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PROTEINS OF WHEATS OF DIVERSE BAKING QUALITY

by

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ABSTRACT

The flour proteins of 26 wheat varieties of widely different baking quality, grown at four stations in Western Canada, were investigated using solubility fractionation and analysis of individual fractions by disc electrophoresis. Both intervarietal and interstation effects were investigated.

Quality parameters that were examined included loaf volume, farinograph development time and mixing tolerance index, Zeleny sedimentation value, amylograph viscosity, and milling yield. Both intervarietal and interstation differences were found for these parameters. The usefulness of such commonly used quality indices as Zeleny sedimentation value and farinograph properties for predicting breadmaking quality, was investigated by calculating the correlation coefficients between these parameters.

The protein solubility distribution varied widely among varieties. Significant interstation differences were also observed for the five varieties that were examined. The interstation differences were generally smaller than the varietal differences.

Correlation coefficients between some quality parameters and the proportion of various protein fractions were calculated. These indicated that both glutenin and residue protein, expressed as percentage of the total flour protein, were significantly correlated with major quality parameters. The proportion of glutenin was negatively correlated with loaf volume, whereas residue protein and loaf volume were positively correlated.

Disc electrophoresis was employed to study the qualitative differences in the proteins of three of the five fractions obtained by solubility fractionation. Intervarietal differences were observed for the gliadin

proteins but there were no obvious relationships between each pattern and baking quality. No interstation differences were discernible in the electrophoretic patterns. These patterns appeared to be largely governed by genetic rather than quality or environmental factors.

PROTEINS OF WHEATS OF DIVERSE BAKING QUALITY

INTRODUCTION

It is now well established that the protein content of the flour from a particular variety of bread wheat determines its breadmaking quality. Furthermore, it is also well known that varieties, of the same type or different type, of the same protein content can have different breadmaking quality. This difference is generally attributed to an all-inclusive property called protein "quality".

Since flour protein comprises a large number of different molecular species, it can be stated, a priori, that the quality of this collective protein for breadmaking must depend on the relative amounts of the individual components as well as on the molecular properties of these components. The objective of the present study was to obtain additional information on the role of two aspects of these factors related to protein quality: 1) the quantitative distribution of the proteins among fractions of different solubility; and 2) qualitative differences, discerned by disc-gel electrophoresis, among analogous fractions of different varieties.

The wheat samples used in this investigation were from the 1969 Uniform Quality Nursery. This nursery comprised 26 varieties, having a broad spectrum of baking quality, grown at four stations in Western Canada; Saskatoon, Lethbridge, Swift Current and Regina. Varietal differences in protein solubility distributions and electrophoretic properties were examined using all of the 26 varieties grown at Saskatoon. The effect of environment (station) was examined using five varieties, selected to represent the maximum variability in baking quality, grown at the four stations.

REVIEW OF THE LITERATURE

Introduction

The fact that wheat is man's basic food in Europe, North and South America, Australia and a large part of Asia makes it an extremely important crop. As most of this wheat is consumed as bread, the importance of studies concerning the breadmaking quality of flour, derived from the diverse wheat varieties of the world, can readily be appreciated. Wheat enjoys this important position because of the unique ability of its flour to form, on hydration, a viscoelastic dough ideal for baking into bread. This dough has the correct structure and physical properties to retain carbon dioxide released during fermentation to give a light, soft-textured bread (1).

The common conception that wheat is merely a starchy food is far from correct. It contains other valuable nutrients, namely, proteins, minerals and vitamins (2). An interesting statistic is that wheat outyields any animal product in yield per acre of all the essential amino acids (3).

The approximate chemical composition of an average Canadian bread flour is: starch 69%; moisture 14%; protein 13%; cellulose 0.2%; fats 1.9%; sugar 1.5%; and minerals 0.4%.

Although protein does not represent the major constituent in a quantitative sense it has been, by far, the most extensively studied because of its nutritional importance and, perhaps more importantly, because of its dominant role in controlling the breadmaking potential of wheat flours.

Study of wheat protein began over two hundred years ago when Beccari (4) isolated the first plant protein-wheat gluten. In the following years publications in this field gave a confused picture

because there was no standard nomenclature. Much of this early work was reviewed by Bailey (5).

Osborne (6), with his classical work on separation of the flour proteins on the basis of their solubilities, began a revolution in Cereal Chemistry. He defined relatively four protein fractions and determined their elementary and amino acid compositions. According to Osborne's classification albumins were the water-soluble proteins, globulins were soluble in salt solutions, gliadins dissolved in 70% aqueous ethanol, and glutenins dissolved in dilute acid or base. Although fractionation on this basis has been shown to yield highly heterogeneous fractions, the nomenclature is still commonly used and will be used in this review.

Flour Protein Content and Breadmaking Quality

It soon became evident that a significant correlation existed between protein, or gluten, content of flour and loaf volume of the bread produced from it. Loaf volume is now accepted as the most important quality parameter in flour evaluation as it takes into account the composite effects of the various ingredient and processing factors (7). Larmour (8) obtained a correlation of +0.906 for loaf volume and protein content for Canadian hard red spring wheats grown in one season. Many other workers have also found similar correlations for the same two parameters (9-12).

Finney and Barmore (13) demonstrated that within a variety, the loaf volume and protein content were directly proportional in the 7-20% range studied, provided that optimal potassium bromate was used at each level. Apart from this quantitative effect, the authors illustrated marked varietal differences in protein quality. Using hard winter and

hard spring wheats, they determined the regression of loaf volume on protein content for many varieties. The increase in loaf volume for each percent increase in protein (i.e. the slope of the plot) varied between 40 and 50 c.c. in a loaf from 100g flour. Certain varieties had distinctly different regression lines representing differences in protein quality. The loaf volumes for different wheats at 13.5% protein varied from 823 to 1015 c.c. which is well outside the statistical variation of the baking test. When the regression lines were extrapolated to zero percent protein, they gave a common intercept of about 275 c.c; theoretically this is the loaf volume for a wheat flour with no protein.

The complexity of the answer to the question, what is protein quality, has kept cereal chemists busy for many years and is still not satisfactorily solved. Many powerful analytical tools and techniques have been used with varied success in this research field. Using various means of fractionating flour proteins, the roles of the albumins, globulins, glutenins and high molecular weight residue protein in breadmaking have been studied. A review of the most successful of these is presented below.

Albumins

There has been considerable disagreement on the influence of the water-soluble proteins or albumins on breadmaking quality. It was suggested by Mattern and Sandstedt (14) that the amount of water-soluble protein that remained associated with the insoluble gluten is an important factor when the role of albumins in breadmaking is considered. Pence and Elder (15) extracted the albumins from a bread flour using a dilute phosphate buffer and subsequently removed the contaminating gliadin and pentosans by ammonium sulfate precipitation. The albumins comprised at least six components similar in molecular size but differing

in electrophoretic mobility. Further investigation by Pence et al (16) dealt with the determination of water-soluble protein contents of thirty-two flours differing widely in baking quality. The amount of soluble protein ranged from 13-22% of the total protein. Absolute amounts of soluble proteins increased directly with the total protein but decreased when soluble protein was expressed as a percentage of the total flour protein. Neither the amount of soluble protein nor the ratio of soluble protein to gluten protein were significantly correlated with breadmaking quality, expressed as loaf volume. For each variety the ratio of albumin to globulin was significantly correlated ($r = +0.60$) with the coefficient of regression of loaf volume against protein content. The fundamental reason for this significant correlation is not known. Accordingly, it might be concluded that Pence (17) was only partially successful in explaining the differences in baking quality of a number of flours on the basis of their albumin content.

In a more recent study Cluskey et al (18) found that thirteen hard and eleven soft wheat flours contained essentially the same amount of water-soluble protein although the total protein content was generally higher in the hard wheat flours. No correlation was found between albumin content and baking performance. Hoseney et al (19) reported that although the water-soluble fraction did not affect loaf volume, it was essential for the production of a normal loaf. This fraction contributed to gas production and affected the physical (handling) properties of the dough. These authors suggested that of the water-solubles, the glycolipids were particularly important for good baking performance.

Globulins

Flour globulins are usually obtained by dialysis of salt-solution extracts. Removal of the salt causes precipitation of the globulins while the albumins remain in solution. The role of the globulins in baking quality has not been delineated. Pence and Elder (15) found three globulin components in preparations from flour and defatted wheat germ. These globulins were characterized by low tryptophan and amide-nitrogen contents and high arginine content compared with other endosperm proteins. The role of these globulins in baking quality was examined by Pence (17) using reconstituted flours, however these experiments were unsuccessful. It was suggested that extraction of the flour with salt solution produced a change in the insoluble proteins that was detrimental to baking quality.

Studies by Koenig et al (20) indicated that long-mixing flours had more salt-soluble protein than short-mixing flours. Mullen and Smith (21), however, found similar amounts of salt-soluble protein in weak and strong flours. There were marked differences between flours in the mobilities of components in the globulin group separated by electrophoresis but these differences did not appear to be related to baking quality.

Gluten or Insoluble Proteins

On the basis of results from experiments with flours reconstituted from gluten, starch and water solubles, Finney (22) showed that the recognized differences in breadmaking quality of three widely different wheats were entirely accountable by differences in their gluten fractions. When each flour was reconstituted to its original composition it gave a loaf volume equal to the loaf volume of the original flour. This

indicated that there were no detrimental effects of the fractionation on the intrinsic functional properties of the three flour fractions examined in these experiments.

The unique rheological properties of wheat gluten (and of dough) result from the combination of the viscous properties of gliadin and the elastic properties of glutenin. On hydration the gluten forms the three dimensional network of the dough and on baking it forms the rigid structure of the loaf of bread.

Gluten is commonly prepared by washing dough under a stream of running water. Crude gluten contains about 85% protein, 8.3% lipid, 6% starch and 0.7% ash (23). The amino acid composition in gluten is dominated by glutamine and asparagine (24) - these form about 30% (moles) of the total amino acids.

Koenig et al (20), in their studies with long- and short-mixing flours, showed that the former flour had less gliadin and glutenin than the latter. In similar work Mullen and Smith (25) fractionated a long-mixing and a short-mixing flour into salt-soluble protein, water-soluble protein, and a protein-starch residue fraction. They found that addition of the protein-starch residue to doughs mixed in a farinograph increased their time to maximum consistency, whereas addition of the water solubles decreased the mixing time.

Fleurent (26), Guess (27) and Snyder (28) suggested that the gliadin to glutenin ratio was correlated with baking quality. According to Sullivan (29) this approach has been generally abandoned because of the difficulties encountered in obtaining a clear-cut separation of these two gluten components.

Maes (30) obtained a negative correlation between baking quality and the percentage of protein soluble in distilled water. On the other

hand the amount of gliadin, expressed as a percentage of the total protein, was highly correlated with baking quality. Maes also obtained a significant correlation between the total protein content of flours and the quantity of protein that was soluble in isopropyl alcohol.

In their recent work, Hoseney et al (31) found an almost constant ratio of 53:47 for gliadin to glutenin for four wheat varieties with widely different baking quality. From reconstitution experiments using gliadin- and glutenin-rich fractions, they concluded that gliadins controlled loaf volume potential whereas glutenins controlled mixing requirement. Further support for this hypothesis was reported by Shogren et al (32). They found that the gliadin to glutenin ratio was significantly correlated with loaf volume, absorption, oxidation requirement and mixing time.

Pomeranz (33) suggested the use of the dispersibility of wheat flour proteins in aqueous urea as a parameter for quality evaluation. Urea causes dissociation of protein aggregates by disruption of hydrogen bonds. The proteins dispersed in urea solution would be all the flour proteins except the very high molecular weight proteins of gluten (glutenin). He found that flours of poor breadmaking quality contained greater amounts of proteins that dispersed in 3M urea.

On comparing two flours with farinograph development times of 20 and 3 minutes, Mullen and Smith (34) found that the former contained much more insoluble protein remaining after repeated water extraction. The ratio of high molecular weight to low molecular weight protein was correlated positively with time to maximum consistency for both varieties. In other studies by the same researchers (21, 25), short-mixing flours were shown to contain more of the β-gluten component and less acid-

insoluble protein. In addition, it was shown that additives which decreased protein solubility produced an increase in farinograph dough development time.

Tsen (35) observed that soft wheat flours had relatively more glutenin than hard wheat flours. With mixing, the rate of conversion of the insoluble protein to protein soluble in 0.05N acetic acid occured more rapidly in doughs from weak flours than in those from strong flours. During this mixing the amounts of albumin, globulin; and gliadin components did not change significantly. On the basis of these findings, Tsen concluded that the protein aggregates in a soft flour dough are considerably more likely to disaggregate under the influence of mixing than those of the hard wheat flours. The mechanism of this disaggregation was not investigated.

Using a modification of the classical Osborne fractionation procedure (6), Ewart (36) fractionated the proteins of wheat, maize, rye, barley and oat flours. Both overall protein solubility and the quantity of protein soluble in acetic acid were correlated with the breadmaking quality of the flours from these widely different cereal grains.

Chen and Bushuk (37) compared the solubility distribution of the proteins of durum wheat, hard red spring wheat, rye, and Triticale. They found that the hard red spring wheat, which was superior in baking quality, had a much higher proportion of gluten protein than the other cereals.

In addition to the proteins that are soluble in dilute acids, aqueous ethanol, and salt solutions, all bread flours contain varying amounts of protein that is insoluble in these solvents. Cluskey et al (38) showed that this protein is glutenin-like and has a very high

molecular weight. The tendency of these proteins to aggregate has been a major obstacle to precise measurement of their molecular weights (39, 40).

Dronzek et al (41) compared the protein solubility distributions of the endosperm proteins of three hexaploid wheats and the AABB tetraploid wheats derived from them. The tetraploids of two varieties contained more gliadin and glutenin and less insoluble protein than their corresponding hexaploids. These also gave lower loaf volumes on baking than their hexaploid counterparts. In contrast, hexaploid and tetraploid Prelude which were equal in baking performance contained almost equal amounts of gliadin, glutenin and insoluble protein.

Most of the acetic acid-insoluble protein of flour can be solubilized in hydrochloric acid-2-chloroethanol solution (42). Electrophorosis of this protein, after reduction and alkylation, showed it to be a mixture of high molecular weight constituents comprising polypeptide chains cross-linked by disulfide bonds. From their electrophoretic mobility these polypeptides appeared similar to the water-soluble proteins of wheat flour. In a similar study, Inamine et al (43) exhaustively extracted flour with 0.01N acetic acid and then removed most of the contaminating starch by centrifugation. The protein that remained in the insoluble residue resembled gluten in physical properties. Treatment of this residue with 0.1N aqueous dimethylaminoethanol solubilized about 85% of its protein. On gel filtration the solubilized residue protein gave two major fractions. By starch-gel electrophoresis, one component was glutenin-like and the other was similar to gliadin. The same workers showed that reduced and alkylated insoluble residue and glutenin proteins

gave very similar patterns after electrophoresis on starch gel.

An interesting electron microscopic study of the proteins of hard and soft wheat was reported recently by Seckinger and Wolf (44). Hard wheats appeared to have compact protein particles whereas soft wheat particles appeared less dense. Moreover the hard wheat protein particles were difficult to disrupt with aqueous salt solutions whereas the soft wheat proteins were expanded and dispersed in distilled water.

Physical and Chemical Structure of Flour Proteins and Baking Quality

With the advent of new, sophisticated analytical techniques more detailed study of flour proteins has become possible. Amongst the most useful of these techniques is electrophoresis. A review of the pertinent literature regarding this and other methods applicable to the study of protein components and baking quality follows.

The separation of proteins based on electrophoresis was first reported by Tiselius in 1937 (45). In 1944 this technique was successfully applied to gliadin proteins by Schwert *et al* (46). These workers did not attempt to relate the electrophoretic patterns to baking quality.

The introduction of starch gels by Smithies in 1955 (47) was a major advance in the application of electrophoresis to the study of proteins. This technique was first used with cereal proteins by Elton and Ewart (48). Another innovation that improved the resolving power of the starch gel method was the incorporation of urea into the gel, by Woychik *et al* (49), to increase the solubility of the gluten proteins.

Elton and Ewart (50) compared starch-gel electropherograms of the proteins of eight wheat varieties. They found the albumin and globulin patterns to be very similar but significant differences were

evident among the gluten proteins. These variations were thought to be sufficiently marked to explain variation in protein quality. The same workers (51) showed that reduced glutenins of four wheat varieties contained components that had the same electrophoretic mobility as the reduced gliadins of the same wheat. On the basis of this evidence, they suggested that glutenin was a complex aggregate of gliadin-like molecules. Varietal differences were observed in the patterns for the reduced glutenins.

An extensive electrophoretic study of the gliadin of eighty flours was reported by Doekes in 1968 (52). He was able to classify the electrophoretic patterns into five broad groups. Group I had a compact gliadin pattern and group V a scattered pattern. Groups II, III and IV were intermediate. Soft winter wheats of poor quality were grouped in I and spring wheats with hard vitreous kernels and very good breadmaking quality in V.

The introduction of polyacrylamide gel to electrophoresis of proteins was the next major advance in this field (53). With this technique Silano et al (54) observed varietal differences in the albumin and globulin fractions of T. aestivum and T. durum. In all, fourteen albumin and fifteen globulin bands were detected. Varietal differences were most evident in the fast moving bands.

Chen and Bushuk (55) used the same technique to study the endosperm proteins of Triticale, its durum and rye parents, and a hard red spring wheat. Marked differences between the patterns of the gliadin and glutenin proteins of the durum and the hard red spring wheats were observed, however further studies are necessary to determine if this observed difference is related to the difference in breadmaking quality between the two wheats.

In a similar study, Dronzek et al (41) found that the patterns of the albumins, globulins, gliadins and glutenins for each three extracted AABB tetraploid wheats, were esentially the same as the patterns for the same fractions of the hexaploid counterpart. Since two of the three extracted tetraploids had significantly inferior baking quality than the hexaploid parents, it appears unlikely that the electrophoretic pattern is related to baking quality.

Various types of chromatography have been successfully used in the separation of wheat flour proteins. Sephadex G-100 was used by Wright et al (56) to obtain three groups of different molecular weight: glutenins having molecular weights in the range 2 to $3x10^6$; gliadins and water-soluble proteins with molecular weights less than 10^5 and low molecular weight non-protein nitrogen compounds. Meredith and Wren (57) used Sephadex G-200 to resolve endosperm proteins into four groups according to molecular weight: 1) over 10^5 or glutenin; 2) between 10^5 and $2x10^4$ or gliadin; 3) between $2x10^4$ and 10^4 or albumin and 4) below 10^4 or non-protein substances. Lee and Wrigley (58) used a combination of electrophoresis and chromatography to study the proteins of fourteen different wheats. The patterns of the acetic acid-soluble proteins were generally the same for primitive and commercial hexaploid wheats. Marked differences in patterns for the tetraploid and hexaploid varieties were noted. Analogous similarities and differences were obtained by ion-exchange chromatography on carboxymethyl cellulose. Each of the eight commercial T. vulgare varieties had characteristic electrophoretic and chromatographic profiles, however these could not be correlated with baking quality. The protein patterns seemed to be genetically controlled since closely related varieties gave similar patterns regardless of their

baking quality.

Huebner and Rothfus (59) used starch-gel electrophoresis and column chromatography on sulfoethyl cellulose to examine the gliadin proteins of different classes and varieties of wheat. Differences were most evident between classes but small varietal differences were also observed. A number of poor and good quality varieties showed very similar electrophoretic patterns and chromatographic profiles.

Of the chemical properties of flour proteins, the amino acid composition has been studied most extensively. Compositions of wheats (and their flours) that differed widely in breadmaking quality, class and variety have been found to be essentially the same by workers (24, 37, 41, 60-63). Tkachuk examined the amino acid compositions of six flours milled from four major types of Canadian wheat. The compositions were the same within experimental error although three of the four wheats differed widely in breadmaking quality. Ewart determined the amino acid compositions of wheat, rye, barley, oats and maize. There were significant differences in the contents of some of the amino acids of these cereals. Wheat proteins contained significantly more amino acids with hydrophilic side chains; this is reflected by their greater solubility in aqueous solvents.

Gliadins separated from good and poor quality flours exhibited very similar amino acid compositions. Solubility of this protein can be readily explained on the basis of its amino acid composition. The sparcity of amino acids with ionizable side chains and the abundance of those that form hydrogen and hydrophobic bonds accounts for the low solubility of gliadin (and glutenin) in water. Dilute acetic acid of low ionic strength provides a useful means of extracting and purifying

these proteins. The fact that they can be almost completely dispersed in urea is attributed to the ability of this substance to disrupt hydrogen bonds.

Chen and Bushuk obtained similar amino acid compositions for single varieties of Triticale, rye, durum wheat and bread wheat. Dronzek et al determined the amino acid compositions of three hexaploid wheats, their extracted AABB tetraploids and the durum wheat, Stewart 63. Their amino acid compositions were essentially the same. These cereals differed markedly in breadmaking quality, accordingly it seems highly improbable that amino acid composition can be used as an index of breadmaking quality.

Although much is known about wheat proteins and, to a somewhat lesser degree, their role in breadmaking, the biochemical factors dictating quality differences are not yet fully understood.

MATERIALS

The wheat samples used in this investigation were from the 1969 Uniform Quality Nursery grown at Lethbridge, Regina, Saskatoon and Swift Current under the supervision of Dr. A. B. Campbell of the Winnipeg Research Station, Canada Department of Agriculture. The 26 varieties in this nursery, their parentage, and origins are listed in Table 1.

For the study of intervarietal differences, the samples of the Saskatoon nursery were selected because this nursery gave the highest yield of material. Inter-station differences were examined using the wheat of the varieties R37, Rushmore, Manitou, Pembina Backcross and Pitic 62 from the four stations. These varieties were selected because they represented the full range of breadmaking quality of the wheats in the nursery. Detailed milling and baking quality data for the 26 varieties and four stations are tabulated in Appendix I.

All chemicals used in the investigation were of laboratory reagent grade.

TABLE 1. WHEATS OF THE 1969 UNIFORM QUALITY NURSERY

Variety or Line	Parentage	Origin
Marquis	Hard Red Calcutta x Red Fife	Canada
Thatcher	(Marquis x Iumillo Durum) x (Marquis x Kanred)	U. S. A.
Kota	Selected from Monad durum	Russia
R37		Italy
Magnif Entrerriano	(Bagé x Sinvalocho) x (Heines Kolben x 38 M.A.)	Argentina
Gabo Cross	(Bobbin^2 x Gaza) x Maria Escobar x Kenya	Bolivia
E931 Cross	E931 - Egypt 86 - 26 x EK_2	India
Aniversario	Reliance x Klein 75	Argentina
Carazinho		Brazil
Gaboto	Bagé x (H44 x Sinvalocho x Bagé)	Argentina
Lerma Rojo 64A	[(Yaqui x Norin 10 x Brevor) x Lerma 52] Lerma Rojo^2	Mexico
Magnif 41		Argentina
Sonora 64	(Yaktana 54 x Norin 10 x Brevor) Yaqui 54^2	Mexico
Rushmore	Rival x Thatcher	U.S.A.
Manitou	P.I.170925 x Thatcher^{6}x [(Frontana x Thatcher^7) Thatcher^6 x Kenya Farmer]	Canada
Thatcher Backcross	Thatcher crossed with 6 rust resistance donors.	Canada
Pembina Backcross	Pembina^6 x (Transfer x Pembina^6) Sr8	Canada
Justin Reselection	(Thatcher-Kenya Farmer x Lee-Mida) x Conley	Canada
Napo 63		Columbia
Comanche x CT736		Canada

TABLE I. WHEATS OF THE 1969 UNIFORM QUALITY NURSERY
(Cont'd.)

Variety or Line	Parentage	Origin
Opal		Germany
Pitic 62	Yaktana 54 x (Norin 10 x Brevor)	Mexico
Svenno		Sweden
Fortuna	(Rescue x Chinook) (Frontana x Kenya 58 x Newthatch)	U.S.A.
6702	[(Sv7389 x Ceres) (C.T.244)] [(Park x Reliance) (Koga II x Lee)]	Canada
6704	[(Svenno x Ceres) x (Saratov x C.T.244)] [C.T.907 x Ceres x Kenya x Canthatch]	Canada

METHODS

Milling and Breadmaking Quality Tests

Approved methods of the American Association of Cereal Chemists (A.A.C.C.) (64) were used for evaluation of milling and breadmaking quality.

