Role in Dough Rheology of High Molecular Weight Glutenin Subunits of Soft White Winter and Club Wheats

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ABSTRACT

The effect of high molecular weight glutenin subunit (HMW-GS) composition of seven soft white winter (SWW) and four club wheat cultivars from the Pacific Northwest region on dough rheology was investigated. All samples were harvested in 1988, 1990, and 1993 (in Walla Walla, WA). Three selected SWW and three club wheats were grown in 1990, in seven locations covering broad growing conditions. The SWW and club wheats grown under the same conditions showed similar protein content (11.70 and 11.65%, respectively) but distinctly different values of total area of HMW-GS (0.9–1.9 for SWW, and 0.7–1.3 for club wheat, excluding Hyak). The quality score of HMW-GS multiplied by area showed much better correlation with dough rheology (alveograph *W*: $r = 0.905$; mixograph mixing time: $r = 0.743$) and SDS sedimentation volume ($r = 0.883$) than for each of these parameters separately. The increase in protein content of SWW, (from 8.5 to 12.5%) and of club wheats (from 7.5 to 11%) resulting from growing conditions accompanies the increase of total area of HMW-GS, from 0.85 to 1.3 and from 0.7 to 0.95, respectively. However, that increase better matched the increase in protein content of SWW wheats ($r = 0.662$) than club wheats ($r = 0.352$). If the increase in protein content is substantial for the cultivars with high quality score HMW-GS, it might cause an increase of gluten strength as measured by dough rheology and SDS sedimentation value. The cultivar Hyak, containing the subunits 7+8 in *Glu-1B* locus and 5+10 in *Glu-1D* locus, is a good example of the latter. The club wheats (not Hyak), having a generally low quality score of HMW-GS, preserve unique properties of weak gluten, even with the increase of protein content.

The quality of wheat for end uses is controlled mainly by its storage proteins (Lorenzo et al 1987, Menkovska et al 1987, Khan et al 1989, MacRitchie et al 1990, Gupta et al 1991, Cornish et al 1991, Lookhart et al 1992, Shewry et al 1992, Blumenthal et al 1995). Considerable research has been centered on particular glutenin subunits 5+10 and 2+12, as the presence of either has provided correlations with dough strength and weakness (Lorenzo et al 1987). However, the research was mostly conducted on hard wheat, and the role of high molecular weight glutenin subunits (HMW-GS) in dough rheology and performance in baking were recognized (Payne et al 1979, 1980, 1982). The soft wheat used for cookies, crackers, noodles, and fine pastries (Rubenthaler 1988) is expected to have lower and much weaker storage proteins than the hard wheat.

The Pacific Northwest soft wheats have a well-established name in international markets. The unusual properties of these wheats and their desirable color stimulate use for many products in eastern Mediterranean countries and countries of the Pacific Rim. The Pacific Northwest club wheats are generally accepted as wheats that traditionally have the lowest and weakest gluten content (Rubenthaler 1988, Souza et al 1994). Also, club wheat cultivars have unique flour milling properties (Pomeranz et al 1988). On the other hand, the Pacific Northwest common soft wheats are stronger in gluten and dough mixing properties than are club wheats, and are more responsive in baked products to protein content (Rubenthaler 1988; Czuchajowska et al 1988; Souza et al 1994). However, there are several factors concerning the quality of Pacific Northwest SWW and club cultivars related to the quality of the end products (Czuchajowska et al 1988). One of these factors is the increase in protein content of both classes, which is of great concern to both domestic and overseas users. At the same time, the uses of wheat in general are being submitted to more narrow and rigorous end use specifications and requirements (Baik et al 1994). Consequently, it is necessary to investigate whether there are any consistent differences in the main protein components between Pacific Northwest SWW and club wheats that are related to strength. At present, there is no data available for both classes based on systematic studies that focus on the quality of SWW and club wheats to define unique features and the role of HMW-GS. The available information focuses on HMW-GS composition but not on its influence on gluten strength (Lookhart et al 1992, Rayfuse and Jones 1993). Therefore, the objective of this study was to relate the content and composition of HMW-GS of SWW and club wheats grown under the broad soil and climatic conditions of the Pacific Northwest to the dough rheology.

MATERIALS AND METHODS

Wheat Samples

Seven SWW and four club wheat cultivars were used in this study. SWW wheats included Daws, Nugaines, Hill 81, Madsen, Dusty, Stephens, and Lewjain. Club wheats included Crew, Moro, Tres, and Hyak. Samples provided by C. Peterson (USDA) were planted in seven locations (Pullman, Pomeroy, Ritzville, Walla Walla, Cunningham, Coulee City, and Cavendish) in the Pacific Northwest, and harvested in 1988, 1990, and 1993. Each cultivar was planted in every location in four replicates.

This study was conducted in two parts. In part one, all SWW and club wheat cultivars under investigation were used. Both classes of wheats were grown in 1988, 1990, and 1993, under the same soil and climatic conditions, in Walla Walla, WA. Average temperatures and total rainfall during these years were: 12.3°C, 411 mm; 12.7°C, 449 mm; and 10.3°C, 648 mm, respectively.

Thirty three samples were examined. To compare classes and varietal differences in HMW-GS pattern, all samples from the same year were run on the same gel. Also, samples of the same cultivar from three crop years were run on the same gel to demonstrate the effect of growing conditions on HMW-GS during each year.

