

Rheological Properties of Full-Formula Doughs Derived from Near-Isogenic 1BL/1RS Translocation Lines^{1,2}

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ABSTRACT

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Four pairs of near-isogenic wheat lines, with and without the 1BL/1RS translocation, and differing at the *Glu-1* loci (coding for high molecular weight [HMW] glutenin subunits) were evaluated for their dough mixing properties, dough stickiness, and baking performance. In all 1BL/1RS translocation lines, weakening of the dough consistency occurred within 2 min past peak time. The full-formula dough from every 1BL/1RS translocation line exhibited poor dough mixing characteristics and increased stickiness compared to the corresponding wheat control. The HMW glutenin subunits coded by the *Glu-A1* locus had no apparent effect on mixing properties, but did have a slight effect on the dough stickiness at two of the four stages of dough mixing. *Glu-B1* and *Glu-D1* loci encoded glutenin subunits produced significant changes in dough mixing properties and dough stickiness, respectively. With respect to baking perform-

ance, there was no significant difference between loaf volumes of 1BL/1RS versus control wheats for three of four near-isogenic pairs. Within the 1RS-group, the translocation lines containing HMW glutenin subunits 5+10 produced bread with greater loaf volumes than the pairs containing its allelic counterpart 2+12. Loaf volume was not influenced by the subunits associated with the *Glu-B1* loci. In general, the breads baked from 1BL/1RS translocation lines had a relatively poor crumb and crust quality and contained larger gas cells than the wheat controls. In comparing isogenic pairs, the magnitude of the difference in loaf volume between the control wheat and the corresponding 1BL/1RS translocation line was greater in the pair unique for HMW subunits 5+10; the difference was primarily due to the stronger mixing properties of the wheat control.

Dough handling is an integral part of the breadmaking process and the problems associated with dough processing can have deleterious effects on quality. Dough stickiness, which causes poor machinability, has surfaced in cultivars of hexaploid wheat (*Triticum aestivum*) containing a segment of the rye (*Secale cereale*) chromosome. In these lines of wheat, the short arm of the 1B chromosome has been replaced with the short arm of rye chromosome (1BL/1RS) (Zeller and Hsam 1984).

Various interpretations have been put forward to explain 1BL/1RS related dough stickiness. The dough stickiness defect has been attributed to pentosan or soluble proteins (Zeller and Fuchs 1983), ferulic acid and hexose (Chen and Hosney 1995), higher protease activity (MacRitchie 1986), sulfhydryl groups and proteinase (Noguchi et al 1976), and to the changes in glutenin-gliadin ratio (Dhaliwal and MacRitchie 1990, Gupta et al 1990, Lee et al 1995). Regardless, Martin and Stewart (1990) reported that the dough stickiness of the rye-derived wheats was independent of the protein content. A possible, but so far unstudied, cause of stickiness could be the quality of the polymeric or monomeric proteins (Hussain and Lukow 1994).

When flour is hydrated and mixed, the textural changes that occur during mixing usually depend on the genetic variance of viscoelastic properties associated with their polymeric proteins (Moonen et al 1983, Branlard and Dardevet 1985, Lagudah et al 1988, Khan et al 1989, Dong et al 1992, Popineau et al 1994, Weegels et al 1996 and references therein) and their interaction with other proteins (Hosney and Rogers 1990, Primard et al 1991, Hammer et al 1992). Therefore, a slight variation in protein composition is expected to produce changes in the physicochemical and mechanical properties of dough during repolymerization of the macropolymer (Popineau et al 1994).

The adverse effects of 1BL/1RS translocation in wheat are well documented (Pena et al 1990). However, Graybosch et al (1990) and Fenn et al (1994) reported a wide variation in dough stickiness implying that the negative effects of 1RS translocation were not uniformly distributed. Thus, the identification of the genetic background capable of alleviating the influence of 1RS translocation would be extremely useful for agronomic improvement of the rye-derived wheat germ plasm. There is still insufficient information on the direct influence of glutenin on the processing problems of the rye-derived wheats. Gupta et al (1994) reported that *Glu-1* controlled subunits (high molecular weight [HMW] glutenin subunits) seem to have a greater effect on the dough properties than *Glu-3*. Therefore, a comparison of genetic lines lacking certain *Glu-1* alleles could provide an insight into the structural-functional role of the associated HMW glutenin subunits.

Previously, it has been difficult to distinguish causes of wheat-rye translocation effects on dough properties because the cultivars investigated not only differed in HMW glutenin subunit composition but also in gliadin and nongluten proteins. The need for precise information on the contribution of *Glu-A1*, *B1*, and *D1* alleles to the mixing and handling properties of the full baking formula dough prompted this investigation.

