PHYSICAL PROPERTIES OF FLOUR PROTEINS IN RELATION TO BREADMAKING QUALITY

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ABSTRACT

The separate roles of quantity and quality of flour proteins were studied in relation to breadmaking performance. To determine the extent to which breadmaking performance is affected by protein content, the flours of five samples of each of two varieties grown under the same environment but of different protein content were examined. The effect of protein quality on breadmaking quality of different wheat varieties was studied using five varieties representing three classes of wheat. These had similar protein content and comprised: (1) three varieties of hard red spring wheat, Manitou, 11-463 A, and Garnet; (2) one soft spring variety, Pitic 62; and (3) one soft winter variety, Talbot.

For each of the two bread wheat varieties used for the first part of the study, breadmaking quality, determined by loaf volume, increased with increasing protein content. The quantitative distribution of the proteins among five solubility groups, and the disc electrophoretic patterns for each solubility group of each variety were not affected by protein content.

Comparison of the proteins from the varieties of different classes showed quantitative differences in solubility distribution, and qualitative differences in the disc electrophoretic patterns. Soft wheat flours had higher contents of water-soluble, and lower contents of alcohol and acetic acid soluble proteins than those of hard wheat

flours. This appears to be the main reason why flours from soft and hard wheats produced doughs which differed in physical properties. Significant differences in disc electrophoretic patterns of alcohol-soluble (gliadins) proteins were found among varieties examined. In this group, the band with relative mobility of 0.34 present in the patterns for 11-463 A and Manitou might be important in breadmaking quality. This band was absent in the patterns for Garnet and Pitic 62, spring varieties of poor breadmaking quality.

In general, the number of bands with gliadin group might be related to the breadmaking performance. Manitou, a variety of extremely good breadmaking quality had the highest number of components (8) and Pitic 62, poorest breadmaking quality had the lowest number (5) of bands. The number of bands for the other varieties were intermediate as was their breadmaking quality.

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INTRODUCTION

It is now reasonably well established that the breadmaking quality of flour from any one type of wheat is directly related to its protein content (1). Furthermore, it is also known that the slope of this correlation varies among different wheats (2). For example, if the breadmaking quality is expressed in terms of loaf volume, high quality wheat, such as Canadian hard red spring, will have a much higher increment of loaf volume per unit of protein than lower quality bread wheats. Accordingly, the overall effect of flour protein on breadmaking quality can be divided into two partial effects: 1) the effect of protein content; and 2) the effect of protein quality.

Studies of the first factor-protein content, are straight forward. A series of flours milled from samples of the same type of wheat, but of different protein content, are evaluated by pertinent physical or baking tests. Studies aimed at relating certain chemical and physical properties of the proteins - protein quality, to breadmaking quality are considerably more complex. In addition, there is a possibility of a strong interaction between the two factors.

As will be seen from the review of the literature which follows, there have been many attempts to relate chemical and physical properties of the proteins of bread flour to its breadmaking quality. So far, the subtle qualitative properties of the proteins that determine

baking quality have not been identified completely.

The present study re-examines the role of quantity and quality of flour protein in breadmaking quality. Two types of wheat samples were collected for this project. The first group comprises five samples of different protein content of each of two varieties of Canadian hard red spring wheat, Manitou and 11-463 A. All of these were grown together in an experimental field. The variation in protein content resulted from variability in soil fertility. This group of samples was selected to determine if the nature of proteins in bread wheats is affected by protein content.

The second group of samples includes five varieties of similar protein content from three different classes: 1) three varieties of hard red spring wheat class, Manitou, 11-463 A, and Garnet; 2) one soft spring variety, Pitic 62;and 3) one soft white winter variety, Talbot.

The flours of these wheats were evaluated by a variety of breadmaking quality tests including the baking tests. Their proteins were extracted, fractionated and examined by appropriate physical techniques.

REVIEW OF THE LITERATURE

Introduction

Wheat flour is a complex mixture of many different biological materials - proteins, carbohydrates, lipids, minerals, vitamins and enzymes. Many of these are important in determining the ability of wheat flour to produce food products such as bread, cakes, etc.

The proteins have received the greatest attention of all the constituents of wheat flour. Aside from their nutritional importance, it is well established that the structural properties of bread are, to the large extent, determined by the nature of the proteins of flour (3).

Over two hundred years ago, Beccari (4) reported the separation of gluten from wheat flour; the first plant protein isolated. About sixty years ago, Osborne (5) found in wheat flour, four major protein fractions that differed in solubility. From 7 to 10% of the protein was soluble in distilled water; this fraction was called albumins. Another 6 to 10% was soluble in salt solutions, but not in water; these were called globulins. Two large fractions, called gliadin and glutenin, were soluble in 70% alcohol and dilute acid, respectively. The latter two fractions comprise the major proteins of gluten and together they give dough its elastic, plastic and cohesive properties. With the impetus given by this classic study, many chemists have devoted much attention to the separation, constitution, structure and rheological properties of wheat proteins, and especially the relationship of these properties to breadmaking quality.

Their work has been reviewed from time to time in the past (6,7-15). Most recently, the relationship between chemical composition and bread-making potentialities of wheat flour was reviewed by Pomerantz (16).

Soluble Proteins

The endosperm of the wheat kernel contains from 6 to 15% protein. From 13 to 22% of this protein is soluble in dilute salt solution (17). These soluble proteins are the albumins and globulins. Earlier, these proteins received little attention, until Finney (18) and Pence et al (17,19) reported their importance for the formation of satisfactory doughs and production of high quality bread. Pence et al (17) determined the contents of albumins and globulins of forty flours and found that the ratio of albumins to globulins was correlated directly with baking quality.

Soluble protein is of interest also because many of the enzymes of flour are in this fraction. Beta-amylase appears to be an albumin, while one of the proteinases might be a globulin (9). Crude gluten prepared by the standard washing procedure, contains significant amounts of soluble proteins (9,20).

Recently, water-solubles were found important to gassing power and proper physical properties of dough (21). Thus, soluble protein seems to be necessary for optimal baking performance of flours.

Albumins

Albumins are proteins that are soluble in water (5). Pence and co-workers (9,22) found gliadin-like material, and possible some

globulins, in the direct water extracts of wheat flour. However, the gliadin material is easily precipitated from these extracts by the addition of salt (23). Globulins can be separated from the albumins by dialysis against deionized water.

The yield of albumins from extracts made with salt solutions of various ionic-strengths, alcohol of various concentrations, and aqueous solvents of various pH has been discussed by Holme (24). He found that the albumin content of the flour represents about 10% of the total flour protein. Pence and co-workers (17) reported that about 6 to 12% of total flour protein consists of albumin.

Albumins have been implicated in the baking quality of flour. Pence (14) attempted to explain differences in baking quality of a number of flours on the basis of their albumin content; he was only partially successful. Cluskey et al (25) found that hard wheat flour of higher protein content than soft wheat flour, contained the same amount of water-soluble proteins; they found no correlation between albumin content and baking performance. Maes (26) reported a negative correlation between baking quality and percentage of water-soluble protein.

Purified albumins have been studied extensively by electrophoresis. Laws and France (27) showed that similar free-boundary electrophoretic patterns were obtained for water extracts from three different flours. From four to eleven components were detected by various workers in the albumin fraction by moving boundary and paper electrophoresis (22,23,24,28,29).

No significant differences were found in starch-gel electrophoretic patterns of albumins and globulins (30), while in a later study, some differences were observed among varieties. Coulson and Sim (32) studied the electrophoretic patterns of different types of wheat. Distinct differences in albumin composition of durum and bread wheat flours were observed (33).

There have been a number of studies on the role of the albumin fraction in the rheological properties of dough (25). At the present time, it is not clear how albumins affect these properties.

The amino acid composition of albumins differs greatly from that of other flour proteins. It has higher tryptophan and lysine contents, and a lower amide nitrogen content than the other wheat proteins (22,34).

Approximate molecular weight of albumin was about 21,000 by sedimentation and 28,000 by osmotic pressure measurements (22).

Feillet and Nimmo (35) isolated and characterized two albumins (13A and 13B) from bread wheat flour. Albumin 13B had a relatively high valine content and no histidine or phenylalanine while albumin 13A contained all the common amino acids and had a relatively high content of alanine. Molecular weights of albumin 13A and albumin 13B were 24,800 and 13,950, respectively, determined by sedimentation - equilibrium.

Globulins

There have not been many studies on wheat globulins. Globulin fractions have been obtained, as precipitates, by dialysis of salt solution extracts of flour against distilled water.

The total globulin contents of wheat flour protein range roughly from 5 to 12% (17).

Simmonds (36) fractionated and purified the salt-soluble proteins by ion exchange chromatography on DEAE-cellulose. Kelley (37) recently isolated and characterized a salt-soluble protein from wheat flour. This protein had an average molecular weight of 75,000 as determined by sedimentation velocity. The molecular weight of wheat globulin determined from the sedimentation constant, ranged from 24,000 to over 200,000 (22).

Three globulin components, alpha, gamma, and delta, were observed by ultracentrifugation (22). Electrophoretic techniques have been used to study the homogeneity of wheat globulins and have revealed at least four or five major components and a large number of minor components (22,38,39).

The amino acid composition of the globulin group is characteristically different from the compositions of other wheat proteins. It has a higher arginine content, and lower contents of tryptophan and amide containing amino acids.

The role of the globulin fraction in the breadmaking quality of

flour has not been delineated. Koenig et al (40) found that better-quality flours contain more salt-soluble proteins. However, Mullen and Smith (41) obtained similar amounts of salt-soluble protein from weak and strong flours. Flour from which the salt-soluble fraction was removed had poor breadmaking quality (13). However it was not possible to determine if this deleterious effect was due to removal of globulins or due to the effect of added salt ions on the gluten proteins.

Insoluble Proteins

Gluten

When a piece of dough is kneaded in a stream of water to remove the starch and the water-soluble components, the residue is a yellowish-grey, elastic material. This residue is proteinaceous in nature and is commonly called gluten.

Gluten was first separated from flour by an Italian, Beccari (4), in 1728. Since the work of Osborne (5) at the beginning of the present century, gluten has been considered to play a major role in the bread-making performance of flour. This role of gluten has been extensively reviewed in the literature (42,43,44).

The ability of gluten to form a viscoelastic system appears to be a unique property of the proteins of this material, which comprise about 85% of dry gluten. The characteristic viscoelasticity of gluten is attributed to the peculiar chemical and physical properties of its protein components.

Glutenin, the major protein component, has extremely high molecular weight and forms the framework structure of gluten (6). Gliadin, the second largest protein component, is considerably lower in molecular weight than glutenin, and contributes the viscous component to the rheological behaviour of gluten. Glutamine and asparagine form about 25% of the amino acids of gluten proteins (45). The amide groups of these two amino acids are essential to the peculiar physical properties of

gluten because they interact with electronegative oxygen or nitrogen atoms to form strong hydrogen bonds. In addition to the hydrogen bonds that are formed by amide (46,47,48) and other functional groups, the disulfide bonds play a very prominent role in the functional properties of gluten. Also closely related, are the sulfhydryl groups. The number of these groups in gluten, as compared with the soluble proteins, is low; however their contribution is magnified through their catalytic effect on the interchange reactions between disulfide bonds. The effects of certain oxidizing and sulfhydryl blocking reagents on the physical properties of gluten have been attributed to the elimination of sulfhydryl groups from participation in the disulfide interchange reactions (49-57).

It is now generally accepted that the viscoelastic properties of bread dough result directly from the same properties of the gluten. In a bread dough, the physical properties of gluten are extensively modified by other flour components, added ingredients, and the mechanical action of mixing. Wheat starch is essential to the formation of a satisfactory crumb structure in bread. Other starches do not have this important property (58,59). Lipids, especially the phospholipids, appear to form an integral part of the gluten structure (60,61). Enzymes, especially the proteases, if present in the flour, produce modifications in gluten and other flour components which are usually deleterious, but at times beneficial, to breadmaking quality (62,63).

Of the added ingredients, the important ones in relation to functional properties of gluten are the reducing and oxidizing agents, salt, and fats. Reducing agents decrease the consistency of dough through their ability to reduce disulfide bonds (55,56,63,64). The functional effect of oxidizing agents is opposite to that of reducing agents (65,66). Salt ions interact with the ionized groups of gluten and thereby affect their interaction with each other and with water (67,68,69). Generally this leads to a decrease in dough consistency. Fat components modify the physical properties of dough through their ability to complex with starch and gluten, and thereby affect their interaction with water. For a particular bread product, made by a specific process, the amounts of all the dough ingredients must be carefully optimized.

The rheological properties of dough can also be modified by the mechanical action of mixing. Changes produced by mechanical action can be beneficial, as in mechanical development of gluten, or detrimental, as in dough breakdown by overmixing. At the present, it is not entirely certain if the changes that occur in gluten during mechanical development are entirely physical resulting from disruption and reformation of noncovalent bonds or if chemical reactions are involved also. Cleavage and reformation of covalent bonds through disulfide interchange (57) and free-radical mechanisms (70,71,72) has been suggested. So far, these hypotheses have not been substantiated by

unequivocal experimental evidence.

The literature contains numerous reports of studies of physico-chemical properties of gluten. The aim of most of these studies was to obtain fundamental information on the structure of gluten proteins that might be related to the functional properties of the gluten.

MacCalla and co-workers (73,74) investigated the solubility of gluten in sodium salicylate solutions and concluded that gluten is a complex mixture of proteins which can be fractionated into many components. Bungenberg de Jong (75,76) suggested that gluten results from the interaction of protein components and the magnitude of this interaction varies with pH and ionic strength.

The solubility of gluten in alkaline and acidic solutions has been extensively investigated (76,77,78,79). Dilute acetic acid solutions of low ionic strength and aluminium lactate-lactic acid buffer of pH 3.1 are suitable acidic solvents for dissolving almost all of the proteins of gluten (80). Molecular weight studies of gluten proteins in these solvents have indicated that not all molecules were completely disaggregated (81,82,83).

Cook and Alsberg (83) found that 5M urea solution dispersed gluten proteins completely. Molecular weights of gliadin measured in 3M urea solution are lower than those in aluminum lactate buffer (84). However even in the presence of high concentrations of urea, it has not been possible to obtain the true molecular weight of glutenin.

In recent years, various electrophoretic techniques have been used to study cereal proteins. The most popular of these has been starch-gel electrophoresis. With this technique, Deschreider and Meaux (85) found twelve components in gluten.

Jones et al (80) used aluminium lactate buffer solution in conjunction with moving boundary electrophoresis to separate gluten proteins into four major and one minor components. Further examination of the electrophorograms for four bread wheats (two with good and two with poor baking qualities) showed the same protein patterns. However, glutens from two durum wheats, examined similarly, showed quite different electropherograms. By starch-gel electrophoresis, Elton and Ewart (30,86) detected nineteen components in wet gluten prepared by hand washing, and Kaminski (87) detected twenty-one components in similarly-prepared gluten. In 1961, Cluskey et al (25) separated, by moving boundary electrophoresis, protein components of gluten and water solubles from hard and soft wheat flours. On the basis of electrophoretic mobility they separated the gluten proteins into five components identified by Greek letters alpha, beta, gamma and omega/delta. Hard wheat flours contained more alpha, gamma and omega components but the same amounts of beta and gamma, the fast moving components. They were able to distinguish between hard and soft bread wheats on the basis of protein composition, although the differences were small.

Laws and France (28) reported that no significant differences could be detected by moving boundary electrophoresis of wheat gluten proteins including gliadins derived from different wheats.

Recently it has been reported that polyacrylamide gel is better than starch-gel for the separation of gluten proteins (88,89). This technique has been used quite successfully by Chen and Bushuk (90) and Dronzek et al (91) in studies of gluten of related species and varieties of wheat.

CM-cellulose has been used quite successfully in ion exchange chromatography to separate gluten components (92). Coates and Simmonds (93) obtained the six major protein fractions by ion exchange chromatography on DEAE-cellulose of flour extracts obtained with 0.001M sodium pyrophosphate.

Studies by electrophoresis and chromatography have shown that gluten is a highly heterogeneous mixture of protein components. However the main limiting factor in these studies seems to be low solubility of gluten in the solvents that can be used for the electrophoresis.

Recently column chromatography on Sephadex G200 was used to separate flour proteins into components according to their molecular weight or size (94). Results of these studies indicated that the elution curve did not reflect noncovalent aggregation of protein molecules.

Gliadins and Glutenins

Over fifty years ago, Osborne (5) showed that gluten could be separated into two fractions, gliadin and glutenin, on the basis of their solubility. Gliadin is soluble in 70% aqueous ethanol while glutenin is insoluble in this solvent. Although gliadin and glutenin have similar amino acid compositions (12,95,96), their physical properties are quite different. Hydrated gliadin is a viscous, highly extensible material, while hydrated glutenin is cohesive and elastic. The properties of these two fractions appear to be blended to give the characteristic viscoelastic properties of gluten.

Gluten has been fractionated into its protein components by a number of techniques (12,94,97). Simmonds and Winzor (98), used CM-cellulose and ion exchange chromatography to fractionate the glutenin fraction into six components. Better separation of these proteins is achieved by gel filtration (99,100). This procedure separates molecules according to their molecular weight. It was found that glutenin is a mixture of large molecules of which molecular weight ranges from 50,000 to 1,000,000 whereas gliadin molecules are considerably smaller and range from 20,000 to 40,000 in molecular weight (81).

Gliadin showed eight components in starch-gel electrophoresis, but glutenin did not migrate into the gel and remained at the origin (101).

Chemical modification has been used to increase the solubility of glutenin. Reduction of the S-S bonds, followed by starch-gel electrophoresis, showed that glutenin comprised a number of components identical with gliadin components (102,103). Nielsen et al (104) reported that reduction of S-S bonds of glutenin decreased its molecular weight to 20,000. On the other hand, reduction of S-S bonds in purified gliadin had no effect on its molecular weight (105). It has been postulated (6) that glutenin consists of long polypeptide chains linked together by S-S bonds to form large crosslinked molecules, whereas in gliadin molecules the S-S crosslinks are within each polypeptide chain. The possibility that glutenin comprises gliadin molecules crosslinked by S-S bonds has been suggested, however this does not appear likely since the work of Bilinski and McCornell (106) indicated that biosynthesis of gliadin follows that of glutenin.

Many workers (107,108,109) have suggested that the ratio of gliadin to glutenin is important in determining gluten quality for breadmaking. According to Snyder (109), the proteins of patent flours comprised from 60 to 65% gliadin. This was considerably less than the gliadin content of lower quality flours. However, the use of gliadin-glutenin ratio as a quality parameter has been abandoned (13).

Relationship Between Flour Protein and Breadmaking Quality

Protein has received the greatest attention of all components of flour in relation to baking quality. Many years ago, significant positive correlations between breadmaking quality and either protein (110, 111,112) or gluten content (113,114) have been obtained.

Mullen and Smith (41) found that long-mixing flours contained more acid-soluble protein than short-mixing flour. Flours of poorer breadmaking quality contained larger quantities of protein that dissolved in 3M urea solution (115). Ewart (116) obtained a direct relationship between the quantity of protein that dissolved in 0.1M acetic acid solution and breadmaking quality.

Recently, Finney and co-workers (21,117,118) used the reconstitution technique to examine the role of various components of flour in breadmaking quality. They found that gliadin, the alcohol-soluble proteins of wheat, forms an integral part of gluten and plays an important role in determining the breadmaking quality of flour. Also water-solubles were essential for production of normal loaves, but they were not involved in quality differences between varieties of bread wheat. These workers concluded that gluten was the protein component that appears to be responsible for quality differences among varieties.

Finney and Barmore (2) obtained a linear relationship between protein content and loaf volume over the range of proteins from 8 to

18%. The variation in the slope of the loaf volume - protein content regression lines for varieties reflected differences in protein quality. Similar linear correlations between loaf volume and protein content were reported by other workers (119,120).

There have been many attempts to relate breadmaking quality of flour to chemical and physical properties of its proteins. Differences in fractional distribution of proteins among solubility groups (91) and in electrophoretic patterns (121,122) have been observed between varieties from the same class of wheat.

In 1962, Elton and Ewart (30) reported significant differences in the starch-gel electrophoretic patterns for gluten proteins of different bread wheats. They attributed these to real differences in the proteins. It was suggested that the observed differences might be sufficient to account for the differences in breadmaking quality of the wheats examined. Later the same authors (31) showed that both qualitative and quantitative differences existed between the starch-gel patterns of the gliadins from several wheat varieties.

Huebner and Rothfus (123) used ion exchange chromatography to isolate the gliadins from wheats of different genetic background. They found that starch-gel electrophoretic patterns of the gliadins showed significant differences between classes and varieties of wheat. Varieties of the same class of wheat such as Comanche and Red Chief, which differed greatly in breadmaking quality, showed small, but significant

differences, in the electrophoretic patterns for the gliadins.

Elton and Ewart (124) reduced the glutenin from four wheats,and separated the components on starch-gel. The electrophoretic patterns showed that there were varietal differences. Huebner et al (125) compared the glutenins isolated from five different classes of wheat. Electrophoretic patterns of the reduced-alkylated glutenins showed significant differences among varieties of the same class, but the greatest differences were among different classes of wheat. Reduced-alkylated glutenin from durum wheat contained few or none of the slow moving components present in the bread wheat glutenins that were examined. Lee and Wrigley (126) could not relate any specific type of chromatographic or electrophoretic pattern with good baking quality. Lee (89) suggested that the gluten pattern obtained by electrophoresis on acrylamide gel is a varietal characteristic but is not directly related to baking quality.

Using starch-gel electrophoresis, Doekes (127) classified 80 varieties and selected lines of wheat into 5 main groups having similar electropherograms. Group I comprised soft winter wheats with poor baking quality while Group V included hard red wheat varieties of relatively good breadmaking quality. Furthermore, Group I varieties showed a compact gliadin pattern while Group V displayed a gliadin pattern in which the components showed a broad range of mobilities. Group II, III and IV included varieties with diverse origins, and

considerable variation in baking quality. Their gliadin patterns were intermediate between those of Group I and V.

It was logical to assume that differences in amino acid composition of flour proteins might account for some of the differences in the baking performance. However, compositions of wheats of widely different breadmaking quality were found to be essentially the same (45,128-132).

Glutamine is the predominant amino acid present in wheat proteins, and proline is also present in relatively high amounts (45). Together they make up approximately 50% of the amino acids in gluten proteins (131). Isoleucine, leucine, phenylalanine, serine, tyrosine and valine contents are relatively high in gluten compared to other proteins (131). The soluble proteins generally contain more cystine, tryptophan, basic amino acids and glutamic acid than the gluten proteins (13). The albumins contain more cystine and cysteine than the globulins or gluten proteins.

Glutamic acid and proline contents have been shown to increase, while lysine tends to decrease as the protein content of wheat increases (131). Lawrence et al (133) found that lysine increased significantly as the protein content decreased below 13.5%. However, for wheats with more than 13.5% protein, there was no significant correlation between lysine and protein contents.

In 1961 Woychik et al (134) determined the amino acid compositions

of six protein components isolated from wheat gluten. While their compositions were similar, significant differences were observed which indicate the individuality of these proteins.

Ewart (135) compared the amino acid compositions of the glutenins and gliadins from two strong and two weak wheats. The compositions of the glutenins were similar to those of the gliadins. There were minor differences in the amounts of some amino acids. No significant differences in composition were observed for varieties of the same class or for strong and weak wheats.

Recently, Tkachuk (45) determined amino acid composition of six flours which differed widely in their breadmaking quality. The compositions for the six flours were essentially the same.

Miller et al (132) suggested that cystine content of flour protein is important in determining the quality of breadmaking. This is supported by the results of Wörstmann (136).

Chen and Bushuk (137) obtained similar amino acid compositions for single varieties of Triticale, rye, durum wheat and bread wheat. Dronzek et al (91) determined the compositions of flours of three varieties of derived AABB tetraploid wheats and their hexaploid parents, and the durum wheat, Stewart 63. Their results showed that the compositions of the seven wheats were essentially the same.

From the foregoing review of the pertinent literature, it is apparent that considerable fundamental information on wheat proteins has been accumulated. However precise information on the structure of the

slightly soluble or insoluble proteins is still lacking. Since this group forms a significant fraction of flour proteins, it is presumed that it plays an important role in breadmaking quality. A full understanding of the nature of breadmaking quality will require additional information on the structure of this group of proteins.

MATERIALS

Samples of one variety and one experimental line of Canadian hard red spring wheat used in the first part of the investigation were grown together on experimental plots in 1967. Variation in protein content resulted from variable soil fertility. The wheats in this group and some of their general agronomic and breadmaking quality characteristics are as follows:

Manitou. This variety was developed by the Rust Area Project Group centered at the Canada Department of Agriculture in Winnipeg, Canada. Its parentage was (Thatcher^{7}- Frontana x Thatcher^{6}- Kenya Farmer) x Thatcher^{6}- P.I. 170925. It is essentially the same as Thatcher but contains two extra genes for stem rust resistance, Sr6 from P.I. 170925 (a red Egyptian wheat) and Sr7 from Kenya Farmer and a gene for leaf rust resistance from Frontana. This variety was licensed in Canada in 1965 and in 1969 formed over 45% of the wheat acreage of Western Canada. Compared with Thatcher, Manitou has better rust resistance, gives higher yields, is earlier maturing, and usually slightly higher in protein content and therefore better in breadmaking quality.