Baking Test

The "Remix" experimental baking procedure described by Irvine and McMullan (65) was used. This method was chosen because it exaggerates quality differences between "weak"and "strong" flours. The weak flour-doughs break down under strong mixing whilst the strong flours are fully developed by the vigorous mixing to produce optimal loaf volumes.

Fractionation of Flour Proteins

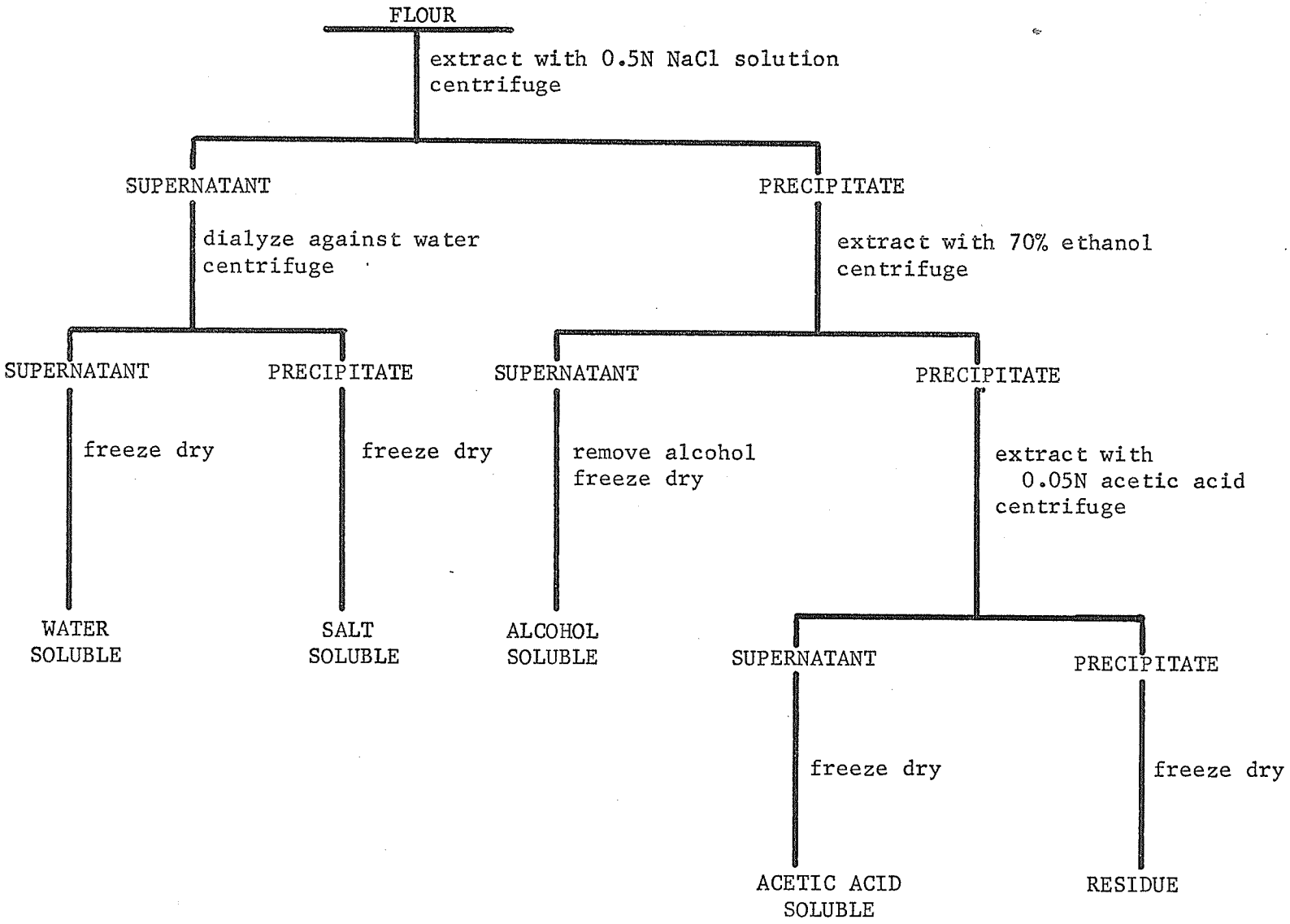
A modified Osborne procedure (6) was used to fractionate the flour proteins into five solubility groups. The procedure is summarized in Figure 1. The protein fractions obtained by this method are: 1) albumins (water-soluble proteins); 2) globulins (salt-soluble proteins); 3) gliadins (alcohol-soluble proteins); 4) glutenins (acetic acid-soluble proteins); and 5) insoluble residue proteins.

The extractions were consecutive and were performed in a cabinet at 5°C to minimize the possible side effects of proteolytic enzymes or thermal denaturation. Protein extracts were freeze dried, weighed and stored at 5°C for future use.

Micro Protein Determination

The Nesslerization procedure of Williams (66) was used to determine the protein content of the protein fractions obtained from the fractionation procedure described above.

Fig. 1 Summary of the solubility fractionation procedure.


FLOUR
extract with 0.5N NaCl solution
centrifuge
SUPERNATANT
PRECIPITATE
dialyze against water
centrifuge
extract with 70% ethanol
centrifuge
SUPERNATANT
PRECIPITATE
SUPERNATANT
PRECIPITATE
freeze dry
freeze dry
remove alcohol
freeze dry
extract with
0.05N acetic acid
centrifuge
WATER
SOLUBLE
SALT
SOLUBLE
ALCOHOL
SOLUBLE
SUPERNATANT
PRECIPITATE
freeze dry
freeze dry
ACETIC ACID
SOLUBLE
RESIDUE

Disc-gel Electrophoresis

Preparation of Gels

Disc electrophoresis on polyacrylamide gel was carried out using a method similar to that of Davis (67) and equipment purchased from Buchler Instrument Incorporated. The stock solutions used for preparation of the gels and buffers are listed in Table 2.

Before polymerization both the upper and lower gels were layered with water to ensure a flat surface on the polymerized gel. This gives straight running bands and better resolution. Photopolymerization of both upper and lower gels was accomplished using ultra-violet light. The lower gel polymerized in approximately 45 minutes and the upper gel required 20 minutes.

After polymerization the tubes were placed in the upper compartment of the apparatus and the upper and lower buffers were added. Special care must be taken to avoid bubbles being trapped at the bottom of the gels.

Sample Preparation and Application

Freeze dried sample containing 10 mgm. of pure protein was dissolved in 0.1N acetic acid containing 4N dimethylformamide. Approximately 10% sucrose was added to increase the sample solution density so that it could be easily layered on top of the gel below the buffer solution. Fifty microliters (µl) of the albumin, eighty µl of the globulin and forty µl of the gliadin preparations were carefully layered on top of the gels. Electrophoresis was carried out using a current of 2 ma per tube. Methyl green indicator was used as a visual marker to indicate the position of the electrophoretic front. When the marker entered the lower, or running gel, the current was increased to 4 ma

per tube. Electrophoresis was terminated when the marker was about 1/8" from the bottom of the gel.

The gels were removed from their glass tubes using a water-filled syringe with a long thin needle. Water was kept flowing steadily from the needle to prevent tearing of the gel. The removed gels were stained for one hour in 0.5% amido black in 70% acetic acid and the unabsorbed dye was removed electrophoretically. All gels were stored in 7% acetic acid and were photographed within one week.

TABLE 2. SOLUTIONS FOR DISC ELECTROPHORESIS

Gel solutions

Reagent	Upper Gel conc./100 ml	Volume Ratio	Lower Gel conc./100 ml	Volume Ratio
Ammonium persulfate	120 mg	2	60 mg	1
Riboflavin	4 mg		4 mg	
Acrylamide	10 g	1	30 g	1
Bisacrylamide	0.8 g		0.8 g	
IN KOH	48 ml	1	24 ml	2
Glacial acetic acid	3.65 ml		53.2 ml	
Temed*	0.2 ml		0.48 ml	

* Temed - N, N, N′, N′ - Tetramethylethylenediamine

Buffer solutions

Reagent	Concentration	Comments
Upper buffer		
		pH 4.0
Glycine	28.1 g/1000 ml	Dilute by 2
Glacial acetic acid	3.1 ml/1000 ml	before use
Lower buffer		
		pH 4.3
Glacial acetic acid	43.0 ml/1000 ml	Dilute by 2
IN KOH	120.0 ml/1000 ml	before use

NOTE: 1. All solutions were stored at 5 °C when not being used.

2. Gel solutions were stored in brown glass bottles to prevent deterioration by light.

RESULTS AND DISCUSSION

The results of this study are presented in four sections. Section I deals with the effect of variety and location of growth on the breadmaking quality of the twenty-six varieties, each grown at four stations. Section II examines the influence of both variety and location of growth on the solubility distribution of the proteins of these wheats. In Section III, statistical relationships between the protein solubility distribution and baking quality are discussed. Section IV deals with the disc-gel electrophoretic patterns of the albumins, globulins and gliadins of the twenty-six wheats grown at Saskatoon, and five varieties each grown at four locations. The significance of these electrophoretic patterns in relation to breadmaking quality is also considered in this section.

I. Milling and Baking Quality

The technological data discussed in this section are tabulated in Appendix I.

Intervarietal Differences for the Saskatoon Samples

Milling Quality. A broad range of milling quality was represented by the 26 varieties. Flour yields varied from 58.1 to 76.2%. Bushel (test) weights ranged from 62.5 to 67.0 pounds and were significantly correlated with flour yields, ($r = +0.54^{**}$). This correlation is of the same order as that determined by Baker and Golumbic (68) for a similar number of hard red spring wheats.

Zeleny Sedimentation Test. The value of this test for predicting the baking quality of a wheat flour is demonstrated by the highly significant correlation, ($r = +0.88^{**}$), obtained between loaf volume and

the sedimentation value. Since the mixing tolerance index (M.T.I.) and the sedimentation value are both considered to be measures of the strength of a flour dough, it was anticipated they would be closely related. A correlation coefficient of -0.90^{**} for these parameters was obtained in the present study.

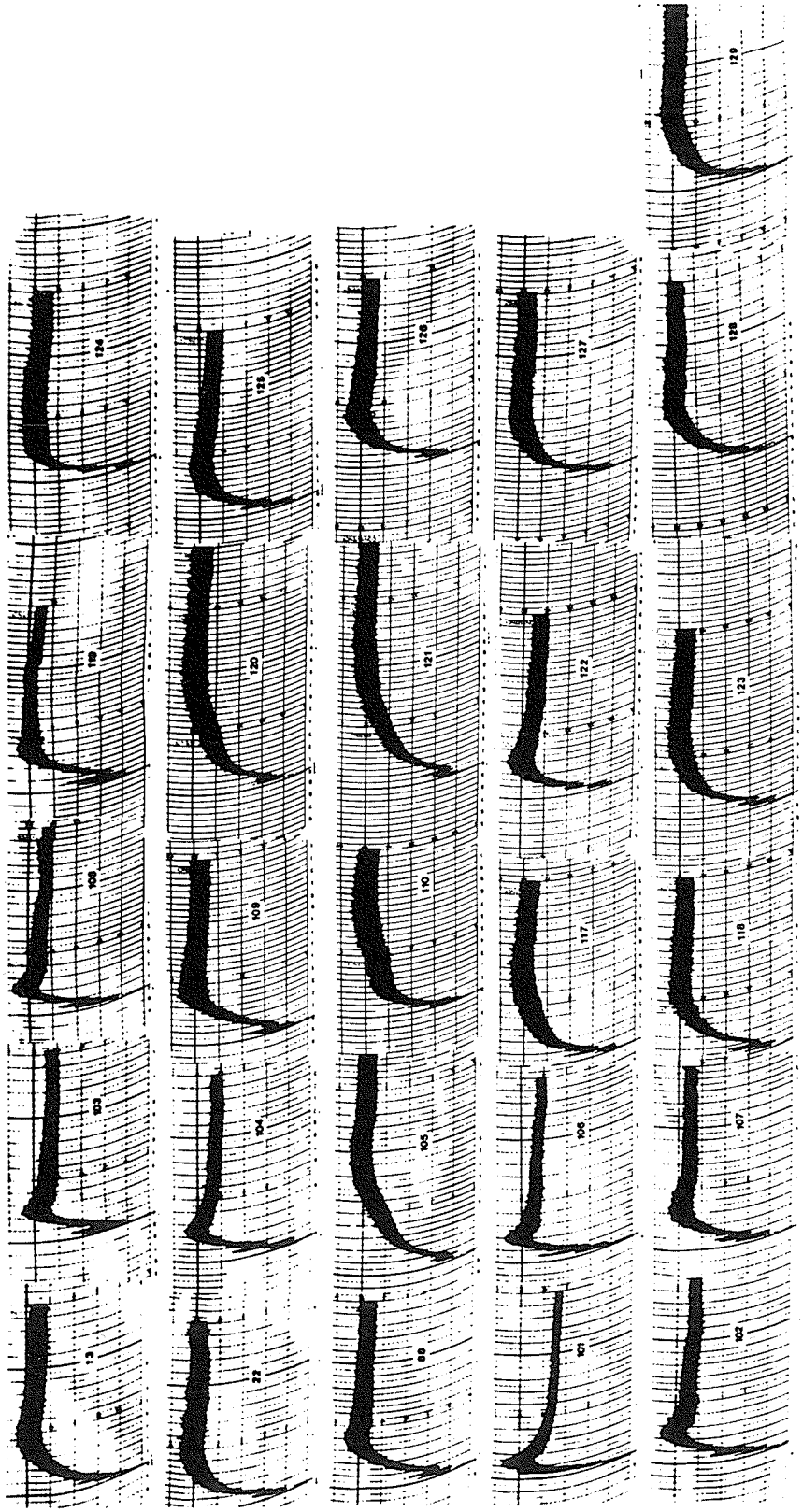
Loaf Volume. The loaf volumes obtained by the remix experimental baking procedure (65) varied from 525 to 1133 cc./100 g flour. These values represent the normal extremes obtained in the baking laboratory and indicate the suitability of these samples for this type of study i.e. the effect of protein quantity and quality on breadmaking quality.

When loaf volume and total protein content were correlated, a non significant correlation coefficient of +0.36 was obtained. It is well known that for single varieties (13, 69, 70), loaf volume is linearly related to protein content. However, the loaf volumes per unit protein vary widely among varieties. For widely different wheats (and varieties), loaf volume per unit protein can be used as a criterion of baking quality. The values obtained for the varieties in the present study are listed in Table 3.

Rheological Tests. When mixed in the farinograph, the varieties gave a series of curves ranging from very weak to very strong. These curves are illustrated in Figure 2. The mixing tolerance index values, (M.T.I.), varied from 10 to 185 B.U. and the development times from 1.3 to 12.0 minutes. A correlation coefficient of -0.79^{**} indicated the strong inverse relationship between M.T.I. and loaf volume. Development time is also a very important consideration in determining flour quality. The correlation between loaf volume and development time was highly significant, ($r = +0.64^{**}$).

Fig. 2 Farinograms of the 26 Saskatoon samples.

Curve Number	Variety or Line	Curve Number	Variety or Line
13	Marquis	117	Rushmore
22	Thatcher	118	Manitou
88	Kota	119	Thatcher Backcross
101	R 37	120	Pembina Backcross
102	Magnif Entrerriano	121	Justin Reselection
103	Gabo Cross	122	Napo 63
104	E931 Cross	123	Comanche x CT 736
105	Aniversario	124	Opal
106	Carazinho	125	Pitic 62
107	Gaboto	126	Svenno
108	Lerma Rojo 64A	127	Fortuna
109	Magnif 41	128	6702
110	Sonora 64	129	6704



Another important quality parameter calculated from the farinogram is the water absorption. The correlation between flour protein and farinograph water absorption was significant at the 1% level, ($r = +0.69^{**}$). A list of simple correlations between various baking quality parameters is presented in Table 4.

Interstation Differences within Varieties

Flour Protein. For each station, the 26 varieties had a wide range of protein contents. Generally the samples of each variety from Lethbridge and Swift Current had approximately the same protein content, and were lower than the corresponding varieties from Regina and Saskatoon. Protein content was largely dependent on environment, the interstation differences were generally larger than intervarietal differences for each station.

Baking Quality. Within a variety, the loaf volume was variable and partially dependent on flour protein content. Values of loaf volume per unit protein for each variety at four stations are given in Table 3. There are significant interstation differences in this quality index for most varieties, indicating that breadmaking quality depends on other environmental factors apart from protein content. However the interstation differences are much smaller than the intervarietal differences for all but a few of the varieties.

The farinograph results also showed the dependence of properties measured by this test on environment. For a large number of varieties the flour with the highest protein content exhibited the weakest mixing behaviour in the farinograph. This was true also for sedimentation values.

It can therefore be concluded from these results that breadmaking quality and technological parameters related to it are controlled by both

varietal and environmental factors. These results are in general agreement with published work in this area (1).

TABLE 3. LOAF VOLUME PER UNIT PROTEIN FOR TWENTY-SIX VARIETIES FROM FOUR STATIONS.

Variety	Loaf Volume per Unit Protein - (cc./%)*			
	Saskatoon	Regina	Lethbridge	Swift Current
Marquis	58.5	51.6	52.6	53.6
Thatcher	62.5	52.5	54.9	56.3
Kota	53.7	52.4	55.0	55.3
R37	33.4	31.8	30.5	30.6
Magnif Entrerriano	45.5	45.5	48.5	47.5
Gabo Cross	39.0	42.2	39.0	46.9
E931 Cross	34.7	33.3	-	-
Aniversario	47.4	34.5	58.6	55.8
Carazinho	39.6	42.5	46.8	49.7
Gaboto	50.0	52.8	56.8	55.1
Lerma Rojo 64A	41.2	40.5	37.5	41.2
Magnif 41	44.8	44.2	41.0	42.6
Sonora 64	63.2	53.2	56.4	55.5
Rushmore	63.3	51.7	54.7	55.6
Manitou	59.7	49.2	50.3	53.1
Thatcher Backcross	43.8	33.6	22.7	38.9
Pembina Backcross	58.3	53.2	47.8	54.2
Justin Reselection	52.4	44.8	55.0	54.4
Napo 63	48.2	46.2	45.8	48.9
Comanche x CT736	51.7	49.3	46.0	53.0
Opal	55.3	50.3	59.5	56.5
Pitic 62	53.3	50.0	50.0	51.1
Svenno	51.0	52.1	51.0	54.1
Fortuna	56.6	52.2	44.8	47.4
6702	57.4	49.1	52.2	54.2
6704	58.2	54.0	57.9	55.7

* based on % protein on a dry basis

TABLE 4. A STATISTICAL ANALYSIS OF QUALITY PARAMETERS

Variables	r value (n = 26)
Flour yield vs. Bushel weight	+0.54**
Loaf volume vs. Zeleny sedimentation value	+0.88**
M.T.I. vs. Zeleny sedimentation value	-0.90**
M.T.I. vs. Loaf volume	-0.79**
Farinograph development time vs. Loaf volume	+0.64**
Flour protein vs. Farinograph water absorption	+0.69**
Loaf volume vs. Flour protein	+0.36

** significant at the 1% level

II. Protein Solubility Distribution

The proteins of the flours milled from the 26 wheat samples grown in Saskatoon were fractionated into five solubility groups using a modified Osborne method (6,70). Although heterogeneous, these solubility fractions divide the proteins into five groups that can be classified as albumins, globulins, gliadins, glutenins, and the insoluble, or residue, protein.

To establish the significance of the differences in protein distribution among samples (varieties and locations), a sample of Manitou flour was fractionated seven times and the statistical error was calculated for each solubility fraction. The results of this reproducibility experiment are presented in Appendix II.

Intervarietal Differences for the Saskatoon Wheats

The results of the fractionation of the Saskatoon samples are given in Appendix III.

Recoveries on a weight basis (not shown in Appendix), varied from 95.5 to 99.1%. The losses can be attributed to two factors:

1. Loss of low molecular weight materials during dialysis of the salt solution extracts used to separate the salt-solubles from the water-solubles. The extent of this loss or the nature of the lost material was not investigated.

2. Cumulative effect of incomplete recoveries due to the normal experimental error of the many steps involved in the overall fractionation procedure.

The protein content, (Nx5.7), of each solubility fraction was used to calculate the percentage recovery of protein in the fractionation

procedure. This varied from 86.8 to 97.3%. If the material losses can in fact be partly attributed to losses of small molecules during dialysis, then these results indicate that most of this material is nitrogenous.

Water-Soluble (Albumin) Fraction. The protein content of this solubility fraction varied from 58.1 to 69.5% indicating the variable amounts of non-protein materials extracted for each variety. There were marked varietal differences in the proportion of albumin in the total flour protein. Values ranging from 6.3 to 10.6% were obtained with an average of 8.3%. Figure 3 illustrates these variations. These results are similar to those of Tanaka and Bushuk (71), and Dronzek et al (41) who reported variations of the same order amongst a small number of varieties of bread wheat.

Salt-Soluble (Globulin) Fraction. Protein contents of the salt-soluble fractions ranged from 43.0 to 88.5%, again illustrating the marked variability in the amount of non-protein materials extracted by this solvent for different varieties. The globulins contributed the least to the total flour protein, varying between 3.4 and 5.9% with an average of 4.4%. These results are somewhat lower than those reported by Pence et al (16) who obtained values ranging from 5 to 12%, but are in agreement with those of Tanaka and Bushuk (71) who obtained values in the range from 2.9 to 4.3%. Figure 4 illustrates the variation obtained in the proportion of salt-soluble protein for the 26 samples grown at Saskatoon.

Fig. 3 Proportion of albumin protein (water-soluble) in the flours from the 26 Saskatoon samples. The varieties are arranged, from top to bottom, in order of decreasing loaf volume per unit protein.

