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Relationships Between Chromosome 1B-encoded Glutenin Subunit Compositions and Bread-making Quality Characteristics of Some Durum Wheat (*Triticum turgidum*) Cultivars

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ABSTRACT

The high and low M_r glutenin subunit compositions (controlled by the *Glu-1* loci and the *Glu-B3* locus, respectively) and the bread-making quality characteristics of 26 durum wheat (*Triticum turgidum*) genotypes were determined. The relationships between quality parameters and *Glu-B1* and *Glu-B3* controlled glutenin subunit composition were also investigated. The *Glu-A1*-controlled null allele was present in all the genotypes. High M_r subunits 20, 6+8 and 7+8 occurred in similar proportions in the cultivars analysed. The *Glu-B3* low M_r allelic variants, LMW-1 and LMW-2, were both represented, with LMW-1 being present in lower proportion. Flour protein, SDS-sedimentation volume, dough strength (Alveograph *W* value), dough mixing time and bread loaf volume varied among the genotypes. Most samples had high Alveograph tenacity/extensibility (*P*/*G*) ratios, typical of tenacious gluten character. SDS-sedimentation volume, dough strength, dough mixing time and bread loaf volume were all interrelated. An association with flour protein content was observed only for mixing time, while the Alveograph tenacity/extensibility ratio was not correlated with the other parameters. Comparisons within the *Glu-B1* and *Glu-B3* loci indicated that the high M_r subunit 7+8 and the low M_r subunit LMW-2 had significantly greater beneficial effects on gluten strength and bread-making quality than the high M_r subunits 6+8 or 20 and the low M_r subunit LMW-1, respectively. High M_r subunit 6+8 had greater beneficial effects on quality than subunit 20.

INTRODUCTION

Gliadin and glutenin proteins interact in the presence of water to form gluten, the protein complex responsible for the viscoelastic properties that make durum wheat (*Triticum turgidum*) important for pasta making and bread wheat (*Triticum aestivum*) important for bread making. The use of durum wheat in bread production is very limited, mainly because its bread-making quality is inferior to that of bread wheat.

This quality difference is partly due to the lack of the D-genome, particularly chromosome 1D, which encodes genes that control some of the gluten proteins contributing to bread-making quality[1–6]. Despite this, intergenotype variability in bread-making quality does exist in durum wheat; some genotypes approach the good bread-making quality of bread wheats[7].

In durum wheat, chromosome 1B-encoded proteins have greater effects on gluten strength, spaghetti cooking quality and on bread-making quality than proteins controlled by any other chromosome[8–10]. Boggini and Pogna[10] examined the relationship between storage protein composition and bread-making quality in 37 Italian durum wheats and found that both high M_r

ABBREVIATIONS USED: M_r = relative molecular mass; LMW = low molecular weight; SDS = sodium dodecyl sulphate; PAGE = polyacrylamide gel electrophoresis; FP = flour protein; SDS-s = SDS-sedimentation; *W* = strength; *P* = tenacity; *G* = swelling (extensibility); MT = mixing time; LV = loaf volume.

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glutenin subunits and γ-gliadins, controlled by genes at the *Glu-B1* and *Gli-B1* loci[9,11], respectively, were associated with variation in viscoelastic properties and bread-making quality; cultivars having γ-gliadin 45 (and, by analogy due to genetic linkage[10,11], *Glu-B3*-controlled low M_r subunit LMW-2) and/or high M_r 7+8 gave higher bread loaf volumes than those possessing type γ-gliadin 42 and/or high M_r subunits 20 or 6+8.

At the International Maize and Wheat Improvement Center (CIMMYT), durum and bread wheat germplasm is used for a two-way movement of important traits using intra-specific (bread × durum) and inter-specific (durum × *T. tauschii* = synthetic hexaploids) hybridization. One concern would be the introgression of undesirable durum wheat glutenin subunits into bread wheat. To avoid this, it is necessary to use parental durum germplasm with desirable bread-making quality characteristics and suitable glutenin subunit compositions. Boggini and Pogna[10] have documented the different effects of allelic variants at the *Glu-B1* and *Gli-B1* loci on the bread-making quality of durum wheat, but research findings in this area are scarce.

