EFFECT OF THE 1BL/1RS TRANSLOCATION ON BREADMAKING QUALITY

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Dora Fenn

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Dora Fenn

To my parents and friends

Trust in the Lord with all thine heart;
and lean not unto thine own understanding.

Proverb 3:5

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I realized that self-discipline, decisiveness and endurance were the keys to successful research.

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ABSTRACT

Rye is used by wheat breeders as an additional source of genes for disease resistance and enhanced agronomic performance. The rye genes can be incorporated into wheat by substituting the short arm of rye chromosome 1R for the short arm of wheat chromosome 1B thereby producing the wheat 1BL/1RS translocation. Wheat cultivars with the 1BL/1RS translocation have been reported to produce very sticky doughs, an undesirable trait in breadmaking. In this study, the objectives were to compare the quality of 1BL/1RS wheats to normal wheats, to evaluate the effect of environment and genotype on quality and to examine the relationship of dough stickiness to various quality characteristics.

The breadmaking quality of seven 1BL/1RS wheats was compared to that of six control wheats by analyzing four replicates grown in three environments. Wide variations among cultivars for physical, biochemical, rheological and baking characteristics were shown. The 1BL/1RS wheat, BR 23, was rated poorest in overall quality. Low flour protein, weak rheological properties and very sticky dough resulted in low loaf volume. Not all cultivars with the 1BL/1RS translocation exhibited excessive dough stickiness. Three 1BL/1RS wheats (8416-Q06E, 8417-BJ03A and 8417-BJ03D), were rated similar in quality to the normal wheat, Biggar. Their milling, biochemical, rheological and baking properties would make them 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.

Cultivar effects were significant for all the quality parameters. Environment effects were significant for the quality characteristics with the exception of remix dough stickiness, grinding time and mixograph first minute slope to peak, energy after peak, peak band width and band width at

2 min after peak. Although the cultivar by environment interactions were significant, they were relatively small in magnitude for the majority of the quality characteristics.

As a group, the 1BL/1RS wheats had inferior breadmaking quality compared to the control wheats. Their major quality defects were low protein content, poor rheological properties, poor quality HMW glutenin subunits, low extensibility and resistance to extension, high degrees of dough stickiness and low loaf volume.

Dough stickiness scores measured at the remix stage of the bake test were associated better with quality characteristics than dough stickiness scores measured at the first mix stage. The remix dough stickiness was unaffected by the environment and was dependent solely on genotypic differences. Breadmaking quality decreased as the degree of remix stickiness increased.

I. INTRODUCTION

The 1BL/1RS translocation refers to the substitution of the short arm (S) of wheat chromosome 1B by the short arm of rye chromosome 1R. The result of this translocation was the development of new lines of hexaploid wheat which are highly resistant to rust (Mettin *et al.*, 1973) and well adapted to different growing environments (Rajaram *et al.*, 1983).

The 1BL/1RS wheat lines were originally developed by German plant breeder, A. Riebesel, before World War II (MacRitchie *et al.*, 1986). The lines and information about them were lost because of the outbreak of the war. Today, most of the lines have been recovered and because of their unique qualities, many wheat producing countries have incorporated them into their plant breeding programs.

It has been estimated that the 1BL/1RS wheats account for 30% of the recent breeding lines in the former German Democratic Republic, 50% of the advanced breeding lines in the 21st International Bread Wheat Screening Nursery (IBWSN), and 45% of the advanced lines in Centro Internacional por el Majoramiento del Maiz y Trigo (CIMMYT) (Dhaliwal *et al.*, 1987; Villareal *et al.*, 1991).

Some of the 1BL/1RS wheats have been reported to produce extensive dough stickiness when they are mixed under high-speed or long-time mixing procedures (Barnes, 1990; Dhaliwal *et al.*, 1987; Martin and Stewart, 1986a, 1986b and 1990; Zeller *et al.*, 1982). Barnes (1990) suggested that the dough stickiness of 1BL/1RS wheats would depend on individual genetic background and growing environment. Graybosch *et al.* (1990) observed a large degree of quality variation among sister lines with the 1BL/1RS translocation. A strong relationship between the environmental factors and the dough unmixing time has also been revealed (Barnes, 1990). Contradictory results exist in the relationship between mixograph

parameters and dough stickiness.

The objectives of this study were as follows:

1) to characterize the breadmaking quality of 1BL/1RS wheats as compared to normal wheats;

2) to evaluate the effect of environment and genotype on the quality of 1BL/1RS wheats and;

3) to investigate the quality parameters associated with dough stickiness.

II. LITERATURE REVIEW

A. Genetics of Hexaploid Wheat and Diploid Rye

Wheat and rye are members of the grass family (Gramineae). Common wheat (*Triticum aestivum*) consists of 21 chromosome pairs, arranged in three related genomes (A, B, D) of seven chromosome groups (1A...7A, 1B...7B, 1D...7D). These wheat genomes originated from different ancestral diploid species and carry a similar set of genetic material (Law and Payne, 1983). The triplication of genetic material enables common wheats to withstand the loss or addition of chromosomes. Common rye (*Secale cereale*) is a diploid and contains one genome of seven chromosome pairs designated as chromosome 1R to chromosome 7R. Rye chromosomes 1R, 2R, 3R, 5R and 6R have been observed to be homeologous to the corresponding wheat chromosome group (Zeller *et al.*, 1973).

Glutenins and gliadins are the fundamental wheat proteins for breadmaking and are encoded specifically in nine loci (Law and Payne, 1983; Payne, 1987). The high molecular weight (HMW) subunits of glutenin are determined by a single complex locus located on the distal half of the long arm of wheat chromosomes 1A, 1B and 1D. These loci are designated as Glu-A1, Glu-B1 and Glu-D1, respectively. The complex loci Gli-A1, Gli-B1 and Gli-D1 encode the ω-, γ- and a few β-gliadins are located towards the end of the short arm of wheat chromosomes 1A, 1B, and 1D, respectively. In addition, the complex loci Gli-A2, Gli-B2, and Gli-D2 control the production of α-, β-, and a few γ-gliadins are located on the distal ends of the short arms of wheat chromosomes 6A, 6B, and 6D, respectively.

For common rye, the sulfur-poor, ω-secalin proteins and the interchain disulphide-linked, 75K γ-secalin proteins were revealed to be related to dough quality (Dhaliwal *et al.*, 1988; Dhaliwal & MacRitchie, 1990; Gupta *et al.*, 1989), and are coded at Sec-1-locus on the short arm

of chromosome 1R and at Sec-2-locus on the short arm of chromosome 2R, respectively (Lawrence and Shepherd, 1981; Shewry *et al.*, 1986). The rye chromosome 1R is similar to the wheat chromosomes 1A, 1B and 1D in having genes coding for alcohol-soluble prolamins on the short arm and genes coding for HMW proteins (> 86,000 apparent molecular weight) on the long arm (Lawrence and Shepherd, 1981).

B. Introduction of the Wheat-Rye Translocation

The transfer of rye genes to wheat can be obtained by methods such as (1) homeologous chromosome pairing, (2) ionizing radiation, and (3) univalent misdivision during the cross of a monosomic and a disomic addition wheat line (Sears, 1974; Zeller and Koller, 1981).

It has been shown that rye chromosomes 1R, 2R and 6R are capable of substituting for three of the chromosomes in the corresponding homeologous wheat groups (Zeller, 1973). Rye chromosome 3R substitutes well for the homeologous group-1 wheat chromosomes and at least two of the group-3 wheat chromosomes (Zeller, 1973). In addition, rye chromosome 5R shows homeology with at least one of group-4 wheat chromosomes, two of the group-5 wheat chromosomes and two of the group-6 wheat chromosomes (Zeller, 1973). According to Gupta (1971) and Koller and Zeller (1976), these substituted rye chromosomes would compensate for the loss of the corresponding homeologous wheat chromosomes.

A translocation line can be obtained by crossing common wheat with common rye, backcrossing one or more times with wheat and then selfing (Sears, 1974). Wheat genes on chromosomes 3A, 3BL, 3D and 5B prevent homeologous pairing and genes on chromosomes 5A, 5BL, and 5D promote pairing. The amount of pairing depends on the balance between promoters and suppressors (Sears, 1974, Zeller and Koller, 1981).

It is possible to produce a chromosomal translocation through the rejoining of two different telosomes originating from the misdivision of univalents at the centromeres. The union of misdivision telosomes between homeologous chromosomes is more desirable and is less deleterious when

compared to that of non-homeologous chromosomes (Zeller and Koller, 1981).

C. Detection and Identification of the 1BL/1RS Translocation Segment

Several techniques have been developed to detect and identify the translocation segments and to distinguish translocation lines from substitution lines. Each technique has its limitations and requires other methods to supplement and confirm the results.

1. Morphological Studies of Wheat Chromosomes

In addition to the improvement in resistance to rust diseases, the 1BL/1RS translocation can be detected in hexaploid wheats through the change in the number of chromosomal secondary constrictions or satellites.

A secondary constriction is a nucleolus organizer with a tandemly arranged rRNA coding gene in wheat and a rDNA coding gene in rye (Friebe *et al.*, 1989). This part of the chromatin becomes less condensed at meiotic metaphase and can be distinguished from other parts of the chromosome. A satellite is a short terminal segment outside the secondary constriction and its presence is determined by the location of the secondary constriction.

A secondary constriction or satellite occurs on each of the homeologous wheat chromosomes 1B and 6B and rye chromosome 1R (Friebe *et al.*, 1989). When the wheat chromosome 1BS is substituted by the rye chromosome 1RS, the secondary constrictions or satellites on 1BS are deleted and those on rye chromosome 1RS disappear through fusing with the wheat segment. Subsequently, only two secondary constrictions or satellites on wheat chromosome 6B remain (Mettin *et al.*, 1973). Hence, the number of secondary constrictions or satellites indicates the presence of the wheat-rye translocation.

The alien segment can also be detected through the use of horseradish peroxidase with glutaraldehyde as a specific probe to the total DNA of the rye segment and the hybridization to the Southern membrane (Heslop-Harrison *et al.*, 1990). Wheats carrying the rye segment

show the strongest hybridization signals on luminographs.

Giemsa c-banding can be used to identify the translocation segment. It is a staining technique that differentiates the constitutive heterochromatin from facultative heterochromatin at meiotic metaphase. Each chromosome has an overall unique banding pattern, translocation between segments with differences in c-band pattern can be recognized. This method provides a recognition of the 1BL/1RS translocation segment as it consists of a large terminal and subterminal c-band, which resembles the short arm of the rye chromosome 1R and has the remainder of the chromosome resembling the long arm of wheat chromosome 1B (Cai and Liu, 1989; Friebe *et al.*, 1989; Merker, 1982).

The rye segment can also be identified through the use of biotin as a specific probe to the total rye genomic DNA, followed by the in situ hybridization (Heslop-Harrison *et al.*, 1990). The rye segment is indicated by fluorescing red in green light.

In situ hybridization is a superior method compared to Giemsa c-banding. In situ hybridization is capable of identifying the size and the breakpoint of the translocation segment at all stages of the cell cycle. According to Heslop-Harrison *et al.* (1990), the translocation point is at or very near to the centromere.

2. Studies of Check Crosses

Zeller and Koller (1981) recognized a wheat line, T8, with a 4A alpha/7RS translocation by crossing the line with a Chinese Spring (CS)-ditelo-4A line and also with a monosomic addition line 7R. The former cross showed a high frequency of pairing of the telosomic 4A alpha arm and the alien chromosome. The latter cross resulted in a trivalent consisting of a single chromosome 7R, 4A and the alien chromosome. Thus, the alien chromosome is made up of the alpha arm of chromosome 4A and a part of the chromosome 7R. Further crossing of T8 to the addition lines 7RS and 7RL produced a telosomic trivalent in the former cross only, indicating that the translocation segment is composed of part of the short arm of rye

chromosome 7R.

According to Cai and Liu (1989), the 1BL/1RS wheats can also be identified by crossing to a CS double-ditelosomic line 1B, in which 100% of cells in the 1BL/1RS wheat contain a heteromorphic bivalent (t1¨) and a 1BS-telosomic univalent (t˙).

A translocation line can be distinguished from a substitution line by crossing separately to a known substitution line and a normal wheat such as Chinese Spring (Mettin *et al.*, 1973). A substitution line would produce a high frequency of the complete bivalent cell (21") in the former cross, but a translocation line would produce some of the complete bivalent cells in both crosses.

3. Electrophoretic Studies of 1BL/1RS Wheat Proteins

Control wheats, 1BL/1RS translocation wheats and 1R(1B) substitution wheats were examined by the polyacrylamide gradient-gel electrophoresis (GG-PAGE) under acidic buffer condition and sodium dodecyl sulfate polyacrylamide gel (SDS-PAGE) electrophoresis (Dhaliwal *et al.*, 1988; Moonen and Zeven, 1984). The 1BL/1RS wheats and 1R(1B) wheats differed from control wheats by having two additional protein bands on GG-PAGE. These additional bands have been identified by immunoassay using antibodies 122/24 (IgG1) and 246/21 (IgM) as rye ω-secalin proteins (Dhaliwal *et al.*, 1988). The ω-secalin proteins are coded at the Sec-1-locus on the short arm of rye chromosome 1R (Lawrence and Shepherd, 1981).

In addition, the 1R(1B) wheats were characterized by the presence of two HMW subunits R_1 and R_2 on SDS-PAGE (Moonen & Zeven, 1984). The subunits R_1 and R_2 were shown by two dimensional electrophoresis (non-equilibrium pH-gradient electrophoresis (NEPHGE) X SDS-PAGE) of the rye proteins which are coded on the long arm of chromosome 1R.

4. Studies of Monoclonal Antibody of γ-Gliadin 45

Immunization of mice with purified γ-gliadin 45 has produced clone P24B which secretes a monoclonal antibody (MAb) against γ-gliadin 45

(Dawood *et al.*, 1989). The gene controlling γ-gliadin 45 is located at locus Gli-B1 on the short arm of chromosome 1B (Howes *et al.*, 1989). Therefore, 1BL/1RS wheats can be detected through the absence of γ-gliadin 45.

The P24B MAb is incorporated into a sandwich-like Enzyme Linked Immunosorbent Assay (ELISA) in which the P24B Mab binds with γ-gliadin 45 and the rabbit-anti-mouse IgG with linked phosphatase binds further onto the complex (Howes *et al.*, 1989). The activity of phosphatase is directly related to the presence of γ-gliadin 45 or the 1BS arm. The presence of γ-gliadin 45 produces an absorbance range of 0.4-1.6 relative to Neepawa. Substitution of 1BL by 1RS decreases the absorbance to less than 0.12 (Howes *et al.*, 1989).

The monoclonal antibody assay is a rapid and specific method for testing the 1BL/1RS translocation in wheats (480 kernels or 6 ELISA plates in 7.5 h). Testing time can be shortened simply by increasing the concentration of MAb. This test can also detect dosage effects (Howes *et al.*, 1989).

D. Disease Resistance and Yield Potential of 1BL/1RS Translocation Wheats

The 1BL/1RS wheats are well-known for their resistance to *Erysiphe graminis* (powdery mildew), *Puccinia striiformis* (strip rust), *Puccinia recondita* (leaf rust) and *Puccinia graminis* (stem rust) (Mettin *et al.*, 1973; Zeller, 1973). Genes controlling these resistance traits occur on the short arm of rye chromosome 1R and are located at loci Pm8, Yr9, Lr26 and Sr31, respectively (McIntosh, 1983). This block of genes is transferred into wheat with the 1BL/1RS translocation.

Friebe and co-workers (1989) suggested that Pm8 was not the only locus conferring resistance against powdery mildew: a 1BL/1RS wheat 'Veery' shows resistance to powdery mildew isolate 3 even though this isolate is virulent to locus Pm8. The 1BL/1RS wheats also have resistance against greenbug, wheat streak mosaic virus, *Septoria tritici* blotch,

yellow spots and moderate tolerance to aluminum toxicity (Barnes, 1990; Rajaram *et al.*, 1983; Zeller and Hsam, 1984).

Wheats with 1BL/1RS translocation are reputed to have high yield potential and are adaptable to a wide range of environmental conditions such as drought (Rajaram *et al.*, 1983). Villareal and co-workers (1990) observed only a slight advantage in the grain yields of 1BL/1RS wheats as compared to control wheats. Lukaszewski (1990) suggested that this yield potential may be controlled by wheat chromosome 1B. Substitution of chromosome 1B in Chinese Spring by the chromosome 1B from Thatcher has shown the greatest yield improvement (58.6%). The genes controlling yield potential were suggested to be located at the proximal region of the short arm of wheat chromosome 1B, where they were tightly linked to the centromere and were transfered as a block with the 1RS arm.

Villareal and co-workers (1990) observed that the 1BL/1RS wheats were significantly higher in above-ground biomass yield compared to the control wheats. The 1BL/1RS wheats had shorter spikes and their heading date were 2.3 days later than the control wheats. No difference in plant height between the two groups was noted.

E. Quality of 1BL/1RS Translocation Wheats

Most of the previous work has focused on the quality comparisons of Australian and German hard wheats and their 1BL/1RS derivatives. The presence of the 1BL/1RS translocation did not adversely affect quality traits such as kernel and flour protein content, kernel hardness, flour yield and color, milling quality, ash content, Falling Number and farinograph water absorption (Dhaliwal *et al.*, 1986, 1987; Van Lill *et al.*, 1990). However, hard wheats with the 1BL/1RS translocation were distinctly poorer in dough strength, dough resistance and extensibility, and more intolerant to overmixing than their normal wheat parents (Dhaliwal *et al.*, 1986, 1987; Van Lill *et al.*, 1990). Soft wheats with the 1BL/1RS translocation only had reduced dough extensibility when compared to the normal controls (Dhaliwal *et al.*, 1986, 1987).

The inferior mixing properties of 1BL/1RS doughs have included short mixograph development time, the thin, descending breakdown curve of the mixogram, low extensigraph resistance and extensibility, small resistograph breaking angle and short un-mixing time (Barnes, 1990; Dhaliwal *et al.*, 1987; Martin *et al.*, 1986a, 1986b; Pena *et al.*, 1990).

The effects of the 1BL/1RS translocation on hard wheat quality such as the test weight, 1,000 kernel weight and SDS-sedimentation volume appeared to be contradictory. Villareal *et al.* (1982) observed the 1BL/1RS wheats to be denser and plumper, while Dhaliwal *et al.* (1987) reported that there were no significant differences in 1,000 kernel weight and test weight between control wheats and 1BL/1RS wheats. Pena *et al.* (1990) reported an increase in SDS-sedimentation volume for 1BL/1RS wheats, but Dhaliwal *et al.* (1989) observed that the SDS-sedimentation volume for 1BL/1RS wheats was reduced. Zeller *et al.* (1982) reported that 1BL/1RS wheats were not significantly different in the SDS-sedimentation volume from control wheats.

Not all wheats with the 1BL/1RS translocation exhibited intense dough stickiness; a German variety Disponent had a dry surface property (Zeller *et al.*, 1982). The 1BL/1RS dough stickiness was found to be independent of growing season, trial location, protein content, mixing tolerance (resistograph), milling process and extraction rate (Martin and Stewart, 1990). However, Barnes (1990) and Dhaliwal *et al.* (1990) observed that variation of temperature and moisture would affect the wheat protein content and the ratio of gliadins and glutenins which in turn affected dough stickiness. A high ratio of gliadins to glutenins would result in a weaker dough due to the strong inter-molecular disulphide bonds being diluted by the weak inter-molecular linkages such as hydrogen bonds, electrostatic and ionic bonds (Pomeranz, 1987).

Barnes (1990) suggested that the ultimate quality of 1BL/1RS wheats was also dependent on the genetic background; good quality HMW glutenins might compensate for the negative dough properties inherent from the 1RS

segment. Graybosch *et al.* (1990) observed that sister lines carrying the 1BL/1RS translocation varied considerably in the mixing time, tolerance and loaf volume.

F. Measurement of 1BL/1RS Dough Stickiness

In preliminary studies, dough stickiness was evaluated according to the tendency of the dough to stick to different surfaces such as the mixing bowl, hand, rolling pin, teflon or paper towel (Dhaliwal *et al.*, 1990). Unfortunately, these subjective methods did not provide precise and reliable results. Assessment of dough stickiness was improved with the use of mechanical measurements such as the Digital Gram Gauge push/pull tensiometer and the Instron 'I026' Universal Testing Machine (Atkins, 1989; Dhaliwal *et al.*, 1990). These measuring devices are similar in operation; a plunger is used to compress an uniform piece of dough to a fixed thickness or to a constant compression force before withdrawal of the plunger. When the plunger is withdrawn from the dough, the adhesiveness of the dough to the plunger (tensile stress) determines the dough stickiness. A marked difference has been shown in the area formed underneath the tensile stress curves (peak height x peak width) for the control wheats and their 1BL/1RS derivatives (Dhaliwal *et al.*, 1990). The area represents the distance travelled by the plunger from the time the plunger is withdrawn to the time the dough-plunger contact is broken.

Dhaliwal *et al.* (1990) showed that dough strength and elasticity also influence the measurement of dough stickiness. Nevertheless, using the Digital Gram Gauge push/pull tensiometer, hard wheats and their 1BL/1RS derivatives grown on the same site differed significantly in the tensile stress and areas underneath the tensile stress curves. Hard wheats and their 1BL/1RS derivatives grown at different sites also varied considerably. No significant difference was shown between soft wheats and their 1BL/1RS derivatives for the tensile stress and areas underneath the tensile stress curves (Dhaliwal *et al.*, 1990).

The compression energy obtained from the Instron 'I026' Universal

Testing Machine was highly correlated to the subjective evaluation of dough stickiness and could be used as an objective measurement for dough surface property (Atkins, 1989). Compression energy is the force required to compress the dough to a fixed thickness. It is an opposing force against the resistance of a dough, and the dough resistance is derived from the strength or elasticity of gluten (Atkins, 1989). Since sticky doughs are low in elasticity, they can be compressed easily with less energy.

Measurement of dough stickiness was highly influenced by the variation of compression force, compression time, dough water content, dough mixing time and resting period, and type of ingredients (Atkins, 1989; Dhaliwal *et al.*, 1990). Dough stickiness of the control wheats and the 1BL/1RS wheats increased as the compression force was increased. Dough stickiness increased within the first 20 sec of compression. Doughs became stickier with the addition of water beyond the optimal level. Some rye-derived lines exhibited high surface stickiness even under the optimum water level. Doughs were stickier when mixed beyond the optimum development time. The effect of overmixing on dough stickiness was more pronounced than the effect of excess dough water. A long resting period allowed the surface of the dough to dry out and reduced the surface stickiness of doughs. Addition of 1-2% salt solution decreased the dough surface stickiness, whereas the addition of yeast, milk powder, soya meal, gluten or fat has no or slight effect on increasing the dough surface stickiness.

G. Causes of 1BL/1RS Dough Stickiness

Interchange of fractions between the 1BL/1RS wheats and their recurrent parents has shown that components of the gluten and water-soluble fraction may be involved in causing dough stickiness (Dhaliwal *et al.*,1988; MacRitchie *et al.*, 1986). Zeller *et al.* (1982) suggested that dough stickiness may be due to the increased water absorption of dough as a result of presence of high amounts of water-soluble proteins, pentosans

and damaged starch in the 1BL/1RS flours.

Flour of rye, common wheats and their 1BL/1RS derivatives were examined by SDS-PAGE and GG-PAGE (Dhaliwal *et al.*, 1988). The 1BL/1RS translocation wheats had a similar pattern of HMW glutenin subunits as their recurrent parents. However, some 1BL/1RS derivatives such as M3344, WW345 and Aurora were characterized by the absence of subunit '8'. Subunit '8' is a HMW glutenin protein coded by a gene on the long arm of wheat chromosome 1B (Payne *et al.*, 1982, 1983). The 1BL/1RS wheats with the absence of subunit '8' would indicate that a transfer of a small part of the long arm of wheat chromosome 1B has taken place (Dhaliwal *et al.*, 1988). The HMW subunit '8' is related to glutenin strength (Law and Payne, 1983; Lukow *et al.*, 1989) and its absence may accentuate dough stickiness in some lines.

