

# Protein Allelic Composition, Dough Rheology, and Baking Characteristics of Flour Mill Streams from Wheat Cultivars with Known and Varied Baking Qualities<sup>1</sup>

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## ABSTRACT

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Flour mill streams obtained by milling grain of 10 bread wheat cultivars grown in the Skopje region of Macedonia were analyzed for rheological and breadmaking quality characteristics and for composition of gliadins and HMW-GS. The objective of this study was to examine the relationships between the composition of gluten proteins and breadmaking quality, as well as to determine the importance of gluten proteins for technological quality of flour mill streams. The grain was milled in an experimental mill according to a standardized milling procedure, with three break and three reduction passages. The addition of two vibratory finishers in the milling scheme enabled better separation of bran. A small-scale baking method for evaluation of the breadmaking properties was

developed, and electrophoretic methods including acid-PAGE and SDS-PAGE were used to determine the composition of the gluten proteins. There were significant differences in the degree of dough softening of individual and total flour fractions of the flour mill streams for cultivars with different alleles from six loci, for farinograph water absorption from seven loci, and for bread loaf volume and crumb quality score from six loci. The Glu-1 quality scores for the wheat cultivars investigated were 3–9 and proved to be a useful indicator of breadmaking quality. The novel feature of the investigation related to the breadmaking potential of the flour mill streams compared with straight-run flours.

The technological qualities of wheat include many quality characteristics of kernel, flour, and bread such as structural-mechanical, chemical, milling, and baking, which are all important in the production of various kinds of baked products such as bread, pasta and cookies. So, the quality of wheat determines its suitability for a particular product and the usage value of the end products.

Baking quality is determined by the physical properties of dough, its oxidative properties, the flour water absorption, bread volume, and the color of the bread crumb and crust. The baking properties of a dough sample depend on the flour's ability to form dough that, after mixing and during fermentation, has appropriate physical properties. The strength thus contributed to the dough is an important part of the breadmaking quality of the flour.

Dough is a hydrated protein complex that has structure and physical-mechanical properties (elasticity, viscosity, and ability to relax) that make it suitable for breadmaking (Bloksma 1978). Flours with good technological quality should give bread with appropriate volume, regular shape, normal brown crust without cracks, and elastic crumb with fine, uniform pores and thin walls. A high bread volume yield indicates better baking properties and better bread crumb structure. The crumb quality score is a numerical expression of the organoleptic evaluation of the bread crumb. It represents a sum of the scores for elasticity and pore structure (Ponte 1978).

The principal component that influences flour strength is the protein fraction (Finney and Barmore 1948; Pomeranz 1988). Most of the significant proteins in dough correspond to the gliadin monomers and glutenin subunits from gluten (Kasarda et al 1976). Investigations using fractionation and reconstruction techniques on the gluten proteins have demonstrated the role of glutenin polypeptides for dough properties and baking performance (MacRitchie 1989, 1990, 1999) and in combination with gliadin monomers for producing optimum loaf volume (Chakraborty and Khan 1988). Physical and biochemical studies of flour proteins have also been conducted

including electrophoretic characterization (Jones et al 1983). The electrophoregrams of gluten proteins are characteristic for each wheat cultivar and they provide information useful for wheat technological quality (Payne et al 1979; Sozinov 1984; Autran 1987; Clements 1987; Menkovska et al 1987; Chakraborty and Khan 1988; Lukow et al 1990). Many researchers have pointed out the relationship between wheat rheological qualities and the composition of gluten proteins (Bernardin 1975; Wrigley 1982; Sozinov 1984; Branlard and Dardevet 1985; Lawrence 1987; Khan et al 1989; Bekes et al 1990; Khan et al 1990; Payne et al 1990; Dong et al 1992). Research has shown that glutenin subunits 1 and 5+10 are superior to the allelic null and 2+12 subunits, respectively (Payne et al 1984). Payne et al (1990) demonstrated allelic variation of *Glu-A1* and indicated that *Gli-A1*, genetically unlinked on chromosome 1A, *Glu-B1* and *Gli-B1* on chromosome 1B, as well as *Glu-D1* and *Gli-D1* on chromosome 1D, can strongly affect the rheological properties of dough and subsequent breadmaking qualities. Khan et al (1990) pointed out that subunits 8 and 9 are strongly associated with desirable rheological and breadmaking quality parameters.

