The Effect of Wheat Flour Proteins on Mixing and Baking—Correlations with Protein Fractions and High Molecular Weight Glutenin Subunit Composition by Gel Electrophoresis[1]

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ABSTRACT

The flours of 44 hard red spring wheats, grown at the same location in North Dakota, were fractionated by three different solubility procedures. Correlations were determined between the quantity of the protein fractions, the gel electrophoretic patterns, and breadmaking quality parameters. All glutenin fractions gave a positive correlation, whereas all gliadin fractions gave a negative correlation with mixing time. However, both the gliadin and glutenin fractions were positively correlated with bread loaf volume. The sodium dodecyl sulfate-polyacrylamide gel electrophoretic patterns of the high molecular weight subunits of glutenin showed that a majority of the cultivars contained the 1 (20%) or 2* (80%), the 7+8 (41%) or 7+9 (57%), and the 5+10 (98%) combinations. Correlations with the high molecular weight subunits of glutenin showed that varieties with subunit 2* present had a significantly lower mixing time, a higher gliadin content, higher farinograph absorption, and higher wet gluten content. Varieties with subunit 8 showed a higher mixing time but a lower gliadin content, a lower farinograph absorption, and a lower wet gluten content. In contrast, varieties with subunit 9 showed the opposite effects, that is, lower mixing time, higher loaf volume, higher gliadin content, higher farinograph absorption, and higher wet gluten content. The positive and negative effects of the A-subunits may not be a direct cause of a particular subunit but rather of the gliadin-glutenin composition, which could be related to the presence or absence of the different A-subunits.

Especially during the last decade, there has been a great deal of research based on the work of Payne et al (1979, 1980, 1981, 1987) focused on the subunit composition of glutenin and its relationship to rheological and breadmaking properties of bread wheats. At the Plant Breeding Institute, Cambridge, England, Peter Payne and co-workers (1979, 1981) used sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) to determine the chromosomal location of the high molecular weight (HMW) subunits of glutenin. They also related the presence or absence of the HMW subunits of glutenin to differences in breadmaking quality (1979, 1980, 1981, 1987). Branlard and Dardevet (1985) also investigated the relationship of the HMW glutenin subunits to the quantity of gliadin and glutenin fractions and to various breadmaking quality parameters such as strength, tenacity, swelling, and extensibility of dough. Recently, Ng and Bushuk (1988) and Lukow et al (1989) also investigated the relationship between the HMW subunits of glutenin and breadmaking quality parameters of Canadian wheats. A recent communication from Australia by Lawrence et al (1988) indicated that quantitative differences in specific HMW glutenin subunits may also be important in determining breadmaking quality differences among bread wheat cultivars.

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We in North Dakota are also interested in utilizing specific biochemical techniques such as PAGE, SDS-PAGE, and reversed phase-high performance liquid chromatography (RP-HPLC) to examine gliadin and glutenin proteins to establish relationships with breadmaking quality parameters. These relationships could be used by plant breeders in establishing strategies for selecting early generation materials in a variety development program.

In the present study we examined a number of U.S.-grown hard red spring (HRS) wheat cultivars. We first fractionated these cultivars into various protein fractions and then examined the relationship of these fractions to various breadmaking quality parameters and to the glutenin subunit composition of their cultivars.

MATERIALS AND METHODS

Flour Samples

Wheat samples grown in the field plot variety trials in North Dakota were milled into flour on a Buhler laboratory mill according to the procedures at the Department of Cereal Science and Food Technology, North Dakota State University, Fargo, ND. Forty-four HRS wheat cultivars were grown at the same location in 1986.

Protein Fractionation

Glutenin was obtained according to a procedure similar to one described by Graveland et al (1982) as outlined in Figure 1.

Gliadin, water-soluble, and salt-soluble proteins were fractionated as follows:

Method A. A 0.4-g sample of flour was suspended in 3 ml of 0.5*M* NaCl solution and stirred for 3 hr. After stirring, it was centrifuged for 20 min at 2,000 × *g*. The residue was suspended in 2 ml of 0.5*M* NaCl solution and again stirred for 3 hr, followed by centrifugation for 20 min at 2,000 × *g*. The supernatants were

combined, and their protein content (albumins and globulins) was determined by the biuret method.

