Relationships of Quantity of Glutenin Subunits of Selected U.S. Soft Wheat Flours to Rheological and Baking Properties

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Cereal Chem. 73(3):358-363

ABSTRACT

The high molecular weight glutenin subunits (HMW-GS) and low molecular weight (LMW) glutenin subunit groups (B and C subunits) in 17 soft wheat patent flours (four wheat classes) and seven straight-grade flours were identified and quantified by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) coupled with densitometry using a known quantity of glutenins as a quantitative standard. Flour rheological properties were evaluated and Japanese-type sponge cakes (JSC) and sugar-snap cookies (SSC) were made to evaluate the flours' baking performances. The quantity of B subunits and the ratio of the quantities of B subunits to C subunits were statistically significantly different among four classes of soft wheat patent flours. Patent flours containing subunit 1 showed significantly smaller alveograph *P* and *P/L* values and farinograph water absorption values, and larger alveograph *L* values, larger JSC volumes and bigger SSC diameters than patent flours containing subunit 2*. The quantities of subunits 2*, 6, 8, and 9 were each correlated with some flour rheological and baking properties. The quantity of A subunits had a significantly negative correlation with JSC volume in club wheat patent flours and the quantity of B subunits was strongly associated with larger JSC volume per unit flour protein in western soft white winter (WSWW) wheat flours. The ratio of the quantities of B subunits to C subunits in flour protein may be an important parameter in relation to the SSC diameter for WSWW wheat flours and to the SSC diameter per unit flour protein for club wheat flours. The quantity of total LMW-GS correlated negatively with JSC volume per unit flour protein for eastern soft white winter (ESWW) wheat flours, and the total glutenin subunits associated negatively with SSC diameter per unit flour protein for ESWW wheat flours and with JSC volume for club wheat flours.

Glutenin proteins are very large polymeric molecules consisting of high molecular weight (HMW) and low molecular weight (LMW) glutenin subunits (GS) linked through intra- and inter-disulfide bonds. The relative size distribution of glutenin proteins is most likely responsible for all the individual and combined effects of different glutenin subunits on dough strength (Gupta and MacRitchie 1994). The variation in the amounts and size distribution of the glutenin polymers is caused by the quantity, type, or both, of the subunits produced during protein synthesis (Gupta et al 1993, Gupta and MacRitchie 1994). Accordingly, both the type and the quantity of individual glutenin subunits are important to dough properties and flour end-use qualities (Branlard and Dardevet 1985, Payne et al 1987, Ng and Bushuk 1988, Marchylo et al 1989, Sutton 1991, Gupta and MacRitchie 1994). One of the most widely used scoring systems for evaluating a flour's bread-making potential, the *Glu-1* quality score was proposed by Payne et al (1987) based on the composition of HMW-GS in flour. This scoring system was derived from the SDS-sedimentation volumes of 250 wheat cultivars, and scores can range from a minimum of 4 to a maximum of 10 for any of the common wheat cultivars.

Previous research has shown that for soft wheat flour, gluten proteins as a whole affect the quality of sugar-snap cookies (Gaines and Finney 1989, Kulp and Olewnik 1989, Gaines 1990, Kaldy et al 1993, Souza et al 1994). Soft wheat products generally require flour with low protein content and weak gluten strength (Bettge et al 1989, Souza et al 1994).

The effects of HMW-GS on soft wheat baking quality have been reported. The *Glu-1* quality score was negatively correlated with British biscuit-making quality (Payne et al 1987), however, the individual HMW-GS (except subunit pair 13+19) and their quality scores did not correlate with sugar-snap cookie-baking quality (Souza et al 1994, Lookhart et al 1993). It is likely that high flour protein content masks the effects of individual HMW-GS on baking quality. The influences of glutenin subunits on cookie-baking quality are more apparent when combined effects of HMW-GS are considered (Souza et al 1994). This combined effect, expressed as a glutenin rank sum (GRS) was calculated according to a modified scoring system of Payne et al (1987). The results showed the GRS was negatively correlated with sugar-snap cookie diameter. However, this correlation was greatest in the year with the lowest average flour protein content and least in the year with the highest average protein content (Souza et al 1994).