Our present study examines the interrelationship between glutenin (high and low M_r) subunit compositions, gluten quality characteristics and bread-making properties for some of our durum wheat cultivars that are considered as potential parental germplasm in inter-specific and inter-generic hybridization aiming at incorporating resistances/tolerances to several biotic–abiotic stresses.

EXPERIMENTAL

Plant material

Twenty-six durum wheat (*Triticum turgidum*) genotypes were grown under irrigation in Cd. Obregon, Sonora, Mexico, during 1990–1991 (Table I) by the durum breeding programme. One kilogram of seed was provided for analyses. The material was grown in a randomized complete block design of four replications. Plot size was of 6 rows of 5 metres each.

Analysis of total proteins by sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS–PAGE)

Total reduced proteins were fractionated in vertical SDS–PAGE slab gels in a discontinuous buffer system[12], using a 4% acrylamide stacking gel, and a 8·7% acrylamide separating gel. High and low M_r glutenin subunits were designated according to the numbering system of Payne and Lawrence[13] and Payne *et al.*[11].

Quality measurements

Flour (straight-run) samples were produced on a Brabender Quadrumat Senior mill for duplicate quality analysis. Flour protein (N × 5·7) was determined using the Kjeldahl procedure 46-14 of the AACC[14] and SDS-sedimentation volume was determined on 1-g flour samples as described previously[15]. Alveograph characteristics (gluten strength value, *W*, and tenacity/extensibility, *P/G*, ratio) were determined according to the manufacturer's instructions, using 60-g flour samples and variable absorption (55–60%) to maintain uniform dough handling consistency as judged by the operator. Variable absorption was used because milling of the typically hard-grained durum wheat into flour was assumed to result in high levels of damaged starch and, consequently, in higher than normal (50%) water absorption requirements in the Alveograph determination.

Bread-making characteristics

Bread was baked using the straight-dough, (100-g flour formula) baking test 10-10 of the AACC[14], adjusting water absorption to maintain uniform dough handling consistency as judged by the baker. Crumb structure (gas-cell size and size distribution) was scored as very poor, poor, fair, good and very good.

Statistical analysis

The results were analysed statistically with the SAS computer package[16], including simple correlation coefficients between quality parameters, and analysis of variance for the quality parameters, considering high M_r and low M_r subunits as treatments.

RESULTS AND DISCUSSION

Glutenin subunit compositions

All the lines examined had the null allele at the *Glu-A1* locus. Three *Glu-B1* allelic variations were

Table I Identification and glutenin subunit compositions of *Triticum turgidum* cultivars

Durum wheat lines		Glutenin subunits	
No.	Pedigree	High M_r	Low M_r
DW1	CHEN 'S'	7+8	2
DW2	MEMO 'S'/MEX 75	7+8	2
DW3	ROK 'S'/KMLI 'S'	20	2
DW4	ALTAR 84	7+8	2
DW5	CNDO/R143/ /ENTE 'S'/MEXI 'S'	7+8	2
DW6	LARU 'S'	6+8	1
DW53	68111/RUGBY/ /WARD RESEL/3/STIL 'S'	7+8	2
DW54	68111/RUGBY/ /WARD	6+8	1
DW55	68111/RUGBY/ /WARD/3/FG 'S'/4/RABI 'S'	6+8	2
DW57	CPT/GEDIZ 'S'/3/GOO 'S'/ /JO 'S'/CR 'S'	20	2
DW58	D67.2/P66.270	20	1
DW59	DACK 'S'/KIWI 'S'/ /WARD/3/RUFF 'S'/FG 'S'	20	1
DW60	STN 'S'	20	2
DW61	RABI 'S'/ /GS 'S'/CR 'S'	6+8	1
DW62	SBA 81/CR 'S'/ /CIT 'S'/3/CHI 'S'/4/PAL 'S'	7+8	2
DW63	SCA 'S'	7+8	2
DW64	SNIPE 'S'/YAV 'S'/ /DACK 'S'/TEAL 'S'	6+8	2
DW65	TK SN 1081	6+8	2
DW67	YUK	6+8	2
DW68	DOY 1	6+8	2
DW69	GR 'S'/BOY 'S'	20	2
DW71	AROS 'S'	7+8	2
DW72	GAN 'S'	6+8	2
DW73	MEXI/VIC//YAV 79	6+8	2
DW75	YAV 'S'/DACK 'S'/RABI 'S'/3/SNIPE 'S'	7+8	2
DW76	YAV 'S'/SCO 'S'/ /JO 'S'/CR 'S'/3/YAV 79	20	2

