FLOUR QUALITY AND DOUGH STICKINESS OF SOFT RED WINTER WHEAT LINES WITH AND WITHOUT 1B/1R TRANSLOCATIONS

by

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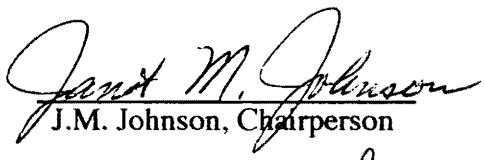

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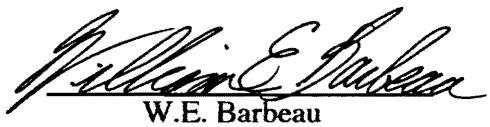

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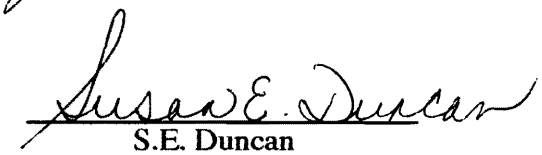

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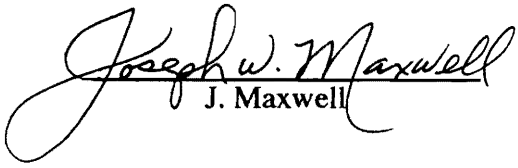

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(ABSTRACT)

Wheat (*Triticum aestivum* L.) is one of the major cereals of the world. Farmers must produce wheat with good yield and quality to meet the high demands for wheat flour. To reduce disease and increase wheat yield, cultivars have been developed by replacing the short arm of chromosome 1B of wheat with the short arm of the 1R chromosome from rye (*Secale cereale* L.). This wheat-rye translocation, 1B/1R, carries linked genes which makes these wheat cultivars more disease resistant and higher yielding. Unfortunately, the 1B/1R translocation in hard wheats has been shown to produce undesirable characteristics such as dough stickiness and reduced mixing tolerance. Many promising wheat lines have been developed by crossbreeding 1B/1R lines with soft wheat in hopes of producing a 1B/1R soft wheat of good quality for use in soft wheat products. The purpose of this research was to determine the end use quality of flours from soft red winter wheats possessing 1B/1R.

Fourteen soft wheat varieties (7 without 1B/1R and 7 with 1B/1R) grown in two Virginia locations, Warsaw and Blacksburg, were assessed for flour quality and dough stickiness. Four pairs of the experimental wheats were sister lines. Flour quality was evaluated by means of protein content, farinograph analysis, cookie spread and protein analysis. Dough stickiness was measured using the "Schwarzlaff-Shephard Dough Stripping Method", specially designed for this study. It is the first method of its kind to measure dough stickiness quantitatively. Results indicated that the 1B/1R translocation,

in general, had no adverse effect on flour quality and dough stickiness of the experimental wheats and even improved mixing tolerance and stability of the wheat flour doughs. The results of the study indicate that flours of 1B/1R wheats can be used in commercial soft wheat bakery formulas.

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CHAPTER 1

INTRODUCTION AND PURPOSE

Wheat is one of the major cereals of the world. It is best grown in temperate climates as characteristic of countries such as the United States, Canada, Argentina, Australia, Punjab, and the USSR (Rogers, 1990). The primary use of wheat is for food production. Wheat flour is one of the main constituents in products such as crackers, cookies, cakes, pasta and breads. Bread, especially, is one of the most common universal food products consumed today. Farmers must produce wheat with good yield and quality to meet the high demands for wheat flour. Often, environmental conditions such as drought and flooding, insects, and disease can reduce yield and quality of wheat.

To help increase wheat yields some wheat cultivars have been developed by replacing the short arm of chromosome 1B of wheat with the short arm of the 1R chromosome of rye. This wheat-rye translocation, 1B/1R, carries linked genes which makes these wheat cultivars more disease resistant (e.g., stem, leaf and stripe rusts, and powdery mildew) (Dhaliwal et al., 1987; Dhaliwal et al., 1988; Moonen and Zeven, 1984) and higher yielding (Carver and Rayburn, 1994; Dhaliwal et al., 1988; Graybosch et al., 1993). Due to these positive attributes, 1B/1R wheat cultivars are now being widely used in wheat breeding programs in many countries (Biliaderis et al., 1992; Dhaliwal et al., 1987; Dhaliwal et al., 1988; Graybosch et al., 1993; Martin and Stewart, 1986; Moonen and Zeven, 1984; Pena et al., 1990; Zellar et al., 1982). However, such wheat-rye cultivars may not be highly suitable for bread manufacturing.

The 1B/1R translocation has been shown to have a detrimental effect on breadmaking quality (Law and Payne, 1983; Moonen and Zeven, 1984; Zeller et al., 1982). Many bread manufacturers claim that the wheat-rye cultivars tend to produce a

sticky dough at high mixing speeds and lack mixing tolerance as well. Research on wheat-rye cultivars (Dhaliwal et al., 1990; Martin and Stewart, 1986; Zeller et al., 1982) also found the 1B/1R translocations to produce undesirable rheological properties such as reduced dough strength and lack of tolerance to overmixing, increased water absorption, and a sticky dough when mixed at high speeds. A sticky dough is unsuitable for the bread manufacturer (Dhaliwal et al., 1990). Mechanical processing can be complicated in many commercial baking applications, especially with modern equipment working at high speeds (Martin and Stewart, 1986; Zeller et al., 1982). Due to inferior breadmaking quality of the 1B/1R lines, they have not been released in Australia and parts of Europe for use in bread production (Henry et al., 1989).

In response to the poor breadmaking quality of the 1B/1R lines, research was conducted to determine the causes of the sticky dough phenomenon. High molecular weight (HMW) proteins (Moonen and Zeven, 1984), differences in protein content (Dhaliwal and MacRitchie, 1990; Dhaliwal et al., 1988; Graybosch et al., 1990; Graybosch et al., 1993), and pentosan content (Biliaderis et al., 1992; Dhaliwal et al., 1988; Henry et al., 1989) were investigated as to what, if any, relation they have regarding dough stickiness. Surprisingly, no major differences in protein and pentosan contents have been found between sister lines of wheat with and without 1B/1R except that the 1B/1R wheats have a shift in protein composition (Dhaliwal and MacRitchie, 1990). Past and recent research have mainly dealt with hard wheats since most of the initial 1B/1R lines were of a hard wheat background and were known to produce undesirable dough properties. However, many promising wheat lines have been developed by crossbreeding 1B/1R lines with soft wheats (Griffey, 1994) in hopes of producing a 1B/1R soft wheat variety of good quality for use in soft wheat products such as cookies. The idea is to reintroduce most of the soft wheat characteristics needed to

produce a good quality dough in the 1B/1R translocation wheats and also realize the advantages of yield and disease resistance.

The purpose of this research was to determine the end use quality of flours from soft red winter wheats possessing or lacking the 1B/1R translocation by testing several rheological properties of the representative doughs and the biological variations possibly associated with dough stickiness. In fulfillment of the purpose, the following objectives were implemented: 1) to determine differences in rheological properties of experimental flours; 2) to determine wheat and flour protein content of experimental wheats; 3) to determine variations in protein composition; and 4) to develop a new method for testing dough stickiness.

CHAPTER 2

REVIEW OF LITERATURE

2.00 WHEAT-RYE TRANSLOCATIONS

The genetic composition of common bread wheat (*Triticum aestivum* L.) includes 21 chromosome pairs that are arranged in 3 genomic groups of seven designated as A, B, and D (Dhaliwal et al., 1987). Each chromosome has a long and short arm. Rye (*Secale cereale* L.), however, has only 1 group (R) of seven chromosomes. So, what genetic composition do 1B/1R substitution lines have? As the letters indicate, the 1B chromosome of wheat has been replaced by the 1R chromosome of rye (1B/1R substitution) wherein the short arm (1B) of wheat has been replaced with the short arm (1R) of rye (Dhaliwal et al., 1987). These translocation lines are denoted as 1RS·1BL.

The introduction of the 1R chromosome into wheat results in wheat varieties that are more disease resistant. The 1B/1R translocation lines also have been found to have other different characteristics compared to normal wheat varieties, some of which are positive and some of which are negative. Test weight and 1,000-kernel weight have been found to be higher for 1B/1R wheats (Fenn et al., 1994; Villareal et al., 1991). However, these findings are inconsistent with those of Carver and Rayburn (1994) and Dhaliwal et al. (1987) who found no difference or deleterious effect on 1000-grain weight or test weight. It has also been determined that 1R has no significant effect on kernel hardness (Dhaliwal et al., 1987; Fenn et al., 1994) and farinograph water absorption (Dhaliwal et al., 1987; Fenn et al., 1994). Inconsistent findings have been found in regard to dough development time for Fenn et al. (1994) found no effect due to the 1R chromosome, but Dhaliwal et al. (1987) found a significantly reduced dough development time. Variations in findings can be attributed to different 1B/1R varieties evaluated and varying growth

conditions. Another interesting finding by Dhaliwal et al. (1987), is that soft wheats with 1B/1R showed no significant reduction in dough development time. In addition to reduced dough development time for some 1B/1R varieties, low protein contents have also been found (Fenn et al., 1994), whereas others showed no deleterious effect on grain or flour protein (Dhaliwal et al., 1987). The most negative or problematic characteristic associated with 1B/1R wheats is dough stickiness, as mentioned earlier. However, not all 1B/1R lines exhibit a high degree of dough stickiness (Fenn et al., 1994).

2.01 WHEAT PROTEINS

Proteins are naturally occurring polymers composed of amino acids linked together by peptide bonds. Wheat contains four types of proteins known as the albumins, globulins, prolamins and glutelins, which are usually classified according to their solubility (Hoseney, 1986). In cereals, the albumins and globulins are concentrated in the aleurone cells, bran, germ and small amounts in the endosperm, and contain most of the active proteins or enzymes (Hoseney, 1986). The prolamins and glutelins are storage proteins found in the endosperm. The storage proteins of wheat are unique because they contribute to the dough forming capabilities of the flour when wetted or hydrated with water. This hydrated flour mass is a complex network called gluten. The proteins responsible for gluten development are the gliadins (prolamins) and glutenins (glutelins). Gliadins provide extensibility for they are compact due to intramolecular disulfide bonding. Whereas, the glutenins provide cohesiveness or elasticity for their molecules are more extended and are tightly associated due to intermolecular disulfide bonding (Penfield and Campbell, 1990a). Together, the proteins give the dough viscoelasticity. In wheat, the gliadins and glutenins are usually of equal proportion. Hard wheats have a greater potential for gluten development compared to soft wheats because of their higher protein levels. Therefore, the doughs of soft wheats are not as viscoelastic as those of

hard wheats. The 1B/1R hard wheats have a similar protein composition to wheats without 1B/1R except that there is a shift in the ratio of the proteins, lower ratio of glutenin proteins to gliadin, albumin and globulin proteins due to the 1R short arm chromosome of rye replacing the short arm chromosome 1B of wheat (Dhaliwal and MacRitchie, 1990). The shift in the protein ratio may be one of the factors causing the hard 1B/1R wheats to have different dough handling properties such as increase in dough stickiness.

2.02 PENTOSANS

Non-starch polysaccharides are comprised of water soluble and insoluble components found in plant cell walls. In cereals the non-starch polysaccharides, pentosans and ß-glucans, are major constituents of the fiber - especially in the endosperm (Henry, 1987). Wheat and rye predominantly contain pentosans in the endosperm, whereas, barley and oats have mostly ß-glucans (Henry, 1987). The pentosan and ß-glucan content of rye is greater than that of wheat (Girhammer and Nair, 1992; Henry, 1987; Henry et al., 1989).

Pentosans are polymers of pentoses, are water soluble, and consist of linear arabinoxylans and highly branched arabinogalactans. The linear arabinoxylans are bound to small amounts of protein and contain D-xylose units which are linked ß-(1-4) glycosidically and in turn a long xylan backbone chain is formed (Girhammer and Nair, 1992). Arabinogalatans consist of L-arabinose residues branched on galactan chain backbone (Izydorczyk et al., 1991). Rye endosperm predominantly contains arabinoxylans, whereas wheat has more arabinogalactans. Biliaderis et al. (1992) found 1B/1R translocation lines to contain substantial amounts of galactose, which the researchers attributed to the arabinogalactan component. Therefore, the introduction of

the rye chromosome apparently had no effect on the composition of water soluble pentosans (Biliaderis et al., 1992).

2.03 DOUGH STICKINESS (1B/1R lines)

The introduction of rye chromosomes into wheat has been associated with reduced breadmaking quality - specifically reduced dough strength and dough stickiness (Martin and Stewart, 1986). The exact explanation for the dough stickiness phenomenon is inconclusive. Increased water absorption by 1B/1R lines was first suggested by Zellar et al. (1982) to be the cause of dough stickiness due to water soluble pentosans and proteins (Bilidarius et al., 1992). Pentosans, however, have been found to have no definite correlation to dough stickiness (Dhaliwal and MacRitchie, 1990; Dhaliwal et al., 1988; Henry et al., 1989; Martin and Stewart, 1986). Also, the ß-glucan proportion in a 1B/1R line was found to be within the range found in normal wheats and thus could not be a contributing factor in dough stickiness (Henry et al., 1989). High molecular weight (HMW) subunits of gluten have been associated with good bread making quality (Moonen et al., 1983; Payne et al., 1979; Payne et al., 1981). Moonen and Zeven (1984) found the 1B/1R translocation glutenin subunits common to those of wheat and, therefore, introduction of the rye HMW subunits into wheat cannot be held accountable for dough stickiness. The soluble fraction of gluten in 1B/1R lines has a lower ratio of polymeric (glutenin) proteins to monomeric (gliadin, albumin, and globulin) proteins (Dhaliwal and MacRitchie, 1990). The shift in protein composition can be attributed to (1) loss of low molecular weight (LMW) glutenin subunits (1B chromosome) and (2) an increase in monomeric secalins (1R - short arm) (Dhaliwal and MacRitchie, 1990; Dhaliwal et al., 1988), which has been associated with those 1B/1R lines producing sticky doughs (Dhaliwal and MacRitchie, 1990). Despite research indicating that 1B/1R lines are notorious for producing dough stickiness, Pena et al. (1990) found certain

cultivars grown in Australia to produce sticky doughs but the same lines grown in Mexico did not. This finding indicated that agronomic environments can also affect the flour quality of the 1B/1R translocation lines. Recently, Chen and Hoseney (1995) isolated and identified a compound found in the flour of 1B/1R translocation wheats which may in fact be the or a contributing factor to dough stickiness. The identified compound was ferulic acid linked with the carbohydrate hexose. To be conclusive regarding this compound in relation to dough stickiness, further research is needed in this area.

2.04 MEASUREMENT OF DOUGH STICKINESS

Dough stickiness has been associated with 1B/1R translocations and is considered an inferior breadmaking property. Various techniques have been utilized to measure dough stickiness among various 1B/1R translocation wheat lines and wheat cultivars. Methods have included hand kneading and hand assessing (Pena et al., 1990), adhesion to various surfaces - bowl, hand, between fingers, teflon rod and paper towel (Dhaliwal and MacRitchie, 1990), machine mixing and assessing by hand (Henry et al., 1989; Martin and Stewart, 1986), and instruments such as a Digital Gram Gauge model DFG2 and the Universal Instron Tester (Dhaliwal et al., 1990). However, all methods propose various problems including inconsistency and/or not separating tackiness or stickiness from viscoelasticity, as Dhaliwal and MacRitchie (1990) state "When a dough that exhibits stickiness is pulled by instruments, the force measured is a composite of an adhesive (surface) force and a bulk force required to stretch the dough pieces. The total force thus depends on the bulk rheological properties of the dough and it is usually not possible to separate the adhesive force".

2.05 FARINOGRAPH

The farinograph has become increasingly important in the food industry in regard to choosing the appropriate flour for a particular baked product based on the rheological properties of doughs. According to D'Appolonia and Kunerth (1984), "The farinograph curve gives two important physical properties of flour: the water absorption, i.e. - the amount of water required for a dough to reach a definite consistency, and a general profile of the mixing behavior of the dough (dough development time and stability) - all of which are good predictors of baking quality." Since the farinograph produces reproducible mixing, rheological differences can be determined due to flour type, ingredients, etc. For example, soft wheat and hard wheat flours have different rheological properties as well as other flours such as soy, rye, and other varieties due to the varying quantities of protein, starch, pentosans, etc. in each. The rheological properties of 1B/1R wheats have also been investigated by use of the farinograph (Dhaliwal et al., 1987; Fenn et al., 1994; Graybosch et al., 1990; Martin and Stewart, 1986). Martin and Stewart (1986) found 1B/1R lines (hard wheats) to be similar to their parents in dough development time, water absorption and dough stability. Dhaliwal et al., 1987 found an increase in water absorption and decrease in dough development time in some 1B/1R lines (hard wheats) and the opposite result for other 1B/1R derivatives. The researchers (Dhaliwal et al., 1987) found no change in dough development time in soft wheats due to the 1B/1R translocation. Fenn et al. (1994), on the other hand, found 1B/1R hard wheats to have shorter arrival and departure times, greater mixing tolerance, lower stability, and shorter time to breakdown. No difference was found in water absorption and dough development times between hard wheats with and without 1B/1R (Fenn et al., 1994). Graybosch et al. (1990) found the effects of the 1B/1R translocation on rheological properties and end-use quality to be highly dependent on genetic background.

Farinograph curves, also known as farinograms, are popular in determining the baking quality of flours by evaluating the representative doughs. Each flour sample produces a uniquely-shaped farinograph curve. By calculating various segments or parts of the curve, a comparison can be made between flour varieties for determining differences in rheological properties in regard to water absorption, dough development time, mixing tolerance and stability. First of all, water absorption indicates the amount of water needed to produce a specific consistency of the dough (maximum peak consistency). This is determined by titrating enough water into the flour being mixed so that the center of the band width should be at the 500 Brabender Units (BU) level of the farinograph curve. Many factors can contribute to varying water absorptions among different flours such as protein content, starch (especially damaged starch), pentosans and gluten strength (D'Appolonia and Kunerth, 1984).

Once the water absorption is determined, the experimental flour can then be evaluated by means of using the farinograph curve. By use of the curve, peak or dough development time can be determined by calculating the time interval from first addition of water to the point of maximum consistency. At this peak time an optimum dough for that particular flour sample is achieved. The mixing tolerance index (MTI) is a good indicator of flour quality. A high MTI indicates that the flour is weak and a low MTI indicates that the flour is strong (a good tolerance to mixing). Mixing tolerance index can be defined as: The difference, in Brabender Units, between the top of the curve at the peak and the top of the curve measured 5 minutes after the peak. In addition to the MTI, the mixing time stability (departure time (time at which the top of the curve leaves the 500 BU. line) minus peak time) can also be determined. Location of where the wheats was grown and crop variety can change the overall characteristics of the curve. During growth of the plant, the weather and soil conditions are contributing factors in affecting the protein content and quality, and thus indirectly affect the farinograph curve.

2.06 COOKIE SPREAD AND HEIGHT

Soft wheat flours of low protein content are superior for making cookies (Loving and Brenneis, 1981; Pyler, 1973). Excellent processing and machining qualities, and high cookie spread (if desired) are characteristic of doughs made with soft wheat flour and an overall quality of the end product which is attractive to the consumer (Loving and Brenneis, 1981). Great demand and high speed production requires uniform supplies of all ingredients in order to prevent significant amounts of off-quality cookies. To achieve consistent cookie spread, strict specifications or requirements are critical for uniform ingredients. To meet the specifications, various tests are carried out to determine and ensure quality. Flour quality, for example, can be determined by evaluating moisture content, protein content, ash content, viscosity and cookie spread, to name a few (Loving and Brenneis, 1981).

Cookie spread or diameter and thickness are important. The cookie manufacturer must be able to rely on the flour in producing cookies that are consistent in texture as well as in spread and height in order to produce an acceptable cookie product that will fit into the specially made/designed package for distribution to the consumer. The snap sugar cookie is most often used in test baking (cookie spread) for determining flour quality.

Many factors can affect cookie spread such as the mixing method (Vetter et al., 1984) and type/amount of ingredients such as shortening (Abboud et al., 1985), sugar (Abboud et al., 1985a; Doescher et al., 1987b; Vetter et al., 1984) and flour (Doescher et al., 1987a; Gaines, 1985; Gaines and Donelson, 1985; Tanilli, 1976). Soft wheat flour with a lower protein content takes up less water than a strong hard wheat flour with a higher protein content, leaving more water to dissolve the sugar. The dissolved sugar forms a syrup and makes the dough more slack, which permits more spreading before the dough becomes too viscous to flow any further (Penfield and Campbell, 1990b). At a certain point, the cookie stops spreading. It has been determined that a halt in spreading is

not due to gelation of the starch. In addition, protein content, pentosan content, water absorption and starch damage have been found not to be good indicators in determining differences in cookie diameter (Gorton, 1984). Doescher et al. (1987a) found baked cookies to have a continuous structure and attributed the differences in cookie diameter to be related to a gluten glass transition found in gluten and in flour. Gluten glass transition can be defined as the temperature at which the gluten proteins expand and in turn become more viscous (Doescher et al., 1987a). The researchers determined that flours of hard wheats have a significantly lower glass transition temperature versus those of soft wheat and "when gluten undergoes a glass transition, it expands to form a continuous matrix, and viscosity increases, causing cookie dough to stop spreading" (Doescher et al., 1987a). Thus, the differences in cookie spread can be partially attributed to varying glass transition temperatures and the flour of choice is a soft wheat flour of low protein.

2.07 SDS-PAGE AND MONOCLONAL ANTIBODIES

Sodium dodecyl sulfate - polyacrylamide gel electrophoresis (SDS-PAGE) is one of the current methods used for electrophoretic characterization of proteins found in different wheat cultivars. In addition to wheat, SDS-PAGE is also an effective protein characterization method for rye, triticale, 1B/1R substitutions, and 1B/1R translocations (Dhaliwal and MacRitchie, 1990; Moonen and Zeven, 1984; Zhen and Mares, 1992). SDS-PAGE allows for analysis of protein composition to determine differences between normal and 1B/1R wheat variations and also may imply possible relationships to flour quality (Zhen and Mares, 1992).

In common wheats, it is known that the short and long arms of the group 1 chromosomes contain genes for the ω and γ gliadins (group 1 and 6), low molecular weight (LMW) glutenin subunits (Zhen and Mares, 1992), and HMW subunits of glutenin, respectively (Moonen and Zeven, 1984). A smaller portion of the sulfur-class

wheat proteins are also regulated by long arm genes of group 1 (Fernández de Caleya et al., 1976; Moonen and Zeven, 1984). The 1R group of rye also possesses genes coding for secalins on the short arm and glutelins on the long arm. Proteins of 1B/1R translocation wheats lack most of the omega gliadins (Dhaliwal and MacRitchie, 1990; Zhen and Mares, 1992) and all dark banded LMW glutenins, where gamma secalins appear instead (Dhaliwal and MacRitchie, 1990; Zhen and Mares, 1992). However, 1B/1R substitution lines not only lose LMW glutenins and gliadins, but also some of the HMW glutenin subunits (Zhen and Mares, 1992). The Sec-3 rye HMW prolamin is the replacement.

SDS-PAGE not only lends itself to protein characterization of different wheat and 1B/1R lines, but also provides a marker for the short arm (gliadins or secalins) (Ellis, 1971; Moonen and Zeven, 1984) as well as the long arm (wheat or rye thionins) (Moonen and Zeven, 1984; Sánchez-Monge et al., 1979). Therefore, SDS-PAGE is an effective technique for identification of the introduction of rye genes (1R) into wheat (1B/1R) and for analysis of protein composition for 1B/1R translocation/substitution lines. By determining protein composition of the 1B/1R translocation/substitution wheats, the relationship between protein composition and dough stickiness may also be investigated.

In addition to SDS-PAGE, the monoclonal antibody - Enzyme Linked Immunosorbent Assay (ELISA) method has been successfully used in rapid detection of the 1B/1R translocation wheats (Howes et al., 1989). Howes et al. (1989) report that specially prepared monoclonal antibodies to the γ-gliadin 45, which strongly binds in many hexaploid wheats, can be used to detect the 1B/1R wheats, for they do not contain the γ-gliadin 45, but contain gliadins that do not bind to the monoclonal antibodies. Graybosch et al. (1993) have also been successful in using a similar method.

CHAPTER 3

MATERIALS AND METHODS

3.00 PURPOSE

The purpose of this research was to determine the end use quality of flours from soft red winter wheat lines possessing or lacking the 1B/1R translocation.