11-463 A. The samples of this group are from an experimental F_3 line isolated from the cross (Pembina^{2}- Bage) x (Sonora 64 - Tezanus Pintos Precos x Nainari 60). Bage is a Brazilian soft red spring variety, Sonora 64 is a short-strawed variety developed in Mexico,

Tezanus Pintos Precos is an Argentinan variety and Nainari 60 was developed in Mexico. In agronomic characteristics, 11-463 A has considerably shorter straw than Pembina and is therefore more responsive to fertilizer and higher moisture. Under similar growing conditions, it produces a higher yield than Pembina. In breadmaking quality, it is similar to Pembina and has its relatively strong mixing characteristics. For optimum loaf volume, it requires about 50% more mixing than Manitou. The field characteristics of the F_3 rod rows did not show any evidence of segregation.

For the second part of this investigation, three other varieties, Garnet, Pitic 62 and Talbot were included with Manitou and 11-463 A. These were selected as representatives of classes of wheat with widely different breadmaking quality.

Garnet. This variety was licensed in Canada in 1925 mainly because of its early maturity. It was developed by C. E. Saunders from a cross between Preston and Riga M. Preston was produced from a cross between Ladoga and Red Fife. Ladoga is an early Russian variety while Red Fife, which is considered to be the origin of the high breadmaking quality of Canadian hard red spring wheats, originally came from Galicia. Garnet is almost a week earlier than Marquis but is susceptible to leaf and stem rust. It is still grown quite extensively outside the rust area, especially in Northern Alberta where early maturity is important. In 1935 it was classified into Special Garnet Grades be-

cause its breadmaking quality was inferior to the standard variety, Marquis.

Pitic 62. This variety was developed in Mexico from the cross Yaktana 54 x (Norin 10 x Brevor). Its kernels are large, dull, light to very light red, soft and non-vitreous. It was one of the first two semidwarf varieties released in Mexico. It was licensed in Canada in 1969 as a feed wheat. This variety is popular because of its high yield under high fertilizer and moisture regimes. However its late maturity and low breadmaking quality limits its production in Canada.

Talbot. This variety is a soft white winter wheat grown in the winter wheat areas of Ontario. Its parentage was (Trumbull - Hope - Hussar) x F. (of Dawsons G.C.^{2}- Ridit x Cornell 595). It was licensed in Canada in 1962 because of its superiority in lodging resistance compared with the leading soft white winter variety, Genesee, grown in Ontario at that time.

For this study, Garnet wheat was grown in Alberta, Pitic 62 in Manitoba, and Talbot in Ontario in 1968.

Table 1 lists the samples used in the present investigation together with pertinent wheat and flour properties. The flour was milled on an experimental Buhler mill using an overnight tempering to 16.5% moisture and a constant milling procedure.

Table 1 WHEAT SAMPLES AND PERTINENT TECHNOLOGICAL DATA ON WHEATS AND FLOURS

Sample	Bushel Weight	1000 Kernel Weight	Flour Yield	Moisture Content		Protein Content		Ash Content		Flour Color
				Wheat	Flour	Wheat	Flour	Wheat	Flour	
	lb.	g.	%	%	%	%	%	%	%	
MANITOU	61.9	32.2	73.4	9.1	14.0	10.7	10.5	1.78	0.48	-0.1
	62.0	33.6	74.1	8.9	13.7	12.2	11.2	1.72	0.48	0.2
	62.1	36.0	74.6	8.8	13.5	13.5	12.5	1.69	0.42	0.5
	62.4	37.3	73.9	8.8	13.6	15.0	14.0	1.73	0.37	0.4
	62.5	38.3	73.9	9.4	13.7	16.5	15.6	1.76	0.39	0.7
11-463 A	63.5	44.1	75.2	11.5	13.6	11.9	11.0	2.01	0.57	0.4
	64.0	41.7	75.8	12.0	13.5	12.1	11.4	1.97	0.56	0.3
	63.5	42.3	75.1	10.7	13.7	12.3	11.8	1.91	0.55	0.6
	63.9	43.2	74.9	11.7	14.0	13.2	12.7	1.86	0.55	1.0
	63.5	45.1	75.8	10.4	13.6	15.2	14.2	1.97	0.49	1.3
GARNET	65.7	28.2	73.6	13.1	13.5	14.0	12.9	1.33	0.50	1.95
PITIC 62	56.5	27.0	73.1	12.8	13.8	11.7	10.8	1.85	0.47	8.2
TALBOT	62.4	34.0	71.1	13.7	14.4	12.3	11.4	1.73	0.44	2.7

METHODS

Milling and Breadmaking Quality

Approved methods of the American Association of Cereal Chemists (A.A.C.C.) (138) were used for the evaluation of the milling and breadmaking quality. A number of procedures not approved by the A.A.C.C. were also used and these are indicated below. Analytical data for wheat and flour are expressed on 13.5 and 14.0% moisture basis, respectively.

Starch Damage. The amount of starch damage was determined by the method Farrand (139) and reported in Farrand units.

Alpha-Amylase Activity. The viscometric method described by Tipples (140) was used to determine the alpha amylase activity of the flour.

Bread Loaf Volume. Two different baking tests were used; the "Remix" procedure described by Irvine and McMullan (141) and an experimental procedure based on the Chorleywood Bread Process (142).

Fractionation of Flour Proteins

Flour proteins were fractionated by a modified Osborne procedure (5). The procedure used is summarized in Fig. 1.

Five protein fractions were obtained by this method; (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.

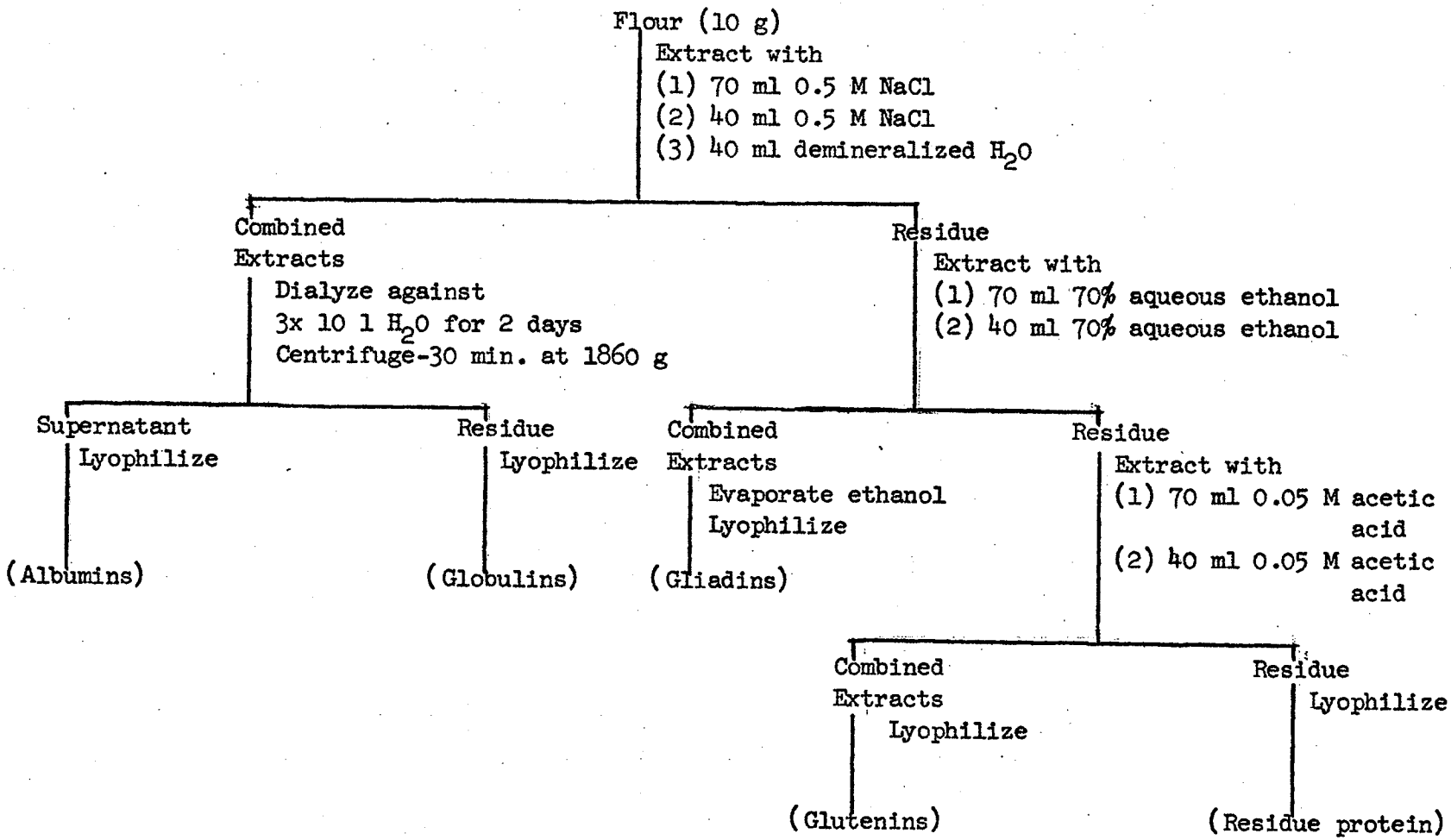

Figure 1 SUMMARY OF PROTEIN FRACTIONATION PROCEDURE

All extractions were carried out in a cold room (4°C) to minimize the effects of enzymes or thermal denaturation. All fractions extracted were freeze dried and used subsequently in the disc electrophoretic experiment. The protein contents of the five fractions were determined by the Nessler procedure (143).

Disc Electrophoresis

The procedure used was that of Davis (144), employing a commercial apparatus manufactured by Buchler Instrument Inc. Solvents used to prepare the gels are shown in Table 2.

Protein solutions were prepared by dissolving 10 mg of each protein in 1 ml of 0.1 N acetic acid solution containing 4N dimethylformamide. Thirty-five ml of this solution was applied to each electrophoresis tube. Methyl green dye was used as the visual marker to ascertain the termination of electrophoresis.

The separated protein bands were stained with amide black dissolved in 7% acetic acid. Unabsorbed dye was removed by electrophoresis and the tube photographed.

Table 2 SOLUTIONS FOR PREPARATION OF GELS AND BUFFER SOLUTIONS FOR DISC ELECTROPHORESIS

Acrylamide Solutions	Amount per 1000 ml	
	Upper Gel	Lower Gel
Acrylamide	10 g	30 g
N,N'-methylene bisacrylamide	0.8 g	0.8 g
Catalyst Solution		
Ammonium Persulfate	60 mg	60 mg
Riboflavin	2 mg	4 mg
Buffer Solution		
1 N. Potassium hydroxide	48 ml	24 ml
Acetic Acid	3.65 ml	53.2 ml
Temed*	o.2 ml	0.48 ml

Temed* N,N,N',N' tetromethylethylenediamine

Upper Buffer	Amount per 1000 ml
Glycine	14.05 g
Acetic Acid	15.25 ml
Lower Buffer	
Acetic Acid	21.5 ml
1N. Potassium hydroxide	60 ml

RESULTS AND DISCUSSION

The results of this study will be presented in two sections. Section I will deal with the effects of quantity of protein obtained on samples of different protein content of the commercial variety, Manitou and an experimental line, 11-463A. Section II will deal with the effects of protein quality based on results for five varieties. Two of these varieties will be those discussed in Section I selected to have comparable protein content to the three additional varieties. In order to minimize the number of figures in the thesis, some figures of Section I will include results for the varieties that will be discussed in Section II only. To facilitate presentation, most of the numerical results are tabulated in the appendix to the thesis.

I. Effect of Flour Protein Content on Breadmaking Quality

Baking Test

Figures 2 and 3 show the relationships between flour protein content and loaf volume by the remix baking test and by the Chorleywood Baking Process (CBP), respectively. These figures show that loaf volume, by the two baking methods used, increases with increasing protein content. In the remix baking test (Fig. 2), Manitou showed a linear relationship between protein content and loaf volume over a range of 10.5 to 12.5%; the relationship was curvilinear above 12.5%. For 11-463A, the relationship was essentially linear over the entire range of protein content examined (11.9 to 15.2%). The slopes of the linear portion of the curves for Manitou and for 11-463A were markedly different indicating that the remix baking test accentuated the qualitative differences between the two flours.

With the CBP baking test (Fig. 3), a single linear relationship between loaf volume and protein content was obtained for all the wheats examined, although there was considerable scatter in the points. The results for Manitou gave a good linear relationship (solid line) over the entire protein content range.

In general, these results are in agreement with published results obtained with other baking tests. Finney and Barmore (2), and Fifield *et al.* (119) obtained linear relationships between loaf volume and protein content (8-18%)for more than 589 samples of wheat using the A.A.C.C. straight dough baking test. Results of the present study emphasize the known fact that loaf volume is strongly influenced by the type of baking test used. The remix test tends to accentuate

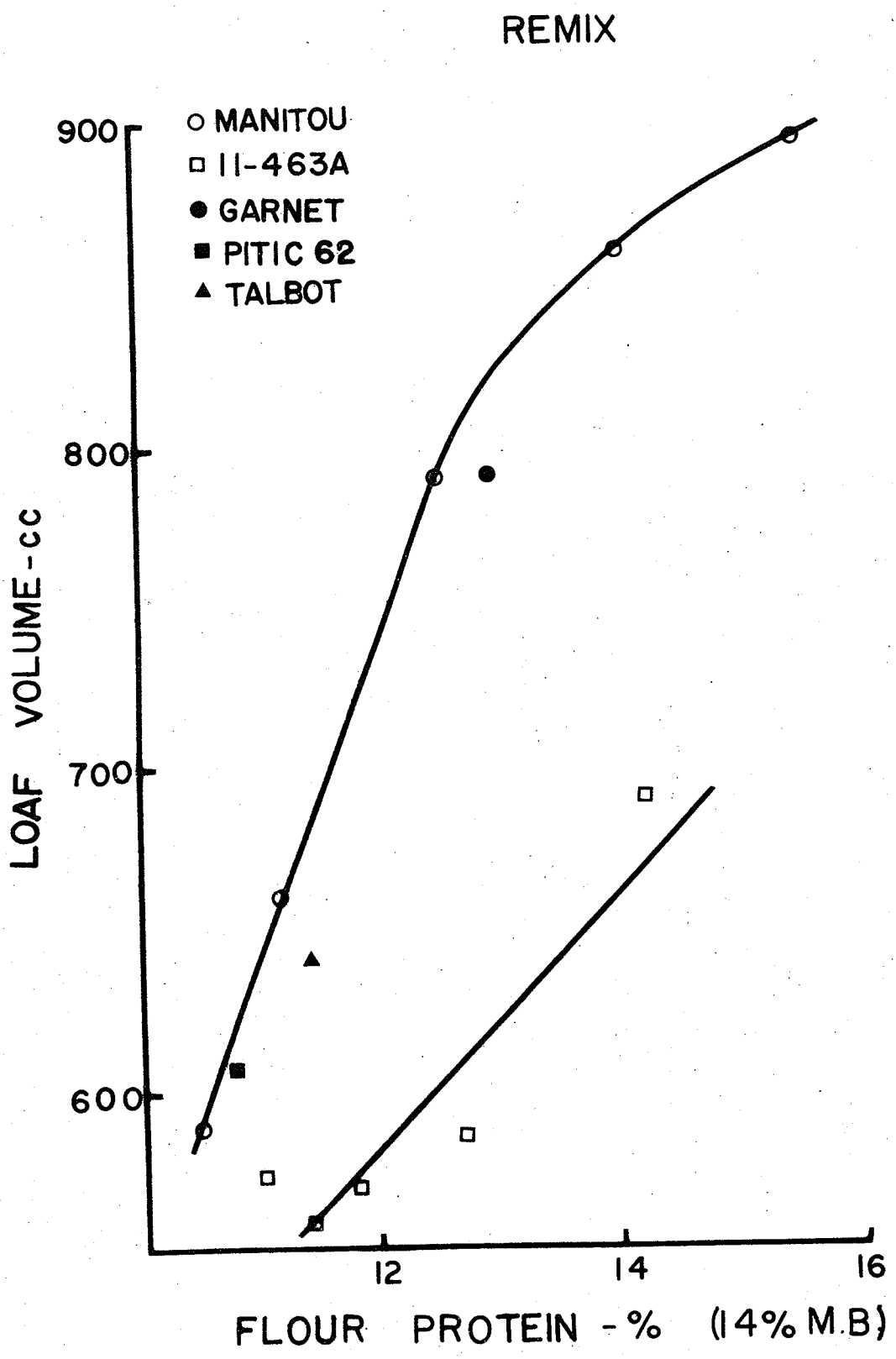

Fig. 2 Relationship between loaf volume by remix baking test and flour protein content.

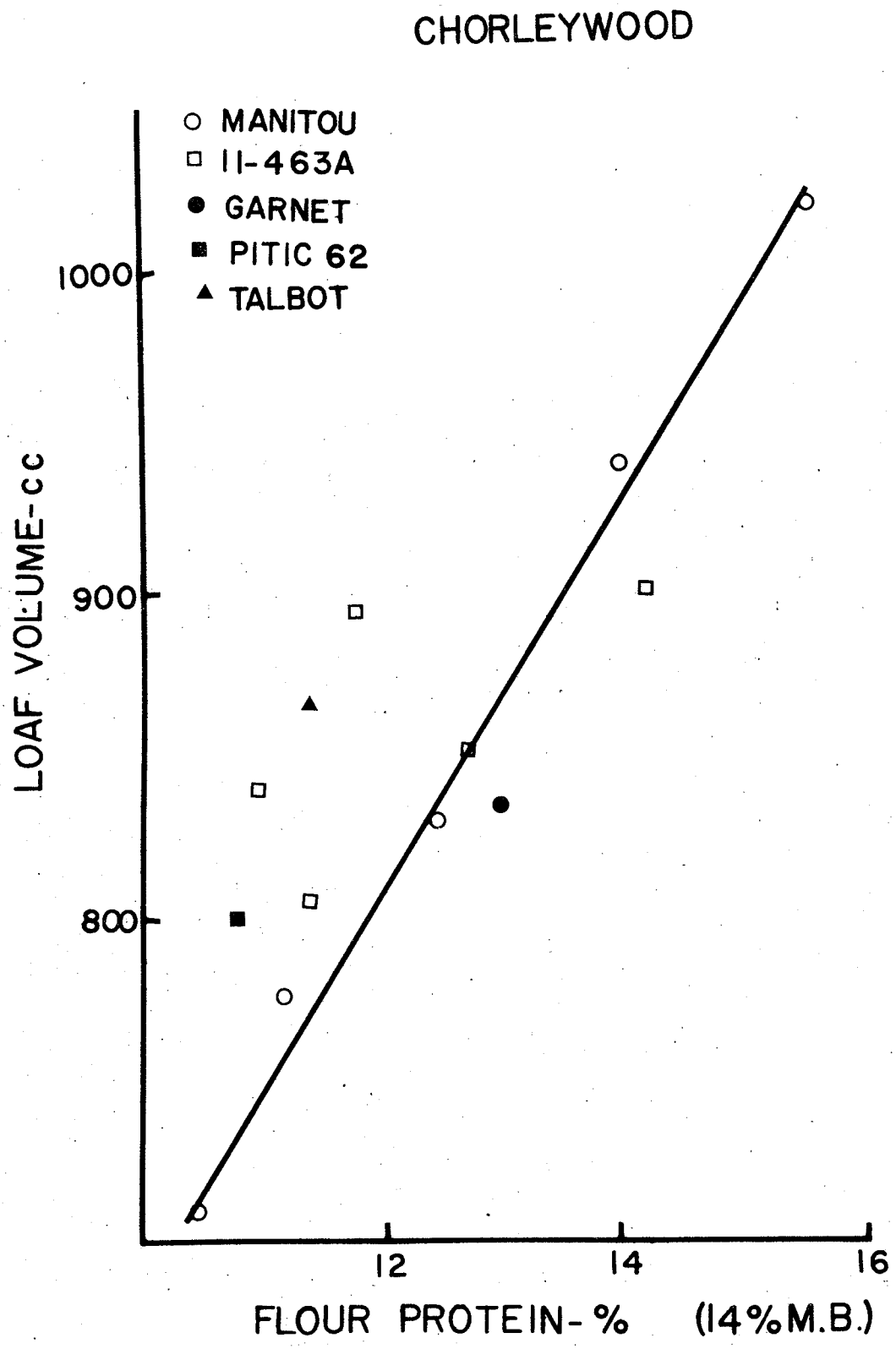

Fig. 3 Relationship between loaf volume by Chorleywood baking process and flour protein content.

differences between very strong flours, whereas the CBP tends to minimize the effects of flour strength on loaf volume. These results will be discussed in greater detail in a later section when the effects of flour strength (protein quality) are considered.

Besides loaf volume, the protein content influences the results of many other physical and chemical tests on flour that are related to breadmaking quality. These will be discussed in the subsections that follow.

Farinograph Test

Figure 4 shows the farinograph curves for Manitou and 11-463A flours of different protein content. By this test, Manitou was classified as a strong wheat and 11-463A as a very strong wheat.

Farinograph absorption increased from 65.4% to 69.2% for Manitou, and from 60.8% to 64.3% for 11-463A with increasing protein content. At the same protein content, Manitou had higher absorption than 11-463A by four to five percentage units. The absorption values given below were extracted from Table 1 (Appendix) for easier reference.

Flour and Protein Content %	Absorption %
Manitou	
10.5	65.8
11.2	65.4
12.5	66.0
14.0	66.9
15.6	69.2

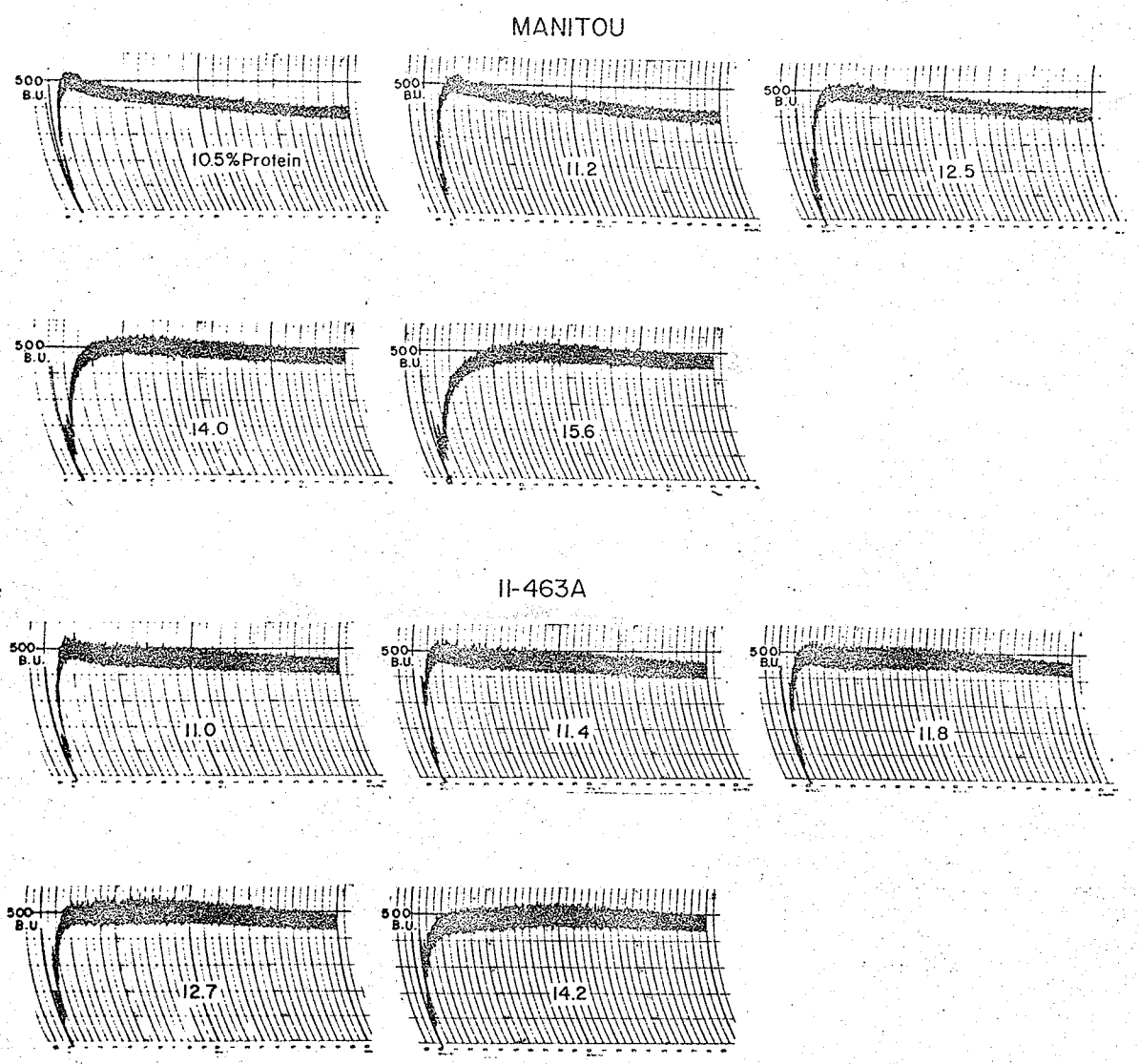

Fig. 4 Farinograph curves and protein contents for Manitou and 11-463 A.