We have reported the results of our investigations on kernel quality properties as indicators of milling properties for Macedonian wheat cultivars (Menkovska et al 1995c, 1997), on milling properties (Menkovska and Zezelj 1999) in relation to the composition of gluten proteins. We have also reported on the allelic variation at the loci for gluten proteins (Knezevic and Menkovska 1994; Knezevic et al 1994). Very little research was reported on the relationship of flour mill streams with respect to gluten composition and their technological properties. Thus, the objective of this study was to investigate the rheological and baking characteristics of the Macedonian wheat cultivars and the composition of their gluten proteins using various mill streams, thereby to find correlations between them.

## MATERIALS AND METHODS

### Wheat Cultivars

The study involved 10 wheat cultivars (*Triticum aestivum*) including seven hard winter wheat bread cultivars (Nova Skopjanka, Radika, Lihmida, Orovchanka, Babuna, Yugoslavia, and Skopjanka), two wheat standards (Partizanka and Super Zlatna, included as references for quality attributes), and one soft wheat cultivar (Pelagonia, taken for comparison) (Table I). The cultivars were grown on experimental fields at the Institute for Crops and Vegetables in the Skopje region of Macedonia during 1989–90. They were classified

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in three technological groups to reflect different technological qualities. Quality group 1 was the group of wheat improvers with excellent breadmaking quality (wheat standard Partizanka); quality group 2 was the group of bread wheats with satisfactory breadmaking quality (Nova Skopjanka, Radika, Lihnida, Orovchanka, Babuna, and Yugoslavia); quality group 3 was the group of wheats with poor breadmaking quality (wheat standard Super Zlatna and Skopjanka). The classification of the cultivars was done according to criterion of quality characteristics including protein content, Zeleny sedimentation value, yields of flour, bread, and loaf bread volume, as well as the bread crumb quality score (Sharic et al 1988).

### Flour Mill Streams

Wheat cultivars were cleaned and conditioned to 16% moisture for 18 hr. Standard milling was performed with an experimental mill (MLU-202, Bühler, Uzwil, Switzerland) with three break, three reduction passages, and two vibratory finishers to produce bran, shorts, and two streams of break and reduction flours (Menkovska 1993; Menkovska and Zezelj 1999). Twelve flour streams from each wheat cultivar were obtained and grouped into four fractions according to their similarity in quality and origins from the milling process. Fraction 1 was a blend of the first break flours; fraction 2 was a blend of the last break flours; fraction 3 was a blend of the first reduction flours; fraction 4 was a blend of the last reduction flours. The summary fraction was the total of the all fractions used for statistical analysis; 40 flour samples were analyzed for rheological and baking quality.

### Rheological Quality

With the micro-Brabender Farinograph, 10-g flour samples were evaluated for farinograph water absorption dough developing time, degree of dough stability, and degree of dough softening.

### Baking Quality

The baking test for the fractions of the flour mill streams was performed by a small-scale baking method (Menkovska 1993), using 50 g of flour and a basic baking formula containing flour, water (farinograph water absorption), fresh baking yeast and salt (2% each of the flour quantity used), and no oxidizing agents. The degree of dough softening determined dough consistency reduced for the water content in the yeast by 1.4% on a flour basis.

### Gliadins

Gliadin proteins were extracted from 250 mg of flour. They were fractionated by modified classical methods of acid-PAGE according to Bushuk and Zillman (1978) and by the electrophoretic method under high voltage according to Novoselskaya et al (1983). The gliadin proteins were determined as heredity blocks described by Metakovsky et al (1984) and Knezevic et al (1994). As a standard, the wheat cultivar Bezostaya-1, as well as the catalog of known patterns of gliadin blocks of other wheat cultivars, were used.