The water- and alcohol-soluble fractions of the 1BL/1RS derivatives were characterized by the presence of two extra clusters of bands and the absence of wheat γ- and ω-gliadin bands on GG-PAGE. These extra bands were identified by immunoassay using antibody 122/24 (IgG1) and 246/21 (IgM) to the rye proteins ω-secalin. Protein fractions were quantified and a high proportion of the proteins was consistently found in the water-soluble fraction of the 1BL/1RS wheats unlike their recurrent parents. Chen and Bushuk (1970) also associated rye with a high content of water-soluble proteins. These water-soluble proteins are believed to be rye ω-secalin proteins. The rye ω-secalin proteins appeared to be more water-soluble than their wheat counterparts, and their presence might be a possible factor leading to dough stickiness.

According to Payne (1987), the 1BL/1RS translocation has replaced the wheat polymeric LMW glutenins and monomeric ω- and γ-gliadins with the water-soluble monomeric rye ω-secalin proteins. As a consequence, Dhaliwal and MacRitchie (1990) reasoned that 1BL/1RS dough stickiness was due to the substitution of the strong bond forming glutenins by the weak bond forming ω-secalins. This was further substantiated from the Size

Exclusion-High Performance Liquid Chromatography (SE-HPLC) profiles of the 1BL/1RS wheats where the ratio of polymeric proteins to monomeric proteins was low and was accompanied by reduced dough strength and increased dough stickiness (Dhaliwal and MacRitchie, 1990). According to Blackman and Payne (1987), the large aggregating glutenins impart dough strength and the small non-aggregating gliadins impart dough extensibility; therefore, these changes in ratios could result in poor 1BL/1RS dough quality. In addition, the substituted rye ω-secalin proteins would be expected to interact with gluten poorly since rye itself does not have good gluten development properties (Shewry and Miflin, 1985).

The level of the potassium hydroxide (KOH) soluble proteins (glutenin and residue proteins) was correlated positively to the mixing time, tolerance and loaf volume (Graybosch *et al.*, 1990). Quality of the 1BL/1RS wheats were expected to be poor since the 1BL/1RS wheats had the reduced level of the KOH soluble protein.

Pentosans and (1->3)(1->4) β-glucans are polysaccharides with high water-binding capacity (Martin and Stewart, 1986a). High amounts of these polysaccharides have been found in rye (Henry *et al.*, 1985) and were also believed to be present in the rye-derived wheats (Zeller *et al.*, 1982). Henry *et al.* (1989) analyzed the pentosan content of control wheats and 1BL/1RS wheats and showed that neither the whole grain nor the endosperm of 1BL/1RS wheats contained a higher amount of total pentosan than control wheats. Dhaliwal *et al.* (1988) found some 1BL/1RS flours with a high level of total pentosan but could not relate their pentosan content to high dough stickiness. More recently, Biliaderis *et al.*(1992) found that the total water-insoluble and water-soluble pentosans were present in similar amounts in flours of 35 1B/1R translocation lines as compared to 36 normal wheat lines. Tao and Pomeranz (1967) and Zeller *et al.* (1982) related high pentosan content to high water absorption and to short dough development time and stability. However, no significant correlation between pentosan

content and these dough parameters of the 1BL/1RS wheats has been found.

Henry *et al.* (1989) observed that the β-glucan content in the whole grain of 1BL/1RS wheats was similar to that of control wheats, but the endosperm of 1BL/1RS wheats appeared to contain a higher content of β-glucan than the endosperm of control wheats. Calcofluor staining for β-glucan on sectioned grains varied in intensity on the endosperm cell wall of different varieties of 1BL/1RS grains. The flour of these 1BL/1RS wheats did not contain a high level of β-glucan and a relationship between β-glucan content and 1BL/1RS dough stickiness was not found.

The action of roller mills would lead to the damage of flour starch granules. Damaged starch is more susceptible to α-amylase as compared to intact starch granules (Evers and Stevens, 1984). During the long fermentation process of baking, α-amylase degrades the damaged starch and releases water. According to Zeller (1982), this free water could result in dough stickiness. High amounts of damaged starch is suspected to be present in 1BL/1RS flours, but this has not been confirmed.

From their work on reconstitution of flours, MacRitchie *et al.* (1986) suggested that the 1BL/1RS dough stickiness might be due to the presence of a high quantity of proteolytic enzymes in flours. This hypothesis remains to be confirmed.

In summary, the 1BL/1RS dough stickiness was caused by the presence of the water-soluble rye ω-secalin proteins, and the reduction in amount of the strong dough forming glutenins. The cause of dough stickiness was also related to the absence of the HMW glutenin subunit '8' in some of the 1BL/1RS wheats. High levels of damaged starch and proteolytic enzymes were thought to be possibly associated with the excessive dough stickiness of 1BL/1RS wheats. High levels of pentosans and β-glucans were not related to the 1BL/1RS dough stickiness.

III. MATERIALS AND METHODS

A. Materials

1. Wheat Samples

Fourteen spring wheat cultivars, including seven 1BL/1RS translocation wheats and seven control wheats, were used in this study. Pedigrees of these wheat cultivars were presented in Table 1. Two wheat varieties, a German cultivar, KavKaz, and a Mexican cultivar, Alondra Sib, were used as sources of the 1BL/1RS translocation. All cultivars were grown at two locations (Glenlea and Swift Current) over two years (1989, 1990) in a randomized complete block design with four replicates at each location. Seeds of the cultivars and of the electrophoretic standards, Chinese Spring and Marquis, were supplied by Agriculture Canada.

B. Milling

Wheats were tempered overnight to 16.5% moisture at room temperature and milled into straight-grade flour on the Buhler Pneumatic Laboratory mill. The break and reduction flours were combined and rebolted through a final 70GG sieve. Flour yields were determined as the percentage of the weight of the rebolted flour over the total weight of the milled fractions.

C. Electrophoresis

1. Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (SDS-PAGE)

Total protein was extracted separately from segments of six kernels of each cultivar and fractionated by SDS-PAGE using 10% acrylamide gels (Lukow *et al.*, 1989). SDS-PAGE using 5% gels was performed to identify HMW glutenin subunit 2* from cultivars containing subunits 2 + 12 (Payne *et al.*, 1988). This study followed the numbering system of Payne and Lawrence (1983) for HMW glutenin subunits.

TABLE 1. Pedigrees of the Wheat Cultivars

Wheat Group/ Cultivar	Pedigree[b]
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	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.
8416-Q06E	""" (as above)
8416-BZ10A	"""
8416-BZ10C	"""
8417-BJ03A	"""
8417-BJ03D	"""
Control Wheat Group	
8417-AJ05C	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
8417-AV06D	"""
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
Oslo	Sonora 64/Yaqui 50E/Guajolote/3/Inia/4/Crano// Egan/Sonora 64
Genesis	Tobari 66/Romany//Pitic 62/Gaines
Biggar	Tobari 66/Romany

[a]Sources of the 1BL/1RS translocation.
[b]Cultivars 8416 and 8417 share a close genetic background. Two of the three parents were identical, and the third parents were sisters from the same cross.

2. Polyacrylamide Gel Electrophoresis (A-PAGE)

The non-embryo half of six kernels of each cultivar were tested separately for the presence or absence of rye secalins by electrophoresis on 6% acrylamide gels at pH 3.1 (Lukow *et al.*, 1990).

D. Enzyme Linked Immunosorbent Assay (ELISA)

ELISA with clone P24B MAb was performed according to Howes *et al.* (1989) for the determination of γ-gliadin 45. The non-embryo half of five kernels of all cultivars at each replication and environment were tested. Volumes of the 50% (v/v) aqueous propan-2-ol and the 70% (v/v) ethanol for protein extraction and for protein binding to the ELISA plate were modified to 160 μl and 80 μl, respectively. Clone P24B MAb was diluted 1:200 in this study.

E. Analytical Tests

1. Test Weight

Test weight was determined on a Schopper chondrometer with a 0.5-L container; twice the weight of the measured 0.5-L container of grains multipled by 100 provided the test weight in kilograms/hectolitre.

2. 1,000 Kernel Weight

Kernel weight was determined by counting 10 g of clean kernels on an electronic seed counter (Audiotronics Model A3310, Ottawa, Canada) and was expressed as the weight (g) of a thousand kernels.

3. Kernel Hardness

Kernel hardness was determined according to the method of Kosmolak (1978); 8 g of wheat were ground on a Brabender SM1 grinder at a clearance setting of 17.6. Grinding time was defined as the time required to obtain 5 g of ground meal.

4. Protein and Moisture Content of Flour

The protein and moisture contents of flour were determined according to AACC approved method (1991) 39-11, using the Dickey-John near infrared

analyzer (Dickey-John Corp, Auburn, IL). The instrument was calibrated for protein content obtained from the Kjeldahl method (AACC approved method 46-12, 1991) and for moisture content obtained from the oven-dried method (AACC approved method 44-15A, 1991).

5. Ash Content

Ash content was determined according to the AACC approved method (1991) 08-01.

6. Falling Number Value

Falling Number value was determined according to the AACC approved method (1991) 56-81B, using the FN Model 1400 apparatus (Falling Number AB, Sweden).

7. SDS-Sedimentation Volume

The SDS-sedimentation test was conducted according to the AACC approved method (1991) 56-70.

8. Zeleny-Sedimentation Volume

Zeleny sedimentation was performed according to the AACC approved method (1991) 56-61A.

9. Farinograph Test

Micro-farinograms (10g) were produced on a constant sample weight basis according to the AACC approved method (1991) 54-21. Correction factors of 2.64 and 3.56 were subtracted from the absorption and mixing tolerance index values, respectively, to convert results into values expected on the 50g farinograph.

10. Mixograph Test

Mixograms were produced on a 10 g electronic recording mixograph (Voisey *et al.*, 1966) using a constant absorption of 60%. The data were analyzed on the IBM-PC system with software ASYST (Pon *et al.*, 1988).

11. Extensigraph Test

Extensigrams were obtained according to the AACC method (1991) 54-10 in which the dough water was 6% less than the micro-farinograph absorption and the dough was prepared in a GRL mixer at a pin speed of 130 rpm for 3 min.

12. Dough Stickiness Measurement

The dough stickiness was determined after the first and the second mix of the remix bake method. Each dough was evaluated subjectively according to five levels: NS, non-sticky; SS, slightly sticky; S, sticky; VS, very sticky and VVS, very very sticky. Non-sticky doughs had no tendency to stick on the mixing bowl and hands. Slightly sticky doughs showed a slight tendency to stick on the mixing bowl and hands, but it could be pulled out cleanly from the mixing bowl and fingers. Sticky dough could not be pulled out from the mixing bowl in one piece and left traces of dough on the fingers; these doughs were difficult to round. The very sticky and very, very sticky doughs showed excessive sticking to the mixing bowl and fingers. The very sticky doughs were slightly easier to handle than the very, very sticky doughs which could not be rounded.

13. Remix Bake Loaf Volume

Baking quality was evaluated by the Grain Research Laboratory remix bake test (Irvine and McMullan, 1960; Kilborn and Tipples, 1981), with baking absorption equal to 6% less than micro-farinograph absorption. A rape seed replacement volumeter was used for loaf volume measurement.

F. Statistical Analysis

Data were analyzed using the Statistical Analysis System (SAS Institute Inc., Cary, NC). Bartletts test was conducted to determine the feasibility of pooling data obtained from Swift Current 1990 with that of the other environments. The analysis of variance and estimates of the components of variance due to cultivar, cultivar by environment, group, group by environment and error were calculated according to Comstock and Moll (1963). The relationship of quality parameters and dough stickiness

was studied using the pairwise T-test and rank correlation.

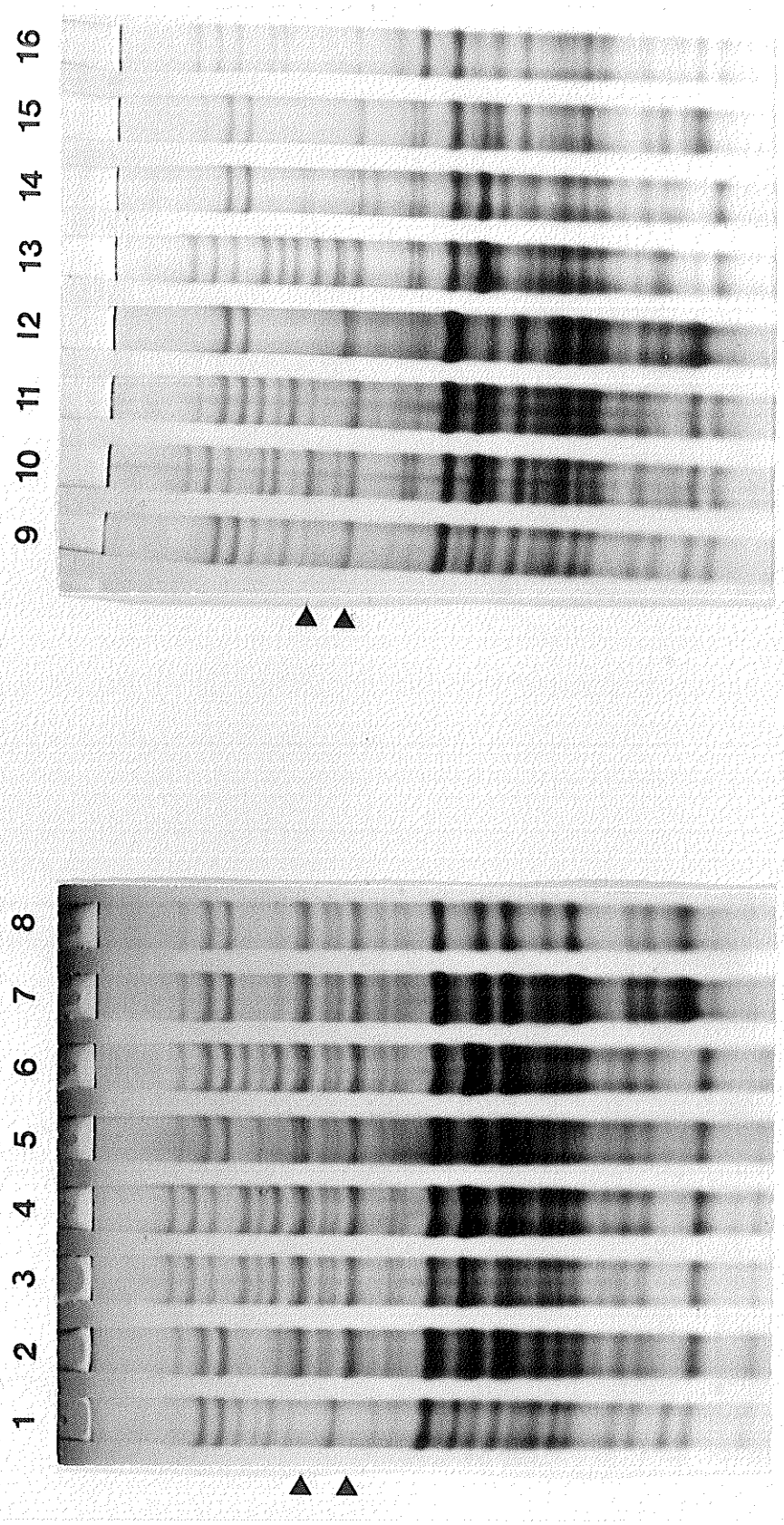
IV. RESULTS AND DISCUSSION

A. Electrophoretic Evaluation

1. Classification of Cultivars by A-PAGE and ELISA with Clone P24B MAb

All the cultivars in this study were examined by A-PAGE and ELISA with clone P24 MAb. The purpose was to confirm that all cultivars in the 1BL/1RS group contained the rye 1RS chromosome arm and that the 1BL/1RS translocation was absent in all of the control cultivars. The A-PAGE electrophoregrams for the 1BL/1RS and control wheats are shown in Figure 1. All of the seven 1BL/1RS cultivars and one of the control cultivars (8417-AJ05C) contained two bands (shown by arrows) that were absent in the other six control cultivars. According to Dhaliwal *et al.* (1988), these two bands represent the rye ω-secalins. Previous work (Lawrence and Shepherd, 1981; Shewry *et al.*, 1986) found that these specific rye ω-secalins were encoded at the Sec-1-locus on the short arm of chromosome 1R. The A-PAGE results indicated that only one cultivar, 8417-AJ05C, was not grouped appropriately in this study. The groupings were further confirmed by the use of P24B MAb to detect the presence or absence of γ-gliadin 45. According to Howes *et al.* (1989), the 1BL/1RS translocation wheats are deficient in γ-gliadin 45 and give an absorbance value less than 0.12 relative to Neepawa. In contrast, the control wheats have the γ-gliadin 45 and give a value ranging from 0.4 to 1.6 relative to Neepawa. The overall absorbance values of all the cultivars fell into the expected ranges (Table 2). However, a control cultivar, 8417-AJ05C, had at least 2 of 5 kernels from each replication and environment with the 1BL/1RS translocation. A further twenty kernels of the control cultivar, 8417-AJ05C were tested and results showed that more than 50% of the kernels at each replication and environment contained the 1BL/1RS translocation. As a result, all the wheat samples of cultivar 8417-AJ05C

Figure 1. Polyacrylamide Gel (6%) Electrophoresis of the Seven 1BL/1RS Cultivars (left) and the Seven Control Cultivars (right). Lane 1 and 9, Marquis (electrophoretic standard); 2, BR 23; 3, 8416-Q06A; 4, 8416-Q06E; 5, 8416-BZ10A; 6, 8416-BZ10C; 7, 8417-BJ03A; 8, 8417-BJ03D; 10, 8417-AJ05C; 11, 8417-AV06D; 12, CEP 14; 13, Neepawa; 14, Oslo; 15, Genesis; 16, Biggar. Arrows indicate the rye ω-secalin protein bands.


16
15
14
13
12
11
10
9
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7
6
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3
2
1

TABLE 2. The Overall Binding of Monoclonal Antibodies from Clone P24B MAb to γ-Gliadin 45 of the 14 Cultivars

Group/Cultivar	ELISA Absorbance at 405 nm
1BL/1RS Wheats	
BR 23	0.107 ± 0.019[a]
8416-Q06A	0.122 ± 0.038
8416-Q06E	0.117 ± 0.034
8416-BZ10A	0.113 ± 0.024
8416-BZ10C	0.115 ± 0.026
8417-BJ03A	0.118 ± 0.025
8417-BJ03D	0.114 ± 0.022
Control Wheats	
8417-AJ05C	0.528 ± 0.187
8417-AV06D	0.883 ± 0.167
CEP 14	0.818 ± 0.303
Neepawa	1.033 ± 0.147
Oslo	0.886 ± 0.217
Genesis	0.882 ± 0.148
Biggar	0.907 ± 0.182

[a]Standard deviation

were eliminated from all further analysis.

2. SDS-PAGE Electrophoregrams (HMW Glutenin Subunits)

Barnes (1990) and Graybosch (1990) have suggested that the overall quality of 1BL/1RS wheats is dependent on their genetic background. Wheats with high quality HMW glutenin subunits might compensate for the inferior properties contributed through the rye 1RS chromosome arm. The HMW glutenin subunits of each cultivar were analyzed by SDS-PAGE using 10% acrylamide gels and the electrophoregrams are shown in Figure 2. The composition of the HMW glutenin subunits of the cultivars, the Glu-1 scores, and the rye-adjusted Glu-1 scores (Payne *et al.*, 1987) are presented in Table 3. The 1BL/1RS group was generally lower in both Glu-1 scores (un-adjusted and rye-adjusted) compared to that of the control wheats. Low Glu-1 scores have been associated with poor breadmaking potential (Payne *et al.*, 1987).

Frequencies of the HMW glutenin subunits in the 1BL/1RS group were compared to that of the control group (Table 4). The null allele and subunit 1 were the most common in the 1BL/1RS and control wheats, respectively. The most frequent subunits of chromosome 2B of both the 1BL/1RS and the control wheats were those associated with good breadmaking quality, that is, subunit 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. The control wheats would be expected to have greater breadmaking potential than the 1BL/1RS groups largely on the basis of the Glu-A1 alleles (Payne *et al.*, 1987).

B. Cultivar Comparisons at Each Environment

The physical, chemical, rheological and baking properties of all the cultivars were determined at the individual environments (SAS statements and an output example are given in Appendix I and II, repectively). The cultivar means, least significant differences (LSD), ranges and

Figure 2. Sodium Dodecyl Sulfate Polyacrylamide Gel (10%) Electrophoresis of the Seven 1BL/1RS Cultivars and the Seven Control Cultivars. Lane 1 and 16, Chinese Spring (electrophoretic standard); 2, BR 23; 3, 8416-Q06A; 4, 8416-Q06E; 5, 8416-BZ10A; 6, 8416-BZ10C; 7, 8417-BJ03A; 8, 8417-BJ03D; 9, 8417-AJ05C (this line had previously been eliminated); 10, 8417-AV06D; 11, CEP 14; 12, Neepawa; 13, Oslo; 14, Genesis; 15, Biggar.

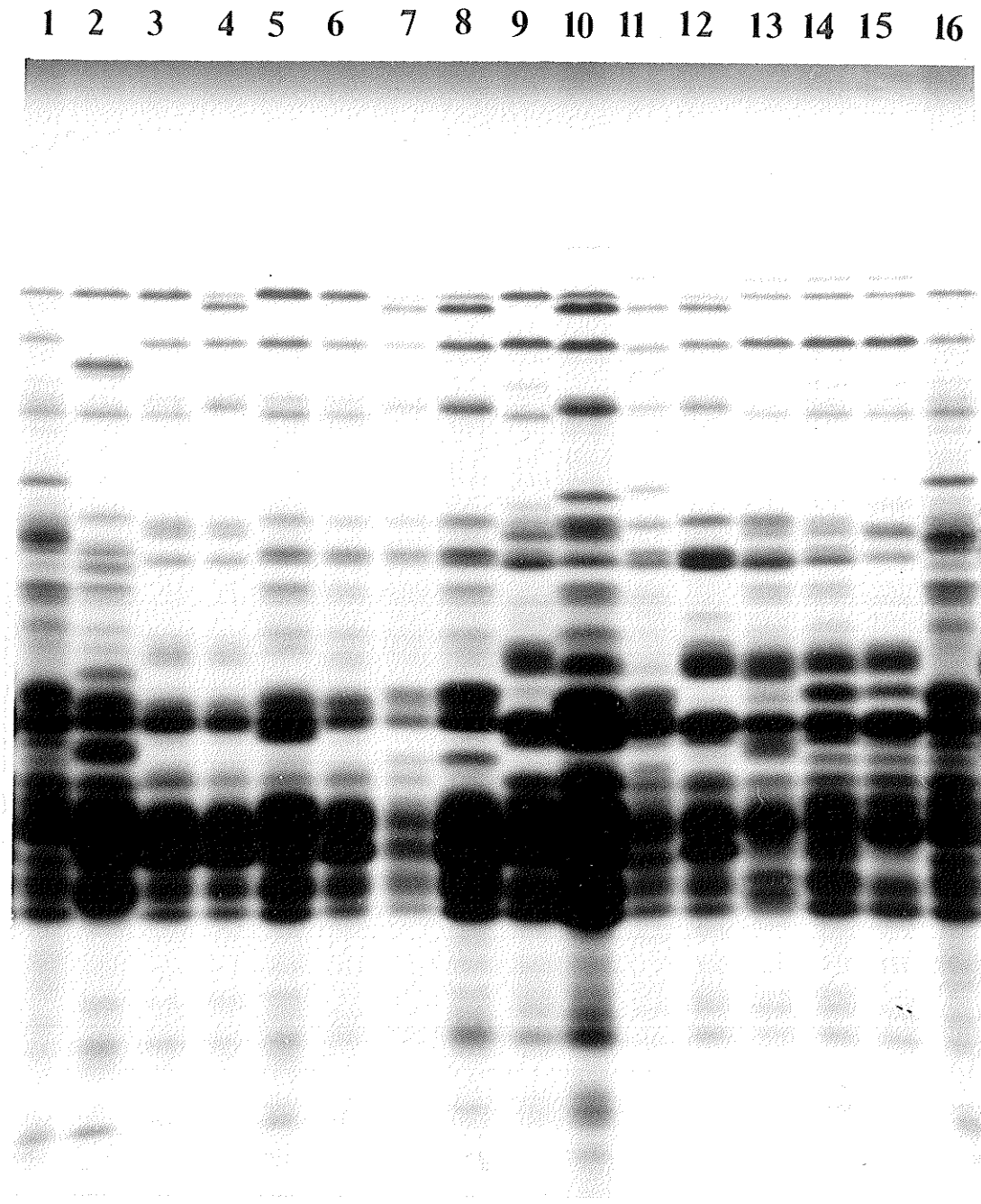

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

TABLE 3. The HMW Glutenin Subunit Composition for the 1BL/1RS and the Control Wheats

Cultivar	HMW glutenin subunits			GLU-1 score	Rye-adjusted Glu-1 quality score[a]
	Chromosome				
	1A	1B	1D		
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]Rye-adjusted Glu-1 quality score was obtained by subtracting 3, 2 and 1 from the Glu-1 score of between 8-10, 5-7, 3-4, respectively (Payne *et al.*, 1987).