In part two of the study, three SWW wheats (Madsen, Hill 81, and Stephens) and three club wheats (Crew, Tres, and Hyak) were investigated. The cultivars were grown in 1990 in seven locations covering broad soil and climatic conditions. Average temperature

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range and total rainfall range for these locations were from 9.3 to 12.7°C, and from 239 to 518 mm. The differences in protein content in a single cultivar exceeded 4.5%.

The study focused on a comparison of HMW-GS patterns and protein content of a particular subunit by location. Therefore, each set of samples of a single cultivar represented by all locations was run on the same gel.

Analytical Methods

Wheat samples were milled on a Buhler experimental mill to 60% flour extraction by approved method 26-20 (AACC 1983).

Flour moisture content was measured by approved method 44-15A (AACC 1983). Protein content (N × 5.7) was determined by a Leco FP-428 nitrogen analyzer (Leco Corporation, St. Joseph, MI).

Alveograph tests were conducted according to approved method 54-30 (AACC 1983) with modifications described by Addo et al (1990). Optimal water absorption and mixing requirement of flours were determined by a 10-g mixograph (method 54-40A, AACC 1983). Sodium dodecyl sulfate (SDS) sedimentation test was performed according to Axford et al (1979).

Electrophoresis

Preparation of glutenin extracts. The methodology of preparation of samples of glutenin extracts was conducted according to Burnouf et al (1989). The flour sample containing 5 mg of protein was extracted with 1 ml of 100% dimethyl sulfoxide (DMSO) four times. The supernatant was removed, and the remaining pellet was extracted with 1 ml of 70% (v/v) ethanol, also four times. The residue after ethanol extraction was freeze-dried. The last step of extraction was done according to SDS-PAGE requirements (Ng et al 1988) with modifications as described below. The dry samples were suspended in 400 μl of Tris/HCl extracting buffer solution, pH 6.8. After extraction, the clear supernatant was transferred to a new tube and heated for 5 min in boiling water. Samples were alkylated with 4-vinylpyridine at 60°C for 30 min.

SDS-PAGE. Glutenin extracts were separated by SDS-PAGE. Glutenin extracts (20 μl) were placed into each slot of gel. The procedure was performed according to Payne et al (1979) and Ng et al (1987, 1988). SDS-PAGE was performed on a PROTEAN II apparatus produced by BIO-RAD Laboratories, Richmond, CA. The HMW protein standards (BIO-RAD) and cultivar Marquis, with a known HMW-GS pattern (Ng et al 1987, 1988), were used as references.

Staining was done with 0.2% Coomassie Brilliant Blue dissolved in 30% (v/v) methanol, 10% (v/v) acetic acid in water solution (750 ml per gel) overnight. Destaining was performed in three solutions of methanol-acetic acid-water, gradually decreased in methanol concentration (30, 25, and 20%).

Identification and quantification of proteins separated by SDS-PAGE. The gels were scanned using a scanning densitometer (BIO-RAD 620). Parameters of scanning were adjusted according to manufacturer recommendations.

Molecular weights of subunits were calculated according to the mobility of protein bands from HMW standards and cultivar Marquis in the same gel (Ng et al 1987, 1988). The relative mobility of HMW-GS and the protein concentration were based on five separate extractions of protein per cultivar per location and year. Two gels were run for each extraction (10 runs of separate gels). The amount of particular HMW-GS and the total amount of HMW-GS were expressed as means of peak area and total peak areas. The nomenclature of HMW-GS used in this article is according to Payne and Lawrence (1983) and Ng et al (1988). A glutenin strength ranking system modified from Souza et al (1994) was used to assign a quality score for each subunit combination in SWW and club cultivars listed in Table II. The data from all runs were evaluated statistically (SAS 1985).

RESULTS AND DISCUSSION

This study was conducted on two sets of SWW and club wheats. One set included cultivars grown in one location during three years, and the second set included samples grown in one year in seven locations.

Cultivars Grown in One Location During Three Crop Years

The protein content, dough rheology and SDS sedimentation volume of seven SWW and four club wheats are summarized in Table I. The results represent average values of three crop years: 1988, 1990, and 1993. Most cultivars had protein content between 11 and 12% (dry basis), while two samples (Madsen, Hill 81) had slightly higher content. However, the highly comparable protein content of SWW and club wheat cultivars showed large variation in dough rheology and SDS sedimentation volume. The strength of gluten protein measured by alveograph, mixograph, or SDS sedimentation volume is affected by both protein content and protein quality (Addo et al 1990, Baik et al 1994). Therefore, the samples under investigation having similar protein content but showing large differences in the above tests reflect differences in protein quality. The lowest values of alveograph *W*, mixing time, and SDS sedimentation volume were for two club wheats, Tres and Crew. Among SWW wheats, Stephens showed the lowest values, while Daws, Lewjain, and Dusty showed the highest values. The club wheat Hyak gave the highest alveograph *W* and SDS sedimentation readings, indicating that Hyak has poor quality as a club wheat. A large range of gluten

TABLE I
Flour Protein Content and Dough Rheology of Soft White Winter (SWW) and Club Wheats Grown in Walla Walla, WA[a]

