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Comparison of Canadian and American Wheat Cultivars

by

John Gerry Waterer

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COMPARISON OF CANADIAN AND AMERICAN WHEAT CULTIVARS

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ABSTRACT

Waterer, John Gerry.M.Sc.,The University of Manitoba, July 25, 1984. A Comparison of Canadian and American Wheat Cultivars. Major Professor; Dr.L.E.Evans.

Exchange of cultivars and commercial trade of Wheat between Canada and The United States is severly restricted because of perceived differences between cultivars, yet we compete for the same sales on the international market.

The American cultivars; Chris, Waldron, Butte, Coteau and Alex were grown with the Canadian cultivars;Manitou, Neepawa, Glenlea, Benito and Columbus in a RCBD experiment at six locations in 1982, and 1983. A complete yield and protein analysis was carried out for all station years and milling and baking analysis were conducted for specific location composites according to AACC guidelines.

The combined yield and protein analysis divides the cultivars into three groups. Glenlea, Butte and Alex are all high yielding, medium to low protein cultivars. Coteau,

Benito and Columbus are medium yielding cultivars with high protein percentages. Neepawa, Manitou, Waldron and Chris are low yielding cultivars with medium to high protein content.

The milling and baking trials conducted under AACC specifications also divide the cultivars into specific quality groups. The poor response of Glenlea to conventional mixing and baking techniques removes it from serious consideration in this trial.

The high flour yield of Alex and the exceptional flour yield of Butte indicate that these cultivars have excellent milling characteristics. The high protein quality indicated by high sedimentation values,high BSI percentages and large loaves indicate that these cultivars also have excellent baking potential.

If any of the American cultivars are to be seriously considered for production in Manitoba, Coteau could likely meet or exceed the yield and protein content of the top Canadian cultivars. The milling quality of Coteau is very high and the acceptable protein quality, indicated by sedimentation values and BSI percentages combine to give Coteau top baking potential.

The loaf volume of Chris was the largest in the test. It combines one of the highest protein percentages with high protein quality to give excellent baking potential. Waldron also has excellent baking quality indicated by a high loaf volume. Both Chris and Waldron have excellent quality that is comparable with the best Canadian cultivars, but their low yields prohibit any serious consideration.

The remaining Canadian cultivars were included as chronological comparisons. Both Neepawa and Manitou had poor milling and baking results and should be replaced by the newer Canadian cultivars.

Benito and Columbus are the two newest Canadian cultivars in this trial and had the best yield and quality characteristics among the Canadian cultivars.

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Chapter I

INTRODUCTION

Canadian Red Spring Wheat has excellent "all-around" quality that makes it suitable for a wide range of end products.

Because of the high quality of licenced cultivars such as Neepawa, and of the protein segregation system Canada Western Red spring (C.W.R.S.) fills requirements for both strong and medium strength types at several protein levels.

From C.W.R.S. production comes the #1 C.W. 13.5% destined for Japan and the United Kingdom, the #3 C.W. favored by China, and other grades and protein levels in between that can meet many other market requirements either singularly or in blends.

While the yields of spring wheat grown under dryland conditions where moisture is generally limiting cannot match the yields of winter wheat or wheat grown under irrigation, yield figures for C.W.R.S. have been steadily increasing. Compared with the United States spring wheat area, where there is neither visual distinguishability nor statutory quality requirements, Canadian cultivars have tried to keep pace while still maintaining an apparent quality advantage.

There appears to be only one major quality factor that puts a constraint on increased yield that being grain protein content. During the 1960's the overall average protein content was 14.0%. By contrast protein content in the 1970's dropped to 13.2% below the 13.5% guaranteed to Japan and the United Kingdom. To date the Expert Comittee on Grain Quality has opposed the licencing of new cultivars of low protein content, even though, a yield increase of 10-15% might be achieved by licencing cultivars one percent lower in protein than that of current licenced cultivars.

If the average protein content of C.W.R.S. drops by half of one percent, i.e., from 13.5 to 13.0, this will cut in half the amount of #1 C.W. 13.5 available for export (Pound 1981). This is a situation which we must prevent because such a large portion of income is generated through these premium shipments.

Exchange of cultivars and commercial trade of wheat between Canada and the United States is severely restricted because of perceived differences between cultivars grown on either side of the border, yet we compete for the same sales on the international market.

In the past several years North Dakota plant breeders have been releasing new H.R.S.W. cultivars at the rate of one per year. Each new release is presumably an improvement over the previous release. Unfortunately none of these cultivars are eligible for release in Canada due to visual indistinguishability or the statutory quality stipulations. There is no doubt, however, that American wheat cultivars have improved significantly over the past few years and the realization must be acknowledged that we have competition in the high protein, high quality export market. In the past ten years only two new Canadian wheat releases have occupied a significant acreage in Manitoba. The first being Benito and, the second being Columbus the sprouting resistant boone to our wet falls. Columbus does yield slightly higher than Benito, but some agronomic problems have been identified. The apparent high productivity of the American cultivars would indicate that they are continually making gains with each new release. The question that immediately comes to mind is; where do these American cultivars stand in comparison to our Canadian cultivars. Are the American cultivars;

Still inferior to our cultivars,

Approaching equality with each new release,

or possibly superior to our Canadian cultivars?

Preliminary data received on the American cultivars indicate that the majority of them have lower protein contents and inferior baking characteristics. The relatively poor performance of our Canadian cultivars in American trials suggests that we cannot compare experimental data from the

United States with our locally generated data. It appears their plot techniques and especially their quality assessments, not to mention the climate, differ sufficiently to make comparisons invalid.

The purpose of this study is to compare Canadian H.R.S.W. cultivars with their American counterparts, and to determine whether climate, location, and fertility do not contribute more to the differences in the end product than the genotype of the cultivars.

To achieve this end the experiment included a comparison of five American H.R.S.W. cultivars, and five Canadian H.R.S.W. cultivars. The five American cultivars include; Chris, a product of Minnesota, Waldron, Butte, Coteau, and Alex all products of North Dakota. The five Canadian cultivars are Glenlea, Neepawa, Manitou, Benito, and Columbus.

In 1982 and 1983 ten entry experiments were planted at Winnipeg, Glenlea, Portage la Prairie, Teulon, Waskada and Dauphin. In addition to yield assessment recognized tests to measure milling and baking quality were conducted on samples each year.

Chapter II

LITERATURE REVIEW

2.1 THE CULTIVARS

The ten cultivars tested were released over a fifteen year span.They are characterised by having wide adaptation and yield stability across environments. Everchanging rust strains, combined with changing yield and quality demands, have and will dictate the success and longevity of these cultivars.