### HMW-GS

Glutenins, like gliadins, were extracted from 250 mg of flour and fractionated by SDS-PAGE according to Kasarda et al (1986). The composition of HMW glutenin subunits was determined according to Payne and Lawrence (1983) and identified as previously reported (Knezevic and Menkovska 1994; Menkovska et al 1997). *Glu-1* quality score was determined for wheat cultivars according to Payne (1986) and Payne et al (1987) by summing up the quality scores of specific glutenin subunits.

### Statistical Analysis

Student *t*-test (Spiegel 1972) and analysis of variance (*F*-test), (McPherson 1990) were used to determine significant difference of mean values of rheological and baking characteristics of the flour mill streams between the groups of cultivars possessing different alleles at the same loci.

## Composition of Gliadin Components

Identification of the gluten proteins determined by the A-PAGE and SDS-PAGE methods showed different numbers of alleles at each of the gliadin and glutenin encoded loci analyzed, as shown in Table II. Identified gliadin components from each block of each cultivar are presented in the form of genetic formulae. The alleles from *Gli-6B* were not analyzed because they were in small numbers in the wheat cultivars analyzed. Nova Skopjanka, Radika, Yugoslavia, and Lihnida, belonging to quality group 2, possess the allele 1B3; so does the cultivar Skopjanka, belonging to quality group 3.

## Relationship to Rheological Characteristics

On the basis of the presence of specific alleles at the each *Gli* and *Glu* locus, the wheat cultivars fell into groups and the average quality score was determined for all fractions of the flour mill streams. The *F*-test analyses showed significant and highly significant differences between average values of farinograph water absorption (WA), dough development time (DDT), and degree of dough softening (DDS) for individual and total flour fractions for the cultivars with different alleles from all loci analyzed (Table III). The highest average WA values were obtained from cultivars possessing *Gli-1A4* and *Gli-A11* for fraction 4, *Gli-1B3* for fractions 2, 4, and total, *Gli-1D1* for fraction 4, *Gli-1D2* for fractions 2, 4, and total, *Gli-6A1* for fractions 2 and 4, *Gli-6D1* and *Gli-6D4* for fraction 4, *Gli-6A6* for fractions 2, 4, and total, 2\* and null from the *Glu-1A* for fraction 4, 7+8 from *Glu-1B* for fractions 2, 4, and total, and 5+10 from *Glu-1D* for fraction 4. The highest average DDT values were obtained from cultivars with *Gli-1B1* for fractions 1 and 2, *Gli-6D1* for fraction 1, 7+9 from *Glu-1B* for fraction 1, and 5+10 and 2+12 from *Glu-1D* for fractions 2, 3, 4, and total. Cultivars that have exhibited the smallest DDS value possessed *Gli-1A11* for fraction 2, *Gli-1B1* for fraction 1, and *Gli-6D1* for fractions 2 and 3. The analysis by Student *t*-test (data not presented here) demonstrated also that gliadin block *Gli-1B3* makes a positive contribution to WA and DDS for the major fractions, while it has a negative relationship with DDT. A positive contribution to WA was also noted for *Gli-1A4*, *Gli-1D2*, *Gli-6A1*, and *Gli-6A6*. The block *Gli-1B1* has also a positive relationship with DDT, while the blocks *Gli-1D2* and *Gli-6D4* have a positive relationship with DDS.

## Relationship to Bread Loaf Volume

Using analysis of variance, the differences between cultivars with different alleles at almost all the particular loci analyzed from *Gli-1A* to *Gli-1D* were determined to be statistically significant (Table IV).