3.01 EXPERIMENTAL DESIGN

The experimental design included 14 wheat varieties (some with and without 1B/1R) harvested from two different locations in Virginia (Blacksburg and Warsaw), thus comprising a 14 x 2 incomplete block design. Wheats were grown in two different locations for comparison purposes of environment. Warsaw is in the coastal plane area of Virginia and has an elevation of ~800 feet, whereas Blacksburg is a plateau situated in the Blue Ridge Mountains of Virginia and has an elevation of ~2,200 feet. The growing season of wheat for the Warsaw location is from middle October to June and for Blacksburg it is from the end of September to July. Flour quality of all experimental wheats was determined by Kjeldahl, Farinograph, Dough Stripping, SDS-PAGE, and Cookie Spread tests. Results of flour quality tests were interpreted and evaluated to determine if there is a relationship regarding dough stickiness. All tests were done in triplicate.

3.02 WHEAT

All wheat lines, with and without 1B/1R translocation, were harvested in mid June and early July, 1994 from experimental plots in Virginia from two different locations (Warsaw (W) and Blacksburg (B), respectively). Experimental wheats were

provided by Dr. Carl Griffey, Dept. of Crop and Soil Environmental Sciences, Virginia Tech, Blacksburg, Virginia. For purposes of this study, wheat varieties (Massey, Saluda, FFR555W) now available to all producers were referred to as common wheats or checks, all of which lack 1B/1R. The experimental wheat lines were divided into groups or pairs. Each pair had a different parentage, but consisted of sister lines with and without 1B/1R of the same or similar parentage. The parentage of each pair or group was as follows: Pair #1 - Balkan (1B/1R donor) crossbred with Massey 4 times; Pair #2 - Massey was crossbred with Balkan 3 times, then crossbred with Saluda and then crossbred with Massey 3 times; Pair #3 - Balkan crossbred with Massey 5 times; and Pair #4 - a complex parentage consisting of many different wheat varieties. A list of the experimental wheats is provided in Appendix A. The letter "c" has been added to those experimental varieties to indicate the presence of the 1B/1R translocation. Massey was chosen as the control since all other experimental wheats consisted of ~70-75% Massey. Different parentage was investigated to determine if parentage had any effect on the quality of wheats with 1B/1R.

3.03 MOISTURE (AIR-OVEN METHOD)

Moisture content of all experimental wheats was obtained by the air-oven one-stage method of the American Association of Cereal Chemists (AACC) 44-15A (1983).

3.04 MILLING OF WHEAT

The grain was milled in a Brabender Quadramatic Junior mill (Hackensack, New Jersey) in the department of Human Nutrition and Foods, Virginia Tech, Blacksburg, Virginia. All grain samples were tempered 24 hours prior to milling to a moisture content of 14%.

3.05 FLOUR YIELD

Before milling, each experimental wheat variety, in its entirety, was weighed on a digital pound scale. The pounds were then converted to grams. During milling, the bran and endosperm were separated and weighed individually after milling was complete. The gram amounts of bran and endosperm were used in the following equation to obtain percent flour yield for each experimental wheat variety:

weight of bran = a grams; weight of flour = b grams; a + b = t grams (total wt.)

$$(b \div t) \times 100 = \text{percent flour yield}$$

Note: Percent flour yield was not obtained in triplicate since there was only one batch of wheat for each variety and therefore, n = 1 for % flour yield.

3.06 PROTEIN DETERMINATION

Whole grain and flour protein content of all wheat varieties was determined by the Kjeldahl method AACC 46-12 (AACC, 1983). A Distillation Unit Controller Büchi 343, the printer, and Dosimat 665 were used. A conversion factor of 5.7 was used to determine the total protein content. Flour and ground whole grain experimental wheat samples of 250 mg and 350 mg, respectively, were tested. Testing was done in triplicate. (See Appendix B for parameters).

3.07 FARINOGRAPH (MIXING TOLERANCE)

Physical tolerance of all experimental doughs was determined by AACC method 52-21 (AACC, 1983) and use of the Brabender farinograph (Hackensack, New Jersey), and compared by the mixing tolerance index. The mixing tolerance index (MTI) is the difference in Brabender Units between the top of the curve at its peak (maximum value)

and the top of the curve 5 minutes later. In addition to the MTI, water absorption (WA), peak time (PT), departure time (DT), twenty-minute drop (TMD) and mixing time stability (MTS) were determined. See Appendix C for definitions and farinograph parameters.

3.08 COOKIE SPREAD AND HEIGHT

The AACC 10-50D method (AACC, 1983) was used for cookie spread testing. Quality of the experimental flours was evaluated by measuring cookie spread of 6 sugar-snap cookies baked from 225 grams of flour. Using a vernier caliper, the diameter (mm) of each cookie was obtained 4 times by rotating the cookie a quarter turn and the diameters averaged. The final 6 averages were then averaged to obtain an average cookie spread for each replication (3 total) of all experimental wheat varieties. To determine the cookie height, all 6 cookies were stacked and measured for height by use of a vernier caliper. The stack was rotated a quarter turn and the height was measured again for a total of 4 times and the heights averaged to obtain the average height (mm) of the cookie stack. The cookie formula is provided in Appendix D and the following ingredients were used:

Flour: All experimental wheats

Shortening: Crisco (Proctor & Gamble, Cincinnati, Ohio)

Sugar: Richfood pure granulated sugar (Richfood, Inc., Richmond, Virginia)

Iodized Salt: Morton® Iodized Salt (Morton International, Inc., Chicago, Illinois)

Soda: Arm & Hammer® (Div. of Church and Dwight Co., Inc., Princeton, New Jersey)

Water: Potable

Dextrose solution: Staleydex® dextrose (A.E. Staley Manufacturing Co., Decatur, Illinois) and water.

3.09 DOUGH STICKINESS

A dough stickiness testing box was developed by the author and a graduate student from the Chemistry Department at Virginia Tech, Blacksburg, Virginia (Shephard, 1995). The test was modeled after typical methodologies of the Center for Adhesives and Sealant Sciences, Virginia Tech, Blacksburg, Virginia (Shephard, 1995). Preparation and formulation of experimental doughs were determined in a pilot study. Fifty gram samples of all experimental flours were used for dough formulations. The amount of water to be added was determined by farinograph water absorption results for obtaining an optimum peak dough for each experimental wheat variety (Appendix E). Flour amounts were kept constant for final testing of dough stickiness. Mixing time of doughs was also determined by using average farinograph peak times for each variety (Appendix E). All doughs were prepared immediately prior to dough stickiness testing by use of a Vacuum Power Mixer Plus - Whip Mixer (Model F, WM (Whip Mix) Corporation, Louisville, Kentucky) . The pre-measured flour and water were placed into the Whip Mix mixing bowl, stirred 12 times to mix flour and water (mixing recommended by the manufacturer), and mixed for optimum dough times. Finished dough portion was halved. One half of the dough sample was wrapped in plastic wrap and the other dough half was rolled onto a clean 13" x 13" x 1/4" glass plate with a wooden rolling pin using stainless steel guides (1/16" thick) at each side. A 1" x 7" pre-cut fiberglass mesh screen strip of 16 squares per inch was placed on top of the rolled out dough (center of dough). The second portion or half of dough was rolled out on top of the first dough layer plus fiberglass strip using stainless steel guides, once again, to make a dough-mesh-dough sample. For testing purposes, the dough-mesh-dough sample was cut into a 1" x 7" strip using a knife and one of the fiberglass mesh strips as a guide. Illustration of the dough-mesh-dough strip is presented in Figure 1. The purpose of the second dough layer was to hold the fiberglass mesh strip in place. Once the dough strip

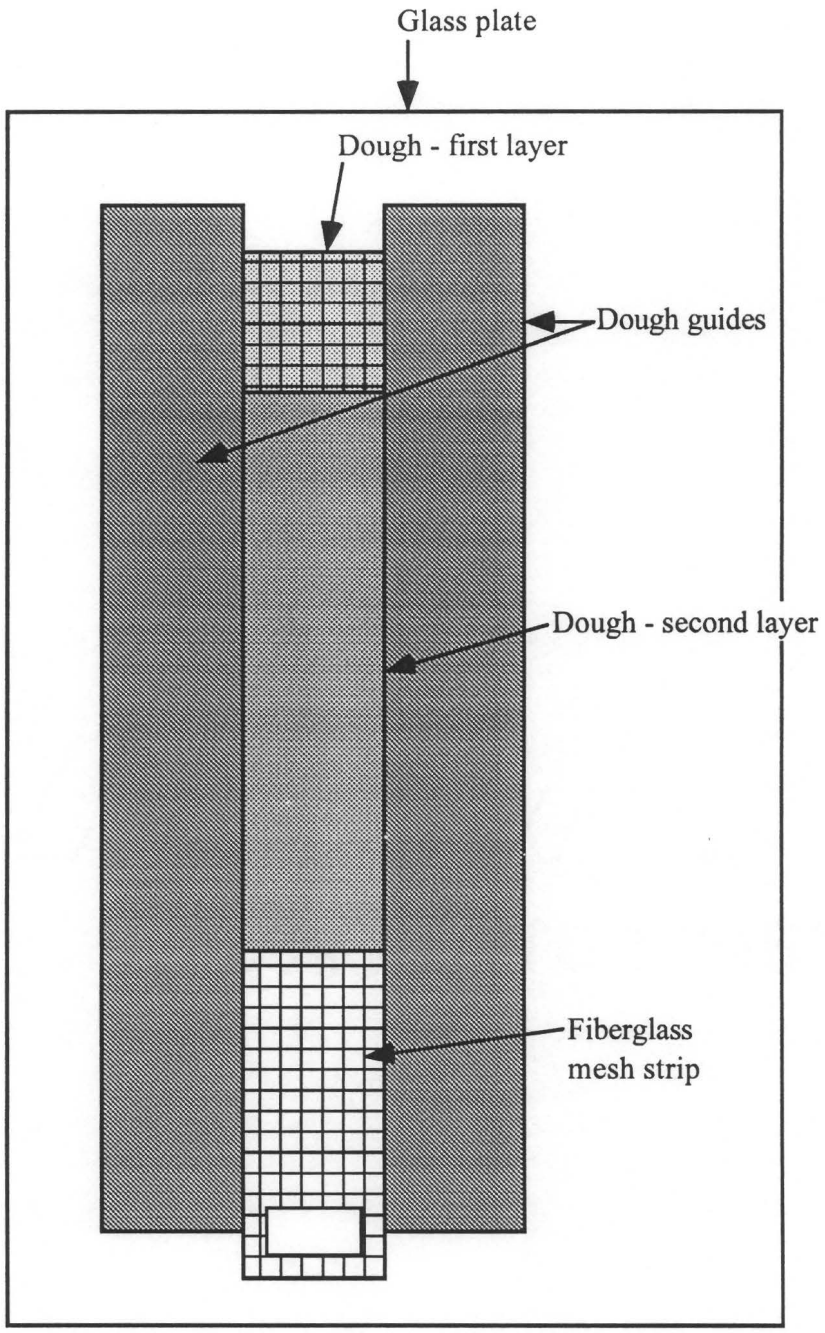


FIGURE 1. Representation of dough strip layout on glass plate.

was completed, the glass plate plus dough strip was transferred to the Nalgene® "Schwarzlaff-Shephard" dough stickiness testing box shown in Figure 2. The glass plate (which was cut to fit on top of the 12" x 12" Nalgene® testing box) was placed in position such that the dough strip was upside down inside the Nalgene® box (Figure 3). A constant relative humidity was maintained in the glass tank as supplied on a continuous basis by having a saturated aqueous salt solution of potassium sulfate in an insert tray placed in the bottom of the Nalgene® box. The humidified air was circulated inside the Nalgene® box by means of a small fan built into the box (Figure 2). Once the glass plate was in place, a clear ruler was taped on top of the glass plate such that a peel distance of 1/2 inch (determined by pilot study) of the dough strip could be determined. Using the affixed gloves, a 25 gram weight was hung on the dough-free end of the fiberglass mesh strip by placing it in the center of the pre-cut rectangle of the mesh strip (Figures 1 and 3). Once the weight was hung onto the mesh strip, timing began. A razor blade was placed above the 1/2 inch mark on the ruler to help ensure that the dough peel distance was in fact 1/2 inch. At the point where the dough had peeled 1/2 inch, timing was stopped and the peel time was recorded. A total of four different weights (10, 15, 20 and 25 grams) were used to determine the peel times for that particular dough. These weights were chosen due to the length of the dough strip. All four peel times (one for each separate weight) were determined by using the same dough strip. Between each weight, the dough strip was prepared for the next run by using a razor blade to even the edge of the dough sample, line it up with the starting mark on the ruler. Results were plotted on a graph - peel time (min.) vs weight (g) - for each experimental dough. The less time it took for the dough sample to peel off, the less sticky the dough was considered.

The development of the "Schwarzlaff-Shephard" dough stickiness tester for this research provides a methodology that tests stickiness to the exclusion of the viscoelasticity factor. By attaching the mesh strip to the first layer of dough with the

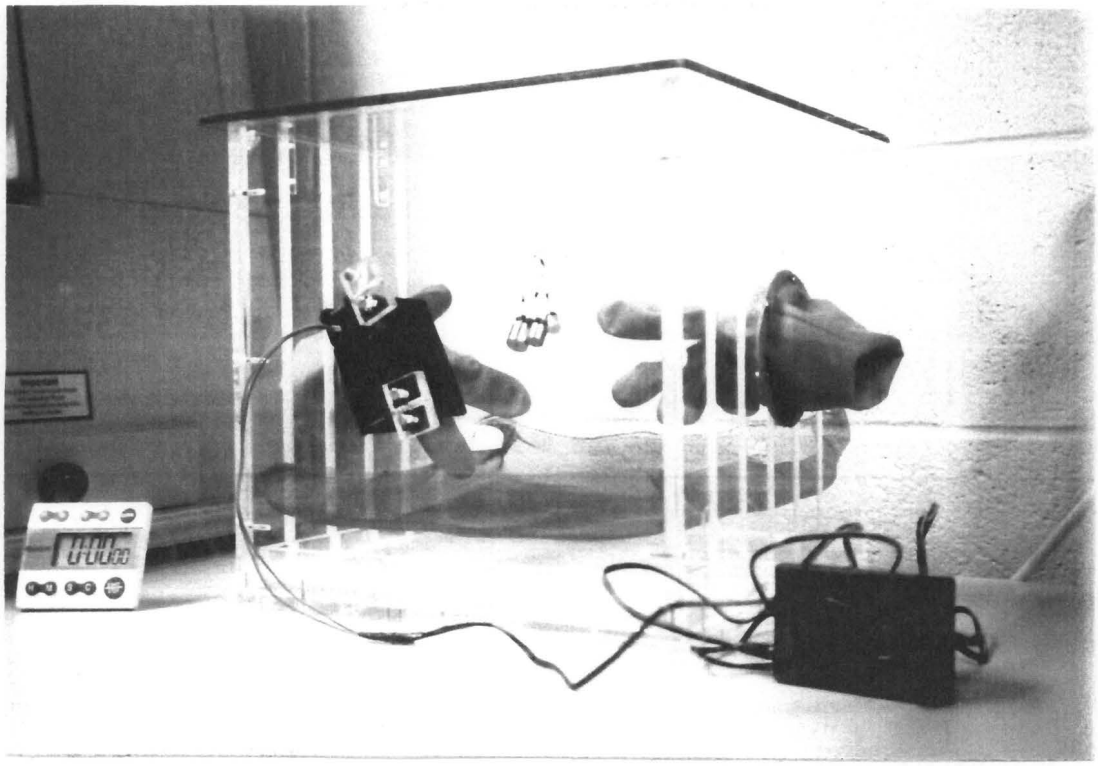


FIGURE 2. "Schwarzlaff-Shephard Dough Stripping" Box.

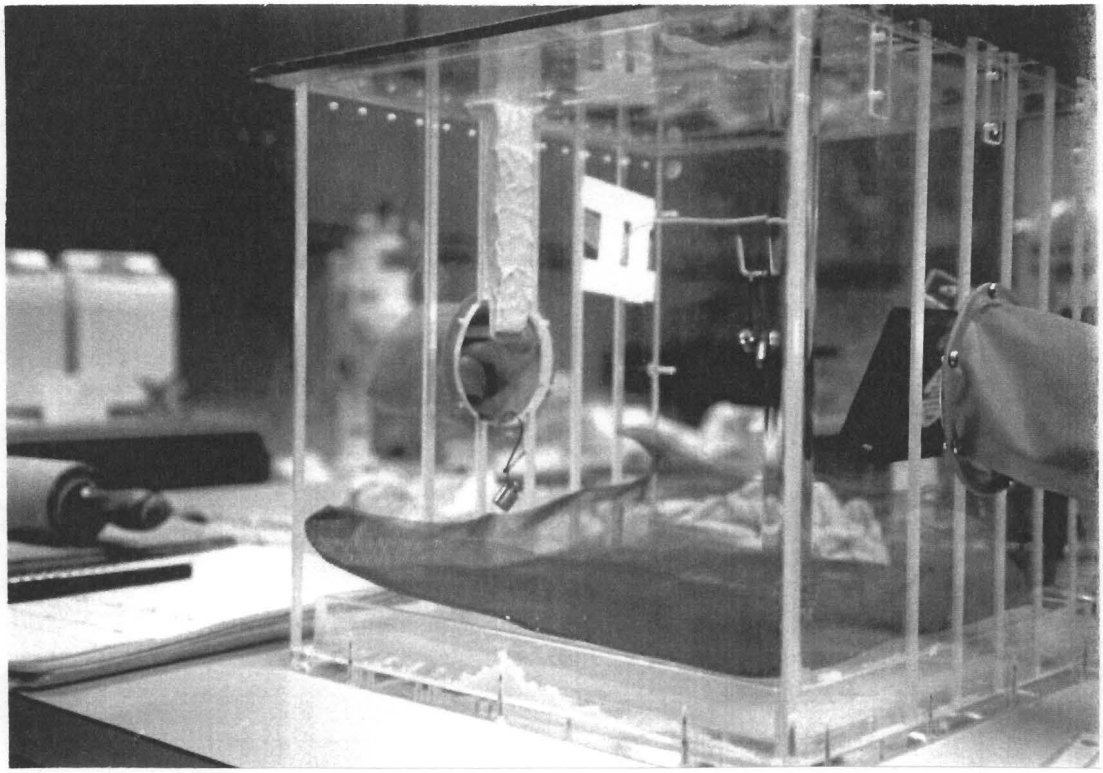


FIGURE 3. Example of dough stripping (peel test).

second layer, the pulling of the weight does not come in direct contact with dough, but the dough-free end of the strip. Thereby, the peeling action of the dough is strictly due to its adhesive property and not its viscoelasticity. The instrument is also relatively inexpensive and easily constructed from commonly available parts.

3.10 SDS-PAGE (PROTEIN ANALYSIS)

Protein analysis of all experimental wheats, by SDS-PAGE (Payne et al., 1981a; Zhen and Mares, 1992), determined protein composition for each variety with and without 1B/1R from each location. The variety 'Neepawa' was used as the control, and a molecular weight standard (SDS-6H lot 15H9418) from Sigma (Sigma Chemical Company, St. Louis, MO) was used as the molecular weight marker in all gels. The molecular weight standard contained six molecular weight proteins as markers to compare protein compositions of the experimental wheats: 205,000; 116,000; 97,400; 66,000; 45,000; and 29,000 kilodaltons (k). A Bio-Rad Protean® IIxi Cell (manufacturer) connected to a Bio-Rad Model 1000/150 power supply was used for electrophoresis. See Appendix F for the materials, procedures, parameters and modifications.

3.11 1B/1R DETECTION

The monoclonal antibody Enzyme Linked Immunosorbent Assay (ELISA) method (Howes et al., 1989) was used to detect the experimental wheats with and without 1B/1R. Small samples of each experimental wheat variety were to sent to Dr. N.K. Howes at the Agriculture Canada Research Station, Winnipeg, Canada where he utilized his method to detect the 1B/1R. Results were based on obtained absorbance values at 405 nm where an absorbance of less than 0.12 indicated the presence of 1B/1R.

3.12 STATISTICAL ANALYSIS

All statistical analyses were performed using the Statistical Analysis System package (SAS, 1985) and Duncan's Multiple Range test was performed to determine significant differences between experimental wheats at $P = 0.05$.

CHAPTER 4

RESULTS AND DISCUSSION

4.00 PURPOSE

The purpose of this research was to determine the end use quality of flours from soft red winter wheat lines possessing or lacking the 1B/1R translocation.

4.01 EXPERIMENTAL DESIGN

The experimental design consisted of an incomplete block comprised of a 14 x 2 factorial with 3 replications for each experimental wheat. Due to unforeseen partial plot pooling of each wheat variety during harvesting, the rest of the same variety plots were pooled together after testing for moisture and protein content, which were found to be nearly the same. The necessity of pooling of plots before measurement yielded subsamples (Lentner, 1995). Therefore, the data will contain what is known as the subsampling effect.

4.02 1B/1R DETECTION

ELISA absorbance readings at 405nm of all experimental wheats were obtained from Dr. Howes (1995) and evaluated for the presence of 1B/1R. Table 1 indicates which of the experimental wheats do and do not contain 1B/1R. Wheat varieties with an absorbance reading of < 0.12 have a positive detection for 1B/1R. The reason the 1B/1R wheat varieties have lower absorbance readings is because they do not contain the γ 45 gliadin, but possess other gliadins to which the monoclonal antibodies do not bind to as they do to the γ - 45 gliadin present in common wheat varieties. Therefore, the common wheats have higher absorbance values which indicates binding of the monoclonal

TABLE 1. ELISA[1] absorbance readings of experimental wheats for detecting 1B/1R.

Variety	Absorbance[2] Warsaw	Blacksburg	1B/1R[3]
Massey	0.324	0.516	-
Saluda	0.396	0.488	-
FFR555W	0.324	0.479	-
VA-46	0.296	0.224	-
VA-50c	0.010	0.034	+
VA-209	0.571	0.447	-
VA-211c	0.007	0.000	+
VA-237	0.423	0.481	-
VA-241c	0.000	0.000	+
VA-247c	0.013	0.024	+
VA-251c	0.032	0.021	+
VA-329	0.447	0.458	-
VA-343c	0.025	0.024	+
VA-351c	0.000	0.026	+

[1]Method by Howes et al. (1989).
[2]Absorbance at 405 nm and values of < 0.12 indicate presence of 1B/1R.
[3](+) = with 1B/1R and (-) = without 1B/1R.

antibodies. According to results in Table 1, the following experimental wheats contain the 1B/1R translocation: VA-50c, VA-211c, VA-241c, VA-247c, VA-251c, VA-343c and VA-351c. These results were in agreement with the 1B/1R varieties that were postulated to have the translocation based on the presence of the Lr 26 gene for resistance to leaf rust (*Puccinia recondita*) (Griffey, 1995).

4.03 WHEAT MOISTURE

Wheat moistures were obtained for all experimental wheats prior to milling. The obtained mean percent moisture values ranged from 12.11 to 12.88 percent for Warsaw and 12.19 to 13.37 percent for Blacksburg as shown in Table 2. Ten out of the 14 wheat varieties from the Warsaw location had moistures that were not significantly different from each other. The Blacksburg location had similar results in that 9 out of the 14 varieties were not significantly different in moisture content. For both locations, the common wheats or checks had moisture contents that were not significantly different from one another (Table 2). It is clear from the results listed in Table 2 that all Warsaw sister lines, given under pairs, had moistures that were not significantly different from each other except the VA-237 and VA-251c lines under Pair #3. The VA-209 and VA-211c lines had the lowest actual moisture content among the wheat lines from Warsaw. However, the moisture content of these lines was similar to all other lines except VA-237. The Blacksburg VA-211c line had the highest actual moisture content, which was similar to all other Blacksburg lines except VA-46, VA-50c, VA-329 and VA-343c. All sister lines, under pairs, for the Blacksburg location, were not significantly different from each other in moisture content. None of the experimental wheat varieties had moistures that were significantly different from their recurrent parent(s) for both locations.

Thus, it can be concluded that there was little to no difference in moisture content among varieties with and without 1B/1R and there was an interaction between variety and

TABLE 2. Mean percent moisture of experimental wheats[1].

