Effects of Genotype and Environment on Glutenin Polymers and Breadmaking Quality[1]

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ABSTRACT

Six genotypes of hard red spring (HRS) wheat were grown at seven environments in North Dakota during 1998. Effects of genotype and environment on glutenin polymeric proteins and dough mixing and baking properties were examined. Genotype, environment, and genotype-by-environment interaction all significantly affected protein and dough mixing properties. However, different protein and quality measurements showed differences for relative influences of genotype and environment. Total flour protein content and SDS-soluble glutenin content were influenced more by environmental than genetic factors, while SDS-insoluble glutenin content was controlled more by genetic than environmental factors. Significant genotypic and environmental effects were found for the size distribution of SDS-soluble glutenins and between SDS-soluble and SDS-insoluble glutenins as well as % SDS-insoluble glutenins. With increased flour protein content, the proportions of monomeric proteins and SDS-insoluble glutenin polymers appeared to increase, but SDS-soluble glutenins decreased. Flour protein content and the size distribution between SDS-soluble and SDS-insoluble glutenin polymers were significantly correlated with dough mixing properties. Environment affected not only total flour protein content but also the content of different protein fractions and size distributions of glutenin polymers, which, in turn, influenced properties of dough mixing. Flour protein content, % SDS-insoluble glutenin polymers in flour, and ratio of SDS-soluble to SDS-insoluble glutenins all were highly associated with dough mixing properties and loaf volume.

Many studies have indicated that wheat quality was affected significantly by genotype, environment, and genotype-by-environment interaction (Fowler and de la Roche 1975; Miezan et al 1977; Baenziger et al 1985; Bassett et al 1989; Lukow and McVetty 1991; Rao et al 1993). Among the quality characteristics, protein content has been extensively studied in relation to environmental factors. Nitrogen fertilization was a significant factor influencing protein content (Hunter and Stanford 1973; Cochran et al 1978; Memon and Jamro 1988). Johnson et al (1972) found that a slight positive correlation between increased temperatures during the early stages of grain filling and protein content existed, while higher average temperatures in grain filling showed no effect on protein content. However, the study by Rao et al (1993) indicated that protein content of soft white winter wheats was positively associated with maximum temperatures during grain filling but the relationships varied among locations. They concluded that the primary environmental factors conditioning protein content differed from location to location.

Nevertheless, variation in total protein content alone does not adequately account for established differences in varietal end-use quality characteristics (Peterson et al 1992). Protein quality, as measured by SDS sedimentation volumes and size-exclusion HPLC, also was highly influenced by environmental factors. Flour protein content was less susceptible to environmental modification than SDS sedimentation volume (Graybosch et al 1995). Temperature during grain development had significant influence on end-use quality (Finney and Fryer 1957; Randall and Moss 1990; Stone et al 1994). Heat stress during grain filling caused the decrease of glutenin to gliadin ratio because gliadin synthesis continued during heat stress while there was a greatly decreased synthesis of glutenin proteins (Blumental et al 1990a,b; 1994). Heat stress reduced the size of glutenin polymers as measured by multistacking SDS-PAGE (Blumental et al 1995) and reverse-phase HPLC (Ciaffi et al 1995) and, as a result, weakened the dough. Therefore, to understand the role of environment on wheat quality, it is necessary to investigate not only protein quantity but also protein quality such as the size distribution of glutenin polymers and the ratio of polymeric to monomeric proteins.

Glutenin polymers were strongly correlated in size distribution with dough properties and breadmaking quality (Singh et al 1990; Gupta et al 1993; Weegels et al 1996). The % SDS-insoluble protein in total polymeric protein was more strongly correlated with dough strength properties than was the % total polymeric protein in total protein or flour. SDS-insoluble polymeric protein contained a significantly greater proportion of larger polymers than its soluble counterpart (Gupta et al 1993). Studies of unreduced glutenin polymers by a multistacking SDS-PAGE procedure (Khan and Huckle 1992) indicated that a high and positive correlation existed between the size distribution of glutenin polymers and breadmaking quality (Huang and Khan 1997a). Obviously, both protein quantity and quality are important in determining dough properties and breadmaking quality.