Number	Variety or Line	Number	Variety or Line
1	Rushmore	14	Comanche x CT 736
2	Sonora 64	15	Svenno
3	Thatcher	16	Gaboto
4	Manitou	17	Napo 63
5	Marquis	18	Aniversario
6	Pembina Backcross	19	Mangif Entrerriano
7	6704	20	Magnif 41
8	6702	21	Thatcher Backcross
9	Fortuna	22	Lerma Rojo 64A
10	Opal	23	Carazinho
11	Kota	24	Gabo Cross
12	Pitic 62	25	E 931 Cross
13	Justin Reselection	26	R 37

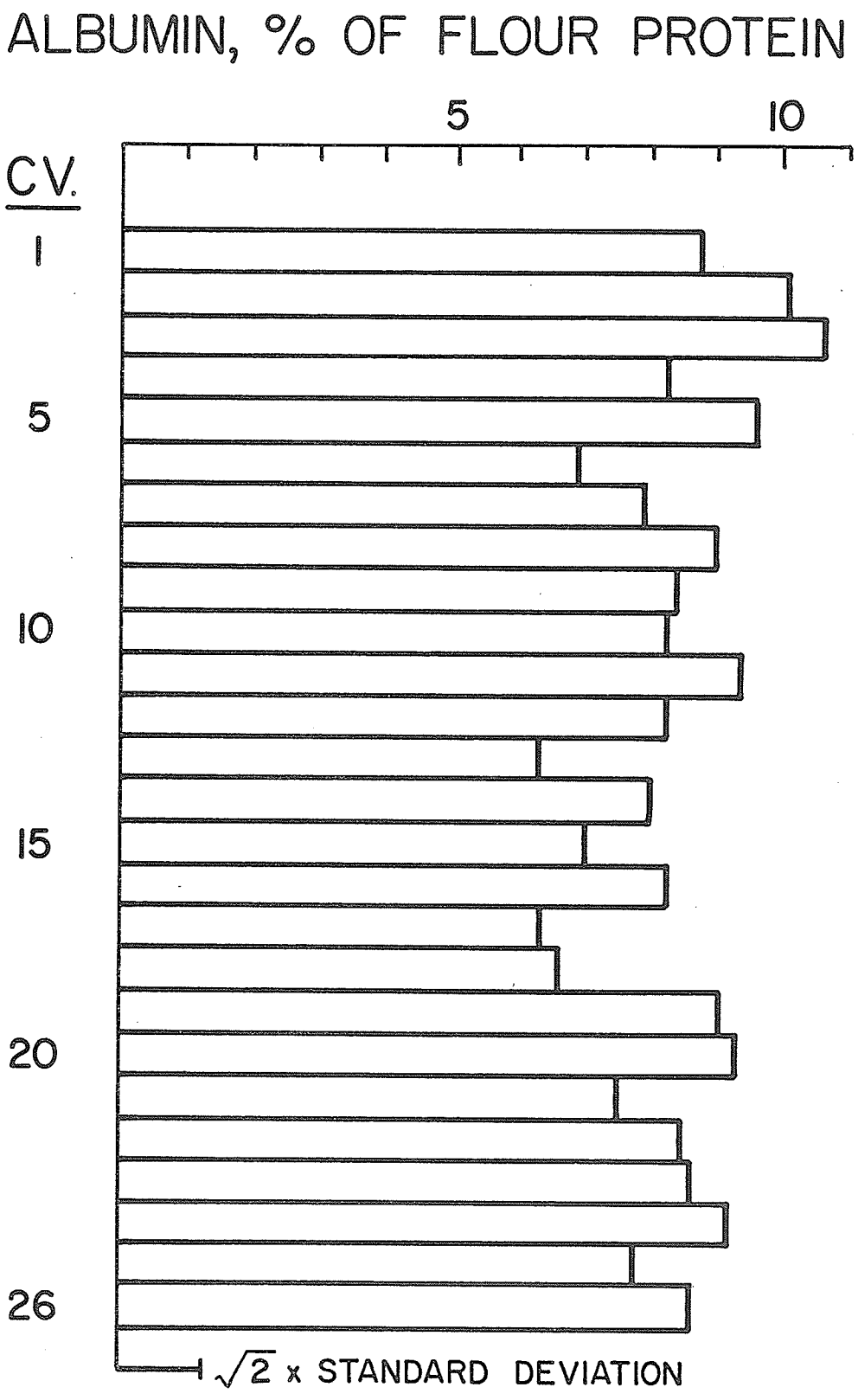
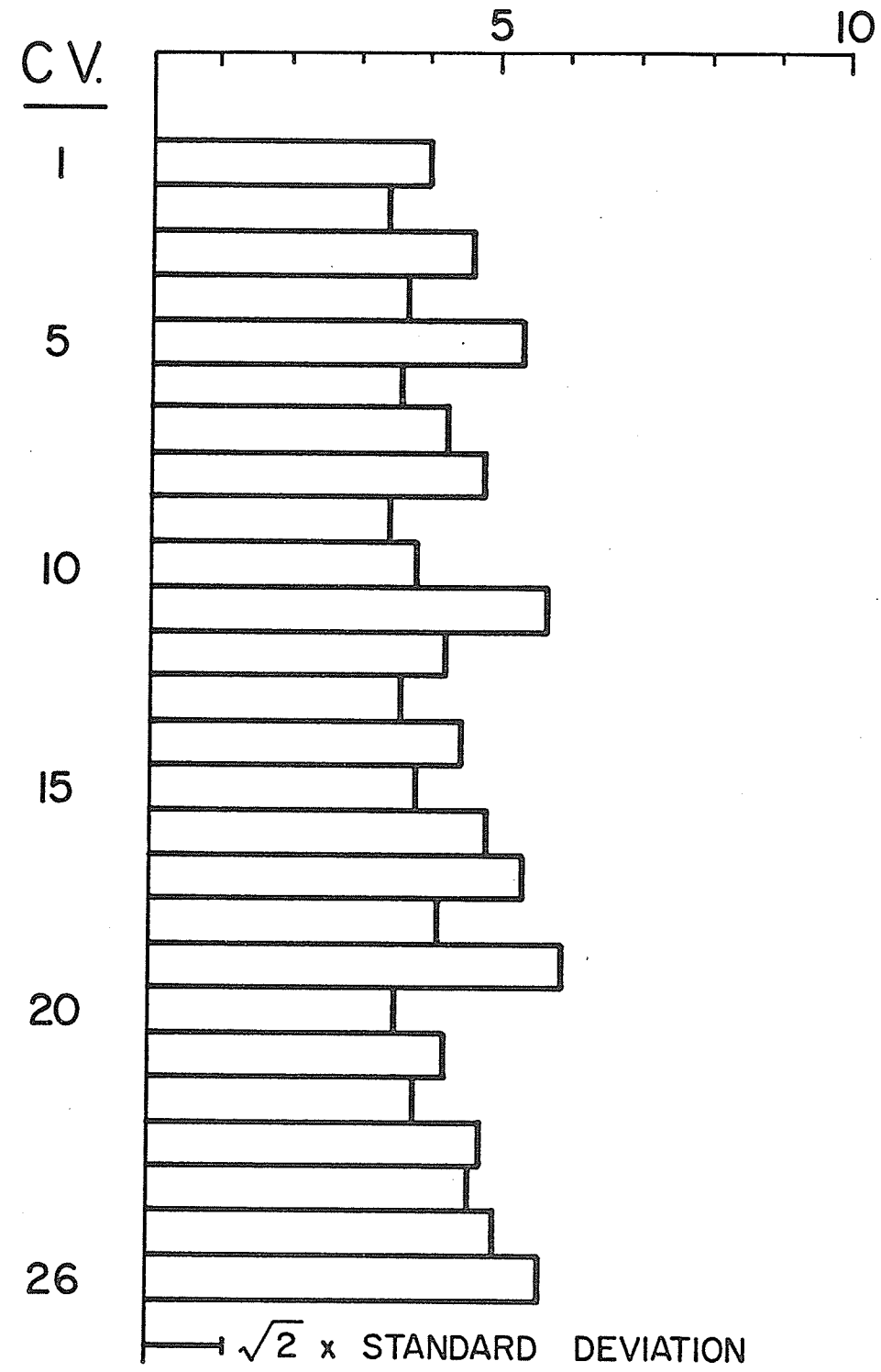

ALBUMIN, % OF FLOUR PROTEIN
5
10
CV.
1
5
10
15
20
26
√2 x STANDARD DEVIATION

Fig. 4 Proportion of globulin protein (salt-soluble) in the flours from the 26 Saskatoon samples. The varieties are arranged, from top to bottom, in order of decreasing loaf volume per unit protein. The order of varieties is as in Fig. 3.


GLOBULIN, % OF FLOUR PROTEIN
5
10
C V.
1
5
10
15
20
26
√2 x STANDARD DEVIATION

Alcohol-Soluble (Gliadin) Fraction. This fraction had the highest protein contents of the five solubility fractions examined, varying from 75.1 to 92.4% on a dry solids basis. Expressed as percentage of total flour protein, the proportion of gliadins was the highest of all the fractions for most varieties; the values ranged from 29.1 to 41.6% with an average of 35.8%. Using the same fractionation procedure, Tanaka and Bushuk (71) reported values of 27.6 to 36.1% for five bread wheats. Figure 5 shows the variation in gliadin content of the flour proteins of the Saskatoon samples.

Acetic Acid-Soluble (Glutenin) Fraction. The protein contents of this solubility fraction varied from 66.9 to 88.5%. Expressed as percentage of total protein, the glutenins exhibited the greatest variability among the 26 varieties. Values ranged from 6.0 to 27.4% and averaged to 15.7%. For all 26 varieties, the ratio of gliadin to glutenin was greater than one, and in most cases it was considerably greater. These values are again of the same order as those determined by Tanaka and Bushuk (71) who reported values from 10.1 to 16.1% for five varieties. Figure 6 shows the variation in the proportion of glutenin for the 26 Saskatoon samples.

Insoluble or Residue Fraction. The protein content of the insoluble residues varied from 2.8 to 8.1%. When expressed as percentage of total protein, this fraction formed from 15.0 and 36.5%, with an average of 26.9%. The amounts of insoluble residue protein for the 26 Saskatoon samples are shown in Figure 7.

Fig. 5 Proportion of gliadin protein (alcohol-soluble) in the flours from the 26 Saskatoon samples. The varieties are arranged, from top to bottom, in order of decreasing loaf volume per unit protein. The order of varieties is as in Fig. 3.

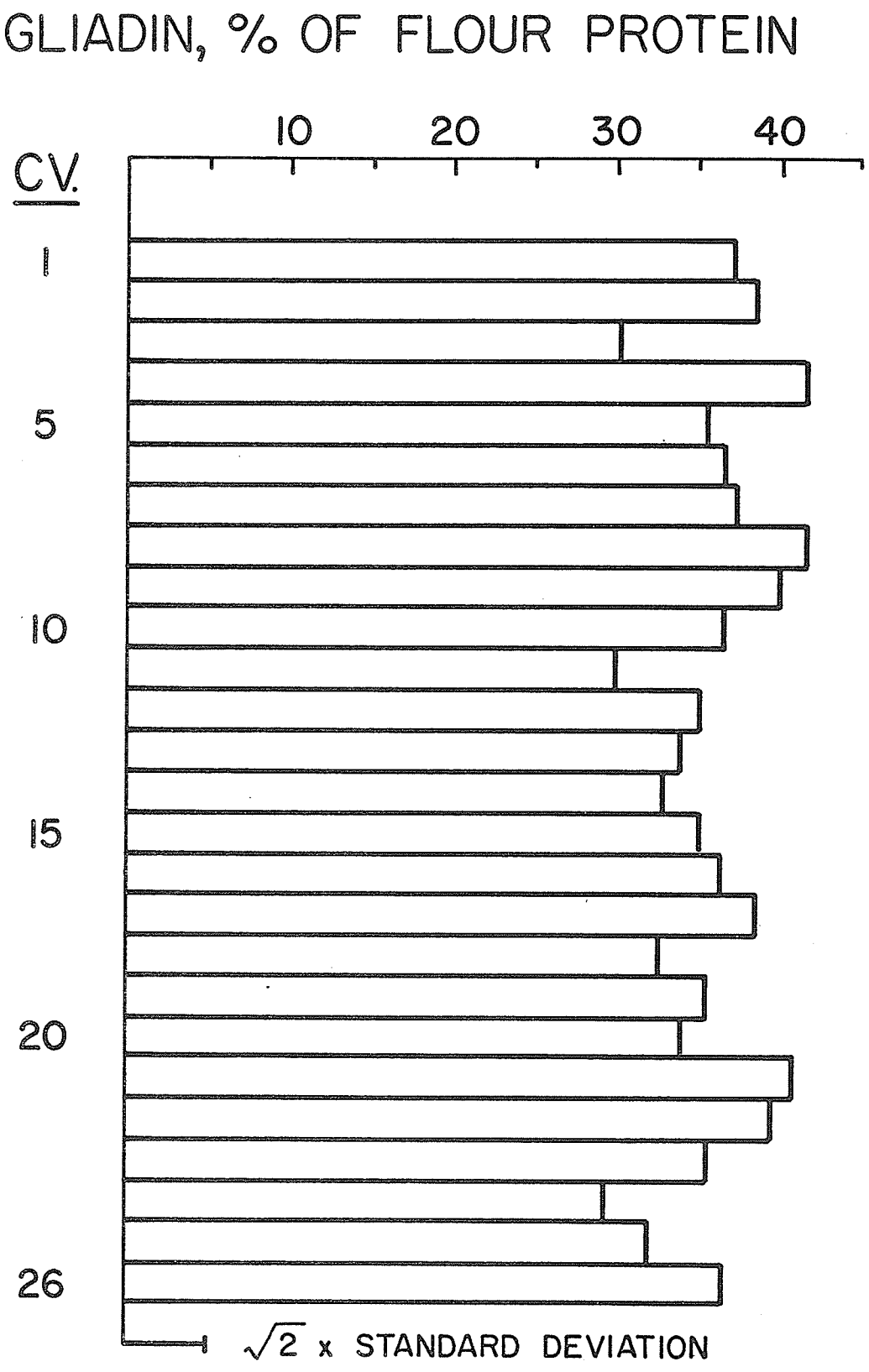

GLIADIN, % OF FLOUR PROTEIN
10
20
30
40
CV.
1
5
10
15
20
26
√2 x STANDARD DEVIATION

Fig. 6 The proportion of glutenin protein (acetic acid-soluble) in the flours from the 26 Saskatoon samples. The varieties are arranged, from top to bottom, in order of decreasing loaf volume per unit protein. The order of varieties is as in Fig. 3.

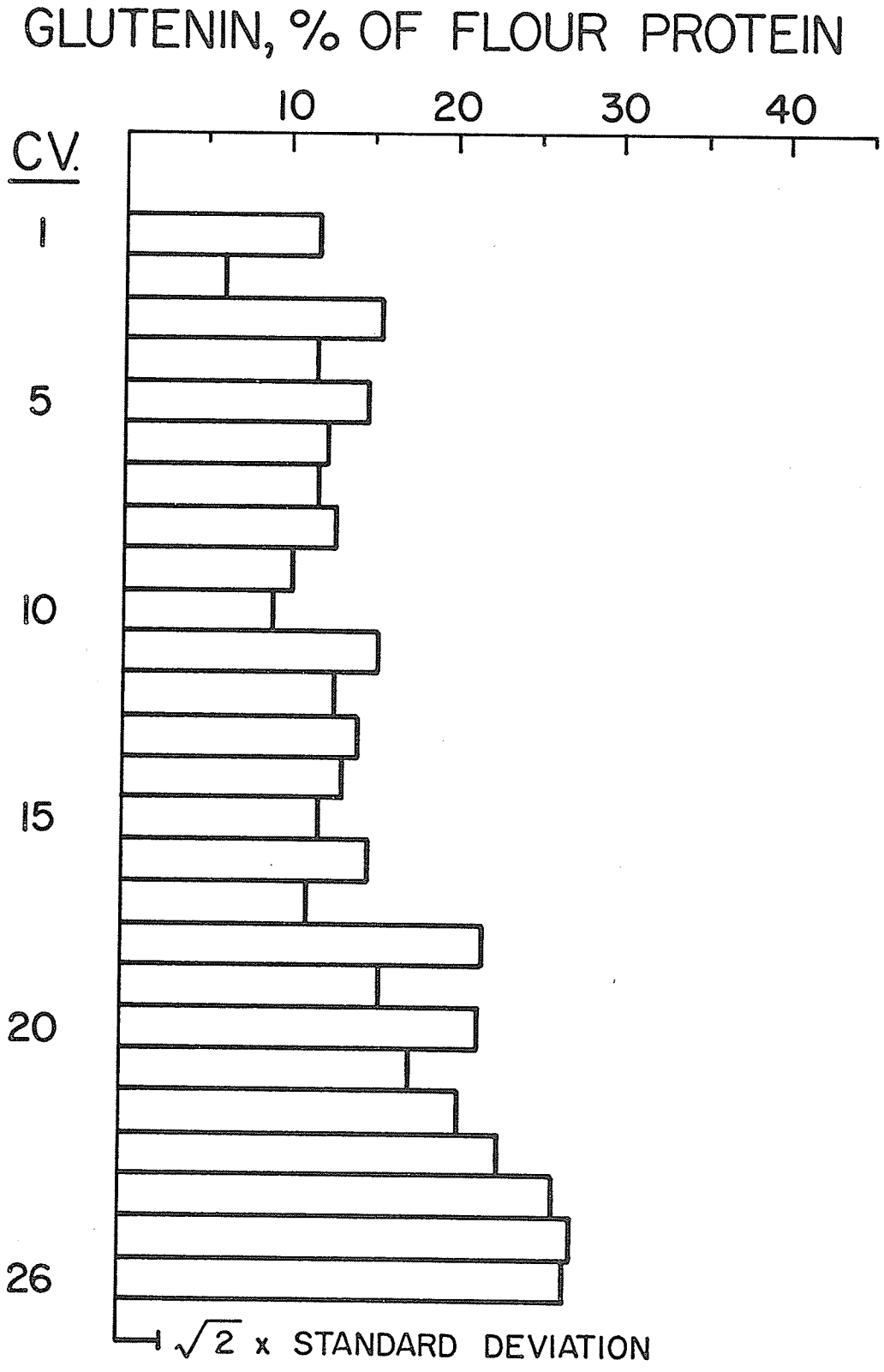
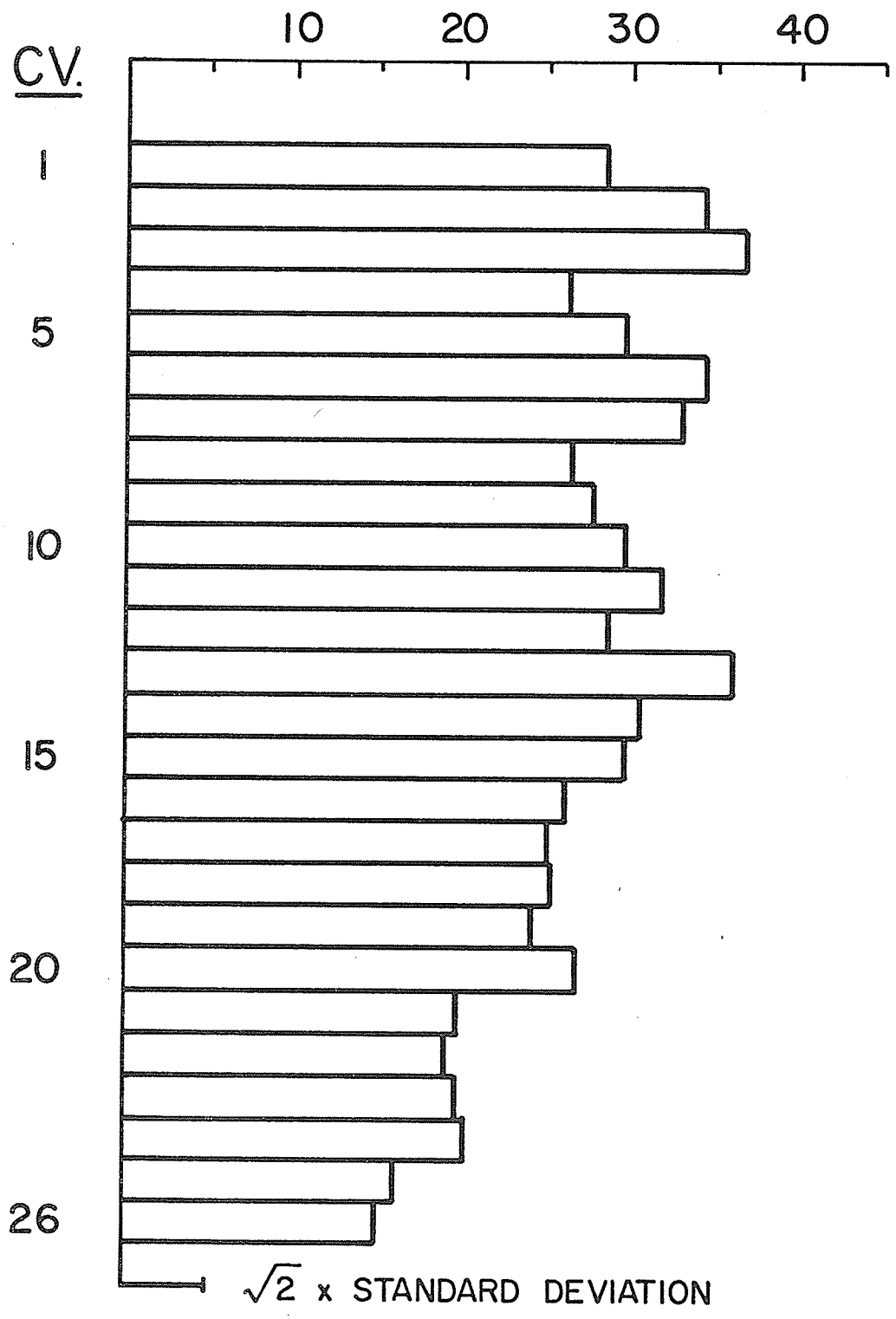

GLUTENIN, % OF FLOUR PROTEIN
10
20
30
40
CV.
1
5
10
15
20
26
√2 x STANDARD DEVIATION

Fig. 7 The proportion of residue (insoluble) protein in the flours from the 26 Saskatoon samples. The varieties are arranged, from top to bottom, in order of decreasing loaf volume per unit protein. The order of varieties is as in Fig. 3.


RESIDUE PROTEIN, % OF FLOUR PROTEIN
10
20
30
40
CV.
1
5
10
15
20
26
√2 x STANDARD DEVIATION

Interstation Differences for Five Varieties

The varieties used for this portion of the study were selected to represent extremes of baking quality. These comprised Rushmore, Manitou and the Pembina backcross which produced high loaf volumes for all stations, Pitic 62 with intermediate loaf volume and the Italian variety, R37, which gave the lowest loaf volume for each station.

Figures 8 to 12 show the proportion of each protein fraction for the five varieties grown at four locations. The data used in these figures are tabulated in Appendix IV. The experimental error is shown in the figures in the usual manner in order to show differences that are greater than the error. While there appear to be significant interstation differences in the protein solubility distribution for each variety, these are small compared with intervarietal differences. The significance of these differences in relation to baking quality will be discussed in Section III.

The greatest interstation variations in the solubility distribution of the protein were in the albumin and globulin proteins. The proportions of gliadin, glutenin and residue protein were less sensitive to environment. As will be discussed later, the proportions of glutenin and residue protein in the flour protein can be related to the breadmaking quality of the wheat varieties used in this study. It is therefore useful to relate the interstation differences in loaf volume per unit protein to the observed differences in the protein solubility distribution for each of the five varieties examined. The data for this comparison are tabulated in Appendix IV and Table 3.

For each variety a range of approximately 10cc./unit protein was obtained in loaf volume per unit protein over the four locations. This

Fig. 8 Proportion of albumin protein (water-soluble) in the flours of five wheat varieties, each grown at four stations. The order of stations is the same for each variety.

S - Saskatoon

R - Regina

L - Lethbridge

SC - Swift Current

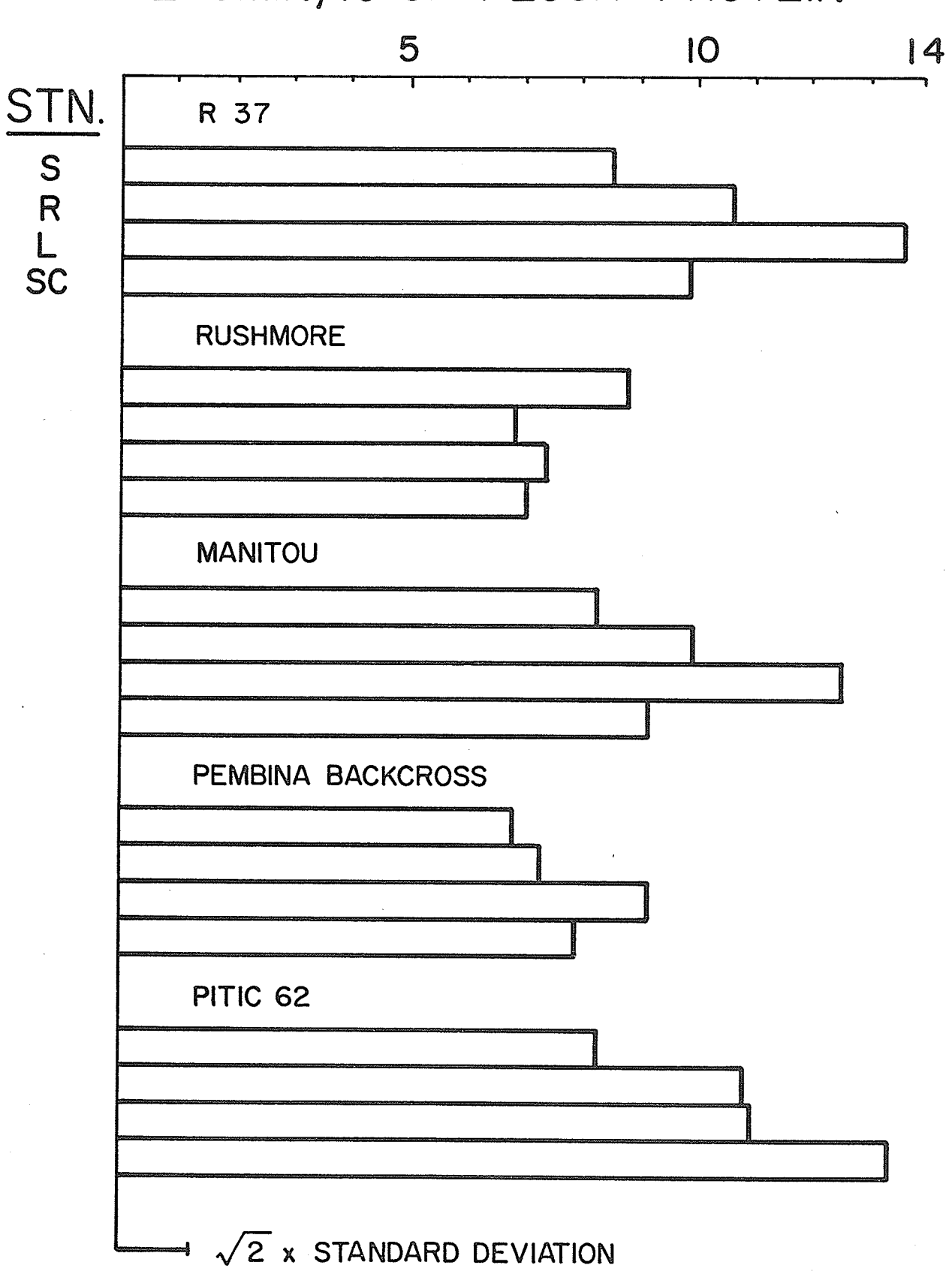

ALBUMIN, % OF FLOUR PROTEIN
5
10
14
STN.
S
R
L
SC
R 37
RUSHMORE
MANITOU
PEMBINA BACKCROSS
PITIC 62
√2 x STANDARD DEVIATION

Fig. 9 Proportion of globulin protein (salt-soluble) in the flours of five wheat varieties, each grown at four stations. The order of stations is the same for each variety.