Flour and Protein Content %	Absorption %
11-463A	
11.0	62.1
11.4	60.8
11.8	62.0
12.7	62.5
14.2	64.3

Figure 5 shows that development time increases, in a nonlinear relationship, with protein content. The relationship is essentially the same for both varieties although there was considerable scatter especially at higher protein contents.

A linear relationship was obtained between farinograph stability and flour protein content (Fig. 6). This agrees with published results which show that in general there is definite strengthening of the farinograph curves with increasing protein content (145, 146).

At constant protein content, the stability values for 11-463A are approximately 4 min. higher than those for Manitou. The slopes for the two varieties are essentially the same.

The highest loaf volume by the remix baking test, was 895cc for Manitou and 688 cc for 11-463A, whilst by the CBP loaf volumes were 1020 cc for Manitou and 900 cc for 11-463A. (Table 2, Appendix). The loaf volumes for Manitou increased with increasing strength as judged

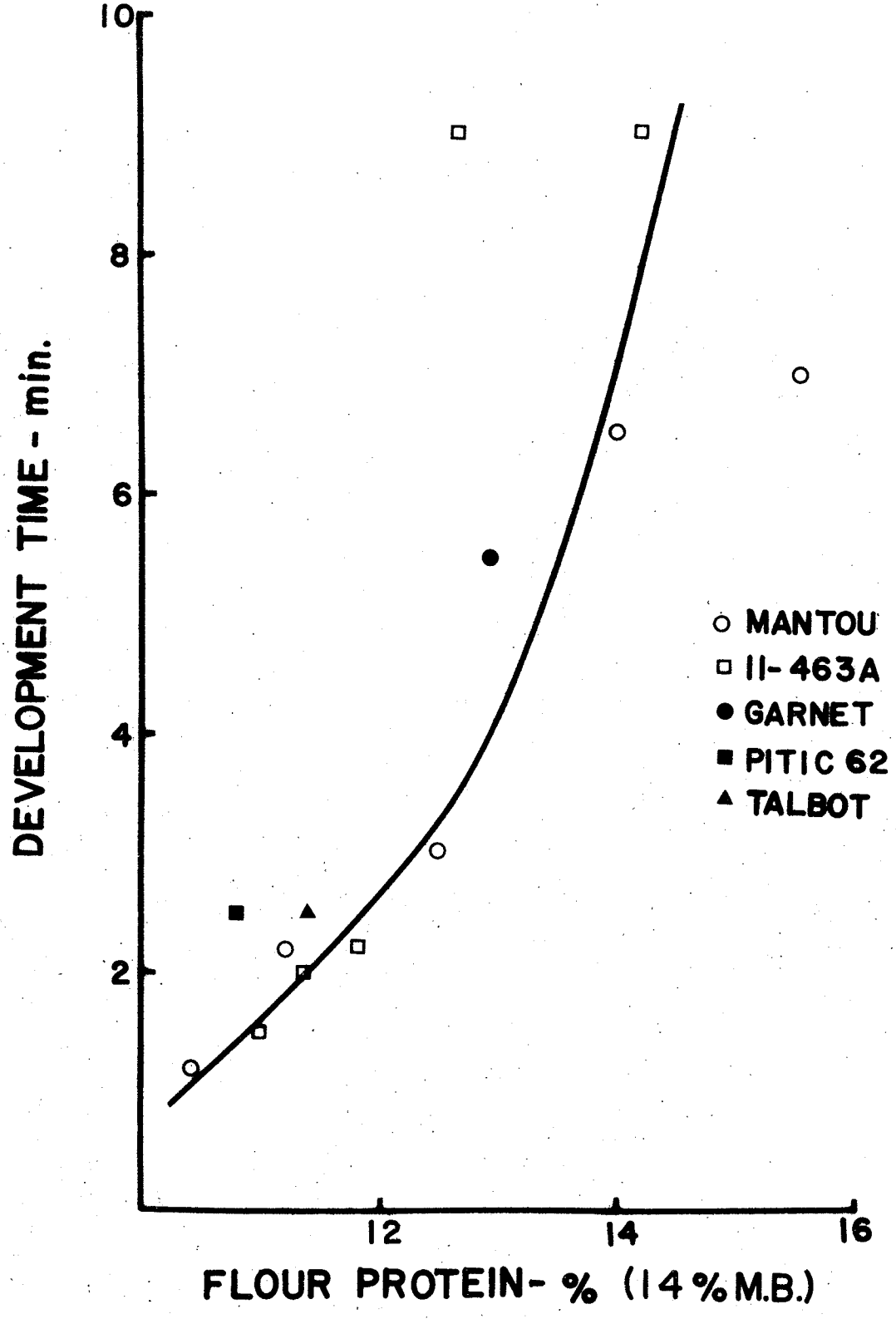

Fig. 5 Relationship between farinograph dough development time and flour protein content.

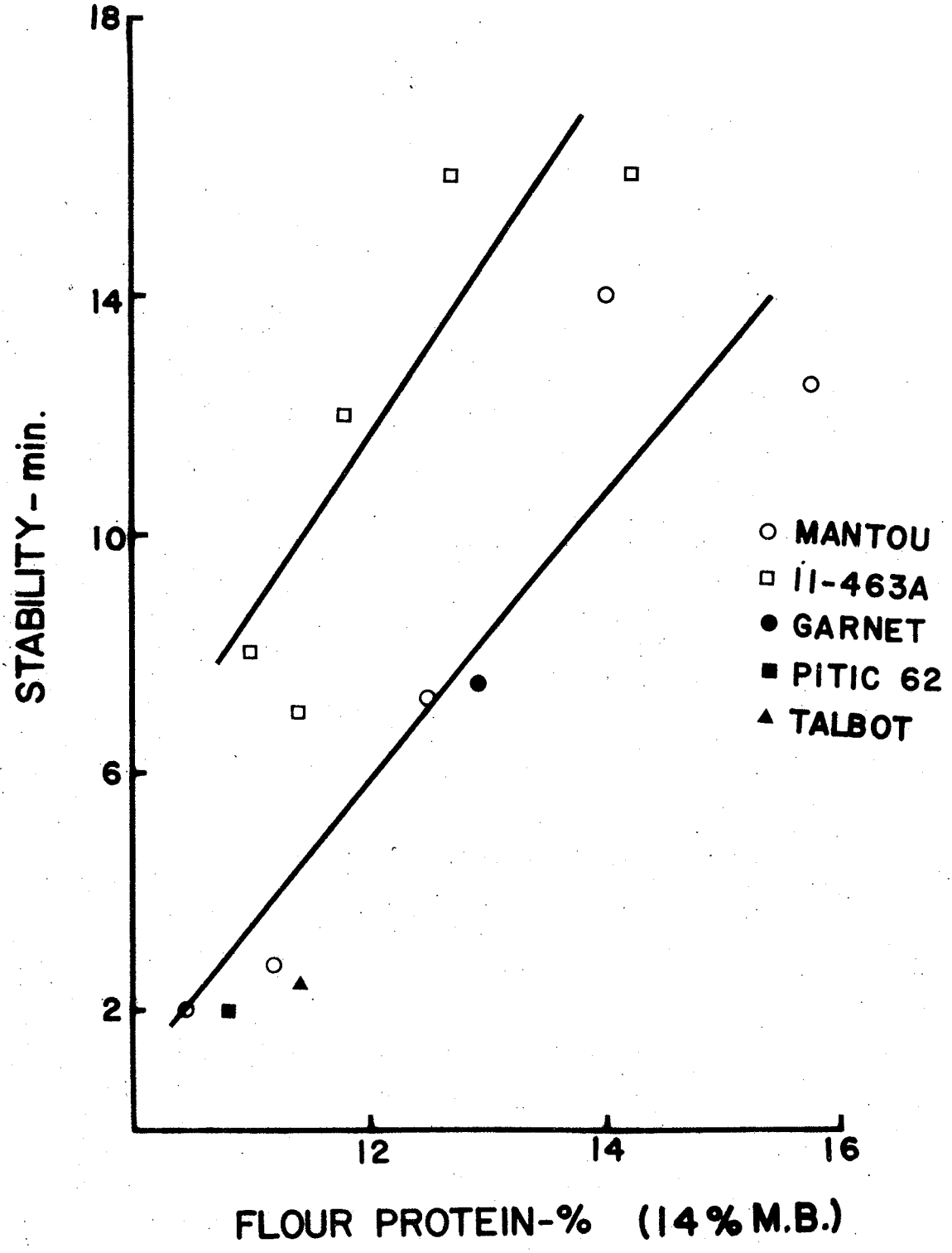

Fig. 6 Relationship between farinograph stability and flour protein content.

by the farinograph test, but this was not the case for 11-463A. This relationship is shown more strikingly in Figs. 7 and 8, where loaf volumes are plotted against farinograph dough development time. The relationships for Manitou are essentially linear. For 11-463A there does not seem to be any correlation between loaf volume and farinograph development time. The extensive scatter of points in Figs. 7 and 8 is attributed to the high experimental error in the values of development time. These results indicate that evaluation of wheats on the basis of the farinograph curve is only of limited value. The experimental variety 11-463A, which appears much stronger than Manitou by farinograph test, gave considerably lower loaf volumes by the remix and CBP baking tests at higher protein contents where the development time was quite long. These results suggest that the strong wheat 11-463A does not perform as well as Manitou in the remix baking test because the normal 2½ min. remix time was inadequate to develop the dough properly. In the CBP baking test the doughs were mixed to peak development as judged by the mixing curve. This is probably the reason why the loaf volume for 11-463A by remix baking test is much lower than that by the CBP test. The loaf volumes for 11-463A are relatively low over the entire protein range presumably because of undermixing. Bushuk et al. (120) suggested that the remix baking test should be modified in order to express the optimum baking potential of this variety. It was demonstrated by simply increasing the remix time for 11-463A from 2½ min. to about 5 min. (for 14% protein), that its baking performance was improved to that of Manitou.

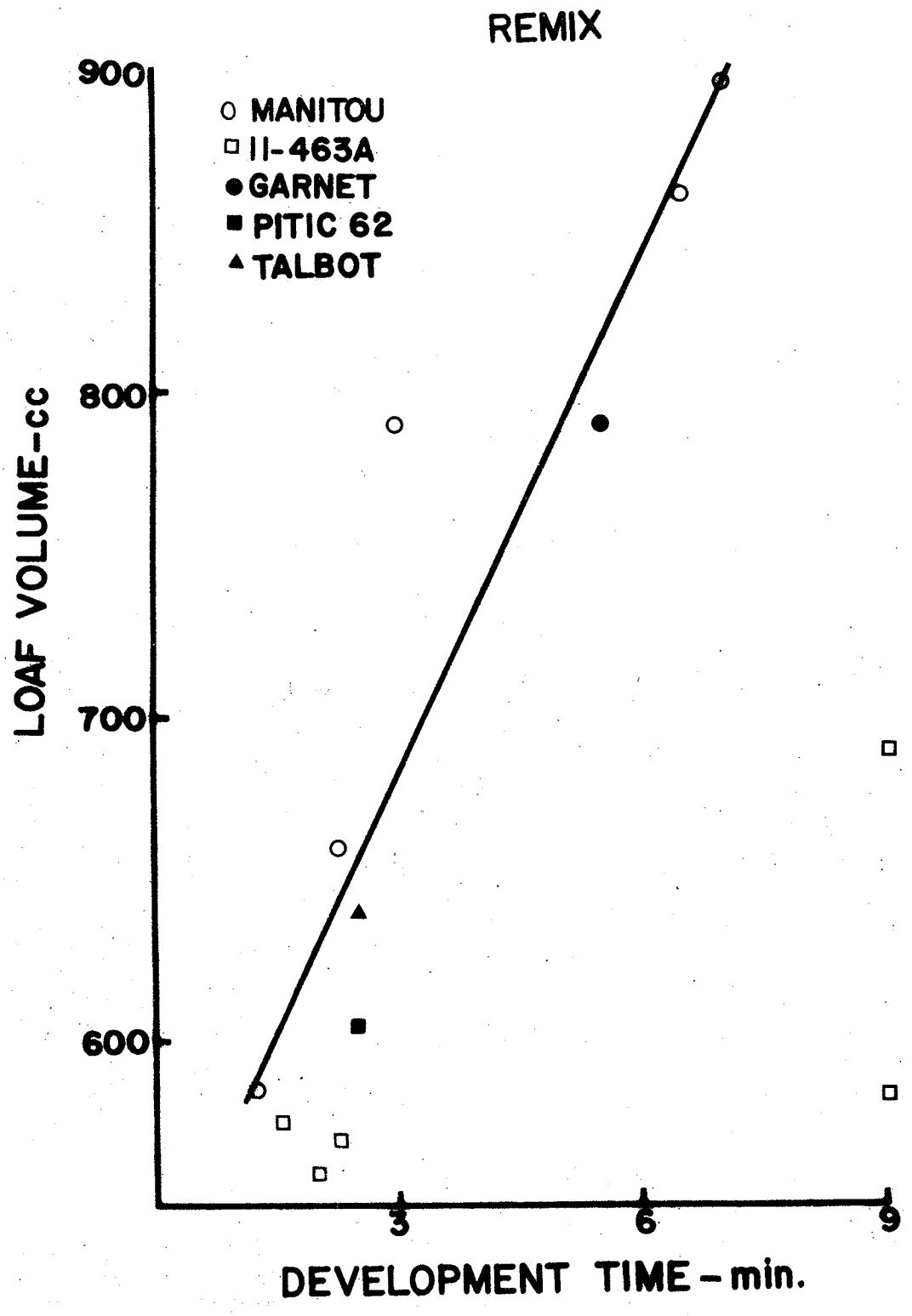

Fig. 7 Relationship between loaf volume by remix baking test and farinograph dough development time.

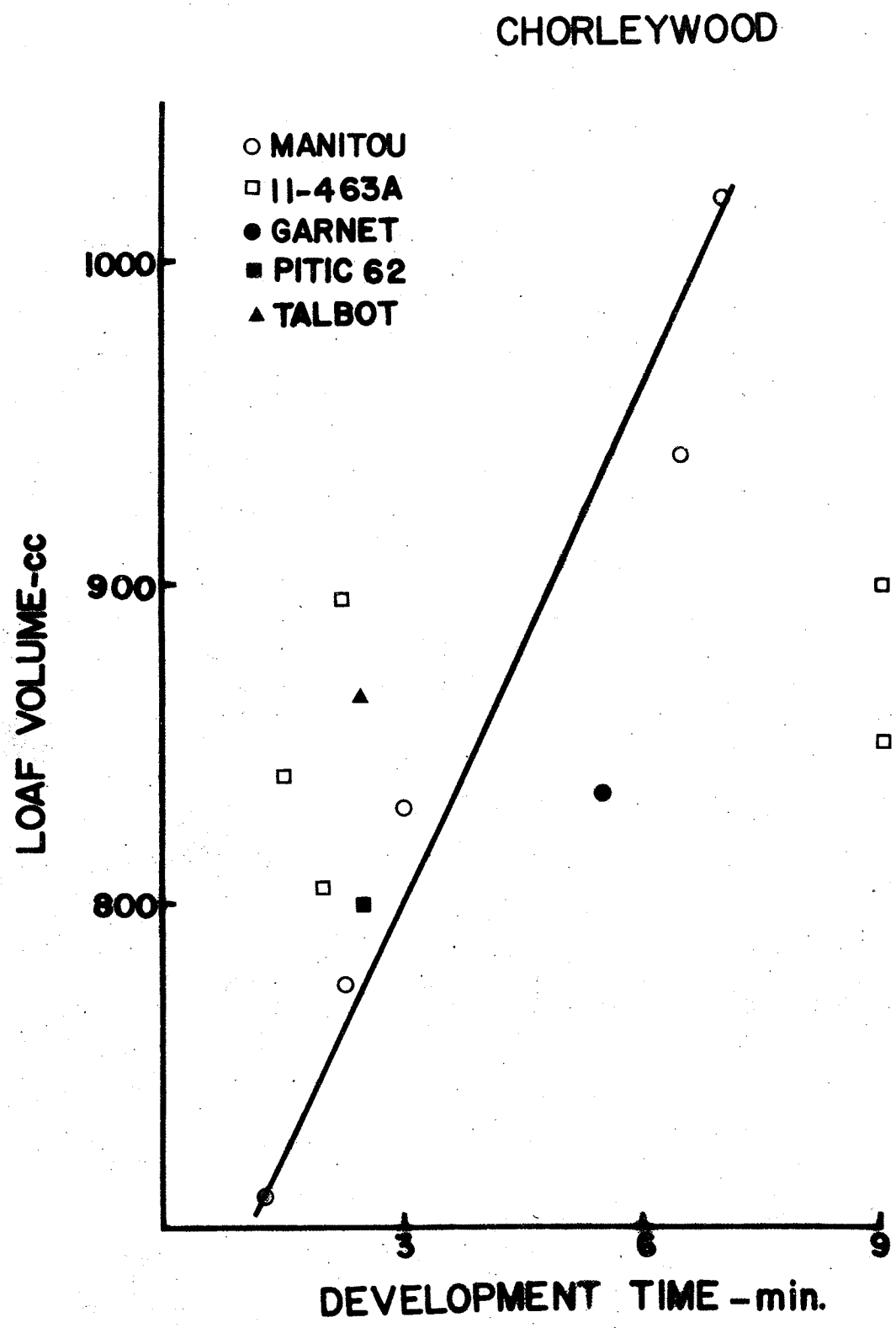

Fig. 8 Relationship between loaf volume by Chorleywood baking process and farinograph dough development time.

Extensigraph Test

Figure 9 shows the extensigraph curves for the two sets of flours used in this study. Farinograph absorptions less four percentage units and a constant mixing time of 2½ min. were used to prepared the doughs for this test. The doughs were allowed to relax for 5 min. after mixing and 15 min. after rounding and shaping before they were stretched. For Manitou, the extensibility increased with increasing protein content. The doughs for the experimental variety 11-463A had a much higher resistance to extension than the Manitou doughs at comparable protein content.

Extensigraph area is considered to be related to dough strength (147). With Manitou, this parameter increased with increasing protein content. For the variety 11-463A, the area was essentially independent of protein content (Fig. 10). On the other hand, resistance to extension (height) decreased as the protein content increased in the case of Manitou; for 11-463A it was independent of protein (Fig. 11).

For both Manitou and 11-463A, the extensibility increased linearly with protein content (Fig. 12). At the same protein content, the values for 11-463A were higher than for Manitou.

When loaf volume was plotted against extensibility (Fig. 13 and 14), a linear relationship was obtained for the samples of Manitou with both baking methods used. The experimental variety 11-463A did not give a linear relationship, however the loaf volume showed an increasing trend with increasing extensibility. Extensigraph extensibility could possibly be used as an index of breadmaking quality especially for varieties similar to Manitou.

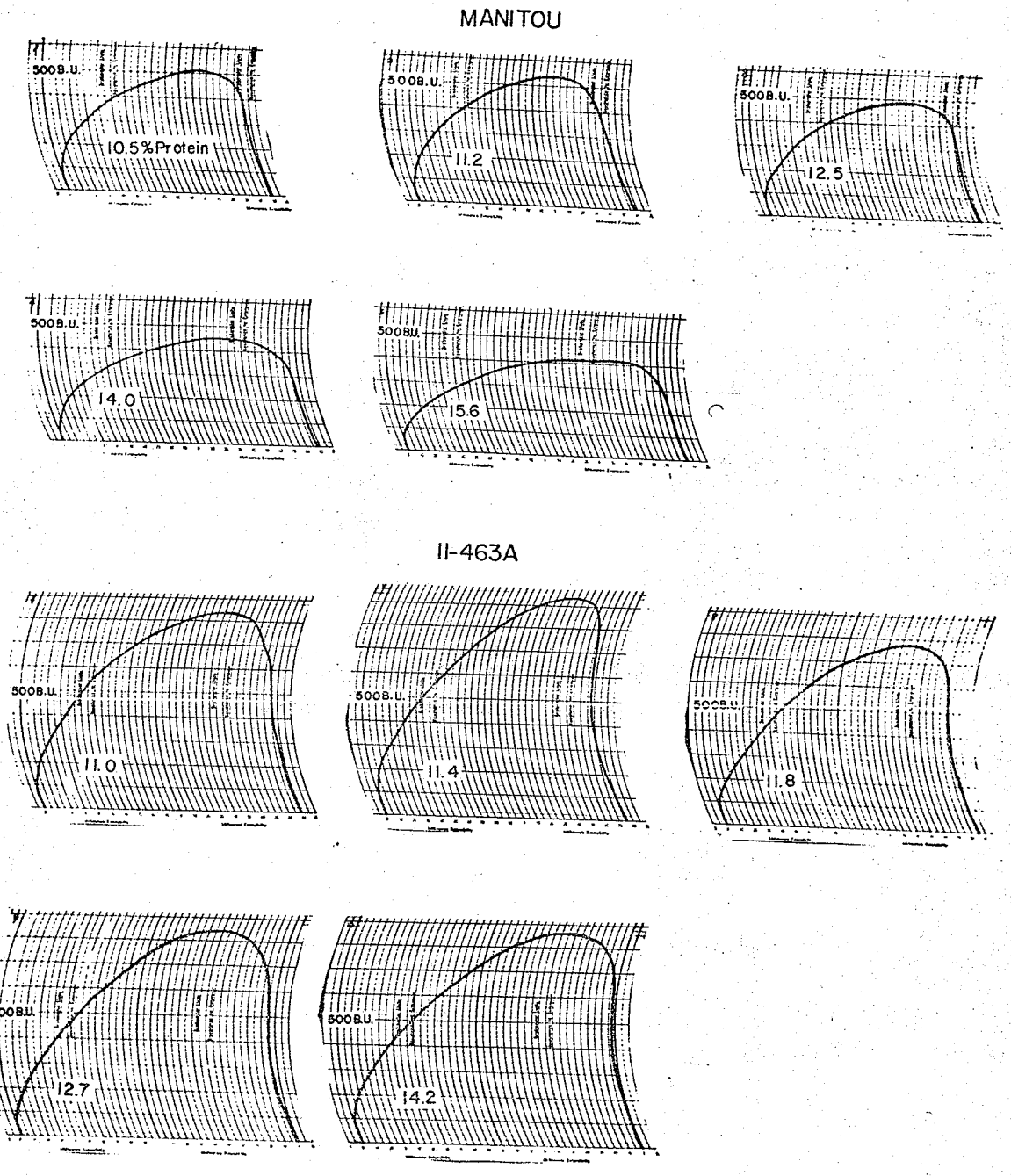

Fig. 9 Extensigraph curves and protein contents for Manitou and 11-463 A.

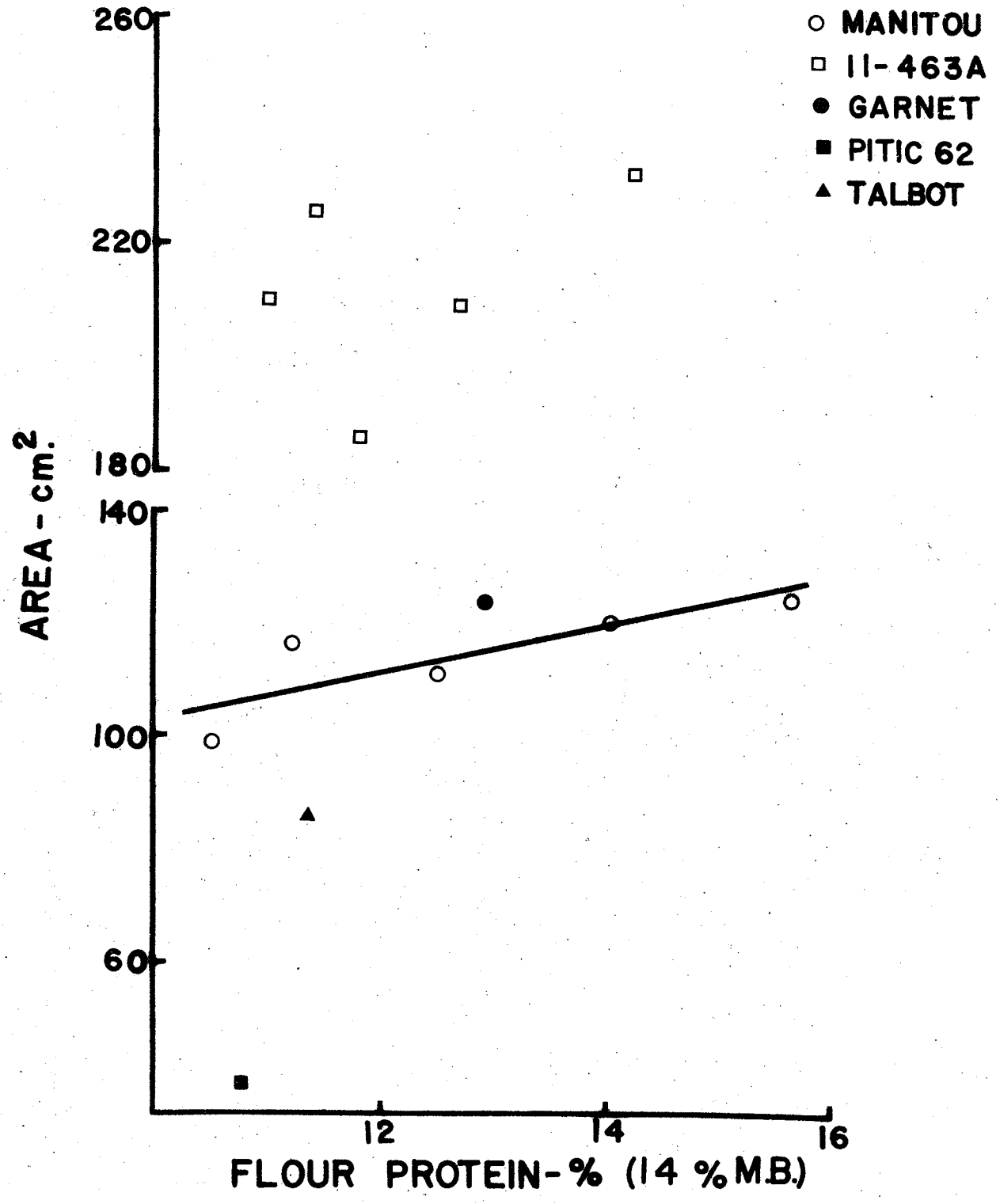

Fig. 10 Relationship between extensigram area and flour protein content.