TABLE 4. Frequencies of HMW Glutenin Subunits in the 1BL/1RS and the Control of Wheats

Chromosome 1A		Chromosome 1B		Chromosome 1D	
Subunit	No. of cultivars	Subunit	No. of cultivars	Subunit	No. of cultivars
1BL/1RS wheats					
1	0	7 + 9	6	5 + 10	3
2*	3	7 + 8	0	2 + 12	4
NULL	4	17 + 18	1		
		13 + 16	0		
Control wheats					
1	4	7 + 9	2	5 + 10	3
2*	2	7 + 8	3	2 + 12	3
NULL	0	17 + 18	0		
		13 + 16	1		

coefficients of variation (CV) are presented in Tables 5a-h. There were wide ranges in most quality characteristics and significant differences among cultivars in all environments with exception of Swift Current 1990 (Table 5c-d). Results from the latter environment indicated relatively high LSD values, small ranges and high coefficients of variation compared to the other environments. Only Swift Current 1990 showed non-significant differences between cultivars for mixograph energy after peak and mixograph slope to peak.

Since the quality of cultivars grown at Swift Current 1990 appeared to be considerably different from that of other environments, further statistical analysis was performed to determine the feasibility of pooling data obtained from Swift Current 1990 with that of the other environments. Bartletts test was performed to examine the homogeneity of variance of the four environments and of the three environments (Swift Current 1989, Glenlea 1989 and Glenlea 1990). Variances of the four environments did not conform to each other in 9 out of 37 parameters but homogeneity was shown in the variances of the three environments (data not shown). This confirmed that cultivars from Swift Current 1990 were statistically different and should not be pooled and analyzed with the other environments. Wheat samples may have been mislabelled prior to analysis. Because of this discrepancy, cultivars from Swift Current 1990 were eliminated from all further analyses.

C. Cultivar Comparisons Over Environments

The cultivar means over environments for the quality characteristics are presented in Tables 6a-b (SAS statements and an output example are given in Appendix III and IV, respectively). For those quality characteristics where the cultivar by environment interaction was significant and greater than 30% of the cultivar variance, the LSD was not reported. There were significant differences among cultivars for 1,000 kernel weight, grinding time, flour yield, SDS- and Zeleny-sedimentation

TABLE 5a. Cultivar Means[a] for Physical, Chemical and Farinograph Properties at Swift Current 1989

	Physical, Chemical and Farinograph Properties[b]																
Cultivar	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
1BL/1RS Wheats																	
BR 23	75.6	28.9	1.07	63.6	12.4	0.38	537	75	68	56.2	4.3	31	2.6	5.6	8.3	10.6	0.550
8416-Q06A	77.1	30.5	0.65	69.2	12.9	0.39	479	64	52	57.8	5.9	12	3.4	8.9	12.3	14.9	0.525
8416-Q06E	77.1	30.4	0.65	68.7	12.6	0.41	517	67	56	54.3	12.8	5	6.1	21.0	27.1	23.5	0.625
8416-BZ10A	77.2	29.3	0.34	70.9	14.4	0.38	770	66	51	59.3	8.3	11	5.6	11.8	17.5	17.3	0.575
8416-BZ10C	77.6	28.5	0.32	71.1	14.6	0.38	758	53	44	59.8	6.6	14	4.5	10.8	15.3	17.0	0.500
8417-BJ03A	76.7	26.4	0.32	71.3	13.5	0.40	642	62	48	57.7	11.6	11	5.1	15.0	20.1	22.0	0.550
8417-BJ03D	77.0	26.9	0.32	71.5	13.9	0.38	673	62	48	58.1	10.8	12	5.0	11.1	16.1	19.8	0.500
Control Wheats																	
8417-AV06D	77.7	28.6	0.32	73.6	14.4	0.37	638	77	63	58.5	14.5	19	8.4	12.4	20.9	21.6	0.675
CEP 14	77.5	28.4	1.56	66.0	14.4	0.38	550	84	87	57.6	5.0	20	2.6	8.0	10.6	13.5	0.600
NEEPAWA	75.8	25.8	0.31	72.6	14.6	0.37	761	77	61	60.2	7.8	7	4.6	14.4	19.1	22.1	0.550
OSLO	73.7	25.3	0.43	72.1	14.0	0.37	633	92	92	55.6	10.8	10	4.4	17.3	21.5	22.1	0.900
GENESIS	73.9	26.0	0.58	66.7	13.1	0.39	601	90	83	59.7	8.0	14	5.0	10.8	15.8	17.3	0.650
BIGGAR	74.7	27.3	0.64	71.3	13.9	0.40	630	92	88	59.4	9.9	15	6.1	9.8	15.9	17.6	0.700
LSD[c]	1.4	1.8	0.27	0.6	0.7	0.02	86	4	7	1.2	2.1	10	1.8	4.2	4.4	3.6	0.091
Range	4.0	5.2	1.25	10.0	2.2	0.04	291	39	48	5.9	10.2	27	5.8	15.4	18.8	12.9	0.400
CV[d]	1.3	4.6	32.78	0.6	3.8	3.27	9	4	7	1.4	16.7	48	25.7	24.1	18.0	13.8	10.457

[a] Means are the average of 4 replicates at Swift Current 1989.

[b] TWT = test weight (kg/hl); TKWT = thousand 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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5b. Cultivar Mean[a] for Mixograph, Extensigraph and Breadmaking Properties at Swift Current 1989

	Mixograph, Extensigraph and Breadmaking Properties[b]																	
Cultivar	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
1BL/1RS Wheats																			
BR 23	2.0	0.15	14.9	42.9	0.077	0.075	0.015	57.8	9.5	0.046	7.5	16.7	0.45	7.5	15.7	0.49	2.3	5.0	544
8416-Q06A	1.9	0.15	14.0	43.2	0.069	0.081	0.012	57.2	9.2	0.043	9.2	17.9	0.52	9.2	17.4	0.53	1.3	5.0	739
8416-Q06E	5.5	0.12	30.6	17.1	0.024	0.061	0.004	47.6	18.9	0.049	14.6	17.5	0.83	15.8	16.6	0.95	1.0	1.5	816
8416-BZ10A	2.9	0.16	21.0	42.5	0.080	0.085	0.010	63.5	13.1	0.056	10.7	19.8	0.55	10.2	17.3	0.59	1.0	4.3	803
8416-BZ10C	2.8	0.15	19.7	40.1	0.081	0.059	0.012	59.8	12.8	0.050	10.5	18.1	0.58	10.0	16.7	0.60	1.0	4.8	741
8417-BJ03A	5.1	0.13	30.8	20.6	0.054	0.065	0.006	51.4	19.3	0.048	10.2	20.6	0.53	14.5	16.1	0.91	1.0	1.0	843
8417-BJ03D	3.8	0.14	24.9	30.1	0.058	0.073	0.009	55.0	16.0	0.049	13.6	18.1	0.76	13.7	16.3	0.84	1.0	2.0	864
Control Wheats																			
8417-AV06D	4.7	0.15	29.8	26.5	0.061	0.084	0.008	56.3	20.1	0.062	14.0	22.4	0.63	16.2	20.8	0.79	1.0	1.0	875
CEP 14	1.7	0.16	14.4	46.9	0.075	0.090	0.012	61.4	9.5	0.058	9.7	19.8	0.49	9.6	19.1	0.51	1.3	4.0	666
NEEPAWA	2.6	0.15	17.6	41.3	0.069	0.083	0.010	58.9	11.1	0.057	11.7	21.0	0.56	10.1	18.6	0.55	1.0	3.5	896
OSLO	3.9	0.15	25.4	33.0	0.034	0.095	0.007	58.4	17.8	0.071	13.7	26.3	0.52	15.5	25.2	0.61	1.0	1.2	924
GENESIS	2.5	0.18	19.9	48.0	0.075	0.104	0.021	67.9	13.3	0.059	12.5	23.5	0.59	13.0	23.4	0.55	1.0	3.3	848
BIGGAR	3.0	0.17	21.6	42.8	0.057	0.095	0.012	64.4	14.2	0.060	11.9	28.4	0.42	12.7	26.4	0.48	1.0	1.5	890
LSD[c]	0.4	0.02	3.8	4.7	0.012	0.017	0.004	6.0	2.5	0.009	3.0	3.3	0.17	1.4	2.0	0.08	0.3	0.9	54
Range	3.8	0.06	16.8	30.9	0.057	0.045	0.017	20.3	10.9	0.028	7.1	11.7	0.41	8.7	10.7	0.47	1.3	4.0	380
CV[d]	9.6	7.45	12.0	9.0	13.421	14.739	28.691	7.2	12.2	10.904	18.3	11.1	20.82	7.8	7.2	8.98	18.3	21.8	5

[a] Means are the average of 4 replicates at Swift Current 1989.

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (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 at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; 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).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5c. Cultivar Means[a] for Physical, Chemical and Farinograph Properties at Swift Current 1990

	Physical, Chemical and Farinograph Properties[b]															
Cultivar	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
1BL/1RS Wheats																	
BR 23	80.7	37.3	0.88	62.8	11.5	0.36	573	82	69	55.7	3.6	37	1.9	6.9	8.8	10.1	0.900
8416-Q06A	81.4	39.0	0.41	68.3	13.0	0.36	426	77	62	57.5	5.1	51	2.4	6.8	9.0	9.3	0.800
8416-Q06E	80.6	38.5	0.42	68.0	13.5	0.36	524	85	74	57.6	7.3	25	3.9	10.2	13.8	13.9	0.975
8416-BZ10A	80.6	36.1	0.39	71.3	12.4	0.38	574	84	71	56.2	3.8	62	1.9	5.1	7.0	7.4	0.825
8416-BZ10C	80.8	35.6	0.37	71.8	12.9	0.37	454	68	51	57.5	3.3	62	2.2	3.6	5.8	6.4	0.750
8417-BJ03A	81.9	36.7	0.35	70.8	12.9	0.39	506	71	54	57.1	5.3	49	2.7	5.8	8.5	9.1	0.775
8417-BJ03D	82.1	35.8	0.35	72.3	12.3	0.38	503	69	52	58.0	3.1	60	1.7	4.2	5.9	6.4	0.750
Control Wheats																	
8417-AV06D	82.3	37.1	0.38	73.2	12.3	0.34	524	83	71	54.9	3.4	51	1.7	5.9	7.5	9.3	0.925
CEP 14	81.2	32.9	0.93	64.5	12.5	0.35	547	82	67	55.9	4.9	26	2.4	9.5	11.9	12.0	0.975
NEEPAWA	80.3	31.3	0.38	72.3	12.7	0.53	473	81	72	56.8	5.6	35	2.9	8.3	11.3	10.6	1.025
OSLO	80.5	39.8	0.39	74.5	13.1	0.38	585	83	70	58.0	5.8	37	2.8	7.0	9.8	10.9	0.825
GENESIS	79.4	35.6	0.48	68.0	12.4	0.37	456	79	65	56.3	3.9	56	1.6	5.7	6.8	7.0	0.700
BIGGAR	81.5	38.4	0.42	72.8	12.2	0.39	566	81	66	56.3	3.8	47	2.5	6.6	8.4	8.9	0.800
LSD[c]	0.4	1.9	0.03	2.0	1.3	0.15	157	12	17	2.6	2.3	30	1.4	4.5	5.3	4.8	0.277
Range	2.9	8.5	0.58	11.7	2.0	0.19	159	17	23	3.1	4.2	37	2.3	6.6	8.0	7.5	0.325
CV[d]	0.3	3.7	4.87	2.0	7.1	27.48	21	11	18	3.2	35.0	46	41.3	47.4	42.1	36.0	22.772

[a] Means are the average of 4 replicates at Swift Current 1990.

[b] TWT = test weight (kg/hl); TKWT = thousand 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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5d. Cultivar Means[a] for Mixograph, Extensigraph and Breadmaking Properties at Swift Current 1990

	Mixograph, Extensigraph and Breadmaking Properties[b]																	
Cultivar	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
1BL/1RS Wheats																			
BR 23	1.9	0.15	13.7	46.5	0.076	0.095	0.010	58.0	9.8	0.060	11.6	18.7	0.53	8.5	17.0	0.69	1.5	2.5	700
8416-Q06A	2.1	0.17	17.1	46.9	0.072	0.095	0.014	64.0	11.4	0.052	12.6	17.7	0.67	13.4	17.8	0.73	1.3	3.5	728
8416-Q06E	3.1	0.16	23.1	40.9	0.076	0.099	0.010	63.4	16.4	0.068	14.4	19.4	0.77	13.6	17.9	0.80	1.0	2.5	829
8416-BZ10A	1.5	0.15	11.0	47.4	0.080	0.105	0.010	58.4	8.6	0.063	8.2	17.9	0.50	8.7	19.1	0.54	1.3	4.5	711
8416-BZ10C	1.7	0.15	11.9	44.8	0.090	0.094	0.016	56.7	8.6	0.047	10.1	14.7	0.65	11.2	16.4	0.68	1.5	4.0	638
8417-BJ03A	2.1	0.15	14.3	43.5	0.083	0.092	0.009	57.9	10.1	0.055	11.1	17.2	0.68	12.4	16.4	0.77	1.0	3.8	689
8417-BJ03D	1.9	0.14	12.1	43.1	0.073	0.093	0.011	55.2	8.9	0.050	9.4	16.0	0.54	9.5	15.3	0.56	1.8	4.0	650
Control Wheats																			
8417-AV06D	1.8	0.15	12.6	43.6	0.083	0.084	0.014	56.2	9.1	0.056	10.4	18.2	0.60	10.0	16.2	0.62	1.5	3.3	674
CEP 14	2.8	0.15	19.3	40.2	0.070	0.088	0.009	59.5	13.4	0.066	13.1	18.1	0.68	13.4	16.0	0.83	1.5	2.0	756
NEEPAWA	2.4	0.16	18.2	43.7	0.071	0.092	0.010	61.9	12.5	0.060	12.9	19.2	0.73	14.1	18.4	0.81	2.0	3.3	740
OSLO	2.1	0.16	15.3	45.6	0.081	0.095	0.008	63.6	10.5	0.067	10.1	18.6	0.55	12.8	18.4	0.69	1.0	2.5	770
GENESIS	1.7	0.15	12.9	45.4	0.075	0.091	0.010	58.3	9.1	0.056	12.1	17.2	0.70	13.2	17.5	0.75	1.0	4.3	703
BIGGAR	2.2	0.15	15.3	42.8	0.074	0.089	0.013	58.8	10.7	0.058	11.1	18.2	0.59	11.5	17.5	0.63	1.3	4.0	688
LSD[c]	1.0	0.02	7.0	9.8	0.021	0.017	0.006	8.3	4.8	0.013	3.9	3.9	0.19	4.5	3.7	0.23	0.9	1.6	131
Range	1.6	0.03	12.1	7.2	0.020	0.021	0.007	8.8	7.8	0.020	6.2	4.7	0.27	5.6	3.8	0.29	1.0	2.5	191
CV[d]	34.6	11.24	32.4	15.5	19.115	12.294	34.070	9.7	31.3	15.977	24.3	15.2	20.72	27.0	14.9	23.02	47.6	33.3	13

[a] Means are the average of 4 replicates at Swift Current 1990.

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (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 at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; 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).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5e. Cultivar Means[a] for Physical, Chemical and Farinograph Properties at Glenlea 1989

	Physical, Chemical and Farinograph Properties[b]															
Cultivar	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
1BL/1RS Wheats																	
BR 23	78.1	32.8	0.97	65.5	11.6	0.46	419	65	45	53.9	2.9	45	1.5	3.5	5.0	6.4	0.675
8416-Q06A	78.4	35.2	0.44	71.8	12.4	0.43	323	58	43	56.7	3.6	46	1.9	5.0	6.9	7.6	0.625
8416-Q06E	78.5	35.6	0.49	71.2	11.8	0.43	295	59	44	53.6	6.0	35	1.3	8.6	9.9	11.3	0.725
8416-BZ10A	78.1	34.2	0.28	72.4	13.6	0.41	474	62	43	60.2	5.8	34	3.6	5.4	9.0	10.1	0.575
8416-BZ10C	77.7	35.0	0.29	73.5	13.4	0.42	487	51	37	58.4	4.0	46	2.3	4.0	6.3	7.1	0.625
8417-BJ03A	77.4	30.3	0.30	71.9	11.5	0.48	528	52	35	54.5	4.7	41	1.1	7.1	8.1	9.3	0.725
8417-BJ03D	79.1	32.3	0.32	73.7	11.6	0.43	592	51	35	55.2	4.1	42	1.0	6.5	7.5	8.9	0.600
Control Wheats																	
8417-AV06D	78.7	35.2	0.27	74.8	13.8	0.41	531	69	52	57.6	6.8	29	3.8	8.0	11.8	13.6	0.750
CEP 14	73.7	25.3	1.51	65.8	11.7	0.42	352	73	55	52.9	1.6	61	0.8	3.4	4.3	4.5	0.600
NEEPAWA	77.6	28.5	0.31	74.0	14.4	0.41	564	75	58	59.1	6.1	17	3.1	10.5	13.6	15.8	0.650
OSLO	77.8	32.8	0.46	74.6	12.8	0.39	525	88	74	53.0	8.4	16	2.6	13.8	16.5	16.6	1.125
GENESIS	75.0	30.0	0.41	70.6	11.5	0.42	461	74	50	56.3	3.6	36	1.9	4.5	6.4	7.6	0.650
BIGGAR	76.9	31.2	0.33	73.5	12.0	0.50	592	84	55	56.8	5.4	19	2.6	9.8	12.4	13.9	0.950
LSD[c]	0.9	1.5	0.22	1.0	0.7	0.02	67	4	5	2.8	1.6	13	0.9	2.2	2.3	2.7	0.152
Range	5.4	10.3	1.24	9.3	2.9	0.11	297	37	39	7.2	6.8	45	3.0	10.4	12.2	12.1	0.550
CV[d]	0.8	3.4	31.27	1.0	3.6	3.86	10	5	7	3.4	22.5	25	31.3	22.2	18.0	18.3	14.824

[a] Means are the average of 4 replicates at Glenlea 1989.

[b] TWT = test weight (kg/hl); TKWT = thousand 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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5f. Cultivar Means[a] for Mixograph, Extensigraph and Breadmaking Properties at Glenlea 1989

	Mixograph, Extensigraph and Breadmaking Properties[b]																	
Cultivar	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
1BL/1RS Wheats																			
BR 23	1.6	0.13	10.7	39.1	0.066	0.087	0.012	49.8	7.9	0.047	5.7	16.2	0.36	5.8	15.4	0.38	3.5	4.8	616
8416-Q06A	2.0	0.14	13.5	37.1	0.071	0.084	0.012	50.6	9.8	0.039	7.7	17.8	0.42	7.2	18.1	0.40	1.8	5.0	653
8416-Q06E	4.4	0.12	25.2	22.0	0.033	0.067	0.009	47.2	17.7	0.044	13.0	17.1	0.78	12.6	16.1	0.78	1.0	2.5	735
8416-BZ10A	2.0	0.15	14.0	40.9	0.081	0.090	0.014	54.8	9.5	0.036	6.4	20.3	0.34	5.8	18.4	0.34	2.0	4.3	774
8416-BZ10C	1.8	0.15	12.8	42.2	0.091	0.100	0.017	55.0	9.6	0.041	6.9	17.0	0.41	6.6	14.7	0.47	2.0	4.5	683
8417-BJ03A	3.7	0.11	18.9	24.8	0.061	0.066	0.008	43.7	13.4	0.035	12.9	16.1	0.81	12.3	14.0	0.86	1.0	1.3	718
8417-BJ03D	3.4	0.12	20.3	28.1	0.067	0.079	0.012	48.4	15.0	0.045	11.6	15.3	0.76	10.1	13.4	0.76	1.0	3.3	725
Control Wheats																			
8417-AV06D	3.4	0.15	22.8	34.0	0.066	0.091	0.012	56.8	16.2	0.054	11.3	22.7	0.50	11.2	20.4	0.55	1.0	2.3	818
CEP 14	2.5	0.12	16.2	33.7	0.056	0.070	0.009	49.9	11.3	0.047	6.0	19.6	0.31	5.0	17.1	0.29	2.5	4.5	595
NEEPAWA	2.8	0.16	20.4	43.2	0.087	0.092	0.009	63.6	13.4	0.069	10.8	20.2	0.54	9.6	18.5	0.53	1.0	1.5	899
OSLO	4.8	0.13	28.6	29.7	0.031	0.083	0.007	52.3	19.7	0.063	14.5	23.5	0.61	13.9	21.6	0.65	1.0	1.0	820
GENESIS	2.3	0.16	17.0	39.9	0.066	0.089	0.022	56.8	11.9	0.043	8.4	20.4	0.42	8.3	19.3	0.44	2.8	4.8	663
BIGGAR	3.0	0.15	19.3	36.5	0.043	0.088	0.013	55.9	12.9	0.054	10.0	23.4	0.43	11.7	22.5	0.52	1.0	2.0	759
LSD[c]	0.7	0.02	3.9	8.5	0.015	0.018	0.005	6.4	3.4	0.014	2.3	2.6	0.12	1.6	2.8	0.12	0.5	1.0	57
Range	3.2	0.05	17.9	21.2	0.060	0.034	0.015	19.9	11.8	0.034	8.8	8.2	0.50	8.8	9.1	0.57	2.5	4.0	304
CV[d]	16.1	9.52	14.8	17.1	17.074	14.824	28.315	8.5	18.2	20.075	16.6	9.3	16.34	11.8	10.9	16.12	24.3	21.2	5

[a] Means are the average of 4 replicates at Glenlea 1989.

