

# Soft Wheat Quality as Related to Protein Composition<sup>1</sup>

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## ABSTRACT

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Soft red and white winter wheats from the eastern United States, used primarily to produce cookies, cakes, and biscuits, have quality requirements very different from those of bread wheats. In general, soft wheats have been bred to have low protein content, and conventional wisdom has been that protein composition of soft wheat is relatively unimportant. To test this hypothesis, relationships between soft wheat protein composition and end-use functional quality characteristics were examined. Quantitative protein compositions of eight cultivars of soft wheats grown in a wide area of the eastern United States during seven years (53 samples total) were analyzed by size-exclusion HPLC. Results were statistically correlated with numerous chemical and physical characteristics and quality factors of these wheats, their flours, and of cookies baked from the flours.

For the entire sample set, wheats containing high molecular weight glutenin subunits 2+12 showed significantly different properties and cookie characteristics from those with subunits 5+10, but amounts of most individual fractions correlated poorly with quality descriptors. For individual soft wheat cultivars, however, amounts of many individual gliadin and glutenin subfractions correlated significantly with quality descriptors such as SDS sedimentation, mixograph absorption, peak mixing time, mixograph number, cookie diameter, and top grain. Protein contents as a function of genotype and environment also differed greatly among cultivars, as did ratios of gliadin to glutenin. These results clearly revealed that suitability of soft wheat cultivars for specific products can be rapidly determined by quantitative and qualitative analyses of protein composition.

Since HPLC became available, many studies have related composition, amount, and size of proteins of hard red winter and spring wheats to baking quality (Huebner and Bietz 1994). In one early study, reversed-phase HPLC also related a durum wheat gliadin fraction to pasta-making quality (Burnouf and Bietz 1984). Methods using size-exclusion HPLC have become especially valuable for indicating quality (Graybosch et al 1994, Huebner and Bietz 1994). One recent study showed amounts of hard red winter wheat  $\gamma$ -gliadins correlated almost perfectly with loaf volume (Huebner et al 1997). Such analyses are quick, accurate, and can be done on small flour samples. Because the composition and amount of proteins within individual cultivars also vary with environment, however, it is nearly impossible to predict breadmaking quality solely on the basis of cultivar. HPLC may identify potential problems during breadmaking by indicating flours unsuitable for specific uses.

Soft wheats have quality factors and end uses very different from those of hard wheats. Soft wheats typically have been bred to have low protein content. This has contributed to the general belief that, in soft wheats, protein composition is of little importance. There is much quality variation among soft wheats, however; some soft wheat cultivars can be used to produce breads as well as typical cookie and cake products. This suggests that proteins may, in fact, also be major contributors to soft wheat functionality and product quality.

In contrast to research on proteins of hard wheats, there have been relatively few studies of the relationship between soft wheat proteins and products. Methods developed for and applicable to hard wheats have provided some new information but have been of limited usefulness for indicating suitability of soft wheats for products as diverse as cookies, cakes, gravies, and breadings. We therefore developed and applied a procedure for detailed quan-

titative analysis of soft wheat flour proteins using HPLC. Protein compositions were statistically related to wheat and flour functional properties and to product quality. Results show that rapid quantitative protein compositional analysis by HPLC can identify and select soft wheats with optimal properties for specific end uses.

## MATERIALS AND METHODS

### Samples

Flour samples were from the Soft Wheat Quality Laboratory (SWQL), Wooster, OH. Cultivars used were six soft red winter wheats (Argee, Becker, Caldwell, Cardinal, Pioneer 2555, and Tyler) and two soft white winter wheats (Augusta and Frankenthuth) grown during a seven-year period over a wide area of the eastern United States. These cultivars were chosen because of their known variation in biochemical, milling, and baking properties, as well as variation in protein content and other physical characteristics. Fifty-nine wheats and their flours had been subjected to 27 biochemical, milling, compositional, and cookie baking tests at the SWQL (Finney and Bains, *in press*). In the present study, 53 of these wheat samples were used.

