Milling and Baking Quality of 1BL/1RS Translocation Wheats. I. Effects of Genotype and Environment[1]

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ABSTRACT

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Seven 1BL/1RS translocation wheats were compared with six control wheats by standard tests used to assess milling and baking quality characteristics. Test weight and 1,000-kernel weight were higher for wheats containing the translocation. The flours of the translocation wheats were of poorer quality, as shown by their lower protein content, weaker dough mixing strength, shorter dough extensibility, higher ratio of extensigraph resistance to extensibility, higher degree of dough stickiness, and lower loaf volume. The translocation had no effect on kernel hardness, flour yield, farinograph absorption, dough development time, or mixograph development time. Growth environment had a marked effect on quality parameters. Group effects (1BL/1RS versus control wheats) were significant for all parameters except kernel hardness, flour yield, falling number, farinograph water absorption, and farinograph and mixograph development time. The group-by-environment interactions were nonsignificant for most of the quality parameters. Wide variations among cultivars or lines for physical, chemical, rheological, and baking characteristics were noted. Not all lines with the 1BL/1RS translocation exhibited a high degree of dough stickiness. Three 1BL/1RS wheats (8416-Q06E, 8417-BJ03A, and 8417-BJ03D) were rated similar in quality to the control wheat Biggar. Accordingly, they would be suitable for registration in the Canada Prairie Spring wheat class. None of the 1BL/1RS wheats had quality characteristics suitable for the Canada Western Red Spring wheat class (i.e., equal in quality to Neepawa). Genetic effects were significant for all quality parameters. Environmental effects were significant for all quality characteristics except remix dough stickiness, kernel hardness, and mixograph band width at 2 min after the peak. Although the genotype-by-environment interactions were significant, they were relatively small in magnitude for most of the quality characteristics. Remix dough stickiness was more highly correlated with quality characteristics than was first mix stage dough stickiness. Breadmaking quality decreased as the degree of remix stickiness increased. Stepwise multiple regression indicated that approximately 62% of the variability in the remix stickiness can be explained by protein content and gluten strength.

Rye is used by wheat breeders as an additional source of genes for disease resistance and enhanced agronomic performance of wheat (Mettin et al 1973, Villareal et al 1991). Substitution of the short arm of the 1R chromosome of rye for the short arm of the 1B chromosome of wheat to produce the 1BL/1RS translocation lines has been used extensively in wheat improvement programs in Europe (Mettin and Bluthner 1984) and in international wheat programs at the International Maize and Wheat Improvement Center, CIMMYT (Pena et al 1990). The translocation lines have been recently introduced into Canadian wheat-breeding programs. Of particular concern, however, is the apparent detrimental effect of the 1BL/1RS chromosome on breadmaking quality (Martin and Stewart 1986a, Dhaliwal et al 1987, Pena et al 1990, van Lill et al 1990). Results on increased dough stickiness and weaker dough strength of the 1BL/1RS wheats as reported in literature are often contradictory (Biliaderis et al 1992). Inferior breadmaking quality of such wheats appears to be dependent on the genotype of the wheat parent (Graybosch et al 1990) and the environment in which the wheats are grown (Rogers et al 1989).

The results reported in this article add to the pool of information on the implication of the 1BL/1RS translocation in breadmaking quality, especially in the context of Canadian wheat-breeding programs.

MATERIALS AND METHODS

Wheat Samples

Thirteen spring wheat cultivars (Table I), comprising seven 1BL/1RS translocation wheats and six control wheats were used in this study. The source of the 1BL/1RS chromosome for BR 23 was Alondra Sib; for the remaining six lines, it was the cultivar Kavkaz. All samples were grown in three environments (Glenlea, MB, 1989, 1990; Swift Current, SK, 1989) in a randomized complete block design with four replicates at each location.

Breadmaking Quality Analyses

The grain was milled into straight-grade flour on the Buhler Pneumatic Laboratory mill after being tempered overnight to 16.5% moisture content. Test weight, 1,000-kernel weight, kernel hardness, ash content, falling number, farinograms, and mixograms were determined according to Buckley et al (1990) and Lukow et al (1990). Flour yield and extensigrams were determined according to Lukow and McVetty (1991). The flour protein content was determined using the Dickey-John near-infrared analyzer according to AACC approved method 39-11 (AACC 1983). The Zeleny sedimentation volumes were determined by AACC approved method 56-61A.