present (Table I): high M_r subunits 7+8, 6+8 and 20 found in nine, ten, and seven cultivars, respectively. Although more than three *Glu-B1* glutenin subunits have been reported in durum wheat[10,17], the above three subunits are observed more frequently in such wheats[9,10,17].

Both low M_r subunits LMW-1 and LMW-2 were present in the germplasm examined (Table I), the first in five and the latter in 21 cultivars. Considering that, in durum wheat, subunit LMW-2 is associated with medium–strong to strong gluten types[9], the low frequency of subunit LMW-1 in this population is more likely due to the selection (with SDS-sedimentation) for gluten strength applied in CIMMYT's durum wheat germplasm. All but one possible high M_r/low M_r glutenin subunit combinations were found in this durum wheat population (Table I).

Quality characteristics

Mean values and ranges of values for the quality characteristics of the population examined are presented in Table II. Flour protein content varied within the population from 9·6 to 12·4%. Large variations were observed for all the gluten strength-related parameters; SDS-sedimentation, Alveograph strength value *W* and dough mixing time. With the exception of three genotypes (DW1, DW2 and DW6), which had intermediate Alveograph *P/G* values (6·0, 5·6, 6·2, respectively), indicative of slightly tenacious gluten character, all samples had high *P/G* values, corresponding to tenacious gluten type.

Bread loaf volume also varied widely (Table II). Seven genotypes produced breads with large (for durum wheat) volumes (>620 ml) with good to very good crumb structure (small, elongated and evenly distributed gas cells). Seven other genotypes gave intermediate loaf volumes (550) to 615 ml) with fair to good crumb structures, while 12 other genotypes gave low loaf volumes (410 to 575 ml) with fair to very poor crumb structures. These results show that, although

Table II Quality characteristic mean values and ranges of values of *Triticum turgidum* lines

Cv No.	FP[a] (%, 14% mb)	SDS-s (ml)	Alveograph		Bread making	
			(*W*)	(*P/G*)	MT (min)	LV (ml)
Mean	11·4	13·0	242	9·6	3·0	572
Range	9·6–12·4	4·0–19·5	51–468	5·6–14·4	1·2–5·0	410–740

[a] FP = flour protein; SDS-s = SDS-sedimentation volume; *W* and *P/G* = Alveograph strength ($W \times 10^{-4}$J) and tenacity/extensibility ratio, respectively; MT and LV = dough mixing time and loaf volume, respectively.

Table III Correlation coefficients between bread-making quality-related characteristics in *Triticum turgidum*

	SDS-s[a]	*W*	*P/G*	MT	LV
FP[a]	−0·142	−0·003	−0·029	−0·412*	−0·026
SDS-s		0·728***	−0·154	0·719***	0·821***
W			0·212	0·461*	0·622***
P/G				−0·147	−0·367
MT					0·597**

[a] Abbreviations as in Table II. Significance: *, **, ***, $P < 0·05$, 0·01, 0·001, respectively.

durum wheat has typically tenacious gluten, in some cases it is possible to produce bread with acceptable quality.