Both Manitou and Chris were released in 1965. The major advantage of each was its resistance to prevalent rust strains (Heiner and Johnston 1967, Campbell et al. 1967). The similarity of their pedigrees indicates that the relative success of these cultivars was due primarily to excellent rust resistance. The yield of Chris was greater than its predecessors in the United States and Manitou was an improvement over Selkirk and Pembina in Manitoba. When compared directly by the Crop Quality Council the major difference was the weak straw characteristic of Chris that caused serious lodging problems. Their similar rust resistance, yield and quality characteristics make these cultivars virtually interchangeable. Manitou was the last

Canadian cultivar to be grown extensively in the United States. No further high protein cultivars were released from Minnesota after 1965.

With the release of Waldron in 1969 North Dakota began the production of high quality cultivars. Waldron was 2 to 3 days earlier than Chris, had exceptionally strong straw, good resistance to leaf rust and a wider range of resistance to stem rust than other current cultivars. Its protein content and baking quality were also regarded as better than that of Chris or Manitou, the baking standards at the time (Smith et al. 1969). Neepawa was licenced in the same year as Waldron and was found to be earlier ,higher yielding, more resistant to lodging and larger seeded than Manitou (Campbell 1970).

With the rust problem largely under control greater breeder emphasis on agronomic improvements was evident in Waldron and Neepawa. Both cultivars possessed higher yields, higher grain protein content, and stronger straw than their predecessors (Campbell 1970, Smith et al. 1969). Some tests faulted Waldron to a minor degree for poor water absorption and flour color, but these were found to be within acceptable limits (Smith et al. 1969). Despite the agronomic similarity of these two cultivars their differing quality characteristics reduces the competition between them.

Glenlea was licensed in 1972,as the first Canadian bred utility wheat . It is higher yielding than the other wheat cultivars reccomended in Manitoba and is well adapted to the moister areas of the Prairie Provinces (Evans et.al 1972). With a yield advantage of about 20% Glenlea replaced a significant acerage of bread wheat. Eventhough Glenlea was intended to be a utility wheat, milling and baking trials were carried out and despite it's low protein percentage it proved to have some baking potential and an extremely strong dough. Its potential as a bread wheat has been a point of serious debate ever since.

In the late 1970's the North Dakota breeders began releasing new cultivars almost yearly; presumably each new release was an improvement over the previous. Butte released in 1977 immediately took over a large percentage of the acreage in North Dakota (Crop Quality Council report 1981). In North Dakota field trials from 1973 through 1976 Butte was earlier,had a higher test weight and yielded more than either Chris or Waldron. In percent vitreous kernels and wheat and flour protein content, it is lower than Chris or Waldron. The baking properties of Butte including the loaf volume were also inferior to these cultivars (Frohberg et al. 1977). From this release it would appear that the North Dakota breeders had produced a utility type cultivar but not a new class as was the case with Glenlea. This increase in yield coincided with a drastic decrease in protein content that put Butte in a distinctly lower protein category than the Canadian bread wheats. In 1978 North Dakota State University released Coteau which is similar in height and lodging resistance to Waldron but superior in leaf rust reaction and test weight. Coteau also generally outyields Waldron. The average protein content for Coteau in 1977 was 15.3%compared to 14.7% for Waldron and 14.3% for Butte. The protein quality was also found to be acceptable for baking purposes (Feight 1978). This abrupt change in quality from Waldron to Butte to Coteau seemed to indicate a dissatisfaction with the quality of Butte, and a return of competition for Canadian Hard Red Spring Wheats (C.H.R.S.W.) in the international market.

The cultivar Benito was licenced in Canada in 1979. Its outstanding attributes are early maturity in the eastern Praries and leaf rust resistance. It is adapted to the rust area of Manitoba and eastern Saskatchewan, and particularly (because of its early maturity) to the northern half of this area (Campbell and Czarnecki 1980). Benito showed no significant differences in quality or yield that would improve our competitive situation with the American cultivars. The comparison between Coteau and Benito is obvious, both are medium yielding , high quality wheats with excellent agronomic characteristics.

In 1980 both Canada and North Dakota released new hard red spring wheats. North Dakota released Alex, which was expected to yield slightly better than Butte and maintain a protein level between Coteau and Butte. Alex also had a test weight slightly below Butte (Feight 1980). The medium protein content of Alex again suggests a reversal in the quality plans of North Dakota. The target of their breeding appears to be high yielding medium quality cultivars. It would seem that they are not as concerned with which market they produce the wheat for as they are about absolute yield. Alex would again likely not compete for the high quality sales to Japan and The United Kingdom. Like Benito the Canadian release of Columbus in 1982 was more a response to the need for sprouting resistance than a breakthrough in quality or yield. Although Columbus does exhibit a small yield advantage over Benito its major attribute is its sprouting resistance,an extremely valuable characteristic during a wet harvest (Campbell and Czarnecki 1980). Columbus maintains the baking quality achieved by Neepawa through high protein content, but a few agronomic problems have been identified, namely problems with achieving even stands due to poor seed germination and the presence of volunteer plants in subsequent crops (Woodbury personal communication 1984). The above review has hopefully illustrated the background sufficiently to justify the indepth comparisons carried out. The remainder of this review will be concerned with the specific comparisons.

The portions of the Prarie Provinces that have the highest annual rainfall coupled with low evapotranspiration, such as much of southern Manitoba usually obtain the highest average wheat yields and lowest protein percentages. (Partridge and Shaykewich 1972).

Percent grain protein and yield have been found to be significantly affected by the availability of soil nutrients, mainly nitrogen, as well as temperature, moisture and other environmental factors (Partridge and Shaykewich 1972).

Schlehuber and Tucker (1959) have suggested that the major factors responsible for variation in grain protein content in order of importance are: environment, soil nitrogen, and the genotype. In the current experiment the genotype is the only variable, therefore it is likely that the differences in protein percentage within a cultivar over years and locations,will be larger than the differences between genotypes within a given year.

Although grain protein content has been used as a measure of baking quality since the turn of the century it was only in 1935 that crude protein content was accepted as a measure and definition of flour strength (Blish and Sandstedt 1935).

The fact that percent protein is a major contributing factor to baking quality and that leavened bread is the major end use of these cultivars it is therefore justifiable that this review concentrate on their protein content (baking potential) and yielding ability.

For any one of the tested cultivars to establish its superiority it must have the desirable balance of yield and quality that makes it stand out across years and environments. The superior genotypes must combine the resources at hand through more efficicent physiologies to better exploit the environment. Grafius (1964) suggested that since the development of component traits is separated in space and time, it is possible that they are controlled by different genetic systems. The expression of these yield and quality components in the cultivars studied could possibly give some idea as to the exact morphology required to produce the ideal bread wheat for Manitoba.