There is little information available regarding the contributions of the quantities of HMW-GS and LMW-GS to soft wheat end-use qualities. The quantity of glutenin subunits determines partially the relative size distribution of the glutenin proteins, which reportedly could alone account for all the allelic differences in dough strength (Gupta and MacRitchie 1994). Quantification of glutenin subunits in soft wheats would allow us to better understand their functionality, if any, in baking quality.

The objectives of the present study were: 1) to quantify the individual HMW-GS and glutenin subunit groups (A, B, and C subunits) defined by Payne and Corfield (1979) in 17 soft wheat patent flours from four wheat classes by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) coupled with densitometry using a known quantity of glutenins as a quantitative standard; and 2) to relate the presence or absence of certain HMW-GS and the quantities of glutenin subunits to dough rheological and baking properties.

MATERIALS AND METHODS

Wheat Samples

Samples used in this study were the same as described in our companion paper (Hou et al 1996).

Chemicals and Reagents

Chemicals and reagents were the same as described by Hou and Ng (1995).

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Publication no. C-1996-0408-05R.

Identification of HMW-GS

Total proteins were extracted from flour according to Ng and Bushuk (1987). SDS-PAGE was conducted in gels 1.5-mm thick (18-cm wide, 16-cm long) according to Ng and Bushuk (1987) on a vertical electrophoresis unit (Hoefer Scientific Instruments, San Francisco, CA). The nomenclature of HMW-GS was based on the method of Payne and Lawrence (1983).

Preparation and Quantification of Extractable GS

Preparation and quantitative determination of individual HMW-GS or glutenin subunit groups (A, B, and C subunits) were performed according to the procedures described by Hou and Ng (1995). A subunits are HMW-GS; and B and C subunits are two groups of LMW-GS.

Soft Wheat Flour Quality Evaluation

Data of flour protein content determinations, alveograph, farinograph, and mixograph tests, Japanese-type sponge cakes (JSC) and micro sugar-snap cookies (SSC) of 17 patent flour samples were obtained from an earlier study (Yamamoto et al 1996). Data of flour protein content determinations, mixograph and micro SSC baking tests of the seven straight-grade flours were from Hou et al (1996).

