Evidence that Minor Sprout Damage Can Lead to Significant Reductions in Gluten Strength of Winter Wheats

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ABSTRACT

Seventeen winter wheat lines were grown in triplicate plots at Warsaw, Painter, and Blacksburg, VA, during the 1999-2000 growing season. Hagberg falling numbers, protein content, farinograms, sedimentation volumes, and total glutenin content were determined for flours derived from 153 harvested wheat samples. Over three inches (8.2 cm) of rain fell during the week before harvest in Blacksburg, resulting in falling numbers of 100 for Recital and 137 for Heyne, two severely sprouted Blacksburg wheat samples, and falling numbers <250 in three other Blacksburg wheats. There were no significant differences across locations in falling numbers of four wheat lines, and one line had significantly greater falling numbers in Blacksburg than in Warsaw or Painter. All 18 Blacksburg flours had a significantly higher mixing tolerance index (MTI) and shorter departure times (DT) than corresponding Warsaw flours. Weaker gluten strength of Blacksburg flours suggestss that all 18 Blacksburg wheats were sprout-damaged and contained active proteases. However, according to falling number data, five of these Blacksburg wheats were sprout-free with falling numbers >400. These data indicate that Hagberg falling number should not be used as the sole criteria for determining the degree of sprout damage in wheat because it does not quantify, nor always accurately reflect changes in protein composition and quality due to grain weathering.

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Amylase and protease activity are often very high in sprouted wheat. These enzymes can cause sufficient damage to the structural integrity of starch granules and storage proteins of wheat kernels that grain becomes unsuitable for use in food products. Starches in sprouted wheat are quickly degraded by amylases. Sekhon et al (1995) reported that the peak viscosity of wheat flour pastes, which is important in applications like sauces and gravies, fell from 1,060 to 220 BU after 24 hr of sprouting. Sprouting can also have deleterious effects on pasta and bread quality. Noodles made from sprouted wheat were darker in color and some breads made from sprouted wheats had sticky crumbs, which led to tearing when the bread was mechanically sliced (Edwards et al 1989). Breakdown of proteins in sprouted wheat often weakens gluten strength and reduces bread loaf volume (Singh et al 1987; Sekhon et al 1992).

Sprouting is detected in wheat by visible inspection and is quantified by Hagberg falling number. Hagberg falling number is the time in seconds that it takes the viscometer-stirrer to fall a specified distance through a heated slurry of ground whole wheat flour and water (Hagberg 1961) According to Skerritt and Heywood (2000), wheat is severely sprouted if it has a Hagberg falling number of <150, and falling numbers of 150–330 indicate moderate to mild sprouting. Some of the data presented in this report indicate that even mild to moderate sprout damage may lead to significant reductions in gluten strength and end use quality of wheat.

MATERIALS AND METHODS

Wheat Cultivation

Seventeen wheat lines were evaluated in this study (Tables I–V). Soft red winter (SRW) wheat lines Renwood 3260 and NC94-7197 have strong gluten strength and were included as checks (controls). Soissons and Recital are French bread wheat cultivars with red and white kernel color, respectively. Heyne is a hard white winter wheat cultivar released from Kansas State University (KSU). The other 12 lines, designated by 92PAN or 92PIN prefixes, are experimental hard red winter (HRW) wheat lines obtained from KSU.

A randomized complete block design was used in planting three replicate plots of each line near Blacksburg, VA, on October 8, 1999; at Warsaw, VA, on October 26; and October 31 at Painter, VA. Wheat was harvested June 21, 2000, at Warsaw; June 22 at Painter; and on July 7 in Blacksburg. Fall fertilizer (N-P_2O_5-K_2O) was applied according to soil test analyses and recommendations just before planting at Blacksburg (28-56-112 kg/ha), Warsaw (34-90-112 kg/ha), and Painter (28-56-56 kg/ha). Blacksburg wheat received one spring application of N (84 kg/ha), Warsaw wheat received three split-applications of spring N (28, 39, and 67 kg/ha) and 17 kg/ha of N (urea) near the heading stage, Painter wheat received two split-applications of spring N (56 and 34 kg/ha)

Wheat samples from each replicate plot (4.2 m^2) was separately harvested, numbered, bagged, and sent to our cereal quality testing laboratory at Virginia Tech for milling and subsequent quality evaluations. A standard cylinder funnel was used to determine daily rainfall at the Warsaw station. Rainfall data was recorded in Painter and Blacksburg using a S12 automated weather system.