The yield components having the greatest influence on individual plant yield, in decreasing order of importance are; spikes /plant, kernels / spike and kernel weight. This sequence attests to the fact that characters developed early in the ontogeny of the plant are more important in determining yield than characters developed late in the plants life cycle (Kibite 1980). It is obvious that each yield component would be significantly correlated with yield. Adams (1967) explained that yield components are genetically independent characters, and further explained that yield component compensation occurs when two developing structures of a plant compete for a common nutrient supply. According to this theory one would expect significant negative correlations to occur among the individual yield components when supplied with limited resources. Conversely yield components may compensate one another when more resources become available (Kibite 1980). This competition and compensation of components makes it difficult to identify, which component is responsible for a genotypes superior performance.

Protein content has also been shown to be under multigenic control with genes on as many as nineteen chromosomes known to control protein content in wheat (Lelley 1976). Environmental factors are also known to affect grain protein content in wheat. Abundant rainfall during the period of kernel filling usually results in low protein content, whereas dry conditions during that period favor high protein content (Sunderman et al. 1965). Increased temperatures within the range of 15-25°C were shown to reduce grain yield and protein content due to decreased rates of carbohydrate accumulation,and nitrogen mineralization,immobilization or loss at high temperatures (Partridge and Shaykewich 1972). They went on to point out from climatic data for Manitoba that temperatures during the growing season can vary sufficiently from year to year to exert a significant influence on grain yield and protein content. Most of the effect of temperature on percent protein is indirect through the influence of temperature on grain yield (Partridge and Shaykewich 1972).

If a potentially low protein content cultivar has the carbohydrate supply restricted and if the protein supply is largely from senescing leaves as suggested by Johnson et al. (1968) then its yield may be reduced but the amount of protein would be constant resulting in a higher protein percentage. Brunori et al. (1977) concluded that a higher percent grain protein was due to a longer period of protein synthesis, rather than higher accumulation rates. If this is the case and extreme temperatures slow protein synthesis as pointed out by Partridge and Shaykewich (1972) then both yield and protein production should be reduced.

The tendency for high yielding lines to express low protein content has attracted the attention of many researchers. In general the attention has centered on nitrogen uptake from the soil, superior nitrate reductase systems, remobilization of amino acids and protein from the leaves to the developing grain, and the source sink relationships within the plant (Kibite 1980). The major problem with obtaining a cultivar that has high yield and high protein content seems to be the highly controversial negative correlation between these two characteristics.

Hutcheon and Paul (1966) found that the percent protein content could be increased along with yield as long as the protein content was below 16 percent. For the 16 percent barrier to be broken the plant had to be stressed, so the potential yield could not be expressed, thereby increasing the relative protein percentage.

In an extensive literature review Kibite (1980) found that grain protein content is positively correlated with loaf volume, and bread and grain texture. In addition wheat proteins are known to largely govern the flour water absorption, oxidation requirement and fermentation tolerance(Kent 1983). Bushuk et al. (1969) found that in grain with protein of the same quality, an increase in protein content resulted in flour with better baking characteristics.

Protein content is recognised as being a reliable indicator of baking strength when the wheats under consideration are of the same class, and when protein content is the only major variable, it is a reliable index of loaf volume (Blish and Sandstedt 1935). There is a general unwillingness to accept protein content as a trustworthy index to strength when cultivars of different classes are under consideration. Variations in gluten quality are alleged to be overshadowed by inherent differences in quantity (Blish and Sandstedt 1935).

It is obvious that supplementary milling and baking tests must be carried out to properly characterise the proteins in similar cultivars grown under a range of conditions.

Different wheat flours vary widely in their capacity to form a dough that will expand by trapping gas produced during fermentation (Marais and D'appolonia 1981). Several factors complicate the understanding of the differences, namely the large number of components, high molecular weights, limited solubility and the difficulty of separating or isolating pure components without altering them, and the interaction of components during dough mixing, fermentation, and baking. (Marais and D'appolonia 1981). Some researchers contend that protein content and strength are one and the same regardless of cultivar or of inherent differences in gluten properties. They had in no single instance found a sample or cultivar that failed to measure up in terms of volume and texture, to the potential that could be predicted from protein content alone, when provided with a suitable baking environment. (Blish and Sandstedt 1935). The purpose of the baking tests was to determine the particular characteristics of the flours and the treatments, lack of treatments or combination of treatments necessary to render it suitable for the Canadian wheat industry. As similar as Canadian and American testing methods are, some critical differences exist. The American cultivars were selected using the American Association of Cereal Chemists (A.A.C.C.) straight dough method, whereas the Canadian cultivars were reccommended using the remix test. All of the baking tests done were of the remix type which could discriminate against the American cultivars. The vigorous

2.5 minute remix test is designed to accentuate the strength of our Western Canadian wheats (Tipples and Kilborn 1974). A weak flour could be considerably overmixed at 2.5 minutes and give a deceptively poor loaf volume not necessarily representative of its potential.

The Baking Strength Index (B.S.I.) is a protein quality measure that expresses loaf volume by the remix baking method as a percent of the volume normally expected for Canadian Western Red Spring Wheat flour of the same protein content. Under Canada's new protein segregation grading system protein quality assumes more significance as previously overall baking quality was affected by both protein quantity and quality. (Tipples and Kilborn 1974). With the protein quantities of these cultivars being so different, a quality parameter is useful in explaining differences in baking performance not attributable to protein quantity.

The remix blend and blend B.S.I. should also help to segregate the cultivars. Stronger flours result in greater loaf volumes in the remix blend method showing greater carrying powers. (Baker et al. 1971.Tipples and Kilborn 1974). This extra strength may be a great asset when the end use involves blending with weaker wheat, as is often practiced by importing countries.

While mixing times and loaf volumes are generally positively related, exceptions occur, since the best loaf volumes are generally obtained from the intermediate mixing flour doughs, too strong a dough, as well as too weak a dough results in reduced loaf volume (Huebner 1977).

The protein fraction most commonly mentioned is the gluten fraction. The differences in the gluten fractions contribute to the large differences in the mixing and baking characteristics of these cultivars. Gluten proteins are generally defined as the proteins left in the gluten ball after the starch and water soluables have been washed out (Huebner 1977). Orth and Bushuk (1973),indicated that the glutenin fraction and residue proteins contain the ingredients controlling loaf volume. Huebner (1977) pointed out that the percentages of each protein fraction can be different among different cultivars. Long mixing, strong flours have high quantities of high molecular weight (M.W.) gluten, while weak flours have less of this fraction. Strong correlations were also found between mixing and bread making quality of wheat flours and the quantity and quality of gliadin in the flour (Huebner 1977). With each protein fraction interacting and modifying the properties of the other proteins, a suitable mixture of the gliadins, glutenins and residue proteins are essential for good dough performance and loaf volume.