S - Saskatoon

R - Regina

L - Lethbridge

SC - Swift Current

GLOBULIN, % OF FLOUR PROTEIN

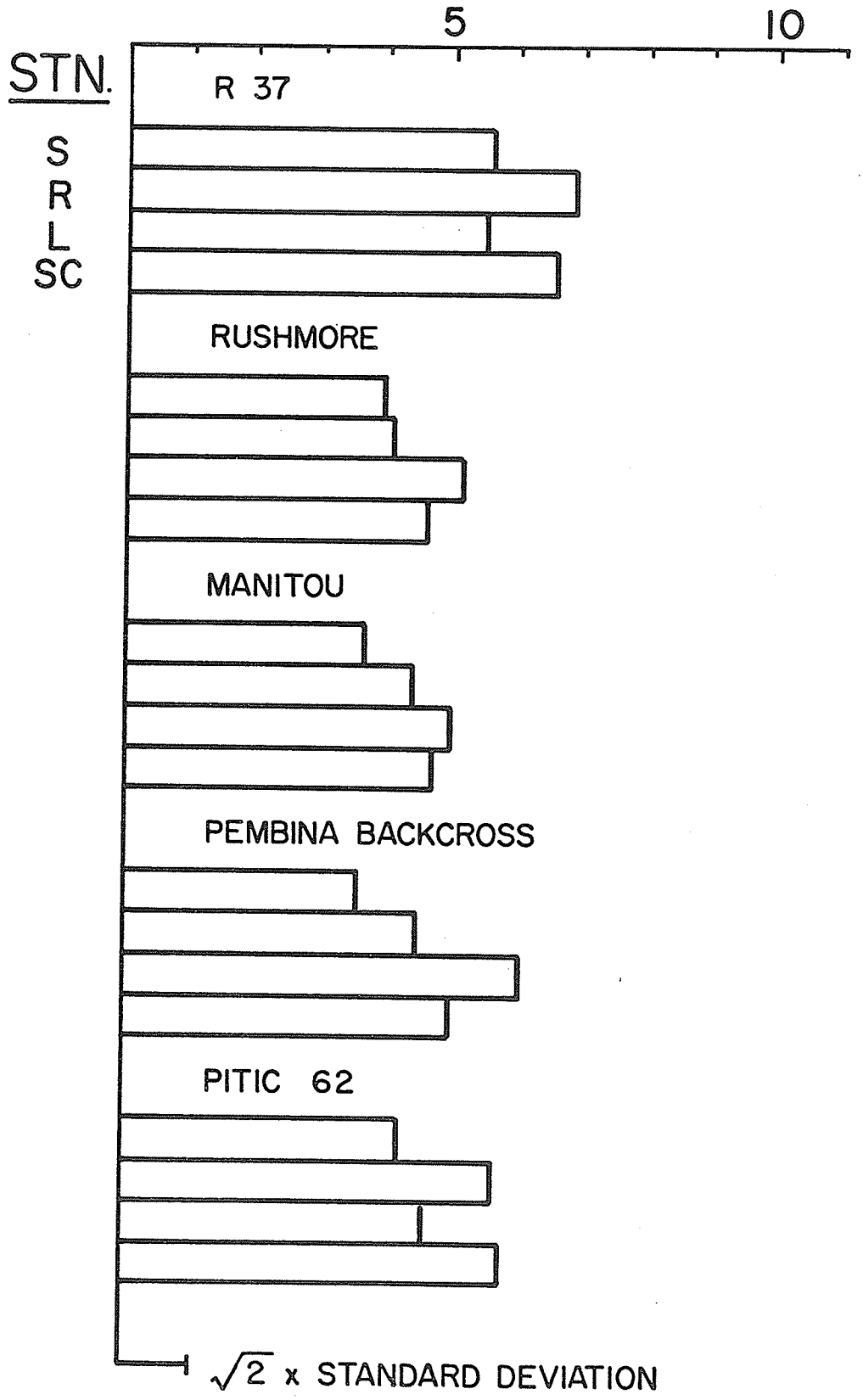


Fig. 10 Proportion of gliadin protein (alcohol-soluble) in the flours of five wheat varieties, each grown at four stations. The order of stations is the same for each variety.

S - Saskatoon

R - Regina

L - Lethbridge

SC - Swift Current

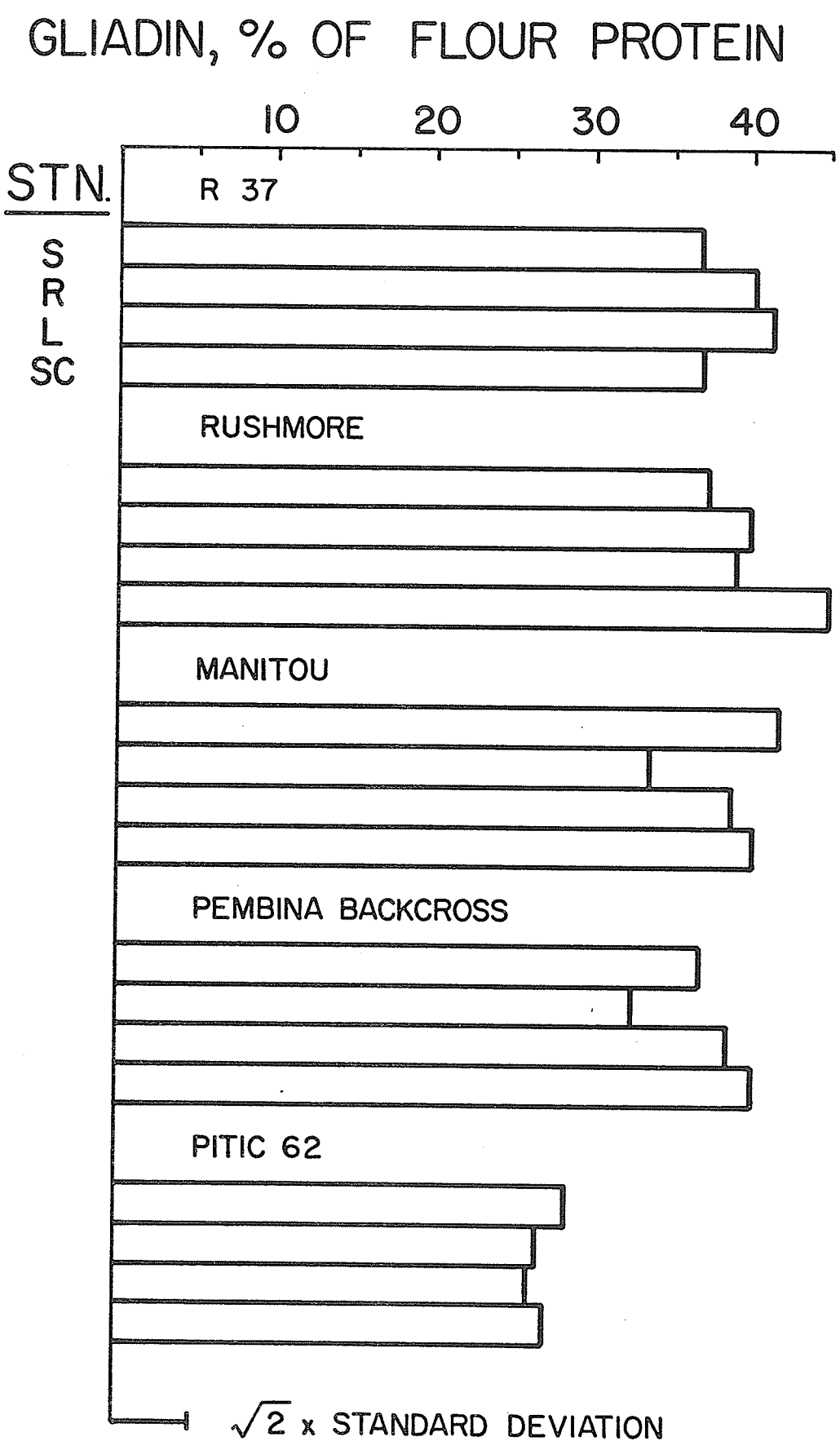

GLIADIN, % OF FLOUR PROTEIN
10
20
30
40
STN.
S
R
L
SC
R 37
RUSHMORE
MANITOU
PEMBINA BACKCROSS
PITIC 62
√2 x STANDARD DEVIATION

Fig. 11 Proportion of glutenin protein (acetic acid-soluble) in the flours of five wheat varieties, each grown at four stations. The order of stations is the same for each variety.

S - Saskatoon

R - Regina

L - Lethbridge

SC - Swift Current

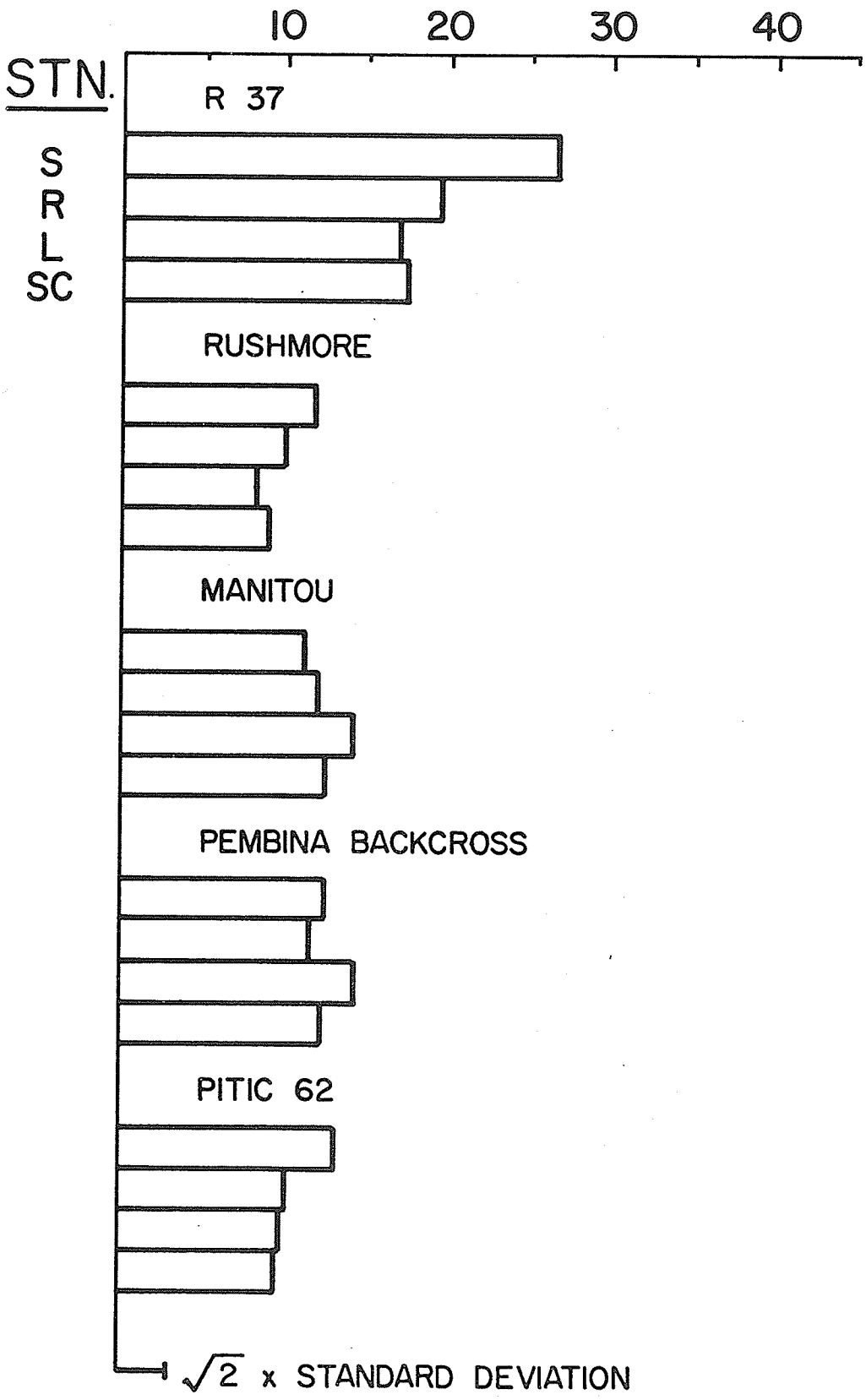

GLUTENIN, % OF FLOUR PROTEIN
10
20
30
40
STN.
S
R
L
SC
R 37
RUSHMORE
MANITOU
PEMBINA BACKCROSS
PITIC 62
√2 x STANDARD DEVIATION

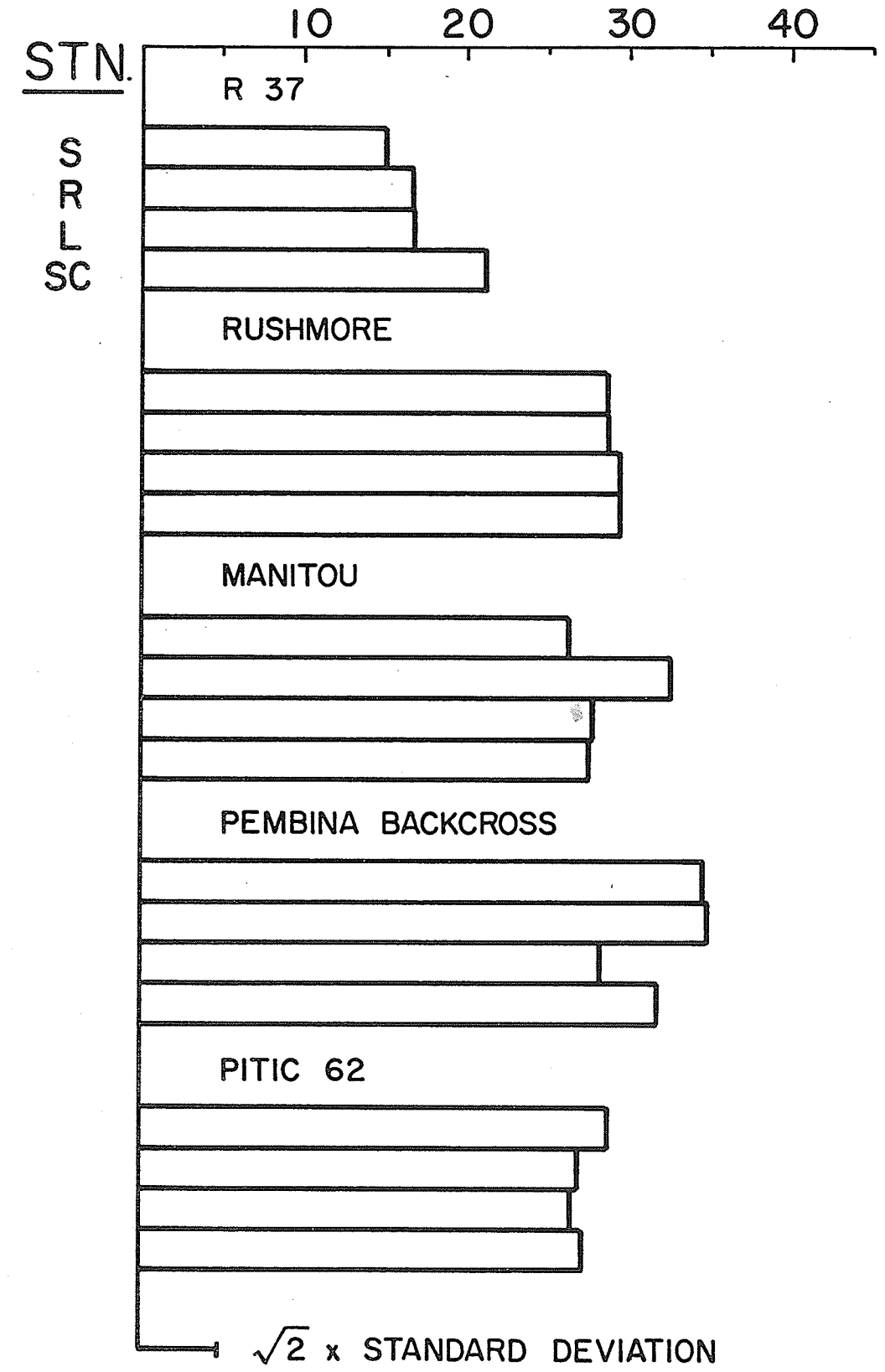
Fig. 12 Proportion of residue protein (insoluble) in the flours of five wheat varieties, each grown at four stations. The order of stations is the same for each variety.

S - Saskatoon

R - Regina

L - Lethbridge

SC - Swift Current


RESIDUE PROTEIN, % OF FLOUR PROTEIN
10
20
30
40
STN.
R 37
S
R
L
SC
RUSHMORE
MANITOU
PEMBINA BACKCROSS
PITIC 62
√2 x STANDARD DEVIATION

is much smaller than the range found in this value for the 26 Saskatoon samples with a maximum range of 33cc./unit protein. Likewise the interstation variations in the proportions of glutenin and residue proteins, for each of the five varieties were much smaller than those obtained for the broad spectrum of varieties grown at Saskatoon. However, the interstation variations in loaf volume per unit protein were not always reflected by variations of the predicted magnitude in the proportions of glutenin and residue proteins. The relatively small interstation baking quality differences within a variety could not be predicted from the protein solubility distribution. It can be concluded that the protein solubility distribution is largely a genotypic characteristic. The effect of environment (location) is quite small.

III. Relationships Between Protein Solubility Distribution and Some Quality Parameters.

The proportions of protein in the five solubility fractions discussed in Section II varied widely among varieties. Various combinations of the proportions of these protein fractions were correlated with some of the parameters that are used as indices of breadmaking quality. The aim of this statistical analysis was to determine if there were significant correlations and if a particular protein solubility distribution was characteristic of a flour with good baking quality. The quality parameters used for these correlations are: loaf volume per unit protein, farinograph dough development time, farinograph mixing tolerance index, and Zeleny sedimentation value. The correlation coefficients and their levels of significance are given in Table 5.

Of the individual fractions, residue protein was correlated at the 1% level of significance with all the quality parameters examined, and glutenin correlated at this level of significance with loaf volume per unit protein, farinograph mixing tolerance index, and farinograph dough development time. A correlation of +0.70** was obtained between loaf volume per unit protein and the gliadin to glutenin ratio. Some of these correlations are discussed further in the following sections.

Residue Protein and Baking Quality

The highly significant positive correlation obtained between residue protein and loaf volume per unit protein is illustrated graphically in Figure 13. It has long been postulated that intervarietal baking quality differences can be largely attributed to quality differences in the gluten proteins (22). Apparently flours of poor

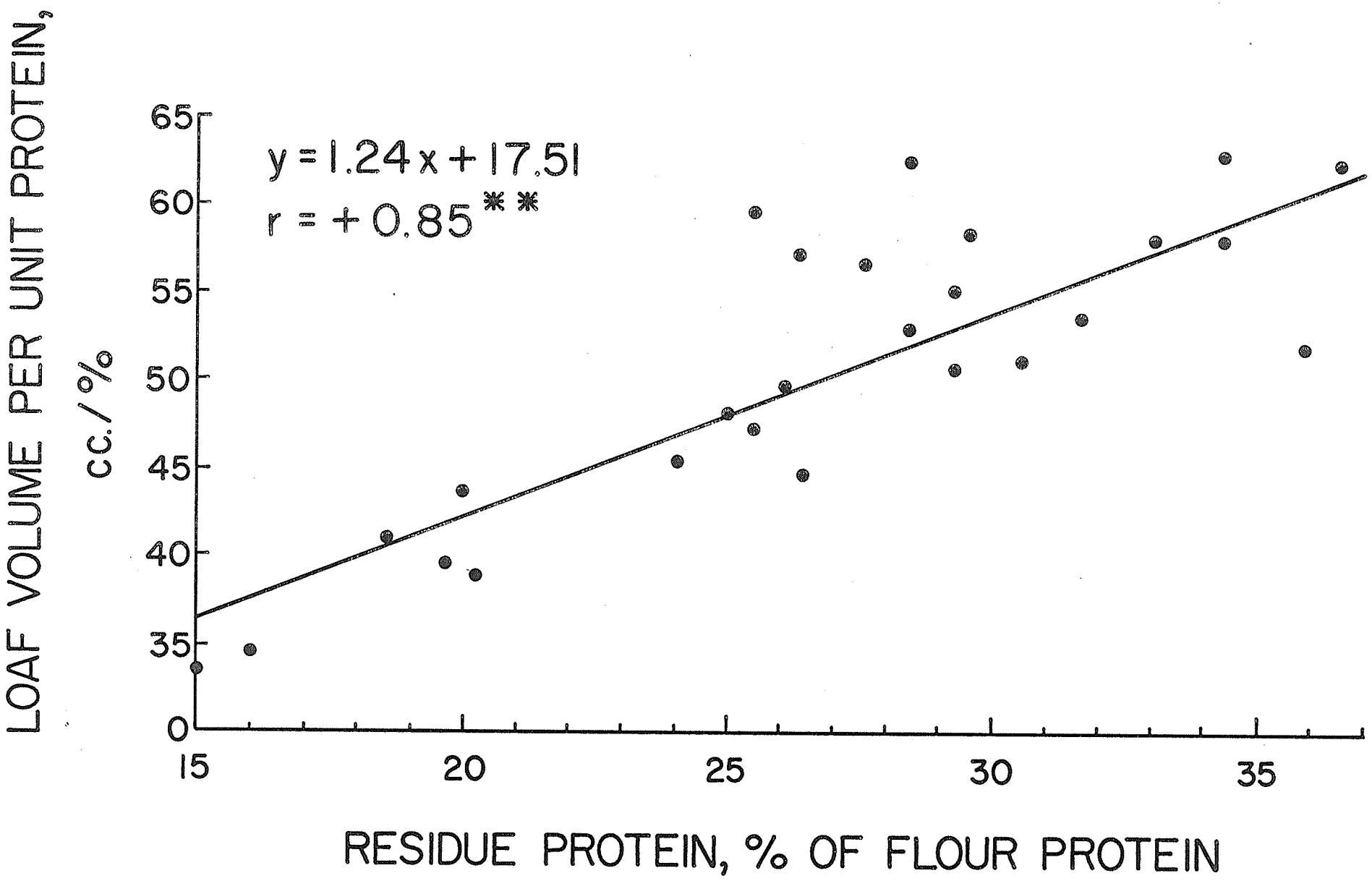
TABLE 5. CORRELATIONS BETWEEN SOME QUALITY PARAMETERS AND VARIOUS PROTEIN FRACTIONS.