Dough stickiness was determined after the first and second mix of the remix test baking method (Kilborn and Tipples 1981). Each dough was classified into one of five levels of stickiness: nonsticky (NS), slightly sticky (SS), sticky (S), very sticky (VS), and extremely sticky (ES). NS doughs did not stick to the mixing bowl and hands. SS doughs showed a minor tendency to stick to the mixing bowl and hands but could be pulled out cleanly from the mixing bowl. S doughs could not be pulled out from the mixing bowl in one piece and left traces of dough on the hands; these doughs were difficult to round. The VS and ES doughs showed excessive sticking to the mixing bowl and hands. The VS doughs were slightly easier to handle than the ES doughs, which could not be rounded.

Determination of High Molecular Weight Glutenin Subunit Composition

Total protein was extracted from individual half-kernels of each cultivar or line and was fractionated by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) using 10% polyacrylamide gels. The high molecular weight (HMW) glutenin subunits were numbered and *Glu-1* quality scores were calculated as described previously (Lukow et al 1989). The scores were ad-

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TABLE I
Pedigrees of the Wheat Cultivars and Lines

Wheat Group and Cultivar or Line	Pedigree
1BL/1RS wheat group	
BR 23	Correcaminos/Alondra Sib[a]/3/IAS 16/5/Norin 10/ Brevor 17//Yaqui 53/Yaqui 50/4/Yaktana 54 B-20/ Veranópolis *2/Egypt Na 101//IAS 20/Nd 81
8416-Q06A 8416-Q06E 8416-BZ10A 8416-BZ10C 8417-BJ03A 8417-BJ03D	Tobari 66/Romany//Pitic 62/Gaines/5/Frontana/3/McMurachy/Exchange//2*Redman/4/ Thatcher*6/Kenya Farmer/6/Kavkaz[a]/Ti 71//Tito "s"/7/Kenya Farmer*2/Kenya 321.BT.1.B.1.
Control wheat group	
8417-AV06D	Tobari 66/Romany//Pitic 62/Gaines/5/Frontana/3/McMurachy/Exchange//2*Redman/4/ Thatcher*6/Kenya Farmer/6/Kavkaz[a]/Ti 71//Tito "s"/7/Kenya Farmer*2/Kenya 321.BT.1.B.1.
CEP 14	IAS 16/3/Yaktana 54//Norin 10/Brevor 21-1C*2/Tokai 66/Arthur 71
Neepawa	Thatcher*7/Frontana//Thatcher*6/Kenya Farmer/3/Thatcher*2//Frontana/Thatcher
Olso	Sonora 64/Yaqui 50E/Guajolote/3/Inia/4/Ciano//Egan/Sonora 64
Genesis	Tobari 66/Romany//Pitic 62/Gaines
Biggar	Tobari 66/Romany

[a] Sources of the 1BL/1RS translocation.

TABLE II
High Molecular Weight (HMW) Glutenin Subunit Composition of the 1BL/1RS and Control Wheats

Cultivar	Chromosome-Encoded HMW Glutenin Subunits 1A	1B	1D	*Glu-1* Score	Rye-Adjusted *Glu-1* Quality Score[a]
1BL/1RS wheats					
BR 23	Null	17 + 18	2 + 12	6	4
8416-Q06A	Null	7 + 9	2 + 12	5	3
8416-Q06E	2*	7 + 9	5 + 10	9	6
8416-BZ10A	Null	7 + 9	2 + 12	5	3
8416-BZ10C	Null	7 + 9	2 + 12	5	3
8417-BJ03A	2*	7 + 9	5 + 10	9	6
8417-BJ03D	2*	7 + 9	5 + 10	9	6
Control wheats					
8417-AV06D	2*	7 + 9	5 + 10	9	...
CEP 14	1	13 + 16	5 + 10	10	...
Neepawa	2*	7 + 9	5 + 10	9	...
Oslo	1	7 + 8	2 + 12	8	...
Genesis	1	7 + 8	2 + 12	8	...
Biggar	1	7 + 8	2 + 12	8	...

[a] According to Payne et al (1987).

justed, where applicable, to account for the presence of rye glutelin subunits, according to Payne et al (1987).

Statistical Analysis

Analysis of variance was applied to the data using the Statistical Analysis System (SAS Institute, Cary, NC). The estimates of the components of variance were calculated according to Comstock and Moll (1963). Pairwise *T*-test and rank correlation were used to analyze dough stickiness. Prediction equations for dough stickiness were generated by stepwise multiple regression.

RESULTS AND DISCUSSION

HMW Glutenin Subunit Composition

The composition of the HMW glutenin subunits of the 13 wheat lines and their *Glu-1* scores are presented in Table II. All samples were genetically pure for the HMW glutenin subunits, based on analysis of 10 kernels. All of the 1BL/1RS lines had lower *Glu-1* scores (adjusted for rye glutelin) than those of the control wheats. Without adjustment for the rye glutelin, three of the 1BL/1RS lines had a *Glu* score of 9, equal to that of the control wheats, all of which were in the range of 8–10.