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (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 at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; 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).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5g. Cultivar Means[a] for Physical, Chemical and Farinograph Properties at Glenlea 1990

	Physical, Chemical and Farinograph Properties[b]															
Cultivar	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
1BL/1RS Wheats																	
BR 23	78.6	35.6	0.95	60.7	10.8	0.40	466	72	57	52.5	2.4	59	1.2	4.3	5.5	5.6	0.700
8416-Q06A	80.1	39.6	0.46	70.8	12.6	0.40	473	68	49	57.2	3.1	56	2.0	4.3	6.3	6.3	0.725
8416-Q06E	80.8	38.7	0.52	69.3	12.1	0.41	482	68	53	53.6	5.9	30	1.5	10.4	12.8	14.0	0.975
8416-BZ10A	79.0	34.9	0.44	71.5	12.0	0.40	518	73	50	54.8	4.3	59	1.7	5.2	6.9	7.3	0.775
8416-BZ10C	79.7	35.8	0.41	72.3	12.1	0.40	545	62	44	54.7	3.1	67	1.7	4.4	6.1	6.4	0.650
8417-BJ03A	78.7	30.8	0.42	72.3	11.6	0.43	529	67	45	54.7	4.3	30	1.0	9.0	10.0	10.6	0.950
8417-BJ03D	79.8	33.6	0.41	72.8	11.8	0.41	532	67	46	55.1	3.5	37	1.0	7.3	8.3	9.3	0.800
Control Wheats																	
8417-AV06D	80.0	37.7	0.39	75.0	12.2	0.39	514	80	57	54.3	6.3	21	1.8	12.6	14.4	13.5	1.175
CEP 14	78.6	31.4	1.19	62.3	11.3	0.38	498	79	62	51.2	2.0	60	0.9	4.1	5.0	4.8	0.975
NEEPAWA	79.9	31.9	0.40	72.3	13.6	0.37	543	84	63	57.5	3.5	26	1.7	7.5	9.7	11.3	0.925
OSLO	78.6	32.9	0.46	74.8	11.7	0.39	526	91	69	51.8	5.8	42	2.2	8.4	10.5	10.3	1.275
GENESIS	77.5	34.5	0.47	70.0	10.5	0.38	528	83	54	54.3	3.3	55	1.8	5.8	7.6	5.4	0.900
BIGGAR	78.8	35.5	0.42	73.5	11.1	0.43	511	87	60	52.9	4.8	34	2.5	7.5	10.0	9.9	1.200
LSD[c]	0.9	2.0	0.07	2.0	0.4	0.02	47	3	5	1.0	1.2	14	0.6	2.0	2.2	2.6	0.186
Range	3.3	8.8	0.80	14.3	3.1	0.05	79	29	25	6.3	4.3	46	1.6	8.5	9.4	9.2	0.625
CV[d]	0.8	4.0	8.97	1.9	2.2	4.13	6	3	6	1.3	20.1	23	26.1	20.4	17.9	20.8	14.006

[a] Means are the average of 4 replicates at Glenlea 1990.

[b] TWT = test weight (kg/hl); TKWT = thousand 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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 2 min after peak (cm).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 5h. Cultivar Means[a] for Mixograph, Extensigraph and Breadmaking Properties at Glenlea 1990

	Mixograph, Extensigraph and Breadmaking Properties[b]																	
Cultivar	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
1BL/1RS Wheats																			
BR 23	1.3	0.11	7.4	35.5	0.034	0.071	0.007	42.9	5.4	0.041	10.1	16.3	0.62	10.3	15.1	0.68	1.8	3.3	554
8416-Q06A	1.4	0.14	9.2	43.2	0.057	0.073	0.013	52.5	5.8	0.039	10.2	17.6	0.57	10.3	17.1	0.61	2.8	4.8	719
8416-Q06E	3.3	0.14	22.5	33.8	0.057	0.081	0.007	56.3	15.2	0.060	16.6	17.1	0.97	16.6	15.5	1.08	1.0	2.5	761
8416-BZ10A	2.4	0.12	13.5	34.7	0.063	0.062	0.007	48.2	8.4	0.043	11.0	16.3	0.67	10.8	16.3	0.62	1.0	4.5	748
8416-BZ10C	2.1	0.13	12.4	37.1	0.072	0.068	0.007	49.5	8.0	0.039	11.3	16.2	0.70	11.3	15.7	0.72	1.3	4.0	699
8417-BJ03A	3.7	0.12	20.9	27.5	0.063	0.063	0.006	48.4	13.8	0.045	14.5	15.7	0.93	16.3	14.7	1.12	1.0	2.8	785
8417-BJ03D	2.8	0.13	17.9	34.3	0.069	0.066	0.008	52.2	11.3	0.043	13.8	16.0	0.87	14.1	14.6	0.97	1.0	2.3	784
Control Wheats																			
8417-AV06D	3.9	0.12	21.8	28.4	0.058	0.070	0.004	50.2	14.0	0.057	16.9	18.4	0.92	17.0	16.7	1.03	1.0	1.0	848
CEP 14	2.4	0.12	14.3	34.9	0.052	0.067	0.004	48.0	9.8	0.051	11.2	18.8	0.60	10.8	17.8	0.61	1.5	3.5	611
NEEPAWA	2.0	0.15	14.3	45.5	0.089	0.090	0.011	59.8	9.8	0.068	13.7	19.1	0.72	13.4	17.8	0.75	1.8	1.8	905
OSLO	2.9	0.13	17.4	34.0	0.044	0.071	0.008	51.4	10.8	0.054	15.2	23.6	0.65	15.8	20.6	0.78	1.0	2.5	784
GENESIS	1.8	0.14	12.3	42.0	0.071	0.076	0.011	54.3	7.8	0.041	11.9	19.0	0.63	12.7	18.3	0.70	1.3	3.5	689
BIGGAR	2.3	0.14	15.2	40.9	0.059	0.080	0.009	56.4	9.5	0.055	13.6	20.9	0.65	13.9	20.7	0.67	1.0	2.8	758
LSD[c]	0.6	0.02	4.5	7.1	0.026	0.018	0.004	7.9	3.2	0.012	1.4	1.2	0.09	1.0	1.1	0.09	0.6	0.8	45
Range	2.6	0.04	15.1	18.0	0.056	0.028	0.009	16.9	9.8	0.029	6.7	7.9	0.40	6.7	6.1	0.51	1.8	3.8	351
CV[d]	18.2	12.00	20.4	13.7	29.520	17.530	37.870	10.7	22.3	17.149	7.6	4.7	8.61	5.2	4.6	7.50	33.6	19.7	4

[a] Means are the average of 4 replicates at Glenlea 1990.

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS =first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (Nm); BWD = band width at 5 min after peak (Nm); R = min (cm); R/E' = ratio of resistance to extension at 135 min; 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).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 6a. Cultivar Means[a] for Physical, Chemical and Farinograph Properties Over Environments

Cultivar	Physical, Chemical and Farinograph Properties[b]															
	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
1BL/1RS Wheats																	
BR 23	77.4	32.5	1.00	63.3	11.6	0.41	474	70	56	54.2	3.2	45	1.8	4.5	6.2	7.5	0.642
8416-Q06A	78.5	35.1	0.52	70.6	12.6	0.40	425	63	48	57.2	4.2	38	2.4	6.0	8.5	9.6	0.625
8416-Q06E	78.8	34.9	0.55	69.7	12.2	0.42	431	65	51	53.8	8.2	23	3.0	13.3	16.6	16.3	0.775
8416-BZ10A	78.1	32.8	0.35	71.6	13.3	0.39	587	67	48	58.1	6.1	34	3.6	7.4	11.1	11.5	0.642
8416-BZ10C	78.3	33.1	0.34	72.3	13.4	0.40	596	55	42	57.6	4.6	42	2.8	6.4	9.2	10.2	0.592
8417-BJ03A	77.6	29.2	0.35	71.8	12.2	0.43	566	60	42	55.6	6.8	27	2.4	10.4	12.8	14.0	0.742
8417-BJ03D	78.6	30.9	0.35	72.6	12.4	0.41	599	60	43	56.1	6.1	31	2.3	8.3	10.6	12.6	0.633
Control Wheats																	
8417-AV06D	79.0	33.9	0.32	74.5	13.5	0.39	561	75	57	56.8	9.2	23	4.6	11.0	15.7	16.3	0.867
CEP 14	76.6	28.3	1.42	64.7	12.5	0.39	467	78	68	53.9	2.9	47	1.5	5.2	6.6	7.6	0.725
NEEPAWA	77.8	28.7	0.34	72.9	14.2	0.38	623	78	61	58.9	5.8	17	3.1	10.8	14.2	16.4	0.708
OSLO	76.7	30.3	0.45	73.8	12.8	0.38	561	90	78	53.5	8.2	23	3.0	13.1	16.2	16.3	1.100
GENESIS	75.5	30.1	0.49	69.1	11.7	0.40	530	82	62	56.7	5.0	35	2.9	7.0	9.9	10.1	0.733
BIGGAR	76.8	31.2	0.46	72.7	12.4	0.44	577	88	68	56.3	6.7	22	3.7	9.0	12.8	13.8	0.950
LSD[c]	----	2.8	0.13	1.2	----	----	---	5	8	---	2.2	--	---	---	3.9	4.1	0.153
Range	3.5	6.8	1.10	11.2	2.6	0.06	198	35	36	5.4	6.3	30	3.1	8.8	10.4	8.9	0.508
CV[d]	2.2	11.1	29.12	2.1	8.3	6.93	18	8	18	4.1	46.0	56	64.7	41.8	42.1	40.7	25.321

[a] Means are the average of 3 environments (Swift Current 1989, Glenlea 1989 and Glenlea 1990).

[b] 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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

TABLE 6b. Cultivar Means[a] for Mixograph, Extensigraph and Breadmaking Properties Over Environments

Cultivar	Mixograph, Extensigraph and Breadmaking Properties[b]																	
	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
1BL/1RS Wheats																			
BR 23	1.6	0.13	11.0	39.2	0.059	0.079	0.011	50.2	7.6	0.044	7.8	16.4	0.48	7.9	15.4	0.52	2.5	4.3	571
8416-Q06A	1.8	0.14	12.2	41.2	0.065	0.079	0.012	53.4	8.3	0.040	9.0	17.8	0.50	8.9	17.5	0.51	1.9	4.9	703
8416-Q06E	4.4	0.12	26.1	24.3	0.038	0.070	0.007	50.4	17.3	0.051	14.7	17.2	0.86	15.0	16.0	0.94	1.0	2.2	771
8416-BZ10A	2.4	0.15	16.1	39.4	0.075	0.079	0.010	55.5	10.4	0.045	9.4	18.8	0.52	8.9	17.3	0.51	1.3	4.3	775
8416-BZ10C	2.2	0.14	15.0	39.8	0.081	0.076	0.012	54.8	10.1	0.043	9.6	17.1	0.56	9.3	15.7	0.60	1.4	4.4	708
8417-BJ03A	4.1	0.12	23.5	24.3	0.059	0.065	0.007	47.8	15.5	0.043	12.5	17.5	0.75	14.4	14.9	0.96	1.0	1.7	782
8417-BJ03D	3.4	0.13	21.0	30.8	0.065	0.072	0.010	51.9	14.1	0.046	13.0	16.4	0.80	12.7	14.8	0.85	1.0	2.5	791
Control Wheats																			
8417-AV06D	4.0	0.14	24.8	29.6	0.062	0.081	0.008	54.4	16.8	0.057	14.1	21.1	0.68	14.8	19.3	0.79	1.0	1.4	847
CEP 14	2.2	0.13	15.0	38.5	0.061	0.076	0.008	53.1	10.2	0.052	9.0	19.4	0.47	8.5	18.0	0.47	1.8	4.0	624
NEEPAWA	2.5	0.15	17.4	43.3	0.082	0.088	0.010	60.8	11.5	0.065	12.0	20.1	0.60	11.0	18.3	0.61	1.3	1.9	900
OSLO	3.9	0.14	23.8	32.2	0.036	0.083	0.007	54.0	16.1	0.062	14.5	24.5	0.59	15.1	22.5	0.68	1.0	1.6	843
GENESIS	2.2	0.16	16.4	43.3	0.071	0.090	0.018	59.7	11.0	0.048	10.9	21.0	0.54	11.3	20.3	0.56	1.3	3.8	733
BIGGAR	2.8	0.15	18.7	40.1	0.050	0.088	0.011	58.9	12.2	0.056	11.8	24.2	0.50	12.7	23.2	0.56	1.0	2.1	802
LSD[c]	0.5	----	3.5	4.7	-----	-----	-----	----	2.5	-----	1.9	1.8	0.12	1.7	1.5	0.11	---	0.7	47
Range	2.8	0.04	15.1	19.0	0.046	0.025	0.011	13.0	9.7	0.025	6.9	8.1	0.39	7.2	8.4	0.49	1.5	3.5	329
CV[d]	22.2	12.70	23.4	16.4	24.020	19.683	39.609	11.6	24.7	19.529	20.1	11.8	24.10	18.4	10.6	20.86	38.2	27.0	8

[a] Means are the average of 3 environments (Swift Current 1989, Glenlea 1989 and Glenlea 1990).

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (Nm); BWD = band width at 2 min after peak; R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = ratio of resistance to extension at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; FSTICK = dough stickiness at first mix of the remix bake; SSTICK = dough stickiness at the remix stage of the remix bake; RLV = remix loaf volume (cc).

[c] LSD = least significant difference at P = 0.05.

[d] CV = coefficient of variation.

volume, farinograph dough development time, departure time, time to breakdown, band width at 5 min after peak, mixograph development time, energy to peak and after peak, band width energy, extensigraph resistance, extensibility and ratio of resistance to extension at 45 min and 135 min, dough stickiness at the remix stage of the remix bake, and remix loaf volume. Narrow ranges were noted for flour protein content, flour ash content, farinograph absorption, farinograph mixing tolerance index, and the ratio of resistance to extension.

The cultivar, Neepawa, was selected as typical of the Canada Western Red Spring wheat class and was used in this study as the standard for milling and breadmaking quality. Neepawa was characterized by high test weight, moderate 1,000 kernel weight and hard kernels which produce high flour yield. The high flour protein content and water absorption and good quality HMW glutenin subunits contributed to its strong rheological properties, good bread crumb texture and high bread loaf volume. Of the control wheats, 8417-AV06D was most similar in quality to Neepawa. For test weight, 1,000 kernel weight, kernel hardness and flour yield, 8417-AV06D was considerably better than Neepawa. Cultivar 8417-AV06D was stronger than Neepawa for some rheological properties such as farinograph dough development time, arrival time, stability, departure time, band width at 5 min after peak, mixograph development time, energy to peak, band width energy, extensigraph resistance, extensibility and the ratio of resistance to extension at 45 and 135 min. Cultivar 8417-AV06D also has less dough stickiness than Neepawa. Cultivar CEP 14 ranked poorest in quality of the control wheats, primarily due to its soft kernels, weak rheological properties, high stickiness values and low loaf volume. Of the 1BL/1RS translocation wheats, 8417-BJ03A and 8417-BJ03D were the best in terms of quality but significantly poorer than Neepawa, particularly in loaf volume. BR 23 had the poorest overall quality of all the wheats. Its soft kernels produced the lowest flour yield. The low flour protein content, poor HMW glutenin subunit composition, low water absorption, weak

rheological properties (farinograph, mixograph, extensigraph) and sticky dough properties combined to produce a low loaf volume.

The control wheats Oslo, Genesis and Biggar have been classified into the Canada Prairie Spring wheat class and are characterized by medium protein content, grain hardness and dough strength. Of these wheats, Oslo ranked the best and Genesis was the poorest in overall breadmaking quality. The 1BL/1RS cultivars 8416-Q06E, 8417-BJ03A and 8417-BJ03D were very similar to Biggar, particularly in terms of flour protein content and loaf volume.

Most of the 1BL/1RS wheats and the control wheats were very sticky and slightly sticky at their remix stage of the remix bake, respectively. This result agreed with other studies in that the greater stickiness characteristic was generally associated with the 1BL/1RS doughs compared to control wheat doughs (Barnes, 1990; Dhaliwal *et al.*, 1987; Martin and Stewart, 1986a, 1986b and 1990; Zeller *et al.*, 1982). However, there were specific cultivars in the two wheat groups that did not follow these stickiness trends. The 1BL/1RS translocated wheats 8416-Q06E, 8417-BJ03A and 8417-BJ03D were non-sticky at the first mix and slightly sticky at the remix stage. The high quality HMW glutenin subunits may have controlled the deleterious effects of the rye translocation. On the other hand, the control wheats CEP 14 and Genesis also contained good quality HMW glutenin subunits but they were slightly sticky at the first mix and very sticky at the remix stage. The Falling Number values of all the cultivars in this study were above 300, indicating that a high level of α-amylase probably was not the cause of dough stickiness.

D. Environment Comparisons

Environment means, the least significant differences and ranges for the quality characteristics are presented in Table 7a-b (SAS statements and an output example are given in Appendix V and VI, respectively). Variation due to environment was significant for all quality parameters

TABLE 7a. Environment Means for the Physical, Chemical and Farinograph Properties

	Physical, Chemical and Farinograph Properties[a]																
Environment	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
Swift Current 1989	76.3	27.8	0.58	69.9	13.7	0.38	630	74	65	58.0	8.9	14	4.9	12.0	17.0	18.4	0.608
Glenlea 1989	77.5	32.2	0.49	71.8	12.5	0.43	472	66	48	56.0	4.8	36	2.1	6.9	9.0	10.2	0.713
Glenlea 1990	79.3	34.8	0.53	70.6	11.8	0.40	513	75	54	54.2	4.0	44	1.6	7.0	8.7	8.8	0.925
LSD[b]	0.6	1.1	0.14	1.4	0.4	0.01	35	5	35	0.9	0.9	6	0.5	1.5	1.7	1.6	0.071
Range	3.0	7.0	0.09	1.9	1.9	0.05	158	9	17	3.8	4.9	30	3.3	5.1	8.3	9.6	0.317

[a] TWT = test weight (kg/hl); TKWT = 1,000 kernel weight (g); GRT = grinding time (min); FLY = Buhler mill protein yield (%, 14% mb); PROT = Buhler mill protein content (%, 14% mb); ASH = flour ash content (%, 14% mb); FN = Falling Number (sec); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).
[b] LSD = least significant difference at P = 0.05.

TABLE 7b. Environment Means for Mixograph, Extensigraph and Breadmaking Properties

	Mixograph, Extensigraph and Breadmaking Properties[a]																	
Environment	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
Swift Current 1989	3.3	0.15	21.9	36.5	0.063	0.081	0.011	58.4	14.2	0.054	11.5	20.8	0.57	12.1	19.2	0.64	1.1	2.8	804
Glenlea 1989	2.9	0.14	18.4	34.7	0.063	0.084	0.012	52.7	13.0	0.047	9.6	19.6	0.51	9.2	17.6	0.54	1.6	3.2	727
Glenlea 1990	2.5	0.13	15.3	36.3	0.061	0.072	0.008	51.6	10.0	0.049	13.1	28.1	0.73	13.3	17.0	0.79	1.3	3.0	742
LSD[b]	0.4	0.01	2.3	3.4	0.008	0.006	0.002	2.5	1.5	0.004	1.1	1.3	0.06	1.1	1.2	0.07	0.3	0.6	39
Range	0.8	0.02	6.6	1.8	0.002	0.012	0.004	6.8	4.2	0.007	3.5	2.7	0.22	4.1	2.2	0.25	0.5	0.4	77

[a] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = time to breakdown (min);BWE = band width energy (Nm); BWD = band width at 2 min after peak; R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = ratio of resistance to extension at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; FSTICK = dough stickiness at first mix of the remix bake; SSTICK = dough stickiness at the remix stage of the remix bake; RLV = remix loaf volume (cc).
[b] LSD = least significant difference at P = 0.05.

except grinding time, mixograph energy after peak, mixograph slope to peak and remix dough stickiness. Kernels were generally smaller, less dense, softer in texture and lower in flour yield in Swift Current 1989 than in the other two environments. These cultivars had higher flour protein content, better gluten quality (SDS- and Zeleny-sedimentation volume), greater dough-mixing strength (mixograph, farinograph), water absorption, loaf volume and lower ash content and dough stickiness than cultivars grown at Glenlea in 1989 and 1990. Cultivars grown in Glenlea 1990 had larger, denser kernels with the lowest protein content, water absorption and dough strength, higher extensigraph resistance and extensibility than the other environments. Cultivars grown in Glenlea 1989 were characterized by hard kernel texture, high ash content, low gluten quality, low resistance, low extensibility, low ratio of resistance to extension, high dough stickiness and low loaf volume.

E. Effect of Cultivar, Environment and their Interaction on Quality Parameters

Analysis of variance was performed to examine the effects of cultivar, environment and their interaction on the quality parameters (Table 8a-d) (SAS statements and an output example are given in Appendix VII and VIII, respectively). Cultivar effects were very highly significant ($P = 0.001$) for all the quality parameters in agreement with the studies of Bassett et al (1989) and Lukow and McVetty (1991). Environments effects were non-significant for grinding time, mixograph energy after peak, mixograph slope to peak, mixograph peak band width, mixograph band width at 2 min after peak and the remix dough stickiness. All other quality parameters were highly significant ($P = 0.01$) or very highly significant ($P = 0.001$) for environment. These results were in contrast to the significant environmental influence for grinding time noted by others (Baker and Kosmolak, 1977; Bassett et al, 1989; Hong *et al.*, 1989; Lukow and McVetty, 1991). Similar results were obtained by Fowler and de la Roche (1975a and 1975b), in which the flour yield, protein content and

TABLE 8a. Means Squares[a] for the Analysis of Variance of Physical and Chemical Properties of Cultivars

Source of Variation	df[c]	Physical and Chemical Properties[b]								
		TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS
Environment	2	121.76***	647.89***	0.100NS	46.85***	50.70***	0.0318***	347778.31***	1296.02***	3584.54***
Replicate (Environment)	9	3.59	6.94	0.032	2.31	1.21	0.0007	7270.53	18.43	45.74
Cultivar	12	13.18***	61.85***	1.233***	136.40***	6.81***	0.0040***	53619.78***	1497.29***	1545.11***
Cultivar X Environment	24	3.76***[d]	8.97***	0.032NS	4.93***	1.21***[d]	0.0007***[d]	11918.01***[d]	36.60***	181.50***
Error	108	0.58	1.59	0.020	0.86	0.18	0.0002	2280.53	7.37	14.50

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

[b] 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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml).

[c] df = degrees of freedom.

[d] Variance component was greater than 30% of cultivar variance.

TABLE 8b. Mean Squares[a] for the Analysis of Variance of Farinograph Properties of Cultivars

Source of Variation	df[c]	Farinograph Properties[b]							
		FAB	DDT	MTI	ART	STA	DEP	TBD	FW
Environment	2	189.34***	360.85***	12849.31***	162.00***	451.54***	1135.31***	1399.78***	1.357***
Replicate (Environment)	9	5.78	3.05	118.15	1.33	10.94	9.01	7.36	0.074
Cultivar	12	37.48***	45.37***	1137.95***	8.43***	101.02***	144.52***	131.10***	0.257***
Cultivar X Environment	24	5.85***[d]	6.54***	346.61***[d]	2.96***[d]	16.30***[d]	20.15***	12.26***	0.023**
Error	108	1.63	1.35	73.70	0.73	4.28	4.80	4.43	0.011

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

[b] FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[c] df = degrees of freedom.

[d] Variance component was greater than 30% of cultivar variance.

TABLE 8c. Mean Squares[a] for the Analysis of Variance of Mixograph Properties of Cultivars

Source of Variation	df[c]	Mixograph Properties[b]									
		MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD
Environment	2	7.84***	0.0058***	561.75***	52.00NS	0.000082NS	0.00189NS	0.000229***	708.27**	246.44**	0.00071NS
Replicate (Environment)	9	0.26	0.0003	15.57	50.16	0.000203	0.00058	0.000010	51.51	16.43	0.00027
Cultivar	12	10.86***	0.0018***	288.78***	548.05***	0.002359***	0.00066***	0.000113***	176.07***	126.34***	0.00074***
Cultivar X Environment	24	0.89***	0.0005***[d]	24.28***	79.67***	0.000504***[d]	0.00039***[d]	0.000028***[d]	63.21***[d]	9.82**	0.00013*[d]
Error	108	0.17	0.0002	8.03	23.61	0.000168	0.00015	0.000010	22.81	4.51	0.00007

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (Nm); BWD = band width at 2 min after peak (Nm).

[c] df = degrees of freedom.

[d] Variance component was greater than 30% of cultivar variance.