### Protein Extraction

Flour samples (75 mg) were first extracted at 3–5°C with 1 mL of 0.05M NaCl for 20 min with vortexing to remove most albumins and globulins, including proteases. After centrifugation, this extract was discarded. Gliadins were then extracted at room temperature with 0.9 mL of 70% ethanol in 10-mL polypropylene tubes for 30 min with vortex mixing. After centrifugation at 15,000  $\times$  g for 10 min, the residue was reextracted with 0.6 mL of ethanol as above. After centrifugation, extracts were combined for HPLC analyses (Huebner and Bietz 1986). Glutenins were then extracted from the residue with 1 mL of 5M urea in 0.05M sodium phosphate buffer, pH 7.7, containing 0.1% dithiothreitol. After 2 hr of vortex mixing at 33°C, 5  $\mu$ L of 50% 4-vinylpyridine in 60% propanol were added to alkylate cysteine residues. After brief vortex mixing, samples were centrifuged at 17,000  $\times$  g for 10 min, and clear supernatants were transferred to autosampler vials. Approximately 1 hr after alkylation, sample pH was lowered to 3.1  $\pm$  0.2 by addition of 4–5  $\mu$ L of 60% trifluoroacetic acid in concentrated acetic acid.

### SE-HPLC

Gliadin and reduced-alkylated glutenin fractions were analyzed by SE-HPLC with an SP8700 solvent delivery system and an SP8780XR autosampler (Thermo Separations Products, San Jose, CA) using a 1-  $\times$  30-cm Superose-12 column (Pharmacia LKB Bio-

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technology, Inc., Piscataway, NJ) with an in-line 2- $\mu$ m Peek filter (A-429X, Upchurch Scientific, Oak Harbour, WA). The solvent system was modified slightly from that used previously (Huebner et al 1994, 1997) to prevent degradation of column material at low pH levels. For gliadins, the solvent used was 44% acetonitrile, 0.08% trifluoroacetic acid, 35 mM NaCl, adjusted to pH  $2.95 \pm 0.03$  with Tris. For glutenins, the solvent was 38% acetonitrile, 0.12% trifluoroacetic acid, 1M urea, 35 mM NaCl, adjusted to pH  $2.95 \pm 0.03$  with Tris. The flow rate was 0.55 mL/min, and column temperature was 34°C. Sample size was 10  $\mu$ L. Proteins were detected at 210 nm (0.2 AUFS/10 mV) with a Spectroflow-100 UV monitor (Thermo Separation Products, San Jose, CA).

### Data Analyses

SE-HPLC data, expressed as voltage output of the UV monitor, were displayed on an Omniscribe recorder (Houston Inst., Austin, TX) and stored in a personal computer providing system control and data analysis using PC1000 software (Thermo Separation Products, San Jose, CA). Areas of chromatographic peaks were determined by integration. Statistical relationships between peak areas and quality factors were determined (SAS Institute, Cary, NC).

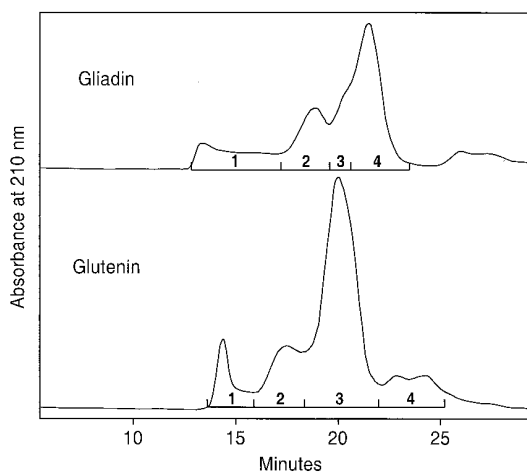
## RESULTS

Typical SE-HPLC separations of gliadins and reduced glutenins are shown in Fig. 1. Areas under peaks were correlated with wheat and flour test results from the USDA-ARS Soft Wheat Quality Laboratory (SWQL). For gliadin, fraction 1 consists mainly of small oligomers, soluble in 70% ethanol, composed of low molecular weight (LMW) glutenin subunits; fraction 2 consists primarily of  $\omega$ -gliadins; fraction 3 consists of  $\gamma$ -gliadins; and fraction 4 consists of  $\alpha$ - and  $\beta$ -gliadins. For glutenin, fraction 1 consists of highly aggregated LMW nonglutelin proteins (generally extracted with glutenins) (Huebner and Wall 1980); fraction 2 consists of high molecular weight (HMW) glutenin subunits; fraction 3 consists of LMW glutenin subunits; and fraction 4 consists of albumins and globulins (Huebner et al 1997).