Frequencies of the HMW glutenin subunits in the 1BL/1RS group were compared with those of the control group. The key difference between the two groups was in the HMW subunits encoded by chromosome 1A. The null allele was the most common in the 1BL/1RS wheats, whereas subunit 1 was predominant in the control wheats.

The most frequent subunits of chromosome 1B of both the 1BL/1RS and the control wheats were those associated with good breadmaking quality, that is, subunits 7+9 and 7+8.

The two wheat groups were similar in the distribution of subunits encoded by chromosome 1D; subunits 2+12 (poor quality) and 5+10 (good quality) were found in almost equal frequency.

In contrast to the results of the present study, Amaya et al (1991) generally found high frequencies of good quality HMW glutenin subunits encoded by chromosome 1A in both 1BL/1RS and control groups and greater differences in the 1B- and 1D-encoded HMW glutenin subunits. Amaya et al (1991) and Graybosch et al (1990) identified some 1BL/1RS lines with high *Glu-1* quality scores. Lines 8416-Q06E, 8417-BJ03A, and 8417-BJ03D of this study fall into this category. Our results provide additional evidence that factors other than the HMW glutenin subunit composition contributes to the sticky dough and weak dough strength in 1BL/1RS translocation wheats.

Differences Between the 1BL/1RS and Control Groups

Breadmaking quality characteristics of the 1BL/1RS translocation group were compared with those of the control group over environments by analysis of variance (Table III). There were significant differences between the two groups for most of the characteristics, in contrast to the limited differences noted by Dhaliwal et al (1987). The 1BL/1RS group was characterized by significantly lower protein and ash content, as well as weaker gluten (lower Zeleny sedimentation volume) than that of the control group. The falling number value of the 1BL/1RS group was significantly lower than that of the control group, but there was no visual evidence of preharvest sprouting. No significant difference was observed between the 1BL/1RS and control groups in kernel hardness and flour yield, as observed by Dhaliwal et al (1987).

The 1BL/1RS wheats were significantly different from the control wheats in some of the farinograph and mixograph parameters. The 1BL/1RS wheats were characterized by weaker dough mixing properties, as shown by their significantly shorter farinograph arrival and departure times, greater mixing tolerance indices, lower stability, shorter time to breakdown, and narrower bandwidth at 5 min after the peak. Significant differences between groups were observed for mixograph peak height, energy after peak, bandwidth at peak, total energy, and bandwidth at 2 min

TABLE III
Group Mean Values for Quality Characteristics[a,b]

	Physical and Chemical			Farinograph and Mixograph			Extensigraph and Baking	
	1BL/1RS	Control		1BL/1RS	Control		1BL/1RS	Control
TWT	78.9	78.0***	FAB	56.3	56.1 ns	R	10.9	11.9**
TKWT	33.7	31.8***	DDT	5.3	5.9 ns	E	17.3	20.8***
GRT	0.48	0.56 ns	MTI	38.1	31.2**	R/E	0.63	0.58**
FLY	70.0	71.2 ns	STA	7.5	8.8*	R′	11.0	12.3**
PROT	12.5	12.8*	FW	0.70	0.85***	E′	16.2	19.5***
ASH	0.397	0.399**	MDT	2.6	2.7 ns	R/E′	0.69	0.64**
FN	521	546***	PKH	0.14	0.15***	FSTICK	1.4	1.3*
ZS	51	66***	BWD	0.047	0.058***	SSTICK	3.5	2.7***
						RLV	723	774***

[a] TWT = test weight (kg/hl); TKWT = 1,000 kernel weight (g); GRT = grinding time (min); FLY = Buhler mill flour yield (%, 14% mb); PROT = Buhler mill flour protein content (%, 14% mb); ASH = flour ash content (%, 14% mb); FN = falling number (sec); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender units); STA = stability (min); FW = bandwidth at 5 min after peak (cm); MDT = mixograph development time (min); PKH = mixograph peak height (Nm); BWD = band-width at 2 min after peak (Nm); R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = ratio of resistance to extension; R′ = resistance at 135 min (cm); E′ = extensibility at 135 min (cm); R/E′ = ratio of resistance to extension; FSTICK = dough stickiness at the first mix of the remix bake; SSTICK = dough stickiness at the remix stage of the remix bake; RLV = remix loaf volume (cc).
[b] *, $P = 0.05$; **, $P = 0.01$; ***, $P = 0.001$; ns, nonsignificant.

after the peak. There was no significant difference between the two groups for the farinograph absorption, farinograph dough development time, and mixograph development time.