This study was undertaken to: 1) determine the effect of the 1BL/1RS translocation on several quality attributes within and between near isogenic pairs; 2) determine the effect of allelic variation at each of three loci on dough mixing, dough handling, and baking performance of the full-formula dough in the 1RS-background; 3) identify instrumental parameters that can discriminate and quantify dough stickiness as evaluated by the sensory method; and 4) generate a prediction equation for dough stickiness.

MATERIALS AND METHODS

Samples

Four pairs of near isogenic lines of wheat, with and without the 1BL/1RS translocation and which differed in the HMW glutenin subunit composition, were used in this study. Pairs 1 and 4 were derived from the cross: HY320*6/7424//HY320*2/RL4137///RL4584/ATA81, and pairs 2 and 3 were derived from the cross: HY320*6/BW553//HY320*2/RL4137///Veery3//HY320*6/7424.

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These two crosses were similar in that they both were mainly in a HY320 background. Pairs 2 and 3 each derived from an F_5 plant heterozygous for the translocation, while pairs 1 and 4 derived from an F_4 that was heterozygous for the translocation. A homozygous selection for each chromosome arrangement was selected from the progeny of the heterozygous plants. The HMW glutenin subunit compositions of these pairs were:

- Pair 1 = N, 17+18, 2+12
- Pair 2 = 1, 17+18, 2+12
- Pair 3 = N, 7+8, 2+12
- Pair 4 = N, 17+18, 5+10

The selection of pairs was such that comparison between pairs 1 and 2 provided the effect of *Glu -A1* subunits null vs. 1; 1 and 3, the effect of *-B1* subunits 17+18 vs. 7+8 and 1 and 4 revealed differences due to *-D1* subunits 2+12 vs. 5+10. The combined effect of *Glu-A1* and *B1*, *A1* and *D1*, and *B1* and *D1* alleles were evaluated by comparing pairs 2 vs. 3, 2 vs. 4, and 3 vs. 4, respectively.

All paired sets of near-isogenic lines were grown at one location (Glenlea, MB, Canada, 1993). Protein content (14% mb) for the normal wheats for Pairs 1–4 were 14.1, 12.4, 12.4, and 12.4%, respectively, while for the corresponding 1RS-translocation lines total protein contents were 13.4, 12.7, 12.1, and 13.5%, respectively.

All samples were milled into straight-grade flour on a Buhler pneumatic laboratory mill after tempering overnight to 16.5% moisture. The farinograms and mixing curves were generated according to Buckley et al (1990) and Lukow (1991) and the protein content by near infrared reflectance (NIR) according to AACC method 39-11 (1995).

The presence of rye translocation in wheat was previously examined using a monoclonal antibody test (Howes et al 1989) and a water-extractable protein concentrate (Hussain and Lukow 1994).

As reported elsewhere (Hussain and Lukow 1994), the electrophoretic band patterns of wheat controls were virtually identical, except they differed in HMW glutenin subunit composition. Similarly the electrophoregrams of the 1BL/1RS translocation lines did not show protein differences other than HMW glutenin subunits.

Polyacrylamide Gel Electrophoresis (PAGE)

To identify HMW glutenin subunits, flour proteins of the four paired sets were separated in 10% polyacrylamide using extracts of a 25-mg flour sample. The flour proteins were extracted in 20 vol. of 2% sodium dodecyl sulfate (SDS)/Tris HCl, pH 8.0, buffer (Hussain and Lukow 1993). Extraction was performed at room temperature (22°C) for at least 4 hr with occasional vortexing. Samples were incubated at 95°C for 3–4 min, followed by centrifugation at 12,000 × *g* for 5 min. Samples (8 μL) were applied in each slot for SDS-PAGE analysis. Uniformity of the seeds within a seed lot was confirmed using SDS-PAGE after the seed increase.

Mixing

Mixing characteristics were determined on dough prepared in a GRL-200 mixer (Hlynka and Anderson 1955) operating at 140 rpm, 30°C. The mixing curves were generated using MixSmart Software from the National Manufacturing Co. The full baking formula, similar to that in Kerr et al (1993), included 100 g (14% mb) of flour, optimal baking water (farinograph absorption – 3%), sugar (6.0%), salt (1.5%), vegetable shortening (3.0%), dry yeast (1.3%), skim milk powder (4.0%), malt (0.4%), and potassium dihydrogen phosphate (0.1%). The farinograph absorptions (100% flour) for normal wheats for Pairs 1–4 were 58.2, 60.2, 61.4, and 58.0, respectively. For the corresponding 1BL/1RS translocation lines, the farinograph absorptions were 57.2, 61.0, 61.0, and 60.8, respectively.