Wheat Milling and Quality Testing

Wheat samples from each replicate plot were tempered overnight to 14% moisture and milled in a Brabender Quadramat Jr. mill (Hackensack, NJ). Milled flours were evaluated for protein content (N × 5.7) using Approved Method 46-12; for Hagberg falling number using Approved Method 56-81B; sedimentation volume using Approved Method 56-61A; and farinograms using Approved Method 54-21 (AACC International 2000). Mixing stability (MS), mixing tolerance index (MTI), departure time (DT), and 20-min drop (TMD) values were determined according to the recommended procedures for analysis and interpretation of farinograph data (Shuey 1984)

SDS-PAGE Quantification of Total Reduced Glutenins

Total protein present in each wheat flour sample was extracted with 2% (w/v) SDS, 0.07*M* Tris-HCL, pH 6.8 buffer (nonreducing sample buffer). Total protein concentration was determined using a protein assay (BCA, Pierce, Rockford, IL). A total of 30 μg of protein from each wheat flour sample was mixed with nonreducing sample buffer and loaded into a 15% SDS ready gel (Bio-Rad, Hercules, CA). For each gel, lane one was empty and lane two was loaded with a prestained set of standard proteins (Bio-Rad). Lane three was loaded with 2 μg of unreduced laminin

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(Calbiochem, La Jolla, CA), which was used as internal reference for glutenin quantification. Lanes four to eight were loaded with wheat flour samples in nonreducing buffer. Each gel was run at manufacturer's recommend conditions for 1 hr. Then each gel was cut into two pieces at the 75 kDa reference position; gel pieces >75 kDa containing glutenin subunits were smashed and 400 µL of millQ water was added, then the gel pieces were incubated at 65°C for 2 hr.

After 2 hr of incubation, the gel slurry was transferred to a 0.22-µm mini column (Ultrafree-MC, Millpore Corp., Bedford, MA) and centrifuged at 25°C, at 14,000 rpm to force glutenin subunits to elute into the sample buffer. Each eluent was concentrated in a 30 mini column (Micocon, Millpore). Concentrated samples were mixed with 62.5 m*M* tris-HCL, pH 6.8, 2% SDS, 5% β-mercaptoethanol, 25% glycerol, and 0.1% bromophenol blue (reducing sample buffer), and heated at 95°C for 5 min. In a separate microcentrifuge tube, 2 µg of laminin (Calbiochem) was also mixed with reducing sample buffer and heated at 95°C for 5 min. All samples were loaded into 4–15% gradient ready gel (Bio-Rad). Each gel was run at manufacturer's recommended conditions for 45 min. For each gel, lane one was empty, lane two was loaded with prestained protein standards (Bio-Rad). Lane three was loaded with 2 µg of reduced laminin (Calbiochem). Lanes four to eight were loaded with wheat glutenin samples. The gel was then washed three times in millQ water and stained with blue-code stain (Pierce, Rockford, IL) for 1 hr, then destained with millQ water for 1 hr. Quantification of glutenin was performed using a gene scanner (Sygene, Cambridge, UK), and GeneTools software.

For protein quantification, the density of a 50 kDa protein band in protein standard lane was used as reference to adjust the stain difference among gels. To adjust for the elution efficiency difference among gels, 2 µg of laminin lane was used as internal reference. Reduced laminin has a molecular mass of ≈200 kDa, which does not interfere with glutenin subunits of wheat, which have molecular mass <150 kDa.

Determination of HMW Glutenin Subunit Composition

Glutenin proteins were extracted from each flour sample and from wheat lines with known high molecular glutenin subunit compositions following the procedures of Ng and Bushuk (1987). Glutenin extract (10 µL each) were loaded into separate lanes of SDS-PAGE gels. Protein electrophoresis was conducted according to Payne et al (1979) as modified by Ng and Bushuk (1987). The

TABLE I
Falling Numbers of Winter Wheats Grown in 1999-2000 at Warsaw, Painter, and Blacksburg, VA[a,b]