The residue was suspended in 3 ml of 70% ethanol, stirred for 3 hr, and centrifuged for 20 min. The residue was suspended in 2 ml of 70% ethanol and stirred for 3 hr, followed by centrifugation for 20 min. The supernatants were combined and the protein content was determined by the biuret method. This procedure gave an NaCl extract (albumins and globulins), a gliadin A, and residue A fractions.

Method B. A 0.4-g sample of flour was suspended in 3.0 ml of 70% ethanol, stirred for 3 hr, and then centrifuged for 20 min at 2,000 × *g*. The supernatant was collected. The pellet was extracted once more as before and the supernatants combined. This procedure gave the gliadin B and residue B fractions. Note that the so-called "gliadin" B fraction contains small amounts of the salt-soluble proteins.

Method C. Method C was the same as method A except that the first step was a water extract followed by salt and the final one a 70% ethanol extract. This method gave water-soluble (albumins) salt-soluble (globulins), gliadin C, and residue C fractions.

Protein Determination

The protein content of the glutenin fraction was determined by the macro-Kjeldahl method according to AACC method 46-10 (AACC 1983). The protein content of the various fractions from methods A, B, and C was determined by the biuret method by adding 1.0 ml of protein solution to 4.0 ml of biuret reagent. The absorbance was measured at 540 nm on a Beckman DU-7 spectrophotometer. The biuret reagent consisted of 3 g of $CuSO_4 \cdot 5H_2O$, 9 g of sodium-potassium tartrate, 8 g of sodium hydroxide, and 5 g of potassium iodide, all dissolved in water and diluted to 1 L.

TABLE I
Ranges in Distribution of Quality Parameters Among 44 Hard Red Spring Wheat Cultivars

Parameter	No. of Cultivars
Flour protein content,[a] %	
12.5–13	6
13.1–14	22
14.1–15	14
15.1–15.5	2
Mixing time, sec	
150–200	15
201–300	17
301–450	12
Falling number, sec	
350–400	2
401–450	29
451–500	12
501–550	1
Loaf volume, cm^3	
750–800	1
801–850	7
851–900	17
901–950	13
951–1,000	5
1,001–1,050	1

[a] Determined on a 14.0% moisture basis.

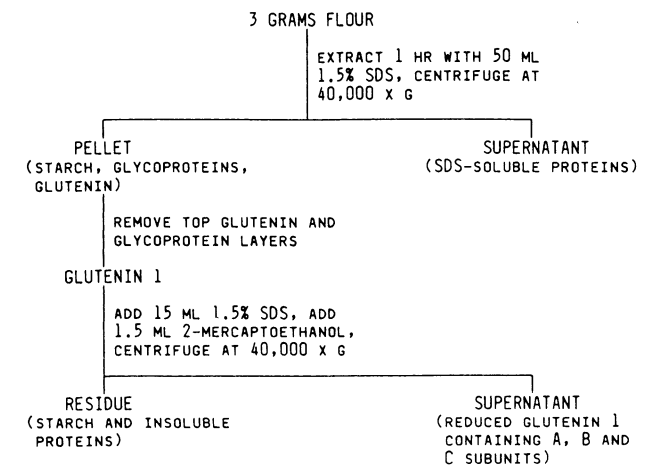

Fig. 1. Schematic outline of the extraction procedure to obtain the glutenin 1 and sodium dodecyl sulfate-supernatant fractions.

SDS-PAGE

SDS-PAGE was carried out on 12% (w/v) acrylamide separating and 5% (w/v) stacking gels according to a modified Laemmli (1970) procedure.

Mixograms

Mixograms were obtained according to the AACC approved method using a 30-g bowl and a mixograph from National Manufacturing, Lincoln, NE.

Breadmaking Quality Data

Breadmaking quality data were obtained from the 1986 HRS Wheat Variety Trial Report, Department of Cereal Science and Food Technology, North Dakota State University, Fargo, ND.

The baking procedure was a partial modification of the straight dough lean formula of D'Appolonia et al (1970). The baking formula consisted of 100 g of flour (constant moisture basis), 3% yeast, 5% sugar, 1% salt, 0.1% ammonium phosphate, fungal amalyse, and variable absorption and mixing time. The dough was fermented in porcelain bowls in a cabinet controlled at 30°C and 78% rh, with two punches during a 3-hr fermentation and a proof period of 55 min, and then baked at 230°C for 25 min. Loaves that had a young appearance were rebaked with 10 ppm bromate.

Wet gluten content was determined according to the Glutomatic procedure (Falling Number AB, Stockholm, Sweden), except that the buffer system of AACC method 38-11 (AACC 1983) was used.