Variables	r value (n = 26)
Loaf volume per unit protein versus:	
proportion of albumin protein	+0.20
proportion of globulin protein	-0.35
proportion of gliadin protein	+0.23
proportion of glutenin protein	-0.86**
proportion of residue protein	+0.85**
gliadin to glutenin ratio	+0.70**
albumin to globulin ratio	+0.43*
residue to glutenin ratio	+0.48**
% recovery of protein	+0.34
Dough development time versus:	
proportion of residue protein	+0.67**
proportion of glutenin protein	-0.49**
gliadin to glutenin ratio	+0.41*
Mixing tolerance index versus:	
proportion of residue protein	-0.75**
proportion of glutenin protein	+0.67**
Zeleny sedimentation value versus:	
proportion of residue protein	+0.82**

** significant at the 1% level

* significant at the 5% level

Fig. 13 Loaf volume per unit protein plotted against the proportion of residue protein for the Saskatoon samples.


LOAF VOLUME PER UNIT PROTEIN,
cc./%
y = 1.24x + 17.51
r = +0.85**
65
60
55
50
45
40
35
0
15
20
25
30
35
RESIDUE PROTEIN, % OF FLOUR PROTEIN

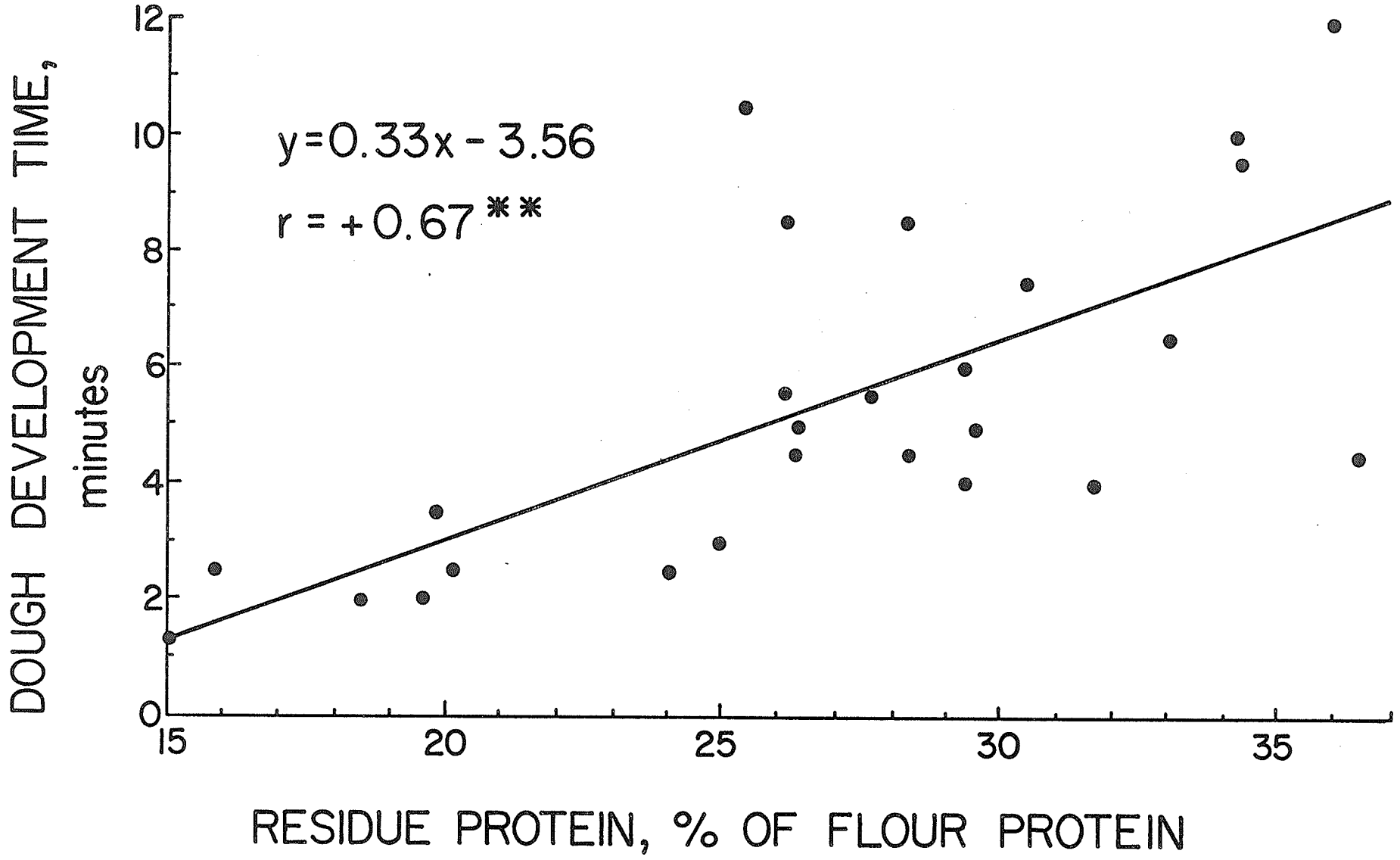
baking quality have relatively low proportions of the high molecular weight gluten proteins.

Many previous workers have indicated the importance of the residue or insoluble protein in baking quality. Pomeranz (33) reported that flours of poor quality had a greater proportion of protein dispersible in 3M urea, or conversely, less protein that was insoluble in this solvent. Dronzek et al (41) concluded that differences in the protein solubility distribution could be related to the breadmaking qualities of three hexaploid wheats and the AABB tetraploid wheats derived from the three varieties. Two of the hexaploid wheats had both better baking quality and a higher proportion of residue protein than their tetraploids. The third, derived from the variety Prelude, had the same baking quality as its hexaploid counterpart and also contained the same proportion of residue protein.

Chen and Bushuk (37) concluded from a study of the baking quality and solubility distributions of the protein of Triticale, its durum wheat and rye parents, and one hard red spring wheat (Thatcher), that the main reason for the superior baking quality of the hard red spring wheat was the lower content of water-soluble protein and higher content of insoluble or gluten protein. On the basis of studies reported so far, the amount of protein that is insoluble in 0.1N acetic acid solution appears to be the most reliable index of quality for widely different wheats.

Dough development time (D.D.T.), which was significantly correlated with loaf volume (See Section I), also showed a significant correlation with the proportion of residue protein. This is shown graphically in Figure 14. The results reported here are in general agreement with

Fig. 14 Farinograph dough development time plotted against the proportion of residue protein for the Saskatoon samples.


DOUGH DEVELOPMENT TIME, minutes
y=0.33x - 3.56
r = +0.67**
0
2
4
6
8
10
12
15
20
25
30
35
RESIDUE PROTEIN, % OF FLOUR PROTEIN

published results of Mullen and Smith (34), and from the University of Manitoba (37, 41). Mullen and Smith (34) showed that a flour with a D.D.T. of twenty minutes had a considerably higher proportion of insoluble residue protein than one with a D.D.T. of three minutes. The results published to date are based on a much smaller number of varieties than used in the present investigation.

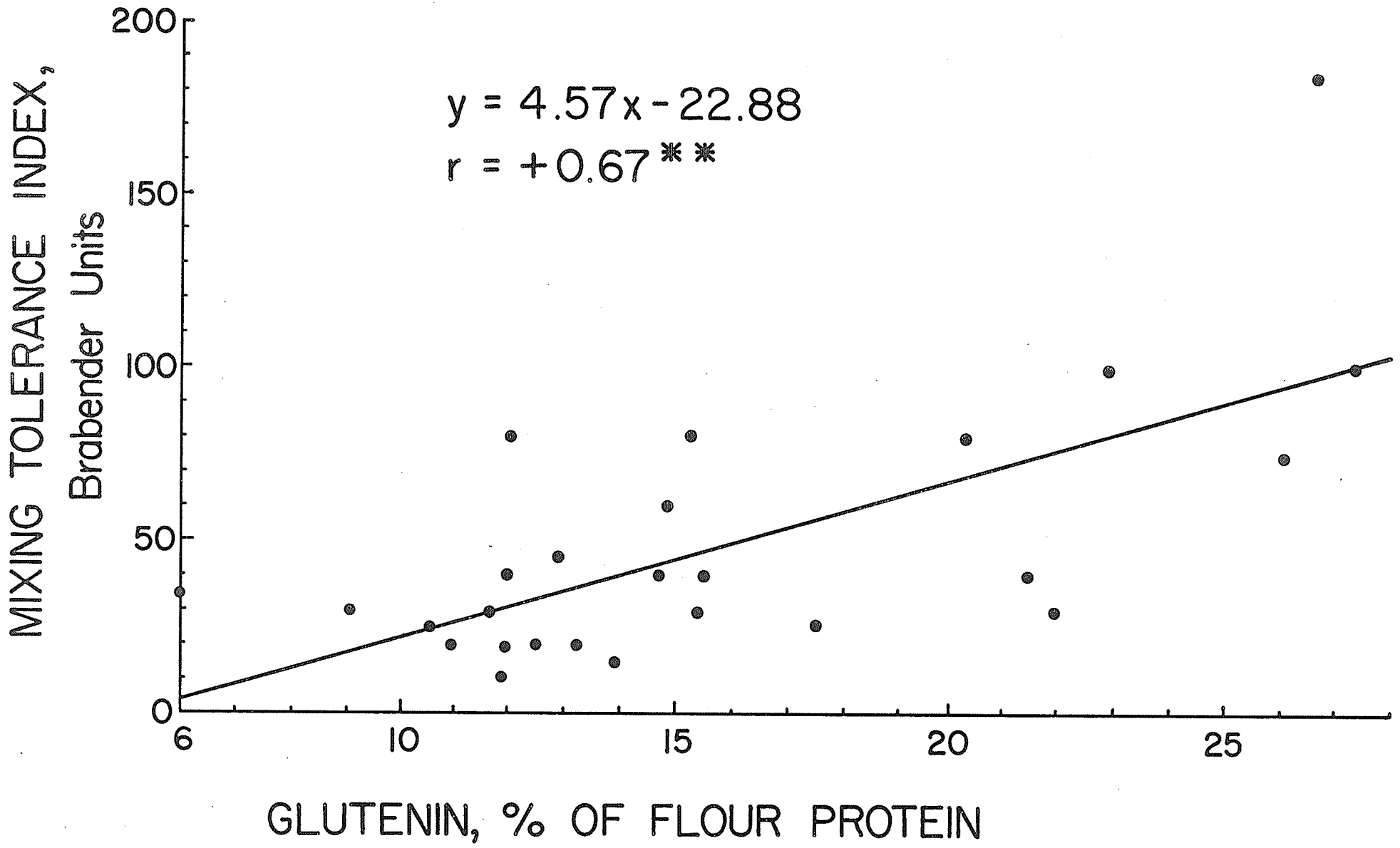
Published results and those reported in this thesis suggest that one of the major functions of mixing in dough development is to lower the aggregate size of the high molecular weight gluten proteins. Since strong flours have a higher proportion of residue protein, they require longer mixing times to disrupt the aggregates and form the proper viscoelastic system essential for a properly developed dough with optimum gas retention. Residue protein content was significantly negatively correlated with mixing tolerance index. That is, the insoluble protein is essential for maintenance of dough consistency during mixing.

Glutenin Protein and Baking Quality

The glutenin content of the flours was correlated positively with mixing tolerance index and negatively with both dough development time and loaf volume per unit protein. A high proportion of glutenin resulted in a weak flour with poor baking quality. A plot of M.T.I. against glutenin content is shown in Figure 15.

The results reported here support the findings of other workers based on a small number of varieties. Tsen (35), in a study of hard and soft wheats, reported that the former contained less glutenin than the latter. Dronzek et al (41) also found that the baking quality of

Fig. 15 Farinograph mixing tolerance index plotted against the proportion of glutenin protein (acetic acid-soluble) for the Saskatoon samples.


y = 4.57x - 22.88
r = +0.67**
MIXING TOLERANCE INDEX,
Brabender Units
200
150
100
50
0
6
10
15
20
25
GLUTENIN, % OF FLOUR PROTEIN

three hexaploid wheats and their AABB extracted tetraploids could be related to their protein solubility distribution, one feature of which was the lower proportion of glutenin in the good quality wheat flours.

For the varieties used in the present study, there was an indication of a reciprocal relationship between the proportion of glutenin and residue protein. The ratio of residue protein to glutenin protein was positively correlated with loaf volume per unit protein but at a lower level of significance than either the proportion of glutenin or residue protein above.

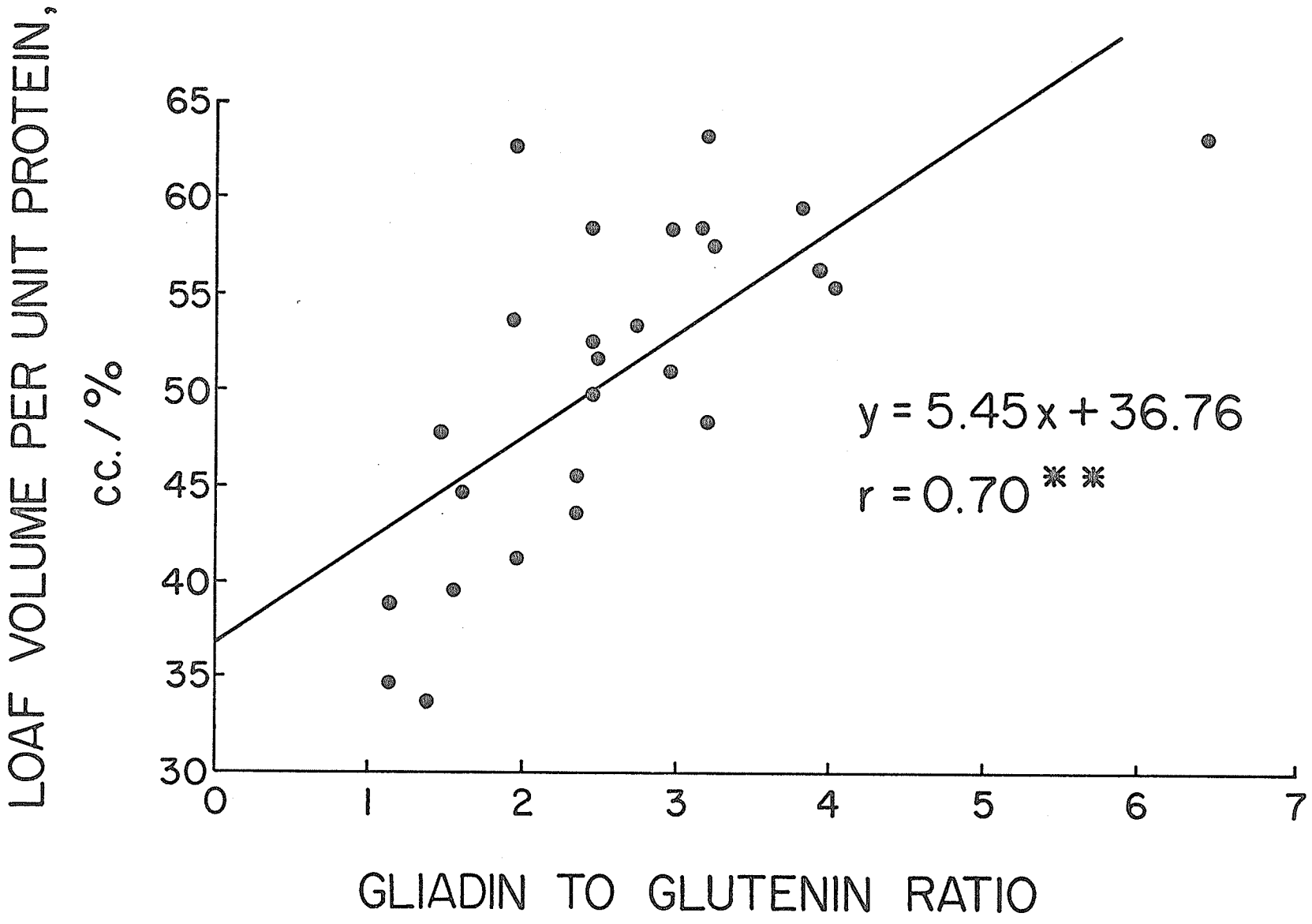
The Albumin to Globulin Ratio and Baking Quality

Although the proportions of both albumin and globulin protein were not correlated with baking quality, their ratio was correlated at the 5% level of significance, ($r = +0.43^{*}$). Pence et al (16) suggested that the ratio of albumin to globulin protein was related to baking quality. They reported a low, but significant, correlation between the albumin to globulin ratio and loaf volume for 32 wheat flours. No fundamental reason was given for this relationship. More recent workers (19) concluded that the water- and salt-soluble fractions could not explain varietal differences, but were essential for a normal loaf. They suggested that the important water-solubles were the glycolipids rather than proteins.

The Gliadin to Glutenin Ratio and Baking Quality

The correlation between the ratio of gliadin to glutenin and loaf volume per unit protein was positive and significant at the 1% level. This relationship is illustrated in Figure 16. The proportion of

Fig. 16 Loaf volume per unit protein plotted against the ratio of gliadin to glutenin for the Saskatoon samples.


LOAF VOLUME PER UNIT PROTEIN,
cc./%
65
60
55
50
45
40
35
30
0
1
2
3
4
5
6
7
y = 5.45x + 36.76
r = 0.70**
GLIADIN TO GLUTENIN RATIO

gliadin protein was not correlated significantly with any of the indicators of baking quality. Since the proportions of gliadin varied over the comparatively narrow range of 29.1 to 41.6% of the total protein, the significant correlation between the gliadin to glutenin ratio and baking quality is perhaps merely a consequence of the significant negative correlation with the proportion of glutenin protein.

Employing fractionation and reconstitution techniques, Shogren et al (32) concluded that there was a specific gliadin to glutenin ratio for optimum loaf volume. An increase in the gliadin to glutenin ratio was accompanied by a consistently large decrease in mixing time and baking absorption, and an increase in oxidation requirement and loaf volume. Earlier studies (26, 27, 28) also implicated the gliadin to glutenin ratio in baking quality.

From the above results a protein solubility distribution characteristic of a good quality wheat flour can be formulated. A high proportion of residue protein and a low proportion of acetic-acid soluble protein are the two most important criteria. Baking quality is less critically dependent on the proportions of albumins, globulins and gliadins, within the range of values obtained for the wheats examined.

IV. Electrophoretic Patterns of the Proteins

The possibility of qualitative varietal differences in protein components was investigated using disc-gel electrophoresis. This method has proven to be very sensitive and capable of resolving complex mixtures of proteins from a variety of sources (67). Electrophoregrams for the albumins, globulins and gliadins of the twenty-six Saskatoon samples and of five varieties grown at four locations were prepared and photographed.

Intervarietal Differences

The albumins of the 26 varieties produced very similar patterns. For the purpose of discussion, results for five representative varieties are shown in Figure 17. Eight distinct major bands are evident in each pattern, the only difference being the presence of an additional group of fine bands for many of the varieties. These fine bands are evident in the electrophoretic patterns of the albumins from flours covering the entire spectrum of baking quality, and represent varying degrees of heterogeneity obtained by the fractionation method employed. This heterogeneity is further illustrated by the large proportion of the water-soluble protein that did not enter the gels. No major qualitative differences were discernible in the electrophoretically distinct proteins of the water-soluble fractions.

The salt-soluble fractions of the Saskatoon flours also gave very similar electrophoregrams. Five representative patterns are shown in Figure 18. Each variety contained thirteen components. An additional component was observed for some of the varieties. Magnif 41 and Opal each had fourteen distinct components in their salt-soluble electrophoretic

Fig. 17 Disc-electrophoretic patterns for the albumin proteins of five wheats grown at Saskatoon.

The varieties, from top to bottom, are:

Thatcher Backcross

Magnif 41

6702

Rushmore

Comanche x CT 736

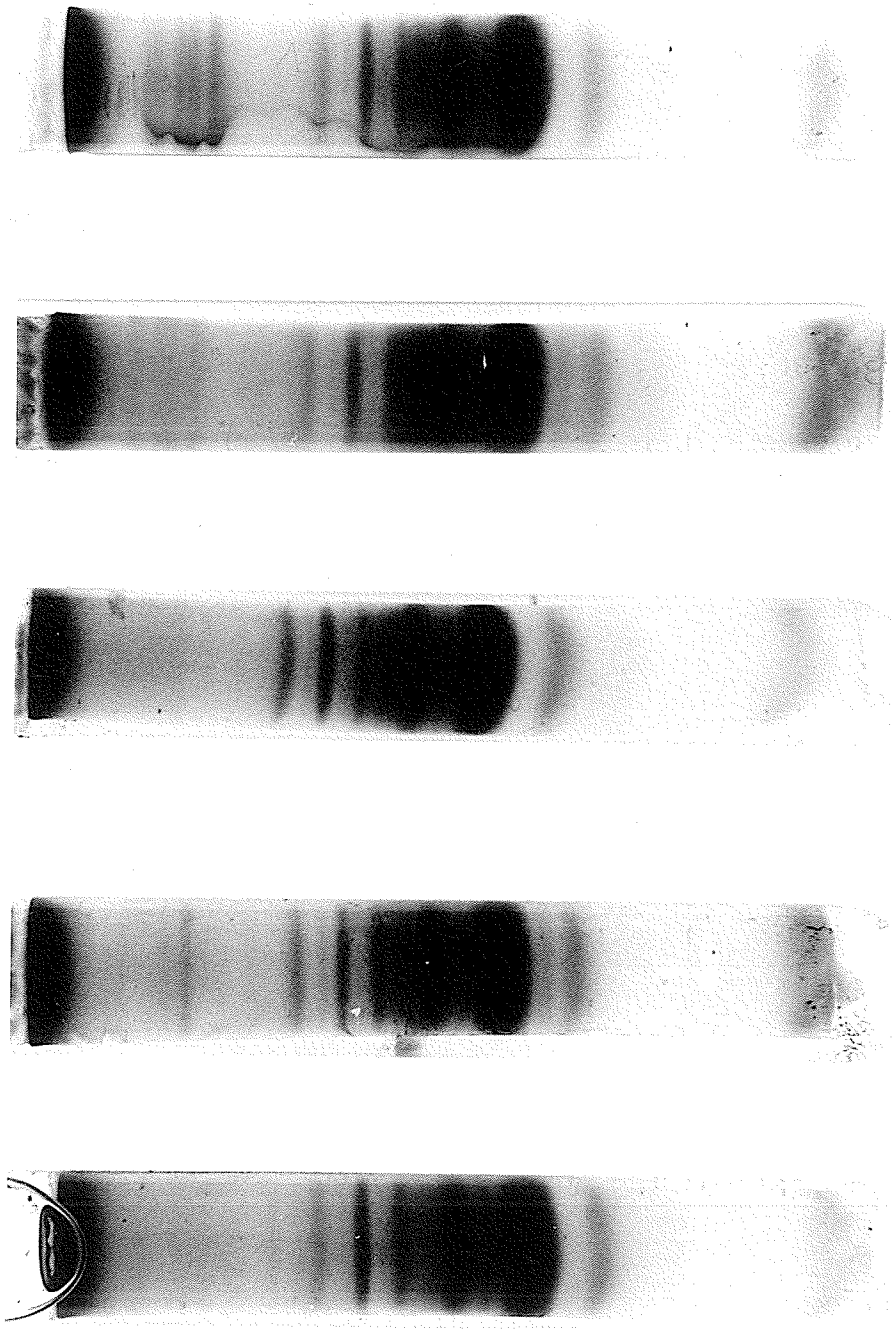


Fig. 18 Disc-electrophoretic patterns for the globulin proteins of five wheats grown at Saskatoon.