Extensigraph test results showed that the 1BL/1RS group had significantly lower resistance to extension and extensibility than did the control group. In addition, the ratio of resistance to extensibility was significantly higher for the 1BL/1RS group; the 1BL/1RS translocation had a greater effect on extensibility than on resistance. Similar results have been reported previously for a group of 1BL/1RS lines grown in Australia (Dhaliwal et al 1987). These results suggest that the 1BL/1RS lines produce doughs that are of lower strength than those of the control wheats.

After the first mix and the remix stages, doughs of the 1BL/1RS group were generally more sticky than those of the control group. Stickiness after the remix stage showed the greatest differences between the two groups. These results are generally consistent with published information (Martin and Stewart 1986a, Dhaliwal et al 1987, van Lill et al 1990).

Bread loaf volume results were significantly lower for the 1BL/1RS group than they were for the control group. The differences between the two groups in crust color and crumb grain were not significant. Most of the loaves had an even, brown crust color and a uniform, fine crumb grain (as recorded in Fenn 1992).

Effect of Environment

Environment mean values, least significant differences, and ranges for the quality characteristics were calculated (data not shown). The 1989 Swift Current crop was characterized by smaller and softer kernels that gave a lower flour yield. These samples had a higher protein content, better gluten quality (i.e., higher Zeleny sedimentation volume), greater dough mixing strength (as indicated by farinograph and mixograph results), higher water absorption, higher loaf volume, lower ash content, and less sticky doughs than the samples grown at Glenlea in 1989 and 1990. The 1990 Glenlea crop was characterized by the highest test weight and largest kernels, lowest protein content, lowest water absorption, lowest dough strength, and highest resistance to extension and extensibility in the extensigraph test. The 1989 Glenlea samples were characterized by the hardest kernels, highest ash content, highest dough stickiness, lowest gluten quality, lowest resistance to extension and extensibility, and lowest loaf volumes.

Effect of Group, Environment, and Their Interaction

The effects of group, environment, and their interaction, on the quality characteristics were examined by analysis of variance (Table IV). Environmental effects were very highly significant for most of the characteristics. Only kernel hardness, mixograph bandwidth 2 min after peak, and remix stickiness were not affected by environment. Variations in flour yield, falling number, farinograph absorption and development time, and mixograph development time were caused largely by the environment rather than by group differences.

TABLE IV
***F*-Values[a] for the Analysis of Variance for the Quality Characteristics[b] of Groups**

Quality Characteristic	Environment[c]	Group	Group × Environment
TWT	34.50***	27.99***	2.42 ns
TKWT	92.68***	28.86***	1.24 ns
GRT	3.28 ns	2.36 ns	0.18 ns
FLY	20.01***	3.11 ns	0.10 ns
PROT	42.67***	4.52*	2.30 ns
ASH	44.58***	8.13**	0.64 ns
FN	46.67***	3.68 ns	1.17 ns
ZS	81.99***	187.58***	10.80***
FAB	33.80***	0.04 ns	2.16 ns
DDT	117.88***	3.15 ns	0.10 ns
MTI	105.32***	8.93**	2.52 ns
STA	39.89***	4.79*	1.52 ns
FW	19.02***	55.14***	3.77*
MDT	28.22***	0.16 ns	1.64 ns
PKH	17.85***	19.73***	0.93 ns
BWD	2.57 ns	61.00***	0.53 ns
R	23.25***	7.02**	0.06 ns
E	15.30**	131.47***	1.68 ns
R/E	23.60***	7.74**	0.06 ns
R′	61.17***	7.15**	0.03 ns
E′	41.58***	148.31***	4.46*
R/E′	49.34***	9.03**	0.27 ns
FSTICK	9.40**	4.88*	0.49 ns
SSTICK	2.01 ns	19.24***	0.05 ns
RLV	22.72***	16.61***	0.61 ns

[a] *, $P = 0.05$; **, $P = 0.01$, ***, $P = 0.001$; ns, nonsignificant.
[b] Abbreviations as for Table III.
[c] Degrees of freedom: environment, 2 and 9; group, 1 and 141; group × environment 2 and 141.

Group-by-environment interactions were nonsignificant for 22 of 25 quality characteristics. For those quality characteristics with significant group-by-environment interactions, the variances were relatively small. Only the falling number value and the farinograph absorption had large variances (>30% of the group variance).