Variety	Moisture (%)[2] Warsaw	Blacksburg
Massey	12.27ab[3]	12.44ab
Saluda	12.67ab	12.61ab
FFR555W	12.55ab	12.42ab
Pair #1		
VA-46	12.84ab	12.19b
VA-50c[4]	12.46ab	12.26b
Pair #2		
VA-209	12.11b	12.60ab
VA-211c	12.11b	13.37a
Pair #3		
VA-237	12.88a	12.63ab
VA-241c	12.35ab	12.72ab
VA-247c	12.86ab	12.84ab
VA-251c	12.11b	12.58ab
Pair #4		
VA-329	12.60ab	12.22b
VA-343c	12.22ab	12.38b
VA-351c	12.58ab	12.39ab

[1] Moisures obtained of ground whole wheat samples.
[2] n = 3
[3] Numbers with the same letter in the same column are not significantly different at P > 0.05.
[4] c = Variety with 1B/1R translocation.

environment. Overall, it appears that the 1B/1R characteristic did not adversely affect the moisture content of whole soft wheat. For wheat, a moisture content of less than 14 % is desired to ensure safe storage of the grain. Differences in moisture are expected even for wheat coming from a single field which can vary widely in moisture due to factors such as differences in soil or stages of ripeness of the grain (Hoseney, 1986).

4.04 PERCENT FLOUR YIELD

Flour yields of all experimental wheats are given in Table 3. The VA-329 line (no 1B/1R) from Warsaw had the highest yield (75.97%), whereas Massey (W) had the lowest (58.00%). Under good growing conditions, Massey generally has a good flour yield (Griffey, 1995). Saluda varies in flour yield, but is generally acceptable, and the FFR555W variety is known to have an excellent flour yield. All three of the Blacksburg common wheats or checks were very similar in flour yield, which was also true for the Warsaw Saluda and FFR555W varieties, but not the Massey. The Warsaw experimental wheat varieties with the 1B/1R translocation had reduced flour yields compared to their respective sister lines without 1B/1R. However, all sister lines had a higher flour yield than Massey. In addition, the flour yields of the sister lines were lower than that of the Saluda and FFR555W check varieties except VA-46, VA-237 and VA-329, all without 1B/1R. Interestingly, the two Warsaw sister lines VA-209 and VA-211c had very different flour yields of 70.31 % and 59.76 %, respectively, despite the fact that they both have the same parentage (Massey/3/Massey/Saluda). In comparing the two lines, the VA-209 was similar in flour yield to that of its recurrent parent Saluda, whereas the VA-211c line was similar to its recurrent parent Massey. Some of the Blacksburg 1B/1R wheats had reduced flour yields while others had an increase, such as pair #4 in Table 3 and the VA-247c line in Pair #3, when compared to the respective sister lines without 1B/1R. The milling of VA-211c variety produced a drastic reduction in yield (10 - 15%) when

TABLE 3. Percent flour yield of experimental wheats.

Variety	Flour Yield (%)[1] Warsaw	Blacksburg
Massey	58.00	66.32
Saluda	70.91	65.67
FFR555W	70.75	65.69
Pair #1		
VA-46	71.62	68.08
VA-50c[2]	68.18	60.44
Pair #2		
VA-209	70.31	75.00
VA-211c	59.76	58.58
Pair #3		
VA-237	75.44	69.09
VA-241c	68.27	67.91
VA-247c	66.67	69.76
VA-251c	61.65	68.93
Pair #4		
VA-329	75.97	68.07
VA-343c	67.77	71.05
VA-351c	64.57	70.37

[1] n = 1
[2] c = Variety with 1B/1R translocation.

compared to its sister line VA-209 for both locations. Despite the reduction in flour yield of some of the 1B/1R wheats when compared to sister lines, all the Blacksburg 1B/1R wheats and sister lines (no 1B/1R) except for the VA-50c and VA-211c lines had yields greater than any of the three check varieties. Increases or decreases in percent flour yield for the experimental wheat varieties were greatly affected by environment as well as variety. Some wheat varieties (hard and soft) with the 1B/1R translocation have been found to have flour yields that are not significantly different from their respective parents depending on the location and other environmental factors that can affect yield (Dhaliwal et al., 1987). Since only one value was obtainable for flour yield of each experimental wheat variety, significant differences could not be determined.

4.05 PERCENT PROTEIN

4.05a Wheat or Grain Protein

Mean wheat protein content of experimental wheats are given in Table 4. Wheat or grain protein contents ranged from 8.99% to 10.99% for the Warsaw location and from 9.40% to 10.93% for the Blacksburg location. Percent protein varies in wheat and has been found to range from 6% to 27%, but most commercial varieties usually range from about 8% to 16% (Hoseney, 1986) with soft wheats being at the lower percentage range. The amount of protein depends partially on variety and class, but environment during growth and maturity of the wheat appears to have the greatest impact. For example, the amount of rainfall during growth and prevalence of dry conditions affect protein content as well as the amount of available nitrogen in the soil (Zeleny, 1971). According to Pyler (1973), "Even simple varieties are apt to show considerable variations among different lots, variations being attributable to differences in the character of the soil in which the various samples were grown".

TABLE 4. Mean wheat protein content for all experimental wheats.

Variety	Wheat Protein (%)[1] Warsaw	Blacksburg
Massey	10.77ab[2]	10.67b
Saluda	9.82f	9.72e
FFR555W	8.99h	9.57ef
Pair #1		
VA-46	10.57bcd	9.57ef
VA-50c[3]	9.49g	9.40f
Pair #2		
VA-209	10.64bc	10.02d
VA-211c	10.40de	9.86de
Pair #3		
VA-237	10.22e	10.02d
VA-241c	10.91a	11.18a
VA-247c	10.65bc	10.69b
VA-251c	10.99a	10.93ab
Pair #4		
VA-329	10.78ab	10.02d
VA-343c	10.48cd	10.36c
VA-351c	10.79ab	10.68b

[1] n = 3

[2] Numbers in the same columns with the same letter(s) are not significantly different at P > 0.05.

[3] c = Variety with 1B/1R translocation.

The VA-251c variety (both locations) had significantly higher percent protein compared to most other experimental varieties, but did not differ from its recurrent parent Massey. In contrast, the VA-50c variety (both locations) had the lowest percent protein of the pairs with and without 1B/1R and differed from its recurrent parent Massey. Of the common wheats, FFR555W was significantly lower in protein content than Massey. All three common wheats (checks) had significantly different protein contents and their range in protein content was greater than that within any of the pairs. There was no distinct pattern of protein increases or decreases due to the presence of the 1B/1R characteristic. For some sister line pairs, the 1B/1R wheats had an increase in protein content (pairs 3 and 4) and for some a decrease (pairs 1 and 2), for which some were significant while others were not as shown in Table 4. In addition, some of the experimental lines without 1B/1R were significantly different in protein content when compared Massey, while others were not. The same held true for the experimental sister lines with 1B/1R. From the Warsaw location, three of the 1B/1R wheats (VA-50c, VA-211c, and VA-343c) were significantly different from the control for percent wheat protein, while the other four were not (VA-241c, VA-247c, VA-251c, VA-351c). Blacksburg, on the other hand, had the opposite, four of the 1B/1R wheats (VA-50c, VA-211c, VA-241c, VA-343c) were significantly different from Massey and the other three (VA-247c, VA-251c, VA-351c) were not. Variety and location had a greater effect on protein content than the presence of the 1B/1R characteristic and the parentage of the sister lines. Therefore, the 1B/1R translocation had no deleterious effect on grain protein for its presence did not determine whether their would be an increase or decrease in protein content of the wheat, which was in agreement with Dhaliwal et al. (1987).

4.05b Flour Protein

Protein content of the experimental flours are presented as percentages in Table 5 (Farinograph Analysis result section). Protein content of experimental flours ranged from 7.92% to 10.22%, including both locations. Percent protein varied widely between varieties and location. For both locations, Saluda and FFR555W wheat varieties had flour protein percentages significantly less than Massey. All three Massey common wheats had significantly different flour protein percentages. However, Saluda and FFR555W from the Blacksburg location had flour protein percentages that were not significantly different. Of the four pairs, with and without the 1B/1R translocation, all the 1B/1R wheats from the Warsaw location except VA-241c and VA-251c lines had significantly decreased flour protein contents compared to their respective sister lines without the 1B/1R. However, for Blacksburg the opposite case was true for two pairs which had significant increases. All the Warsaw experimental lines, without 1B/1R, had an increased flour protein content, of which were significant except the VA-46 line, when compared to Massey. Most of the experimental lines without 1B/1R (except VA-209) from Blacksburg had lower flour protein percentages than control (Massey). Of the wheats with 1B/1R from Blacksburg, all lines had significantly increased flour protein percentages except for VA-50c when compared to Massey. The Warsaw location had about equal increases and decreases in flour protein content for the wheats with 1B/1R when compared to the control.

Differences in flour protein percentages were expected. Environment, location, growing conditions and the soil in which the wheat was grown are contributing factors that affect the protein content of flours. Wheats of the same parentage that were grown in different plots had different flour protein contents. Overall, the 1B/1R characteristic had no consistent or adverse effect on flour protein content, for the soft wheat flour protein

content usually ranges from about 8 to 9% or a little more. This finding was in agreement with Dhaliwal et al. (1987).

4.06 FARINOGRAPH ANALYSIS

Mean farinograph results are given in Table 5. Farinograms were obtained for all experimental flours as illustrated in Figures 4 - 8. Each figure is categorized according to pairs of sister lines with and without 1B/1R. The characteristics of each farinogram curve varied with each flour variety as well as by location. This was expected because each curve represents the variations in water absorption, dough development and dough breakdown for each experimental flour. Various sets of data were obtained from the farinograms as represented in Table 5. Percent flour protein was also included in Table 5 because the amount of protein in the flour is known to affect the water absorption as well as the shape of the curve in relation to protein content and quality (D'Appolonia and Kunerth, 1984). See Appendix G for summary of farinograph data.

4.06a Shape of the Farinogram Curve

The shapes of the farinogram curves (Figures 4 - 8) are typical of soft wheat according to the farinograms obtained by D'Appolonia and Kunerth (1984). Curves are classified into types, for which soft wheats are classified as type I curves - short peak time and low stability. Soft wheat flours usually contain little protein and are utilized for products such as cakes, cookies and crackers (D'Appolonia and Kunerth, 1984). The percent protein of the experimental flours ranged from 7.92 to 10.22% (including both locations), which are typical percentages for soft wheat flour.

4.06b Water Absorption

Differences in water absorption values are given in Table 5. Percentages ranged from 52.7% to 58.8% for Blacksburg varieties and from 53.2% to 57.3% for Warsaw varieties. As can be seen in Table 5, differences in water absorption are present between

TABLE 5. Mean[1] farinogram data for experimental flours[2] with and without 1B/1R.

Variety	Flour Protein (%)		Water Absorption (%)		Peak Time (min)		MTS[5] (min)		MTI[6] (BU)	
	W[3]	B[4]	W	B	W	B	W	B	W	B
Massey	9.57e[7]	9.28e	54.5d	54.3def	1.9ab	1.5ab	6.8a	5.7a	30f	57cd
Saluda	9.17f	8.47g	57.1a	55.3cde	1.9ab	1.4ab	2.6fg	2.7d	95a	62cd
FFR555W	8.25h	8.57g	53.2f	53.6fg	1.3cd	1.1b	1.7g	2.4de	85ab	70bc
Pair #1										
VA-46	9.72cde	8.36h	55.0c	52.7g	2.2a	1.2ab	3.5def	2.2de	72bc	80b
VA-50c[8]	8.41g	7.92i	53.8e	53.0fg	1.1d	1.2ab	4.0de	1.1e	67cd	83b
Pair #2										
VA-209	9.93b	9.37de	56.1b	55.5cd	1.8abc	1.6a	2.1g	2.0de	93a	117a
VA-211c	9.32f	9.39d	57.3a	58.8a	1.9ab	1.4ab	2.8efg	2.6d	58cde	57c
Pair #3										
VA-237	9.75cd	9.09f	56.0b	53.8fg	1.6abcd	1.2ab	3.5def	1.8de	90a	82b
VA-241c	9.82bc	10.22a	54.5d	56.3bc	1.7abcd	1.5ab	3.4def	4.2c	62cd	60cd
VA-247c	9.20f	9.45d	55.0c	55.1cde	1.4bcd	1.4ab	4.0de	2.9d	63cd	60cd
VA-251c	9.68de	9.74c	55.2c	55.3cde	1.7abcd	1.6a	6.2ab	4.9abc	50de	48d
Pair #4										
VA-329	10.22a	9.12f	57.0a	54.4def	2.1a	1.2ab	4.4cd	2.2de	70bc	72bc
VA-343c	9.93b	9.46d	55.2c	55.2cde	1.7abcd	1.4ab	5.4bc	4.4bc	43ef	57cd
VA-351c	9.86bc	10.10b	56.3b	57.6ab	1.8abc	1.5ab	5.8ab	5.5ab	43ef	43d

[1] n = 3
[2] Flour at a 14% moisture level.
[3] W = Warsaw
[4] B = Blacksburg
[5] MTS = Mixing Time Stability
[6] MTI = Mixing Tolerance Index
[7] Numbers in the same column with the same letter(s) are not significantly different at P > 0.05.
[8] c = variety with 1B/1R translocation

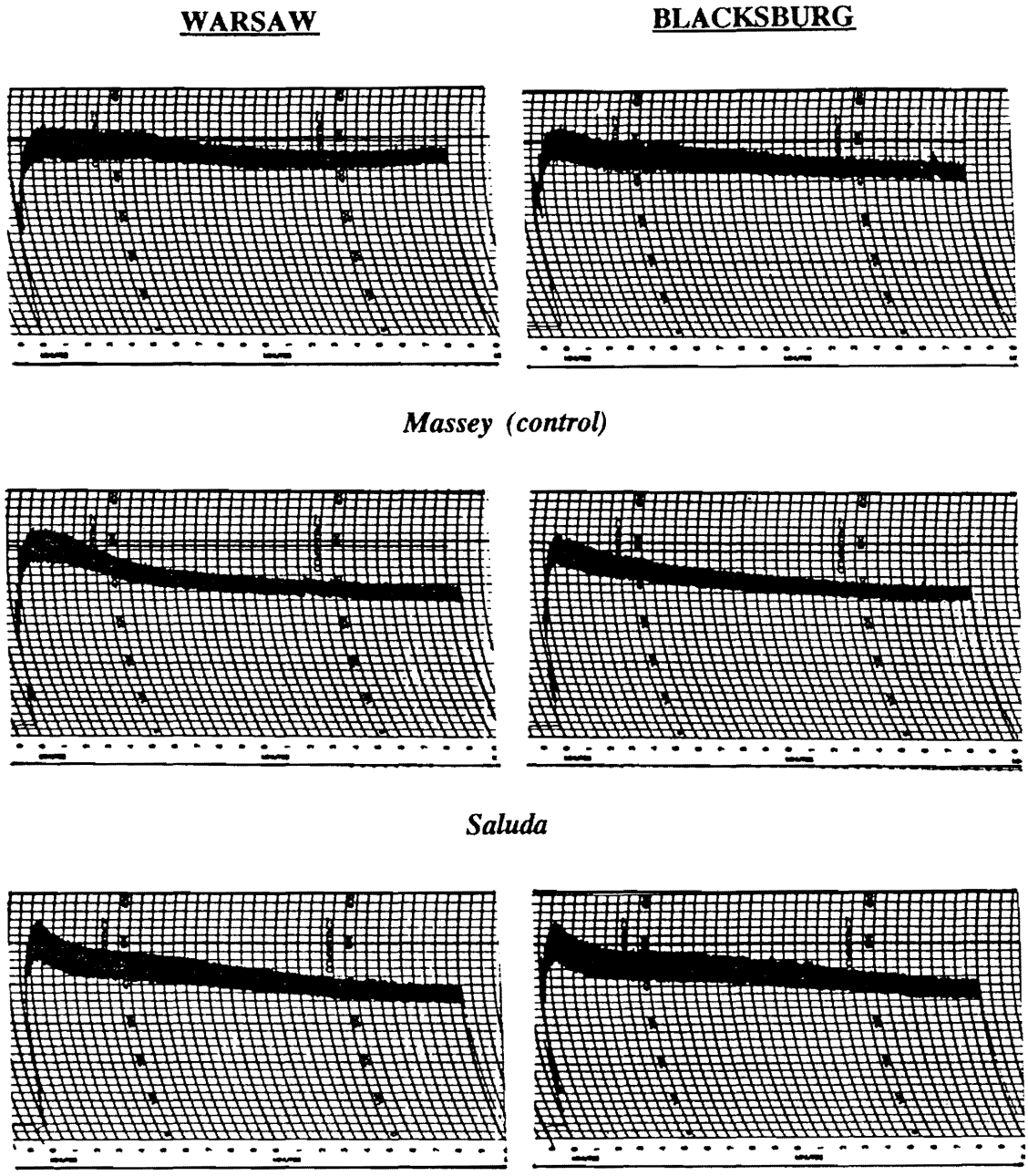
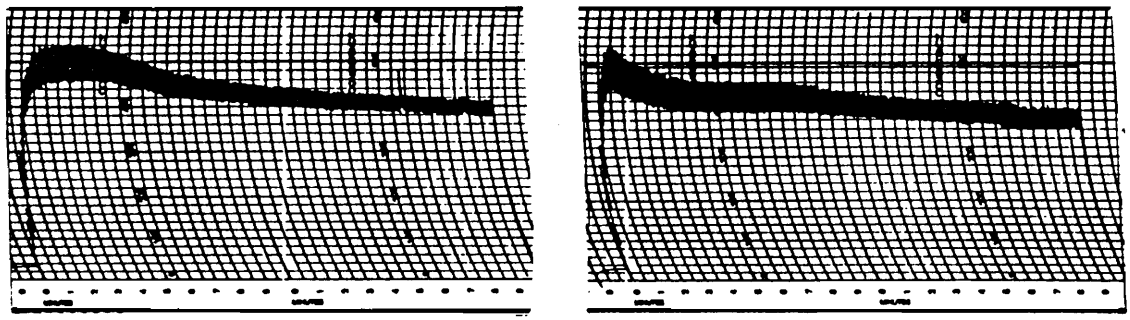
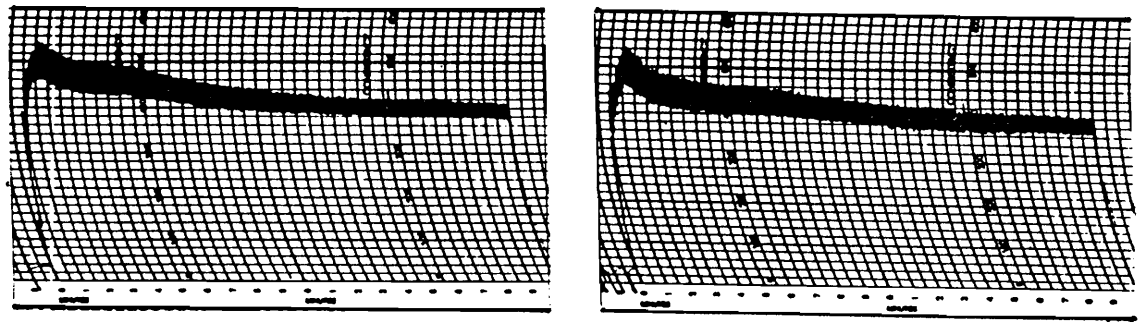


FIGURE 4. Farinograms of the experimental common wheats without 1B/1R.

WARSAW **BLACKSBURG**



VA-46



VA-50 (1B/1R)

FIGURE 5. Farinograms of Pair #1 (sister lines) experimental wheats.

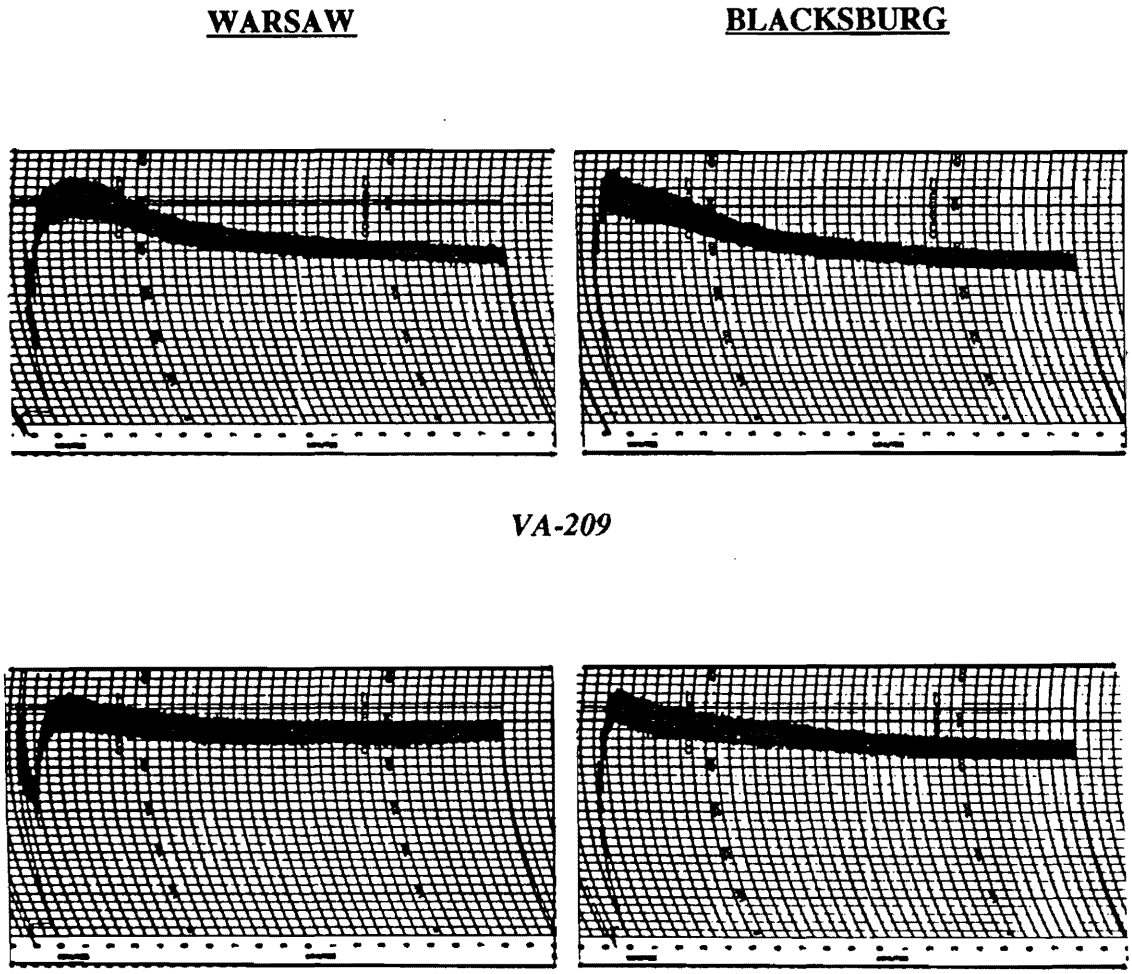


FIGURE 6. Farinograms of Pair #2 (sister lines) experimental wheats.