Class	Cultivar	Protein (%)	Alveograph *W*	Mixograph[b] Peak Time (sec)	Mixograph[b] Water Abs. (%)	SDSS (ml)[c]
SWW	Daws	11.24	150	117	55	76
	Nugaines	11.18	123	118	55	77
	Hill-81	12.62	89	103	54	68
	Madsen	13.08	93	94	56	69
	Stephens	11.52	57	78	53	61
	Lewjain	11.38	157	153	54	75
	Dusty	11.09	113	165	55	75
Club	Crew	11.51	46	69	52	49
	Moro	11.90	94	93	54	69
	Tres	11.64	32	68	50	38
	Hyak	11.52	164	140	55	82

[a] Mean of 1988, 1990 and 1993 crop years.
[b] Optimal water absorption and mixing requirement of flours were determined by a 10-g mixograph (method 54-40A, AACC 1983).
[c] Sodium dodecyl sulfate sedimentation (SDSS) test was performed according to Axford et al (1979).

strength at comparable protein levels oriented the present research towards HMW-GS in these samples. The HMW-GS in hard wheats are related to strength or weakness (Payne et al 1980, Lorenzo et al 1987, Khan et al 1989, Gupta et al 1991). This study was conducted to discover whether this kind of relationship existed in SWW and club wheats.

The HMW-GS pattern of each cultivar grown during three crop years was determined by SDS-PAGE. The single cultivar showed the same pattern of HMW-GS independent of the year of harvesting. To depict this, the HMW-GS patterns of two cultivars, Nugaines and Tres, are given in Figure 1. The HMW-GS pattern was identified based on relative mobility of proteins from SDS-PAGE of single bands. The identification numbers of HMW-GS of SWW and club wheat cultivars for locus *Glu-1A*, *Glu-1B*, and *Glu-1D* are listed in Table II. The assigned quality score for each subunit, subunit pair, and total score are also given.

The pattern of HMW-GS of four SWW wheats (Daws, Hill 81, Nugaines, Stephens) are comparable with the results obtained by Lookhart et al (1992). The identification of molecular weight of protein was based on several runs of SDS-PAGE from several extractions of proteins and densitometer readings compared to the standard. With most bands, there was no problem in identification by densitometer. The bands that created some difficulty were 2 and 2*. These bands sometimes did not completely resolve; the peak from the densitometer was broader than expected, and therefore the bands 2 and 2* were assigned. The same problem was

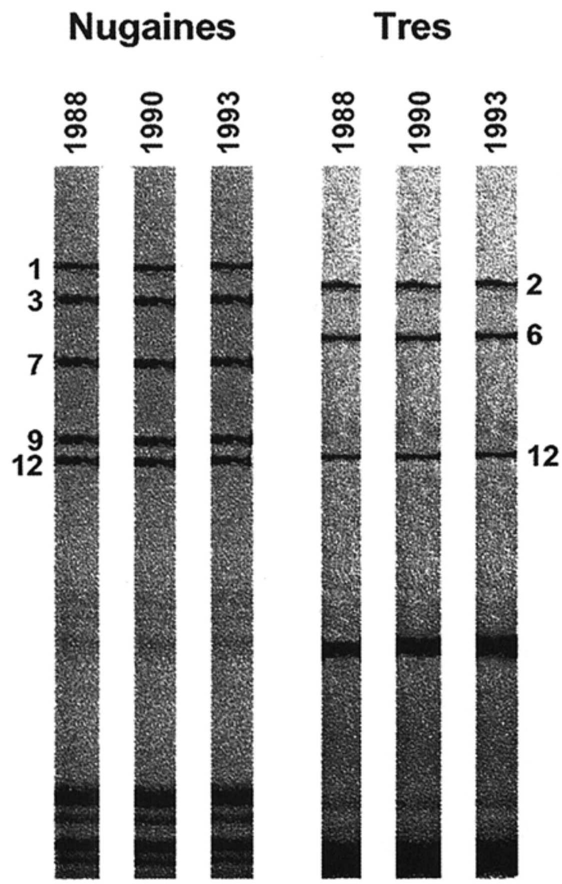

Fig. 1. Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) pattern of high molecular weight glutenin subunits for Nugaines (soft white winter [SWW]) and Tres (club) wheat cultivars from three crop years.

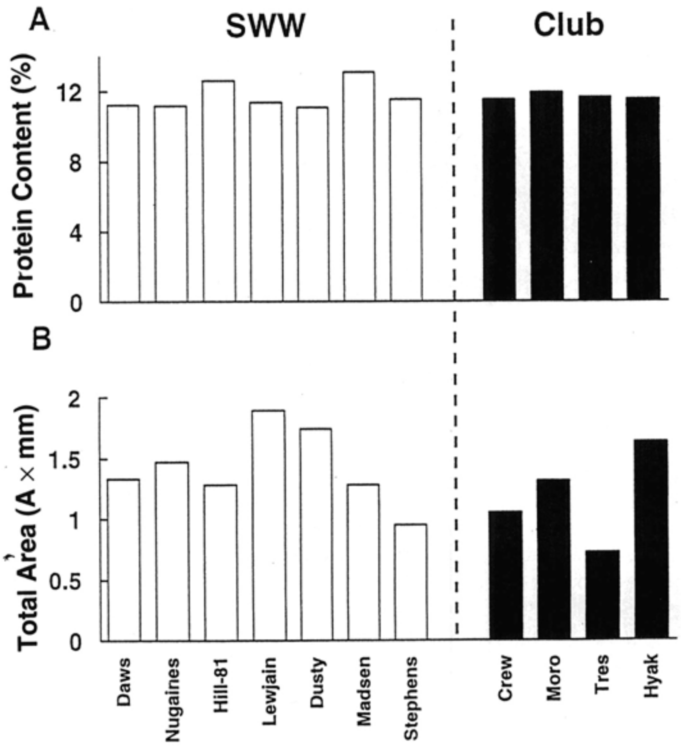

Fig. 2. Three-year average protein content (**A**) and total area of high molecular weight glutenin subunits (**B**) of soft white winter (SWW) and club wheat cultivars grown in Walla Walla.