In North Dakota, a major production region for hard red spring (HRS) wheats, genotype and environment influenced quality characteristics of HRS wheats and very significant differences existed in protein content, mixograms, and loaf volume between genotypes and environments (Harris et al 1945). Other studies also indicated that HRS wheats showed significant differences in quality by environmental variations (Sandstedt and Fortmann 1944;, Bush et al 1969; McGuire and McNeal 1974). The purpose of this study was to examine environmental changes of dough mixing and baking properties of HRS wheats grown in North Dakota and the relationships with protein quantity and quality such as size distributions of glutenin polymers and ratio of glutenin polymers in total proteins.

MATERIALS AND METHODS

Wheat and Flour Samples

Six genotypes of HRS wheat, varying in breadmaking quality, were chosen from field plot variety trials grown in seven locations across North Dakota in 1998. Among six genotypes, five possessed HMW glutenin subunits composition of 2*, 7+9, and 5+10, and one had the composition of 2*, 7+8, and 5+10 according to the nomenclature of Payne and Lawrence (1983). Locations were Langdon, Williston, Minot, Carrington, Casselton, Dickinson, and Hettinger. At each location, genotypes were grown in a randomized complete-block design with three replicates. Samples of grain were tempered to 15.5% moisture for 16 hr. Additional temper of 0.5% was made 5 min before milling. The milling laboratory was controlled at 68% rh and 72°F. Milling was performed in a Buhler laboratory mill (Type MLU-202).

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Mixograph

Flour mixing properties were evaluated using a modified 25-g mixograph (National Manufacturing, Lincoln, NE) with 60% water absorption according to Approved Method 54-40A (AACC 2000). Flour was incubated at 30°C for at least 15 min before mixing. Mixograph dough development time (MT) was measured as the time in minutes required to reach the peak of the curve. The height and width of the mixogram were recorded at different times: peak time, 2 min after peak, and 8 min after mixing. Dough weakening was calculated by the difference between the height at peak time and the height at 8 min after mixing according to Martinant et al (1998).

Protein Extraction, Determination, and Electrophoresis

Extraction of unreduced protein was made from 60 mg of flour at room temperature vortexing for 8 hr in Eppendorf tubes with 1 mL of SDS phosphate buffer containing 0.05 m*M* phosphate, pH 6.8, 2% SDS (w/v), and 10% (v/v) glycerol (Zhu and Khan 1999). The supernatants obtained were determined for protein content by micro-Kjeldahl method (Nkonge and Balance 1982). This extract was regarded as the SDS-soluble fraction that contained all protein classes, including SDS-soluble glutenins. The total amount of SDS-soluble proteins (supernatant) extracted from 60 mg of flour was obtained by multiplying the total volume of the supernatant by the protein content of supernatant. This value was divided by the weight of flour (60 mg) to obtain % SDS-soluble proteins in flour. The amount of protein in residue (SDS-insoluble glutenins) was the difference between total flour proteins and SDS-soluble proteins. Total flour protein content was determined by near-infrared reflectance spectrometry (NIR) (Approved Method 39-11, AACC 2000).

SDS-soluble proteins (unreduced) were separated by multistacking SDS-PAGE (Khan and Huckle 1992) and the different origins (4–14%) were subsequently quantified (Zhu and Khan 1999). To determine total SDS-soluble glutenins in the SDS-soluble fraction, all the origins (4–14%) were quantified by densitometry. In this work, SDS-soluble glutenin aggregates from 12 and 14% origins were combined and regarded as the lowest molecular weight of the polymeric glutenin species. Monomeric proteins were measured and quantified according to Zhu and Khan (1999). The % SDS-soluble glutenins in flour was determined by multiplying the value of SDS-soluble glutenins from densitometry by % SDS-soluble proteins in flour as determined by the micro-Kjeldahl method. The ratio of SDS-soluble to SDS-insoluble glutenins in flour was also obtained.