The varieties, from top to bottom, are:

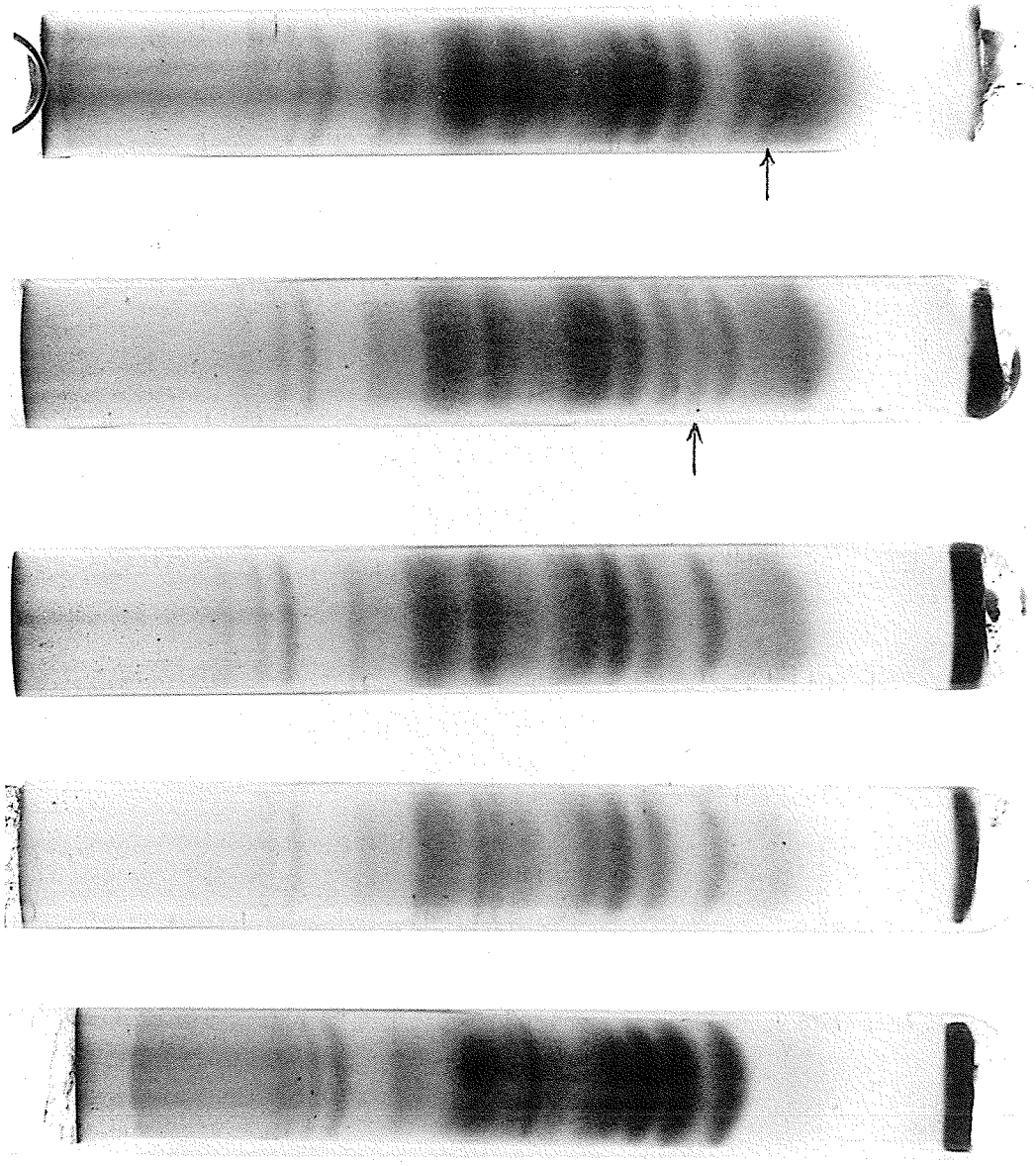
Opal

Magnif 41

Gaboto

Gabo Cross

Thatcher



patterns; these additional components are indicated by arrows in Figure 18. Opal is a fairly good quality wheat whereas Magnif 41 is poor. These additional components were not observed in the other varieties of similar baking quality and therefore are not considered important to the varietal differences in baking quality. This conclusion is in agreement with the results of Tanaka and Bushuk (71) who obtained only minor differences in the electrophoregrams of the salt-soluble proteins of five wheat varieties of widely different baking quality.

The alcohol-soluble fraction of wheat flour has been widely studied because of the important role of gluten in baking quality. In the present study, it was observed that the gliadins gave the greatest intervarietal differences in electrophoretic patterns. These patterns are shown in Figure 19 in which the varieties are arranged in order of decreasing baking quality.

The number of discernible bands varied from ten to fifteen. Each variety had three fast moving components, the remainder being within the 0.0 to 0.3 region of relative mobility. Within this area, there are marked quantitative and qualitative varietal differences in the patterns. Because of the large number of bands in this relatively small region the resolution is quite poor. A further loss of resolution occurs on photographing. It is therefore essential to study the actual gels soon after staining to attain maximum resolution and to detect the very fine bands.

Aniversario and Rushmore have very different baking quality, however the patterns of their gliadin proteins were essentially identical. The same is true for the varieties Carazinho and Thatcher. On the other

Fig. 19 Disc-electrophoretic patterns for the gliadin proteins of the 26 samples grown at Saskatoon.

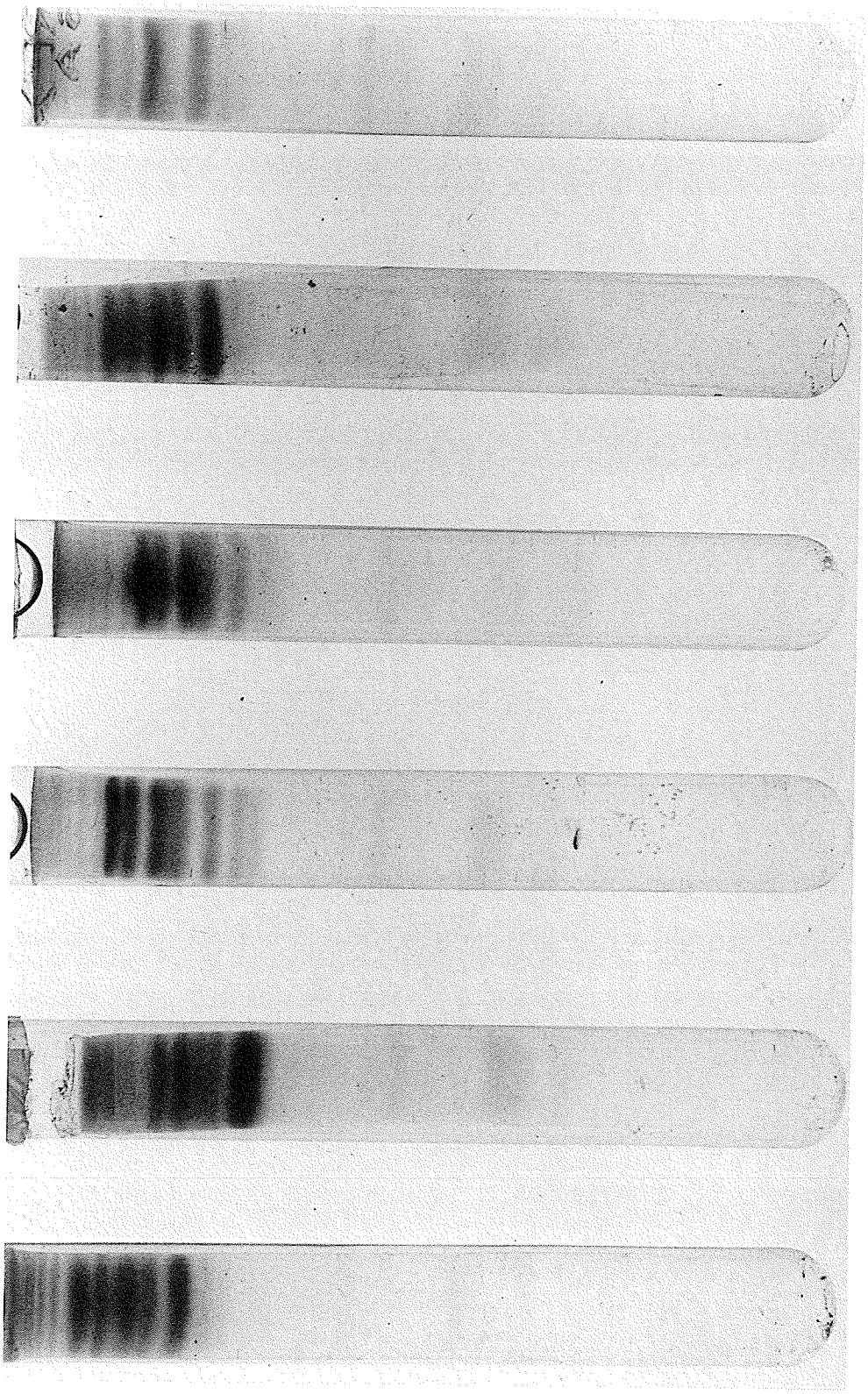
The varieties, arranged in order of decreasing loaf volume per unit protein from bottom to top, are as follows:

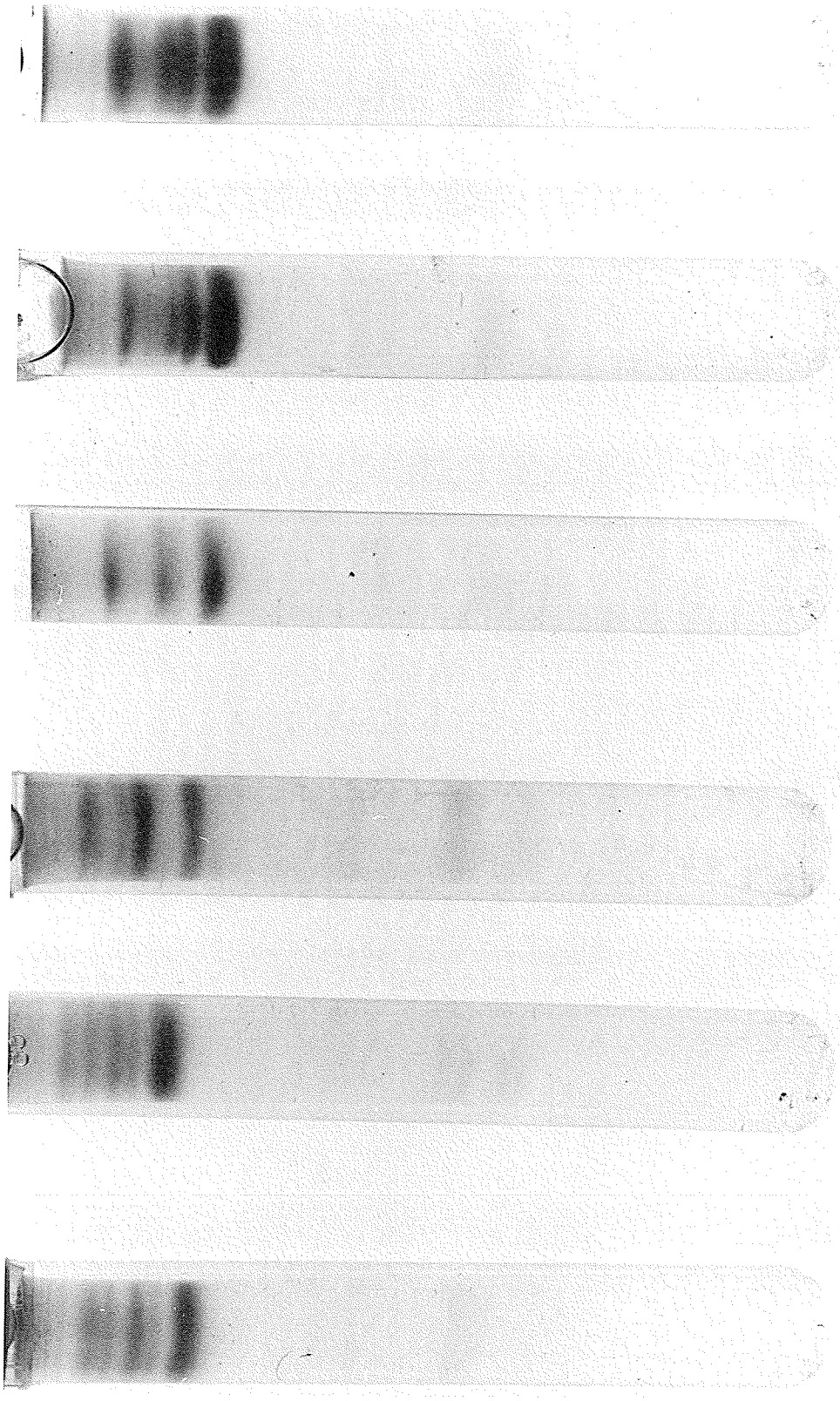
p. 78 Rushmore
Sonora 64
Thatcher
Manitou
Marquis
Pembina Backcross

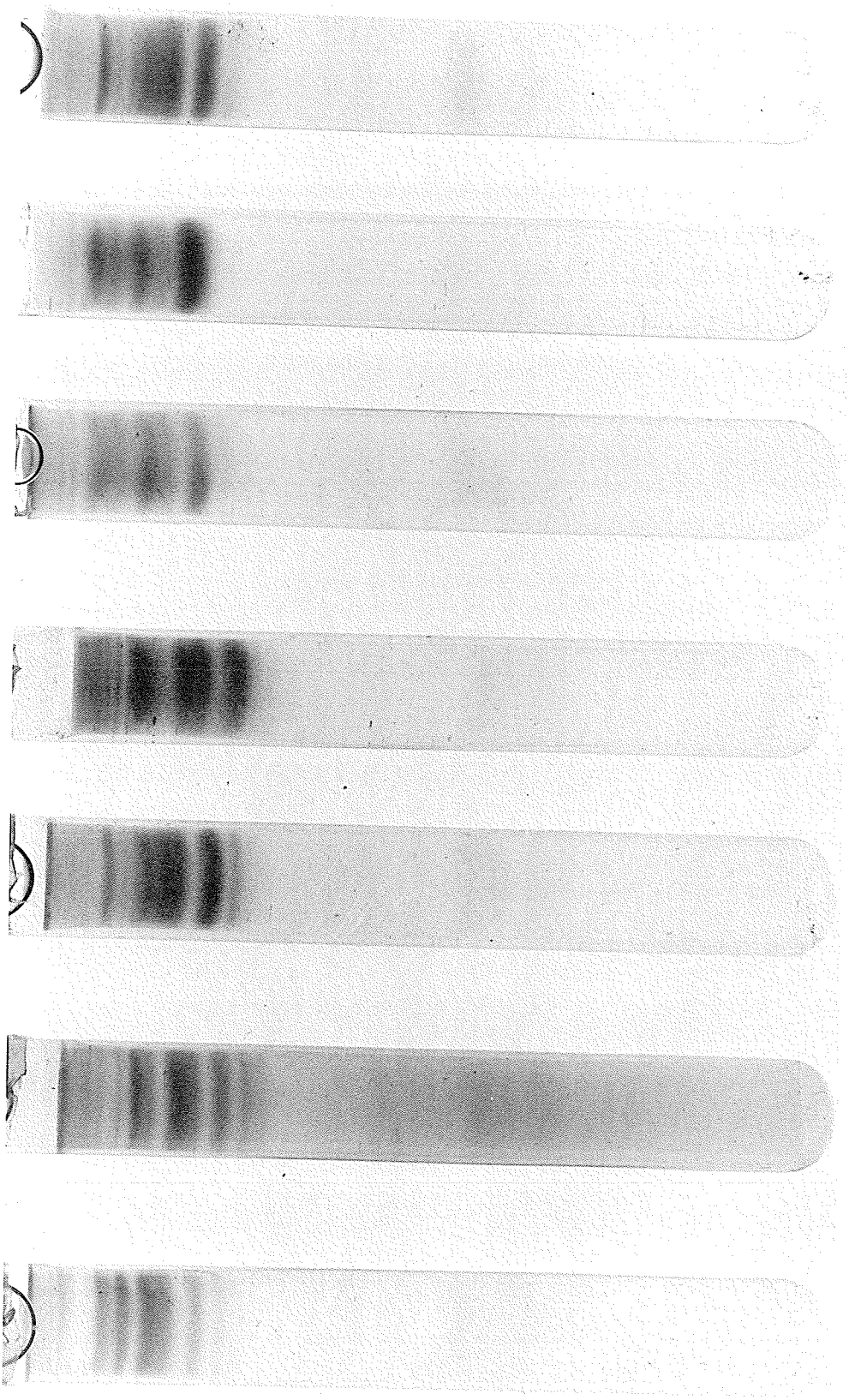
p. 79 6704
6702
Fortuna
Opal
Kota
Pitic 62

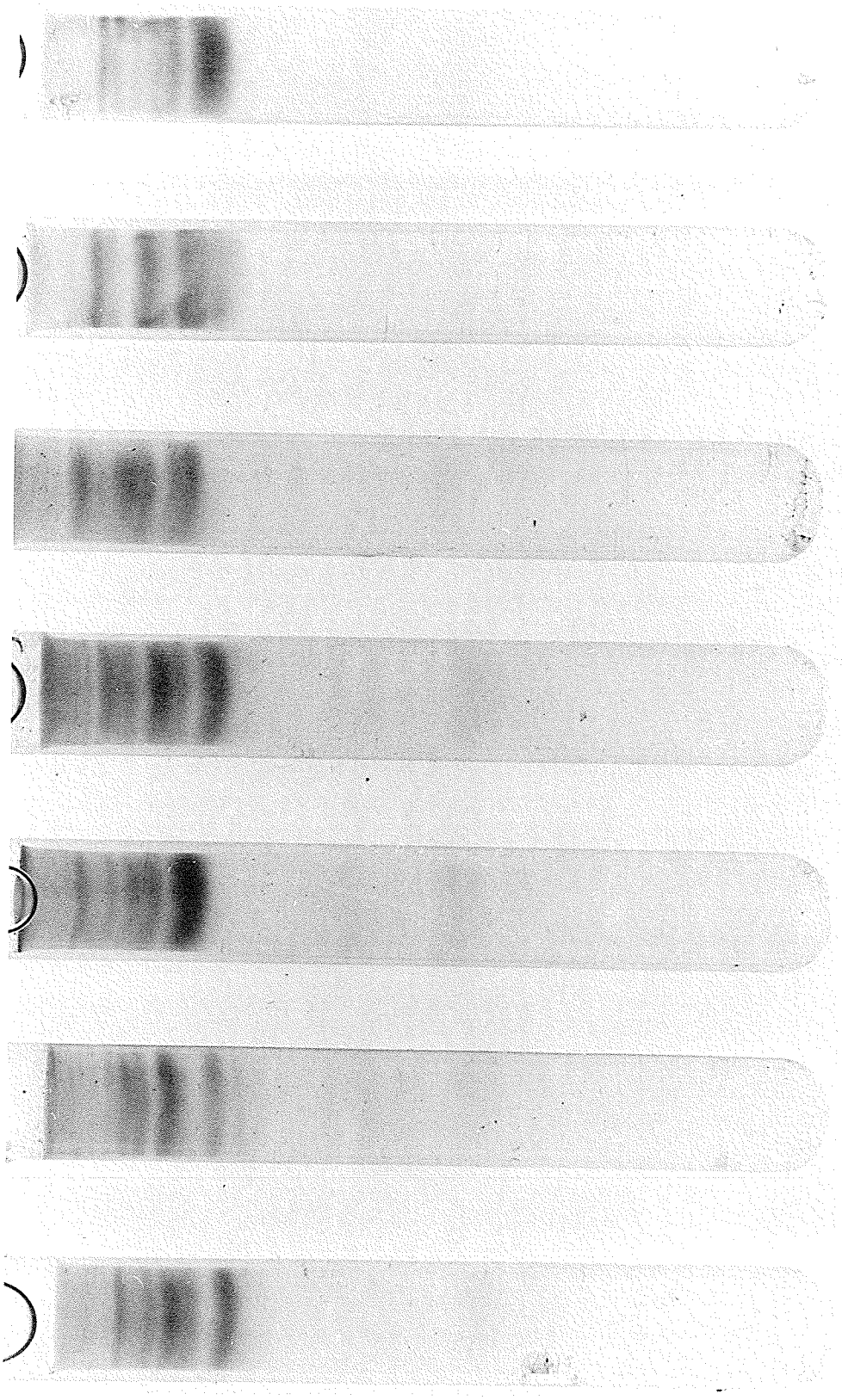
p. 80 Justin Reselection
Comanche x CT 736
Svenno
Gaboto
Napo 63
Aniversario
Magnif Entrerriano

p. 81 Magnif 41
Thatcher Backcross
Lerma Rojo 64A
Carazinho
Gabo Cross
E931 Cross
R37









hand Gaboto and Comanche CT736 showed quite different electrophoretic patterns but both are of intermediate baking quality. Neither the number of electrophoretically distinct gliadin components nor the overall patterns appear to be related to baking quality.

On the other hand, there appears to be a close similarity in the gliadin patterns of genetically related varieties. The gliadins of Marquis, Rushmore, Thatcher, Manitou, Justin Reselection and Aniversario are all very similar electrophoretically although they represent a wide range of baking quality. These varieties, as shown in Table 1, all have Marquis in their parentage. Thatcher backcross, which is also within this related group, lacked two gliadin components. Pitic 62 and Sonora 64, which are genetically related, also had similar electrophoretic patterns although they were quite different in baking quality.

It can be concluded that the electrophoretic patterns for the gliadin group of proteins of widely different varieties are not related to differences in baking quality. There appears to be, however, a consistent similarity in the patterns of genetically related varieties. From a study of the proteins from genetically related wheats, Lee and Wrigley (72) reported that there appeared to be a genetic control over the formation of individual chromatographic or electrophoretic peaks. The results reported in this thesis support this theory.

Interstation Differences

The effect of environment on the electrophoregrams of the wheat flour proteins was studied using the five varieties selected (see Section II) to represent a broad range of baking quality. Disc electrophoretic patterns of the water-soluble, salt-soluble and alcohol-soluble proteins failed to show any environmental effects for these varieties.

Electrophoretic patterns for the gliadins of the five wheats studied are shown in Figures 20 to 24 by way of example.

As there were marked interstation baking quality differences among Pembina backcross, Manitou and Rushmore (see Table 3), and no discernible differences in electrophoretic patterns, it may be that baking quality is a consequence of a critical quantitative balance of protein components rather than the absence or presence of individual protein components.

Lee and Wrigley (72) found that electrophoretic patterns were independent of environment for several varieties grown at widely different locations. In a recent study, Lee and Ronalds (73) examined four varieties grown at six widely separated locations. They found marked varietal differences in electrophoretic and chromatographic patterns for the gliadins but the patterns were essentially independent of environment.

The constancy of the gliadin patterns for a variety suggests that they would be useful aids in quality prediction, if characteristic patterns for good and poor quality wheats could be demonstrated.