TABLE 8d. Mean Squares[a] for the Analysis of Variance of Extensigraph and Breadmaking Properties

Source of Variation	df[c]	Extensigraph and Breadmaking Properties[b]								
		R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
Environment	2	152.93***	94.62**	0.659***	228.36***	67.81***	0.868***	2.56**	1.56NS	85532.24***
Replicate (Environment)	9	6.58	6.44	0.028	3.70	1.76	0.018	0.26	0.79	3872.54
Cultivar	12	64.39***	89.11***	0.199***	87.80***	90.54***	0.349***	2.55***	20.18***	98258.44***
Cultivar X Environment	24	5.09*	6.95**	0.025***	3.15***	5.73***	0.013***	0.71***[d]	1.70***	5904.81***
Error	108	2.66	3.08	0.008	0.86	2.07	0.005	0.13	0.40	1334.20

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

[b] R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = ratio of resistance to extension at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 145 min; 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).

[c] df = degrees of freedom.

[d] Variance component was greater than 30% of cultivar variance.

mixograph peak height were largely influenced by environment. The cultivar by environment interactions were very highly significant (P = 0.001) for the majority of the quality parameters. Only the cultivar by environment interaction for grinding time was non-significant, in contrast to the results of Lukow and McVetty (1991). Although the cultivar by environment interactions were significant, the variance component for cultivars accounted for most of the variation and the interactions were small in magnitude for most of the quality characteristics. Relatively large cultivar by environment interactions (>30% of cultivar variance) indicated that cultivar differences could not be statistically compared in Table 6 for the following characteristics: test weight, flour protein content, ash content, Falling Number value, farinograph absorption, mixing tolerance index, arrival time, stability, mixograph peak height, slope to peak, peak band width, slope after peak, total energy, band width at 2 min after peak and first mix stickiness.

F. Comparison of the Quality of the 1BL/1RS Group to the Control Group

The quality characteristics of the wheat group containing the 1BL/1RS translocation were compared to those of the control group in each environment by analysis of variance (Table 9a-b) (SAS statements and an output example are given in Appendix IX and X, respectively). There were significant differences between the two groups for the majority of quality characteristics. The 1,000 kernel weight, flour yield content, SDS- and Zeleny-sedimentation volume, farinograph band width at 5 min after peak, mixograph band width at 2 min after peak, extensigraph extensibility at 45 min and 135 min and resistance at 135 min, dough stickiness at the remix stage of the remix bake and remix loaf volume showed very highly significant (P = 0.001) differences between groups in all environments. There were significant differences (from P = 0.05 to P = 0.001) between groups in all environments for test weight, grinding time, mixograph total energy, extensigraph resistance at 45 min and the ratio of resistance to extension at 45 and 135 min. The groups were significantly different in

TABLE 9a. Group Means for Physical, Chemical and Farinograph Properties in Each Environment

Environment	Physical, Chemical and Farinograph Properties[a]																
	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
Swift Current 1989																	
1BL/1RS Wheat	76.9	28.7	0.52	69.5	13.5	0.39	625	64	52	57.6	8.6	14	4.6	12.0	16.7	17.9	0.55
Control Wheat	75.5***	26.9***	0.64*	70.4***	14.1***	0.38*	635NS	85***	79***	58.5***	9.3NS	14NS	5.2NS	12.1NS	17.3NS	19.0NS	0.68***
Glenlea 1989																	
1BL/1RS Wheat	78.2	33.6	0.44	71.4	12.2	0.44	445	57	40	56.1	4.4	41	1.8	5.7	7.5	8.7	0.65
Control Wheat	76.6***	30.5***	0.55*	72.2***	12.7***	0.43NS	504***	77***	57***	55.9NS	5.3**	30***	2.5***	8.3***	10.8***	12.0***	0.79***
Glenlea 1990																	
1BL/1RS Wheat	79.5	35.6	0.52	69.9	11.9	0.41	506	68	49	54.6	3.8	48	1.4	6.4	8.0	8.4	0.80
Control Wheat	79.0**	33.9***	0.55**	71.3***	11.7NS	0.39***	520NS	84***	60***	53.6***	4.3*	40*	1.8**	7.6**	9.5***	9.2NS	1.08***

[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 = ash content (%, 14% mb); FN = Falling Number (sec); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[b] NS, non-significant; *, **, ***, significantly different at P = 0.05, 0.01, 0.001, respectively, from analysis of variance.

TABLE 9b. Group Means for Mixograph, Extensigraph and Breadmaking Properties in Each Environment

	Mixograph, Extensigraph and Breadmaking Properties[a]																		
Environment	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
Swift Current 1989																			
1BL/1RS Wheat	3.4	0.14	22.3	33.8	0.063	0.07	0.010	56.0	14.1	0.049	10.9	18.4	0.60	11.5	16.6	0.70	1.2	3.4	764
Control Wheat	3.1***	0.16***	21.5NS	39.8***	0.062NS	0.09***	0.011*	61.2***	14.3NS	0.061***	12.2*	23.5***	0.53*	12.8***	22.2***	0.58***	1.0**	2.3***	850***
Glenlea 1989																			
1BL/1RS Wheat	2.7	0.13	16.5	33.5	0.067	0.08	0.012	49.9	11.9	0.041	9.2	17.1	0.55	8.6	15.7	0.57	1.8	3.7	700
Control Wheat	3.1**	0.15***	20.7***	36.2NS	0.058**	0.09NS	0.012NS	55.9***	14.2***	0.055***	10.2*	21.6***	0.47***	10.0***	19.9***	0.50**	1.4**	2.7***	759***
Glenlea 1990																			
1BL/1RS Wheat	2.4	0.13	14.8	35.2	0.060	0.07	0.008	50.0	9.7	0.044	12.5	16.5	0.76	12.8	15.5	0.83	1.4	3.4	721
Control Wheat	2.6NS	0.13NS	15.9NS	37.6NS	0.062NS	0.08NS	0.008NS	53.3*	10.3NS	0.054***	13.8***	19.9***	0.69***	13.9***	18.6***	0.75***	1.3NS	2.5***	766***

[a] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (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 at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; 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).

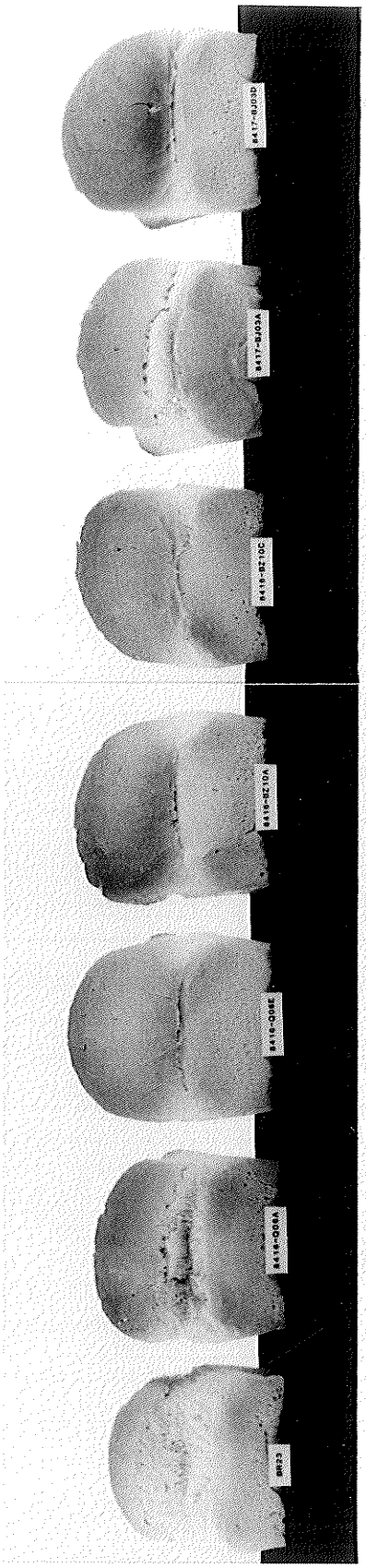
[b] NS, non-significant; *, **, ***, significantly different at P = 0.05, 0.01, 0.001, respectively, from analysis of variance.

two of three environments for flour protein content, flour ash content, farinograph properties (water absorption, development time, mixing tolerance index, arrival time, stability, departure time), mixograph development time, mixograph peak height, and dough stickiness at the first mix of the remix bake. Only one environment showed a significant difference between groups for Falling Number, farinograph time to breakdown, mixograph energy to peak and after peak, slope to peak and slope after peak, peak band width and band width energy.

There were a greater number of quality characteristics with significant differences between the 1BL/1RS group and the control group at Glenlea 1989 than at the other two environments. In most environments, the 1BL/1RS group generally had larger, denser and harder kernels and poorer milling performance as determined by their lower flour yield and higher flour ash as compared to the control group. Flour protein content and gluten strength (SDS- and Zeleny-sedimentation volume) were lower and rheological properties were weaker as determined by the farinograph (development time, mixing tolerance index, arrival time, stability, departure time, time to breakdown, band width at 5 min after peak) and by the mixograph (peak height, total energy, band width at 2 min after peak). The extensigraph resistance and extensibility were lower at both 45 and 135 min in the 1BL/1RS group than in the control group. The ratio of extensigraph resistance to extensibility was higher resulting from a lower proportion of extensibility. For both dough stickiness determinations (dough stickiness at the first mix and at the remix stage of the remix bake), the 1BL/1RS group was stickier than the control group. End-use quality, as determined by the remix loaf volume, was poorer for the 1BL/1RS wheats than the control wheats.

There were no significant differences between the two groups for crust color and crumb texture (Figure 3a and 3b, respectively). Most of the wheats had appealing brown crust color and good crumb texture with uniform and fine grain distributed throughout the loaves. The two poorest

Figure 3a. External Characteristics of the Remix Loaves of the Seven 1BL/1RS Cultivars (first row) and the Six Control Cultivars (second row) Grown at Glenlea in 1990. HY 355 (Genesis); HY 368 (Biggar).


8417-BJ03D
8417-BJ03A
8419-BZ10C
8419-BZ10A
8419-QQ08
8418-QQ08A
HR30

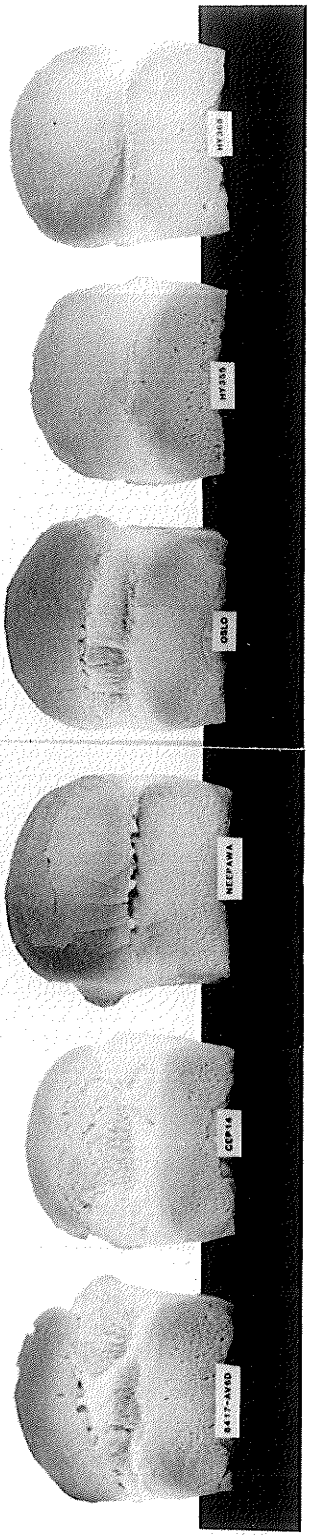
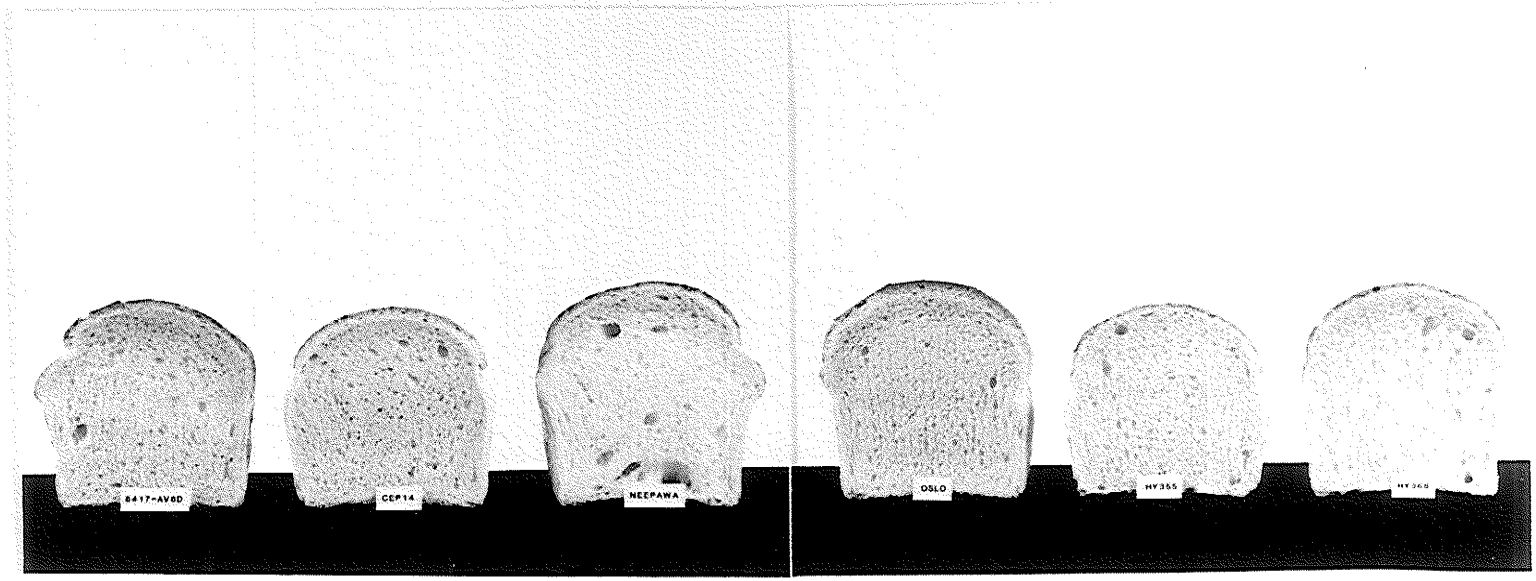

HY369
HY355
GB10
NEEPAWA
CDP14
8417-AY60

Figure 3b. Internal Characteristics of the Remix Loaves of the Seven 1BL/1RS Cultivars (first row) and the Six Control Cultivars (second row) Grown at Glenlea in 1990. HY 355 (Genesis); HY 368 (Biggar).


RR23
8416-Q08A
8416-Q08E
8416-BZ10A
8416-BZ30C
8417-BJ03A
8417-BJ03D


8417-AV6D
CCP14
NEEPAWA
OSLO
HY355
HY365

quality cultivars, BR 23 and CEP 14, had very light brown crust color. Cultivars, 8416-Q06A and 8416-BZ10A, had coarse grain texture.

Inconsistent results were obtained for the farinograph absorption and the mixograph development time. The two environments with significant differences between groups for both quality characteristics gave differing results. There appears to be a high degree of variability that is environment dependent for these two quality characteristics. In addition, many of the mixograph parameters were not useful in identifying significant differences between the groups in the three environments.

G. Effect of Group (1BL/1RS and Control), Environment and their Interaction on Quality Characteristics

The effect of group (1BL/1RS and control), environment and their interaction on quality parameters were examined by analysis of variance (Table 10a-d) (SAS statements and an example output are given in Appendix XI and XII, respectively). Environment effects were very highly significant (P=0.001) for the majority of quality parameters. Only the grinding time, energy after peak and the remix dough stickiness were unaffected by environmental conditions. This latter result was in contrast to that reported by Shelton *et al.* (1990, unpublished data), in which environment was observed to have a high effect on dough stickiness. Variation in the flour yield, farinograph absorption, farinograph development time, mixograph development time, energy to peak, slope after peak and band width energy was caused largely by the environment rather than by the group differences. The group by environment interactions were non-significant for 28 of 36 measured quality characteristics. For those quality characteristics with significant group by environment interactions, the magnitudes of the variances were relatively small. Only Falling Number value, farinograph absorption and mixograph peak band width had large variances (> 30% of the group variance). For these three quality characteristics, environments were treated individually.

TABLE 10a. Means Squares[a] for the Analysis of Variance of Physical and Chemical Properties of Groups

		Physical and Chemical Properties[b]								
Source of Variation	df[c]	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS
Environment	2	121.53***	647.89***	0.100NS	46.85*	50.70***	0.03185***	347778.31***	1296.02***	3584.54***
Replicate (Environment)	9	3.59	6.94	0.031	2.31	1.21	0.00071	7270.53	18.43	45.74
Group	1	50.09***	189.14***	0.292NS	39.82NS	3.93*	0.00488**	29446.29***	14159.86***	13104.21***
Group X Environment	2	4.34NS	8.13NS	0.023NS	1.28NS	2.00NS	0.00038NS	9375.13*[d]	84.59***	754.77***
Error	141	1.79	6.55	0.124	12.80	0.87	0.00060	7996.96	37.68	69.86

[a] *, P = 0.05; **, P = 0.01, ***, P = 0.001; NS, non-significant.
[b] 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 = ash content (%, 14% mb); FN = Falling Number (sec); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml).
[c] df = degrees of freedom.
[d] Variance component was greater than 30% of group variance.

TABLE 10b. Mean Squares[a] for the Analysis of Variance of Farinograph Properties of Groups

		Farinograph Properties[b]							
Source of Variation	df[c]	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
Environment	2	189.34***	360.85***	12849.31***	162.00***	451.54***	1135.31***	1399.78***	1.357***
Replicate (Environment)	9	5.78	3.05	118.15	1.33	10.94	9.01	7.36	0.074
Group	1	0.22NS	18.48NS	1725.13**	10.63*	66.49*	129.88**	116.85**	1.297***
Group X Environment	2	11.40**[d]	0.58NS	486.74NS	0.31NS	21.04NS	23.60NS	25.72NS	0.089*
Error	141	5.27	2.87	193.16	1.70	13.88	18.15	15.44	1.024

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.
[b] FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).
[c] df = degrees of freedom.
[d] Variance component was greater than 30% of group variance.

TABLE 10c. Mean Square[a] for the Analysis of Variance of Mixograph Properties of Groups

Source of Variation	df[c]	Mixograph Properties[b]									
		MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD
Environment	2	7.84**	0.00577***	561.74***	52.00NS	0.000082NS	0.00189***	0.000229***	708.27***	246.44***	0.000709***
Replicate (environment)	9	0.26	0.00033	15.57	50.16	0.000203	0.00058	0.000010	51.51	16.43	0.000274
Group	1	0.19NS	0.00658***	86.57NS	533.65**	0.000261NS	0.00400***	0.000012NS	902.26***	44.48NS	0.005674***
Group X Environment	2	1.94NS	0.00031NS	84.14***	50.29NS	0.000473NS	0.00098**[d]	0.000014NS	23.52NS	17.06NS	0.000050NS
Error	141	1.18	0.00033	33.06	73.79	0.000407	0.00020	0.000022	36.49	15.32	0.000093

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (Nm); BWD = band width at 2 min after peak (Nm).

[c] df = degrees of freedom.

[d] Variance component was greater than 30% of group variance.

TABLE 10d. Mean Squares[a] for the Analysis of Variance of Extensigraph and Breadmaking Properties of Groups

		Extensigraph and Breadmaking Properties[b]								
Source of Variation	df[c]	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
Environment	2	152.93***	94.62***	0.659***	228.36***	67.81***	0.8676***	2.56**	1.56NS	85532.24***
Replicate (Environment)	9	6.58	6.44	0.028	3.70	1.76	0.0175	0.26	0.79	3872.54
Group	1	56.03**	747.93***	0.203**	58.93**	719.82***	0.301**	2.05*	39.08***	153187.69***
Group X Environment	2	0.45NS	9.53NS	0.0016NS	0.21NS	21.67*	0.009NS	0.21NS	0.11NS	5658.38NS
Error	141	7.98	5.67	0.026	8.25	4.85	0.0334	0.42	2.03	9222.74

[a] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.
[b] R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = ratio of resistance to extension at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = ratio of resistance to extension at 135 min; 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).
[c] df = degrees of freedom.

1. Comparison of the 1B/1R Group and the Control Group for Physical and Chemical Properties

The 1BL/1RS group was characterized by significantly (P=0.001) denser and larger kernels and their flours had significantly lower protein content (P=0.05), higher ash content (P=0.01) and weaker gluten as evaluated by SDS- and Zeleny-sedimentation volume (P=0.001) than the control group (Table 11a). No significant difference was observed between the 1BL/1RS wheats and the control wheats in grinding time and flour yield. Villareal *et al.* (1990) also showed that ten 1BL/1RS wheat samples derived from the CIMMYT wheat program had denser and plumper kernels than the control wheats. Dhaliwal *et al.* (1987) observed that only the 1BL/1RS derivatives of the SUN 89 family were plumper in kernel size. There was no significant difference in the test weight between the control wheats (Oxley, Timgalen, Kite) and the 1BL/1RS wheat (QT2870) in the study of Martin and Stewart (1986). This study was in contrast to the non-significant difference observed for SDS-sedimentation volume by others (Martin and Stewart, 1986; Zeller *et al.*, 1990). Van Lill *et al.* (1990) found the flour ash content of their 1BL/1RS wheats (Gamtoos, W38/10) to be non-significantly different from the control wheats (a commercial flour mixture of SST66 and Palmiet). No difference in flour protein content between the two wheat groups was reported in other studies (Dhaliwal *et al.*, 1987; Martin and Stewart, 1986 and 1990). For the grinding time and flour yield, no significant difference was also observed by Dhaliwal *et al.* (1987). Martin and Stewart (1986) reported that the flour yield of their 1BL/1RS wheats were similar to that of the control wheats.

2. Comparison of the 1BL/1RS Group and the Control Group for Farinograph Properties

In earlier studies, the dough development time was the only farinograph parameter that was shown to be significantly different between 1BL/1RS wheats and control wheats (Martin and Stewart, 1987; Van Lill et al., 1990). However, this study showed that the 1BL/1RS wheats were distinctly different from the control wheats in most of the farinograph

parameters (Table 11a). Farinograms of the seven 1BL/1RS cultivars and the normal cultivars grown at Glenlea in 1989 are illustrated in Figure 4a and 4b, respectively. The 1BL/1RS wheats were characterized by weaker dough mixing properties as shown by significantly greater mixing tolerance index (P=0.01), less stability (P=0.05), shorter time to breakdown (P=0.01), and less band width at 5 min after the peak (P=0.001) than the control wheats. The results of this study were in contrast to others for the mixing tolerance index and stability (Martin and Stewart, 1986 and 1990; Pena *et al.*, 1990; Van Lill *et al.*, 1990). The results of this study were similar to those of Dhaliwal *et al.* (1987) and Martin and Stewart (1986) by showing no significant difference between the two wheat groups for the farinograph absorption. However, Van Lill *et al.* (1990) associated the 1BL/1RS wheats with increased farinograph absorption. Dhaliwal *et al.* (1987) and Van Lill *et al.* (1990) showed significant differences in the dough development time between the 1BL/1RS wheats and control wheats. This study and that of Martin and Stewart (1986) showed insignificant difference for the dough development time. Variations of the farinograph absorption and dough development time in some of the earlier studies may have been related to the protein content instead of the presence of the 1BL/1RS translocation (Dhaliwal *et al.*, 1987; Van Lill *et al.*, 1990).