Statistical Analyses

Variance analyses (ANOVA) and Pearson correlations were made using Minitab software. Both genotype and environment were treated as fixed effects because both factors were chosen selectively from the respective sources. Ratios of different variance components were determined using expected mean squares to compare the relative contributions of main effects and interactions according to Peterson et al (1986, 1992). Genotypes and environments were compared using least significant differences (LSD) at $P = 0.05$.

TABLE I
Genotype Means Over Seven Locations for Different Sized Aggregates of Glutenin Polymer at Various Origins of Multistacking SDS-PAGE and Dough Mixing Properties

Genotype	Flour Protein Content (%)	MT[a]	PH[b]	Insoluble Glutenins in Flour (%)[c]	Soluble Glutenins in Flour (%)[c]	Soluble Glutenins in Soluble Proteins (%)[c]	Ratio of Soluble to Insoluble Glutenins in Flour	Densitometry of MS-SDS-PAGE Soluble Glutenins (Unreduced) at Various Origins				
								4%	6%	8%	10%	12% + 14%
Hamer	14.2	3.8	7.3	1.60	1.82	14.3	1.37	10.5	10.4	15.5	21.2	42.5
Sharp	14.4	2.7	7.4	1.28	2.03	15.4	2.66	10.4	11.0	16.1	21.4	41.1
Russ	14.2	3.5	7.7	1.33	2.02	15.6	2.02	10.6	10.7	15.6	21.7	41.7
ND705	15.6	3.4	7.9	1.95	1.95	14.3	1.33	11.0	10.6	14.6	21.5	42.3
Forge	13.8	3.3	7.1	1.62	2.01	16.1	1.88	10.2	11.1	16.3	22.1	40.3
ND706	14.8	4.1	7.5	1.49	1.82	13.7	1.61	10.2	8.7	13.6	20.6	46.8
LSD[d]	0.91	0.64	0.58	1.18	0.41	2.69	0.23	1.24	1.65	2.08	2.52	5.35

[a] Mixograph dough development time.
[b] Peak height from mixograph.
[c] See Materials and Methods.
[d] Least significant difference ($P < 0.05$).

TABLE II
Environmental Means of Six Cultivars for Different Sized Aggregates of Glutenin Polymer at Various Origins of Multistacking SDS-PAGE and Dough Mixing Properties

Location	Flour Protein Content (%)	MT[a]	PH[b]	Insoluble Glutenins in Flour (%)[c]	Soluble Glutenins in Flour (%)[c]	Soluble Glutenins in Soluble Proteins (%)[c]	Ratio of Soluble to Insoluble Glutenins in Flour	Densitometry of MS-SDS-PAGE Soluble Glutenins (Unreduced) at Various Origins				
								4%	6%	8%	10%	12% + 14%
Langdon	13.8	3.2	7.7	1.86	2.13	17.7	1.18	11.3	12.0	15.6	22.6	38.6
Williston	14.6	4.0	7.4	1.77	2.23	17.1	1.57	10.0	11.2	17.6	22.3	38.9
Casselton	14.7	3.5	7.3	0.97	2.34	17.0	3.12	10.7	12.3	15.0	23.1	39.3
Hettinger	15.0	2.9	7.6	1.67	1.96	14.7	1.63	11.5	10.8	16.1	20.8	40.8
Dickinson	13.4	3.8	7.0	0.66	1.80	13.9	2.90	10.9	13.0	18.1	23.7	34.3
Carrington	14.4	3.8	7.4	1.12	2.08	15.3	1.91	8.9	8.0	13.5	19.0	50.6
Minot	15.6	3.1	7.9	2.77	1.06	8.3	0.39	10.2	5.8	11.1	18.4	54.5
LSD[d]	0.84	0.60	0.54	0.81	0.37	2.49	0.21	1.15	1.53	1.92	2.32	4.95

[a] Mixograph dough development time.
[b] Peak height from mixograph.
[c] See Materials and Methods.
[d] Least significant difference ($P < 0.05$).