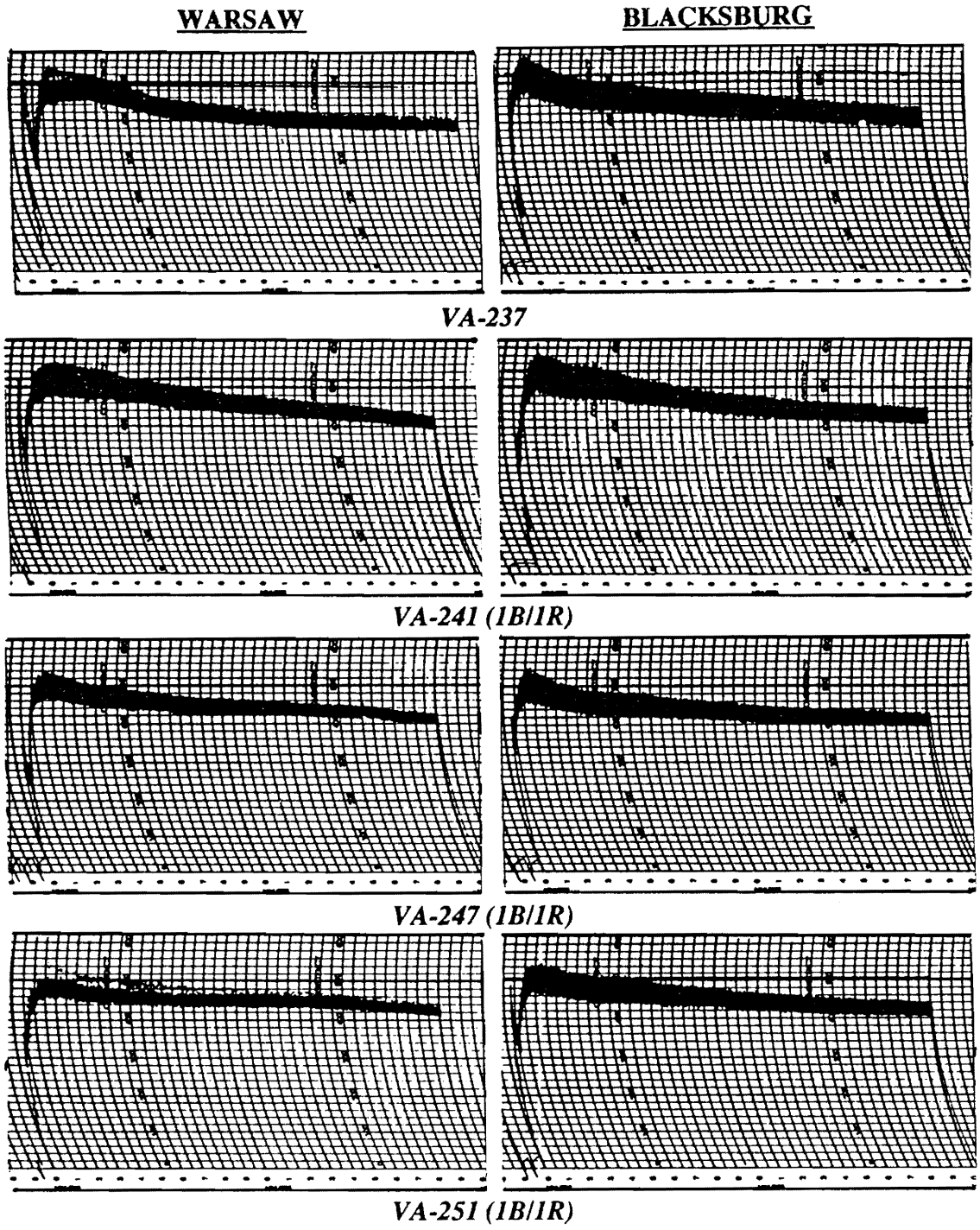


FIGURE 7. Farinograms of Pair #3 (sister lines) experimental wheats.

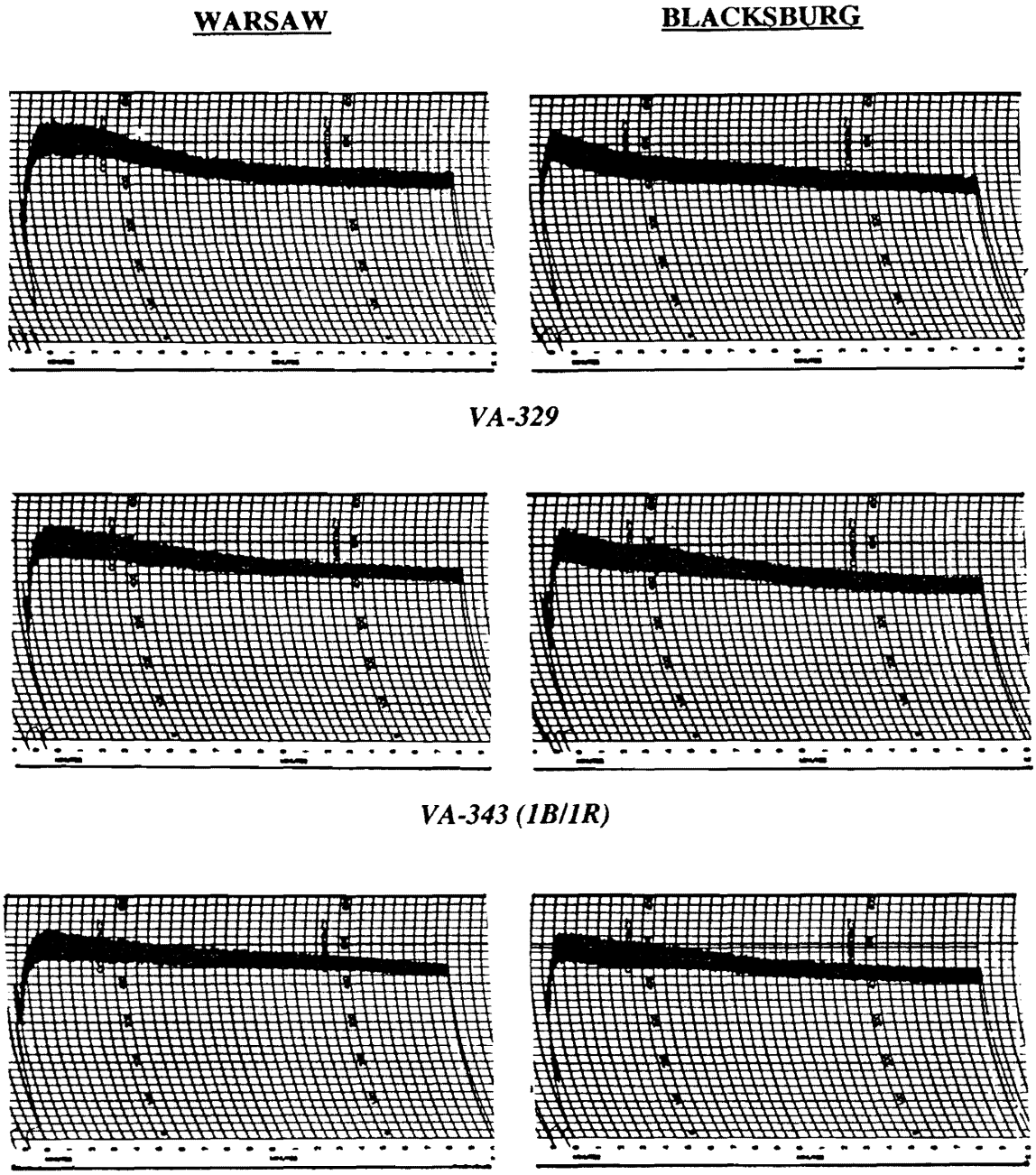


FIGURE 8. Farinograms of Pair #4 (sister lines) experimental wheats.

locations. The VA-211c variety had a significantly higher water absorption for both locations compared to all other varieties with the exception of Saluda (W), VA-329 (W) and VA-351c (B), as can be seen in Table 5. In contrast, the FFR555W variety (no 1B/1R) had the lowest water absorption value for both locations. The other experimental flour varieties had percentages which varied but without any trend. Thus, it appears that the 1B/1R characteristic, overall, caused no major change in water absorption. This finding was in agreement with that of Dhaliwal et al. (1987) and Martin and Stewart (1986), who also investigated the milling quality and/or rheological properties of 1B/1R translocation wheats. Variety, in this particular study, had a greater impact than all other factors (location and 1B/1R characteristic). Absorbency has been found to increase with increasing protein content (D'Appolonia and Kunerth, 1984; Tipples et al., 1978). However, D'Appolonia and Kunerth (1984) found that "a direct correlation between flour protein and flour (water) absorption does not always occur". For this particular study, there was not an association between flour protein and water absorption. Apparently protein quality and other factors such as starch content, pentosan content, etc., contributed to the differences in water absorption of the experimental flours.

4.06c Peak Time (Dough Development Time)

Peak times (PT) ranged from 1.1 minutes to 1.6 minutes for Blacksburg varieties and from 1.1 minutes to 2.2 minutes for Warsaw varieties (Table 5). Shorter peak times would be expected since the 1B/1R translocations were bred into soft wheats, and soft wheats have shorter development times compared to hard wheats. "Peak time is indicative of gluten quality with strong flour yielding a longer developing time than weak flours" (Conforti, 1989). Dhaliwal et al. (1987) also found soft 1B/1R wheats to have PTs between 1.0 to 1.5 minutes. Among the three Warsaw common wheats, Massey and Saluda did not have significantly different PTs. The Blacksburg common wheats had PTs that were not significantly different from each other. Of the Warsaw experimental sister

lines, with and without 1B/1R, only the VA-50c line was significantly different in PT compared to Massey and Saluda. However, the VA-50c line did not have a PT that was significantly different from the FFR555W variety. None of the Blacksburg experimental sister lines had significantly different PTs compared to Massey and Saluda. Even the VA-209 and VA-211c lines (W and B) were not significantly different in PT from their recurrent parents, Massey and Saluda. Thus, no major differences in PT were found among the varieties (except FFR555W (W) and VA-50c (W), but between locations yes! Dhaliwal et al. (1987) had similar findings working with soft wheats containing 1B/1R. The researchers found no evidence that the 1B/1R translocation significantly reduced dough or peak development time in the soft wheats with 1B/1R, but hard wheats with 1B/1R had a substantial and consistent reduction in dough development.

4.06d Stability

The mixing time stability (MTS) gives some indication of the flour's tolerance to mixing. Flours with long times are more stable to mixing than flours with short times. Flours with low protein contents are known to have shorter stability times (D'Appolonia and Kunerth, 1984). Experimental wheat MTSs ranged from 1.1 minutes to 6.8 minutes, including both locations. Data in Table 5 indicate that Massey had the greatest mixing stability of the three checks for both locations. Massey's (W and B) MTS was significantly different from Saluda and FFR555W (W and B), which these two were not significantly different in MTS. From both locations, the experimental lines VA-251c and VA-351c had MTSs that were not significantly different from Massey, but different from all other experimental lines. The VA-209 and VA-211c lines from (W) and (B) had MTSs similar to one of their recurrent parents, which was Saluda and not Massey. Warsaw experimental lines without 1B/1R (excluding checks) had MTSs that were not significantly different one another except the VA-209 line. All the Blacksburg experimental lines without 1B/1R (excluding checks) had similar stabilities. Table 5

shows the differences in MTSs between sister lines under each pair. Mixing time stabilities were not significantly different for the sister lines in Pair #1 (W and B), and Pair #2 (W and B). In Pair #3 from Warsaw, the VA-251c line had a MTS significantly greater than the rest of the sister lines in this particular pair. Blacksburg Pair #3 had two of its sister lines to have significantly higher MTSs. The sister lines VA-329 and VA-343c in Pair #4 from Warsaw had similar MTSs, but the other sister line VA-351c in this pair had a significantly greater mixing stability. From Blacksburg, all three sister lines in Pair #4 had significantly different MTSs. Focusing on the 1B/1R experimental lines from Warsaw, the following lines showed an increase in MTS: VA-50c, VA-211c, VA-247c, and VA-343c. However, the MTS increases were not significantly different from the MTS of their respective sister line without 1B/1R. The Warsaw VA-251c and VA-351c lines had significant increases in MTS when compared to their respective sister lines (Table 5). One Warsaw line, VA-241c had a MTS of 3.4 minutes, which was almost identical to the MTS of its sister line VA-237 (3.5 minutes). The Blacksburg 1B/1R experimental lines, except VA-50c, showed an increase in MTS when compared to their respective sister lines without 1B/1R. However, only three out of the four lines, VA-241c, VA-251c and VA-351c had significantly greater MTSs than their respective sister line without 1B/1R. The VA-46 (B), VA-50c (B), VA-209 (W & B), VA-211c (W & B), VA-237 (B), VA-247c (B) and VA-329 (B) experimental lines had lower MTS values compared to the other experimental lines. Mixing time stability varied between varieties as well as by location. Parentage of the experimental wheat lines appeared to have no effect on MTSs. Experimental wheat lines with 1B/1R generally had greater mixing stabilities compared to the sister lines without the 1B/1R, although they were not consistently significant increases as mentioned above.

4.06e Mixing Tolerance Index

"Mixing tolerance is the ability of a dough to withstand overmixing and resist subsequent breakdown if the dough development time is exceeded" (Dhaliwal et al., 1987). The lower the mixing tolerance index (MTI), the better tolerance to mixing. Flours with high MTIs are considered as weak flours. Depending on the product for which the flour is to be used, the strength of the flour to overmixing is important. For example, for food products that require little mixing, a weaker flour is acceptable, but for a product that requires a longer mixing time, such as bread, a stronger flour is essential.

Mixing tolerance index values, in Brabender Units (BU), ranged from 30 BU to 95 BU for Warsaw and from 43 BU to 117 BU for Blacksburg (Table 5). The MTI for Massey (W) was significantly lower than the other two Warsaw checks, Saluda and FFR555W. However, the Warsaw Saluda and FFR555W checks had mixing tolerances that were not significantly different from one another. All three common wheats or checks from Blacksburg had varying MTIs, but were not significantly different from each other. The 1B/1R wheats in general (all except the VA-50c line) had a better MTI (lower value) compared to their respective sister lines without 1B/1R (Table 5), which associated with the MTS. In Pair #1 (W & B), the experimental sister lines had similar MTIs that were not significantly different from one another. From both locations, the VA-211c line in Pair #2 had a significantly lower MTI value than its sister line VA-209. The VA-209 variety, for both locations, would be considered the weakest flour of all experimental flours (excluding checks) for it had the highest MTI value. Table 5 shows Pair #3 (W & B) sister lines with 1B/1R (VA-241c, VA-247c and VA-251c) having significantly improved mixing tolerances when compared to their sister line without 1B/1R (VA-237). The MTIs of 1B/1R sister lines in Pair #4 (W & B) were not significantly different from one another. However, the Warsaw VA-343c and VA-351c lines had a significantly lower MTI value than its sister line without 1B/1R. The MTI value of the Blacksburg VA-343c

line was lower but not significantly different from VA-329. However, the MTI value of the VA-351c line was significantly lower than its sister line without 1B/1R. All the Warsaw experimental lines had significantly higher MTI values than Massey except VA-343c and VA-351c lines. The Warsaw experimental lines without 1B/1R had MTIs similar and not significantly different to either Saluda or FFR555W (Table 5). The 1B/1R lines from Warsaw had significantly lower MTI values compared to Saluda and FFR555W. From the Blacksburg location, about half (5 out of 11) of the experimental lines (VA- 46, VA-50c, VA-209, VA-237 and VA-329) had MTIs that were significantly higher when compared to Massey. Notice that only one of the lines contains 1B/1R. Blacksburg lines without 1B/1R (excluding checks) had MTIs similar to Saluda and/or FFR555W except for the Blacksburg VA-209 line, which had an MTI significantly higher than all Blacksburg wheat varieties (including checks). Experimental lines VA-343c (W) and VA-351c (W & B) had the lowest MTI values compared to all other experimental lines (excluding checks). Therefore, these experimental lines would be considered as having better mixing tolerances. Apparently this particular parentage produced 1B/1R wheats that were similar to the control for both locations. Once again, the main differences are seen in variety, although location appeared to have an effect as well for a few varieties.

4.07 COOKIE DIAMETER AND HEIGHT

4.07a Cookie Diameter

The most commonly used baking test to characterize soft wheat flour quality is the cookie spread test (Tanilli, 1976). Cookie spread appears to be controlled by genetics of the wheat and is affected by environmental conditions as well (Abboud et al., 1985a; Doescher et al., 1987b). Varietal variations in soft wheats are characterized by wide variations in cookie quality (Doescher et al., 1987b; Yamazaki, 1956). Variations in

cookie diameter of the experimental wheats are illustrated in Figure 9. For means and significant differences see Appendix H. Interestingly, all three common wheats, both locations, had significantly different cookie diameters (Figure 9). The FFR555W variety had the greatest cookie spread of all three common wheats, followed by Massey and Saluda, respectively. In general, Saluda is known to have a low cookie spread (Griffey, 1995). All Warsaw experimental lines, with and without 1B/1R, had cookie diameters that were not significantly different from Massey (W) except for the VA-211c line, which had a significantly lower cookie diameter. In contrast, Blacksburg experimental lines had varying cookie diameters when compared to Massey (B). Of all the Blacksburg experimental lines, with and without 1B/1R, the following lines had cookie diameters that were significantly greater than Massey (B): VA-46, VA-50c, and VA-237. Compared to Massey, Blacksburg experimental lines VA-211c, VA-241c, VA-247c, VA-251c and VA-351c had significantly reduced cookie diameters, and VA-209, VA-329 and VA-343c lines had cookie diameters that were not significantly different. Comparing Pair #1 (W & B), the experimental sister lines VA-46 and VA-50c had cookie diameters that were not significantly different from one another. The cookie diameter of VA-211c (W & B) was significantly reduced compared to its sister line VA-209 (W & B) (Pair #2). Pair #3 experimental sister lines, Warsaw location, had cookie diameters that were not significantly different from each other. Blacksburg Pair #3, however, had different results. All three 1B/1R lines in Pair #3 had significantly reduced cookie diameters compared to their sister line without 1B/1R. The VA-247c (B) and VA-251c (B) lines, Pair #3, had similar cookie diameters, while VA-241c (B) had a cookie diameter that was significantly different from both 1B/1R lines. Once again, Warsaw Pair #4 experimental sister lines had similar cookie diameters. From Blacksburg, 1B/1R lines VA-343c and VA-351c (Pair #4) were not significantly different in cookie diameters compared to their sister line VA-329 (Pair #4). However, the cookie diameters of VA-343c (B) and VA-

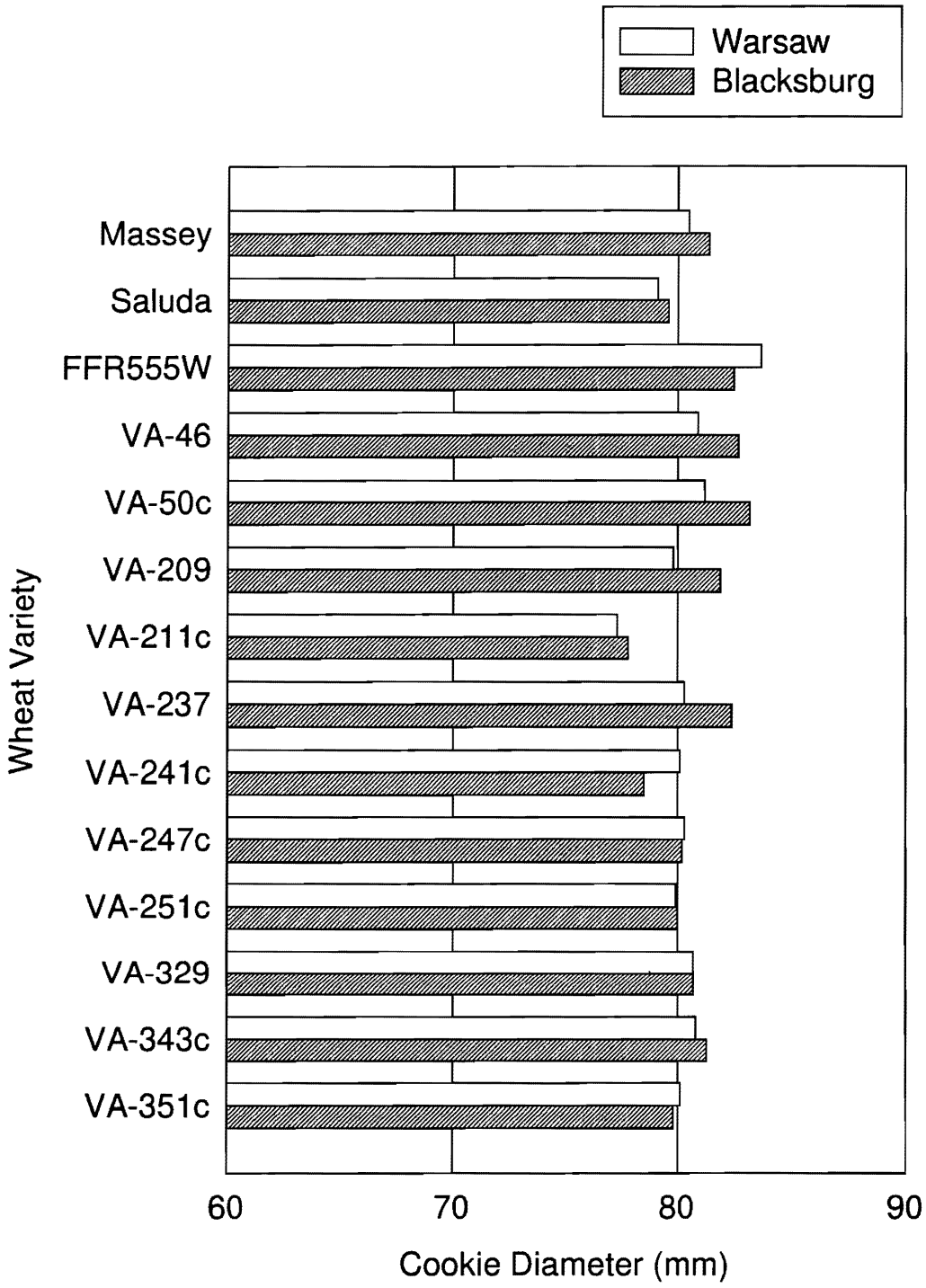


FIGURE 9. Mean[1] cookie diameter of experimental wheats (c = variety with 1B/1R). ([1]n = 3)

351c (B) were significantly different. The Warsaw VA-211c line had a significantly reduced cookie spread compared to all other experimental wheat varieties, which is usually undesirable for making quality cookies. Blacksburg VA-211c had a similar cookie diameter to that of VA-241c (B), but was significantly different (reduced cookie diameter) compared to all other Blacksburg experimental wheats.

Among the experimental common wheats, the FFR555W flour proved to have good baking quality for making cookies - greatest spread (Figure 9). According to Abboud et al. (1985b), a good quality cookie flour produces a dough with a greater spreading rate. For sugar snap cookies, this would be a medium strength flour of about 8 to 9 % protein (Tanilli, 1976). The FFR555W had a flour protein content of ~ 8.25 % for the Warsaw location and ~ 8.5% for the Blacksburg location. The VA-46 (B) and VA-50c (B) sister lines had cookie spreads closest to that of the FFR555W (W) variety, which can be attributed to their low flour protein contents of 8.4 % and 7.9 % or ~8.0 %, respectively. Parentage and location were contributors to differences in cookie diameter of the experimental wheats. The parentage (Massey*4) of Pair #1 from the Blacksburg location appeared to be the best of the experimental lines for producing flours, with and without 1B/1R, with good cookie spread comparable to FFR555W, a variety known to produce cookies with excellent spread (Griffey, 1995). The Pair #2 parentage (Massey and Saluda recurrent parents), on the other hand, appeared not to be the best choice for producing a 1B/1R flour with good cookie spread. Parentage for Pairs #3 and #4 generally appeared to produce flours, with and without 1B/1R, with cookie spreads comparable to Massey.

Research has been done on cookie spread from soft wheat flours (Abboud et al., 1985a; Doescher et al., 1987a; Doescher et al., 1987b; Gaines, 1985; Gaines and Donelson, 1985; Tanilli, 1976; Yamasaki et al., 1977) and some whole wheat soft flours (Gaines and Donelson, 1985). No research has been conducted on cookie spread from

cookies made with soft 1B/1R wheats. Therefore, the results from this study are the first to indicate that several of the 1B/1R experimental wheats behaved as a normal soft wheat flour when compared to the cookie diameters with those of Massey and the other two common wheats, Saluda and FFR555W.