3. Comparison of the 1BL/1RS Group and the Control Group for Mixograph Properties

Earlier studies showed that the 1BL/1RS wheats were lower in mixograph peak height, band trace and development time compared to the control wheats (Dhaliwal *et al.*, 1987; Dhaliwal and MacRitchie, 1990; Martin and Stewart, 1986; Van Lill *et al.*, 1990). Similar results were obtained from this study except for the mixograph development time; the 1BL/1RS group and the control group were non-significantly different in agreement with Pena *et al.* (1990). The greatest significant differences (P=0.001) between groups were noted for mixograph peak height, peak band width, total energy and band width at 2 min after the peak; the 1BL/1RS

TABLE 11a. Group Means for Physical, Chemical and Farinograph Properties Over Environments

	Physical, Chemical and Farinograph Properties[a,b]																
Group	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
1BL/1RS Wheat	78.9	33.7	0.48	70.0	12.5	0.397	521	66	51	56.3	5.3	38.1	2.6	7.5	10.1	11.0	0.70
Control Wheat	78.0***	31.8***	0.56NS	71.2NS	12.8*	0.399**	546***	82***	66***	56.1NS	5.9NS	31.2**	2.9*	8.8*	11.7**	12.5**	0.85***

[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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[b] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

TABLE 11b. Group Means for Mixograph, Extensigraph and Breadmaking Properties Over Environments

	Mixograph, Extensigraph and Breadmaking Properties[a,b]																		
Group	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
1BL/1RS Wheat	2.6	0.14	17.1	36.8	0.067	0.080	0.010	53.8	11.6	0.047	10.9	17.3	0.63	11.0	16.2	0.69	1.4	3.5	723
Control Wheat	2.7NS	0.15***	18.4NS	39.3**	0.064NS	0.086***	0.011NS	57.5***	12.4NS	0.058***	11.9**	20.8***	0.58**	12.3**	19.5***	0.64**	1.3*	2.7***	774***

[a] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (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, non-significant.

Figure 4a. Farinograms of the Seven 1BL/1RS Cultivars Grown at Glenlea in 1989. 1, BR 23; 2, 8416-Q06A; 3, 8416-Q06E; 4, 8416-BZ10A; 5, 8416-BZ10C; 6, 8417-BJ03A; 7, 8417-BJ03D.

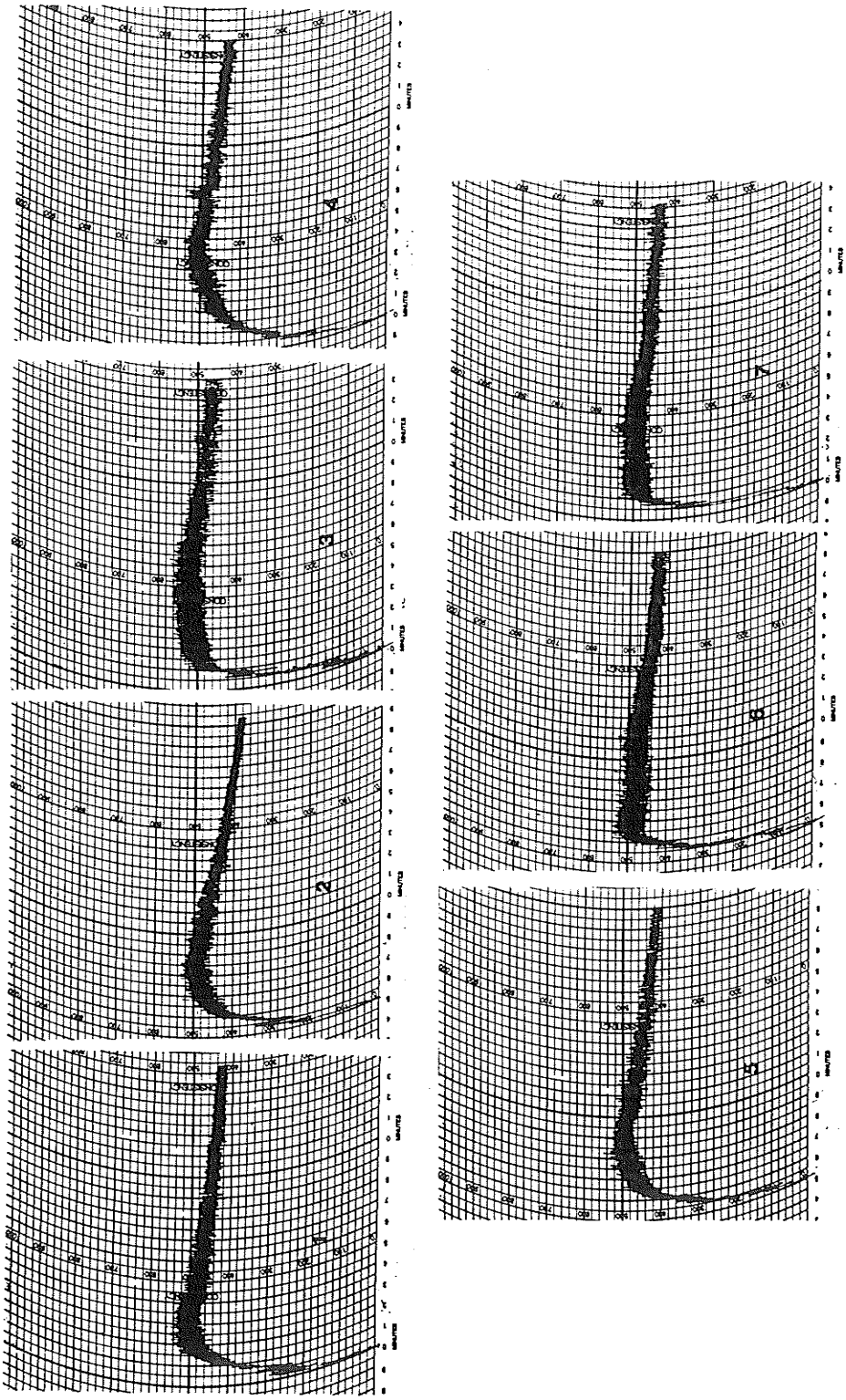
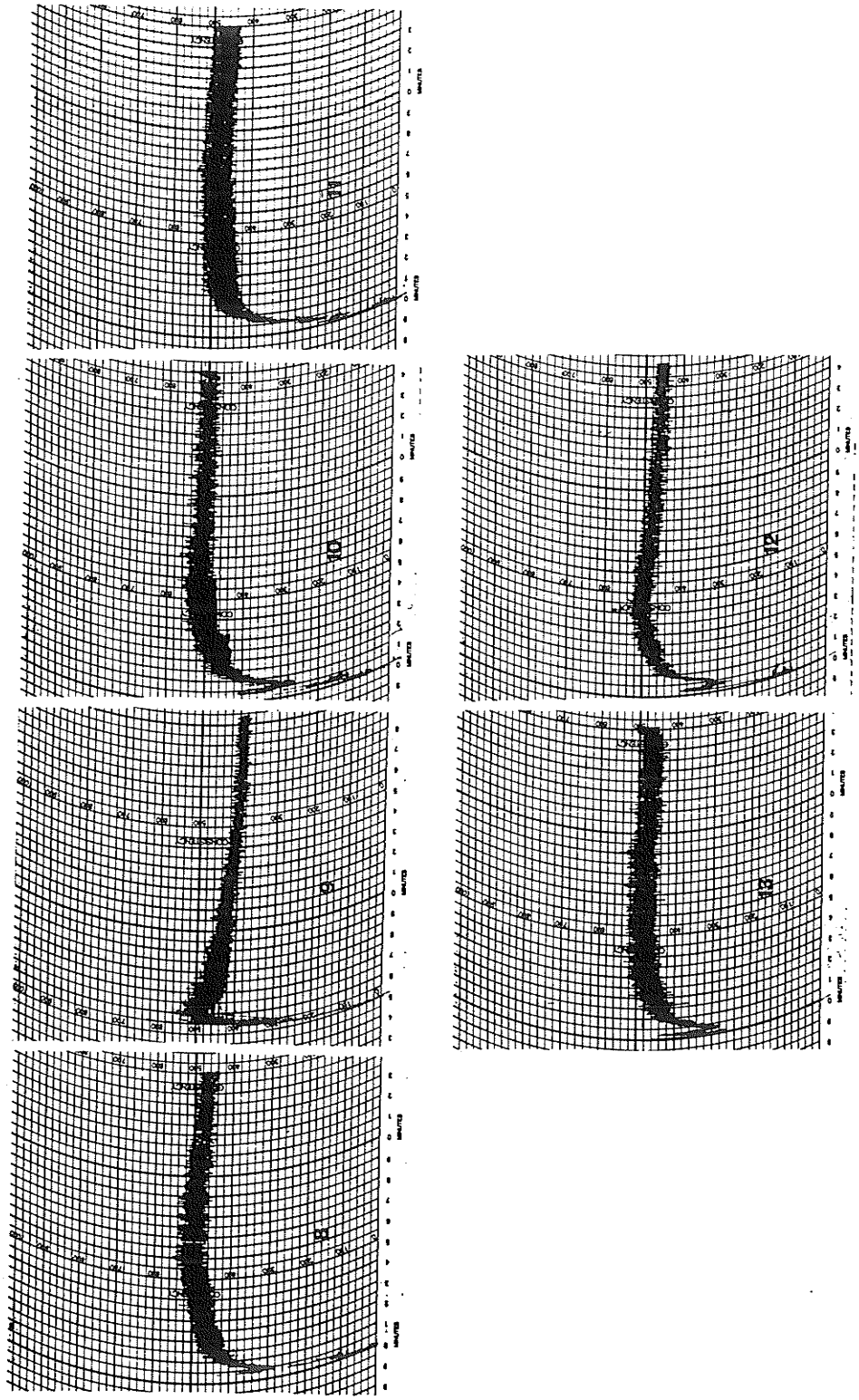


Figure 4b. Farinograms of the Six Control Cultivars Grown at Glenlea in 1989. 8, 8417-AV06D; 9, CEP 14; 10, Neepawa; 11, Oslo; 12, Genesis; 13, Biggar.



group was weaker in mixing properties than the control group (Table 11b). Mixograms of the 1BL/1RS cultivars and control cultivars grown at Glenlea in 1989 are shown in Figure 5a and 5b, respectively.

4. Comparison of the 1BL/1RS Group and the Control Group for Extensigraph Properties

Extensigrams at 45 min and 135 min of the 1BL/1RS cultivars and the control cultivars are illustrated in Figure 6a-b, and Figure 6c-d, respectively. The 1BL/1RS group showed significantly less extensibility (P=0.001) and less resistance (P=0.01) at 45 and 135 min than the control group (Table 11b). These differences were also found in the studies of Dhaliwal *et al.* (1987) and Koebner and Shepherd (1988).

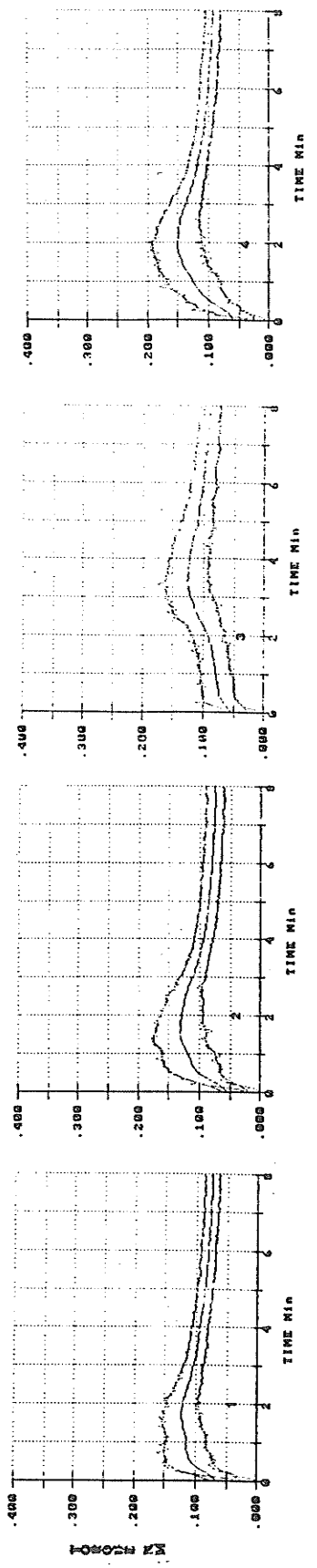
5. Comparison of the 1BL/1RS Group and the Control Group for Baking Properties

Previous studies showed that overmixing of the 1BL/1RS dough would impart extensive surface stickiness (Barnes, 1990; Dhaliwal *et al.*, 1987; Martin and Stewart, 1986a, 1986b and 1990; Zeller *et al.*, 1982). This study showed that at the first mix and at the remix stages, the 1BL/1RS doughs were associated with significantly greater surface stickiness than the controls (P=0.05 and 0.001, respectively) (Table 11b). The remix dough stickiness was superior to the dough stickiness of the first mix in characterizing the two wheat groups. In contrast to the study of Pena *et al.* (1990), this study showed very highly significant differences (P=0.001) between the two groups for the remix loaf volume; the 1BL/1RS wheats had lower loaf volume than the control wheats (Table 11b).

H. Relationship between Dough Stickiness and Quality Parameters

Quality parameters associated with dough stickiness were investigated. Dough stickiness was evaluated at the first mix stage and at the remix stage of the remix bake method. Means for each quality parameter at the four dough stickiness classes of the first mix and the five dough stickiness classes of the remix are presented in Table 12a-b and Table 13a-c, respectively. Pairwise T-test was used to determine the significant

Figure 5a. Mixograms of the Seven 1BL/1RS Cultivars Grown at Glenlea in 1989. 1, BR 23; 2, 8416-Q06A; 3, 8416-Q06E; 4, 8416-BZ10A; 5, 8416-BZ10C; 6, 8417-BJ03A; 7, 8417-BJ03D.


.400
.300
.200
.100
.000
TIME Min
0
2
4
6
8

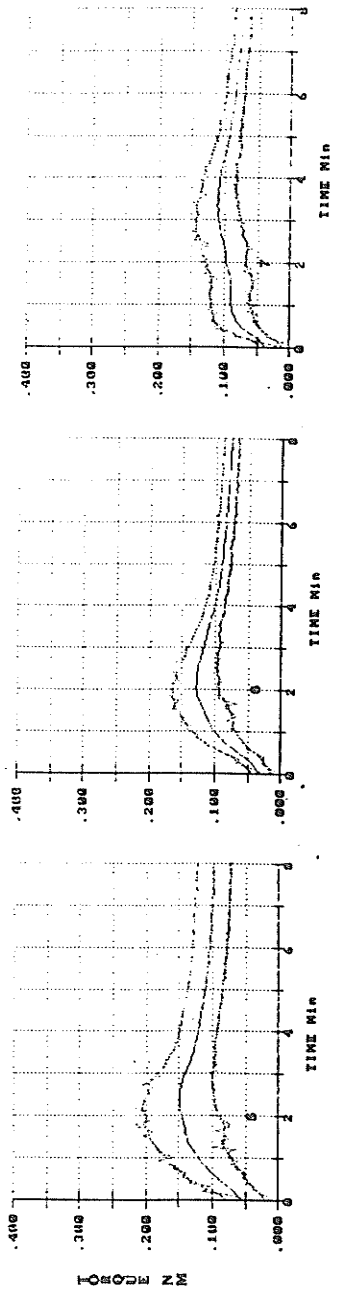

.400
.300
.200
.100
.000
TIME Min
0
2
4
6
8

Figure 5b. Mixograms of the Six Control Cultivars Grown at Glenlea in 1989. 8, 8417-AV06D; 9, CEP 14; 10, Neepawa; 11, Oslo; 12, Genesis; 13, Biggar.

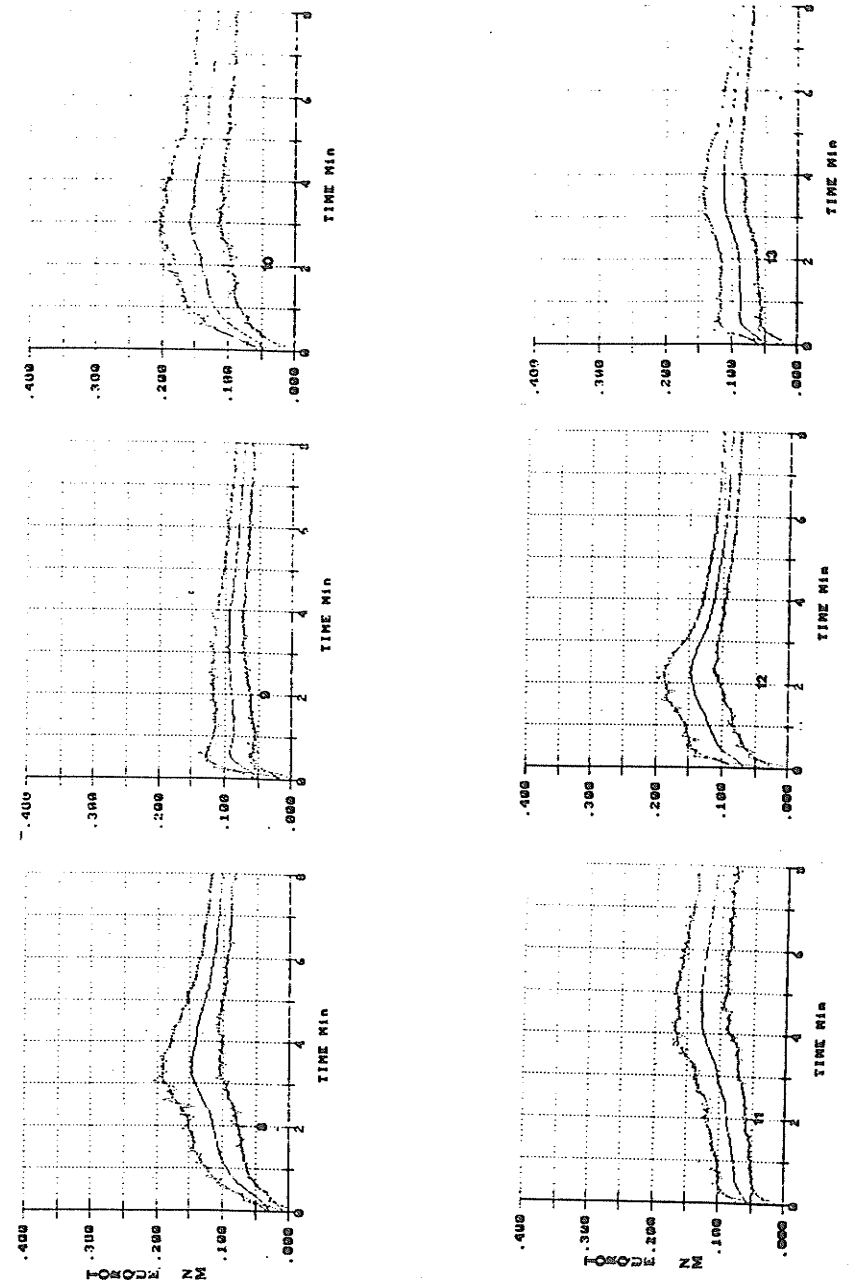

FORCE N
TIME Min
.400
.300
.200
.100
.000
0
2
4
6
8
10
11
12
13

Figure 6a. Extensigrams (at 45 min) of the Seven 1BL/1RS Cultivars Grown at Glenlea in 1989. 1, BR 23; 2, 8416-Q06A; 3, 8416-Q06E; 4, 8416-BZ10A; 5, 8416-BZ10C; 6, 8417-BJ03A; 7, 8417-BJ03D.

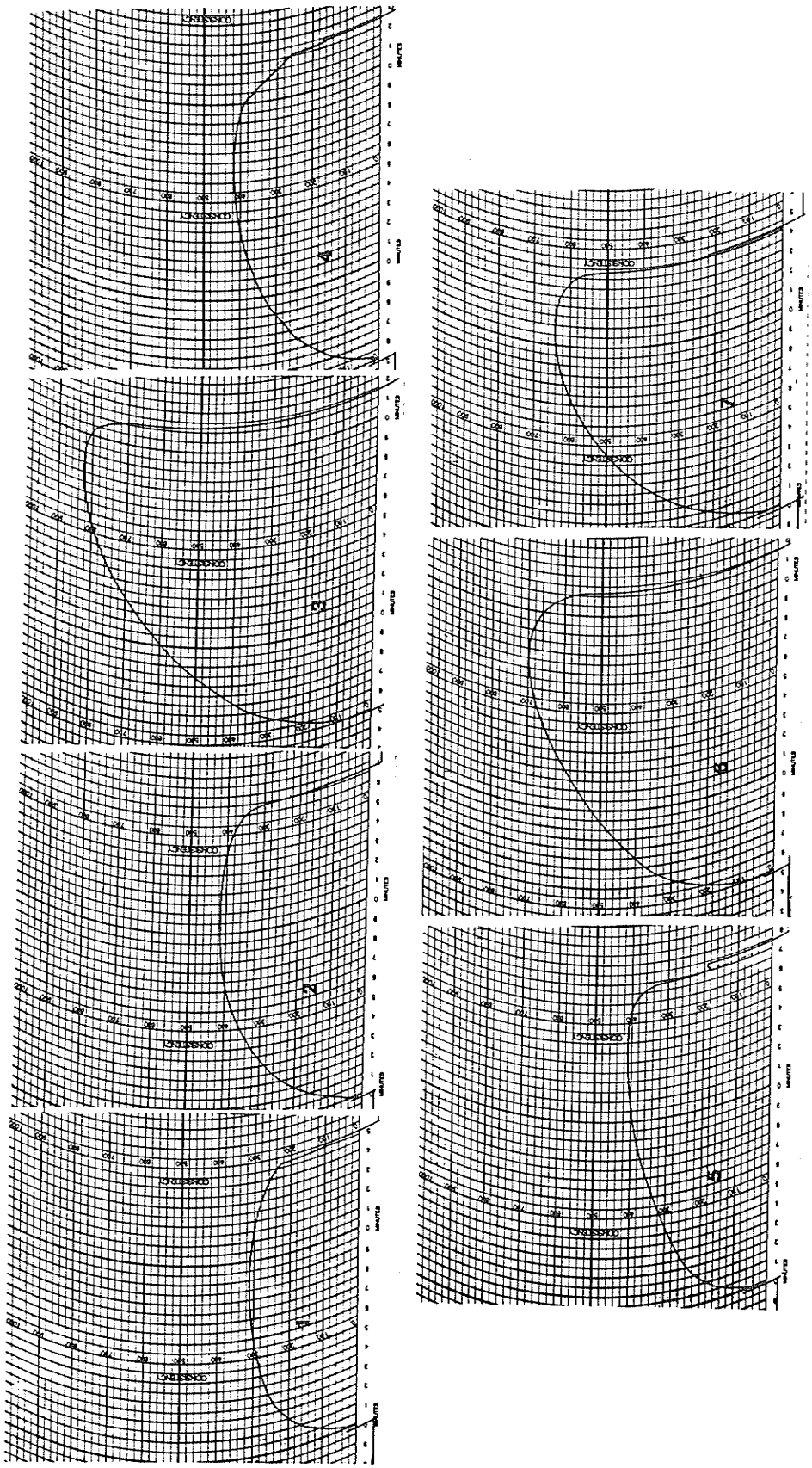


Figure 6b. Extensigrams (at 45 min) of the Six Control Cultivars Grown at Glenlea in 1989. 8, 8417-AV06D; 9, CEP 14; 10, Neepawa; 11, Oslo; 12, Genesis; 13, Biggar.