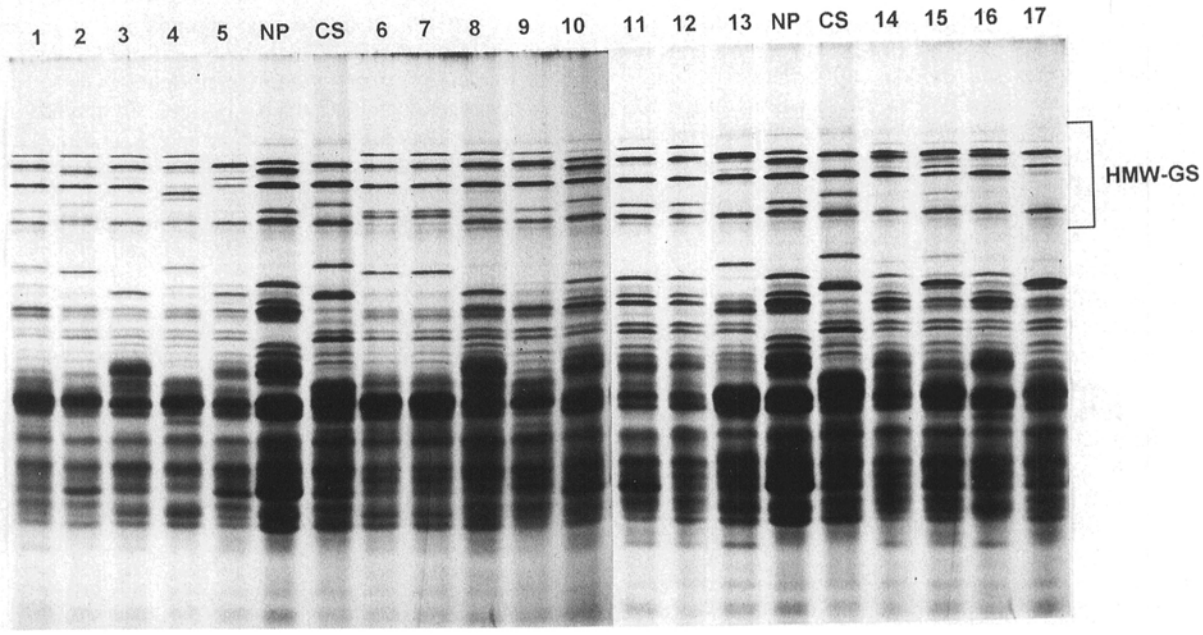

Fig. 1. Sodium dodecyl sulfate polyacrylamide gel electrophoretic patterns of high molecular weight glutenin subunits (HMW-GS). Wheat cultivars are: Augusta (lane 1), Caldwell (lane 2), Chelsea (lane 3), Clark (lane 4), Crew (lane 5), Dynasty (lane 6), Excel (lane 7), Frankenmuth (lane 8), Freedom (lane 9), Hyak (lane 10), Kmor (lane 11), Lewjain (lane 12), Madsen (lane 13), Malcolm (lane 14), Rely (lane 15), Stephens (lane 16), and Tres (lane 17). NP = Neepawa (a Canadian cultivar used as a marker for HMW-GS). CS = Chinese Spring (a marker for HMW-GS).

TABLE I
Measured Quantities[a] of High Molecular Weight Glutenin Subunits[b] in 17 Soft Wheat Patent Flours

Cultivar[c]	*Glu-A1*	*Glu-B1*	*Glu-D1*
ESWW			
Augusta	1 (0.82 ± 0.06)	7 (1.83 ± 0.12); 9 (0.71 ± 0.01)	2 (1.51 ± 0.09); 12 (1.29 ± 0.06)
Chelsea	1 (0.94 ± 0.01)	7 (1.83 ± 0.05); 8 (0.67 ± 0.01)	2 (1.51 ± 0.04); 12 (1.33 ± 0.05)
Frankenmuth	1 (1.06 ± 0.14)	7 (1.83 ± 0.09); 9 (1.01 ± 0.13)	2 (1.67 ± 0.07); 12 (1.28 ± 0.14)
WSWW			
Kmor	1 (1.10 ± 0.01)	7 (2.86 ± 0.05); 9 (1.63 ± 0.02)	2 (2.40 ± 0.11); 12 (2.04 ± 0.17)
Lewjain	1 (1.21 ± 0.05)	7 (2.38 ± 0.17); 9 (1.18 ± 0.07)	2 (2.02 ± 0.14); 12 (1.43 ± 0.09)
Madsen	2* (0.99 ± 0.00)	7 (2.16 ± 0.11)	2 (1.32 ± 0.11); 12 (1.28 ± 0.08)
Malcolm	2* (0.86 ± 0.08)	7 (2.01 ± 0.07)	2 (1.43 ± 0.09); 12 (1.18 ± 0.11)
Stephens	2* (0.73 ± 0.09)	7 (1.84 ± 0.20)	2 (1.19 ± 0.14); 12 (0.95 ± 0.12)
Club			
Crew	2* (0.77 ± 0.00)	6 (1.32 ± 0.00); 7 (1.01 ± 0.09)	2 (1.47 ± 0.08); 12 (1.38 ± 0.16)
Hyak	2* (0.96 ± 0.01)	7 (2.10 ± 0.06); 8 (0.69 ± 0.04)	5 (1.71 ± 0.12); 10 (1.49 ± 0.01)
Rely[d]	2* (0.79 ± 0.04)	6 (2.05 ± 0.00); 7 (1.20 ±0.04); 8 (0.47 ± 0.05)	2 (1.10 ± 0.05); 12 (1.45 ± 0.06)
Tres	null	6 (0.76 ± 0.10)	2 (1.61 ± 0.18); 12 (1.17 ± 0.15)
SRW			
Caldwell	1 (1.12 ± 0.07)	7 (2.13 ± 0.16); 8 (0.82 ± 0.07)	5 (1.78 ± 0.06); 10 (2.37 ± 0.21)
Clark	1 (1.10 ± 0.05)	28 (1.62 ± 0.08); 29 (0.78 ± 0.02)	2 (1.47 ± 0.00); 12 (1.39 ± 0.04)
Dynasty	1 (0.99 ± 0.02)	7 (1.73 ± 0.09); 9 (NA)[e]	2 (1.55 ± 0.10); 12' (NA)
Excel	1 (1.12 ± 0.02)	7 (1.88 ± 0.02); 9 (NA)	2 (1.62 ± 0.01); 12' (NA)
Freedom	1 (0.77 ± 0.01)	7 (2.15 ± 0.18); 9 (0.90 ± 0.05)	2 (1.73 ± 0.15); 12 (1.21 ±0.05)