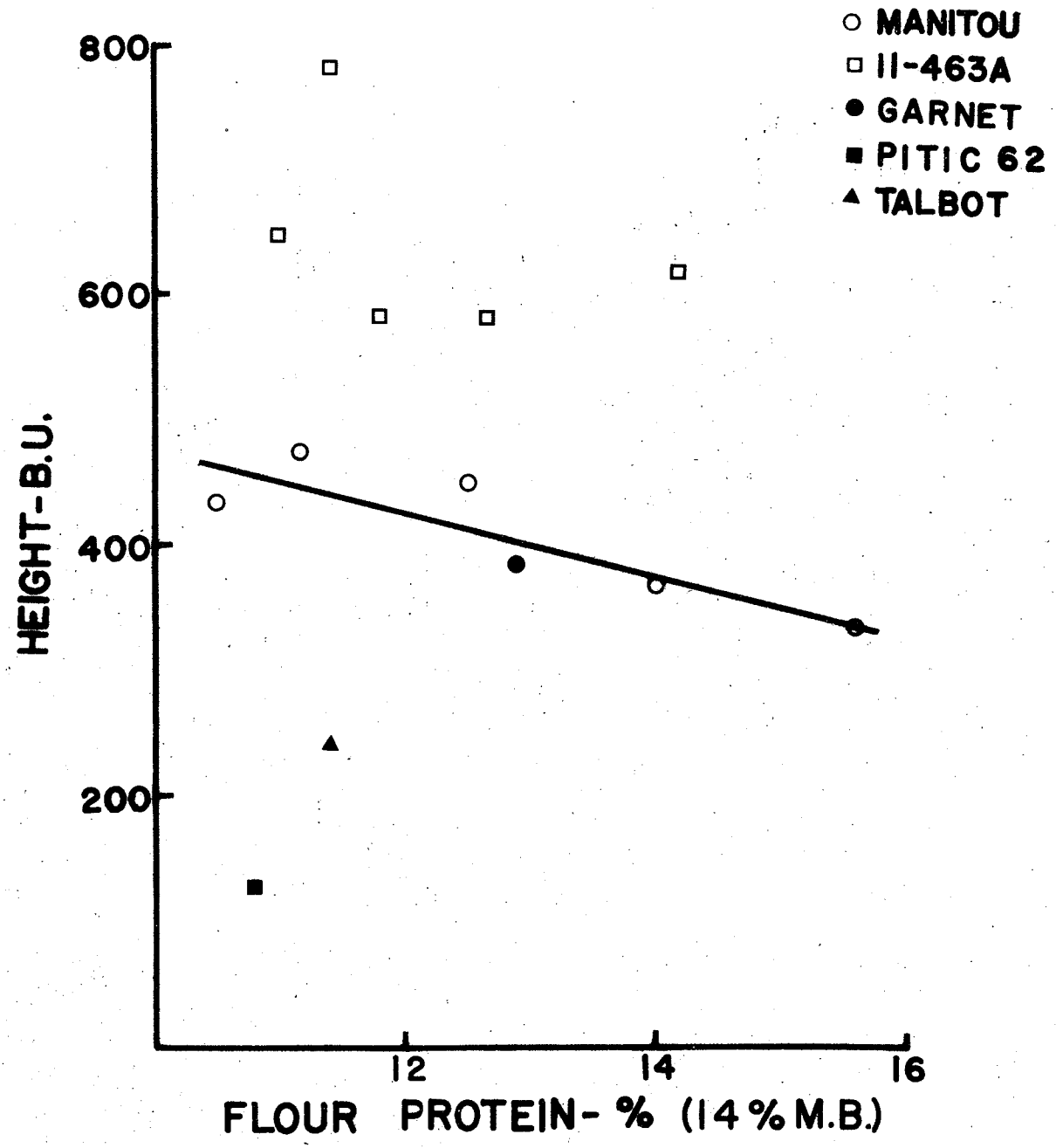

Fig. 11 Relationship between extensigram height and flour protein content.

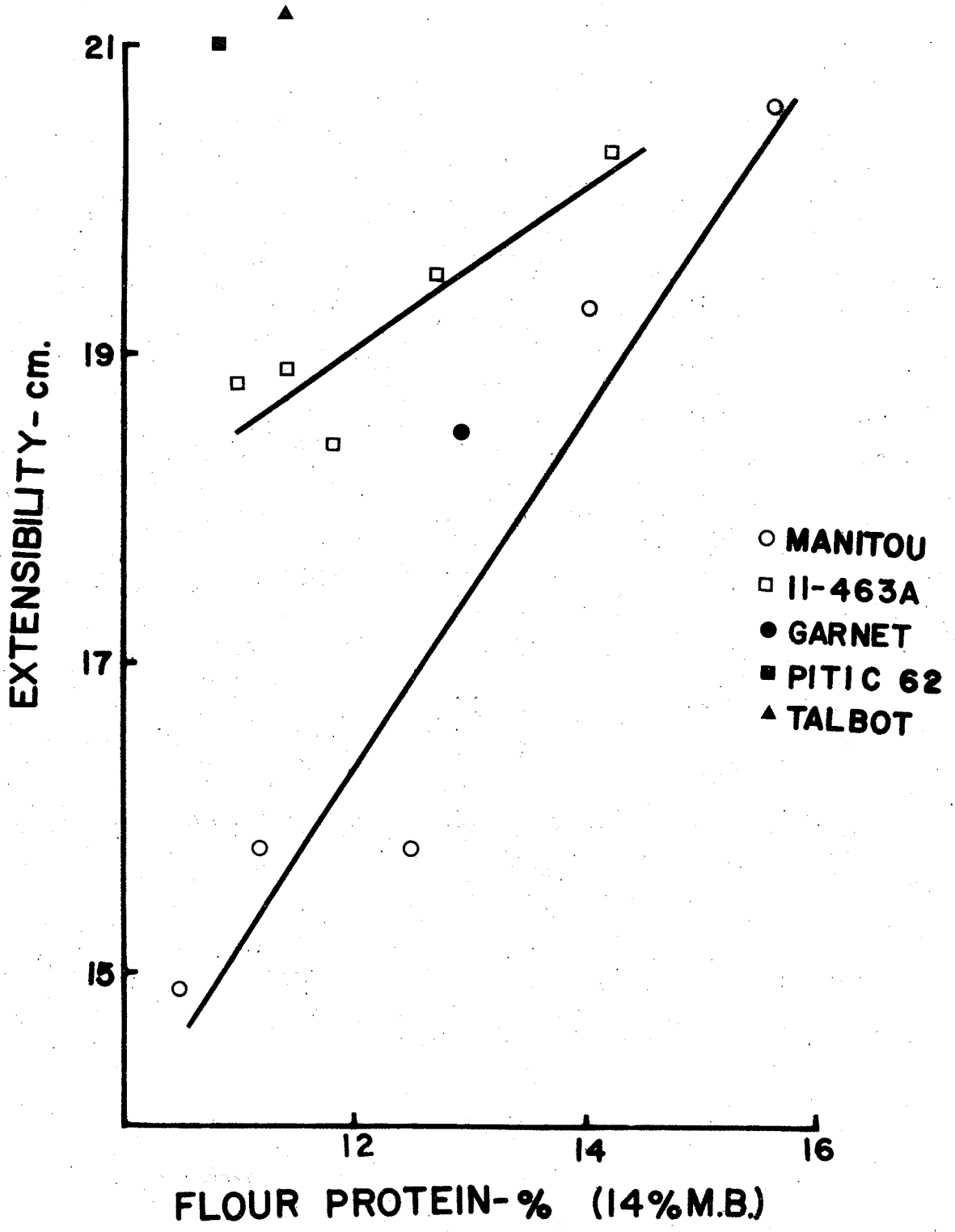

Fig. 12 Relationship between extensigram extensibility and flour protein content.

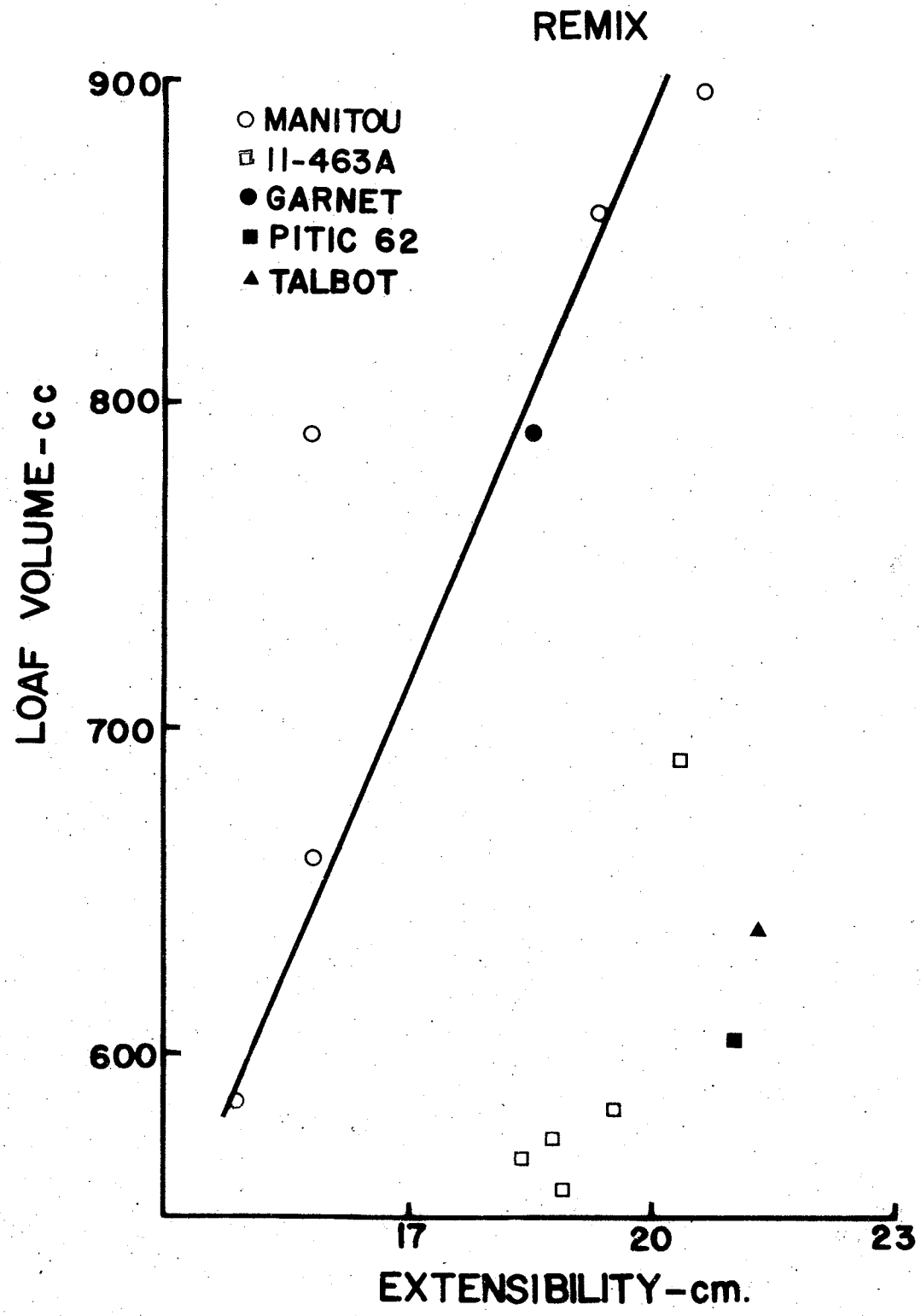

Fig. 13 Relationship between loaf volume by remix baking test and extensigram extensibility.

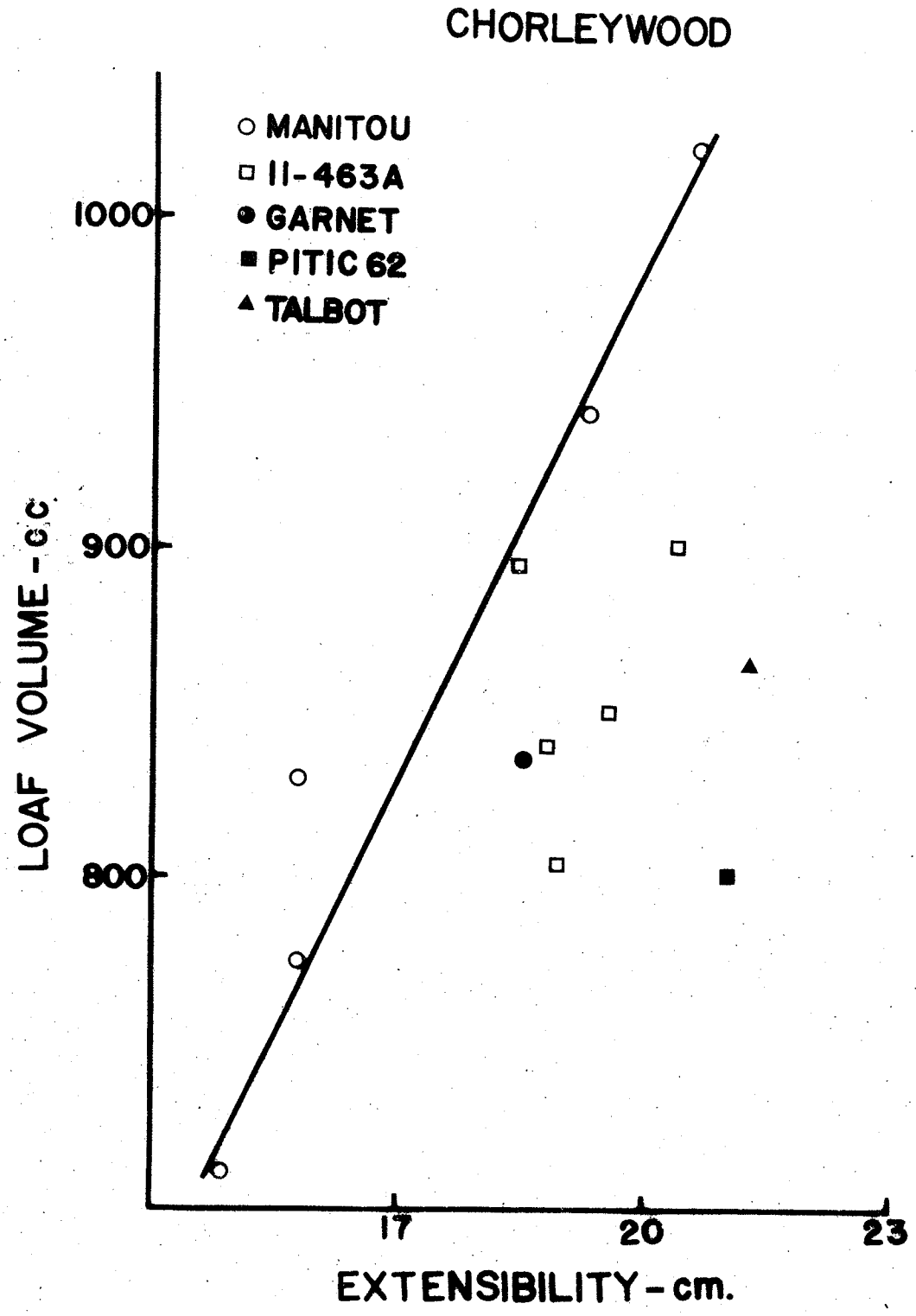

Fig. 14 Relationship between loaf volume by Chorleywood baking process and extensigram extensibility.

Sedimentation Test

The Sedimentation Test is reported to reflect the effects of both protein quantity and quality in overall breadmaking quality (138). Results for Manitou and 11-463A (Table 3, Appendix) showed that the sedimentation value increased with increasing protein content. This relationship is essentially linear of the same slope for both varieties (Fig. 15). Although the two varieties appeared quite different on the basis of the tests discussed above, especially the baking tests, they are essentially indistinguishable by the Sedimentation Test.

Wet Gluten

Analytical data related to gluten content are shown in Table 4 (Appendix). Wet and dry gluten yields, and gluten protein expressed as percent of flour protein, all increased linearly with increasing flour protein for both varieties. The stronger variety 11-463A had a slightly higher wet gluten content than Manitou of the same protein content (Fig. 16). Also the wet gluten of the stronger variety contained more of the flour protein than did the Manitou gluten (Fig. 17). These results indicate that the main difference between 11-463A and Manitou that might be related to baking quality is that the flour of the former variety contains more gluten-type protein in relation to total protein content.

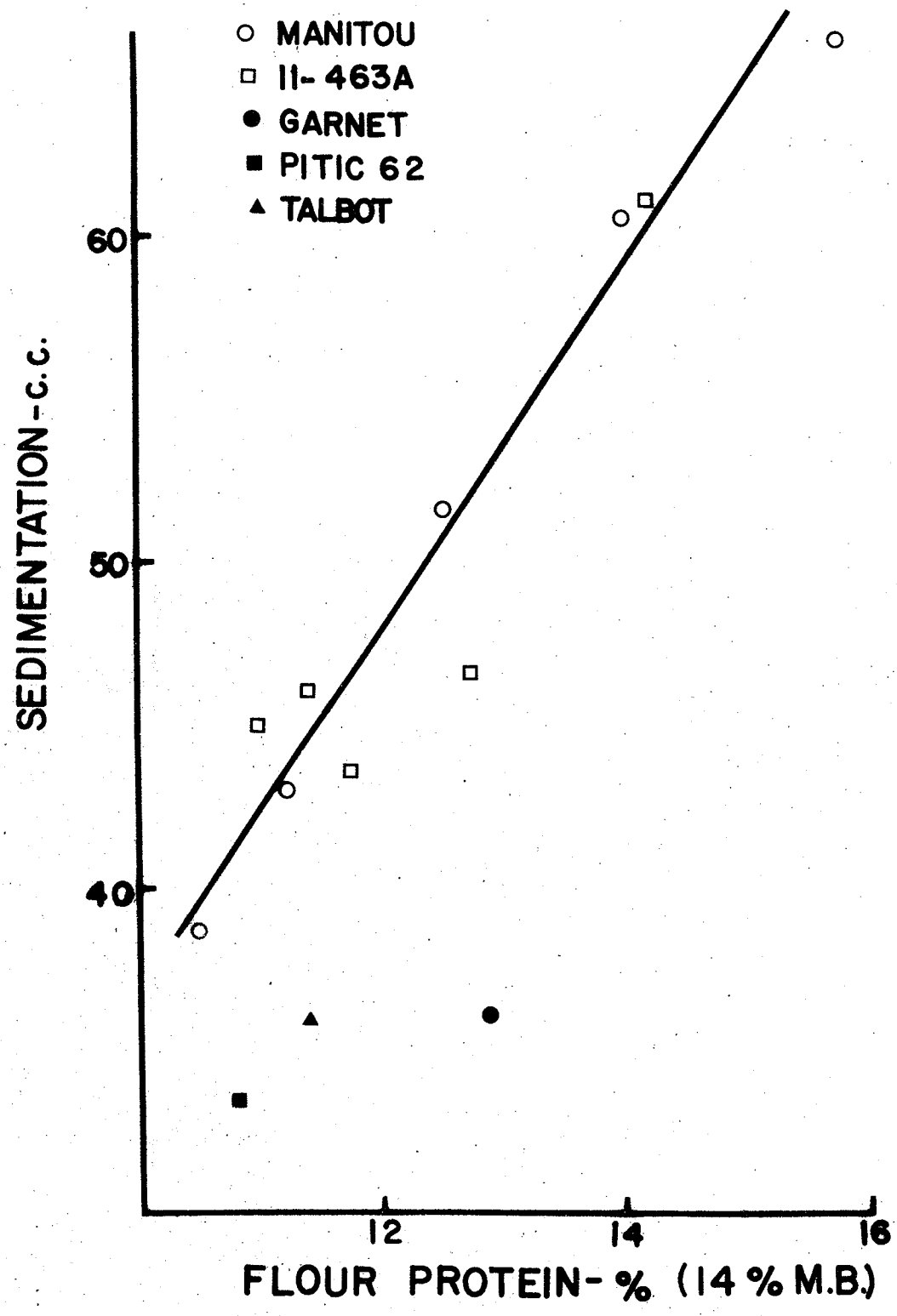

Fig. 15 Relationship between sedimentation value and flour protein content.

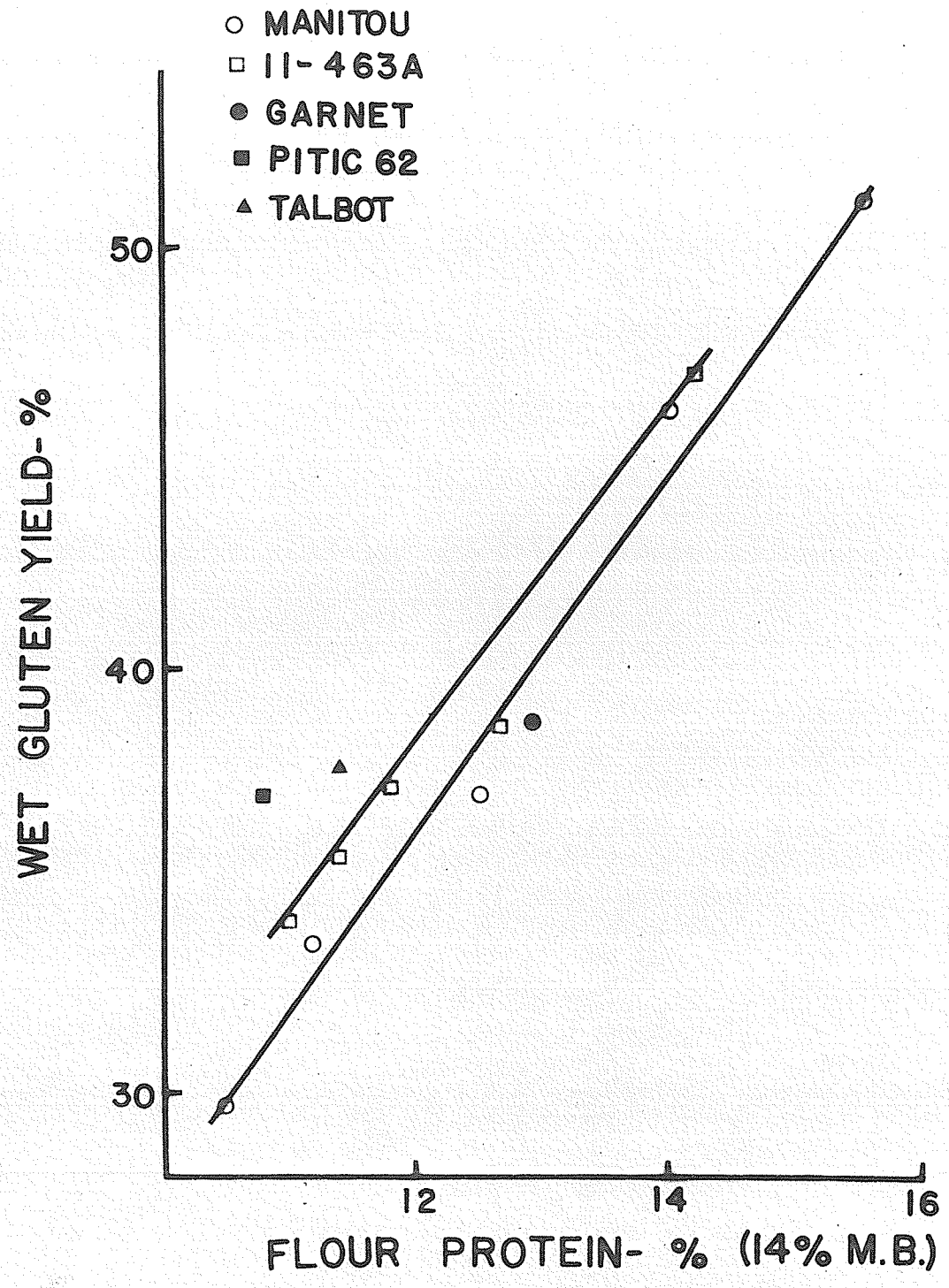

Fig. 16 Relationship between wet gluten yield and flour protein content.