RESULTS AND DISCUSSION

Effect of Genotype and Environment on Protein and Dough Properties

ANOVA indicated that genotype, environment, and genotype-by-environment interaction (G × E) all had significant effects on protein parameters and dough mixing properties. All the measurements showed a wide range of variation by genotypes and environments (Tables I and II). Among the genotypes studied, ND705 had the highest mixograph peak height (PH) and was significantly different from Forge and Hamer (Table I). ND705 showed the highest flour protein content and differed significantly from Forge, Russ, Hamer, and Sharp. There were significant differences in mixograph dough development time (MT) between genotypes. For instance, ND706 appeared to have the longest MT and showed significant differences from Sharp, Forge, and ND705. Also, Hamer and ND706 had the fewest SDS-soluble glutenin polymers but had no significant difference from other genotypes (Table I). There was no significant difference in SDS-insoluble glutenins in flour between the genotypes (Table I), indicating that the quantity of SDS-soluble and SDS-insoluble glutenins was not a significant factor in determining the difference among these genotypes. However, the ratio of SDS-soluble to SDS-insoluble glutenins showed a significant difference among these genotypes, suggesting that the relative quantity of these two different-sized polymers was important in determining the difference in these genotypes.

Differences were found among locations for protein and quality measurements. In contrast to the differences among genotypes, greater differences were observed for variations among locations for all protein parameters including glutenin polymers. Both SDS-soluble and SDS-insoluble glutenin polymers showed significant differences among the locations (Table II). Minot had the lowest ratio of SDS-soluble to SDS-insoluble glutenins, % SDS-soluble glutenins in SDS-soluble proteins, and % SDS-soluble glutenins in flour and was significantly different from all other locations. Furthermore, Minot had the highest % SDS-insoluble glutenin polymers and showed significant differences from other locations like Langdon, Williston, Casselton, and Dickinson.

Flour protein content differed significantly among the locations. At Minot, flour protein content showed the highest value and differed significantly from values at Dickinson, Langdon, Williston, Casselton, and Carrington. For dough mixing properties, Minot had the highest mixograph PH (Table II) and showed significant differences from other locations such as Dickinson and Casselton. MT also showed significant differences among the locations; Williston had the highest value, followed by Dickinson and Carrington. These three locations were significantly different from Hettinger, Minot, and Langdon.

Genotype and environment also affected the size distribution of glutenin polymers in SDS-soluble glutenins (Tables I and II). Significant differences existed among genotypes. For instance, ND706 had the lowest value at 6% origin and was significantly different from other genotypes (Table I). At 8% origin, ND706 differed significantly from Sharp and Forge. Also, ND706 had the highest value at 12 and 14% origins and was significantly different from Forge and Sharp (Table I). However, at 4 and 10% origins, there was no significant difference for the proportions of glutenin polymers.

Among the locations, much greater variations were found for the size distribution of SDS-soluble glutenin polymers. All the origins showed significant differences in their respective proportions of soluble glutenin polymers (Table II). At 4% origin, Carrington

TABLE III
Ratios of Environment to Genotype, and Genotype to Genotype by Environment Interaction Variances for Dough Mixing Properties and Protein Parameters[a]