Statistical Analysis

Statistical analyses were carried out using the Statistical Analysis System (SAS 1982).

RESULTS

HRS Wheat Cultivars and Their Quality Attributes

Table I shows the range of quality attributes of the 44 HRS wheat cultivars used in this study. Protein content, mixing time, falling number, and loaf volume all showed a range of values. We, therefore, had a set of samples that did not show any abnormal quality characteristics, but instead showed a wide range of quality attributes, suitable for comparative studies.

Relationships Between Breadmaking Quality Parameters and Protein Fractions

In the first part of this study, relationships between the amounts of protein fractions and breadmaking quality indexes were examined. Table II shows that protein content had no relationship to mixing time, which should not be surprising since mixing characteristics would be dependent on protein composition and quality. Protein content, however, did show a significant positive

TABLE II
Simple Correlation Coefficients Between Various Quality Parameters of 44 Hard Red Spring Wheat Cultivars

Parameters	Mixing Time (sec)	Loaf Volume (cm^3)
Protein content	−0.15	0.67**
Wet gluten content	−0.63**[a]	0.50**
Loaf volume	−0.10	1.0
Mixograph mix time	1.0	−0.10

[a] **, Less than 1% probability.

correlation with loaf volume, in agreement with the findings of Finney and Barmore (1948) and Bushuk et al (1969). Wet gluten content showed a significant negative correlation to mixing time and a significant positive correlation to loaf volume. Loaf volume showed no relationship to mixing time.

Table III shows the relationship between the amounts of the various protein fractions and quality parameters. Gliadin fractions, isolated by all three methods, and the SDS-supernatant fraction showed a significant negative correlation while the residue fractions showed a positive correlation with mixing time. This agrees with the previous research of Orth and Bushuk (1972). All gliadin fractions and the SDS-supernatant also showed the highest significant positive correlations with wet gluten content. In contrast, the residue fractions (total glutenin) and glutenin 1 showed low correlations to wet gluten content. This would seem to indicate that the gliadin proteins have a greater effect on wet gluten content. Each of the gliadin, residue, glutenin 1, and SDS-supernatant fractions showed significant positive correlations with bread loaf volume, the coefficients being very similar for each fraction within each fractionation procedure except for method A. Farinograph absorption did not show high positive correlations with the various protein fractions.

Table IV shows the coefficients of determination from stepwise linear regression models of mixing time and loaf volume with the fractions from the various isolation procedures. The coefficients for mixing time and loaf volume are highly significant and higher in value in these models than in Table III. This would indicate that the interaction properties between the gliadin and glutenin proteins seem to be the important factor in influencing breadmaking quality parameters. This conclusion was also arrived at by Branlard and Dardevet (1985) from their correlations with gliadin and glutenin fractions.

HMW Subunit Composition of Glutenin by SDS-PAGE

The SDS-PAGE patterns of the 44 HRS wheat cultivars were examined for their high molecular weight subunit composition, and Glu-1 scores were assigned (Table V) according to Payne et al (1987). It should be noted that the Glu-1 scores of Payne et al (1987) are based on the SDS sedimentation test. All cultivars possessed Glu-1 scores of either 9 or 10, which is indicative of good breadmaking quality. Six cultivars contained HMW subunit combinations 1, 7+8, and 5+10; two contained 1, 7+9, and 5+10; one, 1, 7+8, and 2+12; one, 1, 17+18, and 5+10; 12 contained 2*, 7+8, and 5+10; and 23 contained 2*, 7+9, and 5+10. Figure 2 shows the SDS-PAGE patterns of some representative cultivars showing the distribution of the more prevalent HMW subunits found in the 44 cultivars.

Table VI shows the frequency of occurrence of the HMW subunits controlled by the various chromosomes. The 2*, 7+8, or 7+9 and 5+10 subunits occur most frequently, 80, 41, 57 and 98%, respectively, in the 44 cultivars examined. The 5+10 subunit combination has been shown to be associated with gluten strength (Payne et al 1981, Branlard and Dardevet 1985, Ng and Bushuk 1988). Five percent gels were used to look for the 2+12 combination, indicative of poor breadmaking quality, but this combination was found in only one cultivar. Also only one cultivar contained the 17+18 combination. Subunit 1, another indicator of good breadmaking quality, was found in only 19.0% of the cultivars. It is evident that these 44 HRS wheat cultivars show fewer HMW glutenin subunit combinations than those of British-grown wheats (Payne et al 1987). Notably absent or in very low