Flour protein was shown to have a highly significant correlation with baking absorption (Sunderman et al. 1965). Water absorption is an important factor to the baker because it is directly related to the amount of bread he can produce from a given weight of flour. (Holas and Tipples 1978). This factor is especially critical because in North America bread is sold on a weight basis. Any cultivar that can produce a slight percentage increase in the dough yield from the same weight of flour would be exceptionally valuable because a it could represent the difference between profit and loss in the highly competitive baking industry. A number of factors in addition to the various dough ingredients influence the baking absorption of flour. It is well known that absorption depends to some extent on the class of wheat, the cultivar and protein content (Finney 1945). Absorption was observed to be essentially a linear function of protein content within a cultivar, however each cultivar seemed to have a different regression line, the slope of which increased as the absorption level became greater (Finney 1945).

Baker et al. (1971) found that any increase in protein content will result in a proportional increase in loaf volume, regardless of the baking method. When a flour fails to fulfill the baking expectations that its protein content would predict it is likely that the gluten was weak or of inferior quality. Experience has shown, however, that there is justification for challenging the baking method rather than the flour itself. It is impossible to adequately define baking strength without reference to the methods used for its determination (Blish and Sandstedt 1935).

The ideal cultivar having general adaptability is the one with maximum yield potential in the most favourable environment, and maximum phenotypic stability (Finlay and Wilkinson 1963).

Groups of cultivars adapted to any specific environment have been found to have many morphological and physiological factors in common. Although it may be possible eventually to define the characteristics of ideal plants adapted to specific environments it could be much more difficult to define all the possible combinations of characters necessary to provide good general adaptability to a widely fluctuating set of seasons (Finlay and Wilkinson 1963).

Usually when a number of genotypes are grown over a range of environments no single physical factor can effectively descriminate between these environments. Each represents an amalgam of several factors(nutrient levels, moisture level, incoming light energy, etc.) each of which can vary widely and independently of the others (Hill 1975).

If large interactions between genotype and environment exist, there are two questions that should be raised:

1. Are the interactions so large that certain genotypes are adapted to local environments?
2. Is genotype environment interaction such that improvement made in one region will not be carried

over if a selected genotype is transferred to another environment (Baker and Kosmolak 1976).

The presence of genotype X environment interactions automatically implies that the behavior of the genotypes in the trial depends upon the particular environment in which they were grown. Thus the performance of any one of the genotypes relative to the remaining genotypes grown in the same environment will be inconsistent. These inconsistencies result in either alterations to the ranking of the genotypes from one environment to the next, or to changes in the absolute differences between genotypes which leave the rank order unchanged (Hill 1975).

Finlay and Wilkinson (1963) in their discussion of the regression of cultivar mean yield on site mean yield, indicate that a regression coefficient of less than unity indicates that a cultivar has an above average stability of response to environmental influences. A regression coefficient of unity indicates average stability and a regression coefficient greater than unity indicates less than average stability.

The above definition of stability implies that a stable cultivar is one which performs well in poor conditions and relatively poorly in good conditions (Baker, 1969).

Eberhart and Russel (1966) proposed that the criteria for stability should be a regression coefficient of unity and a minimum deviation from the regression line. A cultivar with high mean yield and fulfilling these two criteria would perform well in all environments. (Baker 1969).

The sum of squares due to regression in the Finlay and Wilkinson method includes the environmental sum of squares. When environmental effects are removed the proportion of the genotype X environment interaction sum of squares due to linear regression on environmental effects proves insignificant. The high residual variance indicates that the regression method cannot explain genotype X environment interactions.

It has been argued by some workers (Knight 1970, and Whitcombe and Whittington 1971) that when the genotypes in an experiment differ in their physiological response to the physical factors in the environment, the linear regression technique may over-simplify the true response pattern to an extent which could lead to erroneous conclusions. The point at issue is that if the linear regression model is satisfactory it is immaterial what the underlying cause of the differential response is as long as the limitations of inference are appreciated (Hill 1975).

The relative magnitude of the variance components indicates that the interaction of cultivars with environments can be of considerable importance in determining relative yield. A significant cultivar X location interaction indicates that certain cultivars consistently rank differently at different locations. The influence of years on the relative response of cultivars can be of similar magnitude to that of locations. A large second order interaction would imply that at a location individual years exert a major influence on the performance of the cultivars. Large variance components for cultivar X environment interactions are not unexpected in studies involving a large geographic area and genotypes selected at different sites within and outside the region studied (Campbell and Lafever 1977). A significant cultivar variance component would indicate that cultivars differ in their genetic yield potential. The degree to which a cultivar responds to changes in environments can be measured by the regression of the individual cultivar yields upon the mean yield of all cultivars in a single environment. (Campbell and Lafever 1977).

Regression coefficients significantly greater than one would indicate that they have the genetic potential to respond to a favourable environment when available (Campbell and Lafever 1977).

The fact that the cultivars tested, originated from breeding programs in three distinct regions would indicate that there is potential for large cultivar X environment interactions. It would also seem obvious that the cultivars selected in the United States would be at a significant disadvantage considering that tests were only conducted in Manitoba. However,the main objectives of the experiment were to see how the American cultivars performed in Manitoba, and not to make recomendations for the United States. It must be noted that if a cultivar performs exceptionally well in an environment other than that in which it was selected extra consideration should be given to that cultivar for exhibiting either an exceptionally plastic response or basic superiority.

If wide adaptation is an objective of a breeding program and the number of testing sites must be limited, one should choose sites that are highly correlated with all the other sites in the region. Specific adaptation may be desirable in stabilizing yield at locations not representative of the of the region in general. Campbell and Lafever (1980) studied the effect of varying the number of years of testing and examined the results by calculating the theoretical variance of a cultivar mean with various combinations of years and locations. The near equality of the cultivar X year and cultivar X location variance components indicated that the optimum allocation of a given number of environments would have a ratio of years to locations of near unity. The effect of substituting locations for years was not serious and appeared to be a reasonable practice (Campbell and Lafever, 1977).

The ideal approach to this experiment would have been to obtain data from several years at as many locations as possible throughout all regions concerned. A time constraint of two summers research immediately placed a constraint on years so to obtain as meaningful data as possible the number of locations was maximized within the target area of Manitoba. Substantiated by the above research of Campbell and Lafever (1977) this practice should make the conclusions drawn valid over years.