Measurements	Environment/ Genotype	Genotype/ (Genotype × Environment)
Mixing dough development time (MT)	0.79	2.05
Peak height (PH)	0.85	0.83
Band height at 8 min after mixing (BHt8)	1.49	0.78
Band width at 8 min after mixing (BWt8)	0.52	0.71
Weakening slope (WS)[b]	1.22	0.61
Band width at peak time (BWP)	1.73	0.34
Band height at 2 min after peak time (BHt2)	1.31	0.91
Band width at 2 min after peak time (BWt2)	0.65	0.77
Flour protein content (%)	1.22	1.81
Insoluble glutenin in flour (%)	8.65	1.79
Soluble glutenin in flour (%)	19.20	0.08
Soluble glutenin in soluble proteins (%)	12.04	0.49
Ratio of soluble/insoluble glutenins in flour	3.63	0.24
Soluble glutenins at the various origins by densitometry of MS-SDS-PAGE		
4%	5.57	0.32
6%	11.18	0.69
8%	7.87	0.57
10%	13.12	0.18
12%	13.13	0.56

[a] Ratios calculated according to Peterson et al (1986, 1992).
[b] Difference between peak height and band height at 8 min after mixing.

TABLE IV
Correlation Coefficients Between Protein Parameters and Dough Mixing Properties[a]

Properties[b]	Flour Protein Content (%)	Insoluble Glutenins in Flour(%)[c]	Soluble Glutenins in Flour (%)[c]	Soluble Glutenins in Soluble Proteins (%)[c]	Ratio of Soluble to Insoluble Glutenins in Flour	Densitometry of MS-SDS-PAGE Soluble Glutenins (Unreduced) at Various Origins				
						4%	6%	8%	10%	12% + 14%
MT	–0.22	0.24	–0.07	0.10	–0.06	–0.26	–0.04	0.05	0.15	0.01
PH	0.68**	0.57**	–0.18	–0.27	–0.39**	0.19	–0.23	–0.37*	–0.41**	0.31*
BHt8	0.64**	0.54**	–0.33*	–0.41**	–0.45**	0.22	–0.28	–0.44**	–0.37*	0.34*
BWt8	0.08	0.21	–0.11	–0.04	–0.14	–0.13	–0.10	–0.04	–0.11	0.12
WS	0.31*	0.24	0.15	0.13	–0.07	0.05	0.01	–0.05	–0.20	0.07
BWP	0.36*	0.30*	–0.16	–0.19	–0.23	0.16	–0.08	–0.22	–0.13	0.11
BHt2	0.64**	0.48**	–0.21	–0.31*	–0.36*	0.25	–0.20	–0.40**	–0.42**	0.31*
BWt2	0.1	0.17	–0.03	0.04	–0.07	–0.05	–0.04	–0.12	–0.13	0.12
Flour protein (%)		0.85**	–0.39**	–0.47**	–0.72**	0.12	–0.45**	–0.60**	–0.53**	0.53**
Monomeric proteins (%)	0.53**	–0.40**	0.18	–0.53**	0.38*	–0.02	–0.18	–0.32*	–0.20	0.24
Loaf volume	0.85**	0.51**	–0.50**	–0.53**	–0.37*	–0.01	–0.53**	–0.69**	–0.47**	0.58**

[a] *, ** = significant at 0.05 and 0.01 levels, respectively.
[b] MT, mixing dough development time; PH, peak height of mixograph; BHt8, band height at 8 min after mixing; BWt8, band width at 8 min after mixing; WS, weakening slope, difference between peak height and band height at 8 min after mixing; BWP, band width at peak time; BHt2, band height at 2 min after peak time; BWt2, band width at 2 min after peak time.
[c] See Materials and Methods.

had the lowest value and differed significantly from Hettinger, Langdon, Dickinson, and Casselton. Minot had the lowest value at 6, 8, and 10% origins and differed significantly from all other locations at 6 and 8% origins. At 10% origin, Minot showed significant differences from other locations except Carrington. At 12 and 14% origins, Dickinson had the lowest value, while Minot had the most SDS-soluble glutenin. Dickinson differed significantly from all other locations except Langdon and Williston. The highest proportion of SDS-soluble glutenins at 12 and 14% origins might be associated with the fact that Minot, of all locations, had the highest flour protein content. A higher content of SDS-soluble glutenins of the lowest molecular weight glutenin species from 12 and 14% origins may be a reflection of a higher content of relatively smaller glutenin polymers.