Cultivar Comparisons

The cultivar or line mean values for quality characteristics over the three environments are presented in Tables V–VII. For those characteristics where the genotype-by-environment interaction was significant and greater than 30% of the genotype variance, the least significant difference is not reported. Significant differences among cultivars were obtained for 1,000-kernel weight, kernel hardness, flour yield, Zeleny sedimentation volume, farinograph dough development time, bandwidth at 5 min after peak,

TABLE V

Cultivar Mean Values for Physical and Chemical Quality Characteristics[a] Over Environments[b]

Cultivar	TWT	TKWT	GRT	FLY	PROT	ASH	FN	ZS
1BL/1RS wheats								
BR 23	77.4	32.5	1.00	63.3	11.6	0.41	474	56
8416-Q06A	78.5	35.1	0.52	70.6	12.6	0.40	425	48
8416-Q06E	78.8	34.9	0.55	69.7	12.2	0.42	431	51
8416-BZ10A	78.1	32.8	0.35	71.6	13.3	0.39	587	48
8416-BZ10C	78.3	33.1	0.34	72.3	13.4	0.40	596	42
8417-BJ03A	77.6	29.2	0.35	71.8	12.2	0.43	566	42
8417-BJ03D	78.6	30.9	0.35	72.6	12.4	0.41	599	43
Control wheats								
8417-AV06D	79.0	33.9	0.32	74.5	13.5	0.39	561	57
CEP 14	76.6	28.3	1.42	64.7	12.5	0.39	467	68
Neepawa	77.8	28.7	0.34	72.9	14.2	0.38	623	61
Oslo	76.7	30.3	0.45	73.8	12.8	0.38	561	78
Genesis	75.5	30.1	0.49	69.1	11.7	0.40	530	62
Biggar	76.8	31.2	0.46	72.7	12.4	0.44	577	68
LSD[c]	...	2.8	0.13	1.2	...	...	...	8
Range	3.5	6.8	1.10	11.2	2.6	0.06	198	36

[a] Abbreviations as in Table III.
[b] Average of data from samples grown in Glenlea, MB, 1989 and 1990, and in Swift Current, SK, 1989.
[c] Least square difference at $P = 0.05$.

TABLE VI

Cultivar Mean Values for Farinograph and Mixograph Quality Characteristics[a] Over Environments[b]

Cultivar	FAB	DDT	MTI	STA	FW	MDT	PKH	BWD
1BL/1RS wheats								
BR 23	54.2	3.2	45	4.5	0.642	1.6	0.13	1.144
8416-Q06A	57.2	4.2	38	6.0	0.625	1.8	0.14	0.040
8416-Q06E	53.8	8.2	23	13.3	0.775	4.4	0.12	0.051
8416-BZ10A	58.1	6.1	34	7.4	0.642	2.4	0.15	0.145
8416-BZ10C	57.6	4.6	42	6.4	0.592	2.2	0.14	0.043
8417-BJ03A	55.6	6.8	27	10.4	0.742	4.1	0.12	0.043
8417-BJ03D	56.1	6.1	31	8.3	0.633	3.4	0.13	0.046
Control wheats								
8417-AV06D	56.8	9.2	23	11.0	0.867	4.0	0.14	0.057
CEP 14	53.9	2.9	47	5.2	0.725	2.2	0.13	0.052
Neepawa	58.9	5.8	17	10.8	0.708	2.5	0.15	0.065
Oslo	56.5	8.2	23	13.1	1.100	3.9	0.14	0.062
Genesis	56.7	5.0	35	7.0	0.733	2.2	0.16	0.048
Biggar	56.3	6.7	22	9.0	0.950	2.8	0.15	0.056
LSD[c]	...	2.2	...	...	0.153	0.5	...	...
Range	5.4	6.3	30	8.8	0.508	2.8	0.04	0.025

[a] Abbreviations as in Table III.
[b] Average of data from samples grown in Glenlea, MB, 1989 and 1990, and in Swift Current, SK, 1989.
[c] Least square difference at $P = 0.05$.

TABLE VII

Cultivar Mean Values for Extensigraph and Baking Quality Characteristics[a] Over Environments[b]

Cultivar	R	E	R/E	R′	E′	R/E′	FSTICK	SSTICK	RLV
1BL/1RS wheats									
BR 23	7.8	16.4	0.48	7.9	15.4	0.52	2.5	4.3	571
8416-Q06A	9.0	17.8	0.50	8.9	17.5	0.51	1.9	4.9	703
8416-Q06E	14.7	17.2	0.86	15.0	16.0	0.94	1.0	2.2	771
8416-BZ10A	9.4	18.8	0.52	8.9	17.3	0.51	1.3	4.3	775
8416-BZ10C	9.6	17.1	0.56	9.3	15.7	0.60	1.4	4.4	708
8417-BJ03A	12.5	17.5	0.75	14.4	14.9	0.96	1.0	1.7	782
8417-BJ03D	13.0	16.4	0.80	12.7	14.8	0.85	1.0	2.5	791
Control wheats									
8417-AV06D	14.1	21.1	0.68	14.8	19.3	0.49	1.0	1.4	847
CEP 14	9.0	19.4	0.47	8.5	18.0	0.47	1.8	4.0	624
Neepawa	12.0	20.1	0.60	11.0	18.3	0.61	1.3	1.9	900
Oslo	14.5	24.5	0.59	15.1	22.5	0.68	1.0	1.6	843
Genesis	10.9	21.0	0.54	11.3	20.3	0.56	1.3	3.8	733
Biggar	11.8	24.2	0.50	12.7	23.3	0.56	1.0	2.1	802
LSD[c]	1.9	1.8	0.12	1.7	1.5	0.11	...	0.7	47
Range	6.9	8.1	0.39	7.2	8.4	0.49	1.5	3.5	329