TABLE II
High Molecular Weight Glutenin Subunits (HMW-GS) and Quality Score of Soft White Winter (SWW) and Club Wheats

Class	Cultivar	HMW-GS[a] 1A	1B	1D	Total Score
SWW	Daws	2* (3)	7+9 (3)	5+10 (4)	10
	Nugaines	1 (4)	7+9 (3)	3+12 (2)	9
	Hill-81	2* (3)	7 (2)	2+12 (2)	7
	Madsen	2* (3)	7+9 (3)	2+12 (2)	8
	Stephens	2* (3)	7+9 (3)	2+12 (2)	8
	Lewjain	1 (4)	7+9 (3)	2+12 (2)	9
	Dusty	2* (3)	7+9 (3)	2+12 (2)	8
Club	Crew	Null (1)	6 (2)[b]	2+12 (2)	5
	Moro	2* (3)	7+8 (4)	2+12 (2)	9
	Tres	Null (1)	6 (1)	2+12 (2)	4
	Hyak	2* (3)	7+8 (4)	5+10 (4)	11
HRS[c]	Marquis	1	7+9	5+10	

[a] Quality score indicated in parentheses.
[b] Multiline, major components listed, 7+8 and 7+9 are minor components.
[c] Canadian Hard Red Spring used as reference cultivar.

TABLE III
Protein and High Molecular Weight Glutenin Content of Soft White Winter (SWW) and Club Wheat Cultivars Harvested in 1988, 1990, and 1993 in Walla Walla, WA

Class	Cultivar	Protein Content (%) 1988	Protein Content (%) 1990	Protein Content (%) 1993	Total Area (A × mm) 1988	Total Area (A × mm) 1990	Total Area (A × mm) 1993
SWW	Daws	11.4b[a]	10.7c	11.6a	1.53a	1.36b	1.27c
	Nugaines	12.5a	10.6b	10.4c	1.93a	1.29b	1.19c
	Hill 81	13.1a	12.4b	12.3b	1.62a	1.16b	1.06c
	Madsen	NS[b]	13.4a	12.7b	NS	1.41a	1.14b
	Stephens	NS	11.8a	11.2b	NS	1.03a	0.86b
	Lewjain	11.8a	10.7b	11.6a	1.78c	1.89b	1.99a
	Dusty	11.9a	10.4b	NS	1.84a	1.63b	NS
Club	Crew	12.3a	10.9c	11.3b	1.36a	0.87c	0.93b
	Moro	12.0a	11.7b	12.0a	1.48a	1.11c	1.35b
	Tres	11.9a	11.2c	11.8b	1.04a	0.62b	0.51c
	Hyak	NS	11.3b	11.8a	NS	1.42b	1.83a

[a] Means in the same row followed by the same letter are not significantly different at the 5% level.
[b] No sample.

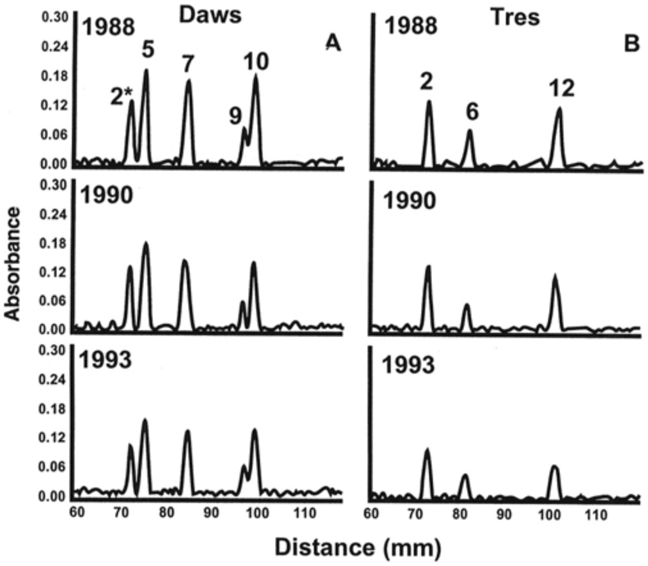

Fig. 3. Densitometry pattern of high molecular weight glutenin subunits of Daws (soft white winter [SWW]) and Tres (club) wheat cultivars from three crop years.