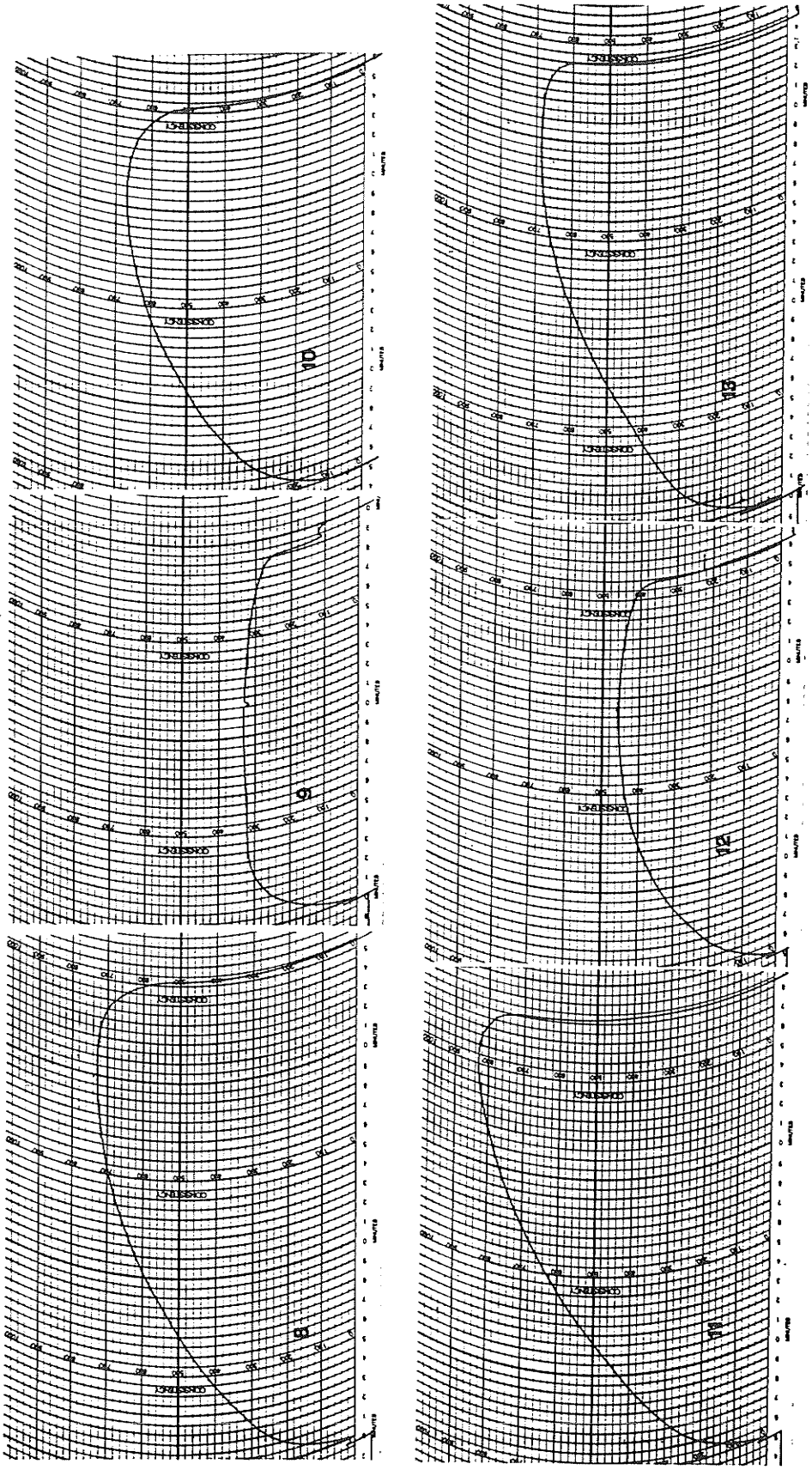


Figure 6c. Extensigrams (at 135 min) of the Seven 1BL/1RS Cultivars at Glenlea 1989. 1, BR 23; 2, 8416-Q06A; 3, 8416-Q06E; 4, 8416-BZ10A; 5, 8416-BZ10C; 6, 8417-BJ03A; 7, 8417-BJ03D.

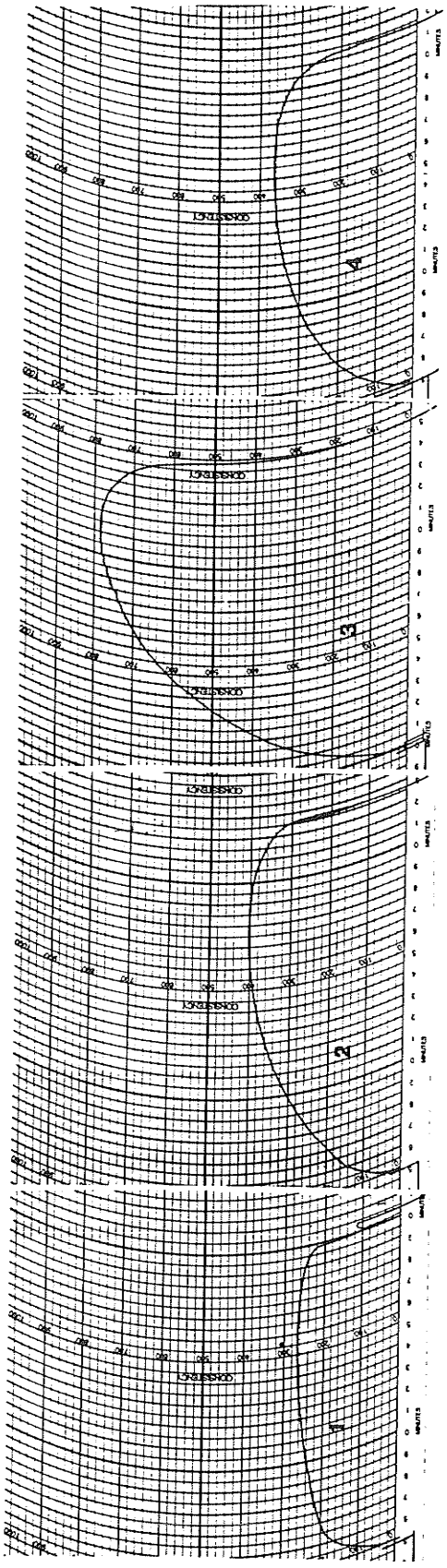


Figure 6d. Extensigrams (at 135 min) of the Six Control Cultivars at Glenlea 1989. 8, 8417-AV06D; 9, CEP 14; 10, Neepawa; 11, Oslo; 12, Genesis; 13, Biggar.

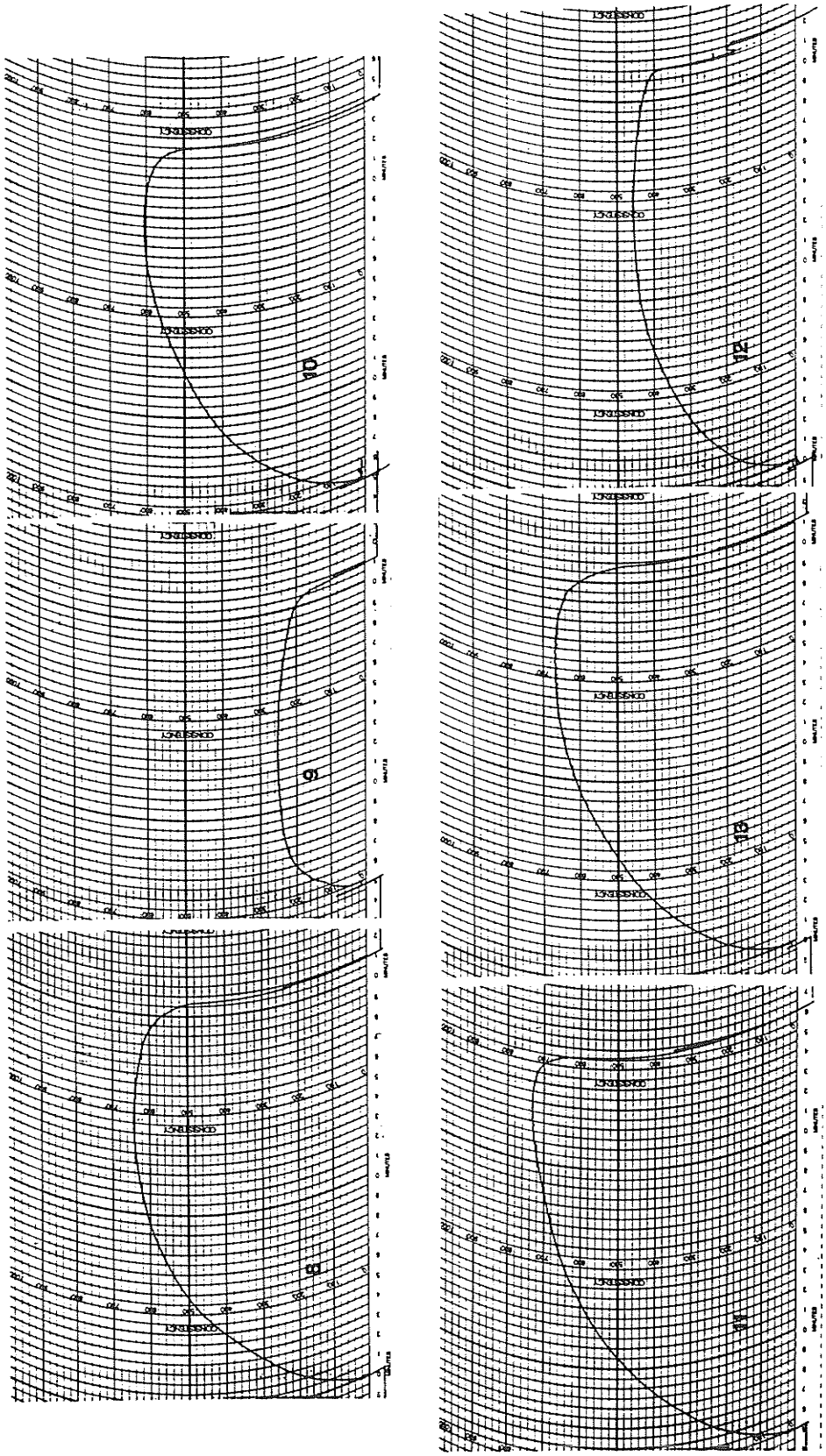


TABLE 12a. Means for Physical, Chemical and Farinograph Properties at Different Dough Stickiness Classes of the First Mix of the Remix Bake Test

Stickiness Class[c]	Physical, Chemical and Farinograph Properties[a]																
	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
NS (n=117)	77.7 a	31.2 a	0.47 b	71.5 a	12.8 a	0.40 b	565 a	73 a	57 a	56.0 a	6.7 a	27 b	3.1 a	9.9 a	13.1 a	14.0 a	0.780 a
SS (n=26)	77.4 a	32.6 a	0.63 ab	69.0 b	12.4 a	0.40 b	464 b	68 a	52 a	56.4 a	3.7 b	43 a	2.1 b	5.0 b	7.1 b	8.2 b	0.642 b
S (n=11)	77.4 a	32.2 a	0.91 a	67.6 b	12.4 a	0.40 b	454 b	70 a	54 a	56.0 a	3.4 b	46 a	2.0 ab	4.5 b	6.5 b	7.6 b	0.664 b
VS (n=2)	77.9 a	32.9 a	1.06 a	65.9 b	11.6 a	0.48 a	422 ab	66 a	45 a	54.0 a	2.8 ab	44 ab	1.5 ab	4.0 ab	5.5 ab	7.0 ab	0.750 ab

[a] TWT = test weight (kg/hl); TKWT = 1,000 kernel weight (g); GRT = grinding time (min); FLY = Buhler mill flour yield content (%, 14% mb); PROT = Buhler mill flour protein content (%, 14% mb); ASH = flour ash content (%, 14% mb); FN = Falling Number (sec); SDS = sodium dodecyl sulfate-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ZS = Zeleny-sedimentation volume (ml); DEP = departure time (min); TBD = time to breakdown (min); ART = arrival time (min); STA = stability (min); FW = band width at 5 min after peak (cm).

[b] No significant difference was marked among classes with same alphabet for each quality parameter; comparison-wide error rate = 0.05; experiment-wide was not applied due to different sample sizes in the five dough stickiness classes at the first mix of the remix bake.

[c] NS, non-sticky; SS, slightly sticky; S, sticky; VS, very sticky; VVS, very very sticky; n = sample size.

TABLE 12b. Means for Mixograph, Extensigraph and Breadmaking Properties at Different Dough Stickiness Classes of the First Mix of the Remix Bake Test

Stickiness Class[a]	Mixograph, Extensigraph and Breadmaking Properties[b]																	
	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	SSTICK	RLV
NS (n=117)	3.2 a	0.14 a	20.5 a	34.6 a	0.061 b	0.078 a	0.009 b	54.8 a	13.6 a	0.053 a	12.5 a	19.7 a	0.65 a	12.7 a	18.3 a	0.72 a	2.6 b	789 a
SS (n=26)	1.9 b	0.14 a	12.9 b	39.8 b	0.069 a	0.082 a	0.013 a	52.7 a	8.7 b	0.042 b	8.5 b	17.9 b	0.48 b	8.3 b	16.8 b	0.50 b	4.3 a	661 b
S (n=11)	2.0 b	0.14 a	13.0 b	39.2 ab	0.061 ab	0.077 a	0.012 ab	52.1 a	8.7 b	0.042 b	7.8 ab	19.0 ab	0.42 b	7.6 b	17.5 ab	0.44 b	4.3 a	675 b
VS (n=2)	1.6 b	0.13 a	10.8 b	40.7 ab	0.063 ab	0.091 a	0.011 ab	51.5 a	8.2 ab	0.055 ab	5.8 b	17.3 ab	0.34 b	6.4 b	15.4 ab	0.42 b	5.0 a	613 b

[b] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (Nm); BWD = band width at 2 min after peak (Nm); R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = resistance to extension at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = resistance to extension at 135 min; SSTICK = dough stickiness at the remix stage of the remix bake; RLV = remix loaf volume (cc).

[a] No significant difference was marked among classes with same alphabet for each quality parameter; comparison-wide error rate = 0.05; experiment-wide was not applied due to different sample sizes in the five dough stickiness classes at the first mix of the remix bake.

[a] NS, non-sticky; SS, slightly sticky; S, sticky; VS, very sticky; VVS, very very sticky; n = sample size.

TABLE 13a. Means for Physical, Chemical and Farinograph Properties at Different Dough Stickiness Classes of the Remix Stage of the Remix Bake Test

Stickiness Class[c]	Physical, Chemical and Farinograph Properties[a]																
	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
NS (n=37)	77.2 b	30.0 b	0.41 b	72.7 a	13.3 a	0.40 a	583 a	76 a	62 a	56.6 a	9.1 a	17 b	4.1 a	12.9 a	17.0 a	17.5 a	0.800 a
SS (n=24)	78.7 a	32.5 a	0.44 b	71.9 ab	12.3 b	0.41 a	528 b	73 ab	54 b	54.4 b	5.5 b	33 a	2.1 c	8.6 b	10.7 b	12.2 b	0.892 a
S (n=27)	77.6 b	32.0 ab	0.49 ab	70.3 bc	12.4 b	0.41 a	553 ab	75 ab	58 ab	56.0 ab	5.9 b	28 a	3.0 ab	9.4 b	12.6 b	13.4 b	0.774 ab
VS (n=36)	77.9 b	32.1 a	0.66 a	69.7 c	12.5 b	0.40 a	530 b	70 bc	54 b	55.9 ab	4.4 bc	41 a	2.4 bc	6.1 c	8.5 c	9.3 c	0.692 bc
VVS (n=32)	77.3 b	32.0 a	0.64 a	69.2 c	12.6 b	0.41 a	490 b	66 c	50 b	56.8 a	4.3 c	38 a	2.5 bc	6.0 c	8.5 c	9.7 c	0.625 c

[a] TWT = test weight (kg/hl); TKWT = 1,000 kernel weight (g); GRT = grinding time (min); FLY = Buhler mill flour yield content (%, 14% mb)); PROT = Buhler mill flour protein content (%, 14% mb); ASH = flour ash content (%, 14% mb); FN = Falling Number (sec); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).

[b] No significant difference was marked among classes with same alphabet for each quality parameter; comparison-wide error rate = 0.05; experiment-wide was not applied due to different sample sizes in the five dough stickiness classes of the remix stage of the remix bake.

[c] NS, non-sticky; SS, slightly sticky; S, sticky; VS, very sticky; VVS, very very sticky; n = sample size.

TABLE 13b. Means for Mixograph Properties at Different Dough Stickiness Classes of the Remix Stage of the Remix Bake Test

Stickiness Class[c]	Mixograph Properties[a,b]									
	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD
NS (n=37)	4.0 a	0.14 a	24.7 a	30.4 d	0.054 c	0.079 a	0.008 c	54.5 c	16.3 a	0.056 a
SS (n=24)	3.1 b	0.13 a	19.0 b	33.0 cd	0.058 bc	0.074 a	0.009 bc	51.9 a	12.8 b	0.052 ab
S (n=27)	2.9 b	0.14 a	19.1 b	36.3 bc	0.058 bc	0.081 a	0.010 bc	55.4 b	12.7 b	0.052 ab
VS (n=36)	2.3 c	0.14 a	15.2 c	38.5 ab	0.068 ab	0.078 a	0.011 b	53.7 d	10.0 c	0.045 c
VVS (n=32)	2.0 c	0.15 a	14.4 c	40.9 a	0.071 a	0.082 a	0.014 a	55.3 a	9.9 c	0.046 bc

[a] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope before peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (Nm); BWD = band width at 2 min after peak (Nm).

[b] No significant difference was marked among classes with same alphabet for each quality parameter; comparison-wide error rate = 0.05; experiment-wide was not applied due to different sample sizes in the five dough stickiness classes of the remix stage of the remix bake.

[c] NS, non-sticky; SS, slightly sticky; S, sticky; VS, very sticky; VVS, very very sticky; n = sample size.

TABLE 13c. Means for Extensigraph and Breadmaking Properties at Different Dough Stickiness Classes of the Remix Stage of the Remix Bake Test

Stickiness Class[c]	Extensigraph and Breadmaking Properties[b]							
	R	E	R/E	R'	E'	R/E'	FSTICK	RLV
NS (n=37)	12.9 a	21.1 a	0.63 a	14.0 a	19.5 a	0.75 a	1.0 b	847 a
SS (n=24)	13.6 a	19.2 ab	0.73 a	13.5 a	17.6 ab	0.79 a	1.1 b	794 b
S (n=27)	13.0 a	19.6 ab	0.68 a	13.0 a	18.1 ab	0.74 a	1.1 b	777 b
VS (n=36)	9.9 b	18.6 b	0.55 b	9.7 b	17.2 b	0.58 b	1.6 a	700 c
VVS (n=32)	8.4 c	17.9 b	0.47 c	8.2 c	17.0 b	0.48 c	1.9 a	676 c

[a] R = resistance at 45 min (cm); E = extensibility at 45 min (cm); R/E = resistance to extension at 45 min; R' = resistance at 135 min (cm); E' = extensibility at 135 min (cm); R/E' = resistance to extension at 135 min; FSTICK = dough stickiness at the first mix of the remix bake; RLV = remix loaf volume (cc).

[b] No significant difference was marked among classes with same alphabet for each quality parameter; comparison-wide error rate = 0.05; experiment-wide was not applied due to different sample sizes in the five dough stickiness classes of the remix stage of the remix bake.

[c] NS, non-sticky; SS, slightly sticky; S, sticky; VS, very sticky; VVS, very very sticky; n = sample size.

differences among the dough stickiness classes.

1. Dough Stickiness at the First Mix Stage

The non-sticky doughs of the first mix stage were generally higher in flour yield, farinograph time to breakdown, mixograph development time, energy to peak, extensigraph resistance at 45 min and 135 min, the ratio of resistance to extension at 45 and 135 min, the remix loaf volume and lower in the remix dough stickiness compared to the other stickiness classes of the first mix. The non-sticky doughs were associated with harder kernels and were different in overall quality from that of the sticky and very, very sticky doughs. Only the very sticky doughs had a higher ash content; the other stickiness classes did not differ significantly from each other. No significant differences were observed between the non-sticky doughs and very sticky doughs for all the other quality parameters.

2. Dough Stickiness at the Remix Stage

The remix stage of the remix bake method includes the process of fermentation and remixing of the dough for 2.5 min. The non-sticky doughs of the remix stage were generally associated with smaller kernels and higher flour protein content, Falling Number value, Zeleny-sedimentation volume and dough strength (farinograph development time, mixing tolerance index, arrival time, stability, departure time, time to breakdown, mixograph development time, energy to peak, band width energy) and greater remix loaf volume compared to other remix sticky doughs. Both the dough stickiness of the first mix and the remix had similar relationships to the grinding time, flour yield and extensigraph extensibility at both time periods. Only the non-sticky doughs of the remix dough stickiness differed significantly from the very, very sticky doughs for the SDS-sedimentation volume, farinograph band width at 5 min after peak, mixograph energy after peak and mixograph slope after peak.

The dough stickiness of the remix stage showed a greater degree of

association to the quality parameters than the dough stickiness of the first mix. Most of the quality parameters varied according to the different levels of remix dough stickiness. As the remix dough stickiness increased, overall quality decreased. The farinograph development time, stability, departure time, time to breakdown, mixograph development time, energy to peak, band width energy and the remix loaf volume generally decreased as the degree of stickiness increased. The results of this study agreed with that of Dhaliwal and MacRitchie (1990) by showing a decrease in mixograph strength with increased dough stickiness. In contrast, Martin and Stewart (1986) found no relationship between mixograph data and dough stickiness. For the extensigraph resistance and the ratio of resistance to extension at 45 min and 135 min, the first three stickiness classes of the remix did not differ significantly from each other but were significantly different from the very sticky and the very, very sticky dough classes. The last two classes of the remix dough stickiness (very sticky and very, very sticky) were significantly different from each other. Hence, this confirmed the findings of Noguchi *et al.* (1976) that doughs with increased stickiness had a reduced ratio of resistance to extension.

In general, very sticky doughs were poor in breadmaking quality as indicated by their poor gluten quality (SDS- and Zeleny-sedimentation volume) and weak dough strength. The latter characteristic was observed from the farinograph parameters (development time, mixing tolerance index, arrival time, stability, departure time, time to breakdown and band width at 5 min after peak) and from the mixograph parameters (development, energy to peak and after peak, slope to peak and after peak, total energy, band width energy, band width at 2 min after peak). In addition, the extensigraph resistance and the ratio of resistance to extension were low and loaf volume was small for very sticky samples.

3. Rank Correlation of Stickiness to Quality Characteristics

Rank correlation of the dough stickiness of the first mix and the remix stages to the quality parameters was performed (Table 14a-b).

Results supported the previous findings by showing the negative relationships between the dough stickiness at the two mixing stages and certain parameters of the farinograph, mixograph, extensigraph and the remix bake. Dough stickiness at the first mix of the remix bake was very highly significant correlated ($|r| > 0.5$, $P = 0.001$) to the ratio of resistance to extension at 45 min and the remix dough stickiness. Only the remix dough stickiness was very highly significant correlated ($|r| > 0.5$, $P = 0.001$) to farinograph total breakdown time and the ratio of resistance to extension at 135 min. There were very highly significant correlations ($|r| > 0.5$, $P = 0.001$) between dough stickiness at both mixing stages and farinograph properties (development time, stability, departure time), mixograph properties (development time, energy to peak, band width energy), extensigraph resistance at both time periods and the remix loaf volume. The predictive capability of quality characteristics to evaluate dough stickiness would be low, since none of the correlation values of the quality parameters were greater than 0.9.

TABLE 14a. Rank Correlation of Dough Stickiness and Physical, Chemical and Farinograph Properties

	Physical, Chemical and Farinograph Properties[b]																
Dough Stickiness[a]	TWT	TKWT	GRT	FLY	PROT	ASH	FN	SDS	ZS	FAB	DDT	MTI	ART	STA	DEP	TBD	FW
FSTICK (n = 156)	-.024NS	.110NS	.279***	-.339***	-.124NS	.093NS	-.465***	-.154NS	-.151NS	-.008NS	-.504***	.400***	-.199*	-.590***	-.554***	-.484***	-.210**
SSTICK (n = 156)	-.006NS	.152NS	.285***	-.435***	-.120NS	.075NS	-.342***	-.305***	-.291***	.090NS	-.516***	.395***	-.160*	-.609***	-.564***	-.510***	-.324***

[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); SDS = sodium dodecyl sulfate-sedimentation volume (ml); ZS = Zeleny-sedimentation volume (ml); FAB = water absorption (%); DDT = dough development time (min); MTI = mixing tolerance index (Brabender Unit); ART = arrival time (min); STA = stability (min); DEP = departure time (min); TBD = time to breakdown (min); FW = band width at 5 min after peak (cm).
[b] *, P = 0.05; **, P = 0.01; ***, P = 0.001; NS, non-significant.