Wheat Line	Warsaw	Painter	Blacksburg
NC94-7197	396 ± 5b	416 ± 6b	445 ± 21a
Soissons	403 ± 58a	420 ± 34a	435 ± 21a
Recital	460 ± 34a	364 ± 6b	100 ± 8c
Heyne	453 ± 5a	440 ± 17a	137 ± 18b
92PAN1#22	519 ± 42a	446 ± 14b	205 ± 24c
92PAN1#33	535 ± 30a	500 ± 8a	388 ± 57b
92PAN2#9	496 ± 38a	462 ± 7ab	418 ± 30b
92PAN2#24	320 ± 30 a	242 ± 7b	256 ± 4b
92PAN2#26	532 ± 40a	461 ± 48a	474 ± 55a
92PIN#31	509 ± 18a	475 ± 51a	366 ± 49b
92PIN#109	379 ± 25ab	400 ± 11a	360 ± 17b
92PIN#110	392 ± 12b	433 ± 29a	377 ± 8b
92PIN#122	564 ± 67a	437 ± 21b	341 ± 15c
92PIN#130	353 ± 35a	338 ± 52a	245 ± 18b
92PIN#135	405 ± 38a	397 ± 18a	308 ± 70a
92PIN#136	447 ± 29a	402 ± 24b	347 ± 9c
Renwood 3260	358 ± 12b	395 ± 22a	357 ± 18b
Mean of 17 lines	443 ± 78a	413 ± 62b	327 ± 107c

[a] Mean values of triplicate plots of wheat grown in Warsaw, Painter, or Blacksburg, VA.
[b] Values ± standard deviations followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE II
Flour Protein Content of Winter Wheat Grown in 1999-2000 at Warsaw, Painter, and Blacksburg, VA[a,b]

Wheat Line	Warsaw	Painter	Blacksburg
NC94-7197	11.4 ± 0.5 a	9.3 ± 0.2b	12.1 ± 1.2a
Soissons	11.4 ± 0.6a	8.3 ± 0.2b	11.5 ± 1.1a
Recital	10.7 ± 0.2b	8.0 ± 0.7c	11.9 ± 0.5a
Heyne	12.8 ± 0.9a	9.6 ± 0.1b	13.0 ± 0.1a
92PAN1#22	11.4 ± 0.1b	10.5 ± 0.4c	12.7 ± 0.6a
92PAN1#33	11.5 ± 0.4a	10.0 ± 0.5b	12.2 ± 0.2a
92PAN2#9	12.6 ± 0.6a	10.5 ± 0.5b	13.2 ± 1.5a
92PAN2#24	11.6 ± 0.9a	10.1 ± 0.7b	11.8 ± 0.6a
92PAN2#26	11.7 ± 0.8a	9.3 ± 0.4b	11.8 ± 0.3a
92PIN#31	12.8 ± 0.3a	10.4 ± 0.9b	13.8 ± 0.1a
92PIN#109	10.0 ± 0.3b	9.0 ± 0.1c	11.3 ± 0.6a
92PIN#110	10.3 ± 0.7b	9.4 ± 0.4b	11.4 ± 0.4a
92PIN#122	11.6 ± 0.4b	10.0 ± 0.8c	13.1 ± 0.5a
92PIN#130	12.3 ± 0.3b	10.0 ± 0.5c	13.3 ± 0.2a
92PIN#135	10.9 ± 0.2b	9.5 ± 0.2c	12.2 ± 0.4a
92PIN#136	11.0 ± 0.5a	9.4 ± 0.3b	11.5 ± 0.7a
Renwood 3260	10.8 ± 0.2a	10.0 ± 1.3a	10.5 ± 0.3a
Mean of 17 lines	11.5 ± 0.8b	9.6 ± 0.8c	12.2 ± 0.9a

[a] Mean values of triplicate plots of wheat grown in Warsaw, Painter, or Blacksburg, VA.
[b] Values ± standard deviations followed by the same letter in the same row are not significantly different ($P < 0.05$).

high molecular weight (HMW) glutenin subunit composition of each flour was determined by comparing the electrophoretic mobility of stained protein bands on SDS-PAGE gels from each flour with the electrophoretic mobility of stained proteins from standard wheat lines with known HMW glutenin subunit compositions.

Statistical Analysis

Data were analyzed using the statistical analysis system (SAS Institute, Cary, NC). Two-way analysis of variance was used to determine significant differences in dependent variables due to wheat line and growing location. Duncan's multiple range test was used to determine significant differences among means of individual wheat lines. Values of $P \le 0.05$ were considered to be statistically significant.