Statistical analysis showed flour protein to be correlated ($P < 0·5$) only with mixing time. The Alveograph *P/G* ratio was not significantly correlated with any gluten strength parameter or loaf volume (Table III). This result may have been influenced in part by the limited variability in the Alveograph extensibility parameter, *G*, (data not shown) of the population examined. In contrast, SDS-sedimentation volume, Alveograph *W* value, mixing time and loaf volume were all interrelated (Table III). The highly significant relationship between SDS-sedimentation volume and bread-making quality-related parameters suggests that this small-scale test may be of great value for the rapid identification of good bread-making durum wheats.

Boggini and Pogna[10] obtained significant correlations between loaf volume and flour protein as well as between SDS-sedimentation volume and Farinograph dough development time in an Italian durum wheat population. They found that harvest year greatly influenced the significance of the correlations between flour protein and loaf volume, however, whilst little environmental effect occurred in the case of the relationship between loaf volume and SDS-sedimentation volume or Farinograph dough development time.

Relationship between *Glu-B1*-controlled high M_r glutenin subunits and quality characteristics

To examine the relationship between chromosome B-encoded glutenin composition and bread-making quality parameters, the genotypes were grouped into *Glu-B1*, *Glu-B3* and *Glu-B1/Glu-B3* genotypic groups.

The mean values for quality characteristics of the *Glu-B1* groups are presented in Table IV. Flour protein, SDS-sedimentation volume and the tenacity/extensibility (*P/G*) ratio were not significantly different among the three groups. The results showed, however, that genotypes with high M_r subunits 7 + 8 tended to have larger SDS-sedimentation values than those with high M_r subunits 6 + 8 or 20. This latter observation agrees with findings by Pogna *et al.*[9] in their study with Italian durum wheats. Both the Alveograph strength values, *W*, and the mixing times of the

Table IV Mean values for quality characteristics of *Triticum turgidum* cultivars grouped according to *Glu-B1*-controlled high M_r glutenin subunit composition

Glu-B1 subunit group	*n*	FP[a]	SDS-s	Alveograph		Bread making	
				W	*P/G*	MT	LV
20	7	11·4*a*[b]	11·5*a*	185*a*	10·0*a*	2·5*a*	512*a*
6+8	10	11·5*a*	12·1*a*	226*ab*	9·9*a*	2·8*ab*	546*a*
7+8	9	11·3*a*	15·2*a*	304*b*	9·0*a*	3·8*b*	648*b*

[a] Abbreviations as in Table II.

[b] Values in the same column followed by the same *italic* letter are not significantly different ($P<0·05$).

Table V Mean values for quality characteristics of *Triticum turgidum* cultivars grouped according to *Glu-B3*-controlled low M_r glutenin subunit composition

Glu-B3 subunit group	*n*	FP[a]	SDS-s	Alveograph		Bread making	
				W	*P/G*	MT	LV
LMW-1	5	11·9	6·8	128	10·3	1·5	480
LMW-2	21	11·3	15·0	297	9·1	3·7	638

[a] Abbreviations as in Table II.

group possessing subunit 7+8 were slightly greater than, but not significantly different from, those of the 6+8 group. The 7+8 group had significantly larger *W* values and longer dough mixing times than the 20 group (Table IV). Pogna *et al.*[9] observed a relationship between *Glu-B1* encoded high M_r subunit compositions and gluten strength in durum wheat. Our results also indicate that high M_r glutenin subunit composition is a good indicator of gluten strength in durum wheat, contrary to the suggestion of Du Cros[18].

The 7+8 group had significantly larger loaf volumes than the groups possessing either subunits 6+8 or 20 (Table IV), an observation similar to that of Boggini and Pogna[10]. The difference in loaf volume between the groups having subunits 6+8 and 20 was small and insignificant. Boggini and Pogna[10], however, found that subunit 20 was superior to subunit 6+8 in this respect. This indicates that other quantitative or qualitative factors, such as gliadin and/or low M_r glutenin subunit composition, could play a role on determining bread-making quality and may, therefore, modulate the contribution to quality of the high M_r glutenin subunits.

