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Dough Rheology of Wheat Recombinant Lines in Relation to Allelic Variants of *Glu-1* and *Glu-3* Loci

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The influence of allelic variants of HMWG and LMWG on viscoelastic properties of dough was evaluated in parents and 98 recombinant lines derived from the crosses Rebeca F2000 × Verano S91 and Galvez M87 × Bacanora T88. Genotypes were grown at Roque, Guanajuato during the Spring–Summer of 2008. Studied traits were mixing time, mixing stability and over-mixing tolerance, general strength of the dough and tenacity/extensibility ratio. HMWG alleles 1, 2*, 17 + 18 and 5 + 10 favored the quality of the dough and variants 2 + 12 and 7 + 9 were associated with low levels of gluten strength. A 7 + 9 allele was associated with genotypes prone to form tenacious dough. Alleles *Glu-A3c, Glu-A3e, Glu-B3g* and *Glu-B3h* from the cross Rebeca F2000 × Verano S91 affected positively the quality of gluten, while allelic variants *Glu-A3b, Glu-B3h* and *Glu-D3c* in the cross Galvez M87 × Bacanora T88 were associated with higher quality standards and its counterparts *Glu-A3c, Glu-B3j* and *Glu-D3b* were associated to lower quality parameters. Results also shown interaction among loci, hence breeders need to be aware not only of the effect of individual alleles but also its interaction.

Keywords: *Triticum aestivum* L., glutenin variants, quality of the dough

Introduction

In Mexico, bread wheat (*Triticum aestivum* L.) is classified on the basis of strength and extensibility of gluten into Group 1, strong and extensible gluten, with W values larger than 300×10^{-4} J and P/L < 1, Group 2, medium-strong and extensible gluten, with values of W between 200 and 300×10^{-4} J and P/L < 1; Group 3, weak and extensible gluten, with values of W less than 200×10^{-4} J and P/L < 1 and Group 4; tough gluten with little stretch P/L > 1.2.

The viscoelastic properties (strength and extensibility) of gluten, define the quality of the dough and their manufacture for bread, biscuits and pastries. In turn, the gluten

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strength and extensibility depends on the presence of specific alleles of gliadin and glutenin, high and low molecular weight (HMWG and LMWG) (Flaete et al. 2003; He et al. 2005 and Cornish et al. 2006) and its interactions (Eagles et al. 2002; Békés et al. 2006 and Cornish et al. 2001).

The individual and combined effect of HMWG (complex *Glu-1*) in Mexican bread wheat has been distinguished mainly for promoting the strength of the dough (De la O et al. 2006; Martinez-Cruz et al. 2007a; Espitia et al. 2008). On the other hand, LMWG (complex *Glu-3*) mainly affect the extensibility of gluten (Liu et al. 2005). It has been found in Mexican wheats that allelic variations of the *Gli-1*/*Glu3* linkage complex (controlling gliadins and ω-LMWG, respectively) affect the strength and extensibility of the dough, depending on the presence of HMWG (Martinez et al. 2007b). However, there are no studies aimed to define the individual effect of LMWG as they are controlled by allelic variants of the *Glu-3* complex, comprising loci *Glu-A3, Glu-B3* and *Glu-D3;* thus, the aim of this study was to identify the effect of the alleles that code for HMWG and LMWG in lines derived from crosses Rebeca F2000 × Verano S91 and Galvez M87 × Bacanora T88.

Materials and Methods

Plant material and field evaluation

Progenitors were evaluated along with 98 F_6 lines obtained by single seed descent from crosses Rebeca F2000 × Verano S91 and Galvez M87 × Bacanora T88. The progenitors have alleles as shown in Table 1. Recombinant lines from the Rebeca F2000 × Verano S91 cross made it possible to comparatively study the effects of allelic variants 1 vs. 2* *(Glu-A1),* 5 +10 vs. 2 +12 *(Glu-D1),* c vs. e *(Glu-A3)* and g vs. h *(Glu-B3)* on rheological traits, while lines derived from Galvez M87 × Bacanora T88 allowed to contrast the effects of allele 1 vs. 2* *(Glu-A1),* 17 +18 vs. 7 +9 *(Glu-B1),* b vs. c *(Glu-A3),* h vs. j *(Glu-B3)* and c vs. b *(Glu-D3)*. Genotypes were grown at Roque, Guanajuato, Mexico during the 2008 Spring-Summer cycle under a randomized complete blocks experimental design with two replications. The experimental unit consisted of four 3-m long rows spaced 30 cm from each other.