The groups of cultivars with the highest average values of loaf volume possessed 11 alleles from *Gli-1A* (for fraction 1), 1 allele from *Gli-1B* (for fraction 2), 1 from *Gli-1D* (for fraction 2), 1 from

TABLE I  
Pedigree of Wheat Cultivars Investigated

Cultivar	Breeding Center <sup>a</sup>	Year	Pedigree <sup>b</sup>
Partizanka (P)	NS	1973	Bez-1/NSR-116
Yugoslavia (Y)	NS	1980	NSR-646/Bez-1//Au
Nova Skopjanka (NS)	SK	1990	P/SK 302/S
Radika (R)	SK	1989	P/S//S
Lihnida (L)	SK	1990	S/BB
Orovchanka (O)	SK	1982	Bez-1/Arg., L-38
Babuna (B)	SK	1987	NSR-2/P//P
Super Zlatna (SZ)	ZG	1977	Sa/TP.114-1965 A//Sa, Zg470-66
Skopjanka (S)	SK	1982	Arg., L-197//Kavkaz
Pelagonia (Pe)	SK	1974	Selection of Arg

<sup>a</sup> NS, Novi Sad, SK, Skopje, ZG, Zagreb.

<sup>b</sup> Bez-1, Bezostaya-1; BB, Blue Boy; NSR, Novosadska Rana; Arg, Argelato; Au, Aurora; Sa, Sanja.

*Gli-6A* (from fraction 2), 1 from *Gli-6D* (for fraction 2), 2\* from *Glu-A1* (for fraction 1), 7+9 from *Glu-B1* (for fraction 2), and 5+10 from *Glu-D1* (for fraction 1). Of five bands analyzed, three showed positive relationships to bread loaf volume (Dong et al 1992). Khan et al (1989) showed that cultivars with subunits 7+9 from the *Glu-B1* locus had higher bread loaf volume. This was confirmed by our investigations on the cultivars Babuna, Yugoslavia, Nova Skopjanka, Partizanka, and Skopjanka. The average values of bread loaf volume for these cultivars were the highest among the other wheat cultivars analyzed (Menkovska 1995a,b). But cultivars Radika and Babuna, possessing subunits 7+9 at the *Glu-B1* locus, had average bread loaf volume values which were among the lowest compared with those of the other cultivars. These cultivars also contain the null subunit at the *Glu-A1* locus and 2+12 at *Glu-D1* locus, while cultivars showing higher values of bread loaf volume possessed subunit 2\* at the *Glu-A1* locus and 5+10 at the *Glu-D1* locus. This indicates the need to consider all the gluten proteins in attempting to predict processing attributes. The *t*-test indicated also that HMW-GS 2\*, 5+10, and 7+9 showed positive relationships to LV and CQS. For subunits null and 2+12, the opposite was proved. There were positive relationships for LV with the gliadin blocks *Gli-1A11*, *Gli-1D2*, *Gli-6A6*, and *Gli-6D1*, as well as with the block *Gli-1B3*, and significant relationship with CQS.

### Relationship to Crumb Quality Score

The *F*-test showed that differences were significant for the CQS values of the breads from specific fractions (2, 3, and 4) and the total fraction of the flour mill streams for all alleles at the *Gli* loci, except those at *Gli-6D*. Differences of the CQS values of individual fractions and total fractions were significant for the alleles at *Glu-1A* and *Glu-1B* (for fraction 2) and at *Glu-1B* (for fraction 3 and total) (Table IV). Bread made from fraction 3 of the flour mill streams of the cultivars with the highest value for crumb quality score had 11 alleles from *Gli-1A*, 3 alleles from *Gli-1B*, 1 from *Gli-1D*, 6 from *Gli-6A*, 1 from *Gli-6D*, 2\* from *Glu-A1*, 7+8 from *Glu-B1*, 7+9 from *Glu-1B*, and 5+10 from *Glu-D1* (Table IV).

### Glu-1 Quality Score

The Glu-1 quality score for the wheat cultivars analyzed ranged from 4 to 10, or from 3 to 9 using the corrected value for the rye translocation in wheat, indicated by the gliadin block *Gld-1B3* (Table II). The Glu-1 quality scores provided useful predictions of technological quality of the wheat cultivars investigated. Two wheat cultivars, Partizanka and Babuna, which had the highest Glu-1 score of 9, possessed the subunits 2\*, 7+9, and 5+10. The lowest

Glu-1 values of 3 and 4 were obtained for the first and the second biotypes of the cultivar Skopjanka, with subunits 0, 7+9, and 2+12, and 0, 7+8, and 2+12, respectively. A Glu-1 score of 4 was obtained for the cultivar Pelagonia with subunits 0, 7, and 2+12. The Glu-1 scores for the other wheat cultivars were between these values.