TABLE 14b. Rank Correlation of Dough Stickiness and Mixograph, Extensigraph and Breadmaking Properties

	Mixograph, Extensigraph and Breadmaking Properties[b]																	
Dough Stickiness[a]	MDT	PKH	ETP	EAP	FMS	PBW	SAP	TEG	BWE	BWD	R	E	R/E	R'	E'	R/E'	FSTICK	SSTICK	RLV
FSTICK (n=156)	-.562***	-.003NS	-.549***	.242**	.199*	.050NS	.316***	-.134NS	-.509***	-.343***	-.610***	-.172*	-.513***	-.593***	-.143NS	-.491***	----	.533***	-.507***
SSTICK (n=156)	-.651***	.126NS	-.594***	.434***	.391***	.079NS	.423***	.042NS	-.541***	-.314***	-.649***	-.291***	-.430***	-.694***	-.183*	-.522***	.533***	----	-.637***

[a] MDT = mixing development time (min); PKH = peak height (Nm); ETP = energy to peak (Nm); EAP = energy after peak (Nm); FMS = first minute slope to peak (Nm/min); PBW = peak band width (Nm); SAP = first minute slope after peak (Nm/min); TEG = total energy (Nm); BWE = band width energy (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, non-significant.

V. GENERAL DISCUSSION

Polyacrylamide gel electrophoresis and monoclonal antibody assay were fast and effective methods to identify the presence of the 1BL/1RS translocation. In this study, all the samples of a supposedly normal line, 8417-AJ05C, were discarded since they were found to be a 50:50 mixture of 1BL/1RS wheat and normal wheat. The identity of the remaining thirteen lines was confirmed.

Very little variability in overall HMW glutenin subunits encoded by chromosomes 1B and 1D was found between the 1BL/1RS wheats and the normal wheats. The major difference was in the alleles encoded by chromosome 1A. The most common 1A allele in the 1BL/1RS wheats was the poor quality null allele whereas in the normal wheats, subunit 1 was found in the highest frequency. As a consequence, the 1BL/1RS group had lower Glu-1 scores than the control group which indicated potentially poorer breadmaking quality.

The cultivars were evaluated individually for milling and baking quality. Statistical analyses were performed with two main objectives. Firstly, cultivars were compared to identify specific similarities and differences in quality between them, whether or not the 1BL/1RS translocation was present. Secondly, data were combined and the quality of 1BL/1RS group was compared to that of the control group to identify general differences between them.

Of the thirteen cultivars, the control wheat, 8417-AV06D, was most similar in overall milling and baking quality to the Canada Western Red Spring wheat standard, Neepawa. None of the 1BL/1RS translocation wheats fit into the Canada Western Red Spring class; their quality was significantly poorer than Neepawa.

The Canada Prairie Spring class was represented in this study by the control cultivars Biggar, Oslo and Genesis. The 1BL/1RS lines 8416-Q06E,

8417-BJ03A and 8417-BJ03D were very similar in quality to Biggar. Their overall milling, chemical, rheological and baking properties would make them suitable for the Canada Prairie Spring wheat class.

Environment had a significant effect on the majority of quality characteristics that were measured for each of the 1BL/1RS and control wheats. Remix dough stickiness was one characteristic that was unaffected by environment indicating that this property was dependent largely on cultivar differences. This makes the remix dough stickiness an effective test to use to evaluate and compare cultivars grown in any environment.

When the group (1BL/1RS and control) comparisons were performed, it was found that environment rather than group differences produced the variation in flour yield, farinograph absorption, dough development time, and mixograph development time, energy to peak, slope after peak and band width energy. Environmental conditions had no effect on remix dough stickiness. The significantly greater remix dough stickiness shown by the 1BL/1RS group as compared to the control group was due exclusively to the genotypes. The majority of the measured quality characteristics were affected significantly by group differences.

The 1BL/1RS group was characterized by significantly denser and larger kernels than the control group. In addition, the flour had significantly lower protein content, higher ash content, weaker gluten, weaker dough mixing properties, less extensibility and resistance to extension, increased remix stickiness and lower loaf volume than that of the control group.

The relationship between the dough stickiness class and the measured quality characteristics was examined. Dough stickiness of the remix stage was associated with greater changes in quality characteristics than dough stickiness measured at the first mix stage. As the degree of stickiness increased, overall breadmaking quality decreased. Very, very sticky doughs were characterized by poor gluten quality, weak dough mixing strength, reduced resistance to extension and low loaf volume. Very highly

significant negative correlations between dough stickiness and quality characteristics were noted, specifically, with dough mixing strength and loaf volume. The correlation values were not large enough to permit the use of quality parameters as a predictive test for dough stickiness.

VI. CONTRIBUTIONS TO KNOWLEDGE AND RECOMMENDATIONS

1. Polyacrylamide gel electrophoresis and monoclonal antibody assay were two techniques that were effective in identifying the 1BL/1RS translocation in wheat.

2. The 1BL/1RS wheats used in this study generally had a higher frequency of HMW glutenin subunits that are known to be associated with poor breadmaking quality than the control wheats.

3. Generally, the 1BL/1RS wheats were poorer in breadmaking quality than the control wheats as determined by physical, biochemical, rheological and baking characteristics. The different genetic backgrounds of the individual cultivars may or may not have contributed to these differences. The cultivars used in this study were a random sampling of 1BL/1RS wheats. Isogenic lines, with and without the 1BL/1RS translocation, would be the best material to study the effects on quality.

4. None of the 1BL/1RS cultivars had quality characteristics that would make them suitable 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.

5. Variations in most of the measured quality characteristics were caused by both the environment and the cultivars. Cultivar by environment interactions were relatively minor.

6. Variation in remix dough stickiness was caused exclusively by cultivar differences rather than environments. This finding requires confirmation in a greater number of varied environments. Since the dough stickiness evaluation used in this study was largely subjective, an objective measurement of dough stickiness utilizing an Instron Universal

Testing Instrument should be considered in future studies.

7. Very, very sticky doughs were associated with poor gluten quality, weak dough mixing strength, reduced resistance to extension and low loaf volume. Further investigation should examine the effect of amount of endogenous enzyme (protease, amylase and lipase) and starch damage on dough stickiness.

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VIII. APPENDICES

APPENDIX I. The SAS Statements for Analysis of Variance of Quality Parameters in Each Environment (TABLE 5)

```
LIBNAME PERM '[DFENN]';
PROC SORT DATA=PERM.CREATE OUT=TEMP;BY LOCYR;
PROC SUMMARY NWAY DATA=TEMP;BY LOCYR;
VAR TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW MDT
PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV;
CLASS VARIETY GROUP;
OUTPUT OUT=MEAN=;
PROC PRINT DATA=MEAN;
TITLE 'MEANS';
PROC SUMMARY DATA=MEAN;BY LOCYR;
VAR TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW MDT
PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV;
OUTPUT OUT=RANGE=;
PROC PRINT DATA=RANGE;
TITLE 'RANGE OF MEANS';
PROC SORT DATA=PERM.CREATE OUT=TEMP;BY LOCYR;
PROC GLM OUTSTAT=OUTSTAT;BY LOCYR;
CLASS VARIETY REP;
MODEL TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW
MDT PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV=VARIETY REP;
MEANS VARIETY/LSD;
```

APPENDIX II. The SAS Output of Analysis of Variance of Flour Protein Content at Swift Current in 1989 (TABLE 5)

MEANS

OBS	LOCYR	VARIETY	GROUP	_TYPE_	_FREQ_	PROT
1	S89	8416-BZ10A	SPEC	3	4	14.375
2	S89	8416-BZ10C	SPEC	3	4	14.625
3	S89	8416-Q06A	SPEC	3	4	12.875
4	S89	8416-Q06E	SPEC	3	4	12.600
5	S89	8417-AV06D	NORM	3	4	14.400
6	S89	8417-BJ03A	SPEC	3	4	13.450
7	S89	8417-BJ03D	SPEC	3	4	13.925
8	S89	BR 23	SPEC	3	4	12.350
9	S89	CEP 14	NORM	3	4	14.400
10	S89	HY 355	NORM	3	4	13.100
11	S89	HY 368	NORM	3	4	13.925
12	S89	NP	NORM	3	4	14.625
13	S89	OSLO	NORM	3	4	13.975

RANGE OF MEANS

OBS	LOCYR	_TYPE_	_FREQ_	PROT
1	S89	0	13	2.275

----------LOCYR=S89----------

General Linear Models Procedure

Dependent Variable: PROT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	36.47942308	2.43196154	8.91	0.0001
Error	36	9.82576923	0.27293803		
Corrected Total	51	46.30519231			

R-Square	C.V.	Root MSE	PROT Mean
0.787804	3.802184	0.52243472	13.74038462

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VARIETY	12	29.75269231	2.47939103	9.08	0.0001
REP	3	6.72673077	2.24224359	8.22	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
VARIETY	12	29.75269231	2.47939103	9.08	0.0001
REP	3	6.72673077	2.24224359	8.22	0.0003

APPENDIX II (cont). The SAS Output of Analysis of Variance of Flour Protein Content at Swift Current in 1989 (TABLE 5)

----------LOCYR=S89----------

General Linear Models Procedure
T tests (LSD) for variable: PROTEIN

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 36 MSE= 0.272938
Critical Value of T= 2.03
Least Significant Difference= 0.7492

Means with the same letter are not significantly different.

T Grouping			Mean	N	VARIETY
	A		14.6250	4	8416-BZ10C
	A				
	A		14.6250	4	NP
	A				
	A		14.4000	4	CEP 14
	A				
	A		14.4000	4	8417-AV06D
	A				
	A		14.3750	4	8416-BZ10A
	A				
B	A		13.9750	4	OSLO
B	A				
B	A		13.9250	4	8417-BJ03D
B	A				
B	A		13.9250	4	HY 368
B					
B	C		13.4500	4	8417-BJ03A
	C				
D	C		13.1000	4	HY 355
D	C				
D	C	E	12.8750	4	8416-Q06A
D		E			
D		E	12.6000	4	8416-Q06E
		E			
		E	12.3500	4	BR 23

APPENDIX III. The SAS Statements for Analysis of Variance of Quality Parameters Over Environments (TABLE 6)

```
LIBNAME PERM '[DFENN]';
PROC SORT DATA=PERM.CREATE OUT=TEMP;BY VARIETY; WHERE LOCYR NE 'S90';
PROC SUMMARY NWAY DATA=TEMP;BY VARIETY;
VAR TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW MDT
PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV;
OUTPUT OUT=MEAN MEAN=;
PROC PRINT DATA=MEAN;
TITLE 'MEANS';
PROC SUMMARY DATA=MEAN;
VAR TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW MDT
PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV;
OUTPUT OUT=RANGE RANGE=;
PROC PRINT DATA=RANGE;
TITLE 'RANGE OF MEANS';
PROC SORT DATA=PERM.CREATE;BY VARIETY;WHERE LOCYR NE 'S90';
PROC GLM OUTSTAT=OUTSTAT;
CLASS VARIETY REP;
MODEL TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW
MDT PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV=VARIETY REP;
MEANS VARIETY/LSD;
```

APPENDIX IV. The SAS Output Analysis of Variance of Flour Protein Content Over Environments (TABLE 6)

MEANS

OBS	VARIETY	_TYPE_	_FREQ_	PROT
1	8416-BZ10A	0	12	13.3167
2	8416-BZ10C	0	12	13.3583
3	8416-Q06A	0	12	12.6250
4	8416-Q06E	0	12	12.1500
5	8417-AV06D	0	12	13.4583
6	8417-BJ03A	0	12	12.1917
7	8417-BJ03D	0	12	12.4417
8	BR 23	0	12	11.5500
9	CEP 14	0	12	12.4500
10	HY 355	0	12	11.7083
11	HY 368	0	12	12.3583
12	NP	0	12	14.2167
13	OSLO	0	12	12.8333

RANGE OF MEANS

OBS	_TYPE_	_FREQ_	PROT
1	0	13	2.66667

General Linear Models Procedure

Dependent Variable: PROT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	87.02006410	5.80133761	5.21	0.0001
Error	140	155.78987179	1.11278480		
Corrected Total	155	242.80993590			

R-Square	C.V.	Root MSE	PROT Mean
0.358388	8.328470	1.05488615	12.66602564

Source	DF	Type I SS	Mean Square	F Value	Pr > F
VARIETY	12	81.72243590	6.81020299	6.12	0.0001
REP	3	5.29762821	1.76587607	1.59	0.1953

Source	DF	Type III SS	Mean Square	F Value	Pr > F
VARIETY	12	81.72243590	6.81020299	6.12	0.0001
REP	3	5.29762821	1.76587607	1.59	0.1953

APPENDIX IV (cont). The SAS Output of Analysis of Variance of Flour Protein Content Over Environments (TABLE 6)

General Linear Models Procedure
T tests (LSD) for variable: PROT

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 140 MSE= 1.112785
Critical Value of T= 1.98
Least Significant Difference= 0.8514

Means with the same letter are not significantly different.

T Grouping	Mean	N	VARIETY
A	14.2167	12	NP
A			
B A	13.4583	12	8417-AV06D
B			
B	13.3583	12	8416-BZ10C
B			
B	13.3167	12	8416-BZ10A
B			
B C	12.8333	12	OSLO
B C			
B C	12.6250	12	8416-Q06A
C			
D C	12.4500	12	CEP 14
D C			
D C	12.4417	12	8417-BJ03D
D C			
D C E	12.3583	12	HY 368
D C E			
D C E	12.1917	12	8417-BJ03A
D C E			
D C E	12.1500	12	8416-Q06E
D E			
D E	11.7083	12	HY 355
E			
E	11.5500	12	BR 23

APPENDIX V. The SAS Statements of Analysis of Variance of Environments (TABLE 7)

```
LIBNAME PERM '[DFENN]';
PROC SUMMARY NWAY DATA=PERM.CREATE;WHERE LOCYR NE 'S90';
VAR TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW MDT
PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV;
CLASS LOCYR;
OUTPUT OUT=MEAN MEAN=;
PROC PRINT DATA=MEAN;
TITLE 'MEANS';
PROC SUMMARY DATA=MEAN;
VAR TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW MDT
PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV;
OUTPUT OUT=RANGE RANGE=;
PROC PRINT DATA=RANGE;
TITLE 'RANGE OF MEANS';
PROC SORT DATA=PERM.CREATE OUT=TEMP;BY LOCYR;WHERE LOCYR NE 'S90';
PROC GLM OUTSTAT=OUTSTAT;
CLASS LOCYR REP;
MODEL TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW
MDT PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV*/=LOCYR REP(LOCYR);
MEANS LOCYR/LSD;
```

APPENDIX VI. The SAS Output of Analysis of Variance of Environments (TABLE 7)

MEANS

OBS	LOCYR	_TYPE_	_FREQ_	PROT
1	S89	1	52	13.7404
2	W89	1	52	12.4596
3	W90	1	52	11.7981

RANGE OF MEANS

OBS	_TYPE_	_FREQ_	PROT
1	0	3	1.94231

General Linear Models Procedure

Dependent Variable: PROT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	112.32532051	10.21139277	11.27	0.0001
Error	144	130.48461538	0.90614316		
Corrected Total	155	242.80993590			

R-Square	C.V.	Root MSE	PROT Mean
0.462606	7.515503	0.95191552	12.66602564

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCYR	2	101.40974359	50.70487179	55.96	0.0001
REP(LOCYR)	9	10.91557692	1.21284188	1.34	0.2221

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LOCYR	2	101.40974359	50.70487179	55.96	0.0001
REP(LOCYR)	9	10.91557692	1.21284188	1.34	0.2221

General Linear Models Procedure
T tests (LSD) for variable: PROT

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 144 MSE= 0.906143
Critical Value of T= 1.98
Least Significant Difference= 0.369

APPENDIX VI (cont). The SAS Output of Analysis of Variance of Environments (TABLE 7)

Means with the same letter are not significantly different.

T Grouping	Mean	N	LOCYR
A	13.7404	52	S89
B	12.4596	52	W89
C	11.7981	52	W90

APPENDIX VII. The SAS Statements of Analysis of Variance of Quality Parameters of Cultivars (TABLE 8)

```
LIBNAME PERM '[DFENN]';
PROC GLM DATA=PERM.CREATE;WHERE LOCYR NE 'S90';
CLASS LOCYR VARIETY REP;
MODEL TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD
FW MDT PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL
EXSR_L FSTICK SSTICK RLV=LOCYR REP(LOCYR) VARIETY LOCYR*VARIETY;
TEST H=LOCYR E=REP(LOCYR);
RANDOM REP(LOCYR)/TEST;
```

APPENDIX VIII. The SAS Statements of Analysis of Variance of Flour Protein Content of Cultivars (TABLE 8)

General Linear Models Procedure

Dependent Variable: PROT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	47	223.10301282	4.74687261	26.01	0.0001
Error	108	19.70692308	0.18247151		
Corrected Total	155	242.80993590			

R-Square	C.V.	Root MSE	PROT Mean
0.918838	3.372540	0.42716684	12.66602564

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCYR	2	101.40974359	50.70487179	277.88	0.0001
REP(LOCYR)	9	10.91557692	1.21284188	6.65	0.0001
VARIETY	12	81.72243590	6.81020299	37.32	0.0001
LOCYR*VARIETY	24	29.05525641	1.21063568	6.63	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LOCYR	2	101.40974359	50.70487179	277.88	0.0001
REP(LOCYR)	9	10.91557692	1.21284188	6.65	0.0001
VARIETY	12	81.72243590	6.81020299	37.32	0.0001
LOCYR*VARIETY	24	29.05525641	1.21063568	6.63	0.0001

Tests of Hypotheses using the Type III MS for REP(LOCYR) as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LOCYR	2	101.40974359	50.70487179	41.81	0.0001

General Linear Models Procedure

Source	Type III Expected Mean Square
LOCYR	Var(Error) + 13 Var(REP(LOCYR)) + Q(LOCYR,LOCYR*VARIETY)
REP(LOCYR)	Var(Error) + 13 Var(REP(LOCYR))
VARIETY	Var(Error) + Q(VARIETY,LOCYR*VARIETY)
LOCYR*VARIETY	Var(Error) + Q(LOCYR*VARIETY)

APPENDIX VIII (cont). The SAS Statements of Analysis of Variance of Flour Protein Content of Cultivars (TABLE 8)

General Linear Models Procedure
Tests of Hypotheses for Mixed Model Analysis of Variance

Dependent Variable: PROT

Source: LOCYR *
Error: MS(REP(LOCYR))

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
2	50.704871795	9	1.2128418803	41.807	0.0001

* - This test assumes one or more other fixed effects are zero.

Source: REP(LOCYR)
Error: MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
9	1.2128418803	108	0.18247151	6.647	0.0001

Source: VARIETY *
Error: MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
12	6.8102029915	108	0.18247151	37.322	0.0001

* - This test assumes one or more other fixed effects are zero.

Source: LOCYR*VARIETY
Error: MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
24	1.2106356838	108	0.18247151	6.635	0.0001

APPENDIX IX. The SAS Statements for Group Analysis of Variance of Quality Parameters in Each Environment (TABLE 9)

```
LIBNAME PERM '[DFENN]';
PROC SORT DATA=PERM.CREATE OUT=TEMP;BY LOCYR;
PROC GLM DATA=TEMP;
CLASS GROUP VARIETY REP;
MODEL TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP
TBD FW MDT PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL
EXSR_L FSTICK SSTICK RLV=GROUP VARIETY(GROUP) REP;
```

APPENDIX X. The SAS Output for Group Analysis of Variance of Flour Protein Content at Swift Current in 1989 (TABLE 9)

General Linear Models Procedure

Dependent Variable: PROT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	36.47942308	2.43196154	8.91	0.0001
Error	36	9.82576923	0.27293803		
Corrected Total	51	46.30519231			

R-Square	C.V.	Root MSE	PROT Mean
0.787804	3.802184	0.52243472	13.74038462

Source	DF	Type I SS	Mean Square	F Value	Pr > F
GROUP	1	4.86703755	4.86703755	17.83	0.0002
VARIETY(GROUP)	11	24.88565476	2.26233225	8.29	0.0001
REP	3	6.72673077	2.24224359	8.22	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	1	4.86703755	4.86703755	17.83	0.0002
VARIETY(GROUP)	11	24.88565476	2.26233225	8.29	0.0001
REP	3	6.72673077	2.24224359	8.22	0.0003

APPENDIX XI. The SAS Statements of Analysis of Variance of Quality Parameters of Groups (TABLE 10)

```
LIBNAME PERM '[DFENN]';
PROC GLM DATA=PERM.CREATE;WHERE LOCYR NE 'S90';
CLASS LOCYR GROUP VARIETY REP;
MODEL TWT TKWT GRT FLY PROT ASH FN SDS ZS FAB DDT MTI ART STA DEP TBD FW
MDT PKH ETP EAP FMS PBW SAP TEG BWE BWD EXFR EXFL EXFR_L EXSR EXSL EXSR_L
FSTICK SSTICK RLV=LOCYR REP(LOCYR) GROUP GROUP*LOCYR;
TEST H=LOCYR E=REP(LOCYR);
RANDOM REP(LOCYR)/TEST;
```

APPENDIX XII. The SAS Output of Analysis of Variance of Flour Protein Content of Groups (TABLE 10)

General Linear Models Procedure

Dependent Variable: PROT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	120.25438187	8.58959870	9.88	0.0001
Error	141	122.55555403	0.86918833		
Corrected Total	155	242.80993590			

R-Square	C.V.	Root MSE	PROT Mean
0.495261	7.360657	0.93230270	12.66602564

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCYR	2	101.40974359	50.70487179	58.34	0.0001
REP(LOCYR)	9	10.91557692	1.21284188	1.40	0.1956
GROUP	1	3.93166209	3.93166209	4.52	0.0352
LOCYR*GROUP	2	3.99739927	1.99869963	2.30	0.1041

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LOCYR	2	103.51124542	51.75562271	59.54	0.0001
REP(LOCYR)	9	10.91557692	1.21284188	1.40	0.1956
GROUP	1	3.93166209	3.93166209	4.52	0.0352
LOCYR*GROUP	2	3.99739927	1.99869963	2.30	0.1041

Tests of Hypotheses using the Type III MS for REP(LOCYR) as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LOCYR	2	103.51124542	51.75562271	42.67	0.0001

General Linear Models Procedure

Source	Type III Expected Mean Square
LOCYR	Var(Error) + 12.923 Var(REP(LOCYR)) + Q(LOCYR,LOCYR*GROUP)
REP(LOCYR)	Var(Error) + 13 Var(REP(LOCYR))
GROUP	Var(Error) + Q(GROUP,LOCYR*GROUP)
LOCYR*GROUP	Var(Error) + Q(LOCYR*GROUP)

APPENDIX XII (cont). The SAS Output of Analysis of Variance of Flour Protein Content of Groups (TABLE 10)

General Linear Models Procedure
Tests of Hypotheses for Mixed Model Analysis of Variance

Dependent Variable: PROT

Source: LOCYR *
Error: 0.9941*MS(REP(LOCYR)) + 0.0059*MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
2	51.755622711	9.08	1.2108084274	42.745	0.0001

* - This test assumes one or more other fixed effects are zero.

Source: REP(LOCYR)
Error: MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
9	1.2128418803	141	0.8691883264	1.395	0.1956

Source: GROUP *
Error: MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
1	3.9316620879	141	0.8691883264	4.523	0.0352

* - This test assumes one or more other fixed effects are zero.

Source: LOCYR*GROUP
Error: MS(Error)

DF	Type III MS	Denominator DF	Denominator MS	F Value	Pr > F
2	1.9986996337	141	0.8691883264	2.300	0.1041