Baker and Kosmolak (1977) went on to study the variances of several baking and quality tests to see which parameters varied within environments and which are stable across environments. Within each trial correlations were divided into two groups of equal size, one containing the eight highest correlations the other the eight lowest. According to this classification mixograph development time, falling number and remix loaf volume had the lowest correlations. For these three traits improvement in one environment would not necessarily carry over to the second environment. Baker and Kosmolak also found that relatively high correlations were observed for flour yield, sedimentation value, flour protein, and grinding time. Smaller differences in variance were observed for these traits. These data suggest that flour traits are relatively insensitive to genotype X environment interactions. For these traits, lines selected as superior in one environment will likely be superior in other environments.

Data such as this gives us insight into the complexity of the situation because loaf volume tends to show low correlations across environments and yet, protein content known to be the major contributor to loaf volume shows a high correlation across environments. A researcher cannot attempt to draw conclusions from established theory when so many confounding variables are involved in the experiment. The development of a wheat kernel is easily such a situation.

Chapter III

MATERIALS AND METHODS

The experimental material included five Canadian and five American conventional height wheat cultivars representing a wide range of yield and quality. These cultivars all had or have significant production in the Northern Great Plains of the United States and Canada during the period from 1965 to present. The Canadian cultivars Manitou and Neepawa and the American cultivars Chris and Waldron represent high quality releases prior to 1970. The Canadian cultivars Benito and Columbus and the American cultivar Coteau represent recent high quality releases. The American cultivars Butte and Alex and the Canadian cultivar Glenlea represent releases with high yields and intermediate quality.

3.1 THE CULTIVARS

Manitou

Pedigree:Thatcher *7 / Frontana // Thatcher *6 / Kenya Farmer /3/ Thatcher *6 / PI 170925 Licenced in 1965 Manitou is a long term Canadian standard. It is now moderately susceptable to rust which can reduce its yield and protein content,and was grown on a limited basis in 1983. Manitou is recognised as being a high protein cultivar with relatively low yield, it was the last Canadian cultivar to be extensively grown in the United States.

Neepawa

Pedigree:Thatcher *7 / Frontana // Thatcher *6 / Kenya Farmer /3/ Thatcher *2 // Frontana / Thatcher Licenced in 1969 Neepawa is the modern standard comprising 62% of the western Canadian wheat crop in 1983. Attack by current rust strains may reduce its yield. Neepawa is a medium yielding, high protein cultivar.

Glenlea

Pedigree:Pembina *2 / Bage /3/ Sonora64 / Tezanos Pintos Precoz // Nainari 60 Licenced in 1971, Glenlea is a high yielding, medium to low protein content cultivar. It is a utility wheat not eligible for the CWRS grades. Glenlea constituted 15% of the wheat area in Manitoba in 1983.

Benito

Pedigree:Neepawa /3/ RL 4255 *4 // Manitou / CI 7090 Licenced in 1979, Benito is a medium yielding high protein cultivar that constituted 20% of the Manitoba wheat crop in 1983.

Columbus

Pedigree:Neepawa *6 / RL 4137 Licenced in 1982 Columbus is the newest Canadian release. It is high yielding has high protein content and is weathering resistant.It constituted 16% of the Manitoba wheat crop in 1983.

Chris

Pedigree:Frontana / 3* Chris // II44-29 / 2*Thatcher Released in 1965 Chris is the hard red spring quality standard from Minnesota and is probably the cultivar most similar to the CWRS.

Waldron

Pedigree: Justin/4/Lee/3/Kenya 338A//Lee/Mida(ND81) Waldron was released in 1969 and was the North Dakota quality standard. It has intermediate protein content and a relatively low yield.

Butte

Pedigree: ND 480//Polk/Wisc 261 Butte is an awned cultivar released in 1977.It is high yielding with intermediate protein content.

Coteau

Pedigree: Nd 496 sib//ND 487/Fletcher Coteau was released in 1978 and is an awned cultivar with high protein content and a moderate to high yield.

Alex

Pedigree: Waldron/ RL4205 / Waldron / ND269 Alex released in 1981 is an intermediate to high yielding cultivar with medium protein content.

All experimental yield data were obtained from randomised complete block experiments at six locations in Manitoba in 1982 and 1983. The 1982 seed source was from a preliminary varietal trial conducted in 1981 at The University of Manitoba. 1983 seed was from rogued increase plots planted at the U of M in 1982. To provide as uniform fertility as possible all plots were planted on summer fallow fields and were fertilized to soil test reccommendations. Six replicate experiments were planted at Winnipeg, Glenlea, and Portage la Prairie. Four replicate experiments were planted at Teulon, Waskada, and Dauphin

Individual plots were harvested at maturity, resulting in some cultivars remaining in the field longer than others. This was done to avoid post maturity weathering damage to early cultivars. All plots were 4 rows 5.6 m long spaced at .30 M and planted at a rate of 60 seeds/M. At maturity .30 M was removed from each end of the two central rows, prior to harvest. Individual plot yields were recorded then a 1200g (200g X 6 replicate, or 300g X 4 replicate) site composite was made of each cultivar. Cultivar composites for each location were analyzed for test weight and grain protein content. Due to insufficient seed for complete baking tests from each location locations with compatable protein and test weights were then composited for quality evaluation as described later. Three quality composites were evaluated for each crop year.

3.2 QUALITY TESTS

Quality tests were conducted to evaluate the potential of each cultivar to perform in commercial milling and baking operations, without resorting to the actual operations. The results of these tests give insight into the unique properties of each cultivar and comparisons of cultivars over years and locations.

3.2.1 Grain Tests

The following tests were conducted on grain samples of each cultivar at each location.

Test Weight: Conducted with a standard .5 liter container filled twice from a cox funnel and leveled with a round striker. The test weight is reported as weight of grain, at 14% moisture content X 100, giving the value in kg/hl,the metric version of bushel weight. This is one of the main grain grading factors and is a good indicator of milling yield.Test weight is influenced by the cultivar and environmental conditions.

Thousand kernel weight: (MKWT) is calculated as 10 X 100 kernel weight at 14% moisture basis. It reflects kernel size and density and like test weight is correlated to flour yield.

Wheat protein: Calculated as nitrogen content X 5.7 at 14% m.b. A.A.C.C. method 46-12. A high protein content is desirable and is indicative of acceptable baking properties.

Falling number: Hagberg falling number recorded in seconds. A.A.C.C. method 56-81 b. The falling number test estimates amylase activity in flour. This test is useful in evaluating the quality of wheat,especially when it has been harvested under wet conditions.

3.2.2 Flour Tests

Flour tests indicate milling quality and efficiency as well as protein quantity and quality.

Flour yield: Calculated as % flour obtained after milling. (14% m.b.) A.A.C.C. method 26-20. Flour yield is directly related to the milling efficiency. Flour yield is influenced by the kernel shape and size and the separability of the bran from the endosperm (Kent 1983).

Flour protein: Is calculated as nitrogen content X 5.7 at 14% m.b. Is generally 1% less than grain protein. A.A.C.C. method 46-12.