TABLE III
Simple Correlation Coefficients of Protein Fractions and Quality Parameters of 44 Hard Red Spring Wheat Cultivars

Fractionation Method/ Protein Fraction	Mixing Time (sec)	Farinograph Absorption (%)	Loaf Volume (cm^3)	Wet Gluten (%)
Method A				
Gliadin	−0.55**[a]	0.32*	0.36*	0.78**
Residue	0.27	0.34*	0.56**	0.28*
Method B				
Gliadin	−0.58**	0.36*	0.46**	0.83**
Residue	0.36*	0.25	0.49**	0.23
Method C				
Gliadin	−0.46**	0.39*	0.53**	0.87**
Residue	0.20	0.33*	0.53**	0.36*
Glutenin 1	0.62**	0.08	0.32*	−0.17
SDS[b]-Supernatant	−0.54**	0.40**	0.33*	0.86**

[a]**, Less than 1% probability; *, less than 5% probability.
[b]Sodium dodecyl sulfate.

TABLE IV
Coefficient of Determination of Linear Least Squares Regression Models of Protein Fractions and Quality Parameters of 44 Hard Red Spring Wheat Cultivars

	R^2	
Protein Fractions[a]	Mixing Time (sec)	Loaf Volume (cm^3)
Method A	0.79**[b]	0.59**
Method B	0.79**	0.58**
Method C	0.81**	0.63**

[a]Methods A, B, and C are outlined in Materials and Methods.
[b]**, Less than 1% probability.

TABLE V
High Molecular Weight Subunit Composition of Glutenin of 44 Wheat Cultivars Grown at the Same Location in North Dakota

Cultivar	High Molecular Weight Subunits 1A	1B	1D	Glu-1 Score
Marshall	2*	7,9	5,10	9
Leif	2*	7,8	5,10	10
Columbus	2*	7,9	5,10	9
Coteau	2*	7,9	5,10	9
Norseman	2*	7,8	5,10	10
Butte	2*	7,9	5,10	9
ND 628	2*	7,8	5,10	10
ND 606 (WB)	1	7,9	5,10	9
Lancer	2*	7,8	5,10	10
ND 618	2*	7,8	5,10	10
Success	2*	7,8	5,10	10
ND 625	2*	7,9	5,10	9
Butte '86	2*	7,9	5,10	9
Katepwa	2*	7,9	5,10	9
Hy 320	1	7,8	2,12	8
Walera	2*	7,8	5,10	10
ND 624	2*	7,9	5,10	9
Stoa	2*	7,9	5,10	9
Telemark	2*	7,9	5,10	9
Solar	2*	7,8	5,10	10
ND 622	2*	7,9	5,10	9
ND 623	2*	7,9	5,10	9
Waldron	2*	7,9	5,10	9
Shield	1	7,9	5,10	9
ND 629	2*	7,9	5,10	9
Nordic	2*	7,8	5,10	10
Wheaton	2*	7,8	5,10	10
Cutless	2*	7,8	5,10	10
Lew	2*	7,9	5,10	9
Celtic	2*	7,9	5,10	9
Alex	2*	7,9	5,10	9
Olaf	2*	7,9	5,10	9
ND 626	2*	7,9	5,10	9
Bronze Chief	1	7,8	5,10	10
Apex 83	1	7,8	5,10	10
ND 617	2*	7,9	5,10	9
ND 627	2*	7,9	5,10	9
ND 747	1	17,18	5,10	9
Len	2*	7,9	5,10	9
Norak	1	7,8	5,10	10
Challenger	1	7,8	5,10	10
Guard	2*	7,9	5,10	9
PR 2369	2*	7,8	5,10	10
Glenman	1	7,8	5,10	10

TABLE VI
Frequencies of High Molecular Weight Subunits of Glutenin in 44 Wheat Cultivars Grown in North Dakota

Chromosome 1A			Chromosome 1B			Chromosome 1D		
Subunit	No. of Cultivars	Frequency (%)	Subunit	No. of Cultivars	Frequency (%)	Subunit	No. of Cultivars	Frquency (%)
1	9	20	7+8	18	41	5+10	43	98
2*	35	80	7+9	25	57	2 + 12	1	2
Null	0	0	17+18	1	2	...	...	...