RESULTS AND DISCUSSION

Location mean for falling number of flours of 17 wheat lines was significantly higher for wheat lines grown at Warsaw and Painter than at Blacksburg (Table I). In the week before harvest, 8.2 cm of rain fell in Blacksburg, while Warsaw and Painter had 0.13 and 1.9 cm of rain, respectively. Preharvest rainfall led to significant reductions in the falling numbers of some of the Blacksburg wheat lines. The mean falling numbers of nine wheat lines were significantly lower when the lines were grown at Blacksburg than at Warsaw or Painter. However, the mean falling number of one of the wheat lines was significantly greater in Blacksburg than at Warsaw or Painter. There were no significant differences due to location in the falling numbers of four other lines. Based on the falling number criteria of Skerritt and Heywood (2000), severe sprouting occurred in the Blacksburg wheat lines Recital and Heyne, and mild to moderate sprouting occurred in four other HRW lines from Blacksburg. All wheat lines grown at Warsaw and Painter, except for 92PAN2#24, had falling numbers >330 and 12–13 of these lines had falling numbers >400.

The results of farinograph testing are summarized in Table III. A high gluten strength flour, when properly hydrated, will have a high mixing stability (MS), a low mixing tolerance index (MTI), a long departure time (DT), and a low 20-min drop (TMD) (Shuey 1984). The gluten strength of Warsaw wheat flours, with very few exceptions, was significantly greater than corresponding flours

TABLE III
Farinograph Data of Winter Wheats Grown in 1999-2000 at Warsaw, Painter, and Blacksburg, VA[a,b]

	Mixing Stability (MS)			Mixing Tolerance Index (MTI)			Departure Time (DT)			20 Min Drop (TMD)		
Wheat Line	Warsaw	Painter	Blacksburg	Warsaw	Painter	Blacksburg	Warsaw	Painter	Blacksburg	Warsaw	Painter	Blacksburg
NC94-7197	11.3±2.4a	4.7±1.3b	4.3±0.9b	22±19b	53±25ab	93±25a	12.8±1.8a	6.0±1.5b	5.8±0.9b	60±10c	97±15b	137±21a
Soissons	20.3±1.6a	5.6±1.1b	6.0±0.9b	27±15a	47±6a	53±15a	21.8±1.6a	6.8±1.0b	7.5±1.1b	33±15b	90±17a	90±10a
Recital	10.3±2.2a	1.4±0.4b	2.4±0.3b	35±5c	80±20b	113±6a	11.6±2.1a	2.3±0.8b	3.7±0.4b	47±10c	133±6b	197±6a
Heyne	19.8±4.9a	8.9±0.8b	3.8±0.4b	30±17b	17±6b	97±15a	22.1±5.0a	10.5±0.9b	5.6±0.8b	30±10c	67±15b	187±15a
92PAN1#22	10.3±5.1a	4.4±0.5b	2.6±0.5b	43±6b	50±10b	103±25a	12.5±4.8a	6.0±0.5b	4.6±0.8b	50±17c	103±6b	187±31a
92PAN1#33	8.3±2.6a	6.3±1.3ab	3.1±1.1b	45±5b	33±12b	90±10a	10.4±2.5a	7.7±1.3ab	5.0±1.1b	67±10b	90±17ab	117±25a
92PAN#9	15.2±2.3a	7.6±1.4b	7.8±0.8b	40±20a	27±12a	53±15a	17.3±2.4a	9.2±1.4b	10.3±1.0b	37±15b	80±17a	73±12a
92PAN2#24	16.6±2.4a	7.4±2.7b	4.7±0.5b	23±6b	57±31a	63±15a	17.8±2.6a	8.2±2.3b	6.5±0.5b	28±10b	93±32a	127±6a
92PAN2#26	11.4±1.9a	3.3±1.8b	3.3±0.6b	35±5b	80±20a	92±10a	13.0±2.0a	4.6±1.8b	4.9±0.7b	50±10b	127±21a	123±21a
92PIN#31	12.8±1.7a	8.3±1.4b	4.9±1.7c	18±13b	27±15b	60±17a	15.2±1.8a	9.7±1.3b	6.9±1.8b	58±20b	110±10a	137±15a
92PIN#109	7.8±5.3a	1.8±0.3a	3.3±1.1a	57±3c	93±6b	110±14a	8.8±5.3a	2.9±0.1a	4.4±0.9a	62±16b	127±6a	150±21a
92PIN#110	12.3±4.5a	2.3±2.0b	4.0±0.7b	48±14b	83±6a	87±12a	13.5±4.5a	3.4±1.8b	5.3±0.8b	48±20b	113±21a	107±6a
92PIN#122	15.4±3.8a	5.4±1.4b	5.1±0.6b	32±13b	33±12b	60±10a	17.0±3.9a	6.8±1.4b	7.3±0.5b	38±10b	92±14a	103±6a
92PIN#130	10.0±5.5a	5.0±0.5a	4.8±0.9a	33±8b	67±12a	60±10a	14.6±2.8a	6.4±0.6b	7.3±1.1b	62±19b	130±0a	157±15a
92PIN#135	12.9±4.6a	1.4±0.1b	3.9±0.9b	23±6b	80±26a	93±6a	14.2±4.6a	2.6±0.1b	5.3±0.8b	50±20c	143±6a	107±6b
92PIN#136	11.8±2.9a	3.2±1.2b	4.1±0.4b	23±6b	53±23b	90±17a	13.3±2.9a	4.5±1.3b	5.5±0.7b	55±15b	113±6a	117±15a
Renwood 3260	19.9±2.7a	5.1±3.1b	4.0±0.4b	27±12b	60±35ab	80±10a	21.0±2.8a	6.2±3.2b	5.2±0.4b	25±15b	103±23a	123±23a
Mean of 17 lines	13.3±4.8a	4.8±2.6b	4.2±1.4b	33±14c	55±27b	82±23a	15.1±4.7a	6.0±2.7b	6.0±1.7b	47±18b	107±24a	131±37a