Studies at the SWQL showed that three of the cultivars tested contained HMW glutenin subunits 5+10, and the other wheats contained subunits 2+12 (Lookhart et al 1993; Finney and Bains, *in press*). Two wheats with HMW subunits 2+12 were white wheats. A preliminary *t*-test showed no statistically significant differences ( $P > 0.10$ ) between white (Augusta and Frankenmuth) and red (Becker,

Cardinal, and Tyler) cultivars with subunits 2+12. Thus, data for these cultivars were combined for comparison to cultivars with HMW glutenin subunits 5+10.

For many tests performed on these wheat samples, and for amounts of protein fractions revealed by SE-HPLC, there were significant differences ( $P < 0.01$  by *t*-test) between wheats with HMW glutenin subunits 2+12 and those with 5+10 (Table I). Flour yield and endosperm separation index (ESI), which are related milling parameters, differ between the two sets of samples. Break flour and Agtron color may also relate to milling performance descriptors and show differences. Falling number, percentage of HMW subunits in gluten, Zeleny protein, hydration, mixing time, mixing height, and mixing number all relate to amount and type of protein and differ between the two wheat sets. In hard wheats, those measurements typically indicate breadmaking quality. Cookie diameter and top grain also differ between the two wheat sets. Quantitative protein compositions of wheats with HMW glutenin subunits 2+12 and those with subunits 5+10 differed significantly (Table I). Amounts



**Fig. 1.** Size-exclusion HPLC (Superose 12 column, 1  $\times$  30 cm) of gliadin and reduced glutenin fractions from a typical soft red winter wheat. Gliadin fractions correspond primarily to low molecular weight glutenin (1),  $\omega$ -gliadins (2),  $\gamma$ -gliadins (3), and  $\alpha$ - and  $\beta$ -gliadins (4) (plus a small amount of albumins and globulins). Glutenin fractions are unreduced or highly aggregated proteins (1), reduced high molecular weight subunits (2), reduced low molecular weight subunits (3), and albumins and globulins (4).

**TABLE I**  
Comparison of Wheat Samples with High Molecular Weight (HMW) Glutenin Subunits 2+12 and 5+10

	Cultivars with HMW Subunits 2+12 ( $n = 33$ )		Cultivars with HMW Subunits 5+10 ( $n = 20$ )	
	Mean <sup>a</sup>	SE <sup>b</sup>	Mean	SE
Flour yield (g/100 g)	76.6	0.14	77.6	0.24
Endosperm separation index (%)	10.2	0.15	9.2	0.28
Friability (g/100 g)	28.1	0.13	29.5	0.23
Break flour (g/100 g)	29.9	0.72	34.7	0.84
Agtron color (%)	67.4	1.38	60.9	1.69
Falling number (sec)	464	12.6	528	22.4
HMW subunits in gluten (g/100 g)	1.28	0.14	1.91	0.12
Zeleny sedimentation (cm <sup>3</sup> /g of protein)	72.9	1.97	81.7	2.86
Gluten hydration (%)	197	2.4	182	1.7
Mixograph mixing time (min)	2.46	0.15	4.68	0.23
Mixograph mixing height (cm)	4.16	0.11	3.63	0.16
Mixograph number <sup>c</sup>	93.8	5.72	151.4	9.38
Cookie diameter (cm)	17.4	0.06	17.8	0.10
Top grain (score)	4.56	0.16	5.48	0.15
Gli-1 (relative peak area)	90	3.2	74	4.1
Gli-3 (relative peak area)	86	2.0	106	6.9
Glu-1 (relative peak area)	82	2.2	70	1.8

<sup>a</sup> Some mean values differ slightly from those reported for the same sample set by Finney and Bains (*in press*) due to the different number of samples available and used for analysis.