Table 1. HMWG and *LMWG* subunits of the parents used in the crosses of the study

Progenitor	HMWG loci			LMWG loci		
	Glu-A1	*Glu-B1*	*Glu-D1*	*Glu-A3*	*Glu-B3*	*Glu-D3*
Rebeca F2000	1	17+18	5+10	c	g	b
Verano S91	2*	17+18	2+12	e	h	b
Gálvez M87	1	17+18	5+10	b	h	c
Bacanora T88	2*	7+9	5+10	c	j	b

Quality variables assessed

The mixing time (MT), mixing stability (MS) and over-mixing tolerance (OMT) were determined in 35 g of refined flour at the Mixograph using the 54-40A Method (AACC

2005). High values of mixing time and stability and low values of over-mixing tolerance are associated to increased dough strength. The general strength properties (W) and the dough tenacity/extensibility ratio (P/L) were calculated out of an alveogram, using 50 g of refined flour in the Alveograph by applying the 54-30A Method (AACC 2005). Electrophoretic analysis of allelic variants was performed using the Peña et al. (2004) protocol. Identification of HMWG and LMWG variants in the lines was conducted at the Wheat Industrial Quality Laboratory at the International Maize and Wheat Improvement Center (CIMMYT). HMWG loci (*Glu-A1, Glu-B1* and *Glu-D1*) were identified based on the nomenclature proposed by Payne and Lawrence (1983) and LMWG loci (*Glu-A3* and *Glu-B3*) according to Singh et al. (1991); Jackson et al. (1996) and Branlard et al. (2003). For the *Glu-D3* locus the nomenclature proposed by Branlard et al. (2003) was used.

Statistical analysis

One-way analyses of variance were performed for each of the crosses, including all the evaluated variables. The genotypes source of variation was grouped and an additional analysis of variance was performed in order to calculate mean squares for loci combinations and each specific locus. Means comparison was also performed by using the Tukey test (P ≤ 0.05) through the GLM procedure of SAS (SAS Institute 2002) to determine differences between loci.

Results

Rebeca F2000 × Verano S91 cross

Table 2 presents the mean squares of the analysis of variance by genotypes, loci combinations of HMWG and LMWG, and by locus, *Glu-A1, Glu-D1, Glu-A3* and *Glu-B3* in relation to the quality traits of lines derived from the Rebeca F2000 × Verano S91 cross. Highly significant differences were found for all the traits in relation to genotypes, combinations and the *Glu-D1* and *Glu-A3* loci. For the *Glu-A1* locus significant differences were

Table 2. Mean squares by genotypes, HMWG and LMWG combinations, and by locus for the quality traits of lines derived from the Rebeca F2000 × Verano S91 cross. Roque, Guanajuato, Mexico. Spring–Summer, 2008

Source of variation	df	Mixing time	Mixing stability	Over-mixing tolerance	Dough strength	Tenacity/ extensibility
Genotypes	38	1.7**	1.9**	46.8**	24420.1**	0.14**
Loci combinations	9	4.7**	4.7**	89.2**	64942.1**	0.29**
Locus *Glu-A1*	1	21.3**	25.3**	294.2**	235470.4**	0.04ns
Locus *Glu-D1*	1	34.6**	25.2**	654.9**	487470.9**	0.62**
Locus *Glu-A3*	1	9.0**	9.3**	147.8**	104213.7**	0.08**
Locus *Glu-B3*	1	0.86ns	4.9**	83.0**	7651.1ns	0.2ns
Error[¶]	75	0.03	0.05	1.7	1884	0.02