4.07b Cookie Height

Mean cookie stack heights of experimental wheats are illustrated in Figure 10. Appendix H gives the significant differences in cookie heights between the experimental varieties. A lower cookie stack height is usually desirable. Of the three common wheats or checks, the FFR555W cookie variety had a significantly lower cookie height than the other two checks, both locations. The Massey (W) and Saluda (W) varieties were not significantly different in cookie height, but Massey (B) and Saluda (B) were. As with the Warsaw cookie diameters, the mean cookie stack heights of all the Warsaw experimental lines, with and without 1B/1R, were not significantly different from Massey's cookie stack height with the exception of VA-211c. Of the Blacksburg experimental wheats, VA-50c had a significantly reduced height, and the VA-211c, VA-241c, VA-247c, VA-329 and VA-351c lines had significantly increased cookie heights compared to Massey. The VA-50c (B) line had a cookie height similar to that of FFR555W, and was significantly lower compared to its sister line VA-46 cookie height and all other Blacksburg experimental lines. Warsaw VA-46 and VA-50c sister lines had different cookie heights when compared to one another, with the VA-50c cookie height being significantly reduced. From both locations, the sister lines in Pair #2 (VA-209 and VA-211c) had very different cookie heights. The VA-211c line had a significantly increased cookie height which is undesirable for most cookies. Once again, the Warsaw Pair #3 sister lines (all 4) had similar cookie heights as well as cookie diameters. Cookie heights of the Blacksburg 1B/1R lines in Pair #3 (VA-241c, VA-247c and VA-251c) were not significantly different from each other. However, all three 1B/1R lines did have

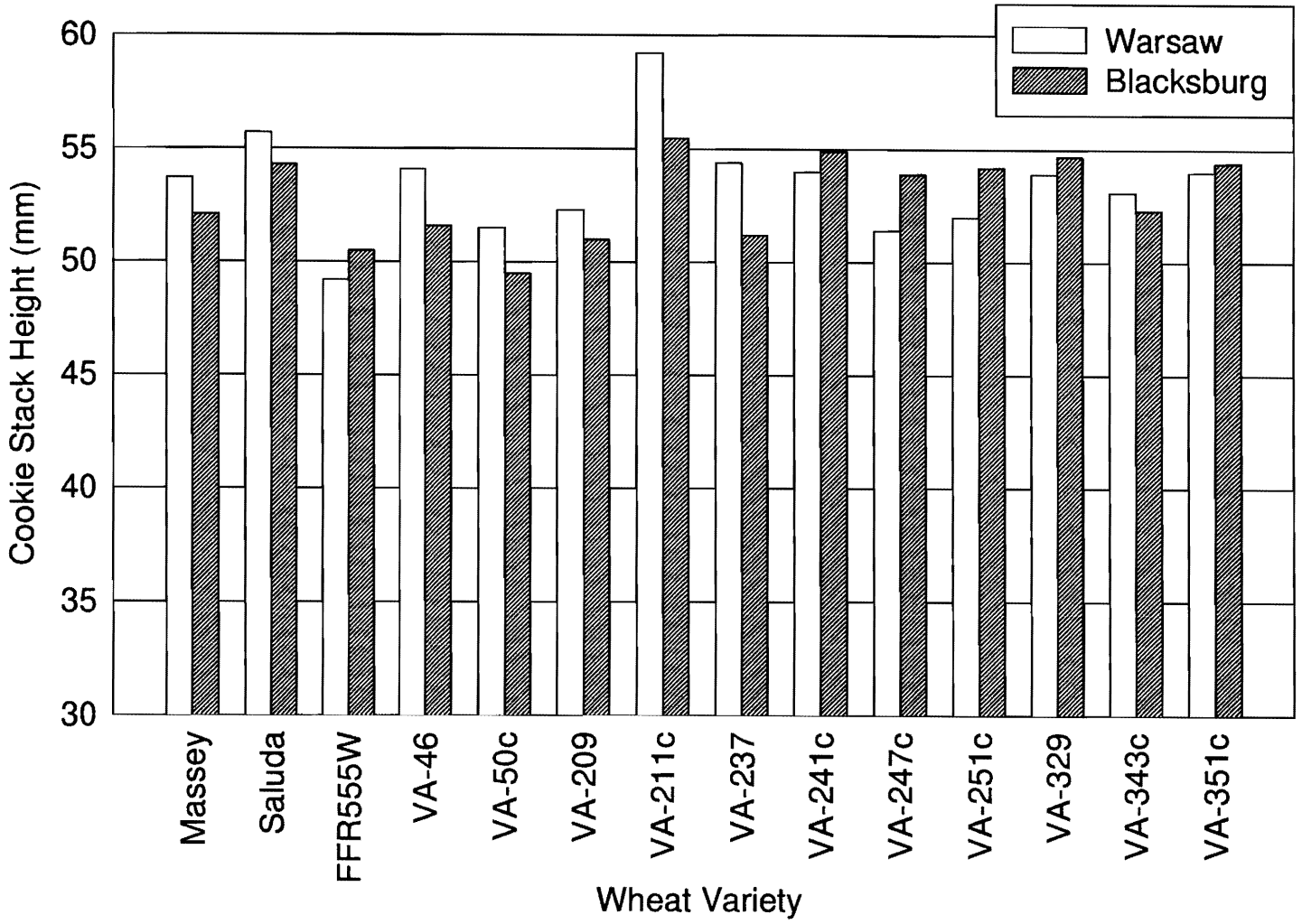


FIGURE 10. Mean[1] cookie height of experimental wheats (c = variety with 1B/1R). ([1]n = 3)

significantly different cookie height compared to the sister line VA-237 (B). In Pair #4, cookie heights of the two Blacksburg sister lines VA-329 and VA-351c were similar, whereas the cookie height of VA-343c (B) was not. All three Warsaw experimental sister lines in Pair #4 (VA-329, VA-343c and VA-351c) had cookie heights that were not significantly different from each other.

The parentage of the VA-50c (Massey*4/Balkan) line appeared to be good in producing a 1B/1R flour that gives good cookie height and comparable to FFR555W. In contrast, the VA-211c parentage (Massey/3/Massey*3/Balkan//Saluda), including Massey and Saluda, produced a 1B/1R flour that resulted in significantly increased cookie heights. The Blacksburg VA-211c cookie height was similar to that of Saluda, and Warsaw VA-211c had a cookie height that was greater than the Saluda cookie height. Parentage of Pairs #3 and #4 did not have an impact on cookie height of the experimental lines from both locations, but location did. Therefore, the presence of 1B/1R did not have an adverse effect on cookie height.

4.08 DOUGH STICKINESS

Dough stickiness of each experimental dough was determined by use of the "Schwarzlaff-Shephard Dough Stripping" method. Mean dough stripping (peeling) times were obtained for four different weights: 10 g, 15 g, 20 g and 25 g for each experimental dough as given in Table 6. For raw data see Appendix I. The following time ranges were obtained for each weight (including both locations): 10 g, 0.56 minutes (min.) to 10.70 min.; 15 g, 0.44 min. to 5.78 min.; 20 g, 0.35 min. to 5.07 min.; and 25 g, 0.26 min. to 3.50 min.

The common wheats, Massey (control), Saluda and FFR555W, had varying degrees of dough stickiness, of which Saluda was significantly more sticky for both locations (Figures 11 and 12). Massey and FFR555W varieties were not significantly

TABLE 6. Mean[1] dough peel times (minutes) of experimental wheats for weights 10, 15, 20, 25 grams.

	Weight							
	10 grams		15 grams		20 grams		25 grams	
Variety	W	B	W	B	W	B	W	B
Massey	1.14d[2]	1.20cde	0.73fgh	0.55ef	0.59fg	0.46ef	0.61cd	0.43cde
Saluda	10.70a	3.01a	5.78a	1.84b	5.07a	1.27b	3.50a	0.87b
FFR555W	0.75d	0.73de	0.54h	0.60ef	0.40g	0.49ef	0.26d	0.26e
Pair #1								
VA-46	1.14cd	0.55e	1.12ef	0.46f	0.72efg	0.51ef	0.53cd	0.45cde
VA-50c[3]	0.96d	1.21cde	0.90efgh	0.82de	0.74efg	0.60def	0.51cd	0.44cde
Pair #2								
VA-209	4.22b	3.01a	2.28b	2.51a	2.14b	1.80a	1.46b	0.90ab
VA-211c	2.48c	1.92b	1.41cde	1.21c	1.02cdef	1.02bcd	0.61cd	1.18a
Pair #3								
VA-237	0.74d	0.61e	0.61gh	0.48ef	0.43fg	0.41ef	0.53cd	0.30de
VA-241c	1.18d	1.31bcd	1.06efg	0.98cd	0.87defg	0.72def	0.72c	0.50cde
VA-247c	1.56cd	1.51bc	1.24de	0.97cd	1.21cde	1.22bc	1.26b	0.51cde
VA-251c	1.58cd	1.87bc	1.27cde	1.21c	1.55c	0.83cde	0.76c	0.74bc
Pair #4								
VA-329	1.90cd	0.56e	1.74c	0.44f	1.43cd	0.35f	0.86c	0.36de
VA-343c	1.41cd	1.34bcd	0.74fgh	0.75def	0.64efg	0.63def	0.65cd	0.53cde
VA-351c	2.53c	1.53bc	1.67cd	1.06cd	1.50c	0.95bcd	0.87c	0.61bcd

[1] n = 3

[2] Numbers in the same column with the same letter(s) are not significantly different at P > 0.05.

[3] c = variety with 1B/1R translocation

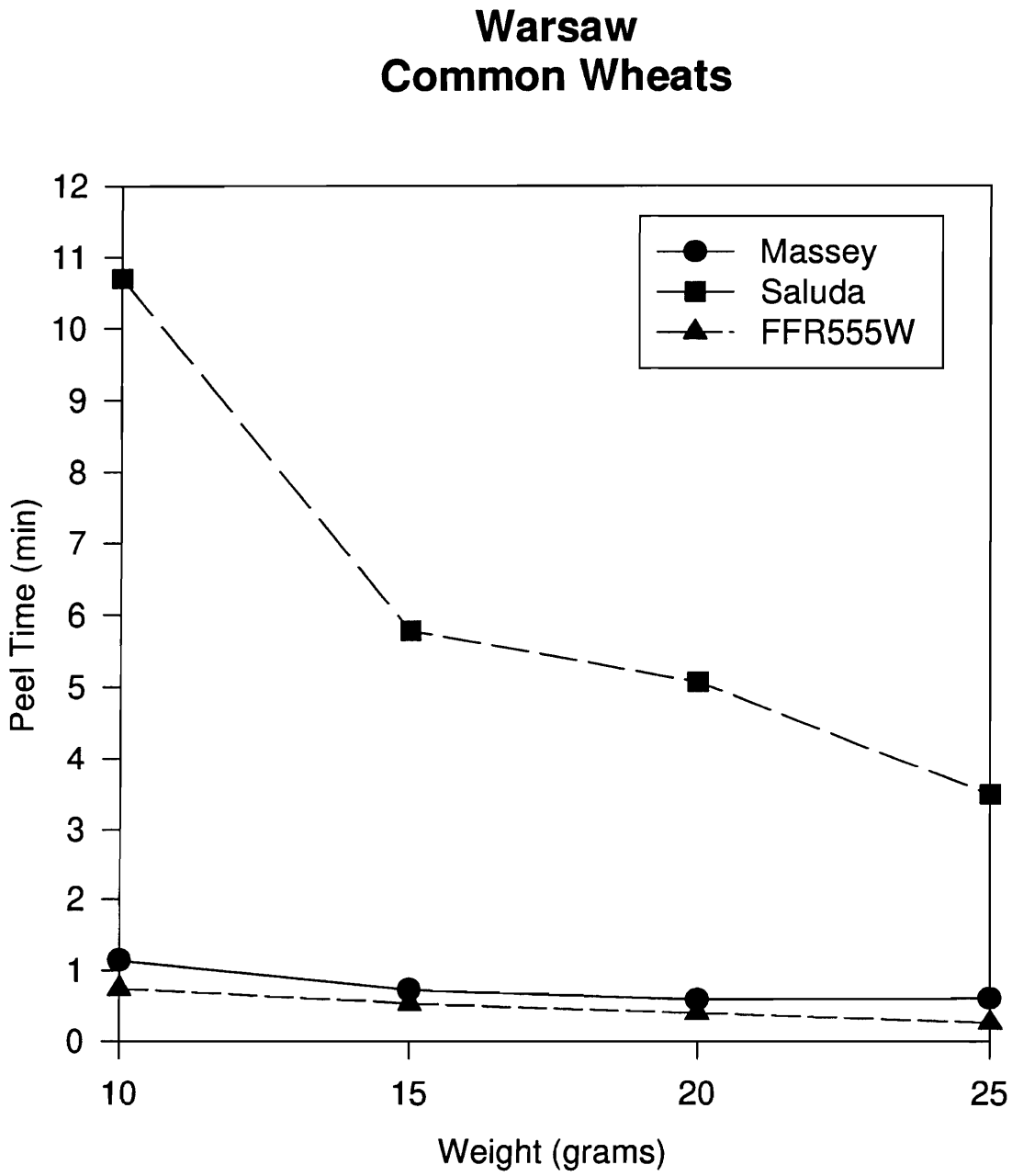


FIGURE 11. Mean[1] dough peel time vs. weight for Warsaw experimental common wheats. ([1]n = 3)

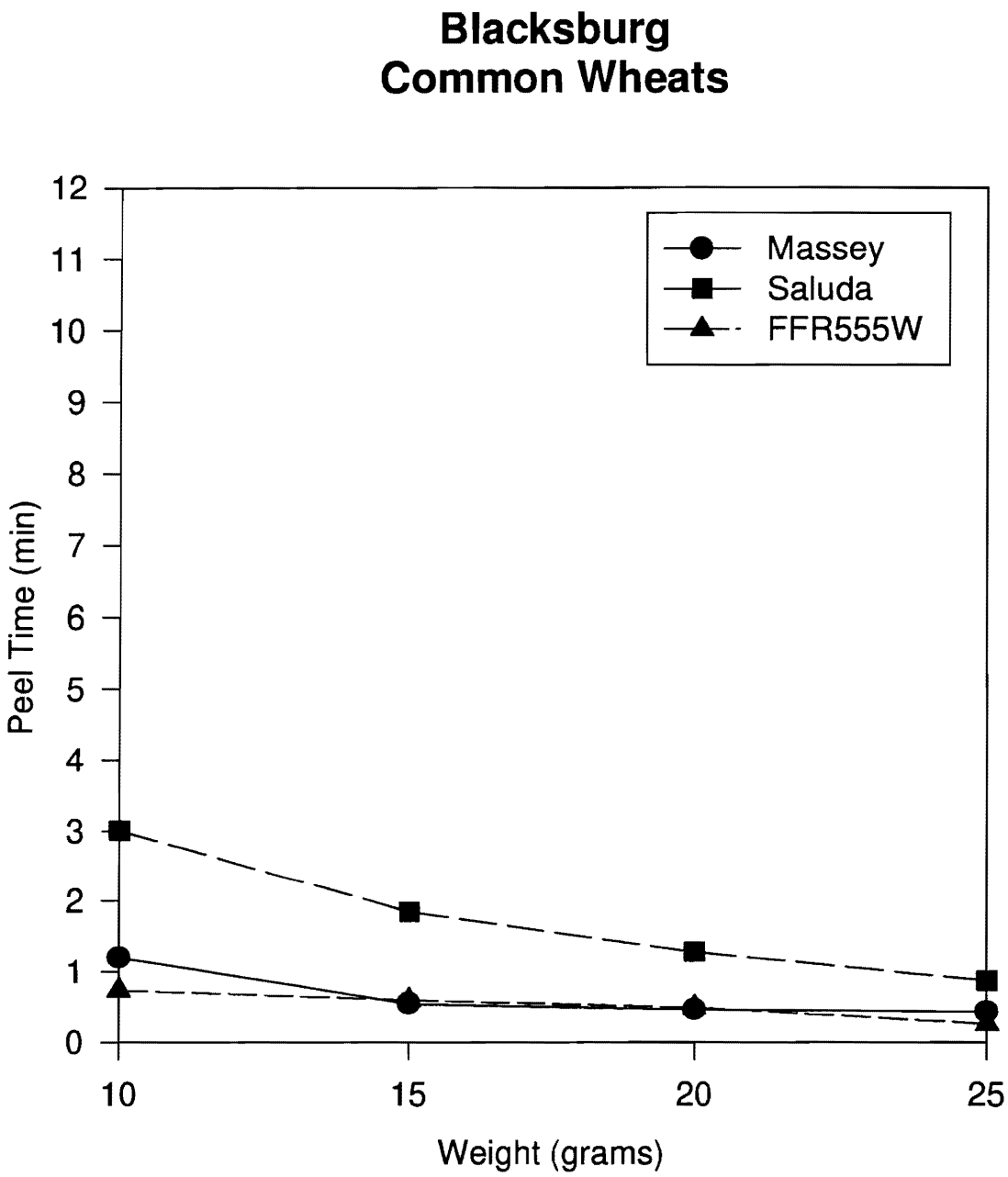


FIGURE 12. Mean[1] dough peel time vs. weight for Blacksburg experimental common wheats. ([1]n = 3)

different from each other in terms of dough stickiness, while the varieties vary for other quality traits. As shown in Table 6, the FFR555W (W and B), VA-46 (B), VA-237 (W and B) and VA-329 (B) varieties had the least amount of dough stickiness, which in most cases were significant when compared to the other experimental doughs. These particular dough varieties all lack the 1B/1R translocation. To the other extreme, Saluda, VA-209 and VA-211c flours had significantly stickier doughs in comparison to most other varieties.

In general, as shown in Figures 13 and 14, the sister lines in Pair number 1 (VA-46 and VA-50c) were not significantly different from each other nor Massey in dough stickiness. Pair number 2 had quite interesting dough stickiness results as can be seen in Figures 15 and 16. The VA-209 dough was significantly more sticky than the sister line VA-211c and even the Massey. Figures 17 and 18 illustrate dough stickiness for Pair number 3 (VA-237, VA-241c, VA-247c and 251c). The VA-237 dough was not significantly different from Massey in dough stickiness. Dough samples from VA-241c were stickier than the VA-237 variety and Massey, but not significantly different. The VA-247c and VA-251c doughs, however, exhibited an increase in dough stickiness which were generally found to be significant. Wheat dough VA-343c (W) had a significantly decreased dough stickiness compared to wheat dough VA-329, and was not significantly different from the Massey. However, the VA-343c (B) dough had an increase in dough stickiness, although it was not different from Massey and VA-329. (Figures 19 and 20). The VA-351c (W) variety exhibited greater stickiness than the VA-329 sister line, but not significantly. However, the Blacksburg VA-351c line was significantly greater in stickiness than the VA-329 (B) sister line (Figure 20). In general, both 351c (W and B) doughs had significantly greater dough stickiness than the Massey.

In addition, two commercial flours were evaluated for dough stickiness to help establish a level of dough stickiness to compare the experimental wheats. The two

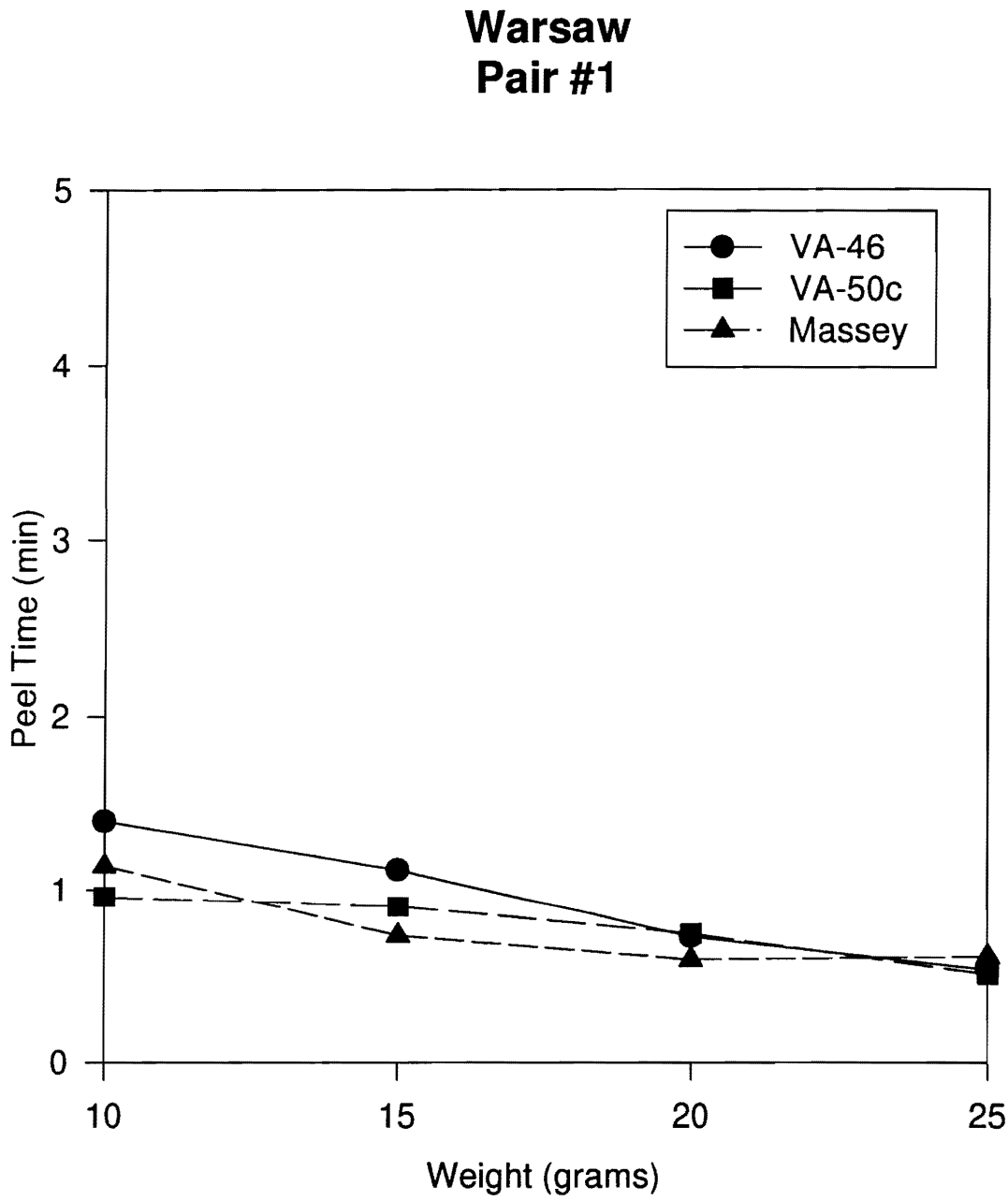


FIGURE 13. Mean[1] dough peel time vs. weight for Warsaw Pair #1 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

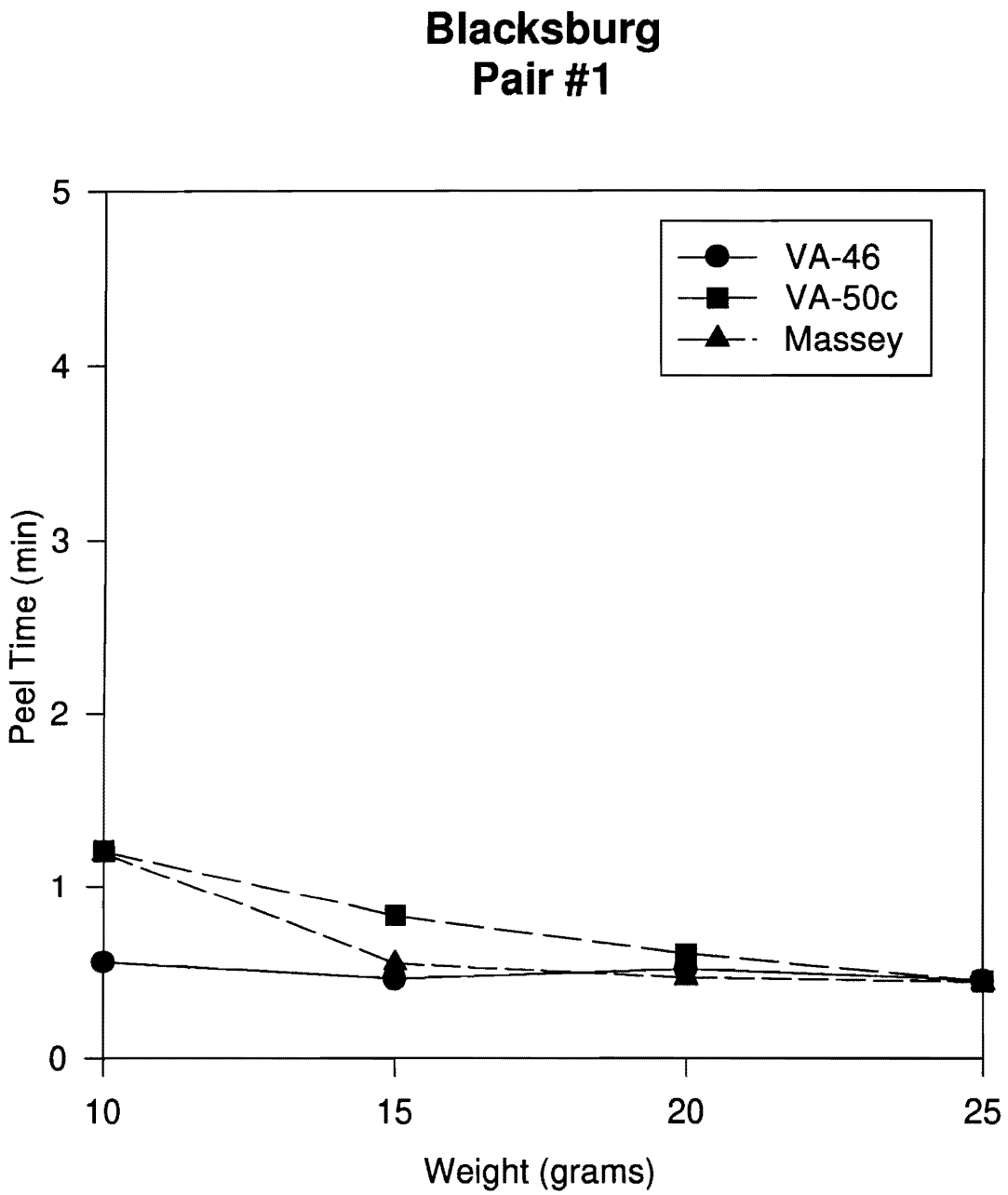


FIGURE 14. Mean[1] dough peel time vs. weight for Blacksburg Pair #1 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