<sup>b</sup> Standard error of the means.

<sup>c</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

of three protein fractions (Gli-1, Gli-3, and Glu-1) differ most between the two groups. Gli-3 is of special interest since, in hard red winter wheats, the amount of Gli-3 (also known as  $\gamma$ -gliadin) is directly related to loaf volume (Huebner et al 1997).

Correlations were also calculated for the entire 53-sample set between protein amounts and results of the 27 quality tests; Table II lists correlations for quality tests that may be useful indicators of soft wheat flour end use. (Data that primarily reflect total protein content or nonprotein factors, or show no significant correlations, are not shown). Similar data for individual wheat cultivars are presented in Tables III–VIII. Individual correlation data for the cultivars Becker and Pioneer 2555 were not included because only four samples of each were available. Data for these samples are, however, included in Tables I and II.

In many cases, total flour protein is highly correlated with amounts of individual protein fractions, so similar relationships of amounts

of various proteins to functional properties might be expected. Relative amounts of protein fractions vary with environment and during kernel development, however, so differences can and do occur. This is clearly evident from Table II, which shows much variation in correlations of individual protein fractions to total % protein, and from Fig. 2, which shows significant differences among cultivars in amount of total protein expressed under differing environmental conditions.

#### Correlations to Sedimentation Analyses

SDS and Zeleny sedimentation procedures were developed to test breadmaking quality of hard wheat flours rather than to estimate quality characters of soft wheats. Thus, it is not surprising that, for all flours tested, many correlations between amounts of protein fractions and SDS sedimentation values (Table II) are fairly low, except for some correlations with fractions Gli-4, Glu-2, Glu-3, and total glutenin.

TABLE II  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Soft Wheat Flours<sup>a</sup>

Fraction	% Protein	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.56	0.33	0.23	-0.51	-0.14	-0.31	-0.42
Gli-2	0.82	0.51	0.49	-0.44	0.10	-0.50	-0.60
Gli-3	0.40	0.13	0.38	-0.29	-0.52	-0.14	0.01
Gli-4	0.90	0.72	0.59	-0.40	0.23	-0.45	-0.52
Glu-1	0.55	0.31	0.32	-0.44	-0.11	-0.42	-0.51
Glu-2	0.74	0.56	0.57	-0.08	0.43	-0.11	-0.42
Glu-3	0.78	0.81	0.54	-0.13	0.43	-0.23	-0.62
Total Gli	0.92	0.64	0.62	-0.31	0.31	-0.47	-0.50
Total Glu	0.90	0.75	0.59	-0.32	0.30	-0.32	-0.62
Glu/Gli	0.58	-0.25	0.41	-0.18	0.20	-0.47	-0.20

<sup>a</sup> For  $n = 53$ , a correlation of 0.273 is significant ( $P < 0.05$ ) and correlations  $>0.354$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

TABLE III  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Argee Wheat Flour<sup>a</sup>

Fraction	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.76	0.63	-0.39	0.83	-0.28	-0.49
Gli-2	0.82	0.77	-0.46	0.84	-0.40	-0.65
Gli-3	0.71	0.68	-0.44	0.72	-0.43	-0.53
Gli-4	0.87	0.77	-0.49	0.81	-0.24	-0.54
Glu-1	0.84	0.97	-0.74	0.52	-0.50	-0.78
Glu-2	0.89	0.87	-0.69	0.70	-0.30	-0.58
Glu-3	0.90	0.91	-0.69	0.69	-0.35	-0.59
Total Gli	0.84	0.76	-0.48	0.81	-0.32	-0.57
Total Glu	0.89	0.87	-0.65	0.72	-0.35	-0.60
Glu/Gli	-0.45	-0.28	-0.06	-0.81	0.24	0.29

<sup>a</sup> For  $n = 8$ , a correlation of 0.707 is significant ( $P < 0.05$ ) and correlations  $>0.834$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

TABLE IV  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Caldwell Wheat Flour<sup>a</sup>