Fig. 20 Disc-electrophoretic patterns for the gliadin proteins of the variety R37 grown at four stations. The locations, from top to bottom, are:

Swift Current

Regina

Lethbridge

Saskatoon

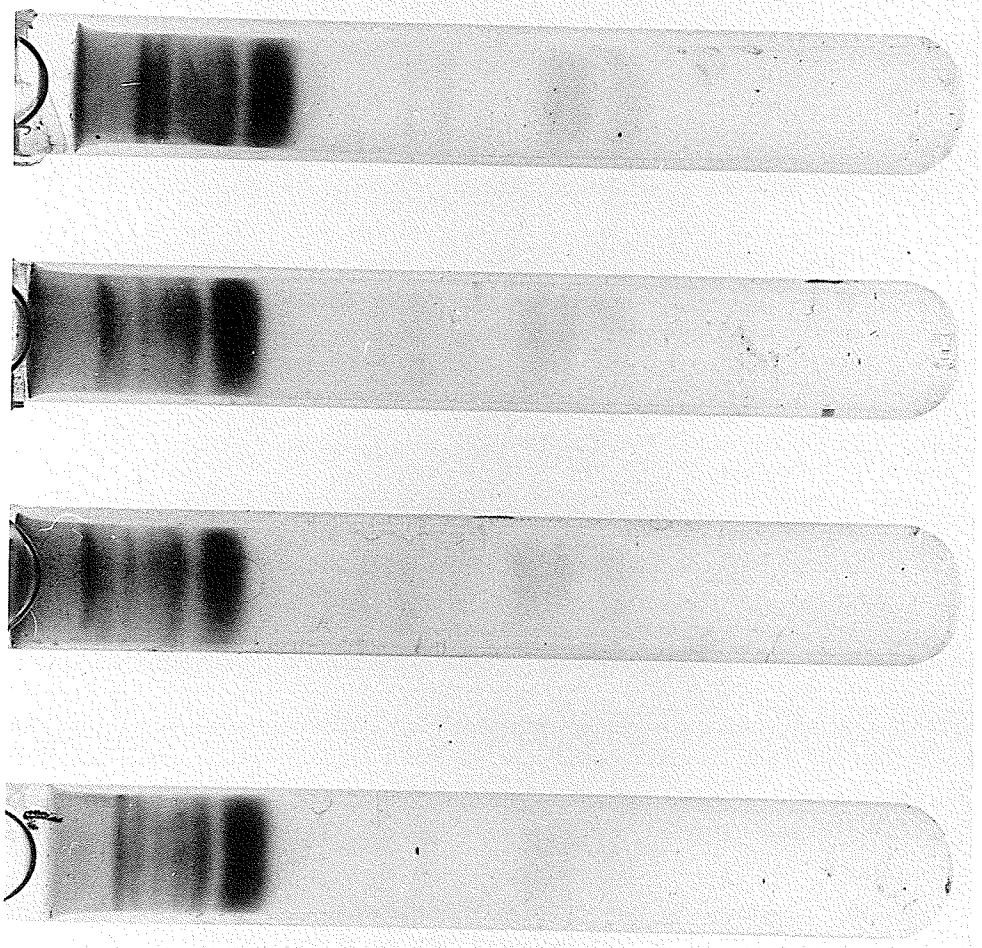


Fig. 21 Disc-electrophoretic patterns for the gliadin proteins of the variety Rushmore grown at four stations. The locations, from top to bottom, are:

Swift Current

Regina

Lethbridge

Saskatoon

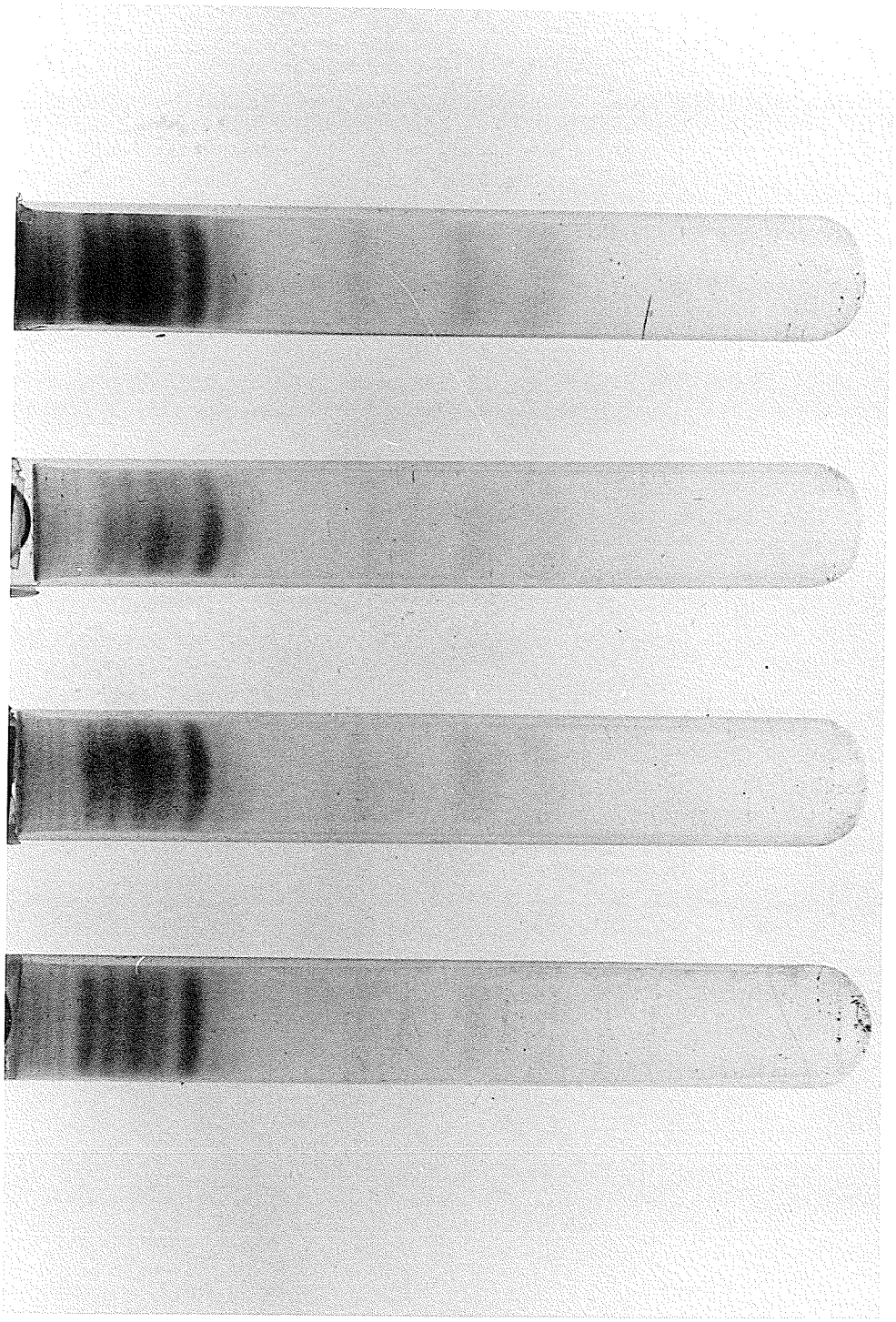


Fig. 22 Disc-electrophoretic patterns for the gliadin proteins of the variety Manitou grown at four locations. The locations from top to bottom, are:

Swift Current

Regina

Lethbridge

Saskatoon

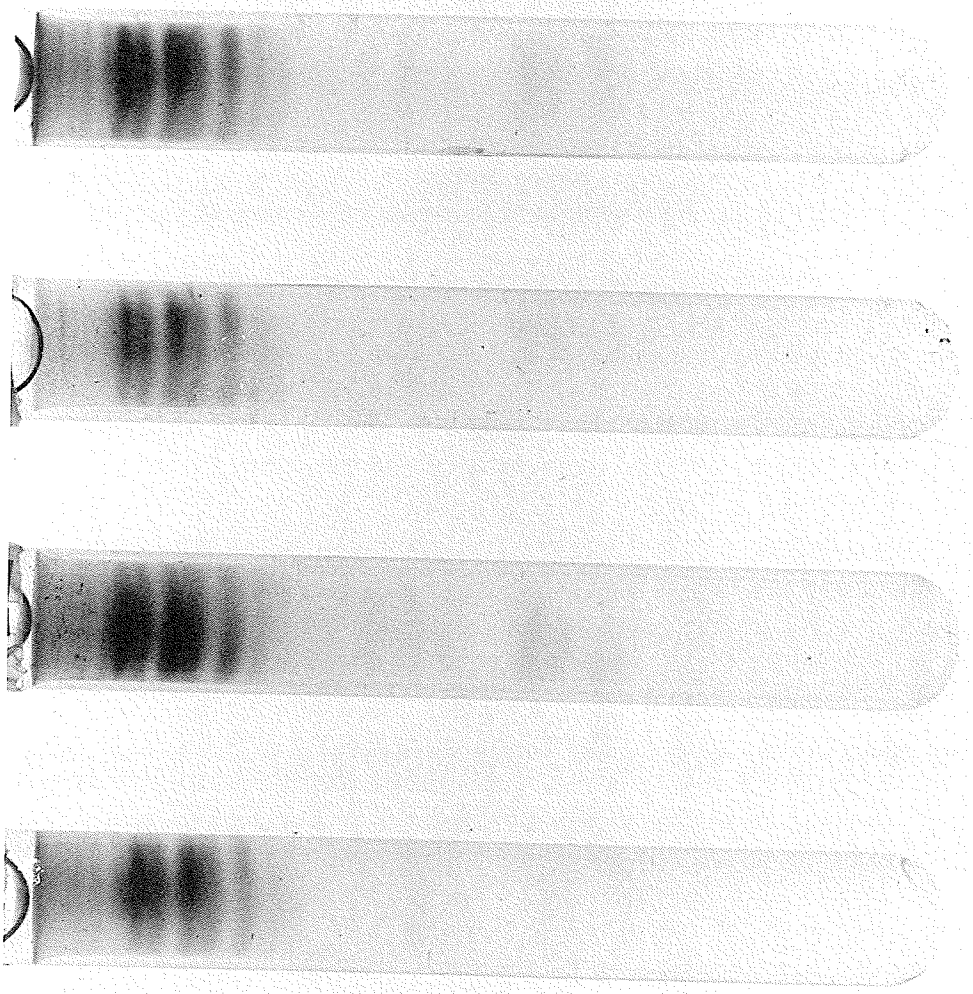


Fig. 23 Disc-electrophoretic patterns for the gliadin proteins of the variety Pembina Backcross grown at four locations. The locations, from top to bottom, are:

Swift Current

Regina

Lethbridge

Saskatoon

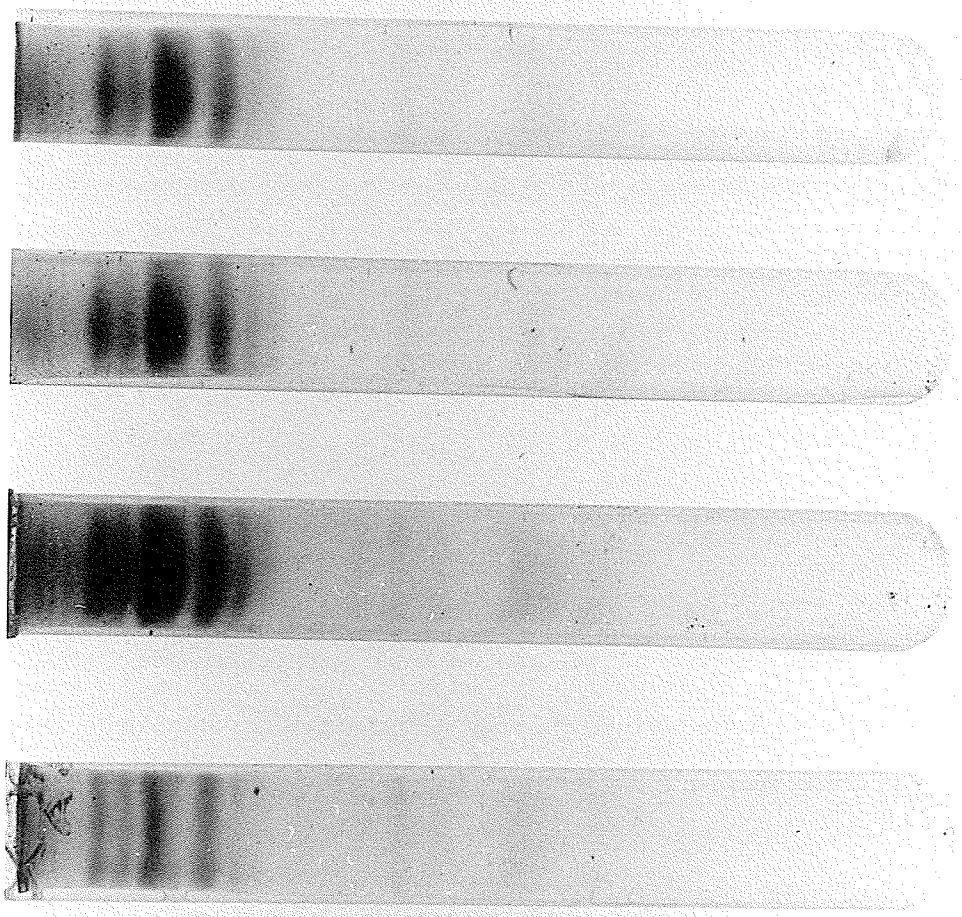


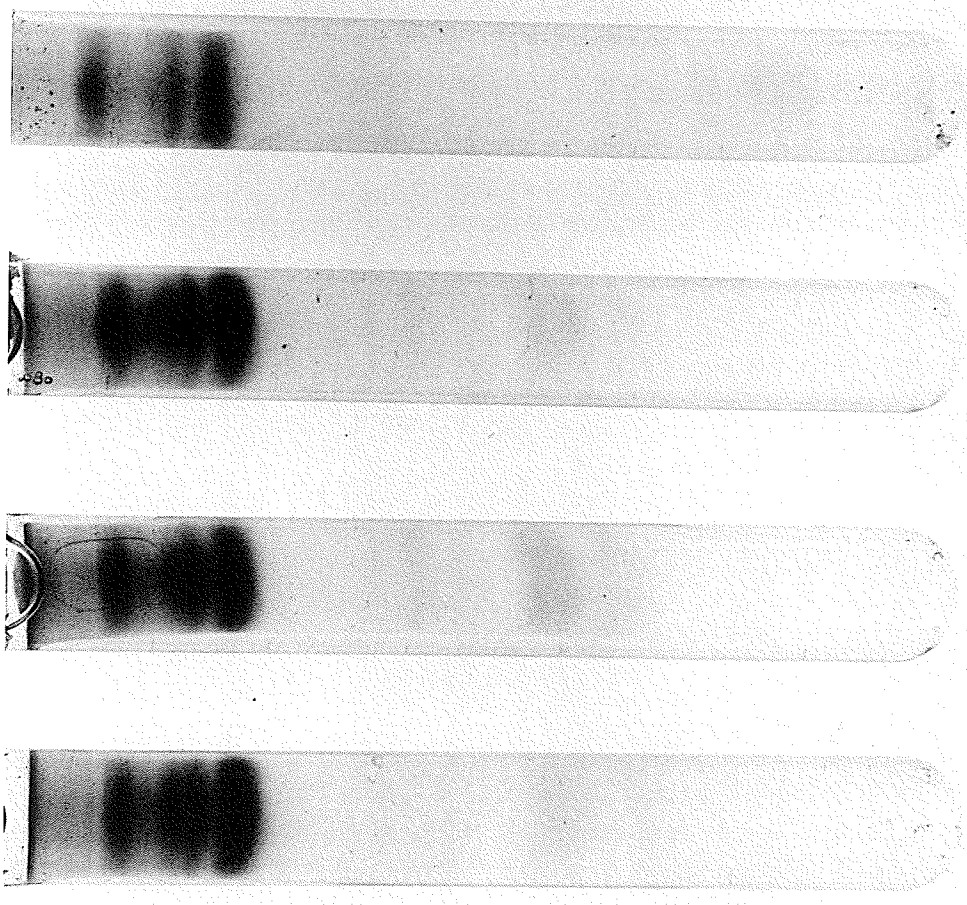
Fig. 24 Disc-electrophoretic patterns for the gliadin proteins of the variety Pitic 62 grown at four locations. The locations from top to bottom, are:

Swift Current

Regina

Lethbridge

Saskatoon



GENERAL DISCUSSION

Protein solubility distribution appears to be a reliable index of breadmaking quality for wheat samples or varieties that show wide differences in quality. However it cannot distinguish small differences among similar varieties. Qualitative disc-gel electrophoresis, on the other hand, did not seem to be related to baking quality. It is quite possible that quantitative distribution among the bands separated electrophoretically could give useful information on baking quality, similar to that from the solubility distribution.

The highly significant correlations between the proportion of both residue protein and glutenin protein with a number of baking quality parameters (loaf volume, dough development time, mixing tolerance index and sedimentation value) indicate that these two protein components can be used as reliable indices of baking quality. The practical limit on the resolution of this method can be judged from the results obtained in the study of the effect of environment on baking quality and protein solubility distribution for five varieties. Interstation differences in baking quality and the proportion of glutenin and residue protein were observed for the five varieties examined, but these differences were not significantly correlated as predicted by the correlations obtained for the 26 varieties grown at Saskatoon. These quality differences were, however, much smaller than the intervarietal differences upon which the correlations are based.

Disc-gel electrophoresis, recognized as an extremely sensitive technique, was unable to yield any qualitative differences that could be directly related to breadmaking quality. This technique did indicate

a wide variation in patterns for the gliadin proteins of the 26 spring wheats studied. As found previously (72), these differences appear to be genotypic. Varieties that were genetically related showed the same or very similar patterns.

An obvious, and severe, limitation of the solubility fractionation procedure used in this study is the large proportion of the total protein that cannot be solubilized i.e. the residue or gluten protein. These proteins have been strongly implicated in baking quality however they cannot be fully characterized because of their insolubility. Successful solubilization and characterization of these highly insoluble endosperm proteins could well be a major advance in the understanding of the breadmaking quality of flour on the basis of the molecular properties of its proteins.

SUMMARY AND CONTRIBUTIONS TO KNOWLEDGE

1. Quality evaluation of the 26 varieties of the 1969 Uniform Quality Nursery, grown at four stations, allowed examination of both intervarietal and interstation effects on their breadmaking quality. Both factors were shown to play important roles in baking performance and related quality parameters.

2. The effectiveness of some of the common quality tests in predicting breadmaking potential was determined by calculating the correlation coefficients between various pairs of these parameters. Of all the quality parameters studied the Zeleny sedimentation value was the best indicator of loaf volume potential. Farinograph dough development time and mixing tolerance index were both significantly correlated with loaf volume per unit protein.

3. For the varieties examined, milling yield was significantly correlated with bushel weight.

4. Remix loaf volume per unit protein was selected as the primary quality index and used for subsequent comparisons and calculations. This factor was used to obtain a better idea of the intrinsic quality of the flour protein by eliminating the known effects of total flour protein content.

5. Significant intervarietal variations in the protein solubility distribution were obtained for the five protein fractions. The largest variations occurred within the glutenin and residue protein fractions; albumin, globulin and gliadin fractions showed significant but smaller variations.

6. Interstation effects on protein solubility distribution were examined for five varieties, selected to represent extremes of baking quality.

Significant differences were observed, especially within the albumins, but the differences were generally much smaller than those between varieties. It can be concluded that the protein solubility distribution is largely genetically determined but is dependent on environment to a small degree.

7. Significant correlations were obtained between the proportion of both glutenin and residue protein and the major quality parameters. The gliadin to glutenin, albumin to globulin and residue to glutenin ratios were significantly correlated with loaf volume per unit protein. The percentage of glutenin and residue protein can be used as reliable indices to baking quality but cannot predict small quality differences.

8. Regression lines were calculated for four of the most significant and useful correlations, ie. loaf volume per unit protein on the proportion of residue protein and the gliadin to glutenin ratio, mixing tolerance index on the proportion of glutenin protein, and dough development time on the proportion of residue protein.

9. A protein solubility distribution characteristic of a good quality wheat flour can be formulated. A high proportion of residue protein and a low proportion of glutenin are the two most important criteria. Baking quality is less critically dependent on the proportions of albumins, globulins and gliadins, within the range of values obtained for the wheats examined.

10. Disc electrophoretic patterns of the albumins and globulins from 26 varieties showed very minor intervarietal differences. Marked electrophoretic differences were evident in the gliadins of these wheats, but the patterns could not be related to baking quality.

11. The electrophoretic patterns of the gliadin proteins seemed to

depend on genetic background and not environment or baking quality. Six varieties, all related to Marquis, showed very similar patterns, even though they were of diverse baking quality.

12. No interstation differences were evident in the electrophoretic patterns of the albumins, globulins or gliadins of five varieties examined.

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APPENDIX I

Quality Data for the 26 Varieties

for Each of Four Stations

SASKATOON SAMPLES

	MARQUIS 13	THATCHER 22	KOTA 88	R 37 101	MAGNIF ENTRER-RIANO 102	GABO-MARIA ESCOBAR-KENYA 103	E931-EGYPT 86-26 x EK_2 104	ANVERSARIO 105	CARAZINHO 106
Lab. No. (All 1970)	2954	2955	2956	2957	2958	2959	2960	2961	2962
Sample No.	1N	2N	3N	4N	5N	6N	7N	8N	9N
WHEAT									
Bushel weight, lb.	66.0	65.0	67.0	65.0	64.0	64.0	62.5	66.5	65.0
1000 kernel weight, gm.	34.4	32.2	32.8	41.2	34.5	56.4	64.8	36.6	41.1
Moisture, %	10.6	11.1	10.8	10.9	11.0	10.6	10.3	11.5	10.8
Protein, % (13.5% m.b.)	15.2	15.6	16.4	13.6	13.9	15.8	16.4	16.5	14.5
Flour yield, % (total)	72.8	74.9	73.9	72.9	69.3	70.3	58.1	70.7	69.6
FLOUR									
Protein, % (14.0% m.b.)	13.8	14.3	15.7	12.8	12.7	14.6	15.3	15.5	13.8
Ash, % (14.0% m.b.)	0.38	0.35	0.41	0.37	0.40	0.41	0.55	0.36	0.42
Color, units	0.2	0.2	1.1	0.7	0.6	1.0	2.9	0.95	0.9
Amylograph Viscosity	840	910	860	780	740	370	245	750	1040
Baking absorption, %	61.0	61.6	66.1	53.6	58.9	59.1	64.2	67.7	57.6
Sedimentation value	62.0	69.5	68.0	21.0	42.5	46.5	31.5	70.0	40.0
BREAD									
Loaf volume, cc. (remix)	1030	1125	1015	525	728	713	658	905	665
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	65.0	65.6	70.1	59.6	62.9	63.1	74.2	71.7	61.6
Development time, min.	5.0	4.5	4.0	1.25	2.5	2.5	2.5	10.5	2.0
M.T.I., B.U.	40	30	40	185	80	75	100	30	100

REMARKS

SASKATOON - 2

	GABOTO 107	LERMA ROJO 64A 108	MAGNIF 41 109	SONORA 64 110	RUSHMORE 117	MANITOU 118	THATCHER B'X 119	PEMBINA B'X 120	JUSTIN RESELECTION 121
Lab. No.	2963	2964	2965	2966	2967	2968	2969	2970	2971
Sample No.	10N	11N	12N	13N	14N	15N	16N	17N	18N
WHEAT									
Bushel weight, lb.	64.5	65.5	63.5	66.0	65.0	65.0	64.0	63.5	65.0
1000 kernel weight, gm.	31.5	43.8	41.5	40.5	37.8	32.8	30.8	31.4	39.1
Moisture, %	10.9	10.7	11.0	10.8	10.9	10.7	10.6	10.7	10.5
Protein, % (13.5% m.b.)	14.8	13.7	17.2	15.5	15.5	15.6	16.5	15.9	16.0
Flour yield, % (total)	67.1	70.1	74.5	74.0	76.2	73.8	71.1	73.4	74.4
FLOUR									
Protein, % (14.0% m.b.)	14.6	13.1	14.8	14.4	14.3	14.4	14.9	15.1	15.4
Ash, % (14.0% m.b.)	0.39	0.38	0.49	0.34	0.38	0.33	0.35	0.38	0.35
Color, units	1.4	0.1	0.9	0.9	-0.2	0	1.1	-0.3	0.2
Amylograph Viscosity	1010	845	780	705	790	870	705	735	755
Baking absorption, %	58.8	58.0	63.3	57.1	59.8	61.1	59.2	61.0	65.8
Sedimentation value	52.0	40.0	66.0	70.5	70.5	66.5	57.5	71.5	73.0
BREAD									
Loaf volume, cc. (remix)	855	650	888	1130	1133	1073	838	1073	970
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	60.8	60.0	67.3	61.1	63.8	65.1	63.2	65.0	69.8
Development time, min.	8.5	2.0	4.5	9.5	8.5	5.5	3.5	10.0	12.0
M.T.I., B.U.	60	80	40	35	30	20	25	20	15

