 1982 Edition. The Institute: Cary, NC.
- SNEDECOR, G. W., and COCHRAN, W. G. 1980. *Statistical Methods*, 7th ed. Iowa State Univ. Press: Ames, IA.
- SORRELLS, M. E., and PATERSON, A. H. 1986. Registration of NY6432-18 and NY6708-18 wheat germplasm lines. *Crop Sci.* 26:392.
- YAMAZAKI, W. T., DONELSON, J. R., and BRIGGLE, L. W. 1968. Micro-tests for soft wheat quality evaluation. *Crop Sci.* 8:199.

[Received January 13, 1989. Accepted May 1, 1989.]