Doughs were mixed to peak development (Stage 01), 2 min past peak development (Stage 02), until dough consistency dropped by at least 10–15 units (Stage 03), and until 10 min (Stage 04). Peak development time was recorded as the time in minutes necessary to obtain peak. The breakdown in dough consistency was determined as the time (min) when the mixing curve showed a sudden, sharp drop in curve height (Fig. 1).

The full-formula doughs prepared to the above mixing stages were divided into two portions, one portion (130 g) was baked, and the remainder was used immediately in the sensory and instrumental evaluation of stickiness.

Evaluation of Dough Stickiness

The sensory scoring scheme of Wang et al (1994) was adapted to determine dough stickiness. In contrast to Wang et al (1994), the full-formula ingredients were mixed in the GRL 200 mixer rather than using a flour and water combination in a 35-g mixograph.

For each instrumental dough stickiness determination, a dough piece (13.8 g), was used immediately to generate a dough profile on a computer-assisted Lloyd material testing machine (model 1000R). The weight of the sample represented ~10% weight of the total mixed dough, and this sample size, compressed to a height of 7.2 mm in a dough-profiling cell, gave the best discrimination between sticky and nonsticky samples (Wang et al 1996). Precaution was taken to avoid unnecessary exposure of the dough piece to humidity and temperature variations. A computer software program (RCONTROL) was used to record the dough profile and calculate parameters derived from the curve (Wang et al 1996). The testing conditions were also modified to accommodate the textural quality of these samples. Testing conditions were as follows: compression rate = 100 mm/min, tension rate = 500 mm/min, compression level = 50%, sample height = 7.6 mm, two cycles of compression + relaxation + tension of the dough profiling technique required 3 min. The sensory and instrumental evaluations of dough stickiness were made in triplicate.

Baking Performance

Doughs were baked by a modification of the AACC straight-dough baking method 10-10B (AACC 1995). After mixing, doughs were fermented for 105 min, hand-punched, proofed for

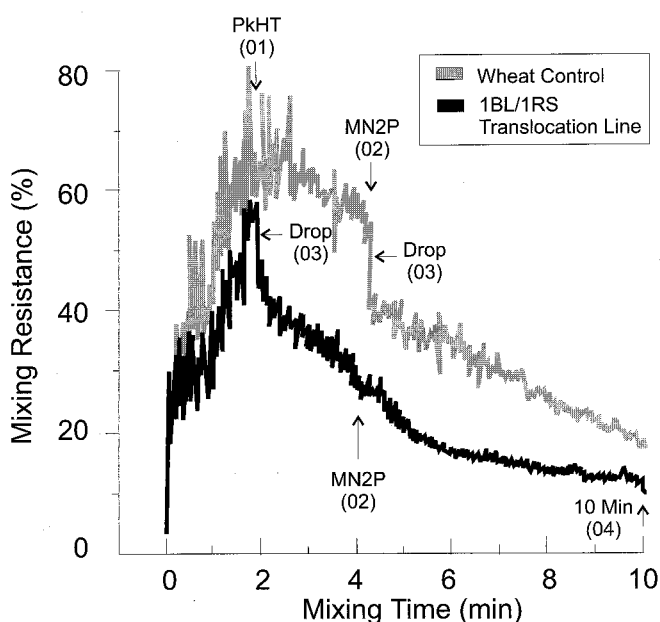


Fig. 1. Typical mixing curves for Pair 4. Stages: 01 = peak height, % scale (PkHT), 02 = 2 min past peak development (MN2P), 03 = drop in curve height (Drop), 04 = 10 min mixing (10 Min).

50 min, hand-punched again, proofed for 35 min, panned, and proofed for 65 min at 30°C in a proofing cabinet. Loaves were baked at 215°C (419°F) for 25 min.

Statistical Analyses

Analysis of variance was used to compare and to identify significant differences between and within 1BL/1RS translocation lines (R) and control wheats (W). Pearson correlation coefficients (*r*) were calculated to determine the linear relationship between primary and secondary parameters of the dough texture profile and sensory evaluation of dough stickiness. Correlation analyses were made using the Statistical Analysis System (SAS 1985) software package.

A stepwise multiple regression procedure with the maximum *R*² improvement option, was used to generate a prediction equation for dough stickiness (dependent variable) from the mixing and textural data (independent variables).

RESULTS AND DISCUSSION

Dough Development and Mixing Properties

The mixing properties of the 1BL/1RS translocation lines (R) were significantly different from those of the corresponding control wheats (W) when means across all pairs were compared (Table I). The 1BL/1RS translocation lines had significantly lower mean values for four of the five parameters, indicating less dough strength. This confirmed the results of Barnes (1990) and Fenn et al (1994). The mean peak time for all four pairs was shorter when compared to the corresponding wheat controls. These results differed from those of Martin and Stewart (1986) and Burnett et al (1995), who reported that 1BL/1RS translocation had no influence on the mixograph characteristics and dough stickiness.