Relative Influences of Genotype and Environment on Protein and Dough Properties

The relative influences of genotype and environment on protein parameters and dough mixing properties were examined according to Peterson (1986). The ratios for environment to genetic variances, and genetic to G × E interaction variances are given in Tables III and IV, respectively. A ratio of >1.0 indicates a greater influence by the component of environment over genetic factors or genetic over G × E interaction. Differences were found in relative influences of genotype and environment for different measurements. For example, a greater environmental over genetic effect was found for flour protein content (Table IV), indicating that flour protein content was more greatly influenced by environmental factors. This observation is in agreement with previous studies (Peterson et al 1986). Also, a stronger genetic influence was found for the variability of flour protein content associated with G × E interaction. A greater environmental influence than genetic factors also was found for the measurements of band height at 8 min after mixing (BHt8), weakening slope (WS), bandwidth at peak time (BWP), and band height at 2 min after peak time (BHt2) (Table III). All genetic components showed a smaller influence than the variability of G × E interaction. In addition, ratios for MT, PH, band width at 8 minutes after mixing (BWt8), and band width at 2 min after peak time (BWt2) were <1.0, indicating that these measurements were more strongly influenced by genetic than environmental factors. The genetic variability of these measurements, except MT, also was less than the influence by G × E interaction (Table III).

Glutenin aggregates from multistacking SDS-PAGE of SDS-soluble glutenins showed differences in proportions for the relative influences of genetic versus environmental factors. Glutenin aggregates from different origins had a greater variation in proportions from environmental factors (Table III). Also, the variability of G × E interaction was relatively larger than genetic factors, indicating that the size distribution of SDS-soluble glutenin polymers was more significantly influenced by environmental factors. In addition, SDS-insoluble glutenins in flour, SDS-soluble glutenins in flour, SDS-soluble glutenins in soluble proteins, and ratio of SDS-soluble to SDS-insoluble glutenins, all were affected more by environmental factors. These protein parameters also showed a larger variation in G × E interaction except SDS-insoluble glutenins in flour.

Correlations Among Protein and Dough Mixing Properties

Flour protein content was significantly and positively correlated with dough mixing properties PH, WS, BWP, BHt8, and BHt2 (Table IV). SDS-soluble glutenins in flour had no significant correlation with dough mixing properties except BHt8. In contrast, SDS-insoluble glutenins had positive and significant correlations with PH, BHt8, and BWP, indicating that SDS-insoluble glutenin polymers were a more important determinant of dough mixing properties than SDS-soluble glutenin polymers. This is in agreement with the findings of Gupta et al (1993). However, in the present study, no significant correlation was found between SDS-insoluble glutenins and MT. This was different from the findings of Gupta et al (1993). The ratio of SDS-soluble to SDS-insoluble glutenins was significantly correlated with PH, BHt8, and BHt2.

Flour protein content was significantly and positively correlated with the monomeric protein content and SDS-insoluble glutenins in flour (Table IV), indicating that both monomeric proteins and SDS-insoluble glutenins increased with the increase of flour protein content. On the contrary, SDS-soluble glutenins were significantly and negatively correlated with flour protein content, indicating that SDS-soluble glutenins decreased as flour protein content increased. This might be due to formation of larger SDS-insoluble glutenins through chemical bonding of the smaller SDS-soluble glutenins. The SDS-soluble glutenin polymers were separated by multistacking SDS-PAGE into different glutenin aggregates, which showed different correlations with mixograph parameters. The glutenin aggregates at 12 and 14% origins from multistacking SDS-PAGE had positive and significant correlations with PH, BHt8, and BHt2, while aggregates at 8 and 10% origins showed negative correlations with these three parameters (Table IV). The rest of the correlations with mixing parameters were not significant.