[a] Percentage of patent flour protein (14%, mb).
[b] Nomenclature based on Payne and Lawrence (1983).
[c] ESWW = Eastern soft white winter; WSWW = western soft white winter; SRW = soft red winter. Values in parentheses are: means ± standard deviation of four measurements.
[d] Potential mixture or biotype.
[e] Not available.

Statistical Analyses

Data were subjected to one-way analysis of variance (ANOVA) using the Minitab program (Minitab Inc., PA), and to Student's *t*-test and correlation analyses using the Microsoft Excel program (Cambridge, MA). A "1" or "0" was assigned for the presence or absence, respectively, of a specific subunit (or subunit pair) in a cultivar for correlation analyses to flour quality parameters.

RESULTS AND DISCUSSION

Quantitative Determination of HMW-GS and GS Groups

Electrophoretic patterns of HMW-GS of the 17 soft wheat cultivars analyzed are shown in Figure 1. Table I lists the HMW-GS compositions and the respective quantities present in the 17 soft wheat patent flours. At the *Glu-A1* locus, all eastern soft white winter and soft red winter (ESWW and SRW) wheats analyzed contained subunit 1, while club wheats and three of five western soft white winter (WSWW) wheats contained subunit 2*. Subunit 12′, whose mobility is between those of subunits 9 and 10, has similar mobility on SDS-PAGE to subunit 10′ reported by Lookhart et al (1993). This 12′ was present only with subunit 2 in the cultivars analyzed, and presumed to be analogous to subunit 12, thus it was assigned the number 12′.

It should be noted that in the report by Lookhart et al (1993), subunit 10′ also was present in association with subunit 2. Most of the soft wheat cultivars analyzed in this study (15 out of 17) contained subunit 2 instead of subunit 5 at the *Glu-D1* locus (see Table I). The presence of the latter subunit sometimes indicates a stronger wheat protein strength (Greene et al 1988, Lafiandra et al 1993).

Among all HMW-GS analyzed, subunit 7 was present in a relatively large quantity, while subunit 8 was present in a lower amount (Table I). Subunits 2 and 5, which have been reported to have opposite effects on dough strength (Lafiandra et al 1993), showed relatively close average quantities in the patent flour protein (1.57 vs. 1.75%).

The quantities of individual glutenin subunit groups for each flour have been presented previously (Hou and Ng 1995). Means for each wheat class are presented in Table II. The results from ANOVA revealed that the means of the quantities of B subunits were significantly different among wheat classes, with ESWW wheats having the highest amount, followed by SRW and WSWW wheats, and club wheats having the lowest amount of B subunits. The ratio of the quantities of B subunits to C subunits followed the same pattern. There were no significant differences in the quantities of A subunits, C subunits, and total glutenin subunits among four classes of soft wheat patent flours.

The average quantities of A, B, and C subunits of seven straight-grade flour samples tested were 6.94, 11.36, and 6.54% of flour protein, respectively. No significant differences ($P < 0.05$) were found between the quantities of each of these glutenin subunit groups and total glutenin subunits present in straight-grade flours and the respective counterpart subunit groups in patent flours (data not shown).

Relationship of the HMW-GS to the Quality Parameters of Soft Wheat Patent Flours

Table III lists the correlation coefficients of the presence of some HMW-GS to patent flour rheological parameters and baking results. Among five HMW-GS or subunit pairs, subunits 1 and 2* are of particular importance, because subunit 1 was positively correlated with JSC volume (JSCV) ($r = 0.487$, $P < 0.05$) and sugar-

TABLE II
Mean Quantity[a] of Glutenin Subunit Groups in Patent Flour Samples of Four Wheat Classes Determined by Densitometry[b,c]