All 1BL/1RS translocation lines showed a sharp decline in dough consistency ~1 min past peak development of the full-formula dough, in contrast to wheat controls that took ~3 min past peak to show a similar drop in dough consistency (Table I). It is for this reason that mixing Stage 03 happens to appear before Stage 02 in 1BL/1RS translocation lines.

The decline in the mixing curve height after 2 min past peak time (PkHT – MN2P) was greater in 1BL/1RS translocation lines than for the respective controls (Table I). The PkHT, however, remained generally unaffected by 1BL/1RS translocation (Table I). This is in contrast to the earlier studies by Van Lill et al (1990), who reported a 1BL/1RS related reduction in peak height.

The effect of HMW glutenin subunit 1 vs. the null allele on dough strength within the 1BL/1RS group was evaluated by comparing Pairs 1 and 2. The only parameter of the mixing curve influenced significantly was the curve height after 10 min (Stage 04), which was greater for Pair 2 (Table I). Thus, it appears as if the *Glu-A1* alleles did not substantially affect dough properties as reported elsewhere (Lagudah et al 1988).

The effect of HMW glutenin subunits 17+18 vs. 7+8 resulting from the allelic variation at the *Glu-B1* locus were assessed by comparing Pair 1 with Pair 3. Both pairs had the N and 2+12 subunit composition for the *Glu-A1* and *D1* loci. The presence of subunit 7+8 in translocated lines produced a significant increase in dough strength as determined by peak development time (PkDEV), dough consistency at 2 min past peak (MN2P) and drop in dough stability (DROP) (Table I).

Considering Pair 1 vs. Pair 4, where HMW glutenin subunits 2+12 and 5+10 were compared, the presence of subunits 5+10 in 1BL/1RS translocation lines increased PkDEV, MN2P, and DROP parameters of the mixing curve, but not to the same extent as by the *Glu-B1* allele encoding subunits 7+8 (Table I). These results demonstrate that the presence of HMW glutenin subunits 7+8 in

TABLE I
Dough Mixing Properties of Four Translocation (R) and Control Wheat (W) Pairs Differing in High Molecular Weight Glutenin Subunit Composition

Properties ^a	Mixing Stage	Genotype	Pairs ^{b,c}				
			1	2	3	4	\bar{X}
PkDEV	01	W	2.9 ^{c,d,e}	3.0 ^c	3.8 ^b	5.2 ^a	3.7
		R	2.5 ^b	2.5 ^b	3.4 ^a	3.4 ^a	2.9
PkHT	01	W	60.0 ^{a,NS}	60.3 ^{a,NS}	53.5 ^{b,NS}	59.3 ^{a,NS}	58.2 ^{NS}
		R	58.5 ^a	58.5 ^a	58.3 ^a	56.3 ^a	57.9
MN2P	02	W	44.0 ^b	44.5 ^b	46.8 ^a	47.8 ^a	45.7
		R	25.5 ^c	27.0 ^{b,c}	31.8 ^a	28.3 ^b	28.1
Drop	03	W	5.4 ^c	5.4 ^c	6.3 ^b	8.6 ^a	6.4
		R	3.2 ^c	3.3 ^c	4.5 ^a	4.0 ^b	3.7
10 MIN	04	W	15.3 ^a	20.3 ^a	22.8 ^a	24.0 ^a	20.6
		R	12.3 ^c	19.5 ^{ab}	21.3 ^a	14.3 ^{bc}	16.8

^a PkDEV = peak development time (9min); PkHT = peak height (% scale); MN2P = mixing curve height 2 min past peak (% scale); Drop = sharp drop in curve height (min); 10 MIN = curve height after 10 min (% scale).

^b High molecular weight glutenin subunits: Pair 1 = N, 17+18, 2+12; Pair 2 = 1, 17+18, 2+12; Pair 3 = N, 7+8, 2+12; Pair 4 = N, 17+18 5+10.

^c Means of three replicates.

^d Values for W and R are significantly different ($P < 0.01$) except where indicated (NS).

^e Values within rows with different letters are significantly different ($P < 0.01$).

TABLE II
Comparison of Dough Stickiness of Four Translocation (R) and Wheat Control (C) Pairs Differing in High Molecular Weight Glutenin Subunit Composition Determined at Dough Mixing Stage 02

Stickiness ^a	Genotype	Pairs ^{b,c}				
		1	2	3	4	\bar{X}
SN	W	22.2 ^{***}	20.1 ^{***}	21.3 ^{**}	20.8 ^{***}	21.1 ^{***}
	R	25.2	26.2	23.5	23.2	24.5
ST	W	2.5 ^{***}	2.9 ^{***}	2.9 ^{***}	2.2 ^{***}	2.6 ^{**}
	R	3.4	3.7	4.1	3.3	3.6

^a SN = sensory stickiness, ST = stringiness.