Loss protein:Calculated as the difference in protein percentage between the grain and milled flour. The bran,germ and aleurone layers are removed in milling and have a higher protein percentage than the endosperm. A large loss of protein is indicative of complete sepera-tion,but may result in a lower flour yield.

Ash: Flour ash content (14% m, b.) % A.A.C.C. method 08-01. The ash content and hence crude fibre content are related to the amount of bran in the wheat and are related to flour yield. Ash content is related to environmental conditions as small shriveled kernels caused by poor filling conditions have a higher bran to endosperm ratio and yield less flour than a well filled kernel.

Sedimentation: Zeleny sedimentation value c.c. A.A.C.C. method 56-60. This is a measure of the volume of sediment resulting from acidulating a flour water slurry,and is useful in estimating the strength of a cultivar. This value varies from 10 to 20 cc for a weak flour to 70 or more for a strong flour. Sedimentation values are influenced by the quantity and quality of gluten and the level of starch damage.

Amylograph: Amylograph viscosity, brabender units, A.A.C.C. method 22-10.This is a measure of the mixing resis-tance of a flour water slurry being digested by a dilute lactic acid solution. The viscosity is related to the level of diastatic activity in the slurry. Diastatic activity is a measure of the activity of the starch hydrolysing enzymes of the flour.

3.2.3 Dough Tests

The rheological properties of a dough play an important role in determining the quality of the bread and the optimal mixing time to achieve optimal dough consistency.

Farinograph Absorption: % of initial flour weight. A.A.C.C. method 54-21. The percentage of water added when the dough reaches its peak consistency. The absorption is related to the amount of dough that can be produced from a given weight of flour.

Dough development time: Time in minutes until the dough reaches its maximum consistency. A.A.C.C. method 54-21. DDT is related to the strength of the dough and its mixing characteristics,a very long DDT is indicative of excessive strength and can result in high mixing costs,conversely,too short a mixing time is indicative of a weak flour that will not produce a large loaf volume.

Mixing tolerance index: Brabender units. A.A.C.C. method 54-21,measures the decrease in viscosity five minutes after peak viscosity. MTI directly measures the tolerance of the dough to withstand extensive mixing. A low value is desirable but exceptionally low values indicate excessive strength.

3.2.4 Baking Tests

Baking tests are the most reliable means of determining the baking potential of a cultivar in a commercial operation. The blend tests indicate the potential carrying power of a cultivar in a blend with a weaker flour.

Remix absorption: Baking absorption in the remix baking test is usually 2% less than Farinograph absorption. This is the percentage of water added to the flour,meeting specific handling requirements. This is a direct test of absorption and is directly related to the dough yield.

Remix loaf volume: The Grain Research Laboratory (malt-phosphate- bromate) Remix pup loaf baking test. Loaf volume is accepted as the most accurate index of flour strength and generally flours which produce satisfactory loaf volumes in the pup loaf test are suitable for baking purposes.

Blend loaf volume: The sample being tested is blended with an equal weight of soft white wheat flour. Blend tests are conducted to give an indication of the carrying power of the cultivar in a blend situation.

Baking strength index: % Tipples and Kilborn, Can.J.Plant Sci.54, 231 (1974). B.S.I. tests are indicators of protein quality,and are expressed as a percentage of the loaf volume expected from a top quality Canadian flour with equivalent protein content.

3.3 STATISTICAL PROCEDURES

All analyses of variance and Duncan's multiple range tests were carried out using the Statistical Analysis Systems in Mantes. The quality differentiations were made using the guidelines set out by Tipples (1977) for selection practices in the co-op testing program. The linear regression of cultivar mean yield on site mean yield was carried out as outlined in Finlay and Wilkinson (1963).

Chapter IV

RESULTS AND DISCUSSION

The yield rankings for 1982 and 1983 were very similar. Glenlea, Butte, and Alex had consistently high yields, while Manitou, Waldron, and Chris had consistently low yields. The intermediate yielding cultivars; Benito, Neepawa, Columbus, and Coteau had variable rankings in 1982 and 1983.

4.1 YIELD COMPARISON

Glenlea significantly (α =.05) outyielded all other varieties in 1982 (Table 1), 1983 (Table 2) and in the combined analysis (Table 3). Glenlea ranked first in 11 out of 12 station years,had an 8% average advantage over Butte the next highest yielder and an 18% advantage over Neepawa.

Glenlea was bred as a utility wheat rather than a bread wheat and was licenced because of its high yielding ability and kernel distinguishability. Its quality characteristics which are discussed later are different from the remaining bread cultivars.

Comparison of the remaining cultivars reveals considerable similarity in their performances in 1982,1983 and the combined 1982-1983 analysis. Butte ranked second behind

TABLE 1

Average plot yields over 6 locations in 1982.

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3396	A
Butte	3156	B
Alex	3150	B
Benito	2966	B C
Neepawa	2896	C D
Coteau	2876	C D
Columbus	2846	C D
Manitou	2680	D E
Waldron	2666	D E
Chris	2470	E

* Means followed by the same letter are not significantly different α = .05.

C.V. = 6.5

TABLE 2

Average plot yields over 6 locations in 1983.

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3213	A
Coteau	2966	B
Butte	2950	B
Alex	2893	B
Benito	2656	C
Columbus	2623	C
Neepawa	2566	C D
Manitou	2550	C D
Waldron	2523	C D
Chris	2393	D

* Means followed by the same letter are not significantly different α = .05.

C.V. = 6.5

Glenlea in 1982 and second in the combined 1982-83 analysis,

TABLE 3

Average plot yields over 6 locations in 1982-83 combined.

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3310	A
Butte	3060	B
Alex	3026	B
Coteau	2930	B C
Benito	2840	C D
Columbus	2740	D E
Neepawa	2723	D E
Manitou	2633	E
Waldron	2603	E F
Chris	2440	F

* Means followed by the same letter are not significantly different α = .05.

and third behind Coteau in 1983 (Tables 1-3). Alex ranked third in 1982, fourth in 1983 and third in the combined analysis (Table 1-3).

Butte and Alex are consistently the highest yielding cultivars in the bread wheat class. Each ranked among the top 4 cultivars 10 out of a possible 12 station years,averaging a full 10% yield advantage over Neepawa (Appendix B) proving that this yield advantage is stable across years and locations.

Finlay and Wilkinson (1963) indicated in their discussion with respect to yield stability that a regression coeffecient of less than unity indicates that a cultivar has an above average stability of response to environmental influences. A regression coeffecient of unity indicates average stability and one greater than unity less than average stability. In addition to the above,Eberhart and Russel (1966) proposed that stability is indicated by a minimum deviation from the regression line, when accompanied with a high mean yield (ie.the deviation decreases as the R^2 value approaches 1).