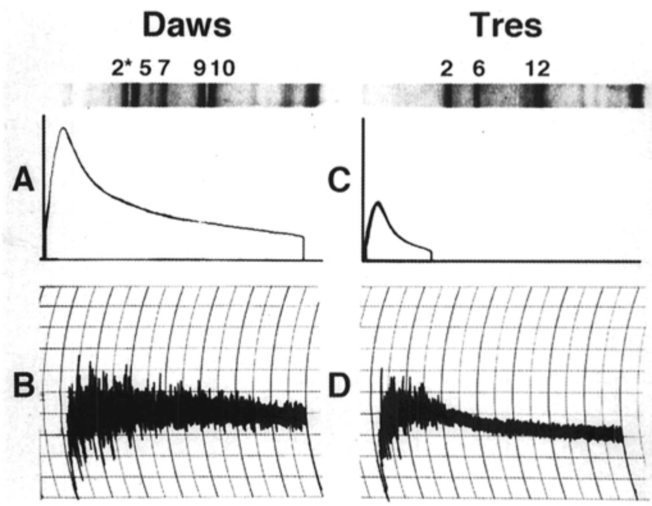

Fig. 4. Mixograms, alveograms, and high molecular weight glutenin subunits for Daws (soft white winter [SWW]) and Tres (club) wheat cultivars grown in Walla Walla.

reported by Lookhart et al (1992). The HMW-GS composition of club wheat cultivars Moro, Tres, Crew, and Hyak are in agreement with the report by Rayfuse and Jones (1993), who studied the composition of HMW-GS of 120 diverse club wheat selections. The quality scores listed in Table II show that Tres and Crew had the lowest glutenin score among club wheats, while Hyak, also a club wheat, had the highest score of all tested wheats. This was due to the fact that Hyak has a pair 7+8 in *Glu-1B* locus and 5+10 in *Glu-1D* locus, that were assigned the high glutenin scores as reported by Ng et al (1988), Lookhart et al (1992), and Souza et al (1994).

As the absorbance (A) of each band reflects the concentration of protein, the magnitude of the area under the curve for each band was used as a measure of protein content of HMW-GS. The overall protein content of all soft wheats grown during three crop years was 11.2%, while the total area of HMW-GS was 1.42 (expressed in A × mm). The overall protein content of club wheats without Hyak was 10.4%, and the overall area of HMW-GS was 1.03 A × mm. When Hyak was included, the protein content of club wheats decreased by 0.48%, while the total area of HMW-GS increased by 0.15 A × mm, indicating that this cultivar had a much higher concentration of protein of HMW-GS.

The average values of protein content and the total area of HMW-GS of SWW and club cultivars from three crop years are presented in Figure 2. The protein content of SWW, and especially club wheats, is very similar. Also, the protein content of cultivars within both classes is comparable. However, the total area of HMW-GS did not reflect protein level. Large changes in concentration of HMW-GS were determined within each class of wheat. The lowest value of the total area of HMW-GS within common wheats was observed for Stephens, followed by Madsen and Hill 81; Lewjain and Dusty had the highest value. Within club wheats, the large differences among cultivars in total area of HMW-GS contrasted with almost identical levels of protein.

Tres, followed by Crew and Moro had the lowest value of total area of HMW-GS. Hyak distinctly showed the highest value of total area of HMW-GS. On average, there were distinct differences between both classes when Hyak was excluded from club wheats.

The variation in protein content and the total area of HMW-GS for each cultivar grown in three crop years is presented in Table III. In spite of significant differences in protein content between growing years for single cultivars, the average protein content covered a very narrow range. The differences in protein content between years for 7 of 11 cultivars were <1%. Also, cultivar differences within one crop year were small, except for Hill 81 and Madsen, which showed higher values.

The total area of HMW-GS showed significant differences between growing years and cultivars (Table III, Fig. 3). Among SWW wheats, Stephens had the lowest value of total area of HMW-GS and Lewjain had the highest. Among club wheats, Tres had the lowest value in all three crop years and Hyak had the highest. These two cultivars of club wheats differed threefold in total area of HMW-GS, while protein content was identical. The large differences in dough rheology between wheat cultivars of the investigated samples are shown in Table I. The differences in pattern, as well as in total area of HMW-GS, were also substantial (Tables II and III). SWW Daws and club wheat Tres are characterized in Figure 4.

The relationship between the HMW-GS parameters and dough rheology and SDS sedimentation volume are summarized in Table IV. As expected, no correlation was obtained between total area of HMW-GS and protein content; the latter was very similar for all samples. The total area of HMW-GS for the combined samples showed strong, statistically significant, positive correlation with dough rheology and SDS sedimentation volume at the 1% level. Eighteen samples of SWW wheats and 11 samples of club wheats showed positive correlation of HMW-GS with the mixograph mixing time and SDS sedimentation volume at the 5% level. The correlation of total area of HMW-GS with alveograph *W* was statistically significant for SWW wheats but not for club wheats because of the limited number of samples (six).

Total quality score of HMW-GS showed positive correlation with dough rheology and SDS sedimentation volume for all SWW and club wheat samples and for club wheat samples when the latter were considered separately. SWW wheats showed significant correlation with alveograph *W*. The correlation between both parameters of HMW-GS (concentration and score, each considered separately) was strong with dough rheology and SDS volume. However, when the score was multiplied by the area of HMW-GS, the correlation with dough rheology and SDS volume was improved for all samples and also for each class of wheat. This is new information concerning soft wheats, although Payne et al (1987) observed the inverse relationship between *Glu-1*, quality score, and biscuit quality of British grown wheat.

The genetically controlled pattern of HMW-GS, and therefore the respective quality score, affect the strength of gluten as measured by dough rheology and SDS sedimentation test. The SWW and club wheats grown under the same conditions showed similar protein content but distinctly different values of total area of HMW-GS. The score of HMW-GS multiplied by area showed much better correlation with dough rheology and SDS sedimentation volume than each of these parameters separately.