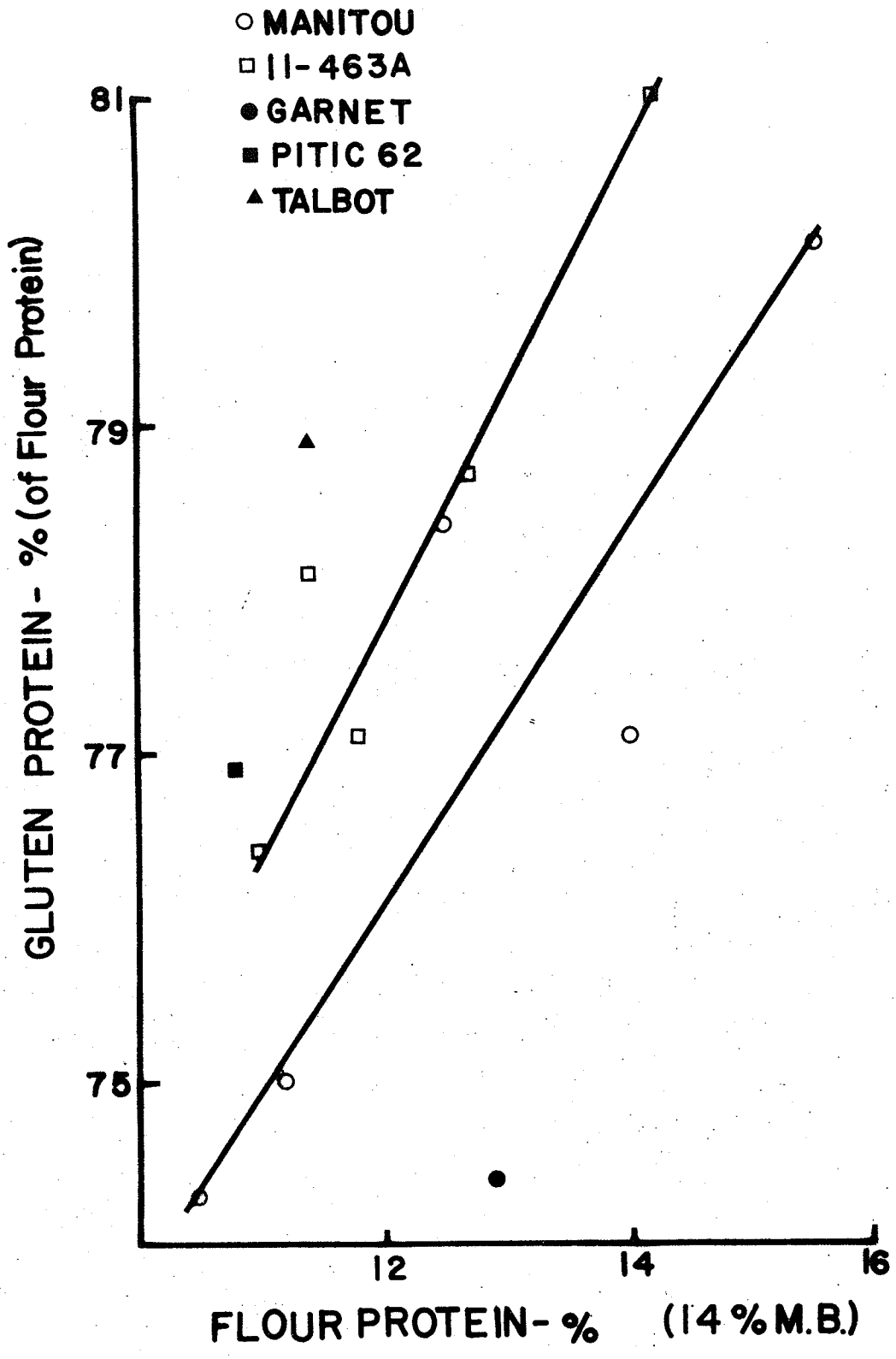

Fig. 17 Relationship between gluten protein, as % of flour protein and flour protein content.

Amylograph Test and Related Properties

Certain enzymes have a profound influence on the breadmaking quality of flour. Munz and Bailey (148) concluded that breakdown of dough plasticity and increase of dough mobility can result from the action of alpha-amylase. Rupp and Bailey (149) showed that additions to doughs of proteolytic enzymes also decreased the plasticity of doughs. In addition they showed that alpha-amylase activity of malted or sprouted wheat can completely mask the effects of proteinase under some conditions.

Wheat flour normally contains a variety of enzymes: alpha- and beta-amylases; protease, lipase; lipoxidase; catalase; and a number of different dehydrogenases. Of these, amylases play an extremely important role in breadmaking. While alpha-amylases perform several functions in breadmaking, the most important is their hydrolytic release of maltose from starch during sponge and dough fermentation. This sugar serves as the substrate for yeast enzymes for the production of carbon dioxide that leavens the dough. Aside from the sugar production needed for yeast fermentation, alpha-amylases exert an indirect effect on crust color by releasing sugars during the early stages of baking which then are available for the melanoidin reaction that causes browning of the crust. Additionally, alpha-amylase brings about a certain amount of starch dextrinization, again during the early stages of baking, which results in an improved grain and softer bread crumb texture.

Beta-amylase splits off two glucose units or maltose, from the end of the starch molecules. Thus this enzyme also produces a fermentable sugar. The amylases therefore are very important in bread-

making. The determination of amylase activity of wheat or flour is one of the most important tests in relation to breadmaking quality. Data related to amylase activity of the samples used in this study are given in Table 3 (Appendix).

Falling number and amylograph viscosity give an indication of alpha-amylase activity,while gassing power and diastatic activity serve as a measure of beta-amylase activity provided that alpha-amylase activity is relatively low.

The falling number value of Manitou increased, and that of 11-463A decreased, as the protein content of the flour increased. The lower the alpha-amylase activity of the flour, the higher is the falling number reading.

Alpha-amylase activity as measured by the amylograph test showed the same trend with protein content (Fig. 18a). This relationship is shown more clearly in Fig. 18, where alpha-amylase activity, as measured by the viscometric procedure of Tipples (140), is plotted against flour protein content. By two indirect procedures discussed above, alpha-amylase activity of Manitou decreased linearly as protein content increased. On the other hand, it increased parabolically as protein content increased in the samples of 11-463A. This is borne out by the direct measurement of alpha-amylase activity (Fig. 18).

As to beta-amylase activity, similar results were obtained to those obtained for alpha-amylase. Beta-amylase activity as reflected by gassing power and diastatic activity decreased with increasing flour protein content for Manitou and increased for 11-463A (Table 3, Appendix).

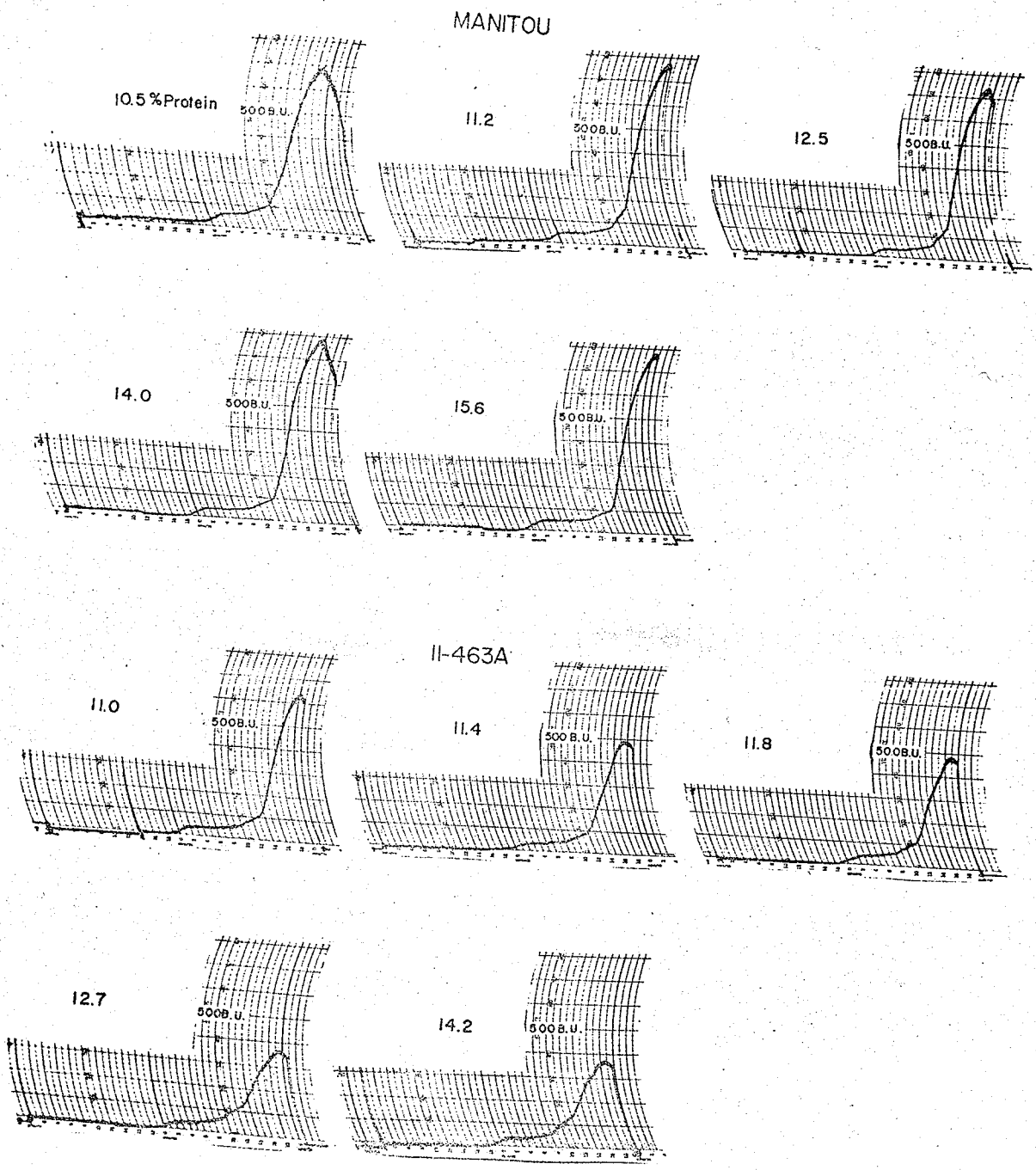

Fig. 18a Amylograph curves and protein contents for Manitou and 11-463 A.

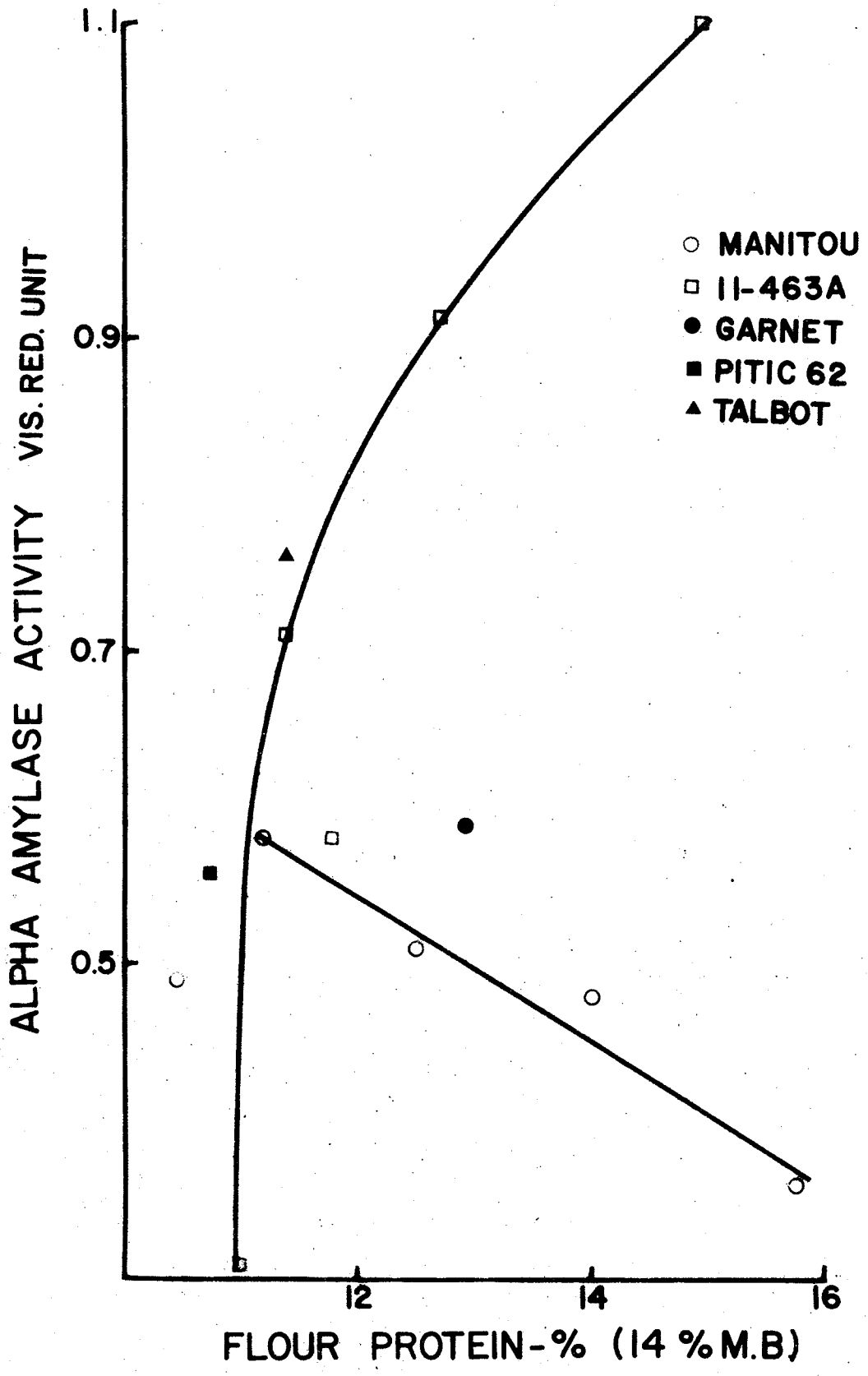

Fig. 18 Relationship between alpha amylase activity and flour protein content.

Normally flour contains a small amount of starch that is readily susceptible to enzyme attack, the so-called damaged starch. The rate of amylolytic activity is, therefore, controlled, to a degree, by the level of damaged starch. Manitou flours ranged in starch damage from 17 to 24%; the extent of damage decreased as flour protein content increased (Table 3, Appendix). This might be one reason why Manitou showed a decrease in amylolytic activity with increasing flour protein contents.

For the 11-463A flours, the difference in starch damage for the lowest and the highest protein samples was only 2%. Accordingly the variation in the amount of damaged starch should have little effect on the amylolytic activity of this variety.

It is presumed that as the protein contents of flour increases so would its total enzyme activity if the enzyme proteins are synthesized at the same rate as the storage proteins. This might be one reason why 11-463A flours with higher protein contents had higher amylolytic activities. However it is more likely to be due to incipient sprouting. With Manitou flours, the condition of the substrate (degree of damaged starch) seems to be an important factor in determining the rate of amylolytic action.

In a dough system, alpha- and beta-amylases usually act jointly and synergistically. Since normal wheat flour normally contains a sufficient amount of beta-amylase, the alpha-amylase activity appears to be the critical factor (150).

Figures 19 and 20 show the relationships between gassing power and diastatic activity and alpha-amylase activity, respectively. Results

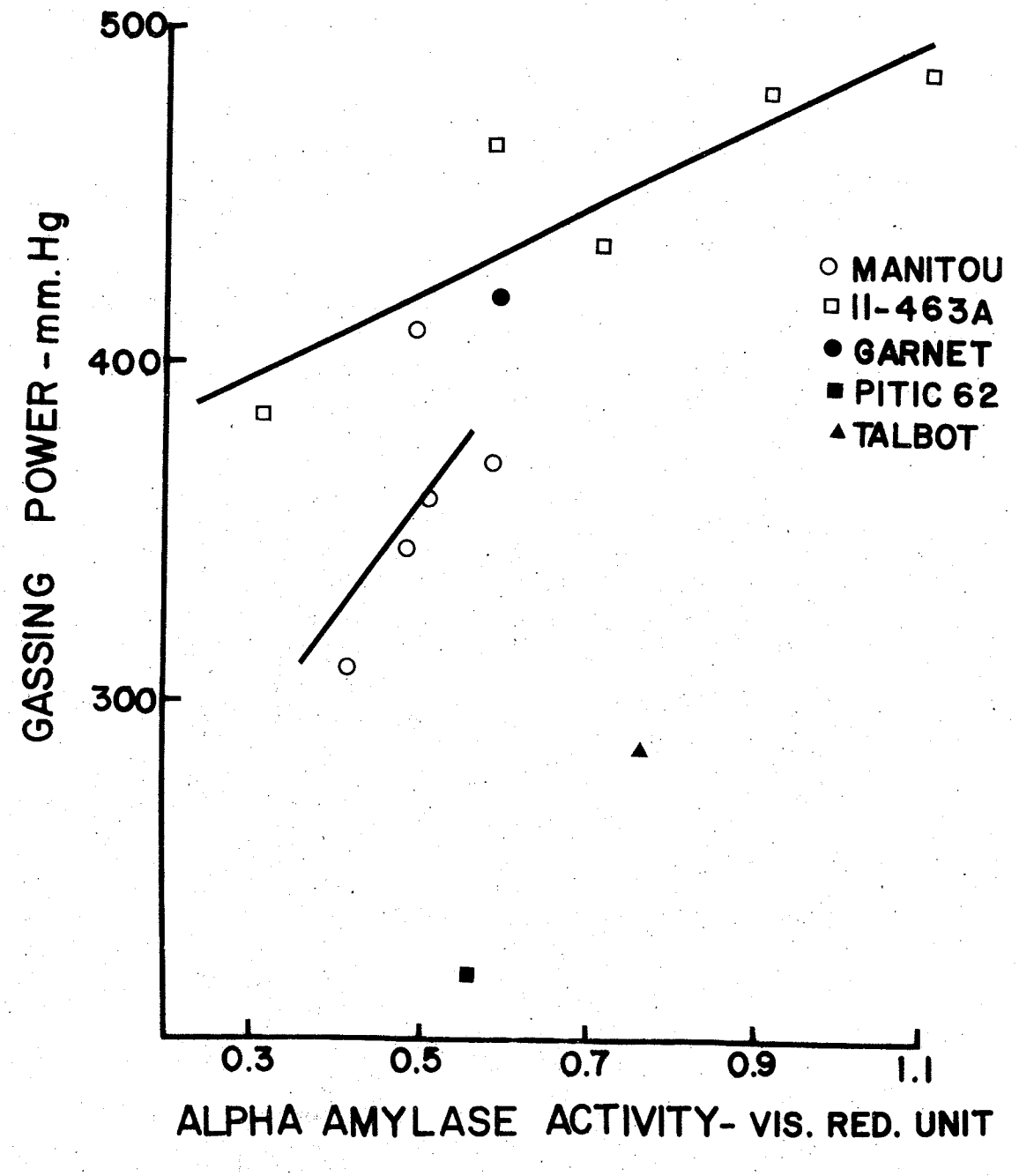

Fig. 19 Relationship between gassing power and alpha amylase activity of flour.

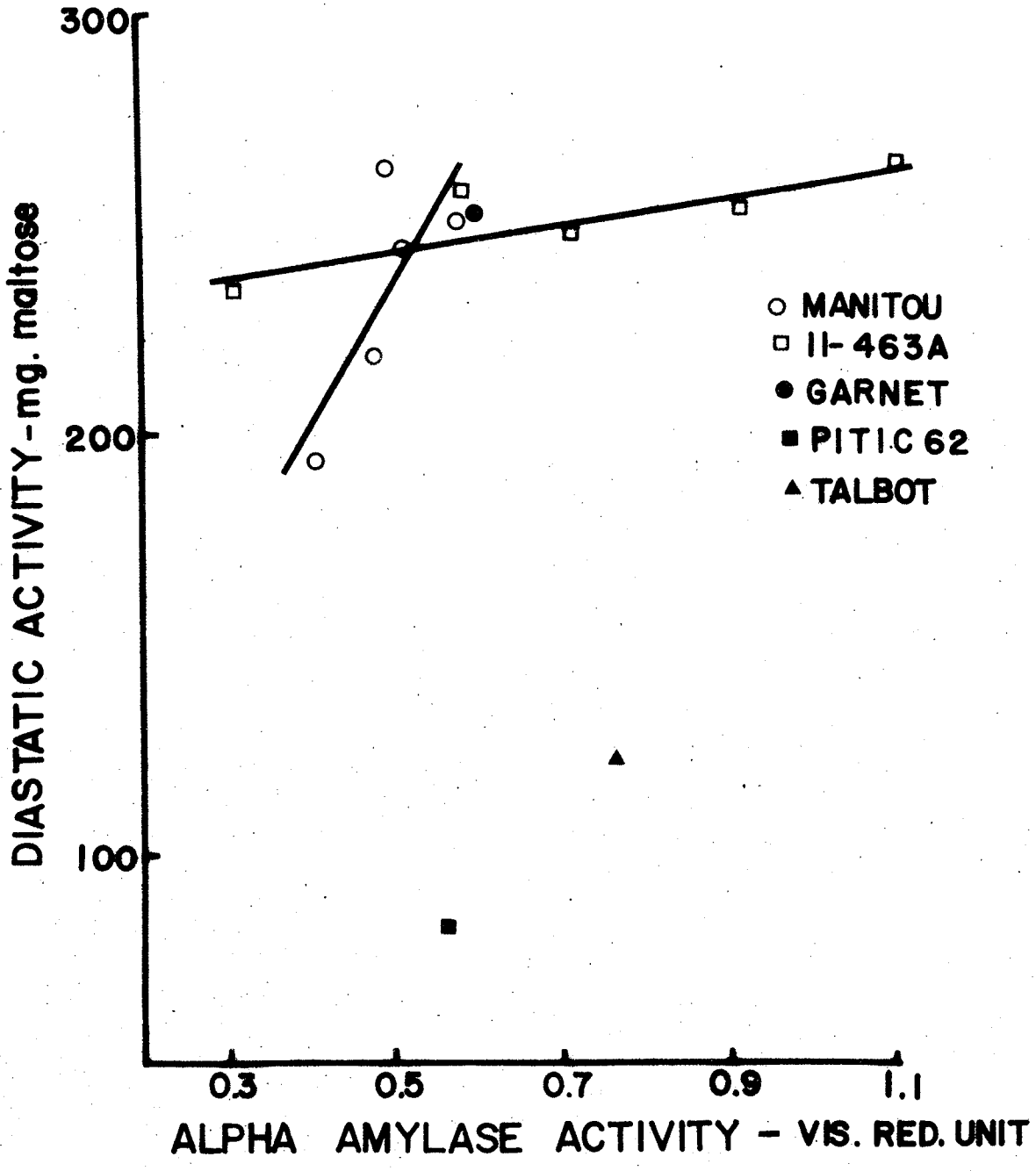

Fig. 20 Relationship between diastatic and alpha amylase activities of flour.

for both varieties showed that the two technological parameters are directly related to alpha-amylase activity. The most interesting feature of these results is that the slopes of the linear relationships for the two varieties are quite different. Whether this is due to differences in the substrate (damaged starch) or the enzyme specificity remains to be investigated.

Besides amylases, many other enzymes are probably involved in the functional properties of doughs, particularly proteases (150, 151). In the wheat kernel, the lowest protease activity is in the endosperm and the highest in the bran (62). However flour from sound wheat has very low proteolytic activity and it is not considered important in baking technology. In this study, measurements of proteolytic activity were not made.

Solubility Distribution of the Flour on a Weight Basis

The flours were fractionated into five solubility groups using a modified Osborne fractionation (5, 137). The analytical data for the ten flour samples are given in Table 5 of the Appendix.

Recoveries of the total solids of original flour were between 97.3 and 99.4%. The incomplete recovery is attributed to the losses of small molecules during dialysis in the separation of the salt-solubles from the water-soluble components.

Data of Table 5 (Appendix) shows that the amounts of three fractions comprising gluten (alcohol-soluble, acetic acid-soluble, and residue) increased with flour protein content. Water- and salt-soluble fractions showed little change with protein content.