When the Finlay and Wilkinson (1963) linear regression of cultivar mean yield on site mean yield (R.C.) was carried out for Butte, the regression coefficient was 1.3 and 1.2 in 1982 (Table 4) and 1983, respectively (Table 5). These figures were the highest in both years, indicating that Butte is not extremely stable, however, the deviations from the regression line are comparatively small. The inference is that Butte is able to exploit a favourable environment when provided, but will also yield well under stress conditions. The fact that Butte ranked second in the overall yield analysis (Table 3) and showed good stability and yield response indicates that it is one of the most reliable cultivars in this trial.

The performance of Alex the other cultivar to consistently rank among the top yielders was somewhat different over the two years of the trial. In 1982 Alex had a R.C.of 1.3 and an R^2 (deviation from the regression line) of .97 (Table 4) indicating a very stable response, with the ability to take advantage of a superior environment. These

TABLE 4

Cultivar stability analysis 1982.

Cultivar	R^2	C.V.	Req Coeff.*
Glenlea	.93	3.7	1.0
Neepawa	.79	5.8	0.7
Manitou	.66	7.3	0.5
Benito	.97	3.1	1.0
Columbus	.91	5.8	1.1
Chris	.79	9.8	1.0
Waldron	.96	4.0	1.1
Butte	.91	6.4	1.3
Coteau	.88	6.4	1.0
Alex	.97	3.6	1.3

* Regression of cultivar mean yield on site mean yield. R.C.

TABLE 5

Cultivar stability analysis 1983.

Cultivar	R^2	C.V.	Req Coeff.*
Glenlea	.47	7.9	0.8
Neepawa	.94	3.0	1.1
Manitou	.83	5.6	1.1
Benito	.63	8.4	1.0
Columbus	.91	4.1	1.2
Chris	.56	5.7	0.5
Waldron	.75	6.4	1.0
Butte	.71	7.5	1.2
Coteau	.92	3.0	1.0
Alex	.56	8.2	0.92

* Regression of cultivar mean yield on site mean yield. R.C.

characteristics combined with excellent yielding capacity make Alex look very acceptable, however, its reaction in 1983 was quite different. The R.C. was slightly below unity at .92 but the R^2 was only .56 (Table 5). This apparent lack of stability may reflect the drought conditions experienced in 1983, which seemed to affect the stability of some of the cultivars (i.e., Glenlea had on R^2 of 0.47 in 1983 and 0.93 in 1982).

This lack of stability in 1983 should not be overemphasised as its yield was not significantly (α =.05) different than that of Coteau or Butte in 1983 or in the combined analysis (Table 3).

In turning to the remaining cultivars, the differences become much more subtle. Theoretically the newer cultivars should have an advantage over the older cultivars,due to superior rust resistance. Fortunately no serious outbreaks of rust occured at any location in either year,so the recorded yields are not seriously confounded by differential disease responses.

When considering the yield rankings at individual locations (Appendix B) it is obvious that the remaining cultivars vary in their rankings between locations.

Chris and Manitou were both released in 1965, and stood as standards, for yield, milling and baking performance in their regions for a considerable period. Chris consistently ranked at the bottom in the yield trials of 1982 and 1983, being significantly (α =.05) lower than Manitou in 1982 and in the combined analysis (Tables 1, 2 and 3) In 1982 Chris showed good stability across environments with a R^2 of .79 and R.C. of 1.0 showing that even when given the opportunity its yield potential is low (Table 4). In 1983 Chris had a R.C. of .5 and an R^2 of .56 (Table 5), showing that during dry conditions such as those experienced in 1983, even old established cultivars will lose their stability, and react very differently to stress situations.

Manitou had a significantly (α =.05) greater yield than Chris in the combined analysis (Table 3), but consistently ranked lowest of the Canadian cultivars. In the stability analysis Manitou reacted opposite to Chris, being stable in 1983 and unstable in 1982 (Tables 4 and 5). This implies that Manitou is better adapted to drought conditions giving a reasonable yield in drought years but is less responsive when conditions are more favourable (Eberhart and Russell 1966). Not unexpectantly Chris and Manitou are the lowest yielding cultivars from each country, as the over-riding emphasis appeared to be on quality of grain rather than high yield.

In 1969 both Waldron and Neepawa were released. Neepawa went on to become the Canadian standard, and the most widely grown cultivar in Canada (1983 Prairie Grain Var. Survey). Waldron was the first high quality cultivar released by North Dakota, and went on to become their standard for several years. Neepawa ranked above Waldron in yield both years (Tables 1 and 2) but not significantly (α =.05), either year or in the combined analysis (Table 3). Neepawa ranked fifth of the ten cultivars, with a R.C. of .7 and a R^2 of .79 (Table 4) indicating a lack of stability, but some potential to exploit a favourable environment.

Waldron ranked ninth in 1982 but was not significantly (α =.05) different from four other cultivars (Table 1). The R.C. of 1.1 and R^2 of .96 (Table 4) indicate a very stable reaction across environments and little ability to react to superior environments.

In 1983 Neepawa ranked seventh, but was in a large group of high protein cultivars in the "medium" yielding group. Neepawa displayed an extremely stable yield under the dry conditions, again showing that the local cultivars are more stable than the American cultivars, when grown under drought conditions in Manitoba. Waldron yielded ninth in 1983 (Table 2.), but statistically (α =.05) was in the same group as Neepawa. In the combined analysis there was no significant (α =.05) difference between the yield of Neepawa and Waldron and both cultivars ranked second last for their country of origin (Table 3). Neepawa out ranked Waldron in only six of twelve locations (Appendix B)indicating that neither cultivar had a consistent yield advantage. It is clear that the variability between locations is at least equivalent to the variability between genotypes, and both cultivars would yield similarly in Manitoba.

This chronological trend of quality maintainance with slowly increasing yield is continued with the next group of cultivars, Coteau released in 1978, Benito in 1979, and Columbus in 1980. These three cultivars are regarded as having the best quality characteristics of the cultivars in this test, and any consistent yield advantage would greatly increase their value. In 1982 there was no significant difference (α =.05) in their yields (table 1) and all showed high stability across environments (Table 4). The variability within their rankings at individual locations (Appendix B) and similarity of yields indicates that under the comparatively normal conditions of 1982 these cultivars have virtually equivalent yields.