Fraction	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.90	0.49	0.10	0.64	-0.43	-0.20
Gli-2	0.80	0.44	0.49	0.89	-0.61	-0.47
Gli-3	0.75	0.80	0.62	0.89	-0.81	-0.57
Gli-4	0.93	0.28	0.21	0.75	-0.45	-0.25
Glu-1	0.00	0.10	0.24	0.02	-0.35	-0.60
Glu-2	0.56	0.52	0.58	0.90	-0.64	-0.54
Glu-3	0.74	0.51	0.58	0.86	-0.77	-0.67
Total Gli	0.91	0.43	0.36	0.84	-0.57	-0.37
Total Glu	0.78	0.55	0.52	0.86	-0.74	-0.65
Glu/Gli	-0.90	-0.20	-0.07	-0.62	0.25	0.05

<sup>a</sup> For  $n = 8$ , a correlation of 0.707 is significant ( $P < 0.05$ ) and correlations  $>0.834$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

The data in Table II represent four to eight samples each of several diverse genotypes. Such diversity must contribute to the low statistical correlations observed. For most individual cultivars, however, correlations between amounts of protein fractions and sedimentation values are quite high (Tables III–VIII). In hard wheats, sedimentation analyses generally relate to glutenin. For some soft wheat cultivars, however, correlation coefficients to gliadin fractions (especially Gli-4 and total gliadin) are also high (Tables IV and VIII). It is not yet known whether such sedimentation analyses might indicate cookie or cake-making potential. It is also interesting to note that some protein fractions have low or nonsignificant correlations with flour characteristics. These results suggest that analyses of all protein fractions during breeding could reveal relative contributions of genotype and environment to quality characteristics as well as end-use potential of individual cultivars.

### Correlations to Dough Mixing

The mixograph was designed to test wheat dough strength, a particularly important determinant of breadmaking quality. Its usefulness for testing soft wheat flours for other baked products is less clear. For cookies or cakes, little or no mixing is required for dough development. Rather, mixing primarily disperses ingredients evenly and promotes water absorption in batters. Mixing is important for dough development in cracker production, however.

For the entire set of soft wheat samples, mixograph absorption, peak mixing time, and mixograph number show some significant correlations with protein fractions (Table II). These correlations are, however, generally much lower than those for sedimentation results. Again, these relationships can differ significantly among soft wheat cultivars. Mixograph absorption is highly correlated with amounts of some protein fractions for Argee and Tyler (Tables III and VII) but not for other cultivars. Similarly, mixograph number is quite highly correlated with some protein fractions for Argee,

Caldwell, and Augusta but not for other cultivars or for the entire sample set (Table II). Correlations for peak mixing time are low and generally negative, although they are positive for Caldwell (Table IV). These observations suggest that protein compositional differences among soft wheat cultivars may strongly influence the properties of these wheats, and thus affect their suitability for various end uses.

### Correlations to Cookie Diameter and Top Grain

Cookie diameter is negatively, sometimes significantly, correlated with amounts of individual protein fractions for all combined cultivars (Table II). These correlations are especially high for Tyler (Table VII). Similarly, top grain is significantly (and negatively) correlated with amounts of many protein fractions for the total sample set (Table II), but few significant correlations are apparent for individual cultivars.

Such results might be expected because low-protein soft wheats generally produce the best cookies and cakes. Thus, low correlations of these product characteristics to amounts of protein fractions may indicate cultivars or flours most suitable for such products, especially for flours with higher protein content.

### Other Correlations

Other significant correlations between protein composition and soft wheat quality parameters are also noteworthy. Because the sample set analyzed is so diverse (several cultivars differing in end-use potential, grown in multiple locations over seven years), such findings may be especially important.