Environmental Effects on Relationship Between Flour Protein Content, SDS-Insoluble Protein, and Baking Properties

Both flour protein content and the amount of SDS-insoluble glutenin polymers in flour were positively and significantly correlated with loaf volume (Table IV). However, SDS-soluble glutenins in flour showed a significant but negative correlation with loaf volume. These relationships might be changed due to different environmental influence. For example, ND705 showed different relationships between locations (Table V). No significant difference was found

TABLE V
Variation in Loaf Volume and Protein Measurements for Genotype ND 705 Between Locations

Location	Flour Protein Content (%)	Loaf Volume (cm^3)	SDS-Insoluble Glutenins in Flour (%)	Ratio of SDS-Soluble/Insoluble Glutenins in Flour
Minot	16.1a[a]	1,240a	3.39a	0.27b
Casselton	14.5b	1,130b	1.17b	2.15a
Carrington	14.7b	1,160a	1.29a	1.54a
Hettinger	15.9a	1,145a	0.69a	0.92b
Minot	16.1a	1,240a	3.38a	0.27b
Hettinger	15.9a	1,145b	0.69b	0.92a
LSD[b]	0.84	50	0.81	0.21

[a] Values followed by the same letter are not significantly different ($P < 0.05$) between two locations.
[b] Least significant difference ($P < 0.05$).

TABLE VI
Variation of Two Genotypes for Loaf Volume and Glutenin Components at a Location with Similar or Different Flour Protein Content

Location and Genotype	Flour Protein Content (%)	Loaf Volume (cm^3)	SDS Insoluble Glutenins in Flour (%)	Ratio of SDS Soluble/Insoluble Glutenins in Flour
Carrington				
ND 706	14.6a[a]	1,135a	1.29a	1.54b
Sharp	14.6a	1,025b	1.10a	2.01a
Langdon				
ND 706	12.8b	995a	1.52a	1.47b
Sharp	14.1a	1,000a	1.45a	1.41a
LSD[b]	0.91	50	1.18	0.23

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$) for one location.
[b] Least significant difference ($P < 0.05$).

in loaf volume of ND705 between Carrington and Hettinger even though there was significant difference in flour protein content and ratio of SDS-soluble to SDS-insoluble glutenins in flour. In contrast, significant differences existed in loaf volume, SDS-insoluble glutenins in flour, and ratio of SDS-soluble to SDS-insoluble glutenins in flour between Minot and Hettinger, even though flour protein content showed no significant difference.

Comparison between genotypes also showed different relationships between protein parameters and loaf volume at different locations (Table VI). ND706 at Carrington was significantly different from Sharp in loaf volume. Also, a significant difference was observed in ratio of SDS-soluble to SDS-insoluble glutenins in flour but no significant difference in flour protein content and % SDS-insoluble glutenins in flour. In contrast, no significant difference was found in loaf volume, % SDS-insoluble glutenins in flour, and ratio of SDS-soluble to SDS-insoluble glutenins in flour between these two genotypes at Langdon, even though their flour protein content showed a significant difference. Because SDS-insoluble glutenins were larger than SDS-soluble glutenins, it would seem that ratio of SDS-soluble to SDS-insoluble glutenins would reflect the size distribution between SDS-soluble and SDS-insoluble glutenin polymers. Therefore, both genetic and environmental variation was significant in influencing flour protein content, SDS-soluble, and SDS-insoluble glutenins in flour and their size distributions, and, hence, breadmaking quality.