Glutenin Subunit Group	ESWW	WSWW	Club	SRW
A	6.99a[d]	7.50a	6.53a	7.76a
B	11.41a	9.64b	9.47c	10.96ab
C	6.60a	6.78a	7.49a	6.89a
B/C	1.76a	1.42b	1.28c	1.60ab
B+C	18.01a	16.43a	16.97a	17.85a
(B+C)/A	2.57a	2.36a	2.77a	2.31a
A+B+C	25.00a	23.93a	23.50	25.61a

[a] Percentage of patent flour protein (14%, mb).
[b] Subunits A = high molecular weight glutenin subunits; B and C = two groups of low molecular weight glutenin subunits; A+B+C = total glutenin subunits.
[c] ESWW = Eastern soft white winter; WSWW = western soft white winter; SRW = soft red winter.
[d] Values within rows with different letters are significantly different at the 5% level (Tukey's pairwise comparisons).

TABLE III
Correlation Coefficients[a] for the Presence of Certain High Molecular Weight Glutenin Subunits (HMW-GS) with Some Soft Wheat Patent Flour Quality Parameters

	HMW-GS				
Parameter[b]	1	2*	6	2+12 or 2+12′	5+10
FP (%)[c]	–0.280	0.088	0.216	0.390	–0.390
P (mm)	–0.429	0.560*	–0.026	–0.548*	0.548*
L (mm)	0.593*	–0.390	–0.531*	0.092	–0.092
P/L	–0.611**	0.588*	0.349	–0.398	0.398
W (×10^{-4} J)	0.182	0.054	–0.527*	–0.692**	0.692**
MPT (min)	0.501*	–0.325	–0.446	–0.637**	0.637**
MS (min)	0.168	–0.015	–0.377	–0.741***	0.741***
FWA (%)	–0.721**	0.713**	0.027	–0.048	0.048
FPT (min)	–0.351	0.378	0.538*	0.193	–0.193
JSCV (ml)	0.487*	–0.494*	–0.413	0.024	–0.024
SSCD (cm)	0.821***	–0.771***	–0.320	–0.046	0.046

[a] *, ** and *** = significant at 5, 1, and 0.1%, respectively.
[b] FP = flour protein; alveograph values: *P* = tenacity, *L* = extensibility, *W* = strength; MPT = mixograph peak time; MS = mixograph stability; FWA = farinograph water absorption; FPT = farinograph peak time; JSCV = Japanese sponge cake volume; SSCD = sugar-snap cookie diameter.
[c] 14% moisture basis.

snap cookie diameter (SSCD) ($r = 0.821$, $P < 0.001$), while subunit 2* was negatively correlated with both the cake volume ($r = -0.494$, $P < 0.05$) and cookie diameter ($r = -0.771$, $P < 0.001$). Subunit 1 also correlated positively with alveograph extensibility (L) and mixograph peak time values, and negatively with alveograph stability (P/L, ratio of tenacity to extensibility) and farinograph water absorption values. In contrast, subunit 2* showed positive correlations with P and P/L values, and farinograph water absorption. These results are consistent with those of Branlard and Dardevet (1985), who found that subunit 2* was positively correlated with P value and that subunit 1 was positively correlated with L value. Previous results with the same set of samples showed that the larger diameter SSC and bigger volume JSC are generally positively correlated with L value, and negatively with P, the ratio P/L, and farinograph water absorption values (Yamamoto et al 1996). It can be inferred that subunit 1 may be beneficial and subunit 2* may be detrimental to the qualities of JSC and SSC.

In their study, Payne et al (1987) assigned the same quality score (3) to subunits 1 and 2* based on their higher SDS-sedimentation volumes. Therefore, the presence of subunit 1 or 2* in a hard wheat is usually an indicator of a strong wheat for good breadmaking (Payne et al 1987). In a recent study calculating glutenin rank sum (GRS) to predict the soft wheat baking quality of sugar-snap cookies, Souza et al (1994) assigned a rank of 4 to subunit 1 or 2*, the same rank as for subunit pair 13+19 or 5+10. They assumed that the best alleles for breadmaking would be the worst for pastry quality. However, results from the present study using patent flours indicated that subunits 1 and 2* in soft wheats did not play the same roles in JSC baking and SSC baking as those same subunits in hard wheats play in breadmaking. Use of Payne's quality score based on HMW-GS (Payne et al 1987) to predict the quality of baked products from soft wheat may not be as satisfactory as it has been for bread from bread wheat.