[a] Mean values of triplicate plots of wheat grown in Warsaw, Painter, or Blacksburg, VA.
[b] Values ± standard deviations followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE IV
SedimentationVolumes of Winter Wheat in 1999-2000 at Warsaw, Painter, and Blacksburg, VA[a,b]

Wheat Line	Warsaw	Painter	Blacksburg
NC94-7197	57 ± 1.2a	43 ± 3.8b	54 ± 1.5a
Soissons	68 ± 2.5a	53 ± 1.7c	60 ± 4.0b
Recital	64 ± 5.3a	54 ± 6.6b	50 ± 1.5b
Heyne	87 ± 1.5a	68 ± 2.5c	75 ± 3.8b
92PAN1#22	65 ± 2.5a	61 ± 1.2a	52 ± 3.5b
92PAN1#33	66 ± 1.2a	59 ± 1.7b	56 ± 2.6b
92PAN2#9	77 ± 1.7a	64 ± 2.5b	55 ± 8.1b
92PAN2#24	58 ± 2.3a	50 ± 5.0b	52 ± 1.5ab
92PAN2#26	63 ± 1.7a	58 ± 6.1ab	53 ± 1.5b
92PIN#31	56 ± 2.0a	46 ± 3.6b	49 ± 2.5b
92PIN#109	61 ± 3.8a	45 ± 2.6c	56 ± 5.6b
92PIN#110	55 ± 3.0a	44 ± 1.2b	57 ± 1.5a
92PIN#122	66 ± 3.2a	57 ± 2.5b	59 ± 5.0ab
92PIN#130	61 ± 1.7a	48 ± 1.5c	56 ± 1.5b
92PIN#135	60 ± 2.5a	53 ± 0.6b	55 ± 2.0b
92PIN#136	58 ± 5.3a	42 ± 1.5b	53 ± 8.1ab
Renwood 3260	65 ± 4.2a	45 ± 8.7b	52 ± 3.8b
Mean of 17 lines	64 ± 7.8a	52 ± 7.7c	56 ± 5.7b

[a] Mean values of triplicate plots of wheat grown in Warsaw, Painter, or Blacksburg, VA.
[b] Values ± standard deviations followed by the same letter in the same row are not significantly different ($P < 0.05$).

from Blacksburg or Painter. All but two of the Blacksburg and Painter flours had a significantly lower MS and shorter DT than corresponding Warsaw flours. All the Blacksburg and Painter flours, except for Painter 92PAN1#33, had higher TMD values than corresponding Warsaw flours. The greatest difference in farinograph parameters was in MTI, where Blacksburg flours had significantly lower MTI values on average and, hence, lower gluten strength than Warsaw or Painter flours. Gluten strength has been related to the amount of protein present in a flour and also to protein quality (Preston and Kilborn 1984) With the exception of Renwood 3600, all the wheat flour samples from Blacksburg were significantly higher in mean protein content than corresponding Painter samples (Table II). However, relatively few significant differences were found in the gluten strength of doughs made from Blacksburg and Painter flours, which is a strong indication that the higher protein Blacksburg flours were lower in protein quality than Painter flours.