^b High molecular weight glutenin subunit composition: Pair 1 = N, 17+18, 2+12; Pair 2 = 1, 17+18, 2+12; Pair 3 = N, 7+8, 2+12; Pair 4 = N, 17+18 5+10.

^c Level of significance: ** = $P < 0.01$, *** = $P < 0.001$.

the genetic background of 1BL/1RS lines increased the dough strength, which is in contrast to the results of Rogers et al (1991), who reported a nonsignificant effect of A1 or B1 alleles on the dough properties.

The combined effect of *Glu-A1/Glu-B1*, *Glu-A1/Glu-D1*, and *Glu-B1/Glu-D1* alleles on dough mixing properties was evaluated by comparing pairs 2 vs. 3 (1, 17+18 vs. N, 7+8), Pairs 2 vs. 4 (1, 2+12 vs. N, 5+10) and Pairs 3 vs. 4 (7+8, 2+12 vs. 17+18, 5+10), respectively. The synergistic effect of *A1/B1*, *A1/D1*, and *B1/D1* combinations was calculated by subtracting differences associated with the individual allelic differences. As an example, the synergistic effect on mixing properties of *A1/B1* alleles was = [(difference between Pairs 2 and 3) - (difference between Pairs 1 and 3)]. The combination of two different alleles did not significantly influence the mixing curve parameters of 1BL/1RS lines compared to the single allele variants (Table I).

The presence of *Glu-B1* allele encoding subunits 7+8 showed less negative effect of 1BL/1RS translocation within a pair than lines containing subunits 17+18. The generally claimed superiority of the HMW glutenin subunits 5+10 with respect to dough strength was not observed. Although the absolute values for mixing properties were high in the 1BL/1RS translocation line containing subunits 5+10 (Pair 4), excessive dough strength of its wheat control sample produced a sizable difference within the pair.

The differences seen in the dough properties were mainly due the genetic influence because the differences in the water absorptions had a negligible effect on dough mixing characteristics (Table I).

Dough Stickiness

Instrumental stickiness (IS) is a derivation of several primary parameters of the dough profile (Fig. 2). The statistical formula ($IS = 1044.2 \times H_1^{-2.262} [T_1 (TW_2/TW_1)]^{1.348}$, developed by Wang et al (1996), when applied to the full-formula dough system did not show trends consistent with the sensory evaluation of stickiness (SN). The lack of correlation, was probably due to the change from a flour-water dough system to a full-formula dough system (Oliver and Allen 1992) and the type of mixer used in this study. Both primary and secondary parameters of the dough profile, such as compression, tension, and relaxation parameters (Bourne 1978), showed poor correlation with sensory evaluation of dough stickiness compared to a secondary tension parameter ST (stringiness). The (first cycle) ST showed a higher correlation ($r =$

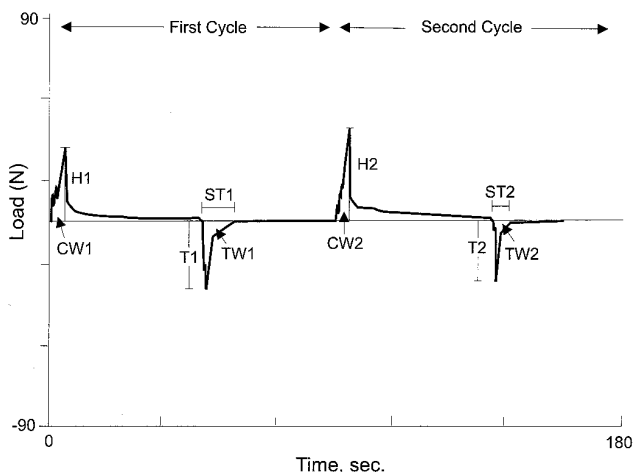


Fig. 2. Typical dough profile of cycles 1 and 2 for compression + relaxation + tension. Testing conditions: compression rate = 100 mm/min, tension rate = 500 mm/min, compression level 50%, sample height = 7.6 mm. H = peak height, CW = compression work, T = tension, TW = tension work, ST = stringiness.

0.66, $P < 0.01$) than IS, which showed a poor correlation ($r = 0.31$, $P < 0.01$) with the sensory stickiness (SN) values.