Relationship between *Glu-B3*-controlled low M_r glutenin subunits and quality characteristics

The differential effect of the low M_r glutenin subunit groups LMW-1 and LMW-2 on dough strength in pasta making was examined in relation to their influence on bread-making quality. Table V shows the mean quality data for the two durum low M_r glutenin subunit groups. Both groups had similar intermediate flour protein contents and large (tenacious type) *P/G* values. In contrast, the LMW-1 group had lower values for SDS-sedimentation volume, Alveograph *W* value, dough mixing time and loaf volume than the LMW-2 group. This difference in bread making performance for the two low M_r subunit groups is consistent with the results of Boggini and Pogna[10], who concluded that the observed effects of γ-gliadins 42 and γ-gliadin 45 on loaf volume results from linkage with low M_r subunits LMW-1 and LMW-2, respectively.

Table VI Mean values for quality characteristics of *Triticum turgidum* cultivars carrying low M_r subunit LMW-2 and grouped according to high M_r glutenin subunit composition

High/low M_r glutenin combination	*n*	FP[a]	SDS-s	Alveograph		Bread making	
				W	*P/G*	MT	LV
20/LMW-2	5	11·3*a*[b]	14·1*a*	213*a*	9·6*a*	2·9*a*	547*a*
6+8/LMW-2	7	11·3*a*	13·9*a*	264*ab*	9·9*a*	3·3*a*	558*a*
7+8/LMW-2	9	11·3*a*	15·2*a*	304*b*	9·0*a*	3·8*a*	648*b*

[a] Abbreviations as in Table II.

[b] Values in the same column followed by the same *italic* letter are not significantly different ($P<0·05$).

Relationship between high M_r and low M_r glutenin subunit combinations and quality characteristics

Variation in some parameters related to bread-making quality of the present durum wheat population appeared to be influenced by allelic variation at the *Glu-B1* and *Glu-B3* loci. Therefore, we examined the effect of different high M_r glutenin subunit compositions in combination with the low M_r glutenin subunit LMW-2 on bread-making performance. The results are shown in Table VI. The differences in flour protein, SDS-sedimentation volume, Alveograph tenacity/extensibility ratio (*P/G*) and dough mixing time among the three high M_r glutenin subunit groups compared (20/LMW-2, 6+8/LMW-2, 7+8LMW-2) were not significant. The 7+8/LMW-2 group had significantly greater gluten strength (*W* value) than the 20/LMW-2 one and slightly, but not significantly, greater gluten strength than the 6+8/LMW-2 group. The 7+8/LMW-2 group showed significantly larger loaf volume than the other two combinations, confirming that the high M_r glutenin subunit 7+8 was superior to subunits 6+8 or 20 in its contribution to bread-making quality, with the latter two groups exerting a similar quality effect.

The results of this study (Tables IV–VI) suggest that in the durum wheat population examined, allelic variations at *Glu-B1* and *Glu-B3* have little influence on flour protein content and on dough extensibility, as measured with the Alveograph. Also, variation at the *Glu-B3* locus is more important than that at *Glu-B1* in relation to the SDS-sedimentation volume. In contrast, variation at the *Glu-B1* locus is more important than that at *Glu-B3* in determining bread-making quality. Variations at both loci had a similar contribution to gluten strength. In this respect, Pogna *et al.*[9] found that high M_r glutenin subunit 7+8 and low M_r glutenin subunit LMW-2 had positive (additive) effects on gluten strength in durum wheat.

CONCLUSIONS

The differences in bread-making quality-related characteristics among the durum wheats examined is partly explained by variations in both high and low M_r glutenin subunit composition. Durum wheats combining high M_r glutenin subunit 7+8 with low M_r glutenin subunit LMW-2 are the best choice (quality-wise) in intra- and inter-specific hybridisation in the *Triticeae*. Crosses should be avoided with genotypes combining high M_r glutenin subunit 20 with low M_r subunit LMW-1.

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