According to Preston and Kilborn (1984), strong gluten flours should have an MTI < 50, a medium strength gluten flour has an MTI of 50–100, and an MTI > 100 is indicative of flour with weak gluten. Strong gluten flours should be used in breadmaking; medium gluten strength flours produce low volume bread, and weak gluten should not be used in bread (Preston and Kilborn 1984). Based on these criteria, all of the Warsaw wheat flours except one, 92PIN#109, possessed strong gluten. Seven of the Painter wheat flours had strong gluten and the remaining 11 Painter flours had medium gluten strength. Three Blacksburg wheat flours had weak gluten and 15 had medium gluten strength. Three of the six sprouted wheat lines (falling numbers 100–308), including white wheat cultivars Recital and Heyne, had high MTI values (97–113).

Doughs made from Blacksburg NC94-7197, a strong gluten SRW wheat line, had significantly lower MS, higher MTI, shorter DT, and higher TMD and significantly lower gluten strength than doughs made from Warsaw NC94-7197, despite the fact that Blacksburg NC-7197 had a significantly higher falling number than Warsaw or Painter NC94-7197. There were no significant differences due to growing location in the falling numbers of Soissons, 92PAN2#26, and 92PIN#135. However, all three lines produced doughs with significantly weaker gluten when grown in Blacksburg than in Warsaw.

The mean sedimentation volumes of the 18 wheat lines are given in Table IV. Twelve wheat lines had significantly higher sedimentation volumes when grown at Warsaw than in Blacksburg, and the mean sedimentation volume of all 18 lines was greater at Warsaw than at Blacksburg. The mean of all 18 lines was significantly higher for Blacksburg than for Painter. Wheat flours with sedimentation volumes of ≥70 are considered to be of "superior bread-baking strength" (Approved Method 56-61A, AACC International 2000). Our hard wheat control Heyne was in this category at two locations, Warsaw and Blacksburg. Warsaw-grown 92PAN#9 was the only other wheat flour sample with a sedimentation volume >70.

Sedimentation volumes are believed to be related to the size of polymeric protein networks present in hydrated flours. Investigations have shown strong positive associations between sedimentation volumes of wheats and bread loaf volumes (Sapirstein and Suchy 1999). The sedimentation volume of 12 wheat lines was significantly higher in wheat flour samples from Warsaw than from Blacksburg, in spite of the fact that the protein content of seven of these lines was higher in Blacksburg than in Warsaw (Table II). These results suggest that there was a disruption in the polymeric protein network of many of the Blacksburg flours, leading to a reduction in SDS sedimentation volume.

SDS-PAGE was used to quantify the total glutenin content of each wheat flour. Each SDS-PAGE gel contained a lane with nine prestained molecular markers with a molecular mass range of 250

TABLE VI
HMW Glutenin Subunit Composition of Winter Wheat Lines Grown in 1999-2000 at Warsaw, Painter, and Blacksburg, VA

Wheat Line	Chromosome 1A	1B	1D
NC94-7197	2*	7+9	5+10
Soissons	2*	7+8	5+10
Recital	2*	8	5+10
Heyne	1	13+16	5+10
92PAN1#22	2*	7+8	2+12
92PAN1#33	2*	7+8	2+12
92PAN2#9	2*	6+8+9	2+12
92PAN2#24	2*	7+9	5+10
92PAN2#26	2*	7+8	2+12
92PIN#31	2*	7+8	5+10
92PIN#109	2*	7+9	2+12
92PIN#110	2*	7+9	5+10
92PIN#122	2*	7+17+18	5+10
92PIN#130	2*	7+8	2+12
92PIN#135	Null	7+9	2+12
92PIN#136	2*	7+9	5+10
Renwood 3260[a]	nd	nd	nd

[a] HMW subunit composition of Renwood 3260 was not determined.