[a] Abbreviations as in Table III.
[b] Average of data from samples grown in Glenlea, MB, 1989 and 1990, and in Swift Current, SK, 1989.
[c] Least square difference of $P = 0.05$.

mixograph development time, extensigraph resistance, extensibility and ratio of resistance to extension, remix stickiness, and loaf volume. Narrow ranges were noted for flour protein and ash contents, farinograph absorption and mixing tolerance index, and the ratio of extensigraph resistance to extension.

Of the 1BL/1RS translocation lines, 8417-BJ03A and 8417-BJ03D were the best in terms of overall quality, but they were still significantly poorer than Neepawa, the official standard of the Canada Western Red Spring class of bread wheat. Of the 1BL/1RS lines, 8416-Q06E, 8417-BJ03A, and 8417-BJ03D would qualify for registration into the Canada Prairie Spring class because they were similar to Biggar, a current cultivar of this wheat class. BR 23 was the poorest in overall milling and baking quality.

Most of the 1BL/1RS wheats were either VS or S at the remix stage of the bake test. These results agreed with those of others (Zeller et al 1982; Martin and Stewart 1986a,b, 1990; Dhaliwal et al 1987; Barnes 1990). However, some cultivars in the 1BL/1RS group showed a lesser degree of dough stickiness. The lines 8416-Q06E, 8417-BJ03A, and 8417-BJ03D were NS at the first mix and SS at the remix stage. The high-quality HMW glutenin subunits, as reflected by the unadjusted *Glu-1* score of 9, may have mitigated the deleterious effects of the rye translocation. This result suggests that the dough stickiness problem can be minimized by transferring the 1BL/1RS chromosome into a genotype with strong gluten (high *Glu-1* score). On the other hand, the control wheats CEP 14 and Genesis also contained good-quality HMW glutenin subunits, but they were SS at the first mix and VS at the remix stage. The falling number values of all the cultivars in this study were above 300, indicating that α-amylase was probably not the cause of dough stickiness.

Effect of Genotype, Environment, and Their Interaction

Analysis of variance was used to examine the effects of genotype, environment, and their interaction on the quality characteristics (Table VIII). Genetic effects were highly significant for all the quality parameters; this is in agreement with the studies of Bassett et al (1989) and Lukow and McVetty (1991). Environmental effects were nonsignificant for kernel hardness, mixograph bandwidth at 2 min after peak, and remix dough stickiness. Environmental effects were highly significant or very highly significant for all other quality characteristics.

The genotype-by-environment interactions were very highly significant for the majority of the quality parameters. Only the interactions for 1,000-kernel weight and kernel hardness were nonsignificant, in contrast to previous results (Lukow and McVetty 1991). Although the genotype-by-environment interactions were significant, the variance component for genotypes accounted for most of the variation and the interactions were small in magnitude for most quality characteristics. The relatively large genotype-by-environment interactions (>30% of genotype variance) indicated that genotype differences could not be statistically compared for test weight, flour protein, ash, falling number value, farinograph absorption, mixing tolerance index, stability, mixograph peak height and bandwidth at 2 min after peak, and first mix stickiness.

TABLE VIII
***F*-Values[a] for the Analysis of Variance for the Quality Characteristics[b] of Cultivars**

Quality Characteristic	Environment[c]	Group	Genotype × Environment
TWT	33.89***	22.70***	6.49***
TKWT	93.34***	38.82***	5.63 ns
GRT	3.27 ns	60.19***	1.56 ns
FLY	20.30***	159.06***	5.75***
PROT	41.81***	37.32***	6.63***
ASH	44.79***	17.04***	3.04***
FN	47.83***	23.51***	5.23***
ZS	78.37***	106.54***	12.51***
FAB	32.75***	23.04***	3.60***
DDT	118.36***	33.62***	4.84***
MTI	108.75***	15.44***	4.70***
STA	41.28***	23.60***	3.81***
FW	18.43***	24.11***	2.16***
MDT	29.67***	63.05***	5.17***
PKH	17.34***	10.19***	2.87***
BWD	2.63 ns	10.57***	1.86*
R	23.24***	24.22***	1.92*
E	14.68**	28.90***	2.25**
R/E	23.60***	23.87***	3.05***
R′	61.76***	101.88***	3.65***
E′	38.42***	43.76***	2.77***
R/E′	49.55***	73.13**	2.79***
FSTICK	9.81**	19.48***	5.42***
SSTICK	1.97 ns	50.86***	4.28***
RLV	22.09***	73.65***	4.43***

[a] *, $P = 0.05$; **, $P = 0.01$, ***, $P = 0.001$; ns, nonsignificant.
[b] Abbreviations as for Table III.
[c] Degree of freedom; environment, 2 and 9; cultivar, 12 and 108; cultivar × environment 24 and 108.