Protein Content of the Solubility Fractions

The protein contents (N x 5.7) of the various solubility fractions are given in Table 6, Appendix. The average total protein recovery for ten samples was 94.7%. Again, the losses of nitrogen could be attributed to losses of the low molecular weight compounds, such as free amino acids and peptides, during dialysis. It is quite possible that the content of these low molecular weight nitrogenous substances might be related to breadmaking quality, but this remains to be investigated.

The water-soluble fractions contained from 50.4 to 60.0% protein on the total solid basis, while the salt-soluble fractions contained from 61.6 to 71.3% protein. Alcohol-soluble fractions had the highest protein content, from 77.6 to 92.1%, while the residue has the lowest protein content (4.6 to 6.9%). The protein contents of the acetic acid soluble fractions ranged from 61.5 to 76.4%.

The fact that the protein content for all of the soluble fractions was considerably less than 100% indicates that relatively large, and variable, amounts of non-protein materials were extracted by the solvents used. Although carbohydrate analyses were not made in this study, it is presumed that most of the non-protein material extracted was carbohydrate (152).

Distribution of Proteins in the Solubility Fractions

The distribution of proteins in the five fractions are shown in Fig. 21 and 22 for Manitou and 11-463A, respectively. All samples contained relatively low quantities of water (9.5 to 12.6%) and salt (2.9 to 4.3%)

Fig. 21 Distribution of flour proteins among the five solubility fractions for Manitou

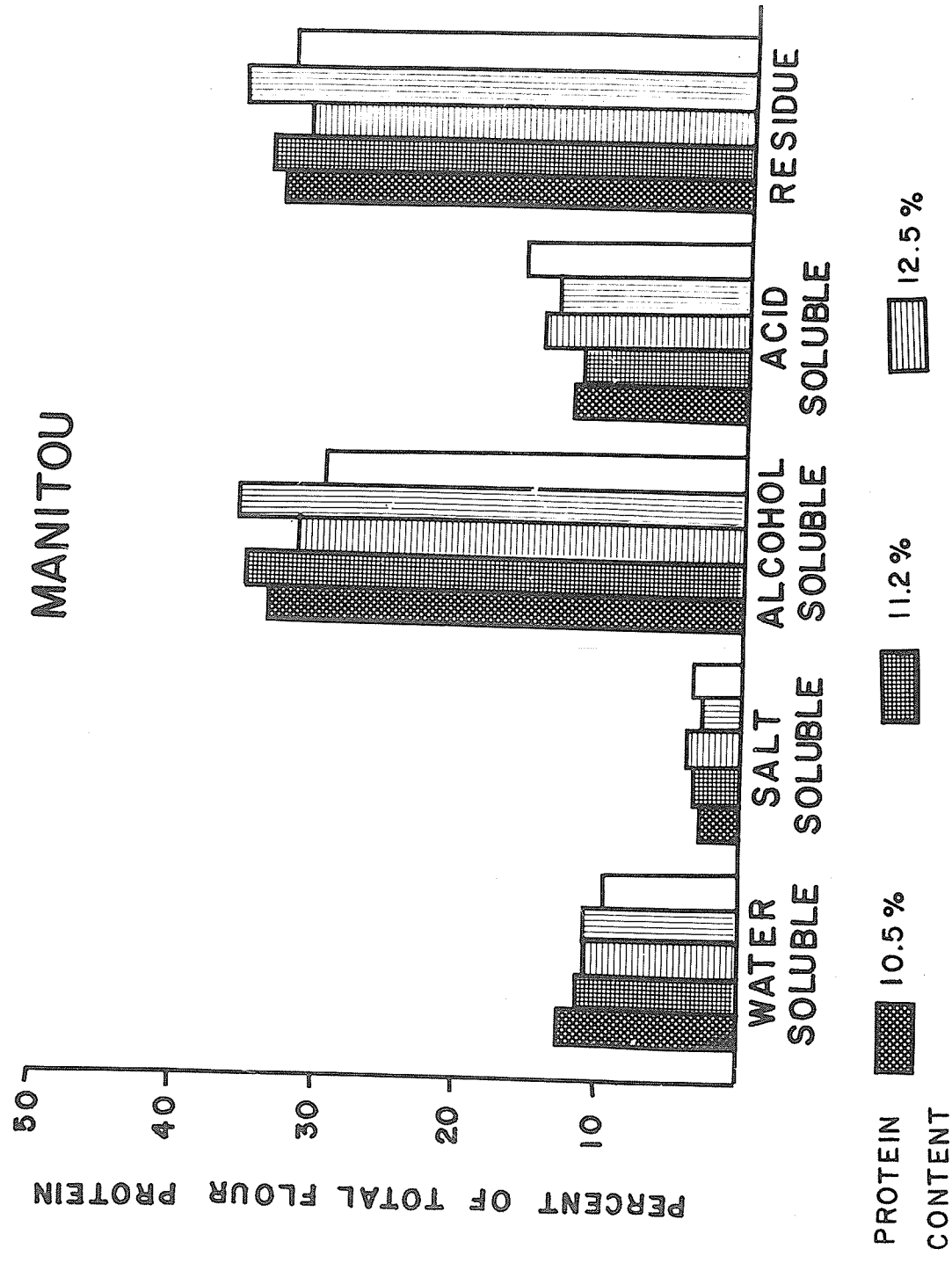

Fig. 21 Distribution of flour proteins among the five solubility fractions for Manitou

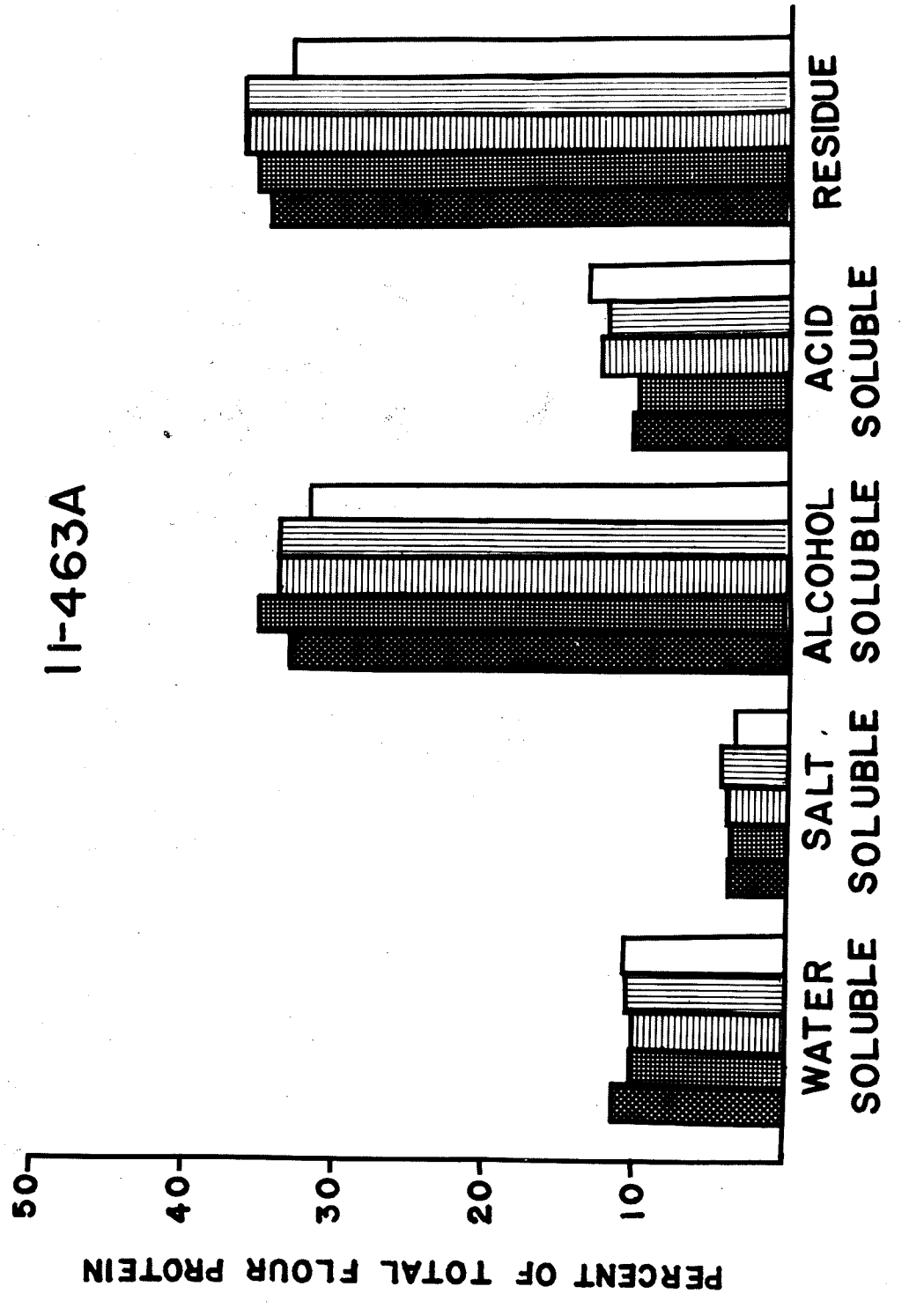

Fig. 22 Distribution of flour proteins among the five solubility fractions for 11-463A

soluble proteins. Together these proteins made up approximately 15% of the flour proteins.

For Manitou, the water-soluble protein showed a slight decreasing trend with increasing protein content of the flour (Fig. 21). Also the sum of water- and salt-soluble proteins decreased slightly as flour protein increased (Table 6, Appendix). Alcohol-soluble protein showed a slight decreasing trend with increasing protein content. On the other hand, the amount of acetic acid-soluble protein increased as flour protein increased. The amount of residue protein remained essentially constant for the five levels of flour protein content. The sum of the last three fractions, which make up the gluten proteins, increased with flour protein content. These results agree with those of Fig. 17 which showed that the percentage of protein in the wet gluten increased with protein content.

The solubility distributions of proteins of 11-463A (Fig. 22) for different protein contents showed similar trends to those obtained for Manitou, however the trends are less marked. Again, the most obvious trend with increasing protein content was the increase in the amount of acetic acid-soluble proteins (glutenins).

Disc Electrophoretic Results

Disc electrophoresis was used to examine the protein components in three of the soluble fractions. Only the water-, salt- and alcohol-soluble fractions can be separated by this technique. The proteins of the acetic acid-soluble fraction do not migrate into the polyacrylamide gel presumably because their molecular weights are too high. Fractions

from the flours with the lowest, intermediate, and highest protein contents were selected for these experiments.

Water-Soluble Proteins. Figure 23 shows the disc electrophoretic patterns of the water-soluble proteins (albumins) of Manitou and 11-463A. Water-soluble proteins are characterized by intermediate and fast moving protein bands with relative mobilities (R_f) from 0.38 to 0.72. The patterns for this fraction comprised at least 12 detectable bands. Four major bands appeared in the R_f region from 0.58 to 0.72. A band at the origin and a few faint bands in the R_f region from 0 to 0.25 were observed for all samples. These bands are probably due to gliadins and glutenins present as contaminants.

The patterns for the three Manitou flours of different protein content were essentially the same. That is, flour protein content had no effect on the electrophoretic patterns of the water-soluble group of protein components. Similar results were obtained for 11-463A. Also there was no difference between the patterns for Manitou and 11-463A.

Salt-Soluble Proteins. Disc electrophoretic patterns for salt-soluble proteins are shown in Fig. 24. Proteins of this fraction migrated in the R_f range from 0.24 to 0.88. The patterns are identical for the three flours of different protein content for each variety; that is, protein content had no effect on the patterns of this group of proteins for the two varieties examined. Again, as was obtained for the water-soluble proteins, there were no discernible differences in the patterns for the two varieties.

The salt-soluble group of proteins contained at least 14 detectable

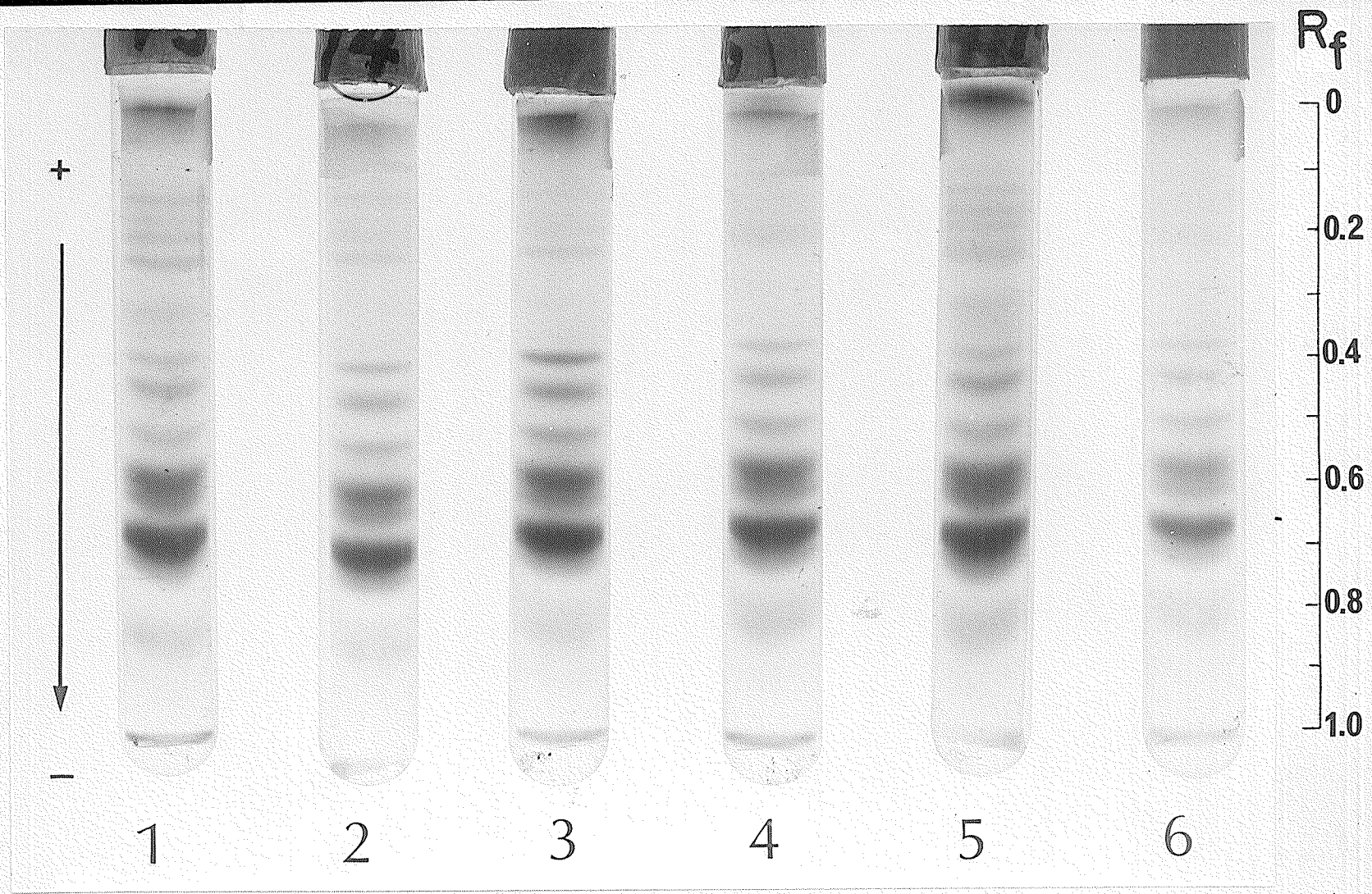

Fig. 23 Disc electrophoretic patterns for the albumins of Manitou and 11-463 A.

Manitou		Protein(%)	11-463 A		Protein(%)
1	-	10.5	4	-	11.0
2	-	12.5	5	-	12.7
3	-	15.6	6	-	14.2

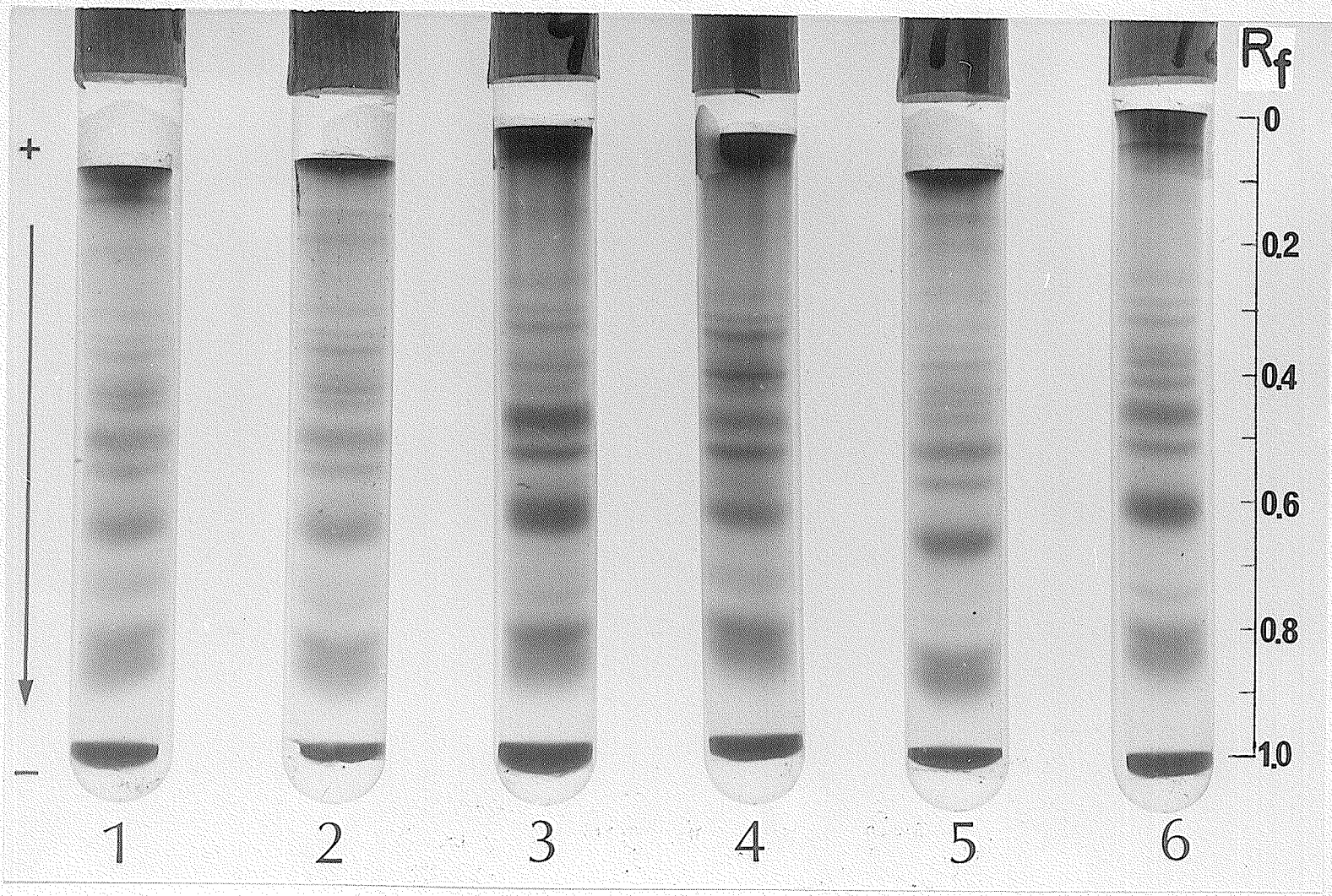

Fig. 24 Disc electrophoretic patterns for the globulins from Manitou and 11-463 A.

Manitou		Protein(%)	11-463 A		Protein(%)
1	-	10.5	4	-	11.0
2	-	12.5	5	-	12.7
3	-	15.6	6	-	14.2

components. The major band had the highest mobility and appeared to be a doublet. This component is probably purothionin (153). All extracts showed a dark band at the origin. Presumably, this could be high molecular weight protein of the glutenin-type which does not migrate into gel, or it could also be the high molecular-weight globulin found in some flours (38).

Distinct differences were observed between the patterns for the water- and the salt-soluble fractions. A number of components in the water- and salt-soluble proteins had the same mobility. It is quite likely that the salt-soluble fraction contained some water-soluble protein due to incomplete separation during dialysis.

Alcohol-Soluble Proteins. Figure 25 shows the disc electrophoretic patterns of alcohol-soluble group of proteins. The proteins of this solubility group migrated slowly with mobilities in the R_f range from 0 to 0.35. At least 13 bands were detected. Two faint faster moving bands were also detected but these are probably albumin or globulin contaminants.

The patterns for this fraction for different protein contents of one variety were essentially the same. There were obvious differences between patterns for Manitou and 11-463A. This will be discussed further in Section II which deals with qualitative differences in the electrophoretic patterns for equivalent protein fractions from varieties that differ significantly in baking quality.

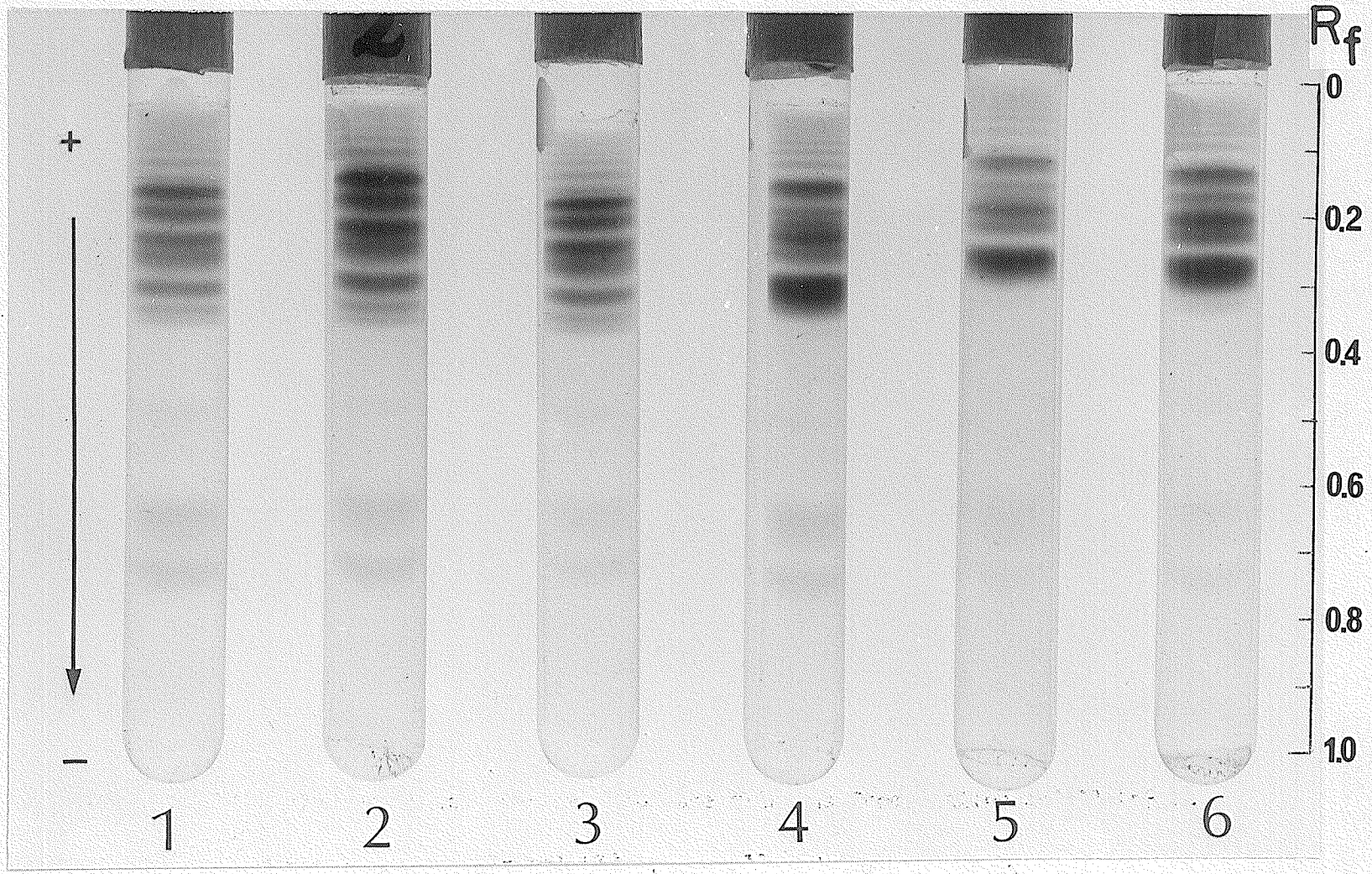

Fig. 25 Disc electrophoretic patterns for the gliadins from Manitou and 11-463 A.

Manitou		Protein(%)	11-463 A		Protein(%)
1	-	10.5	4	-	11.0
2	-	12.5	5	-	12.7
3	-	15.6	6	-	14.2

II. Effect of Flour Protein Quality on Breadmaking Quality

Baking Test

Results with the remix test (see Fig. 2) showed that at constant protein content Manitou gave a much higher loaf volume than 11-463A. Talbot, Pitic 62 and Garnet had essentially the same baking quality by this test as Manitou of the same protein contents. The inferior breadmaking quality of these three varieties can therefore be attributed primarily to their normally low protein content. High quality wheats such as Manitou show good baking performance only if they contain a sufficient level of protein.