For falling number, correlations for all 53 samples are low and not significant. Two cultivars showed a significant correlation of falling number to Glu-1, however. Correlations for endosperm separation index were mostly negative and nonsignificant for the entire sample set, except for Gli-3 (–0.52). For friability, correlations

TABLE V  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Cardinal Wheat Flour<sup>a</sup>

Fraction	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.50	0.66	–0.52	0.02	–0.67	–0.56
Gli-2	0.74	0.38	–0.18	0.39	–0.65	–0.54
Gli-3	0.44	0.62	–0.38	0.12	–0.65	–0.69
Gli-4	0.75	0.58	–0.41	0.21	–0.67	–0.72
Glu-1	0.57	0.61	–0.08	0.30	–0.28	–0.25
Glu-2	0.77	0.56	0.28	0.74	–0.37	–0.72
Glu-3	0.95	0.74	0.22	0.76	–0.44	–0.87
Total Gli	0.75	0.56	–0.37	0.26	–0.70	–0.71
Total Glu	0.92	0.80	0.06	0.64	–0.54	–0.83
Glu/Gli	–0.33	–0.17	0.71	0.24	–0.63	–0.37

<sup>a</sup> For  $n = 8$ , a correlation of 0.707 is significant ( $P < 0.05$ ) and correlations  $>0.834$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

TABLE VI  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Frankenmuth Wheat Flour<sup>a</sup>

Fraction	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.83	0.78	–0.33	0.57	–0.41	–0.28
Gli-2	0.72	0.42	–0.64	0.31	–0.67	–0.32
Gli-3	0.81	0.59	–0.45	0.60	–0.61	–0.21
Gli-4	0.88	0.70	–0.52	0.50	–0.62	–0.41
Glu-1	0.44	0.06	–0.87	–0.16	–0.09	–0.23
Glu-2	0.78	0.42	–0.72	0.31	–0.60	–0.39
Glu-3	0.82	0.50	–0.66	0.39	–0.53	–0.44
Total Gli	0.85	0.62	–0.57	0.47	–0.65	–0.37
Total Glu	0.87	0.58	–0.69	0.41	–0.52	–0.41
Glu/Gli	–0.70	–0.59	0.34	–0.49	0.65	0.26

<sup>a</sup> For  $n = 7$ , a correlation of 0.754 is significant ( $P < 0.05$ ) and correlations  $>0.874$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

TABLE VII  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Tyler Wheat Flour<sup>a</sup>

Fraction	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.30	0.53	-0.64	-0.23	-0.60	-0.54
Gli-2	0.59	0.81	-0.49	0.14	-0.84	-0.65
Gli-3	0.69	0.66	-0.40	0.18	-0.61	-0.60
Gli-4	0.71	0.84	-0.39	0.26	-0.79	-0.59
Glu-1	0.56	0.75	-0.44	0.13	-0.76	-0.52
Glu-2	0.60	0.73	-0.48	0.16	-0.83	-0.72
Glu-3	0.87	0.86	-0.16	0.49	-0.67	-0.44
Total Gli	0.70	0.83	-0.43	0.23	-0.80	-0.62
Total Glu	0.74	0.84	-0.39	0.27	-0.78	-0.59
Glu/Gli	-0.69	-0.80	0.45	-0.21	0.73	0.67

<sup>a</sup> For  $n = 8$ , a correlation of 0.707 is significant ( $P < 0.05$ ) and correlations  $>0.834$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

TABLE VIII  
Correlations of Amounts of Gliadin (Gli) and Glutenin (Glu) Fractions to Quality Descriptors of Augusta Wheat Flour<sup>a</sup>

Fraction	SDS Sedimentation	Mixograph Absorption	Peak Mixing Time	Mixograph Number <sup>b</sup>	Cookie Diameter <sup>c</sup>	Top Grain <sup>c</sup>
Gli-1	0.72	0.63	-0.22	0.92	0.01	-0.62
Gli-2	0.74	0.74	-0.36	0.86	-0.31	-0.53
Gli-3	0.83	0.40	-0.30	0.85	0.12	-0.69
Gli-4	0.92	0.81	-0.42	0.93	-0.09	-0.40
Glu-1	0.10	-0.28	-0.41	0.16	-0.49	-0.89
Glu-2	0.89	0.58	-0.57	0.80	-0.10	-0.52
Glu-3	0.78	0.34	-0.52	0.65	-0.20	-0.63
Total Gli	0.90	0.76	-0.40	0.93	-0.12	-0.49
Total Glu	0.78	0.39	-0.53	0.73	-0.20	-0.70
Glu/Gli	-0.75	-0.94	0.11	-0.86	0.01	0.10

<sup>a</sup> For  $n = 6$ , a correlation of 0.811 is significant ( $P < 0.05$ ) and correlations  $>0.917$  are highly significant ( $P < 0.01$ ).