A comparison of the four different stages of dough mixing showed that Stage 02 provided the best discrimination of stickiness between control wheats and the corresponding 1BL/1RS translocation lines. Therefore, results for this particular stage are presented in Table II. Based on the means across two groups (W and R), the 1BL/1RS translocation lines (R) showed a significant increase in dough stickiness. However, the magnitude of the difference among near-isogenic pairs differed depending on genetic background. Within the 1BL/1RS group (R), Pair 4 (subunits 5+10) showed lower stickiness values (SN and ST) than did lines with subunits 2+12. These results demonstrate that a background of HMW glutenin subunit 5+10 may reduce the dough stickiness associated with the 1BL/1RS translocation. However, the differences in stickiness between R and W in Pair 4 was not any lower than those containing lines containing HMW glutenin subunits 2+12. A large difference in stickiness values for Pair 2 or Pair 3 SN and ST-stickiness may be attributed to the excessive stickiness of the 1BL/1RS translocation lines.

Mixing Stages

The stickiness determinations at four stages of dough formation and breakdown are presented in Fig. 3. Dough samples tested at the occurrence of a sharp drop (Stage 03) and after prolonged mixing (Stage 04) did not show the same trends as those for

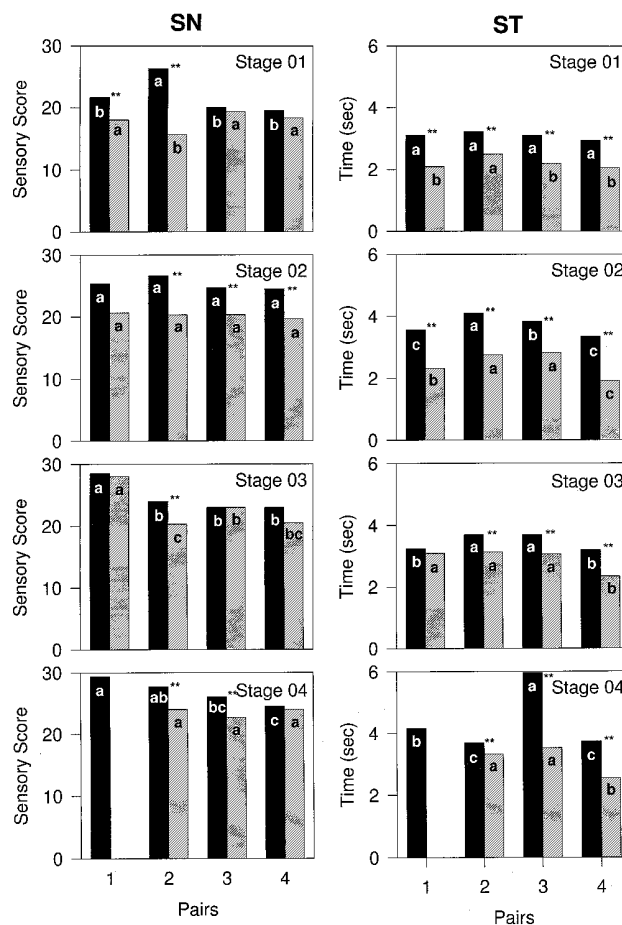


Fig. 3. Histograms showing sensory (SN) and instrumental (ST) stickiness of 1BL/1RS doughs (dark bars) and control (grey bars) for four different near isogenic pairs at four stages of dough mixing. ** = significant differences ($P < 0.01$) between 1BL/1RS translocation lines (R) and corresponding wheat controls (W). Different letters in the same row represent significant ($P < 0.05$) differences between means within R or W pairs at different stages of dough mixing.

Stages 01 and 02. Textural changes due to the loss of repolymerization (Ewart 1977, Atkins 1989) after prolonged mixing (Stage 04) might have reduced differences (Hoseney and Finney 1974) within and between near-isogenic pairs. Regardless, Pair 4 (within R group) showed lower ST-stickiness at Stages 02 and 03 than for Pairs 2 and 3 at Stages 02 and 03.

Within pairs the ST-stickiness of 1BL/1RS translocation lines were significantly different from wheat controls at all stages of

dough mixing, with the exception of Pair 1, Stage 03 (Fig. 3). This trend was not seen in the sensory evaluation of stickiness (SN). Other variables calculated from the dough profile such as cohesiveness, gumminess, hardness, and springiness (Bourne et al 1978) did not provide a similar discrimination between groups W and R, pairs 1–4, and Stages 01–04.

Dough Stickiness and *Glu-1* Alleles

The presence of some *Glu-1* alleles in 1BL/1RS translocation lines ameliorated; some had no effect, while others increased dough stickiness (Fig. 3). The flour for the control Pair 1, Stage 04 could not be tested due to the shortage of flour sample.