REMARKS

SASKATOON - 3

	NAPO 63 122	COMANCHE x CT736 123	OPAL 124	PITIC 62 125	SVENNO 126	FORTUNA 127	6702 128	6704 129	
Lab. No.	2972	2973	2974	2975	2976	2978	2979	2980	
Sample No.	19N	20N	21N	22N	23N	24N	25N	26N	
WHEAT									
Bushel weight, lb.	63.5	65.0	64.5	64.0	64.5	66.0	65.5	65.0	
1000 kernel weight, gm.	36.7	39.7	36.3	38.2	37.5	39.6	34.6	36.2	
Moisture, %	11.1	10.6	11.1	10.9	11.1	11.1	10.8	10.7	
Protein, % (13.5% m.b.)	13.3	14.1	12.8	12.9	15.4	14.5	14.5	14.2	
Flour yield, % (total)	67.9	74.3	73.8	66.7	72.4	75.7	73.3	73.6	
FLOUR									
Protein, % (14.0% m.b.)	12.3	13.4	10.9	11.4	13.7	12.9	13.7	13.2	
Ash, % (14.0% m.b.)	0.46	0.39	0.40	0.38	0.22	0.37	0.37	0.35	
Color, units	0.55	-0.3	0.4	-0.4	0.3	0.9	0.9	0.0	
Amylograph Viscosity	1030	840	645	895	875	565	725	795	
Baking absorption, %	55.8	60.1	57.5	55.7	58.9	59.0	61.9	60.6	
Sedimentation value	50.5	72.5	53.0	46.5	72.0	66.5	65.5	69.0	
BREAD									
Loaf volume, cc. (remix)	738	843	818	795	908	945	965	955	
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	59.8	64.1	61.5	59.7	62.9	63.0	65.9	64.6	
Development time, min.	3.0	7.5	6.0	4.5	4.0	5.5	5.0	6.5	
M.T.I., B.U.	80	20	30	45	40	25	20	10	

REMARKS

REGINA

	MARQUIS 13	THATCHER 22	KOTA 88	R 37 101	MAGNIF ENTRER-RIANO 102	GABO-MARIA ESCOBAR-KENYA 103	E931-EGYPT 86-26 x EK$_2$ 104	ANIVERSARIO 105
Lab. No.	3115	3116	3117	3118	3119	3120	3121	3122
Sample No.	1R	2R	3R	4R	5R	6R	7R	8R
WHEAT								
Bushel weight, lb.	66.0	65.5	66.5	65.0	65.0	65.0	64.0	67.0
1000 kernel weight, gm.	35.0	32.7	33.5	37.6	36.3	48.8	59.1	36.1
Moisture, %	10.0	10.0	10.5	10.2	10.3	10.0	10.2	10.5
Protein, % (13.5% m.b.)	15.6	15.6	16.5	12.5	13.3	15.2	15.8	17.4
Flour yield, % (total)	71.6	73.3	72.6	71.7	68.4	69.8	55.5	72.5
FLOUR								
Protein, % (14.0% m.b.)	13.9	14.4	15.9	12.0	12.0	13.2	14.9	15.4
Ash, % (14.0% m.b.)	0.41	0.40	0.39	0.36	0.39	0.43	0.66	0.35
Color, units	-0.4	0.0	1.8	-0.7	-0.2	*	2.5	0.5
Amylograph Viscosity	325	390	355	445	350	290	170	470
Baking absorption, %	61.5	62.8	68.5	48.1	59.2	58.4	65.4	67.4
Sedimentation value	64.0	62.5	66.6	18.5	45.0	41.4	28.0	69.4
Moisture %	14.2	14.0	14.1	14.3	14.2	13.6	13.8	13.8
BREAD								
Loaf volume, cc. (remix)	928	945	1000	458	700	738	610	693
Blend Loaf Volume cc.								
FARINOGRAM								
Absorption, %	65.5	66.8	72.5	58.1	63.2	62.4	75.4	71.4
Development time, min.	5.0	5.5	4.5	1.5	2.5	2.5	3.0	10.0
M.T.I., B.U.	30	20	20	180	80	80	80	10

REMARKS * Insufficient sample

REGINA - 2

	CARAZINHO 106	GABOTO 107	LERMA ROJO 64A 108	MAGNIF 41 109	SONORA 64 110	RUSHMORE 117	MANITOU 118	THATCHER B'X 119	PEMBINA B'X 120
Lab. No.	3123	3124	3125	3126	3127	3128	3129	3130	3131
Sample No.	9R	10R	11R	12R	13R	14R	15R	16R	17R
WHEAT									
Bushel weight, lb.	65.5	65.5	66.5	64.5	66.0	65.0	65.0	64.5	63.5
1000 kernel weight, gm.	42.3	31.9	43.4	40.5	36.3	37.2	33.1	29.7	31.8
Moisture, %	10.3	10.3	10.2	9.8	9.8	10.0	10.2	10.0	10.0
Protein, % (13.5% m.b.)	14.4	15.4	14.1	16.4	14.9	16.5	16.6	16.6	16.4
Flour yield, % (total)	70.3	68.5	68.9	73.2	73.7	73.2	72.8	72.5	71.9
FLOUR									
Protein, % (14.0% m.b.)	13.6	14.6	13.2	15.5	13.5	15.2	14.9	14.7	14.8
Ash, % (14.0% m.b.)	0.37	0.42	0.38	0.37	0.42	0.44	0.45	0.41	0.35
Color, units	0.8	1.2	0.2	0.5	1.0	0.3	0.5	1.2	1.0
Amylograph Viscosity	580	580	535	545	465	575	610	480	535
Baking absorption, %	56.4	58.8	54.7	62.0	57.0	62.3	63.1	58.5	61.9
Sedimentation value	39.0	63.4	36.8	62.3	68.8	63.0	64.0	40.0	68.0
Moisture %	14.0	13.7	13.9	13.9	14.2	14.1	14.0	14.0	14.1
BREAD									
Loaf volume, cc. (remix)	705	940	660	840	915	988	945	645	1005
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	62.4	62.8	61.1	67.0	61.0	66.3	67.1	64.5	65.9
Development time, min.	2.5	3.0	2.0	3.5	7.0	4.5	5.0	3.0	6.5
M.T.I., B.U.	90	50	80	20	20	30	20	60	40

REMARKS

REGINA - 3

	JUSTIN RESELECTION 121	NAPO 63 122	COMANCHE x CT736 123	OPAL 124	PITIC 62 125	SVENNO 126	FORTUNA 127	6702 128	6704 129
Lab. No.	3132	3133	3134	3135	3136	3137	3138	3139	3140
Sample No.	18R	19R	20R	21R	22R	23R	24R	25R	26R
WHEAT									
Bushel weight, lb.	65.0	65.0	65.0	63.5	64.0	64.0	66.0	65.0	65.0
1000 kernel weight, gm.	37.8	37.8	40.7	37.1	36.6	37.0	44.1	35.1	37.5
Moisture, %	10.0	10.0	10.0	10.7	10.5	10.5	10.5	10.3	10.3
Protein, % (13.5% m.b.)	17.3	13.8	15.1	13.3	13.1	15.4	15.5	14.8	15.0
Flour yield, % (total)	72.8	68.6	72.8	74.2	65.1	72.4	75.3	72.4	73.0
FLOUR									
Protein, % (14.0% m.b.)	15.5	12.5	13.7	11.5	11.6	14.0	14.0	13.8	13.8
Ash, % (14.0% m.b.)	0.35	0.42	0.36	0.43	0.36	0.37	0.41	0.39	0.37
Color, units	0.3	0.35	0.0	0.75	0.2	0.75	0.4	0.5	0.1
Amylograph Viscosity	595	570	630	405	565	435	415	525	515
Baking absorption, %	66.1	56.4	61.8	57.5	57.5	57.7	62.1	63.9	62.7
Sedimentation value	72.0	40.5	72.0	56.0	47.0	70.5	62.0	61.3	67.0
Moisture %	14.4	14.3	14.2	14.5	14.6	14.7	13.9	14.2	14.4
BREAD									
Loaf volume, cc. (remix)	895	735	858	775	755	928	935	840	935
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	70.1	60.4	65.8	61.5	61.5	61.7	66.1	67.9	66.7
Development time, min.	9.0	2.5	6.5	4.5	4.0	4.0	5.0	5.0	5.0
M.T.I., B.U.	30	80	20	50	70	40	20	30	30

REMARKS

	MARQUIS 13	THATCHER 22	KOTA 88	R37 101	MAGNIF ENTRERRIANO 102	CABO-MARIA ESCOBAR-KENYA 103	E 931-EGYPT 86-26 x EK2 104	ANIVERSARIO 105
Lab. No.	3171	3172	3173	3174	3175	3176	3177	3178
Sample No.	1L	2L	3L	4L	5L	6L	7L	8L
WHEAT								
Bushel weight, lb.	64.0	63.5	65.0	63.5	60.0	63.5	62.5	68.0
1000 kernel weight, gm.	27.0	25.9	26.2	30.8	24.2	42.6	57.0	29.3
Moisture, %	8.8	8.9	9.0	9.4	9.1	9.4	8.7	10.0
Protein, % (13.5% m.b.)	15.2	14.8	14.6	11.9	21.7	13.0	15.6	13.9
Flour yield, % (total)	70.5	71.3	73.3	69.0	63.1	69.9	60.4	73.6
FLOUR								
Protein, % (14.0% m.b.)	13.8	13.6	13.8	10.9	12.0	12.1	15.1	13.0
Ash, % (14.0% m.b.)	0.39	0.42	0.46	0.39	0.40	0.41	0.68	0.37
Color, units *								
Amylograph Viscosity	780	845	*	815	710	550	735	930
Baking absorption, %	59.0	60.6	63.4	47.1	56.1	55.0	*	61.0
Sedimentation value	66.5	61.8	63.5	17.0	47.0	30.5	25.4	64.7
BREAD								
Loaf volume, cc. (remix)	925	925	930	418	708	585	*	938
Blend Loaf Volume cc.								
FARINOGRAM								
Absorption, %	63.0	64.6	67.4	57.1	60.1	60.0	64.7	65.0
Development time, min.	5.0	5.0	5.0	1.5	2.5	2.0	2.5	6.0
M.T.I., B.U.	50	20	20	180	80	130	90	20

REMARKS 3177 - Not enough flour to rebake
Doughs too wet to mould at first attempts at baking absorption of 56.7% and 58.7%.

* Insufficient Sample

	CARAZINHO 106	GABOTO 107	LERMA ROJO 64A 108	MAGNIF 41 109	SONORA 64 110	RUSHMORE 117	MANITOU 118	THATCHER BACKCROSS 119	PEMBINA BACKCROSS 120
Lab. No.	3179	3180	3181	3182	3183	3184	3185	3186	3187
Sample No.	9L	10L	11L	12L	13L	14L	15L	16L	17L
WHEAT									
Bushel weight, lb.	63.0	64.0	65.0	63.0	65.0	64.0	63.0	63.0	62.0
1000 kernel weight, gm.	29.8	24.9	39.2	34.1	34.6	29.5	28.7	24.8	26.1
Moisture, %	9.1	9.4	9.4	9.2	9.4	9.0	8.7	8.7	9.2
Protein, % (13.5% m.b.)	12.1	12.7	13.2	15.3	14.0	15.5	15.0	15.8	16.0
Flour yield, % (total)	66.4	65.7	69.1	73.2	73.7	73.3	71.1	70.0	72.5
FLOUR									
Protein, % (14.0% m.b.)	11.3	12.2	12.4	14.9	12.9	14.3	13.8	14.2	15.0
Ash, % (14.0% m.b.)	0.33	0.37	0.33	0.38	0.32	0.39	0.37	0.39	0.48
Color, units *									
Amylograph Viscosity	910	795	700	485	790	790	625	*	750
Baking absorption, %	54.0	53.7	54.7	60.3	56.5	59.4	60.3	53.7	59.3
Sedimentation value	35.5	48.5	26.0	62.5	68.0	66.5	64.0	31.0	66.7
BREAD									
Loaf volume, cc. (remix)	650	835	570	725	913	980	870	415	885
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	59.0	57.7	59.7	64.3	60.5	63.4	64.3	61.7	63.3
Development time, min.	2.0	2.5	2.0	3.5	6.0	5.5	5.0	3.0	4.0
M.T.I., B.U.	100	80	100	50	40	20	30	100	30

REMARKS

	JUSTIN RESELECTION 121	NAPO 63 122	COMANCHE x CT736 123	OPAL 124	PITIC 62 125	SVENNO 126	FORTUNA 127	6702 128	6704 129
Lab. No.	3188	3189	3190	3191	3192	3193	3194	3195	3196
Sample No.	18L	19L	20L	21L	22L	23L	24L	25L	26L
WHEAT									
Bushel weight, lb.	64.0	64.0	62.5	61.0	62.0	64.0	64.5	62.5	62.0
1000 kernel weight, gm.	32.4	33.4	30.5	29.0	29.8	30.6	38.1	26.8	27.1
Moisture, %	9.2	9.0	9.2	9.7	9.7	9.8	9.8	9.8	9.8
Protein, % (13.5% m.b.)	15.5	13.4	13.4	12.3	11.5	13.0	14.4	13.9	12.6
Flour yield, % (total)	70.5	67.3	72.0	71.9	64.4	71.0	74.9	71.0	70.7
FLOUR									
Protein, % (14.0% m.b.)	14.1	12.5	12.8	11.1	9.9	11.9	13.1	13.1	12.4
Ash, % (14.0% m.b.)	0.36	0.40	0.38	0.43	0.33	0.33	0.39	0.42	0.38
Color, units *									
Amylograph Viscosity	670	825	615	765	745	550	780	825	670
Baking absorption, %	60.0	56.6	59.6	55.9	54.9	56.1	60.1	61.3	59.4
Sedimentation value	68.9	44.4	70.5	50.3	37.0	56.2	54.0	60.5	66.5
BREAD									
Loaf volume, cc. (remix)	985	710	713	845	660	765	743	835	840
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	64.0	60.6	63.6	61.9	59.9	60.1	64.1	65.3	63.4
Development time, min.	6.0	2.5	4.5	4.0	3.0	3.0	4.5	4.5	6.0
M.T.I., B.U.	20	80	20	40	50	70	30	20	40

REMARKS

SWIFT CURRENT SAMPLES

	MARQUIS 13	THATCHER 22	KOTA 88	R 37 101	MAGNIF ENTRER-RIANO 102	GABO-MARIA-ESCOBAR-KENYA 103	E 931-EGYPT 86-26 x EK2 104	ANIVERSARIO 105	
Lab. No.	3143	3144	3145	3146	3147	3148	3149	3150	
Sample No.	1S	2S	3S	4S	5S	6S	7S	8S	
WHEAT									
Bushel weight, lb.	64.0	64.5	65.5	64.0	62.0	64.5	63.5	67.5	
1000 kernel weight, gm.	26.4	25.8	27.5	31.0	28.8	41.0	54.8	31.1	
Moisture, %	9.8	9.4	9.8	9.9	10.2	9.6	9.6	10.2	
Protein, % (13.5% m.b.)	13.3	13.5	13.9	12.1	12.3	12.9	15.0	14.7	
Flour yield, % (total)	71.4	72.3	73.4	69.5	66.7	69.3	61.6	63.5	
FLOUR									
Protein, % (14.0% m.b.)	12.3	12.5	12.9	11.4	11.5	12.1	14.1	13.8	
Ash, % (14.0% m.b.)	0.44	0.41	0.48	0.41	0.41	0.42	0.69	0.43	
Color, units *									
Amylograph Viscosity	750	725	705	*	515	500	*	695	
Baking absorption, %	58.3	60.6	63.5	47.7	56.4	55.1	-	62.5	
Sedimentation value	55.5	63.5	62.0	19.5	40.7	40.3	26.5	64.7	
BREAD									
Loaf volume, cc. (remix)	825	878	885	425	675	698	*	948	
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	62.3	64.6	68.5	57.7	61.4	59.1	71.6	66.5	
Development time, min.	5.0	5.0	4.0	1.5	2.0	2.0	2.5	9.0	
M.T.I., B.U.	30	20	40	150	90	90	90	20	

REMARKS #3149 - Not enough to rebake - too wet at first attempts with baking absorption of 66.6% + 63.6%

* Insufficient sample

SWIFT CURRENT - 2

	CARAZINHO 106	GABOTO 107	LERMA ROJO 64A 108	MAGNIF 41 109	SONORA 64 110	RUSHMORE 117	MANITOU 118	THATCHER BACKCROSS 119	PEMBINA BACKCROSS 120
Lab. No.	3151	3152	3153	3154	3155	3156	3157	3158	3159
Sample No.	9S	10S	11S	12S	13S	14S	15S	16S	17S
WHEAT									
Bushel weight, lb.	63.0	64.0	66.0	64.0	65.0	65.0	64.0	63.5	63.0
1000 kernel weight, gm.	33.6	27.2	39.0	34.6	32.3	31.5	27.8	24.6	26.1
Moisture, %	9.9	10.0	9.8	9.8	10.1	9.8	9.8	9.8	9.8
Protein, % (13.5% m.b.)	13.3	14.0	14.2	16.4	14.3	15.5	14.8	15.2	15.1
Flour yield, % (total)	66.2	66.5	67.8	73.0	74.3	74.8	73.2	73.1	72.3
FLOUR									
Protein, % (14.0% m.b.)	12.7	13.2	13.8	15.6	13.5	14.3	13.8	13.8	13.8
Ash, % (14.0% m.b.)	0.43	0.43	0.42	0.42	0.42	0.41	0.40	0.40	0.47
Color, units *									
Amylograph Viscosity	835	795	750	665	620	745	805	700	655
Baking absorption, %	54.4	55.2	56.4	59.9	55.5	59.3	60.3	56.4	59.4
Sedimentation value	45.2	58.9	34.8	65.9	68.5	67.0	65.5	42.9	69.0
BREAD									
Loaf volume, cc. (remix)	760	893	675	805	915	995	908	680	943
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	59.4	59.2	60.4	64.9	59.6	63.3	64.3	62.4	63.4
Development time, min.	2.5	3.5	2.0	3.5	7.0	6.5	6.0	4.0	5.5
M.T.I., B.U.	80	50	80	40	40	40	20	50	50

REMARKS

	JUSTIN RESELECTION 121	NAPO 63 122	CAMANCHE x CT736 123	OPAL 124	PITIC 62 125	SVENNO 126	FORTUNA 127	6702 128	6704 129
Lab. No.	3160	3161	3162	3163	3164	3165	3166	3167	3168
Sample No.	18S	19S	20S	21S	22S	23S	24S	25S	26S
WHEAT									
Bushel weight, lb.	65.0	65.0	63.0	61.0	59.5	61.0	63.5	63.0	64.0
1000 kernel weight, gm.	31.6	34.1	33.5	29.6	26.4	27.7	31.9	27.7	30.5
Moisture, %	9.8	9.8	9.8	10.5	10.1	10.4	10.1	9.9	10.0
Protein, % (13.5% m.b.)	13.9	13.0	13.0	12.0	12.2	15.3	13.8	14.0	13.0
Flour yield, % (total)	73.9	66.9	72.9	72.6	63.7	71.5	73.1	72.0	72.7
FLOUR									
Protein, % (14.0% m.b.)	13.3	12.5	11.8	10.7	11.1	14.1	13.0	12.7	11.4
Ash, % (14.0% m.b.)	0.40	0.43	0.43	0.51	0.47	0.42	0.47	0.47	0.40
Color, units *									
Amylograph Viscosity	755	795	770	595	740	770	575	700	785
Baking absorption, %	62.0	55.5	59.0	54.7	54.9	62.5	57.9	60.3	59.3
Sedimentation value	69.0	49.0	69.8	52.2	44.5	70.9	63.5	57.2	57.5
BREAD									
Loaf volume, cc. (remix)	870	733	795	780	720	958	913	878	835
Blend Loaf Volume cc.									
FARINOGRAM									
Absorption, %	66.0	59.5	63.0	60.7	58.9	66.5	61.9	64.3	63.3
Development time, min.	7.5	3.0	4.5	4.0	3.5	4.0	4.5	5.0	5.0
M.T.I., B.U.	30	90	40	50	50	30	30	40	40

REMARKS

APPENDIX II

Reproducibility of the Solubility Fractionation of Flour Proteins

No.	% Albumin	% Globulin	% Gliadin	% Glutenin	% Residue	% Recovery
1	10.9	4.4	33.5	12.1	31.1	92.0
2	10.0	2.8	36.4	11.5	30.6	91.3
3	10.4	3.9	35.8	10.8	29.4	90.3
4	10.9	4.2	28.8	12.4	34.4	90.7
5	9.0	3.9	33.0	11.5	32.3	89.7
6	9.5	5.2	38.5	16.9	22.9	93.0
7	9.0	3.7	31.4	12.6	34.0	90.7
Mean	10.0	4.0	33.9	12.5	30.7	90.1
Standard deviation	0.8	0.7	3.3	1.9	3.6	1.3

APPENDIX III

Protein Solubility Distribution for the Saskatoon Samples

Variety or Line	% Albumin	% Globulin	% Gliadin	% Glutenin	% Residue	% Recovery
Marquis	9.6	5.3	35.6	14.7	29.6	94.8
Thatcher	10.6	4.6	30.2	15.4	36.5	97.3
Kota	9.4	5.7	29.8	15.5	31.7	92.1
R37	8.6	5.6	36.5	26.7	15.0	92.4
Magnif Entrerriano	9.1	5.9	35.4	15.3	24.1	89.8
Gabo-Maria Escobar-Kenya	9.2	4.6	29.1	26.1	20.2	89.2
E931-Egypt 86-26 x EK_2	7.8	4.9	31.5	27.4	15.9	87.5
Aniversario	6.6	4.1	32.6	21.9	25.4	90.6
Carazinho	8.6	4.7	35.5	22.9	19.7	91.4
Gaboto	8.3	4.8	36.3	14.9	26.2	90.5
Lerma Rojo 64A	8.5	3.8	39.6	20.3	18.5	90.7
Magnif 41	9.3	3.5	33.9	21.4	26.4	94.5
Sonora 64	10.1	3.4	38.6	6.0	34.3	92.4
Rushmore	8.8	4.0	37.0	11.6	28.4	89.8
Manitou	8.3	3.7	41.4	10.9	26.2	90.5
Thatcher Backcross	7.5	4.2	40.9	17.5	19.9	90.0
Pembina Backcross	6.9	3.6	36.7	12.4	34.3	93.9
Justin Reselection	6.3	3.6	33.8	13.9	35.9	93.5
Napo 63	6.4	5.3	38.1	12.0	25.0	86.8
Comanche x CT736	8.0	4.4	32.8	13.2	30.6	89.0
Opal	8.3	3.8	36.4	9.1	29.4	87.0
Pitic 62	8.3	4.2	35.1	12.9	28.4	88.9
Svenno	7.0	3.8	35.0	11.9	29.4	87.1
Fortuna	8.4	3.4	40.0	10.5	27.7	90.0
6702	9.0	4.8	41.6	12.9	26.4	94.7
6704	7.9	4.3	37.2	11.8	33.1	94.3

APPENDIX IV

Protein Solubility Distribution for

Five Varieties Grown at Four Stations

Variety	% Albumin	% Globulin	% Gliadin	% Glutenin	% Residue	% Recovery
R 37						
Saskatoon	8.6	5.6	36.5	26.7	15.0	92.4
Regina	10.7	6.9	40.2	19.6	16.5	93.9
Lethbridge	13.6	5.5	41.1	16.9	16.6	93.7
Swift Current	9.9	6.6	36.5	17.4	21.2	91.6
Rushmore						
Saskatoon	8.8	4.0	37.0	11.6	28.4	89.8
Regina	6.9	4.1	39.7	9.9	28.4	89.0
Lethbridge	7.4	5.2	38.7	8.0	29.4	88.7
Swift Current	7.1	4.7	44.8	8.5	29.4	94.5
Manitou						
Saskatoon	8.3	3.7	41.4	10.9	26.2	90.5
Regina	10.0	4.4	33.5	11.6	32.4	91.9
Lethbridge	12.6	5.0	38.4	14.1	27.7	97.8
Swift Current	9.1	4.7	40.1	12.1	27.2	93.2
Pembina B'x						
Saskatoon	6.9	3.6	36.7	12.4	34.3	93.9
Regina	7.3	4.5	32.5	11.5	34.6	90.4
Lethbridge	9.2	6.1	34.6	13.8	27.9	91.6
Swift Current	7.8	5.0	34.9	12.2	31.4	91.3
Pitic 62						
Saskatoon	8.3	4.2	35.1	12.9	28.4	88.9
Regina	10.9	5.7	34.2	9.9	26.7	87.4
Lethbridge	11.0	4.6	34.2	9.7	26.1	85.6
Swift Current	13.4	5.8	33.0	9.5	27.0	88.7