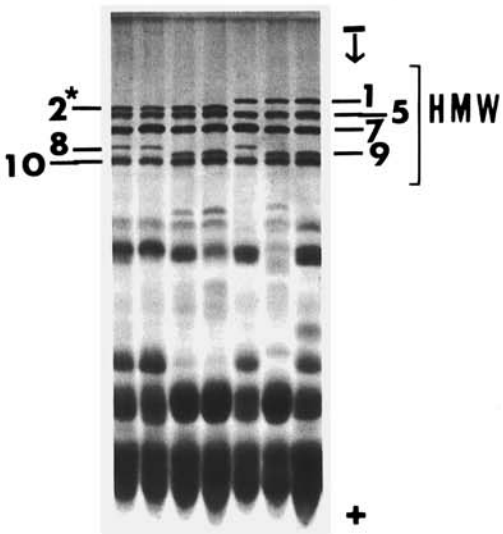

Fig. 2. Sodium dodecyl sulfate-polyacrylamide gel electrophoretic patterns of representative hard red spring wheat cultivars grown in North Dakota showing the high molecular weight glutenin subunit composition according to the system of Payne et al (1979, 1980, 1987).

percentages of occurrence in these HRS wheats were subunit combinations associated with poor breadmaking quality characteristics, such as the null form, the 6+8 and the 2+12, which are high, 73.0, 44.0 and 53.0%, respectively, in British-grown wheats (Payne et al 1987). In contrast, much lower percentages of subunits, such as the 7+8 (12.0%), 7+9 (8.0%), and 5+10 (19.0%) combinations, associated with good breadmaking quality characteristics, occur in the British-grown wheats than in the 44 HRS wheat cultivars of this study.

In the present study, however, the greatest variation in subunit composition was found in the 7+8 (41.0%) and 7+9 (57.0%) subunit combinations. The 2*, 7+8, and 7+9 subunits were therefore used to establish relationships with various quality parameters.

Relationship of the HMW Subunits of Glutenin to Breadmaking Quality

Table VII shows that the presence of 2* showed a negative correlation with mixing time and positive correlations with farinograph absorption and wet gluten. The presence of subunit 8 showed a significant negative correlation with most quality parameters listed in Table VII. The presence of subunit 9, however, showed just the opposite effect to subunit 8, that is, a significant positive correlation with all quality parameters except mixing time shown in Table VII.

The student's *t* test was used to show the effect of the presence or absence of subunits 2*, 8, and 9 on various quality parameters (Table VIII). Cultivars with 2* present showed a significantly lower mixing time, a higher gliadin content, a higher farinograph absorption, and a higher wet gluten content but their loaf volume, residue protein, and flour protein content were not significantly affected. The presence of subunit 8 did not have a significant effect on mixing time but showed significantly lower loaf volume, gliadin content, farinograph absorption, wet gluten, residue protein, and flour protein. The presence of subunit 9 had the opposite effect to subunit 8, that is, cultivars showed a significantly

TABLE VII
Simple Correlation Coefficients of High Molecular Weight Subunits of Glutenin and Various Quality Parameters of 44 Wheat Cultivars

High Molecular Weight Subunits of Glutenin		Mixing Time (sec)	Farinograph Absorption (%)	Loaf Volume (cm^3)	Wet Gluten (%)	Flour Protein (%)
2*	Present[a]	−0.39*[b]	0.36*	0.12	0.39*	0.16
8	Present	0.13	−0.47**	−0.39*	−0.52**	−0.45**
9	Present	−0.29	0.45**	0.35*	0.63**	0.51**

[a]Correlations were done by assigning 1 or 0 to indicate presence or absence, respectively, of a subunit.
[b]*, Less than 5% probability; **, less than 1% probability.

lower mixing time and significantly higher loaf volume, gliadin content, farinograph absorption, wet gluten, residue, and flour protein content. The presence or absence of subunits 8 and 9, therefore, seems to affect the flour protein content and the content of the protein fractions isolated from the respective cultivars. Table IX shows that environment had no effect on the relationship between the presence or absence of subunit 8 and 9 and flour protein content. This relationship, therefore, seems to be genetically determined.