<sup>b</sup> Protein (g/100 g)  $\times$  peak height (cm)  $\times$  peak time (min).

<sup>c</sup> Determined by Approved Method 10-52 (AACC 1995).

for all 53 samples are -0.46 for Gli-1 and 0.38 for Gli-3. For the cultivar Augusta, correlations with friability are -0.86 for Gli-4 and 0.98 for the glutenin-to-gliadin (Glu/Gli) ratio. For Frankenthuth, friability was significantly correlated with Glu-3 (-0.87).

Flour yield for all samples is correlated with Gli-3 (0.58) and Glu-2 (0.38). Alkaline water retention capacity (AWRC) for all samples correlated significantly with Gli-4 (-0.47), total gliadin (-0.46), and total glutenin (-0.51). For Argee, significant correlations are found between AWRC and Gli-4 (0.85), Glu-2 (-0.88), Glu-3 (-0.89), total gliadin (-0.82), and total glutenin (-0.87). For Caldwell, AWRC is significantly correlated (0.83) with the Glu/Gli ratio.

Thus, many diverse relationships exist between soft wheat protein composition and functional properties. Such relationships vary considerably among cultivars, demonstrating that soft wheat cultivars have very different end-use potentials and suggesting that protein compositional analysis can be valuable for breeding and selecting soft wheats for specific applications.

#### Correlations with Protein Content and Glu/Gli Ratio

Soft wheats vary considerably in protein content within cultivars (e.g., 7.2–10.8% [mean 8.97%] for Tyler and 8.1–11.4% [mean 9.04%] for Argee), as well as among cultivars (Fig. 2). Samples with high protein content typically have lower Glu/Gli ratios ( $r = -0.56$ ), which may compensate for the negative effects often associated with high protein content in soft wheats.

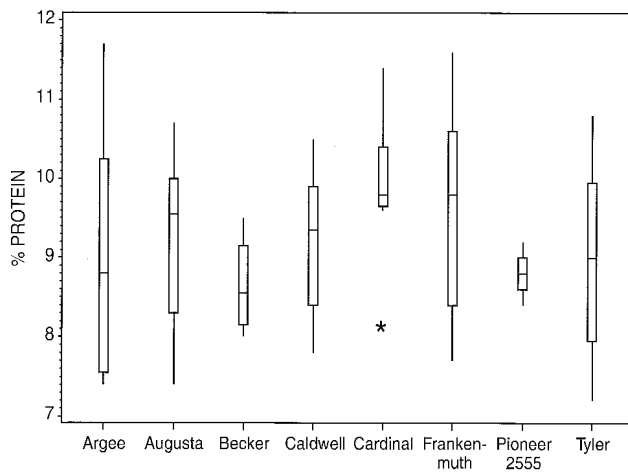
Our data also show that soft wheat cultivars differ considerably in how their protein contents vary with environmental or agronomic factors (Fig. 2). Some cultivars such as Argee, Frankenthuth, and Tyler vary widely in protein content. Diverse samples of other cultivars such as Pioneer 2555 have very similar protein contents. Nevertheless, cultivars such as Argee, Caldwell and Pioneer 2555 consistently produce good cookies and cakes, even though some of these cultivars may vary considerably in protein content (Fig. 2).

Protein composition, reflected by the presence of HMW glutenin subunits 5+10, may thus be of greater significance than protein content. Similarly, quality characteristics of some hard wheats are little affected by environment, even though protein content varies (Huebner et al 1994). Thus, for soft wheats, quantitative analyses of protein composition, rather than protein content alone (which often varies with year or location), may best indicate quality. Such analyses may reveal effects of both genotype and environment, revealing cultivars most consistent and suitable for specific products.