No significant correlations were found among subunits 6, 2+12 (or 2+12′), and 5+10 and patent flour baking quality. However, they all showed various relationships with dough rheological properties (Table III). For example, subunit pair 2+12 (or 2+12′) had significantly negative correlations with P and W (strength) values, and mixograph peak time and stability value, while subunit pair 5+10 showed significantly positive correlations with each of those parameters. These results are consistent with previous findings that subunits 5+10 generally produce stronger doughs, and that subunits 2+12 weaken dough strength (Payne et al 1981, Branlard and Dardevet 1985, Ng and Bushuk 1988, Lafiandra et al 1993). In the present study, subunit 6 was shown to be negatively correlated with L and W values and positively correlated with farinograph peak time.

A recent study by Souza et al (1994) showed that individual HMW-GS did not have any significant correlations with SSCD except for subunit pair 13+19, whose presence seemed to have an adverse effect on cookie diameter. In 51 soft white spring wheats they analyzed, the largest factor in determining cookie diameter was flour protein content. They also found that when all the HMW-GS were combined to calculate the GRS, cookie diameter had greatest negative correlation with GRS score in the year with the lowest average flour protein content. In our present study, the protein contents of the 16 patent flours (excluding cultivar Crew) also showed a significant correlation with cookie diameter ($r = -0.578$, $P < 0.05$). However, the presence of any HMW-GS did not correlate significantly with flour protein content (Table III).

With the exception of cultivar Tres, all cultivars studied contained either subunit 1 or 2* (Table I). The Student's t-test was used to examine the effects of subunit 1 vs. 2* on various quality parameters of these 16 flours (Table IV). No significant differences were noticed in patent flour protein content between flours containing subunits 1 and 2*. However, the quantity of subunit 1 was significantly higher than that of subunit 2* in the patent flours studied (1.02 vs. 0.85% of flour protein). Even so, patent flour samples containing subunit 2* showed significantly higher P and P/L, and farinograph water absorption values, and lower L value, cake volumes and cookie diameters than flours containing subunit 1. Among these patent flours, subunit 1 is likely qualitatively weaker than subunit 2* and, therefore, is likely good for JSC and SSC baking.

Relationship of Quantities of Glutenin Subunits to Soft Wheat Patent Flour Quality

Correlations between the quantities of four individual HMW-GS and the quality parameters of patent flours are shown in Table V. The quantity of subunit 2* was positively correlated with mixograph tolerance value ($r = 0.833$), indicating that the higher quantity of subunit 2* would make the flour stronger, leading to poor JSC- and SSC-baking qualities. The quantity of subunit 6 correlated positively with W value ($r = 0.998$), and the quantity of subunit 8 correlated negatively with mixograph peak height ($r = -0.993$), farinograph peak time ($r = -0.954$) and stability values ($r = -0.982$). The quantity of subunit 9 positively correlated with mixograph peak height value ($r = 0.878$), but negatively correlated with mixograph stability value ($r = -0.939$). These results confirmed that both the type and the quantity of certain HMW-GS could be

TABLE IV
Comparative Results of the Effects of Subunits 1 vs. 2* on Some Quality Parameters of 16 Soft Wheat Patent Flour Samples[a]

	Mean		
Parameters[b]	1 ($n = 10$)	2* ($n = 6$)	t[c]
FP (%)	7.7	8.0	0.87 ns
SQ (g/100g FP)	1.02	0.85	2.58*
P (mm)	29.6	39.5	2.41*
L (mm)	142.3	111.1	2.40*
P/L	0.22	0.38	2.93*
W ($\times 10^{-4}$ J)	105.5	103.2	0.16 ns
MPT (min)	3.7	2.6	1.82 ns
MS (min)	4.2	3.9	0.30 ns
FWA (%)	49.5	52.3	4.09**
JSCV (ml)	1162	1119	2.19 *
SSCD (cm)	8.74	8.35	5.41***

[a] *, ** and *** = significant at the 5, 1, and 0.1% levels, respectively; ns = not significant at the 5% level.
[b] FP = flour protein (14%, mb); alveograph values: P = tenacity; L = extensibility; W = strength; MPT = mixograph peak time; MS = mixograph stability; FWA = farinograph water absorption; JSCV = Japanese sponge cake volume; SSCD = sugar-snap cookie diameter.
[c] Student's t-test.