Dough Stickiness and Quality Parameters

Mean values for each quality characteristic of the dough stickiness classes for the first mix and remix stages were calculated. The first mix NS doughs were from cultivars or lines with higher flour yield, mixograph development time, extensigraph resistance, ratio of resistance to extension, and loaf volume. First mix NS doughs were lower in remix stickiness than the other first mix stickiness classes (data not shown). The NS doughs were associated with harder kernels; their overall quality differed from that of the S and VS doughs. Only the VS doughs had a high ash content. The other stickiness classes did not differ significantly from each other. No significant differences were observed between the NS and the VS doughs for any of the other quality parameters.

The NS doughs at the remix stage were generally associated with smaller kernels and higher flour protein content, falling number value, Zeleny sedimentation volume, dough strength (farinograph development time, mixing tolerance index, stability, mixograph development time), and loaf volume than those of the other remix stickiness classes (Tables IX–XI). Amaya et al (1991) found greater dough strength but no difference in loaf volume for NS doughs developed by high-speed mixing. Both the first mix and remix dough stickiness groups had similar associations with kernel hardness, flour yield, and extensibility. Only the remix NS samples differed significantly from the ES samples for farinograph bandwidth at 5 min after peak and for mixograph bandwidth at 2 min after peak.

Remix stickiness showed a greater variability than did the first mix stickiness. As overall quality decreased, remix stickiness increased. The farinograph development time and stability, mixograph development time, and loaf volume generally decreased as the degree of stickiness increased. These results agree with those of Dhaliwal and MacRitchie (1990). In contrast, Martin and Stewart (1986a) found no relationship between mixograph data and dough stickiness. For the extensigraph resistance and the ratio of resistance to extension, the first three stickiness groups

TABLE IX
Mean Values for Physical and Chemical Quality Characteristics[a] of Different Dough Stickiness Classes[b] at the Remix Stage of the Remix Bake Test

	NS	SS	S	VS	ES
TWT	77.2 b[c]	78.7 a	77.6 b	77.9 b	77.3 b
TKWT	30.0 b	32.5 a	32.0 ab	32.1 a	32.0 a
GRT	0.41 b	0.44 b	0.49 ab	0.66 a	0.64 a
FLY	72.7 a	71.9 ab	70.3 bc	69.7 c	69.2 c
PROT	13.3 a	12.3 b	12.4 b	12.5 b	12.6 b
ASH	0.40 a	0.41 a	0.41 a	0.40 a	0.41 a
FN	583 a	528 ab	553 b	530 b	490 b
ZS	62 a	54 ab	58 b	54 b	50 b

[a] Abbreviations as for Table III.
[b] NS = nonsticky; SS = slightly sticky; S = sticky, VS = very sticky; ES = extremely sticky.
[c] No significant difference was marked among classes with the same letter for each quality parameter; comparison-wise rate = 0.05; experiment-wise rate was not applied because of different sample sizes in the five dough classes of the remix stage of the remix bake.

TABLE X
Mean Values for Farinograph and Mixograph Quality Characteristics[a] of Different Dough Stickiness Classes[b] at the Remix Stage of the Remix Bake Test

	NS	SS	S	VS	ES
FAB	56.6 a[c]	54.4 b	56.0 ab	55.9 ab	56.8 a
DDT	9.1 a	5.5 b	5.9 b	4.4 bc	4.3 c
MTI	17 b	33 a	28 a	41 a	38 a
STA	12.9 a	8.6 b	9.4 b	6.1 c	6.0 c
FW	0.800 a	0.892 a	0.774 ab	0.692 bc	0.625 c
MDT	4.0 a	3.1 b	2.9 b	2.3 c	2.0 c
PKH	0.14 a	0.13 a	0.14 a	0.14 a	0.15 a
BWD	0.056 a	0.052 ab	0.052 ab	0.045 c	0.046 bc

[a] Abbreviations as for Table III.
[b] NS = nonsticky; SS = slightly sticky; S = sticky, VS = very sticky; ES = extremely sticky.
[c] No significant difference was marked among classes with the same letter for each quality parameter; comparison-wise rate = 0.05; experiment-wise rate was not applied because of different sample sizes in the five dough classes of the remix stage of the remix bake.