DISCUSSION

Understanding the mechanisms responsible for differences in breadmaking quality due to different environments would be useful for improving breadmaking quality and maintaining consistency. Wheat proteins, especially glutenins and gliadins, have been extensively studied and were significantly associated with breadmaking quality (Pomeranz 1988; Shewry et al 1992; Gupta et al 1992). Results of the present study suggested that responses of different protein fractions differed when flour protein content increased. The present study showed that an increase in monomeric proteins was observed with increased flour protein content. This phenomenon agrees with previous studies (Graybosch et al 1993). In addition, it showed that SDS-soluble glutenin polymers, quantified from multistacking SDS-PAGE by densitometry, decreased while SDS-insoluble glutenin polymers increased as flour protein content increased (Table V). The relative decrease of SDS-soluble glutenins might be associated with utilization for formation of larger SDS-insoluble glutenins. Our earlier research on glutenin polymer composition in developing grains seems to support this conclusion (Zhu and Khan 1999). In the present study, the relative quantity of SDS-soluble and SDS-insoluble glutenin polymers significantly changed with both genotype and environment, indicating that both genotype and environment affected the formation of the larger SDS-insoluble glutenin polymers. Environmental factors might modify molecular sizes of glutenin polymers by influencing the rate of protein synthesis and incorporation of high and low molecular weight glutenin subunits in forming glutenin polymers. However, this hypothesis needs more research to be justified.

Correlation coefficients of SDS-soluble glutenin polymers with mixing properties differed in magnitude from those observed for SDS-insoluble glutenins (Table IV). SDS-insoluble glutenins had a stronger association with dough mixing properties, suggesting that larger glutenin polymers were more significant in determining dough-mixing properties. This finding is in agreement with that of Gupta et al (1993), in which SDS-insoluble glutenin polymers were more significantly correlated with dough strength, as measured with extensigraph, than SDS-soluble glutenin polymers.

Previous studies showed that high molecular weight glutenin compositions of HRS wheats had significant association with dough mixing properties and baking quality (Khan et al 1989; Huang and Khan 1997b). Our results indicate that size distribution between SDS-soluble and SDS-insoluble glutenin polymeric proteins were also an important factor in influencing dough mixing properties, in addition to HMW glutenin subunit compositions. Therefore, both the HMW glutenin subunit compositions and the size distribution of glutenin polymers were biochemical indicators for predicting dough properties and breadmaking quality. These findings might be helpful in explaining the differences in breadmaking quality for HRS wheats across different locations in this study because all the genotypes had HMW glutenin subunits 5+10. However, quantification of individual HMW glutenin subunits would be necessary to study the relationships with the size of glutenin polymers in relation to environmental factors and the influences on breadmaking quality. This is currently being pursued. In addition, low molecular weight glutenin subunits also need to be considered because they were also an important factor in determining the size of glutenin polymers (Southan and MacRitchie 1999).

Other studies also showed that SDS-soluble and SDS-insoluble glutenin polymers were significantly influenced by environmental factors (Graybosch et al 1995; Jia et al 1996). However, these findings are contradictory to the results of Gupta et al (1993) that found that the relative size distributions of polymeric proteins were independent of growth environment. Other research showed that high temperature could change the ratios of glutenins to gliadins (Blumenthal et al 1990b). It is more likely that growth environments could significantly influence the size distributions of glutenin polymers that form the basis for differences in breadmaking quality from different environments. More studies are needed to examine the relationships between size distributions of glutenin polymers between SDS-soluble and SDS-insoluble glutenins with different environmental factors such as temperature.

CONCLUSIONS

Changes of percentage of different protein fractions were asynchronous as total flour protein content increased under different environments. SDS-soluble glutenin polymers decreased in percentage while SDS-insoluble glutenin polymers increased with the increase of total flour protein content.

Environment had a significant effect on characteristics of glutenin polymers. The size distribution of SDS-soluble glutenin polymers, examined by multistacking SDS-PAGE, % SDS-soluble glutenins in flour, and the size distribution between SDS-soluble and SDS-insoluble glutenin polymers, all were influenced more by environmental than genetic factors. However, % SDS-insoluble glutenins in flour was controlled more by genetic than environmental factors. SDS-insoluble glutenin polymers were a better determinant of dough mixing properties than SDS-soluble glutenin polymers.

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