*, ** Significance at P ≤ 0.05 and P ≤ 0.01, respectively; ns = no significance; df: degrees of freedom;
[¶] overall experimental error

observed only for tenacity-extensibility ratio (P/L), whereas for the *Glu-B3* locus no significant differences were detected for mixing time, overall strength of the dough and P/L. Results indicate that in the Rebeca F2000 × Verano S91 cross, the progeny shows different patterns of dough viscoelastic traits, which is related to the different loci combinations of HMWG and LMWG, mainly due to allelic variation at loci *Glu-D1, Glu-A3* and its interactions.

In the comparative analysis of alleles 1 and 2* of the *Glu-A1* locus on quality traits, no differential influence was observed at the P/L ratio. In contrast, allele 1 is associated to higher levels of MT, MS and W, and at the same time to lower levels of OMT (Table 3). By comparing variants of the *Glu-A3* locus, it is clear that the *Glu-A3c* allele was associated with higher values of MT, MS and W, in comparison with *Glu-A3e*. Additionally, *Glu-A3c* showed lower average of OMT than allele *Glu-A3e* (Table 4). Both allelic variants, *Glu-A3c* and *Glu-A3e,* are related with dough extensibility as indicated by their values of P/L lower than 1.0 (Table 4). Alleles *Glu-B3g* and *Glu-B3h* alleles were associated with strong and extensible gluten wheat (Table 4).

Table 3. HMWG allelic means for viscoelastic traits of the dough averaged over lines from the Rebeca F2000 × Verano S91 cross. Roque, Guanajuato, Mexico. Spring–Summer, 2008

Traits	Locus *Glu-A1*			Locus *Glu-D1*		
	alleles			alleles		
	1	2*	HSD	5 + 10	2 + 12	HSD
Mixing time (min)	3.3	2.5	0.24	3.2	2.0	0.23
Mixing stability (min)	3.2	2.2	0.25	3.0	1.9	0.28
Over-mixing tolerance (mm)	10.9	14.1	1.38	11.1	16.5	1.40
Dough strength (10^{-4} J)	345	255	31.7	337	189	30.2
Tenacity/extensibility	0.7	0.7	0.94	0.7	0.6	0.10

HSD = Honest significant difference (0.05)

Table 4. LMWG allelic means for viscoelastic traits of the dough averaged over lines from the Rebeca F2000 × Verano S91 cross. Roque, Guanajuato, Mexico. Spring–Summer, 2008

Variable	Locus *Glu-A3*			Locus *Glu-B3*		
	allele			allele		
	c	e	HSD	g	h	HSD
Mixing time (min)	3.2	2.6	0.27	3.0	2.8	0.28
Mixing stability (min)	3.0	2.4	0.28	2.9	2.5	0.29
Over-mixing tolerance (mm)	11.4	13.6	1.45	11.7	13.4	1.47
Dough strength (10^{-4} J)	330	270	34.17	307	291	35.8
Tenacity/extensibility	0.7	0.7	0.09	0.7	0.7	0.09

Galvez M87 × Bacanora T88 cross

Table 5 shows the mean squares of the analysis of variance by genotypes, HMWG and LMWG loci combinations and by locus (*Glu-A1, Glu-B1, Glu-A3, Glu-B3* and *Glu-D3*), for the quality variables of those lines derived from the Galvez M87 × Bacanora T88 cross. Highly significant differences were detected for all the studied traits for genotypes, combinations of glutenins and loci. No significant differences for MS and OMT were detected between allelic variants of the *Glu-A1,* whereas highly significant differences were found for MT, W and P/L.