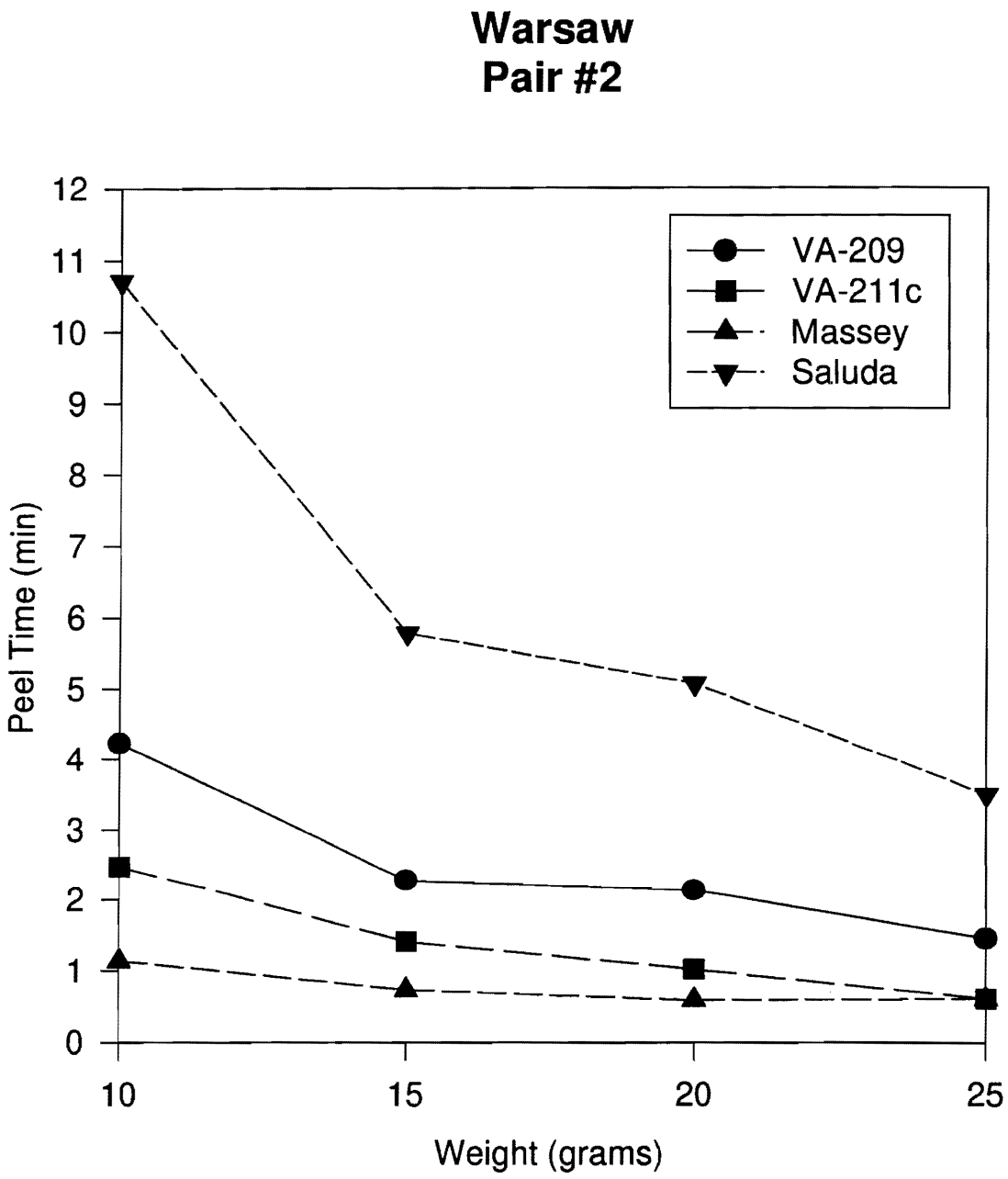


FIGURE 15. Mean[1] dough peel time vs. weight for Warsaw Pair #2 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

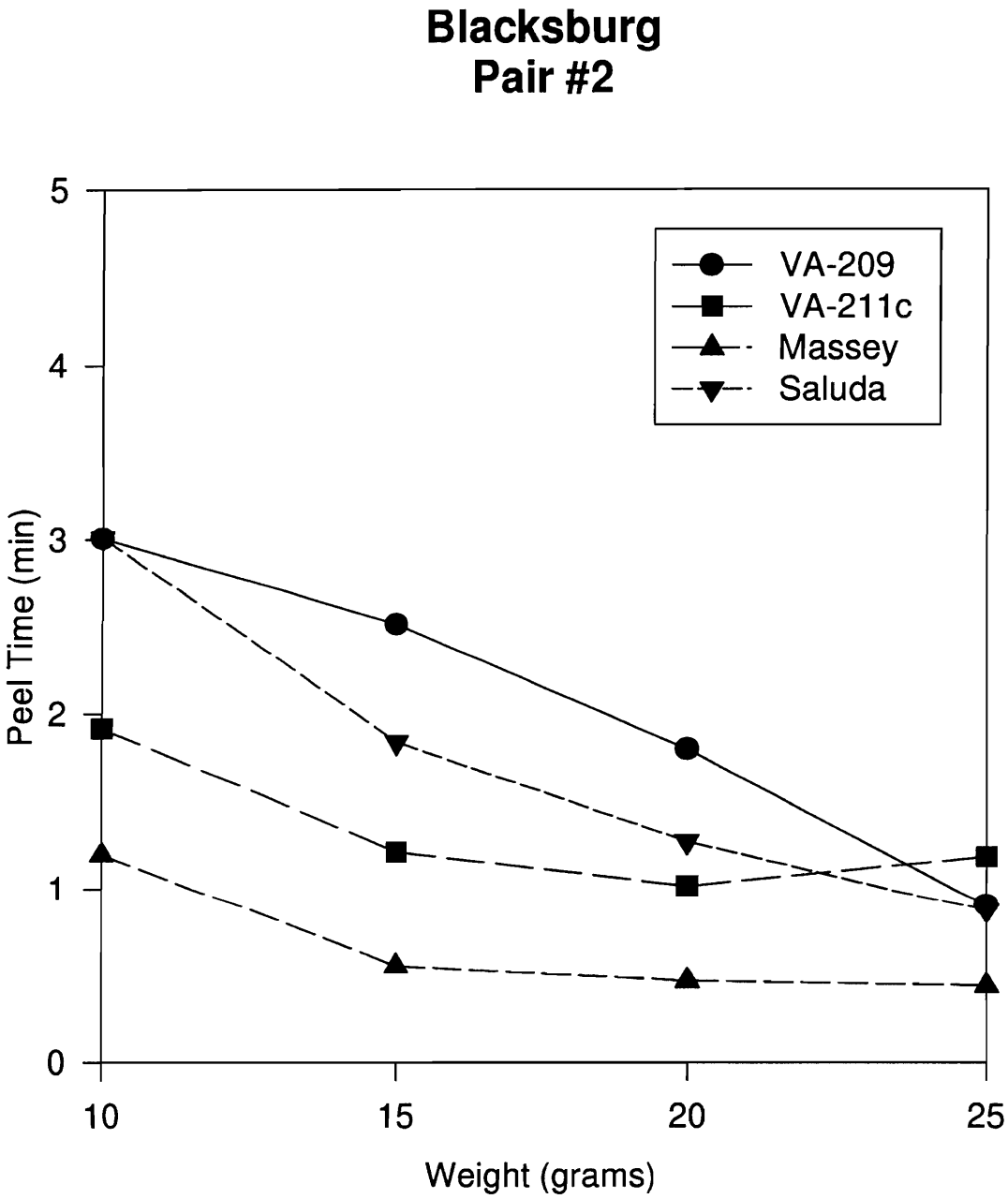


FIGURE 16. Mean[1] dough peel time vs. weight for Blacksburg Pair #2 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

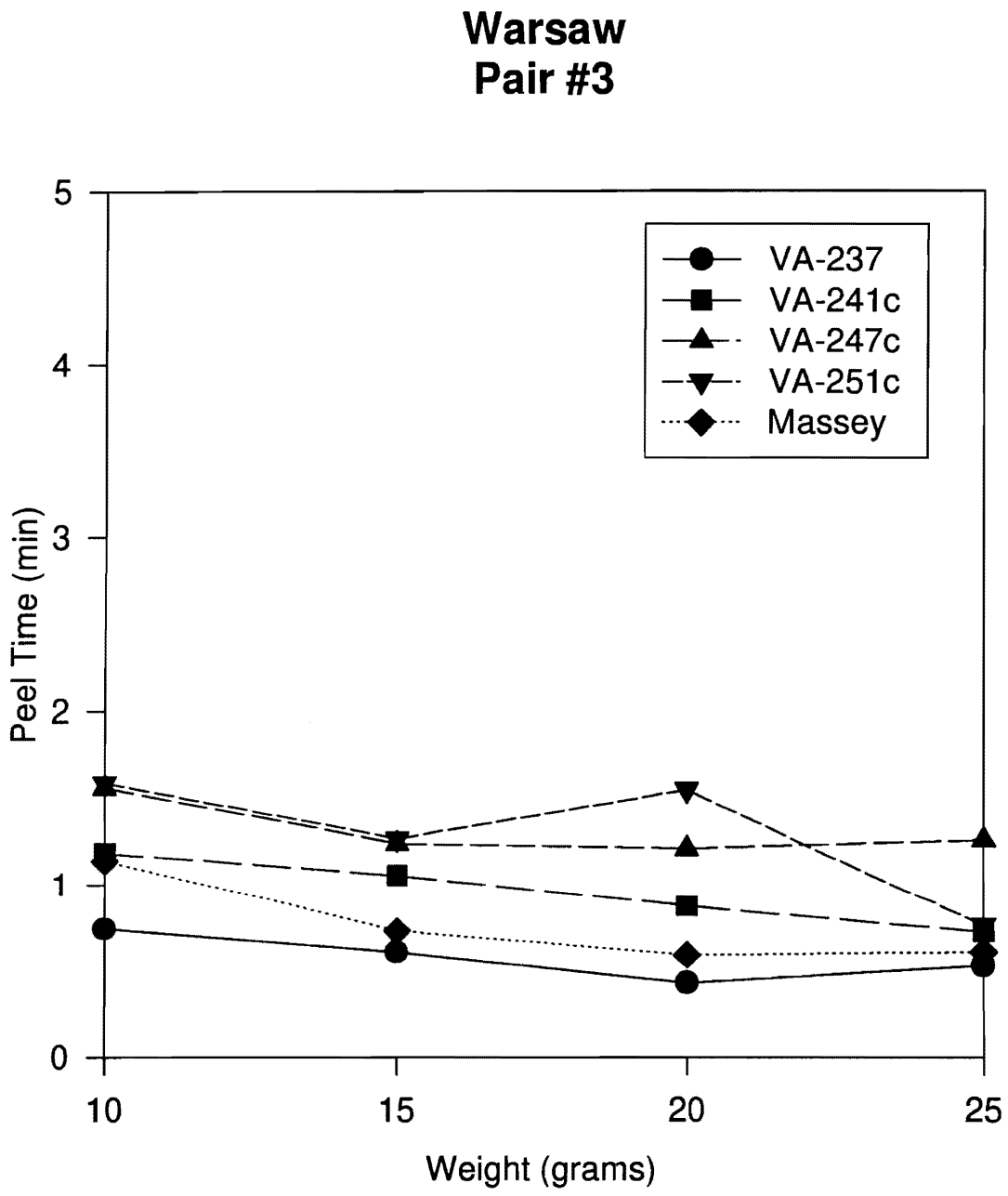


FIGURE 17. Mean[1] dough peel time vs. weight for Warsaw Pair #3 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

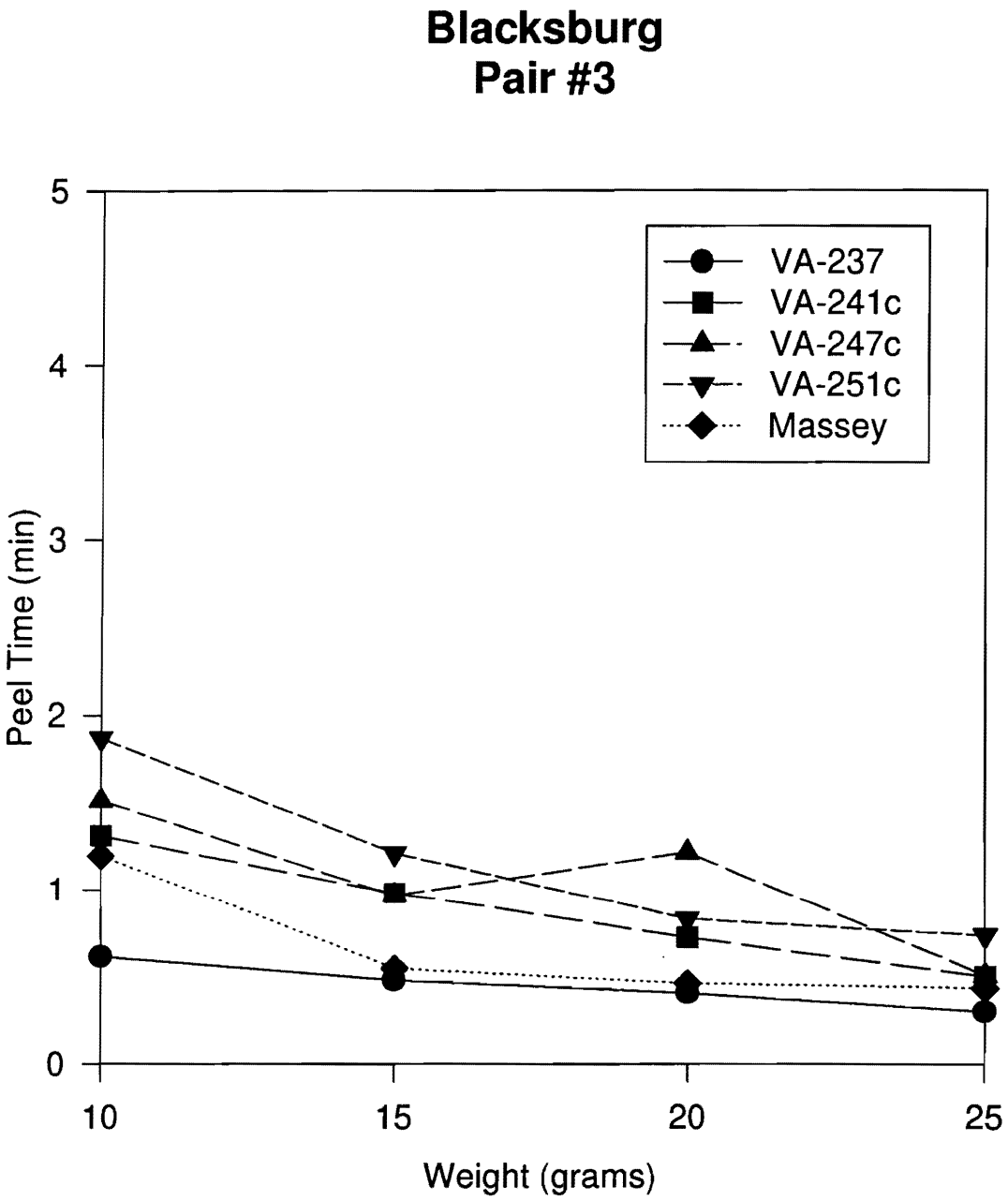


FIGURE 18. Mean[1] dough peel time vs. weight for Blacksburg Pair #3 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

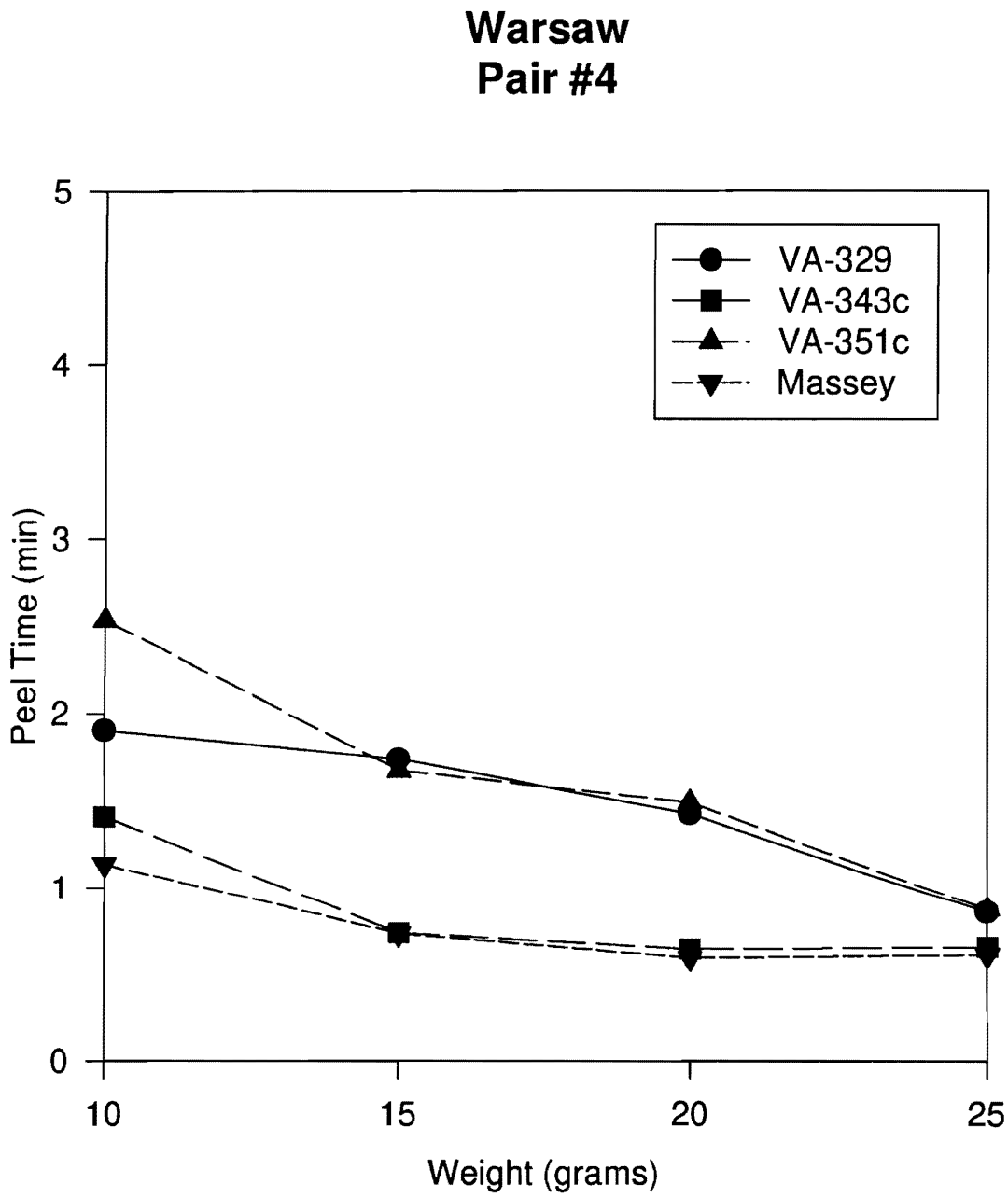


FIGURE 19. Mean[1] dough peel time vs. weight for Warsaw Pair #4 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

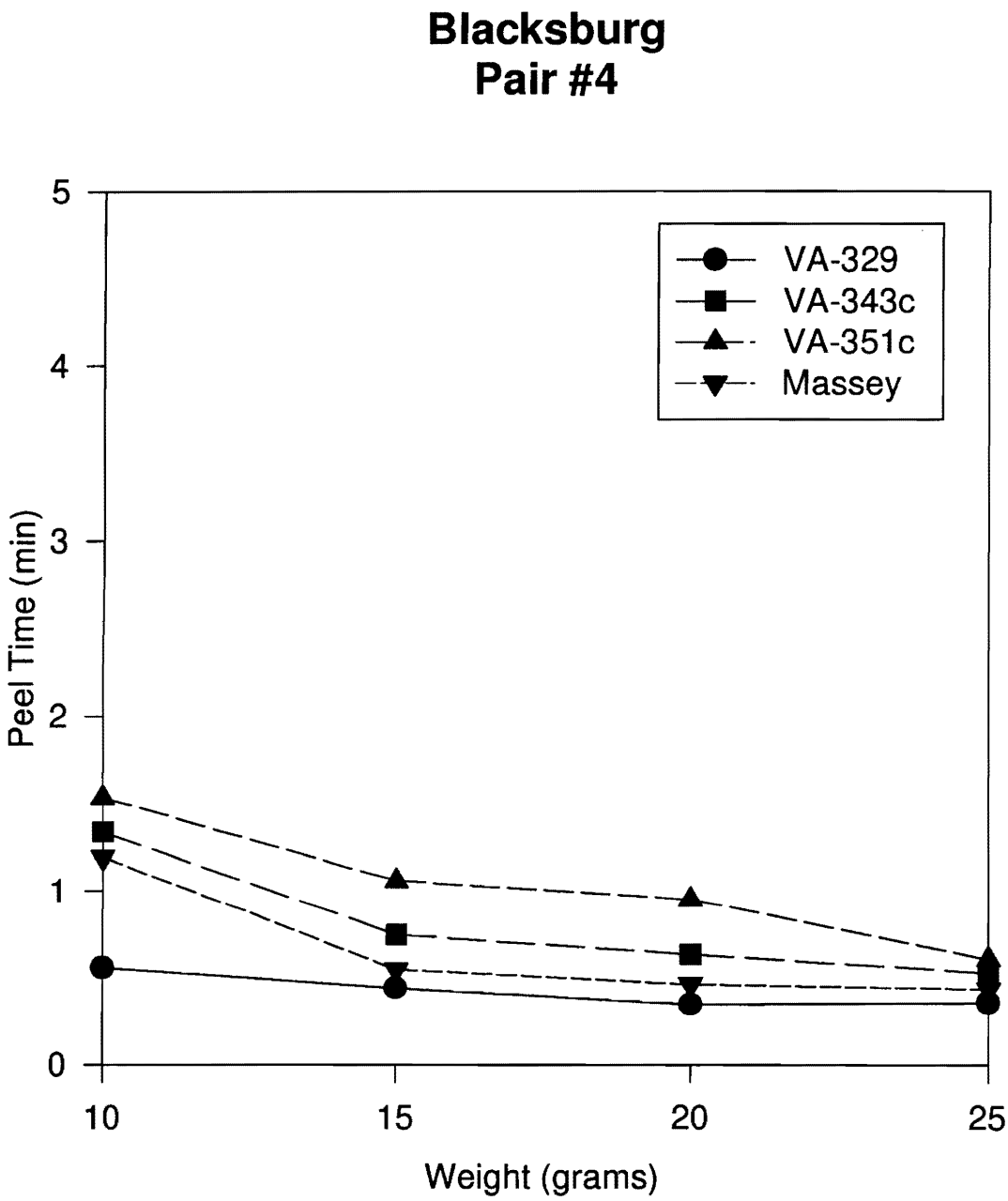


FIGURE 20. Mean[1] dough peel time vs. weight for Blacksburg Pair #4 experimental wheats (c = variety with 1B/1R). ([1]n = 3)

additional flours were White Lily (WL) (The White Lily Foods Company, Knoxville, TN), a soft wheat flour, and Pillsbury's Best Bread Flour (PB) (The Pillsbury Company, Minneapolis, MN), a hard wheat flour. The mean peel times for the two commercial flours were found to be as follows: 10 g, 0.20 min. (WL) and 1.52 min. (PB); 15 g, 0.18 min. (WL) and 0.88 min. (PB); 20 g, 0.18 min. (WL) and 0.69 min. (PB); and 25 g, 0.12 min. (WL) and 0.49 min. (PB). It is evident from the peel times that the WL flour produced a dough that was basically not sticky. The WL dough strip peeled quickly for all four weights. None of the experimental varieties compared with the WL flour in terms of dough stickiness. It had the least amount of stickiness compared to all experimental wheat varieties, including the common wheats. The PB flour, however, had a dough with stickiness quite similar to most of the experimental wheat varieties except Saluda and VA-209, which had a greater dough stickiness than the PB flour.