Cultivars Grown in Several Locations in one Crop Year

The protein content, the parameters characterizing dough rheology, and the SDS sedimentation test of SWW and club wheats are summarized in Table V. The wheat cultivars were grown in seven locations in 1990. The largest difference in protein content was 4.9% for Madsen; the lowest was 3.4% for Hyak. Generally, the SWW wheats had slightly higher average values of protein content than did club wheats (≈1%). The ranges and average values of dough rheology parameters and SDS sedimentation values for club wheats Tres and Crew were distinctly lower than for SWW wheats. For Tres and Crew, on the average, the alveograph *W* values were 28 and 42 (10^{-4}J); mixograph mixing times were 59 and 75 sec; and SDS sedimentation volumes were 19 and 38 ml, respectively. Hyak had the highest values for these

TABLE IV
Correlation Coefficients Between High Molecular Weight Glutenin Subunit Content, Quality Score, and Rheological Parameters

Parameter	Cultivar	Protein (%)	Alveograph *W*	Mixograph[a] Peak Time (sec)	Mixograph[a] Water Abs. (%)	SDSS (ml)[b]
Total area (A × mm)	All[c]	0.093	0.732**[d]	0.684**	0.680**	0.747**
		(29)	(22)	(28)	(29)	(29)
	SWW	–0.018	0.732*	0.693*	0.462	0.619*
		(18)	(16)	(18)	(18)	(18)
	Club	0.447	0.648	0.402	0.778*	0.824*
		(11)	(6)	(10)	(11)	(11)
Total score	All	–0.140	0.804**	0.565*	0.733**	0.881**
		(29)	(22)	(28)	(29)	(29)
	SWW	0.519*	0.632*	0.227	0.134	0.461
		(18)	(16)	(18)	(18)	(18)
	Club	0.116	0.961*	0.762*	0.904**	0.962**
		(11)	(6)	(10)	(11)	(11)
Score × area	All	–0.044	0.905**	0.743**	0.750**	0.883**
		(29)	(22)	(28)	(29)	(29)
	SWW	–0.211	0.848**	0.663**	0.428	0.680*
		(18)	(16)	(18)	(18)	(18)
	Club	0.237	0.948*	0.722*	0.879**	0.969**
		(11)	(6)	(10)	(11)	(11)

[a] Optimal water absorption and mixing requirement of flours were determined by a 10-g mixograph (method 54-40A, AACC 1983).
[b] Sodium dodecyl sulfate sedimentation (SDSS) test was performed according to Axford et al (1979).
[c] All = soft white winter (SWW) and club wheats.
[d] * = $P < 0.05$, ** = $P < 0.001$. Sample number indicated in parentheses.

TABLE V
Protein Content and Dough Rheology of Soft White Winter (SWW) and Club Wheats Harvested in Seven Locations in 1990

Class	Cultivar	Protein Range	Protein Mean	Alveograph *W* Range	Alveograph *W* Mean	Mixograph Peak Time Range	Mixograph Peak Time Mean	SDSS[a] Range	SDSS[a] Mean
SWW	Hill-81	8.21 ~ 12.42	10.83	71 ~ 124	92	60 ~ 150	96	46 ~ 67	56
	Madsen	8.85 ~ 13.73	11.69	63 ~ 129	92	75 ~130	95	49 ~ 69	61
	Stephens	8.28 ~ 11.83	10.14	69 ~ 127	83	65 ~ 140	98	42 ~ 72	57
Club	Crew	7.21 ~ 10.92	9.45	42[b]	42	60 ~ 87	75	28 ~ 47	38
	Tres	7.42 ~ 11.17	9.67	24 ~ 32	28	50 ~ 65	59	20 ~ 36	29
	Hyak	7.84 ~ 11.27	9.83	141 ~ 194	166	130 ~ 160	141	58 ~ 78	70

[a] Sodium dodecyl sulfate sedimentation (SDSS) test.
[b] One sample tested.

parameters. The pattern of HMW-GS was identical for any single cultivar, independent of growing conditions.

The overall picture of protein content and the total area of HMW-GS of SWW and club wheats dependent on growing conditions is shown in Figure 5. The effect of growing conditions on protein content of both classes was similar. In each of seven locations, the average protein content of club wheats was lower than that of SWW. The effect of growing conditions on protein content accompanied the changes in total area of HMW-GS.

The effect of location on protein content and on content of HMW-GS of individual cultivars is summarized in Table VI. Two locations, Cavendish and Ritzville, recorded the lowest protein