A reduction in DDT has been reported for hard wheats with the 1B/1R translocation, while the opposite has been claimed for soft wheats (Dhaliwal et al 1987). According to Fenn et al (1994), these 1B/1R translocation wheats have poorer milling and baking quality than the control wheats, yielding sticky doughs associated with poor gluten quality and low loaf volume. A reduction in DDT for the investigated bread wheat cultivars with the 1B/1R translocation (Radika, Lihvida, Nova Skopjanka, and Yugoslavia) was noted, while the soft wheat Pelagonia without the 1B/1R translocation exhibited the smallest DDT value. The average value of flour yield for these cultivars was smaller (with the exception of Yugoslavia). The soft wheat Pelagonia exhibited the smallest bread loaf volume value. Milling, rheological, and baking quality characteristics of soft wheat, according to Johanson et al (1999) are affected by genetic and environmental factors, rather than by translocation.

Much research has established the importance of the composition of both gliadins and HMW-GS on breadmaking quality, and our observations are generally consistent with the results of these investigations (Burnouf and Bouriquet 1980; Moonen et al 1982; Branlard et Derdevet 1985; Payne 1986; Autran 1987; Payne et al 1987, 1988; Van Gelder et al 1987; Lawrence et al 1988; Ng and Bushuk 1988).

## CONCLUSIONS

A-PAGE and SDS-PAGE techniques were used to identify and characterize heredity blocks of allelic variants of gliadins and HMW-GS glutenins. This resulted in the identification and differentiation of wheat cultivars. Significant differences in farinograph water absorption of individual and total fractions of the flour mill streams were found between cultivars with different alleles from seven loci (*Gli-1A*, *Gli-1B*, *Gli-1D*, *Gli-6A*, *Gli-6D*, *Glu-B1*, and *Glu-D1*); for dough development time from 6 loci (*Gli-1A*, *Gli-1B*, *Gli-1D*, *Glu-B1*, and *Glu-D1*), and for the degree of dough softening from 6 loci (*Gli-1B*, *Gli-1D*, *Gli-6A*, *Glu-A10*, *Glu-B1* and *Glu-D1*). Significant relationships were also demonstrated between the gliadin blocks or the HMW-GS and the baking characteristics of flour mill streams investigated. Significant differences in bread loaf volume of individual fractions and of the total fractions were found between cultivars with different alleles from 6 loci (*Gli-1A*, *Gli-*

TABLE II  
Composition of Gliadin Variants and HMW-GS of Wheat Cultivars Investigated

Cultivar	Gliadin Variant						HMW-GS					
	1A	1B	1D	6A	6B	6D	1A	1B	1D	Glu-1 Score	1B/1R <sup>a</sup>	Glu-1 Score <sup>b</sup>
Quality Group 1												
Partizanka	11	1	1	11	21	1	2*	7+9	5+10	9	-	9
Quality Group 2												
Babuna	4+11	1	1	1+11? <sup>c</sup>	21	1	2*	7+9	5+10	9	-	9
Lihvida	4	3	2	1	5	7?	2*	7+8	5+10	10	+	7
Yugoslavia	11	3	2	2	1	6	2*	7+9	5+10	9	+	6
Nova Skopjanka	11+4	3	2	6+1	11?	4(15)	2*	7+9	5+10	9	+	6
Orovchanka	4	1	1	1	2	4	0	7+9	2+12	5	-	5
Radika	4	3	1	6+2	1?	1	0	7+9	2+12	5	+	3
Quality Group 3												
Super Zlatna	4	4	12	11	30+25	18	1	6+8	2+12	6	-	6
							1	7+9	2+12	7	-	7
Skopjanka	4	3	2	6+2	1	4	0	7+9	2+12	5	+	3
							0	7+8	2+12	6	+	4
Pelagonia	5	16	1	2	?	4	0	7	2+12	4	-	4

<sup>a</sup> 1B/1R, wheat-rye chromosomal translocation.