The loaf volumes obtained by the CBP baking test are much higher than those obtained by the remix test for all varieties examined (Fig. 3). In general, 11-463A and the two soft wheats had slightly higher loaf volumes than Manitou, while the loaf volume for Garnet was similar to that for Manitou at equivalent protein content. Differences in loaf volumes by the CBP test among five varieties were not as large as by the remix test. The CBP seems to minimize quality differences between flours and actually produced higher volumes from flours that were considered weaker or stronger than Manitou by the farinograph test.

Farinograph Test

It is apparent that differences in farinogram characteristics exist among varieties, especially between the soft and hard wheats (Fig. 26). However the differences are decreased when flours from different varieties are compared at approximately the same protein content (e.g. compare the curves for Talbot and Manitou). The two soft wheats, Pitic 62 and Talbot,

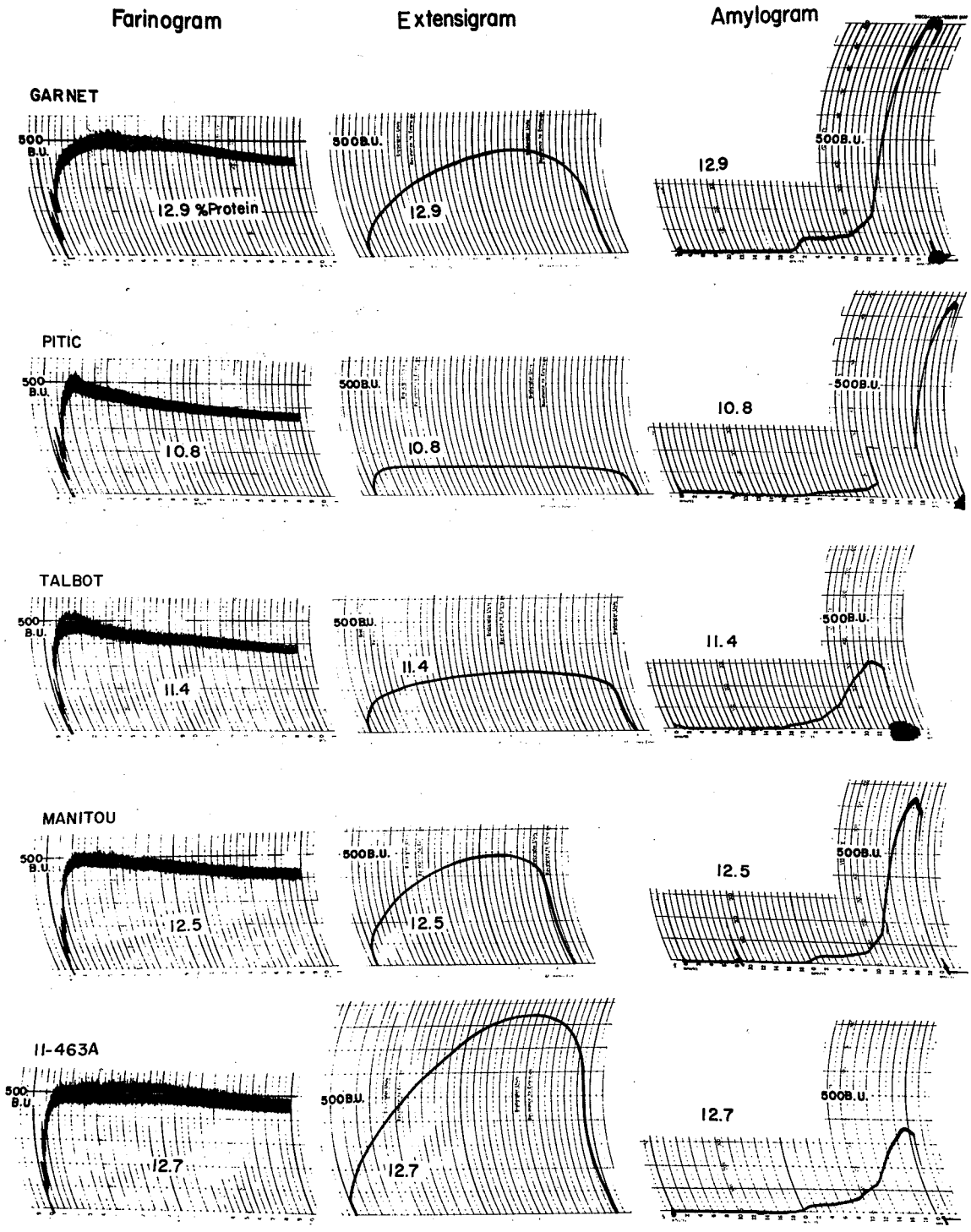

Fig. 26 Farinograph, extensigraph and amylograph curves for five wheat varieties of similar protein content.

showed slightly longer development times and lower stabilities than Manitou at the same protein level (see Figs. 5 and 6). However varietal differences in these two parameters at constant protein content were small when the experimental error was taken into account.

Definite differences in stability were obtained between Manitou and 11-463A (Fig. 6); the values for the latter were considerably higher. Garnet, Pitic 62 and Talbot flours were similar in this property to Manitou flours of comparable protein content.

It might be of interest to examine the relationship between development time and breadmaking performance since development of the dough is considered to be important in baking quality. By the remix test (Fig. 7) the three weaker wheats, Garnet, Pitic 62 and Talbot, gave loaf volumes that were only slightly lower than those for Manitou flours with comparable dough development time. Presumably this results from the fact that both loaf volume and development time depend strongly on protein content. The variety 11-463A is quite different in this respect. By the CBP test (Fig. 8), Pitic 62 and Talbot gave higher volume whereas Garnet gave lower volumes than Manitou (see Fig. 3). Variety 11-463A performed better than Manitou for short development times (at low protein contents) but was inferior to flours of much longer development time. The extensive scatter of points in Fig. 8 is probably due to the large experimental error in the determination of development time.

Farinograph absorptions were quite different between soft and hard wheat (see Table 3, Appendix). The absorptions for Pitic 62 and Talbot were 57.7 and 55.2% respectively, whereas for the two hard wheats of equivalent protein content the values were higher than 60%. This difference

could be attributed to differences in starch damage which will be discussed later.

Extensigraph Test

Very definite varietal differences were observed in extensigraph properties (Fig. 26). Variety 11-463A had the highest values of extensigram area and height (Figs. 10 and 11); Manitou and Garnet had similar values, and Talbot and Pitic 62 were lowest for a comparable protein level.

In extensibility (Fig. 12), the doughs of 11-463A were considerably higher than those of Manitou; Garnet dough was intermediate while the doughs from Pitic 62 and Talbot flours were the most extensible. This is probably due partly to differences in the proteins and partly to differences in the amount of starch damage.

In the relationship between loaf volume and extensibility (Figs. 13 and 14), Garnet was similar to Manitou whereas Pitic 62 and Talbot were similar to 11-463A. It is not possible to attribute these similarities and differences to any single specific factor.

Sedimentation Test

Sedimentation value of flour is considered to be indicative of both the quantity and the quality of its gluten for breadmaking. A single linear relationship was obtained between the sedimentation value and flour protein content for samples of the two varieties discussed in Section I, Manitou and 11-463A (Fig. 15). The values for Pitic 62, Talbot and Garnet were significantly lower than the values for Manitou and 11-463A of

equivalent protein content. These results suggest that Garnet, Pitic 62 and Talbot have considerably poorer gluten quality as judged by the Sedimentation Test. However this was not borne out by baking tests and it might be that the low sedimentation values for Pitic 62 and Talbot result from the extremely low starch damage in these flours (see Table 3, Appendix). Garnet flour, on the other hand, had high starch damage, accordingly its low sedimentation value is probably related to its protein quality.

Wet Gluten

At equivalent flour protein contents, 11-463A, Pitic 62 and Talbot gave higher yields of wet gluten than Manitou, while Garnet gave the same yield (Fig. 16). The results obtained for the two soft wheats, Pitic 62 and Talbot, were unexpected as it is commonly believed that soft wheats are much lower in gluten content than hard red spring wheats. Presumably this belief arose from the fact that hard red spring wheats are usually considerably higher in protein content than soft wheats so that it is not always possible to make comparisons at the same protein content.

Figure 17 shows that the washed glutens from 11-463A, Pitic 62 and Talbot contained a somewhat higher percentage of the flour proteins than did the glutens from Manitou flours. Garnet flour, on the other hand, contained a much lower percentage of the flour protein. These results are interesting, and are probably related to the dough forming properties of the flours and/or proteolytic activity, but it is not possible to make a general conclusion on the basis of the small number of samples examined in the present study.

Amylograph Test and Related Properties

Talbot and 11-463A had high and the other three varieties had low alpha-amylase activities as determined by the amylograph (see Fig. 26). However alpha-amylase activity, measured by falling number, was higher for soft wheats Talbot and Pitic 62, than for the three hard wheats. Manitou had the lowest, and Garnet and 11-463A had similar and higher, alpha-amylase activities than Manitou. Garnet and Pitic 62 had high alpha-amylase activities as indicated by falling number and low activities by the amylograph test. Since these two procedures are quite similar, it is difficult to explain the discrepancy in the ranking of the varieties by two tests.

As mentioned previously, alpha-amylase activity by the viscometric method showed significant varietal differences (Fig. 18). The soft wheats, Pitic 62 and Talbot, fitted on the parabolic curve of 11-463A. Manitou had the lowest activity and the activity of Garnet was intermediate.

Pitic 62 and Talbot had lower beta-amylase activity, as measured by gassing power and diastatic activity, than did the hard wheats (Figs. 19 and 20). This probably arises from the extremely low degree of starch damage (Table 3, Appendix) in the flours of the soft wheat varieties. Pitic 62 had only 3% and Talbot had 4% of damaged starch. Garnet was similar to 11-463A in these two properties.

It is apparent from these results that amylase activity and related properties of flour depend on variety and on environmental conditions during the growing period. Furthermore these properties can be extensively modified by post harvest factors such as sprouting and processing factors such as starch damage.

Solubility Distribution of the Flour on a Weight Basis

The weights of various fractions and total recoveries of solids in the fractionation are given for Garnet, Pitic 62 and Talbot in Table 5 (Appendix) together with the data for Manitou and 11-463A. Recoveries of the flour solids were 97.0% for Garnet, 97.6% for Pitic 62 and 96.7% for Talbot. These values are slightly lower than the values obtained for Manitou and 11-463A flours of comparable protein content. The incomplete recoveries are attributed to losses of low molecular weight compounds during dialysis. The amounts of each of the four soluble fractions for the soft wheats, Pitic 62 and Talbot, were somewhat lower than those for the three hard wheats. Conversely, larger amounts of residue were obtained for the soft wheats than for the hard wheats.

Protein Content of the Solubility Fractions

Table 6 (Appendix) gives the protein content (N x 5.7) of the five solubility fractions for each variety. Total protein recoveries ranged from 89.4 to 96.5%. In general, soft wheats, Pitic 62 and Talbot, gave lower protein recoveries than the hard wheats (Tables 5 and 6, Appendix). These results indicate that a fair proportion of the low molecular weight compounds that are lost during dialysis are nitrogenous substances. These substances might be related to breadmaking quality, however this possibility remains to be investigated. The soft wheats examined in this study had much more of the low molecular weight nitrogenous compounds.

Pitic 62 and Talbot had higher protein contents in the water-, salt- and acetic acid-soluble fractions, and lower contents in the alcohol-soluble fractions compared to analogous values for Manitou and 11-463A. Garnet,

a hard red spring wheat, was more similar in this respect to the soft wheats than to Manitou and 11-463A. The differences in protein content of the various solubility fractions from hard and soft wheats appear to be related to the differences in breadmaking quality of these wheats.

Distribution of Proteins in the Solubility Fractions

Figure 27 shows the distribution of proteins in five solubility fractions for the five varieties at approximately comparable protein content. These results showed a definite difference in distribution patterns for soft and hard wheats. Soft wheats, Pitic 62 and Talbot, had similar distribution patterns. The flours from these wheats contained more water-soluble, and less alcohol- and acetic acid-soluble proteins. Garnet appears to be intermediate between the soft wheats and other hard wheats. All varieties had similar proportions of salt-soluble protein. The residue protein showed some variability; soft wheats had a somewhat higher proportion of their flour protein in this group.

The two soft wheats had similar distribution patterns; on the other hand, the three hard wheats showed considerable varietal differences. Of the latter wheats, 11-463A, the strongest variety (by farinogram) contained the highest quantity of alcohol-soluble protein and the lowest quantity of water-soluble protein. Garnet had the highest quantity of residue protein. This could be a varietal characteristic that leads to the short highly elastic doughs usually obtained from flour of this wheat variety.

The results of Fig. 27 are consistent with the rheological (farinograph and extensigraph) properties of doughs of the five varieties. Higher water-soluble and alcohol-soluble protein contents would give doughs that develop

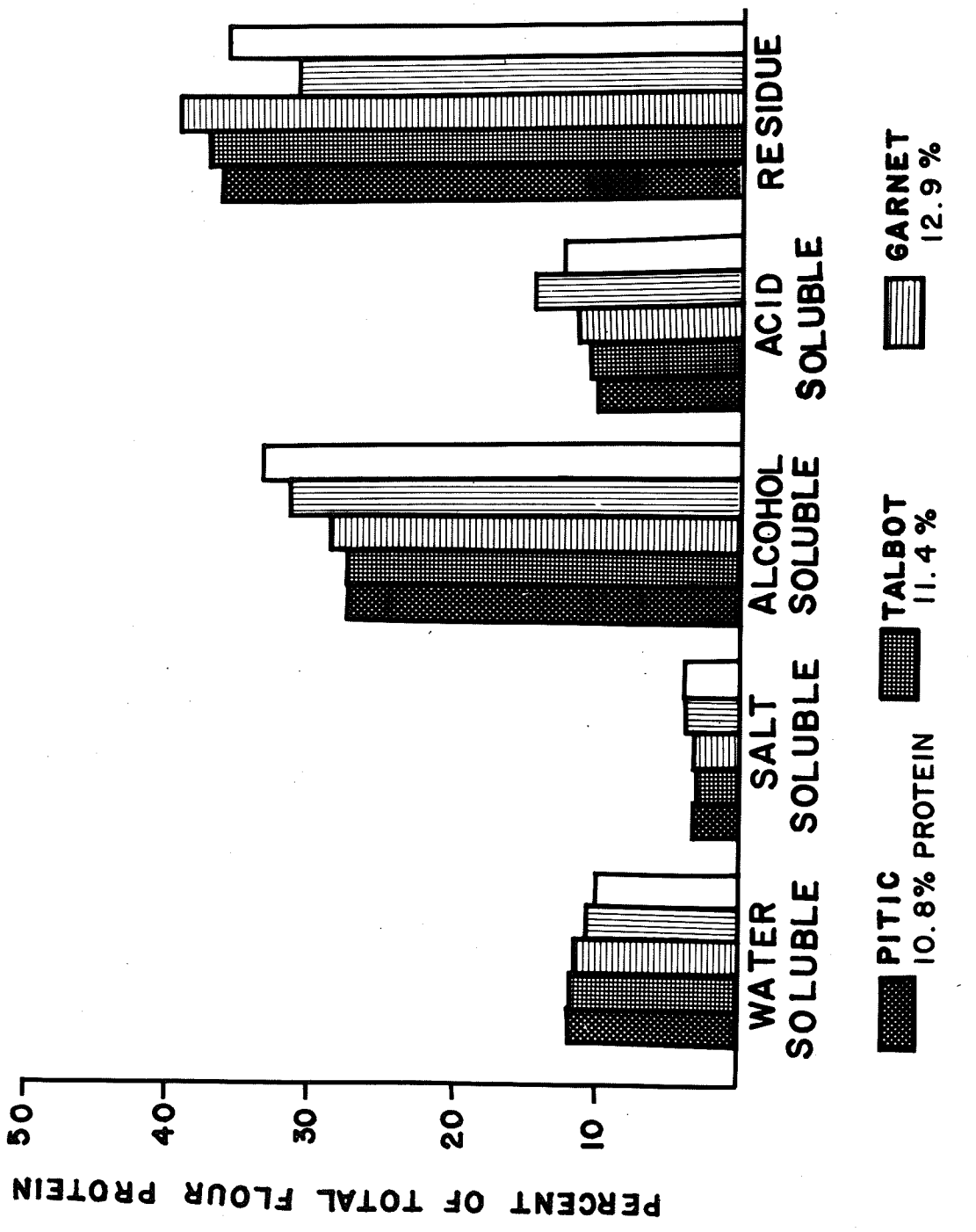

Fig. 27 Distribution of flour proteins in the five solubility fractions for five wheat varieties of similar protein content.

quickly and are more extensible whereas higher quantities of the more insoluble proteins (acetic acid-soluble and residue) would give doughs that are highly elastic and more difficult to develop in the mixer.

There is a slight discrepancy between the results of Figs. 16 and 27. Figure 16 showed that Pitic 62 and Talbot flours contained more gluten protein than the hard wheat flours. The reverse is indicated by the results of Fig. 27 although the differences are not very large. On the basis of experience with the techniques used to obtain the two types of data, the results of Fig. 27 are considered more accurate and dependable. The determination of wet gluten has a relatively high error (about 8%). This error would be magnified in the calculation of the fraction of the flour protein that is in the wet gluten (ordinate of Fig. 17). Further work is required to clarify this discrepancy.

The results of this study showed that the distribution of proteins among various solubility groups are significantly different for widely different wheat varieties. This type of information could be used to distinguish soft wheats from hard wheats. However these differences become much less significant when varieties of the same type of wheat are compared. Accordingly, it is not possible to state conclusively on the basis of the limited data obtained in this study if the quantitative distribution patterns can be correlated with breadmaking quality.

Disc Electrophoretic Results

Water-Soluble Proteins. Figure 28 shows the disc electrophoretic patterns of the water-soluble proteins of the five varieties used in this study. Each variety had two fast moving major bands and three to five

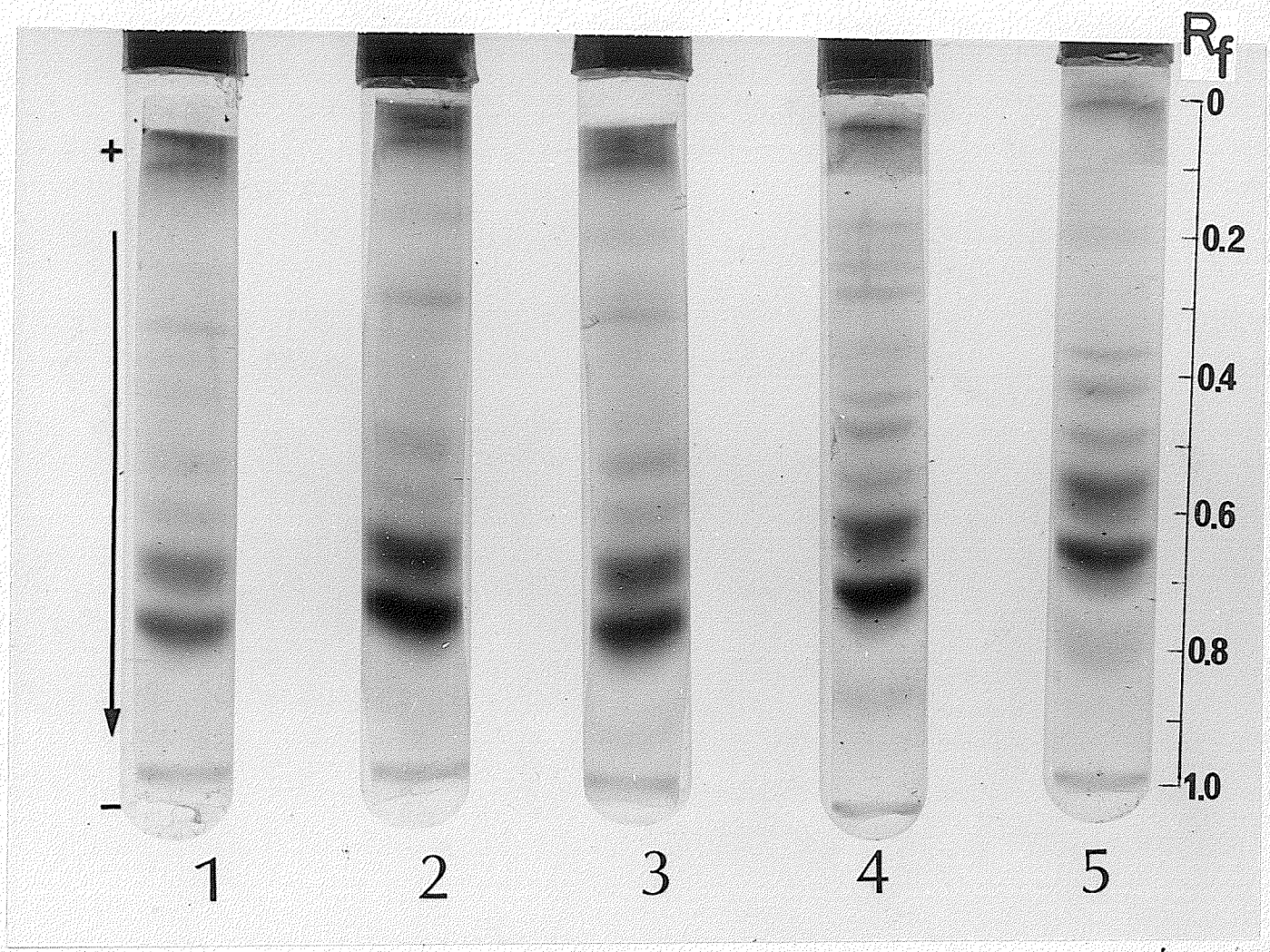

Fig. 28 Disc electrophoretic patterns for the albumins.

1.-Garnet (12.9% Protein)
2.-Pitic 62 (10.8%)
3.-Talbot (11.4%)
4.-Manitou (10.5%)
5.-11-463 A (11.0%)

slower minor bands. Each pattern showed a number of very faint bands of extremely low mobility; these are probably gliadin contaminants. The patterns for the five varieties showed some quantitative differences, especially in the minor bands, but there were no obvious qualitative differences when the patterns were compared carefully using fluorescent underlighting.

Salt-Soluble Proteins. Figure 29 shows the disc electrophoretic patterns for the salt-soluble proteins. These patterns are quite complex, however a close examination showed that they were all quite similar. There were obvious quantitative differences in the patterns of Garnet, Pitic 62 and Talbot. The major band at R_f 0.69 was more distinct in the pattern for Garnet and the doublets at R_f 0.33 and 0.35 were stronger in the pattern for Talbot than in the others. The patterns of Fig. 29 were obtained by two separate experiments. Garnet, Pitic 62 and Talbot were examined separately from Manitou and 11-463A. There is a small discrepancy in mobilities for the two separate experiments.

Alcohol-Soluble Proteins. Figure 30 shows the electrophoretic patterns for alcohol-soluble proteins. Both quantitative and qualitative differences were readily apparent in the patterns for the five varieties. These observations are in general agreement with published results (90, 91).

The major bands of the alcohol-soluble proteins migrate in the R_f range from 0.12 to 0.34. The number of discernible bands in this mobility region was five for Pitic 62, six for Garnet, seven for Talbot and 11-463A, and eight for Manitou. All five patterns had bands with approximate R_f values of 0.13, 0.20, 0.23, and 0.29. The patterns for all varieties except that for Manitou had major bands with R_f values of 0.13 and 0.29.