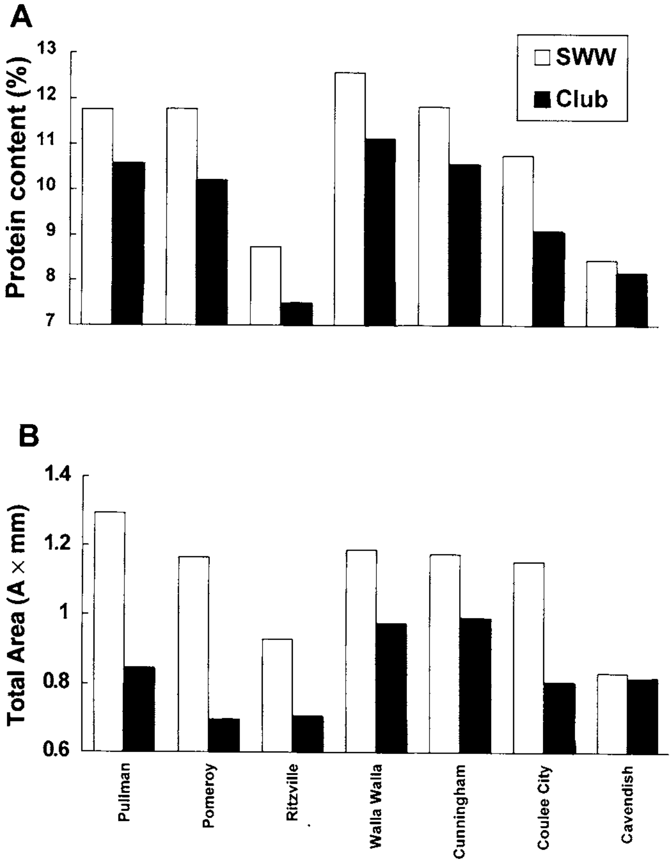

Fig. 5. Average protein content (**A**) and average total area of high molecular weight glutenin subunits (**B**) of three soft white winter (SWW) and three club wheats from seven locations.

for all six cultivars. Among the SWW wheats, Stephens showed distinctly lower total area of HMW-GS than Hill 81 and Madsen. Club wheat Tres had the lowest total area of HMW-GS of all wheats, followed by Crew. Such a low area of HMW-GS of Tres, Crew, and Stephens was discussed earlier. In general, the changes in total area of HMW-GS followed the changes in protein content, with the lowest total area of HMW-GS recorded in Cavendish and Ritzville. The statistically significant correlation coefficients of $r = 0.61$ ($P < 0.001$, $n = 40$) between the protein content and total area of HMW-GS have been obtained for combined SWW and club wheats over different growing conditions. The SWW wheats also showed significant correlation coefficient of $r = 0.66$ ($P < 0.05$, $n = 21$) between these parameters. However, there was no statistically significant relationship between these parameters for club wheats over growing conditions.

As far as the single cultivars are concerned, each of the three cultivars of SWW wheats showed good relationship over growing conditions between protein content and total area of HMW-GS. For Madsen and Stephens, the correlation coefficients ($r = 0.88$ and 0.86, respectively) were statistically significant ($P < 0.05$, $n = 7$). The three club wheat cultivars also showed a positive relationship between these parameters, but none was statistically significant.

The correlation coefficients between protein content or total area of HMW-GS and dough rheology and SDS sedimentation, for combined SWW and club wheats grown in seven locations, are listed in Table VII. The protein content showed statistically significant correlation with SDS sedimentation volume and mixograph water absorption, but not with mixing time. Also, the protein content did not show correlation with alveograph *W* for 17 samples (only 17 samples were tested due to size requirements). However, for the same number of samples, the total area of HMW-GS showed statistically significant correlation with dough rheology and a substantial increase of correlation coefficients with SDS sedimentation test for combined SWW and club wheats grown in several locations, which confirms the importance of HMW-GS in dough strength. The differences in gluten strength discussed earlier result from the protein content of HMW-GS and its quality score, the latter reflecting the presence of different bands. Therefore, high correlation between total area of HMW-GS and dough rheology or SDS sedimentation volume for combined samples can be said to be a varietal contribution. The HMW-GS pattern of cultivars investigated in this part of the study differed between cultivars (Table II), as well as gluten strength measured by dough rheology and SDS sedimentation test (Table V).

When a single cultivar grown in several locations was examined, it had the same HMW-GS pattern and quality score. As shown in Table VI, the responses of cultivars to growing conditions, as reflected in protein content and content of HMW-GS, were not the same.

TABLE VI
Protein Content (%) and Total Area (A × mm) of High Molecular Weight Glutenin Subunits of Soft White Winter (SWW) and Club Wheats Grown in Seven Locations and Harvested in 1990

Class	Cultivar		Pullman	Pomeroy	Ritzville	Walla Walla	Cunningham	Coulee City	Cavendish
SWW	Hill 81	Protein	11.91b[a]	11.53c	8.30e	12.42a	11.97b	10.45d	8.21f
		Total area	1.481ab	1.38b	1.04d	1.159cd	1.323bc	1.631a	0.811e
	Madsen	Protein	12.06d	13.73a	8.92f	13.42b	13.11c	11.71e	8.85f
		Total area	1.507a	1.402ab	1.02c	1.411ab	1.449a	1.21bc	1.081c
	Stephens	Protein	11.31b	10.08d	9.01e	11.83a	10.41c	10.07d	8.28f
		Total area	0.878b	0.717cd	0.73c	0.995a	0.76c	0.628de	0.604e
Club	Tres	Protein	10.64b	10.68b	7.42d	11.17a	NS[b]	8.44c	NS
		Total area	0.576	0.491	0.50	0.617	NS	0.565	NS
	Crew	Protein	10.32b	9.55d	7.21f	10.92a	9.97c	10.07c	8.08e
		Total area	0.824ab	0.492c	0.516c	0.888a	0.760ab	0.846ab	0.720b
	Hyak	Protein	10.75b	10.38c	7.84f	11.27a	11.12a	8.97d	8.26e
		Total area	1.139b	1.100bc	1.110bc	1.424a	1.218b	1.007cd	0.913d

[a] Different letters in the same row represent differences between means at the 5% level.
[b] No sample.