Table 5. Mean squares by genotypes, HMWG and LMWG allelic combinations and by locus for quality traits of lines from the Galvez M87 × Bacanora T88 cross. Roque, Guanajuato, Mexico. Spring–Summer, 2008

Source of variation/ variables	df	Mixing time	Mixing stability	Over-mixing tolerance	Dough strength	Tenacity/ extensibility
Genotypes	48	1.4**	3.3**	25.7**	16658.6**	0.31**
Loci combinations	17	3.0**	7.6**	52.9**	37141.3**	0.65**
Locus *Glu-A1*	1	7.1**	0.28ns	1.1ns	105903.7**	0.52*
Locus *Glu-B1*	1	7.2**	30.4**	312.6**	218843.6**	2.1**
Locus *Glu-A3*	1	7.5**	21.3**	76.5**	21263.1**	0.13**
Locus *Glu-B3*	1	7.2**	30.4**	312.6**	218843.6**	2.1**
Locus *Glu-D3*	1	20.9**	55.9**	313.0**	242848.0**	0.11**
Error¶	94	0.03	0.1	2.1	1220	0.03

*, ** Significance at $P \leq 0.05$ and $P \leq 0.01$, respectively; df: degrees of freedom; ns = no significance;
¶ overall experimental error

Alleles 1 and 2*, averaged over the whole group of lines of the cross Galvez M87 × Bacanora T88, showed similar values for all the traits, which correspond to wheat that produces medium strong and extensible dough (Table 6), even though allele 1 was statistically associated to greater strength (W) and extensibility (lower P/L) of gluten than 2*. Allele 17 + 18 showed higher values MT, MS and W as well as a smaller value of P/L than the 7 + 9 allele, indicating that in this population the presence of HMWG 17 + 18 is more favorable than 7 + 9 in terms of strength and extensibility.

Table 6. HMWG allelic means for viscoelastic traits of the dough averaged over lines from the Galvez M87 × Bacanora T88 cross. Roque, Guanajuato, Mexico. Spring–Summer, 2008

Traits	Locus *Glu-A1*			Locus *Glu-B1*		
	alleles			alleles		
	1	2*	HSD	7+9	17+18	HSD
Mixing time (min)	3.4	2.9	0.22	2.8	3.3	0.24
Mixing stability (min)	4.2	4.1	0.37	3.4	4.4	0.37
Over-mixing tolerance (mm)	7.5	7.7	1.05	9.9	6.6	1.02
Dough strength (10^{-4} J)	299	245	24.8	207	292	25.2
Tenacity/extensibility	0.6	0.8	0.12	0.9	0.6	0.12

HSD = Honest significant difference (0.05)

In regard to the *Glu-A3* locus, both allelic variants, *Glu-A3b* and *Glu-A3c* showed somewhat similar values for some traits corresponding to medium strong and extensible gluten (Table 7), but the *Glu-A3b* allele had values significantly higher than *Glu-A3c* for

MT, MS and W. In the *Glu-B3* locus, the genotypes containing allele *Glu-B3h* showed higher values of gluten strength and were associated to better extensibility than the contrasting *Glu-B3j* allele (Table 7). *Glu-B3j* conferred low levels of gluten strength, corresponding to weak-middle gluten, and limited extensibility. The variant *Glu-D3c,* from the *Glu-D3* locus was associated to strong and extensible gluten (Table 7).

Table 7. LMWG allelic means for viscoelastic traits of the dough averaged over lines from the Galvez M87 × Bacanora T88 cross. Roque, Guanajuato, Mexico. Spring–Summer, 2008

Variable	Locus *Glu-A3*			Locus *Glu-B3*			Locus *Glu-D3*		
	alleles			alleles			alleles		
	b	c	HSD	h	j	HSD	b	c	HSD
Mixing time (min)	3.4	2.9	0.22	3.3	2.8	0.24	2.8	3.5	0.19
Mixing stability (min)	4.5	3.8	0.34	4.5	3.5	0.36	3.5	4.8	0.3
Over-mixing tolerance (mm)	6.9	8.3	1.0	6.7	9.9	1.0	9.0	6.0	0.92
Dough strength (10^{-4} J)	280	256	25.8	292	207	25.0	228	310	22.3
Tenacity/extensibility	0.7	0.7	0.12	0.6	0.9	0.12	0.7	0.7	0.12