Overall, increases and decreases in dough stickiness of the experimental flour doughs depended on variety and location. The presence of the 1B/1R translocation could not be directly related to dough stickiness, for some of the experimental flour doughs without the 1B/1R characteristic exhibited the same or much greater stickiness than those with the 1B/1R. Some of the 1B/1R wheats were comparable to the control and their respective sister lines, and in some cases even showed a decrease in stickiness. In general, the 1B/1R wheats with an increase in stickiness were not significant. Similar findings were obtained by Dhaliwal et al. (1990), who found a soft-grained wheat and its 1B/1R derivative not to be significantly different in dough stickiness. Other research has indicated that hard-grained 1B/1R wheat derivatives exhibit increased dough stickiness (Dhaliwal and MacRitchie, 1990; Dhaliwal et al., 1987; Dhaliwal et al., 1988; Dhaliwal et al., 1990; Martin and Stewart, 1986; Moonen and Zeven, 1984; Zeller et al., 1982). Differences in dough stickiness have been attributed to a shift in the protein composition of the 1B/1R wheats (Dhaliwal and MacRitchie, 1990). In the current study, major

differences in dough stickiness of the experimental doughs were found in Saluda (W and B) and VA-209 (W and B) varieties, both lacking 1B/1R. Interestingly, these two varieties did exhibit differences in protein composition compared to the other experimental wheats (SDS-PAGE results section). Both Saluda and VA-209 lacked the high molecular weight (HMW) subunits (bands) 5 and 12. High molecular weight subunits have been found to contribute greatly to dough handling properties (Graybosch et al., 1990; Howes et al., 1989; Law and Payne, 1983; Payne et al., 1981). The two varieties also have an additional protein around 50kd, which the other experimental wheats do not have. Whether these differences in protein composition affect dough stickiness still needs to be determined. Differences in flour protein content had no effect on dough stickiness. One noticeable aspect was that the Saluda and VA-209 varieties, in general, had higher MTIs and low MTSs in comparison to the other experimental flours. This finding is in agreement with (Dhaliwal et al., 1987; Dhaliwal et al., 1990; Martin and Stewart, 1986), who found doughs with greater stickiness to have a reduced MTS and a higher MTI. Thus, in conclusion, the 1B/1R translocation had no adverse effect on dough stickiness.

The dough stripping method, in general, was reproducible. Some doughs reproduced better than others (see Appendix I for replication data). The stickier doughs often had varying times between replications for the same weights. Even though the laboratory was climate controlled, a contributing factor to this occurrence is that the doughs may have lost or picked up moisture depending on the relative humidity in the room at time of dough strip sandwich preparation. For improvement of the method, the Nalgene® box needs to be larger with longer gloves and wider glove openings, the fan needs to be directed more away from the dough strip and the work area may need to be in a chamber with controlled temperature and atmosphere to prevent fluctuations in temperature and relative humidity outside the box while preparing the dough samples.

The "Schwarzlaff-Shephard Dough Stripping" method has a possible future in measuring dough stickiness quantitatively with the proper modifications and some adjustments in the overall method. Further research needs to be done using the dough stripping method to determine its true feasibility for use in determining dough stickiness and its reproducibility. This method, hopefully, represents a true measurement of dough stickiness that eliminates or reduces the inclusion of the viscoelasticity of the dough, which often masks or overcomes the real adhesion capability of the dough that is to be measured.

4.09 SDS-PAGE (PROTEIN ANALYSIS)

Figures 21 - 23 represent SDS-PAGE gels of the experimental wheats. The gels were interpreted regarding which high molecular weight (HMW) glutenin subunits were or were not present in the respective wheat varieties as well as other proteins that are characteristic for regular wheats and/or the 1B/1R varieties. Protein analysis of the common experimental wheats indicated that all three had different protein compositions as illustrated in Figure 21. Massey (control) contained bands 1, 5, 8, 7, 9, 10 and 12 of the HMW subunits, whereas Saluda contained bands 2, 2 prime (2*), 6, 8, 9 and 10, and FFR555W contained bands 2*, 5, 6, 8, 9 and 10, as shown in Table 7. Differences in protein composition are common and can be expected due to variations in genetic backgrounds of the parents from which the wheats were bred (Graybosch and Morris, 1990; Graybosch et al., 1990; Law and Payne, 1983; Zhen and Mares, 1992). Also associated with genetics, the 1B/1R wheats (short arm of the rye (1R) replacing the short arm of the wheat (1B)) also showed distinct protein composition patterns as can be seen in Figures 21, 22, and 23. All the 1B/1R experimental wheats contained the following HMW subunits: 1, 5, 7, 8, 9, 10, and 12. Bands 7 and 9 are characteristic for 1B/1R wheats (Graybosch et al., 1990). According to Dhaliwal et al. (1988) and Howes et al.

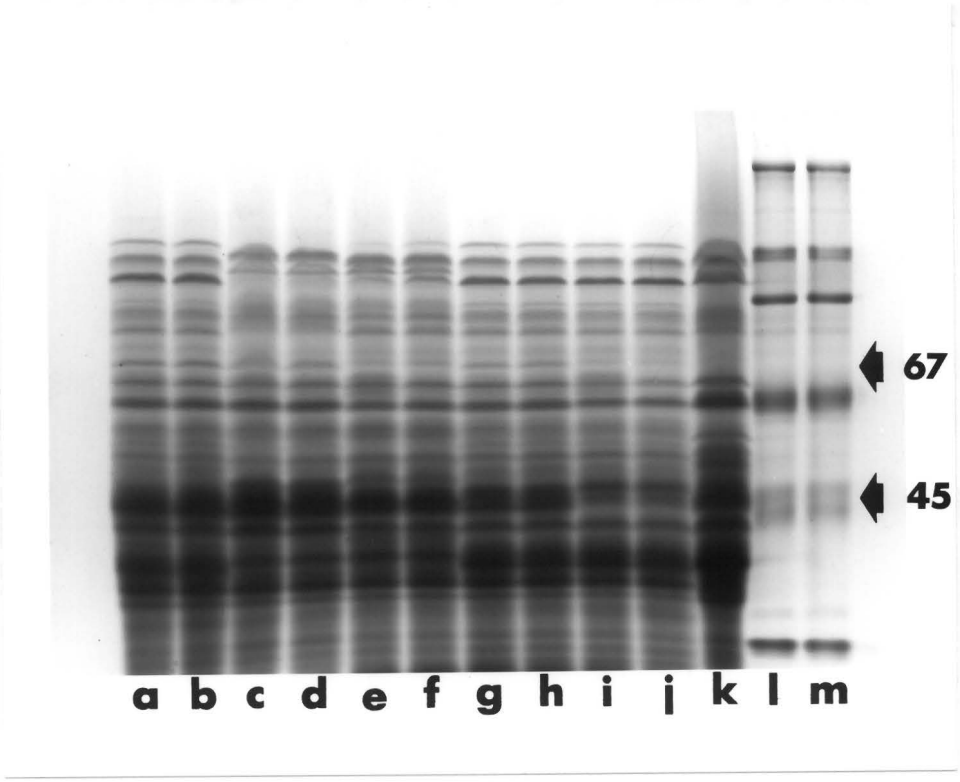


FIGURE 21. Comparison by SDS-PAGE of experimental wheats with and without the 1B/1R translocation. From left to right: a = Massey (Warsaw), b = Massey (Blacksburg), c = Saluda (Warsaw), d = Saluda (Blacksburg), e = FFR555W (Warsaw), f = FFR555W (Blacksburg), g = VA-46 (Warsaw), h = VA-46 (Blacksburg), i = VA-50c[1] (Warsaw), j = VA-50c (Blacksburg), k= Neepawa (Control), l = Molecular weight marker and m = Molecular weight marker. Arrows indicate proteins lacking in 1B/1R wheats. ([1]c = 1B/1R)

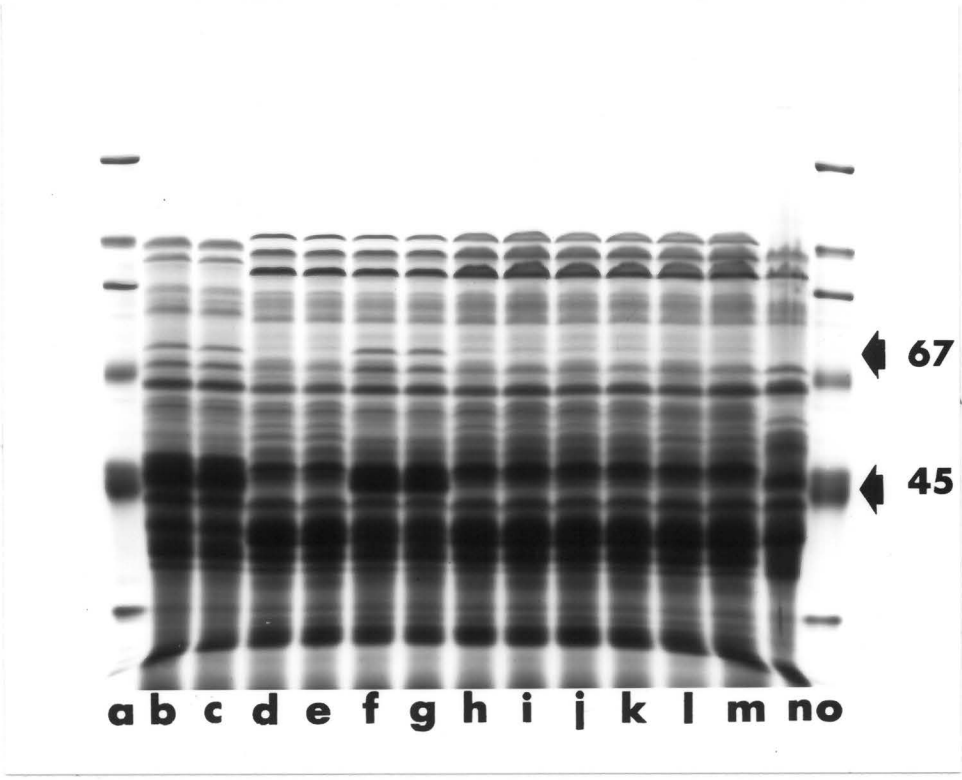


FIGURE 22. Comparison by SDS-PAGE of experimental wheats with and without the 1B/1R translocation. From left to right: a = Molecular weight marker, b = VA-209 (Warsaw), c = VA-209 (Blacksburg), d = VA-211c[1] (Warsaw), e = VA-211c (Blacksburg), f = VA-237 (Warsaw), g = VA-237 (Blacksburg), h = VA-241c (Warsaw), i = VA-241c (Blacksburg), j = VA-247c (Warsaw), k = VA-247c (Blacksburg), l= VA-251c (Warsaw), m = VA-251c (Blacksburg), n = Neepawa (Control) and o = Molecular weight marker. Arrows indicate proteins lacking in 1B/1R wheats. ([1]c = 1B/1R)

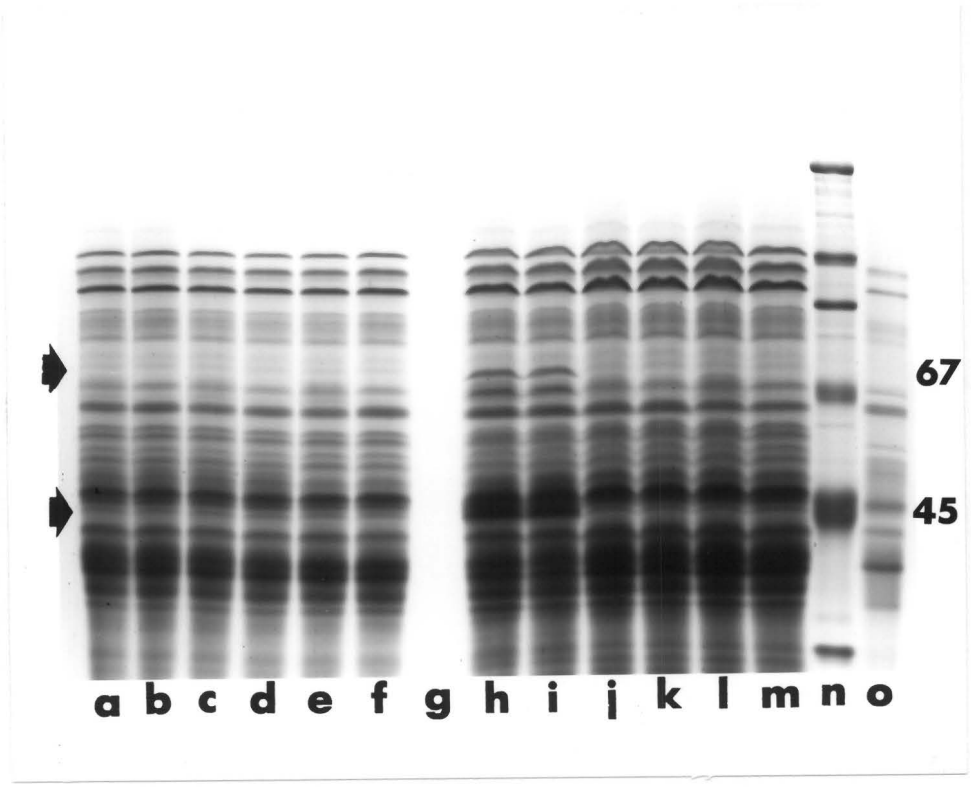


FIGURE 23. Comparison by SDS-PAGE of experimental wheats with and without the 1B/1R translocation. From left to right: (first six are repeats) a = VA-241c[1] (Warsaw), b = VA-241c (Blacksburg), c = VA-247c (Warsaw), d = VA-247c (Blacksburg), e = VA-251c (Warsaw), f = VA-251c (Blacksburg), g = blank, h = VA-329 (Warsaw), i = VA-329 (Blacksburg), j = VA-343c (Warsaw), k = VA-343c (Blacksburg), l= VA-351c (Warsaw), m = VA-351c (Blacksburg), n = Molecular weight marker, and o = Neepawa (Control). Arrows indicate proteins lacking in 1B/1R wheats. ([1]c = 1B/1R)

TABLE 7. Protein composition of experimental wheats by SDS-PAGE.

	Variety													
Band[1]	Mass[2]	Saluda	FFR[3]	46	50c[4]	209	211c	237	241c	247c	251c	329	343c	351c
1	x			x	x		x	x	x	x	x	x	x	x
2		x				x								
2*		x	x			x								
5	x		x	x	x		x	x	x	x	x	x	x	x
6		x	x			x								
7	x			x	x		x	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x	x	x	x	x	x	x	x
9	x	x	x	x	x	x	x	x	x	x	x	x	x	x
10	x	x	x	x	x	x	x	x	x	x	x	x	x	x
12	x		x	x	x		x	x	x	x	x	x	x	x
67k[5]	x	x	x	x		x		x				x		
45k	x	x	x	x		x		x				x		

[1] Band = High molecular weight protein subunit.
[2] Mass = Massey.
[3] FFR = FFR555W.
[4] c = 1B/1R translocation.
[5] k = kilodaltons.

(1989), the "8" band is lacking in many of the 1B/1R wheat varieties. This particular HMW glutenin subunit is coded by a gene on the 1B chromosome arm (Howes et al., 1989; Payne et al., 1982; Payne and Lawrence, 1983). However, as indicated earlier, all of the experimental 1B/1R wheats contained band 8.

One of the major noticeable differences between the varieties with and without the 1B/1R, was that the M_r 67,000 (67k) and M_r 45,000 (45k) proteins were missing in all of the 1B/1R wheats. This is in agreement with the findings of Dhaliwal et al. (1988) and Howes (1995), respectively. In comparing pairs 1, 3 and 4, all sister lines were identical in protein composition except that the 1B/1R wheats lacked the 67k and 45k proteins, and the second band of the triplet proteins were less prominent than in the sister lines without the 1B/1R. Pair number 2 however, (VA-209 and VA-211c) was an exception. The VA-209 variety did not have a similar protein composition characteristic to that of the sister line with the 1B/1R (VA-211c). The VA-209 variety did, however, have the identical protein composition as the Saluda variety. A possible reason for this difference may be attributed to the fact that the VA-209 and VA-211c varieties were also crossbred with Saluda, and the genetic background of the Saluda carried over into the VA-209 variety, but, not the VA-211c variety possibly due to the 1B/1R characteristic being present. The other sister line varieties with no 1B/1R had predominant characteristics identical to that of Massey, which would be expected since they were only crossbred with Massey.

CHAPTER V

CONCLUSIONS

Assessments of the flour quality of 1B/1R wheats have been evaluated and the following conclusions have been made:

(1) The 1B/1R characteristic does not adversely affect the moisture content of whole soft wheat.

(2) The 1B/1R translocation wheats, in general, had reduced flour yields when compared to their respective sister lines. However, location appears to be another contributing factor of flour yield, as well as the 1B/1R characteristic.

(3) There was no distinct pattern of grain protein increases or decreases due to the presence of the 1B/1R characteristic. Therefore, the 1B/1R translocation had no effect on grain protein.

(4) Flour protein percentages varied widely, and the 1B/1R translocation had no major contributing effect on flour protein as did variety and location.

(5) The 1B/1R characteristic, in general, caused no major change in water absorption of the flour.

(6) There was no evidence that the 1B/1R translocation significantly reduced dough or peak development time in the soft wheats with 1B/1R.

(7) In general, wheats with the 1B/1R translocation had greater mixing stabilities than their respective sister lines. Thus, the 1B/1R characteristic produced a positive effect in enhancing mixing stability time of the dough.

(8) The 1B/1R translocation, in general, improved the mixing tolerance index.

(9) The 1B/1R translocation had no deleterious effect on cookie spread or height when compared to their respective sister lines and even the control.

(10) Increases and decreases in dough stickiness of the experimental flour doughs depended on variety and location. The presence of the 1B/1R translocation could not be directly related to dough stickiness, and some of the experimental flour doughs without the 1B/1R characteristic exhibited the same or much greater stickiness than those with the 1B/1R.

(11) For both locations, by SDS-PAGE analysis, the 1B/1R wheats contained protein bands 7 and 9, and lacked 45k and 67k proteins, which is characteristic of 1B/1R wheats.

(12) All 1B/1R experimental wheats were confirmed as "positive" for the presence of 1B/1R by the ELISA test and were in agreement with the SDS-PAGE.

(13) The parentage, Massey/3/Massey//Saluda, produced a flour of poorer quality compared to the other experimental wheats of parentage with less or greater Massey and no Saluda; there was an obvious trend between the VA-209 and VA-211c varieties compared to the other wheat varieties.

The purpose of this study was to determine the feasibility of the "end use" of flours from soft red winter wheats possessing 1B/1R. The overall conclusion, in general, is that the 1B/1R characteristic had no adverse effect on the flour quality and dough stickiness of the wheats, and even improved mixing tolerance and stability of the wheat flour doughs when compared to sisiter lines without 1B/1R. The source of the genetic material (i.e. Massey or Saluda) had more effect on the stickiness quality than the extent of breeding with the same genetic material. Apparently some other factor in the original genetic material contributed to stickiness and not the 1B/1R. The flour of 1B/1R wheats could be used by the baking industry with the expectation of similar results in most cases as the flour without 1B/1R. As with all wheats, variety and location or environmental

conditions were significant factors of equal or greater importance than presence of 1B/1R.

CHAPTER VI

SUMMARY

Wheat is one of the major cereals of the world. Farmers must produce wheat with good yield and quality to meet the high demands for wheat flour. To reduce disease and increase wheat yield, cultivars have been developed by replacing the short arm of chromosome 1B of wheat with the short arm of the 1R chromosome from rye. This wheat-rye translocation, 1B/1R, carries linked genes which makes these wheat cultivars more disease resistant and higher yielding. Unfortunately, the 1B/1R translocation in hard wheats has been shown to produce undesirable characteristics such as dough stickiness and reduced mixing tolerance. Many promising wheat lines have been developed by crossbreeding 1B/1R lines with soft wheat in hopes of producing a 1B/1R soft wheat of good quality for use in soft wheat products. The purpose of this research was to determine the end use flour quality of soft red winter wheat possessing 1B/1R.

Fourteen soft wheat varieties (7 without and 7 with 1B/1R) grown in two locations, Warsaw and Blacksburg, were evaluated for flour quality and dough stickiness. Wheats were grown in two different locations for comparison purposes of environment. For purposes of the study, wheat varieties (Massey, Saluda, FFR555W) available to all producers were referred to as common wheats. Four groups of wheat with similar parentage but with and without 1B/1R made up the experimental wheats. All experimental wheats were harvested in mid June or early July, 1994, tempered to 14 % moisture and milled to obtain flour. Flour yield was determined for experimental wheats. Whole grain and flour protein contents of the experimental wheats were determined by Kjeldahl method using a nitrogen conversion factor of 5.7 to obtain percent protein. To investigate the properties of the experimental doughs, the Brabender farinograph was used to determine water or flour absorption of the experimental flours as well as dough

development time, MTS and MTI of the respective doughs. The shape of the farinograms provided an overall picture of the stability of the dough. To further investigate flour quality of the experimental wheats, the cookie spread test was done, obtaining mean cookie diameters and heights of cookies made with the flours. In addition to protein content, the protein composition of the experimental wheats was determined by SDS-PAGE. Presence of the 1B/1R was determined by the monoclonal antibody ELISA method.

Dough stickiness was measured using the "Schwarzlaff-Shephard Dough Stripping" method, specially designed for this study. It is the first method of its kind to measure dough stickiness quantitatively. The test was modeled after typical methodologies of the Center for Adhesives and Sealant Sciences, Virginia Tech, Blacksburg, Virginia. Flour doughs were made using fifty gram samples of flour. The amount of water to be added and mixing time was determined by farinograph analysis. Doughs were rolled out onto a clean glass plate and prepared for dough stripping. To determine peel times of dough strips four different weights were used (10, 15, 20 and 25 grams). Weights (one at a time, successively) were hung onto the dough strip and timed for how long it took the dough strip to peel off the glass plate for 1/2 inch (one dough strip for all four weights). Results were plotted on a graph as time (min) vs weight (g) for each experimental dough.

The results indicated that the 1B/1R characteristic does not adversely affect moisture content of whole soft wheat. Location appeared to be a contributing factor as well as the 1B/1R characteristic in reducing flour yields of the 1B/1R wheats. The 1B/1R translocation had no effect on grain protein, and was not a major contributing effect on flour protein like variety and location. No major change in water absorption of the flour was observed with the presence of 1B/1R. Farinograms indicated there was no evidence that the 1B/1R translocation significantly reduced dough development time. In general,

wheats with 1B/1R had greater mixing stabilities than their respective sister lines, and therefore 1B/1R had a positive effect. Additionally, 1B/1R, in general, improved the MTI. The 1B/1R translocation had no deleterious effect on cookie spread or height. Increases and decreases in dough stickiness of the experimental flour doughs depended on variety and location. The presence of the 1B/1R translocation could not be directly related to dough stickiness, and some of the experimental flour doughs without the 1B/1R characteristic exhibited the same or much greater stickiness than those with the 1B/1R. For both locations, by SDS-PAGE analysis, the 1B/1R wheats contained protein bands 7 and 9, and lacked 45k and 67k proteins, which is characteristic of 1B/1R wheats. All 1B/1R wheats were confirmed as "positive" for the presence of 1B/1R by the ELISA test and were in agreement with the SDS-PAGE.

The overall conclusion, in general, is that the 1B/1R characteristic had no adverse effect on flour quality and dough stickiness of the wheats, and even improved mixing tolerance and stability of the wheat flour doughs when compared to sister lines without 1B/1R. The flours of 1B/1R wheats could be used by the baking industry with the expectation of similar results in most cases as the flour without 1B/1R. As with all wheats, variety and location or environmental conditions were a significant factor of equal or greater importance than the presence of 1B/1R.

CHAPTER VII

SUGGESTIONS FOR FURTHER RESEARCH

The results from this particular study indicated that, in general, the 1B/1R soft wheats produced wheats with a flour quality as good or even better than the sister lines without the 1B/1R and in some cases even the control. Since research pertaining to the quality of 1B/1R soft wheat is limited, further research is suggested to determine the best use of 1B/1R soft wheats in soft wheat products such as cookies, cakes, etc. Suggestions for future research include the following:

- Measure the impact of 1B/1R flours on gluten glass transition temperature during baking.
- Conduct sensory evaluation on cookies made from soft wheats containing the 1B/1R translocation for determination of texture profile and flavor.
- Further refinement on dough stickiness test method to factor out variability as a result of water absorbancy and temperature.
- Evaluate the presence of 1B/1R flour in a blended flour sold for retail purpose or as a substitute for blended retail flour.
- Compare dough stickiness of 1B/1R wheats with band '8' and 1B/1R wheats without band '8'.
- Additional research to determine the factors of stickiness as to whether environment or the presence of a component (i.e. ferulic acid) plays a major role.
- Study the relationship between mixing tolerance, dough stickiness and dough development for the purpose of determining if alteration of mixing or processing could utilize the flours prone to stickiness.