TABLE V
Correlation Coefficients for the Quantity[a] of Certain High Molecular Weight Glutenin Subunits with Soft Wheat Patent Flour Quality Parameters[b]

	High Molecular Weight Glutenin Subunits			
Parameter[c]	2*($n = 6$)	6 ($n = 3$)	8 ($n = 4$)	9 ($n = 5$)
FP (%)	–0.009	–0.255	–0.521	0.435
W ($\times 10^{-4}$ J)	0.705	0.998*	0.539	0.429
MPH (mm)	–0.036	0.349	–0.993**	0.878*
MS (min)	0.544	0.578	0.573	–0.939*
MT (mm)	0.833*	0.595	0.723	–0.300
FPT (min)	–0.277	0.901	–0.954*	0.578
FS (min)	–0.251	0.992	–0.982*	–0.160
JSCV (ml)	0.013	–0.910	0.713	–0.599
JSCV/FP (ml/%)	0.081	–0.021	0.744	–0.525
SSCD (cm)	–0.321	–0.846	0.562	–0.464
SSCD/FP (cm/%)	0.046	0.166	0.667	–0.495

[a] Percentage of patent flour protein (14%, mb).
[b] * and ** = significant at the 5% and 1% levels, respectively.
[c] FP = flour protein (14%, mb); W = alveograph strength; MPH = mixograph peak height; MS = mixograph stability; MT = mixograph tolerance; FPT = farinograph peak time; FS = farinograph stability; JSCV = Japanese sponge cake volume; SSCD = sugar-snap cookie diameter.

that both the type and the quantity of certain HMW-GS could be responsible for the structure and molecular size distribution of polymeric proteins, which were reported to most likely account for the combined effects of individual glutenin subunits on dough strength (Gupta et al 1993, Gupta and MacRitchie 1994).

Table VI lists the correlation coefficients for the quantities of glutenin subunit groups (A, B, and C subunits) to flour quality parameters for each wheat class. In ESWW wheat flours, the quantity of C subunits correlated positively with *P/L* value, and the quantity of total LMW-GS (B and C subunits) showed positive correlations with *P* and flour protein content and a negative correlation with JSCV per unit flour protein. These results suggested that the association of the quantity of LMW-GS with flour rheological and baking properties may be partially related to the flour protein content. The amount of total glutenin subunits also correlated positively with farinograph water absorption and negatively with SSCD per unit flour protein.

Contrary to ESWW wheat flours, the quantity of B subunits in WSWW was positively correlated with mixograph peak time and SSCD per unit flour protein, and negatively with farinograph stability time; the quantity of C subunits was negatively correlated with *L* value; and the ratio of B subunits to C subunits correlated negatively with the corresponding farinograph water absorption value and positively with cookie diameter. In contrast, to ESWW wheat flours, the quantity of total glutenin subunits in WSWW wheat flour proteins had a negative association with farinograph water absorption value.

In club wheat flours, the quantity of A subunits correlated negatively with JSCV. The ratio of B to C subunits correlated negatively with flour protein content and positively with SSCD per unit flour protein, and the LMW-GS to HMW-GS ratio also positively correlated with JSCV. However, the total glutenin subunits associated negatively with JSCV. There was no significant correlation between the quantity of each glutenin subunit group, LMW-GS or of total glutenin subunits and the flour quality parameters in SRW wheat flours. These preliminary results suggested that the quantity of each glutenin subunit group in different classes of soft wheat contributed differently to flour rheological and baking properties.

In the present study, the LMW glutenin subunits have been classified into two groups: B subunits and C subunits. However, within the B and C subunits, a total of over 40 different subunits have been detected, with each cultivar exhibiting 7 to 16 subunits (Gupta and Shepherd 1990). These subunits have been assigned to three groups which are genetically controlled by the *Glu-3* locus on the short arms of chromosomes 1A, 1B and 1D (Gupta and Shepherd 1988, 1990). The allelic variation at the *Glu-3* locus of bread wheat has been linked to physical dough properties (Gupta et al 1989, Metakovsky et al 1990, Gupta et al 1994, Gupta and MacRitchie 1994). Certain LMW glutenin subunits have also been identified as affecting cookie- (biscuit-) making quality (Morel, cited by Autran 1993). The variation in the quantities of certain