Since subunits 8 and 9 are allelic and are controlled by genes on chromosome 1B, the presence or absence of these subunits may, in turn, affect the composition of proteins in the respective fractions. Subjective evaluation of Figure 2 shows an apparent quantitative difference in subunits 8 and 9, the latter being more intensely stained than subunit 8. Also in the low molecular weight (LMW) glutenin region there are more subunits and subunits that are more brightly stained in those cultivars that contain subunit 9. Therefore, the presence or absence of subunits 8 and 9 also seems to be associated with compositional differences in gliadin and glutenin fractions. These compositional differences in gluten proteins may have, therefore, influenced the functional (breadmaking) property differences of the respective cultivars.

HMW Subunit Composition of Glutenin of other HRS Wheat Cultivars

To assess the variability in older cultivars, we also looked at the HMW glutenin subunit composition of 40 other HRS wheat cultivars grown in North Dakota in different years in field plot variety trials over the past 40 to 50 years (Table X). The Glu-1 scores for most of the cultivars were 9 and 10, indicative of good breadmaking quality. Only two cultivars have Glu-1 scores of 6 and 8, respectively, which are indicative of poorer breadmaking quality.

The frequency of occurrence of the various subunit combinations found in the 40 cultivars was calculated. As for the 44 cultivars in Table V, the 5+10 combination occurred most frequently (93.0%), followed by the 2* (66.0%), the 7+9 (48.0%), the 7+8 (32.0%), the 17+18 (17.0%), and the 1 (25.0%). Much lower frequencies of other combinations such as the null (5.0%) and 2+12 (7.0%) occurred. Therefore, as indicated in Table V, the subunit combinations indicative of good breadmaking quality also predominated in these 40 cultivars.

DISCUSSION

The HMW glutenin subunit composition of the 84 HRS wheats grown in North Dakota showed that the majority of these cultivars

TABLE VIII
Relationship Between the Presence or Absence of Certain High Molecular Weight Subunits of Glutenin and Some Quality Parameters of 44 Wheat Cultivars Grown in North Dakota

Subunit	No. of Cultivars	Mixing Time (sec) Mean	SD[a]	t[b]	Loaf Volume (cm^3) Mean	SD	t	Gliadin Content (mg) Mean	SD	t	Farinograph Absorption (%) Mean	SD	t	Wet Gluten (%) Mean	SD	t	Residue Content (%) Mean	SD	t	Flour Protein (mg) Mean	SD	t
2* Present	37	242	66.7	2.78	904	52.1	0.84	671	46.7	2.08	670	20.6	2.50	362	28.6	2.75	732	51.8	0.31	13.8	0.68	1.05
2* Absent	7	319		($P<0.01$)	866		($P>0.10$)	632		($P>0.05$)	648		($P>0.02$)	328		($P<0.01$)	738		($P>0.10$)	13.5		($P>0.10$)
8 Present	17	266	71.9	0.85	876	48.2	2.81	584	41.8	2.95	653	23.3	3.44	336	30.8	3.90	703	35.7	2.27	13.4	0.60	3.27
8 Absent	27	249		($P>0.10$)	918		($P<0.01$)	622		($P<0.01$)	675		($P<0.01$)	369		($P<0.01$)	752		($P<0.01$)	14.1		($P<0.01$)
9 Present	28	239	60.6	1.97	915	49.2	2.43	625	39.2	3.98	674	18.4	3.30	371	24.6	5.27	749	50.0	3.02	14.1	0.59	3.79
9 Absent	16	282		($P>0.05$)	878		($P>0.02$)	576		($P<0.01$)	653		($P<0.01$)	330		($P<0.01$)	705		($P<0.01$)	13.4		($P<0.01$)

[a]Standard deviation of the mean.
[b]Student's t test.

TABLE IX
Relationship of the High Molecular Weight Subunits of Glutenin and Flour Protein Content of Hard Red Spring Cultivars Grown at Different Locations in North Dakota

	Hettinger				Carrington				Williston			
Subunit	No. of Cultivars	Mean Protein Content (%)	SD[a]	t[b]	No. of Cultivars	Mean Protein Content (%)	SD	t	No. of Cultivars	Mean Protein Content (%)	SD	t
2* Present	37	13.9	0.69	1.06	31	14.2	0.77	1.49	32	13.6	0.77	1.17
2* Absent	7	13.6		($P>0.10$)	5	13.6		($P>0.10$)	6	13.2		($P>0.10$)
8 Present	17	13.4	0.61	3.27	13	13.6	0.74	3.42	14	13.1	0.88	2.71
7 Absent	27	14.1		($P<0.01$)	23	14.4		($P<0.01$)	24	13.8		($P<0.01$)
9 Present	28	14.1	0.59	3.79	24	14.3	0.61	3.02	25	13.9	0.61	3.57
9 Absent	16	13.4		($P<0.01$)	12	13.6		($P<0.01$)	13	13.0		($P<0.01$)