The effect of individual subunits among 1RS-lines was much more apparent in the ST results than in the SN scores. The comparison of ST-stickiness among 1BL/1RS translocation lines differing in HMW glutenin subunits N and 1 (Pairs 1 and 2) showed that the presence of the null allele caused a significant reduction in ST values at Stages 02 and 03 of dough mixing. At dough development (Stage 01), these alleles (N and 1) did not preferentially affect ST-stickiness. The SN estimates for the same samples were not entirely correlated with the ST data. The presence of *Glu-B1* allele encoding HMW glutenin subunits 7+8 compared to its contrasting allele (subunits 17+18) increased ST-stickiness of 1BL/1RS lines at Stages 02, 03, or 04. At Stage 01, the difference between the ST-values was insignificant. The presence of *D1* subunits 5+10 in 1BL/1RS translocation lines compared to its contrasting allelic subunits 2+12 showed a significant reduction of ST. The importance of HMW glutenin subunits 5+10 vs. 2+12 as a major determinant of dough quality in normal wheats is well documented (Lafiandra et al 1993, Popineau et al 1994). Our results indicate that it is also true for 1BL/1RS translocation lines at Stages 02 and 03. Table II shows that the presence of HMW glutenin subunits 7+8 and 2+12 in 1BL/1RS background would enhance stickiness more than lines containing HMW glutenin subunits 17+18 and 5+10. This combination of subunits 17+18 and 5+10 was present in Pair 4, which outperformed the other three pairs. The difference between control wheat and its 1BL/1RS line in Pair 4 was greater because the wheat control had a lower sensory score (SN) and stickiness value (ST) relative to the Pairs 1, 2, and 3 (Table II).

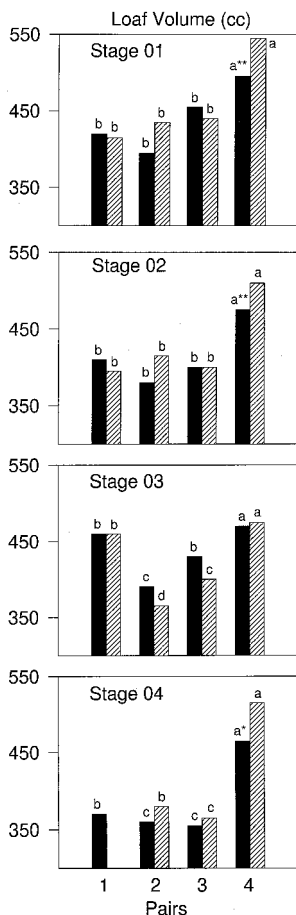


Fig. 4. Histograms representing loaf volumes (cm^3) of bread baked from 1BL/1RS lines (dark bars) and wheat controls (grey bars) for four near-isogenic pairs at four stages of dough mixing. *, ** = Significant differences ($P < 0.05$ and $P < 0.01$) between 1BL/1RS translocation lines (R) and wheat controls (W). Different letters in the same row represent significant differences ($P < 0.05$) between means within R and W pairs at different stages of dough mixing.

Relationship Between Sensory Stickiness and Mixing and Dough Profile Parameters

Pearson correlation of the sensory stickiness (SN) and individual parameters of the compression and mixing curve showed a significant correlation between SN and ST ($r = 0.66$). A positive relationship was also identified between dough stickiness (SN) and collective curve heights (HGT) (a parameter of the mixing curve) taken at all four time stages ($r = 0.69$, $P < 0.01$). A step-wise linear regression was used to generate a prediction equation.

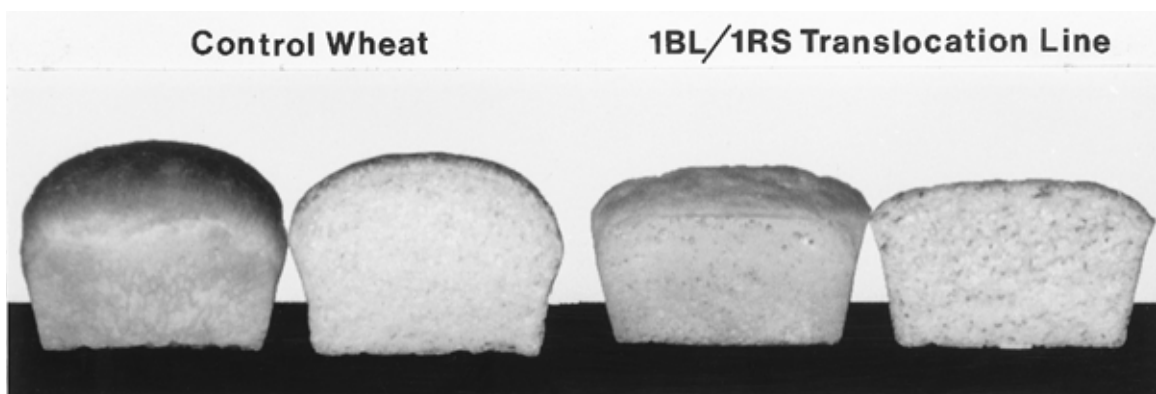


Fig. 5. External and internal appearance of loaves baked from wheat flours with and without 1RS-translocation. Doughs were removed at 2 min past peak (mixing stage 02) and baked.