TABLE V
Peak Areas of Total Glutenins of Winter Wheats Grown in 1999-2000 at Warsaw, Painter, and Blacksburg, VA[a,b]

Wheat Line	Warsaw	Painter	Blacksburg
NC94-7197	9,184 ± 1,178a	10,609 ± 460a	10,858 ± 6,012a
Soissons	10,756 ± 1,215a	10,302 ± 1,576a	8,039 ± 1,807a
Recital	12,218 ± 1,496a	11,348 ± 820a	10,312 ± 1,292a
Heyne	11,742 ± 826a	10,472 ± 1,283ab	8,706 ± 1,547b
92PAN1#22	10,434 ± 942a	9,424 ± 2,038a	8,515 ± 3,333a
92PAN1#33	10,793 ± 2,189a	12,456 ± 1,219a	11,382 ± 5,176a
92PAN2#9	11,397 ± 1,144a	13,199 ± 3,301a	8,952 ± 482a
92PAN2#24	10,858 ± 2,274a	7,507 ± 1,470a	10,709 ± 2,464a
92PAN2#26	11,745 ± 2,071a	13,330 ± 6,811a	9,766 ± 2,139a
92PIN#31	9,898 ± 1,679a	10,169 ± 174a	8,960 ± 1,763a
92PIN#109	10,489 ± 698a	11,541 ± 5,214a	10,499 ± 3,132a
92PIN#110	15,912 ± 2,960a	9,757 ± 3,032b	9,858 ± 1,478b
92PIN#122	9,876 ± 1,412a	9,244 ± 1,033a	8,518 ± 1,755a
92PIN#130	10,765 ± 3,183a	11,696 ± 2,378a	8,167 ± 1,447a
92PIN#135	9,051 ± 1,441b	11,329 ± 969ab	12,963 ± 188a
92PIN#136	11,544 ± 2,241a	11,284 ± 1,763a	9,317 ± 3,750a
Renwood 3260	10,525 ± 1,756a	8,502 ± 2,588a	9,902 ± 1,270a
Mean of 17 lines	10,999 ± 2,147a	10,549 ± 2,680a	9,591 ± 2,678b

[a] Mean values of triplicate plots of wheat grown in Warsaw, Painter, or Blacksburg, VA.
[b] Values ± standard deviations followed by the same letter in the same row are not significantly different ($P < 0.05$).

kDa to 10 kDa. The 10 kDa marker appeared close to the bottom of each gel. Most small peptides (<10 kDa), therefore, ran off the gels and were not added to the glutenin content of any of the flours.

Results of SDS-PAGE analysis of the glutenins are reported in Table V. Wheat lines Heyne and 92PIN#110 had a significantly higher content of glutenins when grown in Warsaw than in Blacksburg. The glutenin content of 92PIN#135 was significantly higher in Blacksburg than in Warsaw There were no significant differences in the glutenin content of the other corresponding Warsaw and Blacksburg flours, or in the glutenin content of any of the Blacksburg or Painter flours.

Sprouting resistance in wheat has been linked to inheritance of genes that encode for gliadin proteins with high electrophoretic mobility in sodium lactate PAGE gels (Lukow et al 1989). There is no published information to our knowledge about possible relationships between HMW glutenin subunit composition of wheat and sprouting. One of two hard white wheat cultivars that sprouted at Blacksburg was Recital, which possesses four HMW subunits, subunit 2*, 8, and 5+10 and the second sprouted wheat cultivar was Heyne, which has HMW subunits 1, 13+16, and 5+10 (Table VI). Wheat lines NC94-7197 and Soissons, which had consistently high falling numbers at all three locations, also possess the 5+10 HMW subunits. The HMW subunits 5+10, present in both sprouted and nonsprouted wheat lines, are associated with good bread-baking quality and are commonly found in wheat cultivars bred for this purpose (Payne et al 1987). Wheat lines NC94-7197, Soissons, and 92PAN#26, which have consistently high falling numbers, have all inherited the chromosome 1B HMW 7 subunit. However, subunit 7 does not appear to be associated with sprouting tolerance because all three moderately sprouted wheat lines also have the HMW 7 subunit. There does not appear to be any clear relationship, therefore, between HMW glutenin subunit composition of wheat lines and susceptibility to sprouting or to sprout resistance.

CONCLUSIONS

According to falling number determinations, sprout damage occurred in only six Blacksburg wheat lines. However, data from farinograph, and sedimentation volume testing indicates that gluten strength of all 17 Blacksburg flours was significantly reduced and, in some cases, weakened to such an extent that they were no longer suitable for breadmaking. Therefore it appears, based on data presented in this report, that falling numbers cannot be relied upon as a sole indicator of sprout damage when wheat is exposed to preharvest rains.

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