<sup>b</sup> Corrected Glu-1 score for the 1B/1R

<sup>c</sup> Gliadin variants not determined with certainty.

1B, Gli-6A, Gli-6D, Glu-A1 and Glu-D1) and also for crumb quality score from 6 loci (Gli-1A, Gli-1B, Gli-1D, Gli-6A, Glu-A1, and Glu-B1).

Cultivars with similar genetic origin and similar composition of gluten proteins showed similarities in technological properties. This means that wheat technological quality can be predicted by determination of the composition of the gluten proteins. The investigations on the breadmaking potential of the flour mill streams of major Macedonian wheat cultivars, together with their gluten-protein composition, provided data that might be useful for the production of various wheat end products and for breeding new wheat cultivars with better quality.

The quality of flour mill streams depends on the wheat kernel quality and the milling process. The data obtained with this research

might serve for composing flours intended for a special purpose and for improving quality. This can be useful for the local grain industry, as well as for wheat breeding programs for better selection of the new wheat cultivars of desired quality. But, it must be realized that in addition to the gliadins and HMW-GS, other factors are also important, including the LMW-GS, the quantity of the gluten proteins, and other monomeric proteins, as well as other factors such as the distribution of molecular weight of HMW glutenins (Huang and Khan 1999a-c), as well as the ratio between HMW and LMW glutenin subunits (Gupta 1990). Relationships should also be considered for gliadins and LMW-GS to loaf volume and the quantity of specific gliadins ( $\gamma$ -gliadins) (Lew et al 1992), and the relationship of these gliadins to quantitative protein distribution to loaf volume (Huebner et al 1997). Attention should

**TABLE III**  
Relationship Between Specific Allelic Gliadin Variants and HMW-GS and Rheological Quality of Mill Fractions<sup>a</sup>

Fr	Parameter	Alleles															
		Gliadins										HMW Glutenins					
		1A4	1A11	1B1	1B3	1D1	1D2	6A1	6A6	6D1	6D4	1A2*	1A0	1B(7+8)	1B(7+9)	1D(2+12)	1D(5+10)
1	WA	62.3	63.0	62.4	64.7	60.8	65.0	64.0	64.7	62.6	61.8	63.7	61.5	66.7	63.4	59.6	63.7
	F	23.67**		3.34		3.42		5.62		15.75*		1.45		7.83*		1.85	
	DDT	4.1	5.4	6.9	3.9	5.1	3.8	5.4	3.8	5.3	4.3	4.7	4.4	3.1	5.3	3.7	4.7
2	WA	66.3	65.7	66.1	67.2	64.4	67.3	67.7	67.0	65.8	64.6	66.5	64.6	68.1	66.5	63.8	66.5
	F	8.54**		1.08		1.38		1.58		2.03		2.03		2.71		1.18	
	DDT	3.8	3.3	5.0	2.9	3.9	2.8	4.6	2.8	3.6	3.6	3.3	3.7	2.5	3.9	3.5	3.3
3	WA	61.5	61.3	60.7	63.5	59.4	64.0	63.1	63.5	60.9	60.8	62.4	60.3	65.8	61.9	58.8	62.4
	F	320.28*		3.35		4.54		18.84*		15.35**		1.67		7.39		1.63	
	DDT	1.2	2.1	2.1	1.3	1.7	1.2	1.4	1.1	2.2	0.8	1.8	1.0	1.1	1.6	1.0	1.8
4	WA	70.4	71.8	69.5	74.0	68.2	74.6	71.8	74.7	70.0	71.0	72.2	69.7	75.5	71.9	67.6	72.2
	F	7.31*		6.91*		7.09*		1.50		18.10**		1.62		2.32		1.70	
	DDT	2.4	2.4		2.8	2.1	2.2	2.6	2.4	2.3	2.2	2.2	2.1	2.0	2.6	2.1	2.2
Summary	WA	65.1	65.5	64.7	67.4	63.2	67.7	66.7	67.5	64.8	64.5	66.2	64.0	69.0	65.9	62.5	66.2
	F	35.74**		2.87		7.29*		4.82*		59.30**		1.43		3.26		4.22*	
	DDT	2.9	3.3	4.2	2.6	3.2	2.5	3.5	2.5	3.3	2.7	3.0	2.8	2.2	3.3	2.6	3.0
Summary	WA	81.5	67.9	41.7	97.3	67.0	101.6	72.5	90.0	56.7	88.7	77.3	88.8	118.8	69.1	87.3	77.3
	F	1.68		11.56**		4.00		1.59		2.66		2.49		6.37*		2.67	