The mixograph curves depict the effect of protein content on the strength of gluten for a single cultivar (Fig. 6). For example, the mixograph curves of Tres club wheat grown in Walla Walla, with the highest protein content in this location, showed a mixograph pattern characterized by short mixing time and sudden breakdown after development of gluten. Therefore, even at high protein content, Tres, which had a low quality score, showed weakness in developing gluten. On the other hand, Hyak club wheat, which had a high quality score and a higher total area of HMW-GS, showed a mixograph pattern of much stronger gluten protein than the patterns of other cultivars. Hyak, grown in Walla Walla as well as Pullman, had long mixing time and strong dough with high resistance after development of the peak. At highest protein content, the SWW wheats, Hill 81 and Madsen, showed curves typical for gluten stronger than that in Tres, but weaker than that in Hyak. At low protein content it was difficult to detect the peak of gluten development for all cultivars because gluten was diluted by starch.

The increase of protein content that accompanies the increase in total area of HMW-GS in some cultivars might be of concern if the increase in protein is substantial for the cultivars with high HMW-GS quality score. For these cultivars, the increase in total protein, and consequently in HMW-GS, is equivalent to the increase of gluten strength measured by dough rheology and SDS sedimentation volume. The cultivars with low quality score HMW-GS may not create this problem, even with the increase of protein content, due to growing conditions.

TABLE VII
Correlation Coefficients between Protein Content, High Molecular Weight Glutenin Subunit Total Area, and Dough Rheology of Soft White Winter (SWW) and Club Wheat Cultivars Grown in Seven Locations and Harvested in 1990[a]

		Mixograph		
	Alveograph *W*	Mixing Time	Water Abs.	SDSS[b]
Protein, %	0.126	0.285	0.508**[c]	0.465*
	(17)	(31)	(40)	(40)
Total area, (A × mm)	0.584*	0.437*	0.771**	0.703**
	(17)	(31)	(40)	(40)

[a] Sample number indicated in parentheses.
[b] Sodium dodecyl sulfate sedimentation (SDSS) test.
[c] * = $P < 0.05$, ** = $P < 0.001$.

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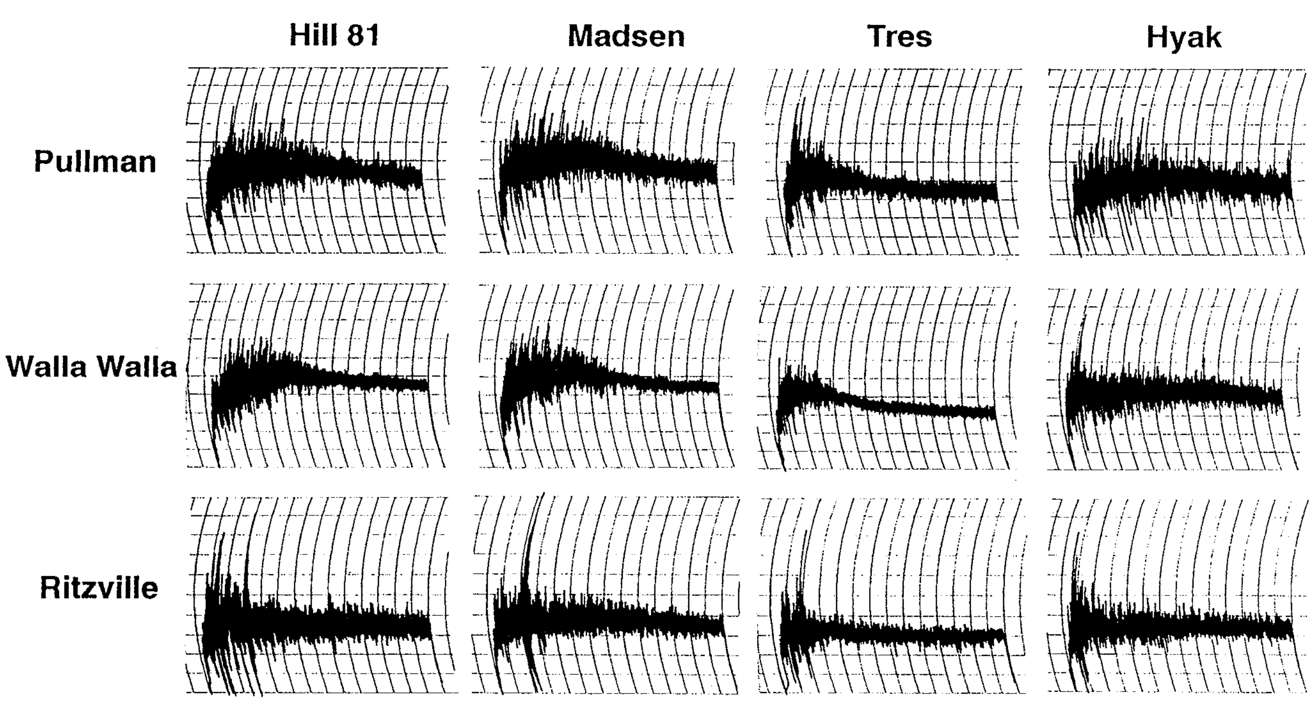

Fig. 6. Mixograms of Hill 81, Madsen, Tres, and Hyak wheat cultivars grown in 1990 from Walla Walla, Pullman, and Ritzville.

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