A combination of three variables such as combined (Stages 01–04) GRL mixer curve height (HGT); compression work-1 (CW1) and compression work-2 (CW2) (dough profile) could determine 74% ($r = 0.74$) of variation in SN-stickiness

The following equation would best predict the dough stickiness:

$$\text{Predicted stickiness (SN)} = 54.649 \text{ CC} + 0.846 \text{ CW1} - 1.103 \text{ CW2} - 0.141 \text{ HG} - 13.683$$

where $\text{CC} = \text{CW2/CW1}$. The equation was validated with a second set of samples.

Baking Performance and Bread Quality

The results of the analysis of variance for loaf volume of four pairs differing in HMW glutenin subunit allele composition are presented in Fig. 4. The missing data for the control Pair 1, Stage 04 (Fig. 4) was due the unavailability of flour sample in sufficient quantity. The presence or absence of 1BL/1RS translocation in wheat did not greatly influence the loaf volume. Loaves baked from flours of wheat controls and the corresponding 1BL/1RS lines did not show any significant differences in loaf volume for Pairs 1, 2, or 3. However, the crumb characteristics for loaves baked from 1BL/1RS flours were inferior in internal and external appearance (Fig. 5). The crumb cell structure of 1BL/1RS loaves had a very open and coarse crumb structure.

In evaluating the relative effect of *Glu-1* background across 1BL/1RS pairs, it was noted that loaves baked from flours of 1BL/1RS lines containing *Glu-D1* subunits 5+10 (Pair 4) showed a significant increase in loaf volume compared to the translocation line containing its allelic counterpart 2+12 (Pair 1) for three of the mixing stages (Fig. 4). The positive effect of these HMW glutenin subunits (5+10) on baking performance in normal bread wheats has been reported by several authors (Payne et al 1987, Ng and Bushuk 1988, Kolster et al 1991, Dong et al 1992, Hamer et al 1992).

The loaf volume of 1BL/1RS lines was reduced when the *A1* Null allele and *D1* allele (bands 5+10) occurred together. Replacement of *Glu-B1* allele 17+18 by 7+8 did not alter the baking performance of the 1BL/1RS lines.

The changes in loaf volumes that occurred during different time stages are also presented in Fig. 4. Bread baked from dough mixed to peak time (Stage 01) produced significantly higher loaf volume when compared to dough mixed to 10 min mixing (Stage 04) in all samples. At Stage 04, the dough was overmixed, weaker, and difficult to sheet and mould, and it produced a loaf of poor crumb and crust quality. The breads baked at Stages 01 and 02 were of relatively better quality because the dough structure at these stages was optimally developed as compared to Stages 03 and 04, where it was broken down, losing physicochemical and functional properties (Pardes-Lopez and Bushuk 1983). In comparing the four different pairs, it was apparent that Pair 4 outperformed Pairs 1, 2, or 3. The baking results also demonstrate that 1BL/1RS-associated changes in gliadins did not have a significant effect on the loaf volumes as advocated by Van Lonkhuijsen et al (1988).

CONCLUSION

With respect to the dough mixing and stickiness properties, near-isogenic 1BL/1RS translocation lines were significantly different from the wheat controls. The 1BL/1RS translocation caused a significant decline in dough strength and increased stickiness. However, the changes in dough properties of 1BL/1RS lines depended on the genetic background. The magnitude to which *Glu-1* alleles improved the rheological properties varied between isogenic pairs. Some alleles improved dough properties, while others had negative or no effects. The drop in dough consistency during mixing was delayed in the presence of the *Glu-B1* allele type 7+8 while changes at *Glu-A1* and *Glu-D1* loci had no appar-

ent effect on mixing characteristics within 1BL/1RS genotypes. On the other hand, incorporation of *Glu-D1* 5+10 in the 1RS background caused a significant reduction in dough stickiness and improved baking performance, whereas subunits 2+12 were associated with increased stickiness. Thus, a selection of subunits 7+8 and 5+10 in 1RS genotypes may have a positive impact in ameliorating the damaging effects of translocation on the physical performance of dough. The translocation lines containing *Glu-D1* subunits 5+10 also showed superior baking performance when compared to its allelic counterpart 2+12.

A dough profile parameter (ST) has the potential to screen for inherent surface stickiness. Samples for stickiness determinations should be drawn before the drop in dough consistency (Stage 03) and prolonged mixing (Stage 04), as these later stages of dough mixing can include stickiness due to physical deformation.

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