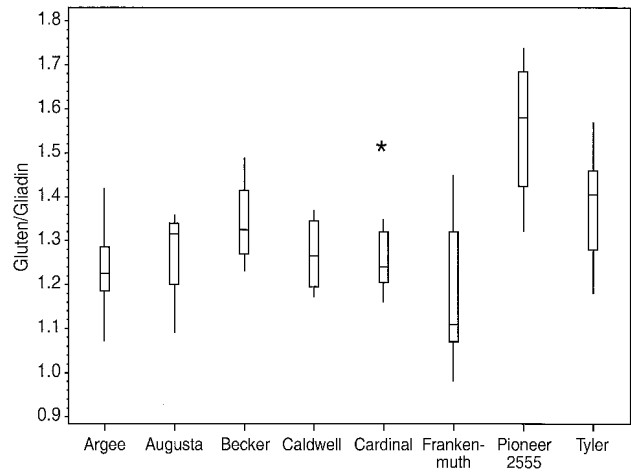
Glu/Gli ratios also vary considerably within and among soft wheat cultivars (Fig. 3), supporting a relationship between protein composition and end-use potential. For example, Frankenthuth had Glu/Gli ratios ranging from 0.98 to  $>1.4$  (mean 1.19). Pioneer 2555 samples have Glu/Gli ratios of 1.3–1.7 (mean 1.55), higher than that of other cultivars, but total protein content of Pioneer 2555 is consistently low, as desired for most soft wheat products. For most individual soft wheat cultivars, however, Glu/Gli ratios are not significantly correlated with most quality characteristics (Tables II–VIII).

## DISCUSSION

Determinants of soft wheat quality are numerous and complex. Thus, while our data cannot fully explain why certain cultivars are better for specific products, they do emphasize the value of protein compositional analyses for partial prediction and explanation of end-use potential. Several significant relationships of protein composition to quality descriptors of soft wheats and their flours exist. Also, results for soft white wheats (Augusta and Frankenthuth) in this study do not appear to differ from those for soft red wheats. Thus, based on those relationships, rapid methods capable of analyzing small flour samples can estimate quality and optimize end-use for soft wheat types. Such tests could be especially val-



**Fig. 2.** Box and whisker graph of % protein in wheat cultivars. For each cultivar, the box represents 50% of the observations and the horizontal line is the median (i.e., 50% of cultivars fall above and below that line). Vertical lines (whiskers) show the range of data (except for an outlier represented as ★ for Cardinal).



**Fig. 3.** Box and whisker graph of the ratio of glutenin to gliadin in wheat cultivars. Box represents 50% of the observations and the horizontal line is the median (i.e., 50% of cultivars fall above and below that line). Vertical lines (whiskers) show the range of data (except for an outlier represented as ★ for Cardinal).

uable during breeding to indicate suitability of new cultivars for specific products.

For all 53 samples combined, most correlations were not high between protein fractions and other parameters (Table II). That might have been expected when considering the intended heterogeneity of this sample set. Also, because proteins per se may have some effect on final product characteristics, it is not surprising when amounts of specific fractions do not correlate highly with specific quality descriptors. However, the fact that wheats containing subunits 5+10 produce better cookies indicates, as in bread wheats, the importance of glutenin subunits. Their contribution to formation of optimal glutenin and gluten polymers strongly affects soft wheat product characteristics. That is apparent from the data in Table I which show significant differences between 5+10 and 2+12 wheats for hydration, mix-time, and mix-number, even though total amounts of gliadins and glutenins, as well as Glu/Gli ratios, did not differ significantly between those sets of wheat. In soft wheats, as in bread wheats, amounts and types of HMW subunits determine glutenin size and shape, influencing gluten polymeric structure and interactions with other system components. HMW subunits 5+10 clearly show polymeric glutenin structures different from those formed from subunits 2+12. Such structural differences induce differences in the physical structure, continuity, interactions, and strength of the endosperm protein matrix, affecting kernel hardness and, ultimately, class and end-use (Stenvert and Kingswood 1977).

Thus, it is probable that the relationships we identified, as well as other relationships of protein composition to functional or physical characteristics, can be useful for selection and quality improvement during soft wheat breeding, and can help optimize utilization of soft wheats and flours in various products. Additional studies that relate protein distributions of soft wheat samples to specific products are needed to help clarify and identify those relationships.

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