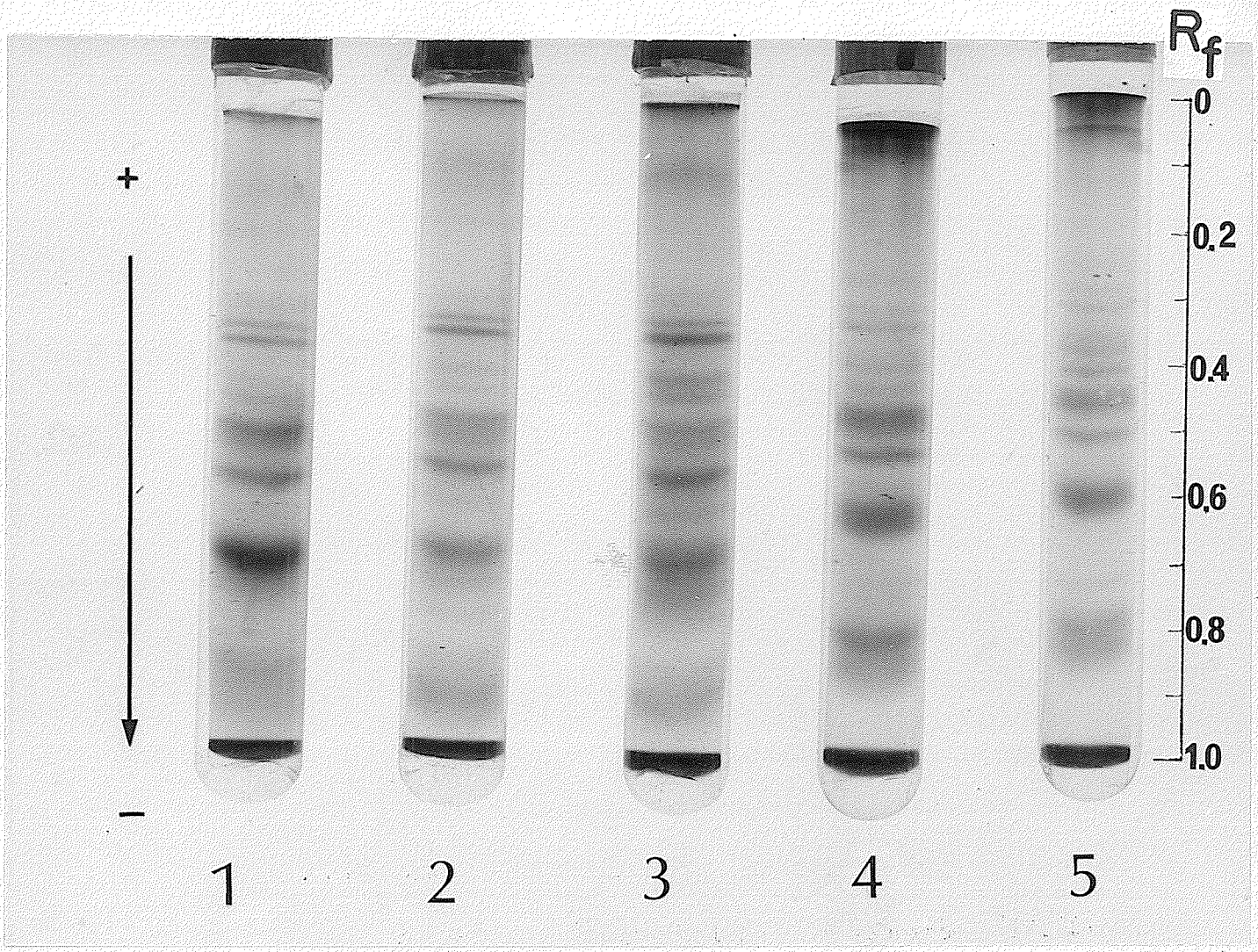

Fig. 29 Disc electrophoretic patterns for the globulins.

1.-Garnet (12.9% Protein)
2.-Pitic 62 (10.8%)
3.-Talbot (11.4%)
4.-Manitou (15.6%)
5.-11-463 A (14.2%)

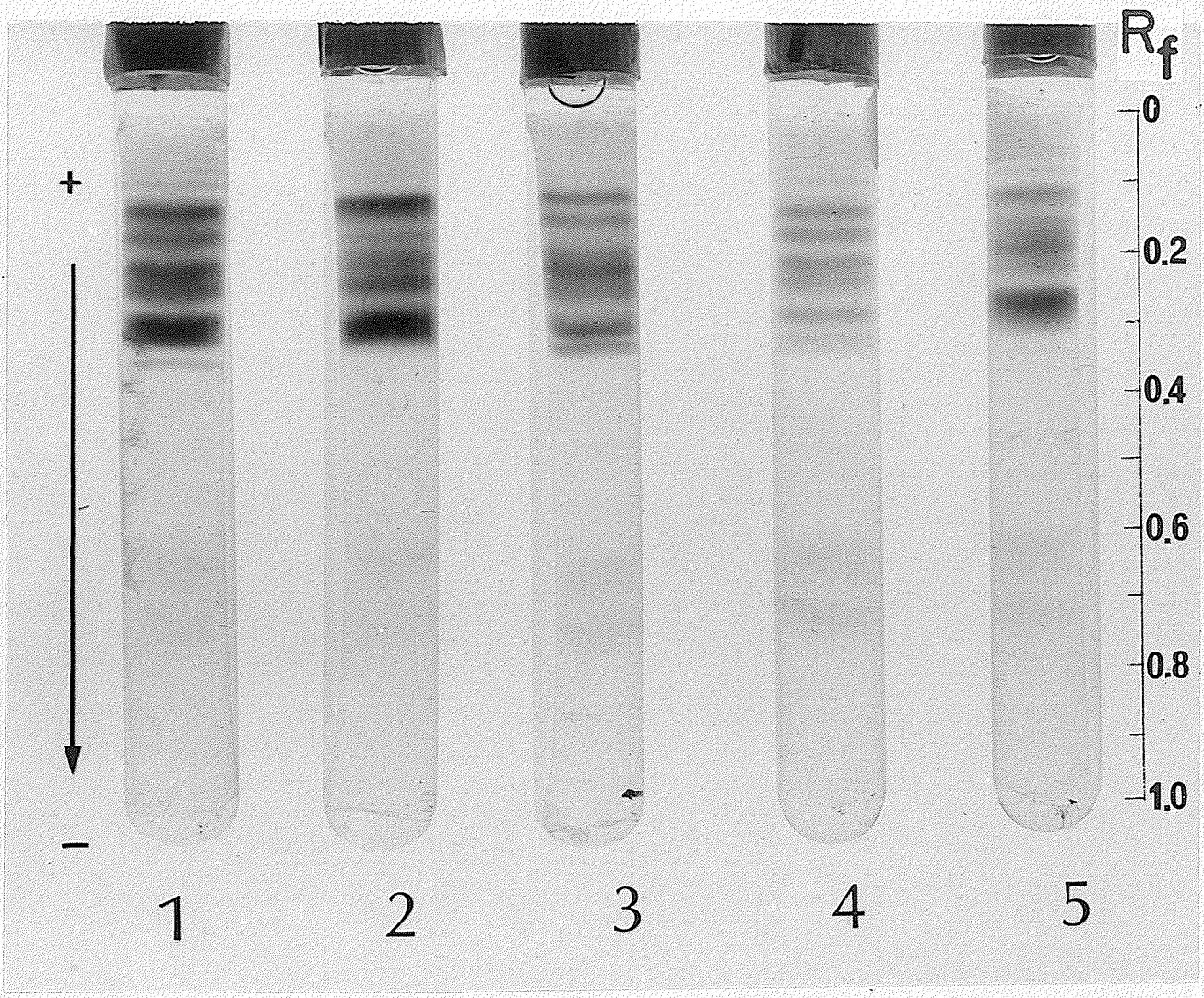

Fig. 30 Disc electrophoretic patterns for the gliadins.

1.-Garnet (12.9% Protein)
2.-Pitic 62 (10.8%)
3.-Talbot (11.4%)
4.-Manitou (10.5%)
5.-11-463 A (11.0%)

These two bands comprised the main components of the alcohol-soluble proteins. They might play an important role in breadmaking performance but this would have to be confirmed by fractionation and reconstitution studies. However since all the patterns had these two bands, varietal differences in breadmaking quality must arise from other bands if qualitative differences in the patterns for this group of proteins are indeed related to baking quality.

Major differences were observed in the higher mobility region. Manitou had two bands with R_f values of 0.30 and 0.32, Talbot had one at R_f of 0.32, and Garnet and 11-463A had one band at R_f of 0.34. Talbot showed no bands with mobility higher than 0.29. Accordingly the fast moving bands might be important in breadmaking quality. For example the pattern for Garent was very similar to that for Pitic 62 except that the former showed an additional band with R_f value of 0.34. Again, this possibility remains to be confirmed.

The total number of bands in alcohol-soluble group might also be related to the breadmaking performance. Manitou, a high quality variety, had eight bands while Talbot, the poorest variety, had only five bands. The pattern for the experimental variety 11-463A, had seven bands, although it is quite possible that the band at R_f of 0.29 might be a doublet.

There were no distinct differences in electrophoretic patterns for hard and soft wheats. The varietal differences observed could not be grouped into similar types.

All patterns showed two faint bands in the very high mobility region. These are considered to be contaminants from the salt-soluble group of proteins.

Results presented above indicate that of all the soluble endosperm proteins that can be studied by gel electrophoresis, only the alcohol-soluble group or the gliadins showed the greatest variability among varieties. However, it does not appear likely that qualitative differences observed for this group are related to differences in breadmaking quality. The final answer to this question can only be obtained from studies of the effects on baking quality of increments of the major components of the alcohol-soluble groups obtained by very careful fractionation and reconstitution experiments.

SUMMARY AND CONTRIBUTIONS TO KNOWLEDGE

1. The effects of the quantity were studied using five samples of different protein content of each of two hard red spring varieties, Manitou, a licenced Canadian variety, 11-463A, an experimental variety related to Pembina.

2. The loaf volumes obtained with the remix baking test increased, approximately linearly, with increasing protein content for both varieties. The slope of the regression line was higher for Manitou and at any protein content over the range examined the loaf volumes for this variety were higher than for 11-463A. Extrapolation of the lines to lower protein content showed that two varieties would give the same loaf volumes at 9.5% protein. The difference in the functional properties of the two varieties is attributed to qualitative differences between their proteins.

3. The loaf volumes obtained with the Chorleywood Bread Process (CBP) baking test increased linearly with protein content for Manitou and were essentially independent of protein content for 11-463A. Loaf volumes by this test were about 20% higher than by the remix test. These results suggest that with some varieties (and perhaps wheat types) protein content is not important in relation to loaf volume obtained by CBP.

4. Both varieties showed a regular change in farinograph curve shape with protein content. By this test 11-463A appeared much stronger than Manitou. With the exception of the samples with the lowest protein for the two varieties, farinograph absorptions increased directly with protein content. In the low protein samples, absorption by starch (damaged starch) appears to be sufficiently high to counteract the effect of protein. The farinograph test is useful for determining the baking absorption of the

flour, otherwise it appears to be of limited value for assessing bread-making quality.

5. The changes in extensigraph curves with protein content did not show any specific trend. Extensigraph areas for 11-463A were much higher than for Manitou. For the ten samples of these two varieties, extensigraph extensibility was directly correlated with loaf volume.

6. Sedimentation values increased approximately linearly with protein content. The data for the two varieties gave a good fit for one regression line.

7. Wet gluten content increased linearly with protein for both varieties. The values for Manitou were somewhat lower than for 11-463A; this difference is considered to be partly responsible for the difference in breadmaking quality between the two varieties.

8. Alpha-amylase activity decreased linearly for Manitou and increased parabolically for 11-463A as protein content increased. Similar results were obtained for beta-amylase activity.

9. The proteins of each flour were fractionated according to solubility into five fractions. The amounts of the three fractions comprising gluten (alcohol-soluble, acetic acid-soluble and residue) increased with flour protein content. The amounts of water- and salt-soluble fractions showed little change with protein content.

10. The protein content of each soluble fraction was considerably less than 100%. Significant, and variable according to fraction, amounts of non-protein materials were extracted by the solvents used.

11. The sum of water-, salt- and alcohol-soluble proteins decreased slightly and the amount of acetic acid-soluble protein increased as flour

protein increased. The amount of residue protein remained essentially constant as flour protein varied.

12. For each variety, flour protein content had no effect on the electrophoretic patterns of the water-, salt-, and alcohol-soluble groups of proteins. No qualitative varietal difference in electrophoretic patterns were observed in the water- and salt-soluble proteins. The patterns for the alcohol-soluble proteins (gliadins) showed obvious qualitative differences.

13. The effect of protein quality on the breadmaking quality of different wheat varieties was studied using five varieties representing three classes of wheat: (1) three varieties of hard red spring wheat, Manitou, 11-463A, and Garnet; (2) one soft spring variety, Pitic 62; and (3) one soft white winter variety, Talbot.

14. High quality wheats such as Manitou show good baking performance only if they contain a sufficient level of protein. Pitic 62 and Talbot gave the same loaf volumes as Manitou of the same protein content. In the CBP baking test, the loaf volumes were much higher than those obtained by the remix baking test for all varieties examined. Pitic 62 and Talbot gave higher volumes by this test than Manitou of the same protein.

15. The differences in farinogram characteristics among varieties (especially between soft and hard wheats) were decreased considerably when flours from different varieties were compared at approximately the same protein content.

16. In the relationship between loaf volume and extensigraph extensibility, Garnet was similar to Manitou whereas Pitic 62 and Talbot were similar to 11-463A. It was not possible to attribute these similarities and

differences to any single specific factor such as protein content. Presumably the roles of different factors in extensigraph properties vary with variety.

17. Garnet, Pitic 62 and Talbot had considerably poorer quality than two hard wheats, Manitou and 11-463A as judged by the Sedimentation Test.

18. Wet gluten contents for Pitic 62, Talbot and 11-463A were somewhat higher than for Manitou at equivalent protein content. The glutens from 11-463A, Pitic 62 and Talbot contained a somewhat higher percentage of the flour proteins than did the glutens from Manitou flours. Garnet flour, on the other hand, had the lowest wet gluten content and contained a much lower percentage of the flour protein in the gluten. The peculiar bread-making quality of the variety Garnet might be related to this factor.

19. Amylase activity and related properties of flour are to a certain extent varietal characteristics as indicated by the results of this study.

20. Total recoveries of the solids in the five fractions were somewhat lower for the two soft wheats, Pitic 62 and Talbot, than the recoveries obtained for the hard wheats. Presumably the soft wheats contain greater quantities of low molecular weight substances which are lost during the dialysis used to separate the water-solubles from the salt-solubles.

21. Significant differences in protein content of the various solubility fractions were obtained for hard and soft wheats; these might be related to differences in breadmaking quality.

22. The flours from soft wheats (Pitic 62 and Talbot) contained more water-soluble and less alcohol- and acetic acid-soluble proteins than Manitou and 11-463A. Garnet was intermediate in this respect between the soft wheats and other hard wheats. All varieties had similar proportions of salt-soluble proteins.

23. The disc electrophoretic patterns for the water- and salt-soluble proteins of the five varieties were qualitatively similar but showed some quantitative differences.

24. Disc electrophoretic patterns for the alcohol-soluble proteins showed both quantitative and qualitative differences for the five varieties. The patterns for all varieties except that for Manitou had major bands with R_f values of 0.13 and 0.29. The band at R_f of 0.34 might be related to varietal differences in breadmaking quality; for example the pattern for Garnet was very similar to that for Pitic 62 except that the former which was somewhat better in baking performance showed an additional band with R_f value of 0.34.

25. The total number of bands in alcohol-soluble group might also be related to the breadmaking performance. Manitou, a high quality variety had eight bands while Talbot, the poorest variety, had only five bands.

26. There were no distinct differences in electrophoretic patterns for hard and soft wheats. The varietal differences could not be grouped into similar types.

27. The present study has shown that protein quantity is the major single factor that controls breadmaking quality of bread flour. This probably applies to flours of the same wheat variety, varieties of the same class or type, and varieties of different classes. With some wheat types, (e.g. 11-463A) and breadmaking processes (CBP), the protein content plays a minor role in breadmaking performance.

28. The major differences among the proteins that were observed that might be related to functional properties of the flour are quantitative differences in the distribution of proteins among different solubility groups. For

similar varieties these differences were quite small. Solubility distribution of proteins might be useful for differentiating widely different varieties but would be of limited value for differentiating similar varieties.

29. In the three groups of proteins that could be examined by disc electrophoresis, discernible qualitative differences were observed in the alcohol-soluble group. Although these differences do not appear to be related to differences in breadmaking quality, they are obviously varietal characteristics and should be useful in studies of inheritance of proteins in wheat varieties.

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A P P E N D I X

Table 1

FARINOGRAPH AND EXTENSIGRAPH DATA

Sample	Flour Protein	Farinogram			Extensigram			
		Absorption	Development Time	Stability	Absorption	Extensibility	Height	Area
	%	%	min.	min.	%	cm.	B.U.	cm^2
MANITOU	10.5	65.8	1.25	2.0	61.8	14.9	437.5	98
	11.2	65.4	2.25	2.75	61.4	15.8	477.5	116.5
	12.5	66.0	3.0	7.25	62.0	15.8	445	111
	14.0	66.9	6.5	14.0	62.9	19.3	370	120
	15.6	69.2	7.0	12.5	65.2	20.6	335	123.5
11-463A	11.0	62.1	1.5	8.0	58.1	18.8	547.5	209.5
	11.4	60.8	2.0	7.0	56.8	18.9	782.5	225.5
	11.8	62.0	2.25	12.0	58.0	18.4	580	186.5
	12.7	62.5	9.0	16.0	58.5	19.5	580	209.5
	14.2	64.3	9.0	16.0	60.3	20.3	617.5	232
GARNET	12.9	64.3	5.5	7.5	60.3	18.5	385	123
PITIC 62	10.8	57.7	2.5	2.0	53.7	21.0	130	45
TALBOT	11.4	55.2	2.5	2.5	51.2	21.3	242.5	86

Table 2 RESULTS OF BAKING TESTS

Sample	Flour Protein	Remix		Chorleywood		
		Absorption	Loaf Volume	Absorption	Work Input	Loaf Volume
	%	%	c.c.	%	WH/lb/min.	c.c.
MANITOU	10.5	61.8	585	63.0	14.0/20.3	710
	11.2	61.4	660	64.0	7.5/11.3	715
	12.5	62.0	790	65.0	10.0/ 9.8	830
	14.0	62.9	860	65.0	7.5/ 6.8	940
	15.6	65.2	895	66.0	7.5/ 4.8	1020
11-463 A	11.0	58.1	573	62.0	16.0/19.8	840
	11.4	56.8	558	61.0	16.0/18.7	805
	11.8	58.0	568	62.0	18.0/24.0	895
	12.7	58.5	583	62.0	9.5/11.6	850
	14.2	60.3	688	64.0	14.0/15.5	900
GARNET	12.9	60.3	790	65.0	6.0/ 7.0	835
PITIC 62	10.8	53.7	605	59.0	4.0/ 3.0	800
TALBOT	11.4	51.2	638	56.0	5.0/ 3.8	865

Table 3

RESULTS OF TECHNOLOGICAL TESTS ON FLOURS

Sample	Flour Protein	Sedimentation Value	Starch Damage	Amylogram	α-Amylase Activity	Falling Number	Gassing Power	Diastatic Activity
	%	c.c.	Farrand Unit	B.U.		sec.	m.m.	mg.
MANITOU	10.5	39	24	680	0.49	513.2	410	263
	11.2	43	23	760	0.58	620.0	370	251
	12.5	51.5	22	730	0.51	622.9	360	244
	14.0	60.5	19	775	0.48	660.7	345	218
	15.6	66	17	770	0.41	677.7	310	193
11-463 A	11.0	45	21	630	0.31	520.1	385	234
	11.4	46	20	485	0.71	498.2	435	247
	11.8	43.5	21	480	0.58	450.8	465	257
	12.7	46.5	19	360	0.91	446.6	480	253
	14.2	61	20	370	1.10	429.3	485	264
GARNET	12.9	36.0	32	>1000	0.59	464.0	420	252
PITIC 62	10.8	33.5	3	860	0.56	391.0	220	82
TALBOT	11.4	36.0	4	305	0.76	285.0	285	122

Table 4

GLUTEN CONTENT AND RELATED DATA

Sample	Flour Protein (14% M.B.)	Flour Protein (Dry Basis)	Wet Gluten Yield	Wet Gluten Moisture Content	Gluten Yield (Dry Basis)	Gluten Protein Content (Dry Basis)	Dry Gluten from 10g flour	Total Protein in Dry Gluten	Gluten Protein / Flour Protein
	%	%	%	%	%	%	g.	g.	%
MANITOU	10.5	12.2	29.7	67.3	11.3	79.2	0.98	0.78	74.3
	11.2	13.0	33.5	67.0	12.9	75.8	1.11	0.84	75.0
	12.5	14.5	37.0	65.3	14.9	76.2	1.29	0.98	78.4
	14.0	16.3	46.0	68.3	17.0	73.8	1.46	1.08	77.1
	15.6	18.1	51.0	67.7	19.2	75.2	1.65	1.25	80.1
11-463 A	11.0	12.8	34.0	66.4	13.3	73.5	1.15	0.84	76.4
	11.4	13.3	35.5	65.2	14.4	71.7	1.24	0.89	78.1
	11.8	13.7	37.2	65.9	14.8	72.0	1.27	0.91	77.1
	12.7	14.8	38.6	65.8	15.4	75.5	1.32	1.00	78.7
	14.2	16.5	46.9	65.1	19.0	70.5	1.64	1.15	81.0
GARNET	12.9	15.0	38.8	68.0	14.4	77.3	1.24	0.96	74.4
PITIC 62	10.8	12.6	37.0	70.3	12.8	75.1	1.10	0.83	76.9
TALBOT	11.4	13.3	37.7	69.0	13.6	77.3	1.17	0.90	78.9

Table 5 DISTRIBUTION OF THE DRY MATTERS FROM FLOURS AMONG FIVE SOLUBILITY GROUPS

Sample	Protein Content	Water Soluble	Salt Soluble	Ethanol Soluble	Acetic Acid Soluble	Residue	Recovery
	%	%	%	%	%	%	%
MANITOU	10.5	2.9	0.6	5.0	2.4	88.2	99.1
	11.2	2.9	0.7	5.3	2.5	87.4	98.8
	12.5	2.7	0.9	5.9	2.9	84.9	97.3
	14.0	3.2	0.7	6.4	3.0	84.2	97.5
	15.6	3.0	0.9	6.6	3.8	85.0	98.8
11-463 A	11.0	2.6	0.8	5.3	2.1	87.5	98.3
	11.4	2.5	0.8	5.5	2.0	87.5	98.3
	11.8	2.8	0.9	5.5	2.5	87.0	98.7
	12.7	2.7	0.9	6.1	2.6	86.9	99.2
	14.2	2.9	0.8	6.5	3.1	84.8	98.1
GARNET	12.9	2.9	0.6	5.7	2.2	85.6	97.0
PITIC 62	10.8	2.5	0.6	4.8	1.7	88.0	97.6
TALBOT	11.4	2.6	0.6	5.2	1.9	86.4	96.7

Table 6 DISTRIBUTION OF FLOUR PROTEINS AMONG FIVE SOLUBILITY GROUPS

Sample	Flour Protein	Water-Soluble			Salt-Soluble		
		Protein Content	Protein Yield	Recovery	Protein Content	Protein Yield	Recovery
	%	%	mg.	%	%	mg.	%
MANITOU	10.5	52.5	154.2	12.6	62.6	37.7	3.1
	11.2	52.8	152.0	11.7	67.0	45.0	3.5
	12.5	52.6	156.4	10.8	64.6	56.3	3.9
	14.0	55.4	177.3	10.9	67.0	47.4	2.9
	15.6	57.2	172.0	9.5	71.3	65.1	3.6
11-463 A	11.0	55.1	148.7	11.6	64.3	50.9	4.0
	11.4	55.8	138.9	10.4	62.5	50.5	3.8
	11.8	50.4	139.7	10.2	61.6	54.5	4.0
	12.7	54.8	149.6	10.5	67.9	63.4	4.3
	14.2	60.0	175.7	10.7	69.8	57.3	3.5
GARNET	12.9	59.9	170.8	11.4	75.1	48.5	3.2
PITIC 62	10.8	59.7	150.4	12.0	68.5	41.8	3.3
TALBOT	11.4	59.5	155.2	11.7	69.1	40.7	3.1

Table 6 (continued)

Sample	Flour Protein	Ethanol-Soluble Protein Content	Ethanol-Soluble Protein Yield	Ethanol-Soluble Recovery	Acetic Acid-Soluble Protein Content	Acetic Acid-Soluble Protein Yield	Acetic Acid-Soluble Recovery	Residue Protein Content	Residue Protein Yield	Residue Recovery	Protein Content	Protein Recovery
	%	%	mg.	%	%	mg.	%	%	mg.	%	mg.	%
MANITOU	10.5	82.3	409.1	33.5	61.5	150.0	12.3	4.6	404.4	33.2	1220	94.7
	11.2	86.9	458.6	35.3	62.1	152.8	11.8	5.1	442.7	34.1	1300	96.4
	12.5	77.6	456.8	31.5	72.5	210.9	14.6	5.3	451.8	31.2	1450	92.0
	14.0	92.1	588.5	36.1	73.8	217.7	13.4	6.2	520.9	35.9	1630	99.2
	15.6	81.1	537.2	29.7	76.4	291.7	16.1	6.9	588.3	32.5	1810	91.4
11-463 A	11.0	79.5	419.3	32.8	63.2	133.9	10.5	5.1	443.9	34.7	1280	93.6
	11.4	84.8	464.1	34.9	66.7	133.2	10.0	5.4	470.0	35.3	1330	94.4
	11.8	83.1	458.8	33.5	69.4	172.9	12.6	5.7	496.1	36.2	1370	96.5
	12.7	80.8	495.6	33.5	67.5	177.0	12.0	6.2	535.2	36.2	1480	96.5
	14.2	80.1	521.0	31.6	71.6	220.0	13.3	6.5	547.5	33.2	1650	92.3
GARNET	12.9	74.4	427.4	28.5	76.8	171.7	11.5	6.8	594.8	39.7	1500	94.3
PITIC 62	10.8	72.5	346.3	27.6	73.8	126.4	10.1	5.1	457.8	36.5	1260	90.7
TALBOT	11.4	70.1	366.6	27.7	76.0	142.1	10.7	5.6	500.5	37.7	1330	90.9