TABLE VI
Correlation Coefficients for Quantities[a] of Glutenin Subunit Groups in Soft Wheat Patent Flours with Flour Quality Parameters[b,c]

	ESWW ($n = 3$)	WSWW ($n = 5$)	Club ($n = 4$)	SRW ($n = 5$)
A subunits and				
JSCV (ml)	−0.790	−0.278	−0.985*	−0.311
FP (%)	0.841	−0.497	−0.722	0.010
B subunits and				
MPT (min)	−0.912	0.996*	0.840	0.085
FS (min)	0.709	−0.892*	0.345	−0.438
JSCV/FP (ml/%)	−0.639	0.565	0.762	0.687
SSCD/FP (cm/%)	0.143	0.910*	−0.695	−0.423
FP (%)	0.600	−0.743	−0.862	−0.361
C subunits and				
L (mm)	−0.758	−0.929*	0.671	−0.632
P/L	0.999*	0.758	−0.854	0.843
FPT (min)	0.291	0.428	0.685	−0.038
JSCV/FP (ml/%)	−0.936	0.270	−0.747	−0.524
FP (%)	0.952	−0.294	0.729	−0.048
B/C and				
MPH (min)	−0.644	0.133	−0.753	−0.296
FWA (%)	−0.857	−0.926*	0.597	−0.674
JSCV (ml)	−0.757	−0.054	−0.068	0.710
JSCV/FP (ml/%)	0.782	0.465	0.906	0.746
SSCD (cm)	0.987	0.930*	−0.254	−0.004
SSCD/FP (cm/%)	0.900	0.831	0.955*	0.205
FP (%)	−0.812	−0.654	−0.964*	−0.208
B+C and				
P (mm)	0.998*	0.360	0.756	−0.027
JSCV/FP	−0.999*	0.540	0.299	0.458
FP (%)	1.000**	−0.688	−0.412	−0.399
(B+C)/A and				
JSCV (ml)	−0.802	0.303	0.969*	0.235
FP (%)	0.745	0.325	0.748	−0.193
A+B+C and				
FWA (%)	0.999*	−0.942*	−0.126	−0.600
JSCV (ml)	−0.979	−0.153	−0.954*	−0.156
SSCD/FP (cm/%)	−0.999*	0.821	0.580	0.143
FP (%)	0.993	−0.646	−0.629	−0.414

[a] Percentage of patent flour protein (14%, mb).
[b] * and ** = Significant at the 5 and 1% levels, respectively.
[c] ESWW = Eastern soft white winter; WSWW = western soft white winter; SRW = soft red winter; subunits A = high molecular weight glutenin subunits; B and C = two groups of low molecular weight glutenin subunits; *P* = alveograph tenacity; *L* = alveograph extensibility; MPT = mixograph peak time; MPH = mixograph peak height; SSCD = sugar-snap cookie diameter; FP = flour protein (14%, mb); FS = farinograph stability; JSCV = Japanese sponge cake volume; FWA = farinograph water absorption; FPT = farinograph peak time.

LMW-GS was also shown to affect the molecular size distribution, quantity, or both, of the glutenin proteins (Gupta and MacRitchie 1994). Therefore, further identification and quantification of LMW-GS encoded by genes on each *Glu-A3, Glu-B3,* and *Glu-D3* locus, along with consideration of HMW-GS compositions, would allow better understanding of the functionality of glutenin proteins in soft wheat end-use quality. Eventually, it may be possible to manipulate the glutenin protein compositions, aiming at breeding of soft wheats for specific products.

ACKNOWLEDGMENTS

We thank P. L. Finney (USDA-ARS Soft Wheat Quality Laboratory, Wooster, OH) for providing some of the wheat samples and for use of the milling facility, W. G. Helfrich (Michigan State University) for use of the densitometer, and S. T. Worthington (Michigan State University) for technical assistance. Partial support of this research from Michigan Agricultural Experiment Station, from Michigan State Millers' Association, from Yamazaki Baking Co., Ltd. of Japan, and from USDA-National Research Initiative Competitive Grants Program, grant number 93-37500-9520, is gratefully acknowledged.

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[Received July 20, 1995. Accepted February 26, 1996]