[a]Standard deviation of the mean.
[b]Student's t test.

contained subunit combinations that are characteristic of good breadmaking quality. Over 90% of the cultivars contained the 5+10 subunit combination controlled by chromosome 1D. The 5+10 combination is associated with strong dough characteristics (Branlard and Dardevet 1985) typical of North Dakota HRS wheats, which are blended with weaker-type European wheats in which the 5+10 combination is very low, for example, 19.0% in English wheats (Payne et al 1987).

Another finding of the present study is the opposite effects of the presence or absence of subunits 8 and 9 and their relationship to breadmaking quality parameters. Both these subunits are controlled by the 1B chromosome and are allelic to each other. The presence of subunit 8 results in lower protein content and negative relationships with other quality parameters. The presence of subunit 9, on the other hand, results in higher protein content and more positive relationships with breadmaking quality parameters than subunit 8. Therefore, in a variety development program, selection of cultivars with subunit 9 would seem to be advantageous.

The results of this study showed that the majority of cultivars contained the HMW glutenin subunit composition characteristic of good breadmaking quality. Yet there were large differences in breadmaking quality parameters among these cultivars. The obvious question, therefore, is what factors are causing these differences? Perhaps the answer lies in the overall gluten protein composition, which may be influenced by the presence or absence of subunits such as 8 and 9. Subjective evaluation of SDS-PAGE patterns indicated both qualitative and quantitative differences in subunit composition in both the HMW and LMW regions. These differences may, therefore, in turn affect the functional (breadmaking) properties of the respective cultivars. Recent evidence by Lawrence et al (1988) suggests that quantitative differences in the HMW subunit composition may also explain breadmaking property differences among cultivars. These compositional differences may, therefore, influence the interactive properties of the gluten proteins. These interactive properties, as suggested by the results of Branlard and Dardevet (1985) and those in this study, may be the important factor(s) in determining breadmaking quality differences among bread wheats. Direct evidence of qualitative and quantitative differences would have to be obtained from sequence analysis of specific subunits and

TABLE X
Glutenin Subunit Compositin of 40 Wheat Cultivars from Previous Field Plot Variety Trials in North Dakota

Cultivar	High Molecular Weight Subunits 1A	1B	1D	Glu-1 Score
Alex	2*	7,9	5,10	9
Angus	2*	7,9	5,10	9
Anza	N	7,8	2,12	6
Bonanza	1	7,9	5,10	9
Bounty 208	2I	17,18	5,10	10
Bounty 309	2*	17,18	5,10	10
Buckshot	2*	7,9	5,10	9
Canuck	1	7,9	5,10	9
Chester	2*	7,8	5,10	10
Centana	2*	7,9	5,10	9
Chinook	?	7,9	5,10	9
Chris	2*	7,9	5,10	9
Ellar	2*	7,9	5,10	9
Era	2*	7,8	5,10	10
Erik	2*	7,9	5,10	9
Fortuna	?	7,8	5,10	?
James	2*	7,9	5,10	9
Kitt	2*	7,9	5,10	9
Leader	2*	7,8	5,10	10
Lark	2*	17,18	5,10	10
Manitou	2*	7,9	5,10	9
Marberg	2*	7,9	5,10	9
Napayo	2*	7,9	5,10	9
Neepawa	2*	7,9	5,10	9
Oslo	1	7,8	2,12	8
Polk	2*	7,8	5,10	10
Pondera	1	7,8	5,10	10
Probrand 711	2*	7,8	5,10	10
Prodax	2*	17,18	5,10	10
Profit 75	1	17,18	5,10	10
Protor	1	7,8	5,10	10
PR2348	1	17,18	5,10	10
Sawtana	2*	7,9	5,10	9
Selkirk	1	6,8	5,10	8
Sinton	2*	7,9	5,10	9
Tioga	1	7.8	5,10	10
Tracey	N	7,8	2,12	6
Wared	2*	7,8	5,10	10
World Seeds 1825	1	17,18	5,10	10
World Seeds 1809	2*	7,9	5,10	9

protein fractionation/quantitation/reconstitution (gliadin-glutenin ratio) studies. These areas of research remain to be explored.

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