<sup>a</sup> Fr, milling fraction; Summary fraction, all fractions; WA, farinograph water absorption; DDT, degree of dough development time; DDS, degree of dough softening; F, Fisher test. Significant and highly significant = \* and \*\*, respectively.

**TABLE IV**  
Relationship Between Specific Allelic Gliadin Variants and HMW-GS and Baking Quality of Mill Fractions<sup>a</sup>

Alleles	N	Quality Parameter																			
		Fraction 1				Fraction 2				Fraction 3				Fraction 4				Summary Fraction			
		LV	F	CQS	F	LV	F	CQS	F	LV	F	CQS	F	LV	F	CQS	F	LV	F	CQS	F
1A4	3	366		4.6		389		2.3		360		5.3		305		1.3		355		3.4	
1A11	6	413	3.15	5.3	1.63	373	7.24*	1.2	1.19	380	1.03	6.2	1.30	323	1.82	1.2	9.00*	372	1.03	3.5	90.98**
1B1	3	392		5.0		435		3.0		358		5.8		305		1.2		373		3.8	
1B3	5	394	70.05**	5.4	1.50	374	5.10	1.5	1.63	384	11.24*	6.0	3.73	320	1.45	1.5	2.13	368	12.93**	3.6	29.44**
1D1	5	369		4.5		406		2.4		357		5.0		310		1.3		306		3.3	
1D2	4	398	1.06	5.3	1.46	375	1.08	1.5	1.44	385	4.90	6.0	1.06	325	2.02	1.5	4.50	371	2.16	3.6	7.93**
6A1	3	380	12.52*	5.0	1.00	428	1.34	3.0	1.73	368	2.07	5.7	1.00	311	11.69*	1.5	0.00	372	6.46*	3.8	47.95**
6A6	3	383		5.3		380		1.8		378		6.0		316		1.5		364		3.7	
6D1	3	399	2.43	5.3	1.27	404	44.54**	3.0	1.06	371	5.8	5.8	2.08	312	26.29**	1.5	1.40	371	1.23	3.9	1.29
6D4	4	355		4.1		398		1.8		355		4.9		315		1.3		356		3.0	
1A2*	5	404	4.42	5.2	1.18	389	15.53**	2.2	6.21*	380	2.98	5.9	1.00	324.0	2.63	1.5	2.83	374	1.98	3.7	1.32
1A0	4	355		4.4		397		1.8		356		4.9		307.0		1.3		354		3.1	
1B(7+8)	2	384	3.08	5.0	1.61	374	1.47	2.0	89.36**	382	1.62	6.0	21.86**	324.0	1.18	2.0	3.49	366	13.53**	3.8	66.88**
1B(7+9)	7	395		5.3		403		2.1		372		5.9		312.0		1.2		371		3.6	
1D(2+12)	5	404	6.48*	5.2	2.05	389	6.38*	2.2	2.12	380	4.47	5.9	2.04	324.0	4.38	1.5	1.00	374	5.50*	3.7	2.06
1D(5+10)	5	404		5.2		389		2.2		380		5.9		324.0		1.5		374		3.7	

<sup>a</sup> Summary fraction, all fractions; LV, bread loaf volume; CQS, crust quality score; F, Fisher test. Significant and highly significant = \* and \*\*, respectively.

also be paid to the importance of size distribution for the glutenin polymers in relation to environmental influences (Wrigley and Bekes 1999).

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