HSD = Honest significant difference (0.05)

Discussion

In the Rebeca F2000 × Verano S91 cross, results on the influence of alleles at the *Glu-A1* locus in this study are in line with those of He et al. (2005) and Espitia-Rangel et al. (2008) who reported that allele 1 favors the viscoelastic properties of the dough and contradicts the assertion of Martínez-Cruz et al. (2007a), who reported similar effects in both variants. In the *Glu-D1* locus, allele 5 + 10 was associated with higher values of dough strength than 2 + 12 (Table 3). This is in agreement with reports of several researchers (Luo et al. 2001; Peña et al. 2004; He et al. 2005; De la O et al. 2006; Nishio et al. 2007; Espitia-Rangel et al. 2008), who associated subunits 5 + 10 and 2 + 12 with high and low values of gluten strength, respectively.

In the case of LMW glutenins coded by locus *Glu-A3*, alleles *Glu-A3c* and *Glu-A3e* are typical of strong and medium-strong gluten wheats, respectively, which agrees with other reports on these alleles (Branlard et al. 2001; Luo et al. 2001; Flaete et al. 2003; Liu et al. 2005; Cornish et al. 2006). Alleles *Glu-B3g* and *Glu-B3h* were associated with strong and extensible gluten, which is in agreement with reports of Wesley et al. (2001); Peña et al. (2004) and Meng et al. (2007) who recommended those alleles for improving strength of the dough.

In the cross Galvez M87 × Bacanora T88, our results on the *Glu-B1* locus agree with those of Branlard et al. (2001) and Martínez et al. (2007b), who found that allele 17+18 positively contributes to the strength and extensibility of gluten; however, contrary to our observations at the *Glu-D3* locus, Cornish et al. (2001) and Meng et al. (2007) found that alleles *Glu-D3c* and *Glu-D3a* are not significantly correlated with the quality of the dough. In regard to the *Glu-A3* locus, our data are in agreement with the findings of Branlard et al. (2001), who noted that both alleles (*Glu-A3b* and *Glu-A3c*) contribute positively to the quality of the dough.

Our results are opposite to what was observed by Branlard et al. (2001) and Gobaa et al. (2008) since they observed no association of the *Glu-D3c* allele to a strong and extensible gluten. On the other hand, in our study allele *Glu-D3b* showed characteristic values of medium strong and extensible gluten, which is consistent with the findings of Branlard et al. (2001), but not with that of Gobaa et al. (2008) who associated it to weak gluten. Furthermore, Luo et al. (2001) found similar values of mixing time, while Meng et al. (2007) reported that the allele *Glu-D3c* was not significantly correlated to sedimentation volume, dough strength, tenacity and extensibility.

In both Rebeca F2000 × Verano and Galvez M87 × Bacanora T88 crosses loci combinations resulted important for gluten strength and extensibility, these results are in accordance with that reported by Eagles et al. (2002) and Békés et al. (2006).

Results of this study contribute to understand the effects of alleles on the final quality of worldwide important products. Alleles 2* at *Glu-A1*, 7 + 9 at *Glu-B1*, 5 + 10 at *Glu-D1,* g at *Glu-B3* and c at *Glu-D3,* were identified as conferring favorable effects on gluten strength. According to Shan et al. (2007), those alleles are frequent in winter wheats of the USA, and are readily available for their use in plant breeding programs. The most frequent alleles in genotypes of France and China are 0 and 2 + 12 (Branlard et al. 2003; Liu et al. 2005) which might be replaced by 2* and 5 + 10 to improve dough strength. In China, alleles *Glu-B3g* and *Glu-B3h* might replace *Glu-B3j* which is the most common one and negatively affects the rheology of the dough (Liu et al. 2005). Results also shown interaction among loci, hence breeders need to consider not only effect of individual alleles but also interaction among loci in the end-use quality improvement.

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