- Determine if the reduced yield of flour is a factor of environment or the presence of 1B/1R.

- Determine if the presence of 1B/1R alters the rate of staling of baked goods.

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APPENDIXES

APPENDIX A

EXPERIMENTAL WHEATS

EXPERIMENTAL WHEATS

Wheat Variety[1]	Location Grown[2]
Massey	B, W
Saluda	B, W
FFR555W	B, W
Pair #1 (Massey * 4/Balkan)[3]:	
VA 93-54-46	B, W
VA 93-54-50c[4]	B, W
Pair #2 (Massey/3/Massey * 3/Balkan//Saluda):	
VA 93-54-209	B, W
VA 93-54-211c	B, W
Pair #3 (Massey * 5/Balkan):	
VA 93-54-237	B, W
VA 93-54-241c	B, W
VA 93-54-247c	B, W
VA 93-54-251c	B, W
Pair #4 (Complex, ST1-25)[5]:	
VA 93-54-329	B, W
VA 93-54-343c	B, W
VA 93-54-351c	B, W

[1] Wheat varieties under pairs are sister lines.
[2] Location where wheat was grown in Virginia: B = Blacksburg, W = Warsaw
[3] Balkan - hard wheat 1B/1R variety (used in varieties with 1B/1R).
[4] c = variety with 1B/1R
[5] Massey/8/CI13836/9*Chancellor//Wheeler/3/Severn/4/Coker 916/5/ST1-25//ASII/9* Chancelor/6/Tyler/7/2*Massey.

APPENDIX B

KJELDAHL PARAMETERS

KJELDAHL PARAMETERS

PARAMETER	
MODE	01.00
H20	50.00
NAOH	80.00
REACTION S	15.00
H3BO3 ML	70.00
H3BO3 ASPIR.	30.00
ENDPOINT PH	4.65
START TITR.S	120.00
DELAY ENDP.S	5.00
BLANK VAL.ML	0.000
NORMAL TITR.	0.100
FACTOR TITR.	1.000
CF-PROTEIN	5.70
LAST PH-CALIBRATION	DAY/MONTH/YEAR
BUFFER 1 PH	4.00
BUFFER 2 PH	7.00
TEMPERATURE C	22.00
SLOPE	108.00
ASYMMETRIC POTENTIAL MV	0.00

APPENDIX C

FARINOGRAPH PARAMETERS AND DEFINITIONS

FARINOGRAPH PARAMETERS

Flour	50 grams
Water	Variable
Bowl Temp.	30° C
Run Time	20 minutes

FARINOGRAPH DEFINITIONS

1. **Water Absorption:** As required to reach a specific consistency of the dough (the center of the bandwidth should be at the 500 BU level).

2. **Arrival Time:** The difference between zero minutes and the point where the top of the curve first intersects the 500 BU-line.

3. **Peak Time:** This is the interval from first addition of water to the point of maximum consistency.

4. **Departure Time:** The time from zero to the point where the top of the curve leaves the 500 BU-line.

5. **Mixing Tolerance Index (MTI):** The difference between the top of the curve at the peak and the top of the curve measured 5 minutes after the peak (the higher the MTI the weaker the dough).

6. **Twenty Minute Drop:** Difference in BU from 500 BU-line to the center of the curve measured at twenty minute from the addition of the water.

APPENDIX D

COOKIE FORMULA

COOKIE FORMULA

Ingredients	Grams or Milliliters
Shortening	64.0 g
Sugar	130.0 g
Salt	2.1 g
Soda	2.5 g
Dextrose solution (8.9 g in 150 ml of water)	33.0 ml
Water	16.0 ml
Flour	225.0 g

1. Cream shortening, sugar, salt and soda. Low speed. **Three** minutes.
2. Add dextrose solution and water. Low speed. **One** minute.
3. Add flour. Low speed. **Two** minutes. Scrape bowl at 30 seconds.
4. Preheat the cookie sheet at 400 degrees F for **10** minutes. Cool.
5. Divide into 6 portions. Place on special design preheated cookie sheet.
6. Press portions slightly with the palm of the hand.
7. Roll each portion 1/2 of a roll forward and one roll back. Lifting and placing the rolling pin each time.
8. Roll to the end of the sheet with even pressure 3 times - up and back.
9. Push cookie cutter firmly in the center of each flattened portion of dough. **Do not twist the cutter**. Remove the excess dough from around the cutter and discard. Wipe off cutter.
10. Bake **10** minutes at **400 degrees F**.
11. Immediately remove to absorbent paper (wax paper) with a wide spatula to cool.
12. Measure the diameter of each individual cookie and then stack and measure the height of the stack.

APPENDIX E

DOUGH STICKINESS PARAMETERS

DOUGH STICKINESS PARAMETERS
(Water and Mixing Time)

Warsaw

Variety[1]	Water (ml)	Mixing Time (min.)
Massey	27.20	1:56
Saluda	28.55	1:54
FFR555W	26.60	1:15
VA-46	27.50	2:10
VA-50c	26.90	1:08
VA-209	28.05	1:45
VA-211c	28.65	1:55
VA-237	28.00	1:34
VA-241c	27.25	1:40
VA-247c	27.50	1:26
VA-251c	27.60	1:41
VA-329	28.50	2:04
VA-343c	27.60	1:39
VA-351c	28.15	1:49

Blacksburg

Variety[1]	Water (ml)	Mixing Time (min.)
Massey	27.15	1:32
Saluda	27.65	1:26
FFR555W	26.80	1:07
VA-46	26.35	1:10
VA-50c	26.50	1:10
VA-209	27.75	1:38
VA-211c	29.40	1:21
VA-237	26.90	1:13
VA-241c	28.15	1:30
VA-247c	27.60	1:20
VA-251c	27.65	1:35
VA-329	27.20	1:10
VA-343c	27.60	1:26
VA-351c	28.75	1:30

[1]Weight for all wheat varieties = 50 grams.

APPENDIX F

SDS-PAGE MATERIALS, PROCEDURE, AND PARAMETERS

SDS-PAGE MATERIALS

A. **Stock Extraction Buffer**

20.0 ml Glycerol
12.5 ml Stacking Buffer
24.1 ml Water
4.0 g SDS (Bio-Rad)
20.0 g Pyronin Y

B. **Ammonium Persulfate**

10 % Ammonium Persulfate (Bio-Rad)
100 mg/1 ml or 500 mg/5 ml
Make Fresh Daily

C. **Staining Solution**

Sigma Brilliant Blue Staining Solution (B-4523)

D. **Acrylamide Solution**

35 g of Acrylamide, bring to a total volume of 100 ml with HPLC Grade Water.

E. **Bis Solution**

Bio-Rad Bis Solution (Methylenbisacrylamid)

F. **1M Tris (MW 121.4) Separation Buffer**

24.2 g of tris, bring to total volume of 200 ml with HPLC Grade Water. pH to 8.8 with HCL before bringing to volume.

G. **1M Tris (MW 121.4) Stacking Buffer**

24.2 g of tris, bring to total volume of 200 ml with HPLC Grade Water. pH to 6.8 with HCL before bringing to volume.

H. **10 % SDS**

Bio-Rad 10 % (w/v) SDS (Sodium dodecyl sulfate)

I. **Rinse Solution**

100 ml of 100 % TCA, 330 ml methanol and 570 ml water.

J. **Running Buffer**

Premix. One pkg. per 4 liters of water, rinse packet. Check pH. Should be close to 8.3.

SDS-PAGE PROCEDURE - GELS

Separation Gel (one gel) - Method of Zhen and Mares (1992) for 10 % Gel

Ingredient	Amount
35 % Acrylamide	* 14.28 ml
2 % Bis-Acrylamide	3.24 ml
1M Tris pH 8.8	18.99 ml
Water (HPLC Grade)	11.71 ml
10 % SDS	500.00 μl
DEGASS	
10 % Persulfate	1.25 ml
TEMED	25.00 μl

*Modified.

Stacking Gel (one gel)

Ingredient	Amount
35 % Acrylamide	1.75 ml
2 % Bis-Acrylamide	1.00 ml
1M Tris pH 6.8	2.50 ml
Water	7.20 ml
10 % SDS	200.00 μl
DEGASS	
10 % Persulfate	750.00 μl
TEMED	15.00 μl

SDS-PAGE PROCEDURE (continued) - EXTRACTION and PARAMETERS FOR RUNNING GEL

Stock Extraction Buffer

20.0 ml Glycerol
12.5 ml Stacking Buffer
24.1 ml Water
4.0 g SDS
20.0 mg Pyronin Y

Working Extraction Buffer ***(Prepare Fresh Daily)***

12.0 ml water
5.1 ml Extraction Buffer
0.9 ml Mecaptoethanol

Procedure

Place 80 mg of ground wheat into a 2 ml plastic Microvial with screw cap. Add 1 ml of freshly prepared extraction buffer to the bottle. Tightly shut screw cap on Microvial. Vortex well and hold at room temperature for 2 hours. Mix each 30 minutes on vortex. Boil in a boiling water bath for 2.5 minutes. Allow to cool.

Centrifuge at 4000 rpm for 10 minutes.

Load 20 μl of the supernatant to the gel.

Use Neepawa Wheat as a control. Load 10 μl of the supernatant to the gel.

Run Molecular Weight Markers. Load 10 μl.

Running Conditions

15 milliamps	1.5 hours
30 milliamps	2.5 hours
8 milliamps	overnight - until marker reaches the bottom. Then run an additional 30 minutes.

SDS-PAGE PROCEDURE (continued) - RUNNING OF THE GEL IS COMPLETE

Fixing the Gel

Remove gel and remove from glass plates.
Use a spacer to lift the plates apart. Do not use spatula it will break the glass plates.
Carefully lift gel off of glass plate and place into rinse solution. Agitate for 1 hour at room temperature.

Staining Procedure

After the rinse, place the gel in the stain solution and add a few drops of Comassie Blue stain solution. Stain overnight.

Drain the dye solution and rinse the gel twice with water. Note the gel will have expanded somewhat from the original size. No destaining step is required with this staining solution.

Photographs

Photograph gel. Gel will stay good for 1 - 2 months after staining.

APPENDIX G

SUMMARY OF FARINOGRAPH DATA

Mean[1] Farinograph data for experimental wheats.

Variety	1B/1R	Location	WA	AT	PT	DT	MTI	TMD	MTS
Massey	N	Warsaw	54.4	1.33	1.93	8.75	30.00	41.67	6.82
Massey	N	Blacksburg	54.3	1.05	1.53	7.25	56.70	63.33	5.72
Saluda	N	Warsaw	57.1	1.33	1.90	4.50	95.00	106.70	2.60
Saluda	N	Blacksburg	55.3	1.12	1.43	4.10	61.70	98.33	2.67
FFR555W	N	Warsaw	53.2	0.83	1.25	2.92	85.00	130.00	1.67
FFR555W	N	Blacksburg	53.6	0.77	1.12	3.53	70.00	103.33	2.42
VA-46	N	Warsaw	55.0	1.13	2.17	5.63	71.70	105.00	3.47
VA-46	N	Blacksburg	52.7	0.85	1.17	3.37	80.00	110.00	2.20
VA-50	Y	Warsaw	53.8	0.75	1.13	5.08	66.60	98.33	3.95
VA-50	Y	Blacksburg	53.0	0.80	1.17	2.30	83.30	110.00	1.13
VA-209	N	Warsaw	56.1	0.82	1.75	3.85	93.30	126.67	2.10
VA-209	N	Blacksburg	55.5	0.92	1.63	3.67	116.67	150.00	2.03
VA-211	Y	Warsaw	57.3	1.25	1.92	4.67	58.33	43.33	2.75
VA-211	Y	Blacksburg	58.8	1.00	1.35	3.95	56.67	83.33	2.60
VA-237	N	Warsaw	56.0	1.10	1.57	5.07	90.00	108.33	3.50
VA-237	N	Blacksburg	53.8	0.87	1.22	3.03	81.67	113.33	1.82
VA-241	Y	Warsaw	54.5	0.95	1.67	5.07	61.67	110.00	3.40
VA-241	Y	Blacksburg	56.3	1.07	1.50	5.67	60.00	86.67	4.17
VA-247	Y	Warsaw	55.0	0.92	1.43	5.42	63.30	90.00	3.98
VA-247	Y	Blacksburg	55.1	0.85	1.40	4.33	60.00	85.00	2.93
VA-251	Y	Warsaw	55.2	1.00	1.68	7.92	50.00	65.00	6.23
VA-251	Y	Blacksburg	55.3	0.93	1.58	6.50	48.30	83.33	4.92
VA-329	N	Warsaw	57.0	1.08	2.07	6.50	70.00	88.33	4.43
VA-329	N	Blacksburg	54.4	0.77	1.17	3.33	71.67	103.33	2.17
VA-343	Y	Warsaw	55.2	0.97	1.65	7.08	43.30	73.33	5.43
VA-343	Y	Blacksburg	55.2	1.08	1.43	5.78	56.67	101.67	4.35
VA-351	Y	Warsaw	56.3	1.17	1.82	7.58	43.30	70.00	5.77
VA-351	Y	Blacksburg	57.5	1.08	1.50	6.97	43.30	76.67	5.46

WA = Water Absorption, AT = Arrival Time, PT = Peak Time, DT = Departure Time, MTI =Mixing Tolerance Index, TMD = Twenty Minute Drop, MTS = Mixing Time Stability.
[1]n = 3

APPENDIX H

MEAN COOKIE SPREAD DATA

Summary of Mean[1] Cookie Spread Data of Experimental Wheats

Variety	Location	Cookie Diameter[2]	Cookie Stack Height[3]
Massey	W[4]	80.5bc[6]	53.7bcd
Massey	B[5]	81.4cd	52.1c
Saluda	W	79.1d	55.7b
Saluda	B	79.6f	54.3ab
FFR555W	W	83.7a	49.2e
FFR555W	B	82.5ab	50.5de
Pair #1			
VA-46	W	80.9bc	54.1bc
VA-46	B	82.7ab	51.6cd
VA-50c[7]	W	81.2b	51.5d
VA-50c	B	83.2a	49.5e
Pair #2			
VA-209	W	79.8cd	52.3cd
VA-209	B	81.9bc	51.0cd
VA-211c	W	77.3e	59.2a
VA-211c	B	77.8g	55.5a
Pair #3			
VA-237	W	80.3bc	54.4bc
VA-237	B	82.4ab	51.2cd
VA-241c	W	81.1bcd	54.0bc
VA-241c	B	78.5g	54.9ab
VA-247c	W	80.3bc	51.4d
VA-247c	B	80.2ef	53.9b
VA-251c	W	79.9cd	52.0cd
VA-251c	B	80.0ef	54.2ab
Pair #4			
VA-329	W	80.7bc	53.9bc
VA-329	B	80.7de	54.7ab
VA-343c	W	80.8bc	53.1cd
VA-343c	B	81.3cd	52.3c
VA-351c	W	80.1bcd	54.0bc
VA-351c	B	79.8ef	54.4ab

[1] n = 3
[2] diameter in mm
[3] stack height in mm of six cookies
[4] W = Warsaw
[5] B = Blacksburg
[6] Numbers with the same letter(s) in the same location are not significantly different at P > 0.05.
[7] c = variety with 1B/1R translocation

APPENDIX I

SUMMARY OF DOUGH STICKINESS DATA

SUMMARY OF DOUGH STICKINESS DATA

			Minutes			
Variety	**Location**	**Rep**	**10 g**	**15 g**	**20 g**	**25 g**
Massey	W	1	1.3507	0.9018	0.5845	0.7014
		2	1.1336	0.7181	0.6179	0.5678
		3	0.9352	0.5678	0.5678	0.5511
Average			**1.1398**	**0.7292**	**0.5901**	**0.6068**
Massey	B	1	1.3006	0.5511	0.5511	0.6179
		2	0.9686	0.4843	0.4175	0.3841
		3	1.3173	0.6012	0.4175	0.3006
Average			**1.1955**	**0.5455**	**0.4620**	**0.4342**
Saluda	W	1	9.8138	6.0501	5.2505	3.5678
		2	11.7181	5.3173	4.7348	3.5845
		3	10.5678	5.9686	5.2171	3.3507
Average			**10.7014**	**5.7787**	**5.0675**	**3.5010**
Saluda	B	1	3.5010	1.6847	1.1503	0.8684
		2	2.1503	1.7348	1.3006	0.7348
		3	3.3841	2.1002	1.3674	1.0000
Average			**3.0118**	**1.8399**	**1.2728**	**0.8677**
FFR555W	W	1	0.8350	0.5845	0.4342	0.2672
		2	0.6680	0.4008	0.2672	0.2839
		3	0.7348	0.6346	0.5010	0.2338
Average			**0.7459**	**0.5400**	**0.4008**	**0.2616**
FFR555W	B	1	0.7181	0.6179	0.5845	0.2171
		2	0.7348	0.5511	0.4008	0.3173
		3	0.7515	0.6179	0.4843	0.2338
Average			**0.7348**	**0.5956**	**0.4899**	**0.2561**
VA-46	W	1	1.4843	1.0835	0.6847	0.6179
		2	1.5177	1.2171	0.7181	0.5177
		3	1.1837	1.0501	0.7682	0.4676
Average			**1.3952**	**1.1169**	**0.7237**	**0.5344**
VA-46	B	1	0.5177	0.6179	0.8183	0.8183
		2	0.4843	0.4175	0.3006	0.2338
		3	0.6513	0.3340	0.4175	0.2839
Average			**0.5511**	**0.4564**	**0.5121**	**0.4453**
VA-50c	W	1	0.9853	0.9018	0.8183	0.4008
		2	0.8350	0.8350	0.6513	0.4509
		3	1.0501	0.9686	0.7515	0.6680
Average			**0.9568**	**0.9018**	**0.7404**	**0.5066**

DOUGH STICKINESS DATA in MINUTES (continued)

Variety	Location	Rep	10 g	15 g	20 g	25 g
VA-50c	B	1	1.1002	0.9853	0.7515	0.5845
		2	1.1503	0.8517	0.6346	0.4342
		3	1.3674	0.6346	0.4175	0.3006
Average			**1.2060**	**0.8239**	**0.6012**	**0.4398**
VA-209	W	1	4.6179	2.9018	2.0835	1.0816
		2	2.4008	2.1503	1.2338	1.0334
		3	5.6513	1.8016	3.1169	1.5344
Average			**4.2233**	**2.2846**	**2.1447**	**1.4565**
VA-209	B	1	2.7849	2.0835	1.4342	0.8851
		2	2.5344	2.7014	2.2004	1.0668
		3	3.7014	2.7515	1.7682	0.7515
Average			**3.0069**	**2.5121**	**1.8009**	**0.9011**
VA-211c	W	1	2.5511	0.9519	0.6847	0.3674
		2	2.3674	1.6680	1.3674	0.6513
		3	2.5177	106012	1.0167	0.8016
Average			**2.4787**	**1.4070**	**1.0229**	**0.6068**
VA-211c	B	1	2.0501	1.2839	1.2338	1.3507
		2	1.9352	1.2171	0.9352	1.2839
		3	1.7682	1.1336	0.8851	0.9185
Average			**1.9178**	**1.2115**	**1.0180**	**1.1844**
VA-237	W	1	0.5511	0.6179	0.4676	0.4676
		2	0.8183	0.4843	0.4175	0.5678
		3	0.8517	0.7181	0.4008	0.5511
Average			**0.7404**	**0.6068**	**0.4286**	**0.5288**
VA-237	B	1	0.6179	0.4843	0.5676	0.5177
		2	0.6680	0.4843	0.3507	0.2171
		3	0.5511	0.4676	0.4008	0.1670
Average			**0.6123**	**0.4787**	**0.4064**	**0.3006**
VA-241c	W	1	1.2839	1.0000	0.7515	0.8684
		2	1.0334	1.0000	1.0668	0.7014
		3	1.2338	1.1670	0.8016	0.6012
Average			**1.1837**	**1.0557**	**0.8733**	**0.7237**
VA-241c	B	1	1.2839	0.9519	1.0668	0.8016
		2	1.2171	0.8183	0.4509	0.2338
		3	1.4342	1.1670	0.6513	0.4676
Average			**1.3117**	**0.9791**	**0.7230**	**0.5010**
VA-247c	W	1	1.7348	1.7014	1.1169	0.9519
		2	1.8517	1.1503	1.0167	1.0835
		3	1.0835	0.8684	1.5010	1.7515
Average			**1.5567**	**1.2400**	**1.2115**	**1.2623**

DOUGH STICKINESS DATA in MINUTES (continued)

Variety	Location	Rep	10 g	15 g	20 g	25 g
VA-247c	B	1	2.0835	1.1670	1.2171	0.4509
		2	0.7849	0.7849	1.6847	0.5678
		3	1.6680	0.9519	0.7515	0.5010
Average			**1.5121**	**0.9679**	**1.2178**	**0.5066**
VA-251c	W	1	2.3507	1.4676	1.7181	0.3841
		2	1.1837	1.3006	1.4175	0.8684
		3	1.2171	1.0334	1.5010	1.0334
Average			**1.5838**	**1.2672**	**1.5455**	**0.7620**
VA-251c	B	1	1.8851	1.4676	0.6680	0.8684
		2	1.9519	0.9185	0.9018	0.5845
		3	1.7682	1.2505	0.9185	0.7515
Average			**1.8684**	**1.2122**	**0.8294**	**0.7348**
VA-329	W	1	2.2672	1.8684	1.4342	0.8684
		2	1.6179	1.5177	1.3841	0.8517
		3	1.8183	1.8350	1.4676	0.8517
Average			**1.9011**	**1.7404**	**1.4286**	**0.8573**
VA-329	B	1	0.5678	0.5177	0.3340	0.3841
		2	0.4843	0.3340	0.2672	0.2171
		3	0.6179	0.4676	0.4342	0.4676
Average			**0.5567**	**0.4398**	**0.3451**	**0.3563**
VA-343c	W	1	1.3340	0.8016	0.7014	0.6012
		2	1.5845	0.8684	0.7348	0.6680
		3	1.3173	0.5344	0.4843	0.6847
Average			**1.4119**	**0.7348**	**0.6402**	**0.6513**
VA-343c	B	1	1.7849	0.7348	0.5010	0.4843
		2	0.8684	0.7682	0.7181	0.5344
		3	1.3674	0.7348	0.6847	0.5678
Average			**1.3402**	**0.7459**	**0.6346**	**0.5288**
VA-351c	W	1	3.1837	1.6346	1.7181	0.8016
		2	2.7348	1.8016	1.6680	1.0668
		3	1.6847	1.5845	1.1002	0.7515
Average			**2.5344**	**1.6736**	**1.4954**	**0.8733**
VA-351c	B	1	1.2505	1.3841	1.1837	0.4175
		2	1.4943	0.8016	0.6847	0.7849
		3	1.8684	1.0000	0.9853	0.6179
Average			**1.5344**	**1.0619**	**0.9512**	**0.6068**

VITA

The author, Sabine Susanne Schwarzlaff, is a native of Blacksburg, Virginia, and was born on October 12, 1957. She attended Gilbert Linkous Elementary School in Blacksburg, Virginia, and graduated from Blacksburg High School in 1976. Fall of 1976, the author began her undergraduate study at Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, Virginia in the Department of Human Nutrition and Foods, and in June 1980, received her B.S. degree in dietetics.

On October 1, 1980, the author began her career as a WIC Nutritionist for the Cumberland Plateau Health District. In 1990, she took a leave of absence for one semester from work to update her course work at Virginia Tech to become R.D. eligible once again.

July, 1991, the author moved back to Blacksburg, Virginia to begin her graduate study for a Master's degree in Foods after 11 years of work as a WIC Public Health Nutritionist. In August, 1993, she received her Master's Degree and at the same time decided to continue her graduate study in pursuit of a Ph.D. in Foods.

The author is presently a doctoral student and will give her defense seminar, "FLOUR QUALITY AND DOUGH STICKINESS OF SOFT RED WINTER WHEAT LINES WITH AND WITHOUT 1B/1R TRANSLOCATIONS" on September 22, 1995.