TABLE XI
Mean Values for Extensigraph and Baking Quality Characteristics[a] of Different Dough Stickiness Classes[b] at the Remix Stage of the Remix Bake Test

	NS	SS	S	VS	ES
R	12.9 a	13.6 a	13.0 a	9.9 b	8.4 c
E	21.1 a	19.2 ab	19.6 ab	18.6 b	17.9 b
R/E	0.63 a	0.73 a	0.68 a	0.55 b	0.47 c
R′	14.0 a	13.5 a	13.0 b	9.7 b	8.2 c
E′	19.5 a	17.6 ab	18.1 ab	17.2 b	17.0 b
R/E′	0.75 a	0.79 a	0.74 a	0.58 b	0.48 c
FSTICK	1.0 b	1.1 b	1.1 b	1.6 a	1.9 a
RLV	847 a	794 b	777 b	700 c	676 c

[a] Abbreviations as for Table III.
[b] NS = nonsticky; SS = slightly sticky; S = sticky, VS = very sticky; ES = extremely sticky.
[c] No significant difference was marked among classes with the same letter for each quality parameter; comparison-wise rate = 0.05; experiment-wise rate was not applied because of different sample sizes in the five dough classes of the remix stage of the remix bake.

at remix did not differ significantly from each other, but they were significantly different from the VS and ES groups. VS and ES doughs were significantly different from each other.

In general, VS doughs were poor in breadmaking quality, as indicated by their low gluten quality (Zeleny sedimentation) and weak dough strength (farinograph and mixograph parameters). The extensigraph resistance and the ratio of resistance to extension were low for the VS samples, and loaf volume was small.

Rank correlations of the first mix and remix stickiness to individual quality parameters were calculated (data not shown). The inverse relationships between dough stickiness at the two mixing stages and mixing strength was confirmed. First mix stickiness was very highly significantly correlated ($|r| > 0.5$, $P = 0.001$) to the farinograph dough development time and stability, mixograph development time, extensigraph resistance, the ratio of resistance to extension at 45 min, the remix dough stickiness, and the loaf volume. Also, the remix stickiness was very highly significantly correlated ($|r| > 0.5$, $P = 0.001$) to the same quality characteristics with one exception: the ratio of resistance to extension was more highly correlated to remix dough stickiness at 135 min than it was at 45 min.

Stepwise multiple regression was used to generate regression equations for the prediction of dough stickiness from breadmaking quality parameters. These regression equations for first mix and remix stickiness were very highly significant. All variables that entered and remained in the regression equation were significant at the $P = 0.05$ level. A greater proportion of the variability was explainable in the remix dough stickiness (62%) compared to the first mix stickiness (40%). The prediction equation for remix dough stickiness was:

$$\begin{aligned} \text{SSTICK} = &-0.216\,(\text{PROT}) - 0.021\,(\text{ZS}) - 0.458(\text{MDT}) \\ &+ 10.403\,(\text{PKH}) - 1.025\,(\text{R/E}') - 0.006\,(\text{RLV}) \end{aligned}$$

where SSTICK = dough stickiness at the remix stage of the remix bake; PROT = Buhler mill flour protein content; ZS = Zeleny sedimentation volume; MDT = mixograph development time; PKH = mixograph peak height; R/E′ = ratio of resistance to extension; and RLV = remix loaf volume. Protein content and dough mixing strength were the dominant variables in the remix stickiness prediction equation.

CONCLUSION

The 1BL/1RS translocation wheats used in this study had poorer breadmaking quality than that of the control wheats. Genetic and environmental effects accounted for the differences in most of the quality characteristics. For some characteristics (including flour yield, farinograph dough development time, and mixograph development time), differences between the 1BL/1RS and the control wheats were due exclusively to the environment. Kernel hardness and remix dough stickiness differences between groups were due exclusively to genetic effects. The absence of environmental effect on dough stickiness simplifies the screening for this characteristic in 1BL/1RS wheats.

None of the 1BL/1RS wheats had quality characteristics that would make them acceptable for registration in the Canada Western Red Spring wheat class. Three 1BL/1RS cultivars (8416-AV06D, 8417-BJ03A, and 8417-BJ03D) had quality characteristics that would make them suitable for registration in the Canada Prairie Spring wheat class. Genotype-by-environment interactions were relatively minor for all quality parameters. Variation in remix dough stickiness was caused exclusively by genetic effects rather than by environmental effects. Dough stickiness at the remix stage was associated with greater variation in quality characteristics than that of the first mix stage stickiness. ES doughs were associated with poor gluten quality, weak dough mixing strength, reduced ratios for extensigraph resistance to extension, and low loaf volume.

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