In 1983 Coteau was the second ranking variety behind Glenlea and had a significantly (α =.05) higher yield than Benito or Columbus (Table 2). Coteau had a R.C. of 1.0 and an R^2 of .92 (Table 5) indicating that this yield advantage in dry conditions is a stable reaction across environments. Coteau ranked in the three highest yielding cultivars in five of six locations in 1983, whereas Columbus and Benito rarely ranked higher than fifth (Appendix B). This consistently superior ranking and higher average yield in 1983 indicates that Coteau has a significant yield advantage under the stress conditions experienced. The fact that neither Benito or Columbus exceeded the yield of Coteau at any location in 1983 indicates that the variability between these three cultivars is greater than the variability between locations. In the overall analysis the genotypic superiority is not as evident and the environment appears to cause more variability between these top quality cultivars than their genotypes.

The Canadian grain industry relies on export of high quality bread wheat to generate a large portion of its income. Any cultivar that can increase this income through improved yields,while maintaining Canadian quality standards would be exceptionally valuable. Yield advantages coupled with decreases in baking quality greatly reduce the marketability of bread wheat and the income generated from its sale.

The general yield results indicate that the older cultivars can no longer compete with the newer releases, due to disease susceptability or genotypic inferiority. The three highest yielding cultivars Glenlea, Butte and Alex show definite superiority, however, their quality characteristics (discussed later) are inferior to the remaining cultivars.

As the number of years and locations increases and the combined data are analysed, the emphasis placed on data such as the regression coefficients and R^2 values should greatly decrease, if the goals of this experiment are kept in mind. The purpose is to make general observations and comparisons of all the cultivars when grown in Manitoba. The sophisticated regression techniques can be misleading and tend to oversimplify a much more complex situation (Hill 1975). Yield cannot be considered without reference to quality and yield advantages can only be useful when comparing cultivars of equivalent quality.

4.2 KERNEL WEIGHT

With the uniform planting densities used in this experiment, the plot yields should be entirely dependent on the individual plant yields. The components of plant yield are;spikes per plant, kernels per spike, and kernel weight (Kibite 1980). In this experiment kernel weight was the only one of these measured. This measurement was included because of its significance in milling performance.

The effect of MKWT on yield is clearly shown when the overall correlation coefficient for yield on MKWT is .68 on 60 data points.

Glenlea has a 21% higher MKWT than the next largest seeded cultivar and this is one of the major contributing factors to its large yield advantage (Tables 7 - 9). The impact is equally high when considering the lower yielding cultivars. Both Chris and Manitou had the lowest or near lowest MKWT of all the cultivars and this could be a causal factor in the low yield of these cultivars (Table 7).

The MKWT of the "medium yielding" cultivars is not nearly as indicative of their yield. In the combined analysis Waldron, the second lowest yielding cultivar had the same MKWT as Alex and Butte, and Columbus had the second highest value. Obviously there are other yield components responsible for the differences in these cultivars.

The fact that Coteau had a 3.0 g drop in MKWT and a small yield increase from 1982 to 1983, indicates that Coteau has an excellent yielding capacity initiated early in the season, possibly through increased tillering, that is not greatly affected by kernel filling. Cultivars like Neepawa and Benito on the other hand had large yield reductions in 1983, accompanied by large reductions in MKWT, indicating that they rely heavily on grain filling to produce a high yield. Lower correlations between yield and MKWT, and many confounding factors make any explanations for the "medium yielding" cultivars very speculative.

4.3 PROTEIN ANALYSIS

Grain protein content is one of the major factors influencing value of wheat on the international market. The final grain protein percentage exhibited by a cultivar at a particular location is a function of the environment, soil fertility, and the plant genotype. With soil fertility and environment removed from the variability by experimental design, the differences in protein content at each location depend on the genotype. The cultivars tested exhibited a wide range of protein contents and reactions to the different environments.

The presence of distinct threshold values for protein content on the international market often make statistical differences irrelevant, and small differences at critical percentages extremely important. Tipples (1977) set out guidelines for varietal assessment relative to a standard, that are not based on statistical differences, but on the practical differences for that quality parameter and are used throughout this thesis to give an indication of the differences relevant to "Canadian" market conditions. The values assigned for protein percentage are ± .4 to .9 percentage points greater or less than the standard as being significantly higher or lower than the standard and ± 1.0 as being highly significant.

The standard most frequently used is Neepawa, (being the most widely grown cultivar in Canada) which in this case was very appropriate because in the 1982, 1983 and combined analysis Neepawa was within 0.2% units of the mean protein level. For the protein contents to be significantly different they would have to be >15.2 or <14.4 in 1982 and >16.3 or <15.5 in 1983. For the protein contents to be highly significantly different the protein contents would have to be >15.8 or <13.8 in 1982 and >16.9 or <14.9 in 1983. Clearly the effect of a very hot and dry filling period in 1983 had a large effect on the protein contents of these cultivars, resulting in a full 1% increase in the

TABLE 6

Cultivar average protein percentages

Cultivar	1982	1983	1982-83 Combined
Alex	14.3-*	15.5-*	14.9
Benito	15.1	16.4*	15.8
Butte	14.1-*	15.2-*	14.6
Chris	15.3*	15.8	15.6
Columbus	15.5*	16.0	15.7
Coteau	15.4*	15.9	15.6
Glenlea	13.6-**	14.7-**	14.2
Manitou	14.7	16.0	15.3
Neepawa	14.8	15.9	15.4
Waldron	14.7	15.7	15.2

* significantly greater than standard.
-* significantly less than standard.
-** highly significantly less than standard (Tipples 1977).

average grain protein percentage (Table 6).

In 1982 Chris, Columbus and Coteau all had protein percentages much higher than the standard, averaging at least a 0.5% advantage. The individual location protein percentages (Appendix C, Table 24) indicate that these cultivars rank consistently above the location average, displaying high genotypic stability across locations.

Benito, Manitou, Neepawa, and Waldron had similar protein percentages in 1982. the individual locations (Appendix C, Table 24) show that these cultivars vary widely in their rankings and no consistent differences can be identified.

Alex and Butte had significantly lower protein percentages in 1982 (Appendix C, Table 24). Neither cultivar had a protein content greater than the average at any location (Appendix C, Table 24) indicating that the genotype is restricting the protein percentage.

Glenlea was bred as a utility wheat and as expected its protein content was far below the standard. It regularly had the lowest protein content at each location, showing little genotypic flexibility.

In 1983 the extreme conditions experienced at grain filling caused a clustering of the cultivars into an artificially high protein group. Johnson et al. (1968) claimed such an increase was due to the termination of carbohydrate synthesis. With a large portion of the protein coming from senescing leaves, the amount of protein per kernel would remain approximately the same, resulting in higher protein percentages.

In 1983 Benito was the only cultivar to show a significantly greater protein percentage. It had the highest percentage in four of six locations (Appendix C, Table 25) indicating that it consistently produces high protein contents under dry conditions.

Chris, Columbus, Coteau, Manitou, Neepawa, and Waldron all had similar protein percentages in 1983. Their ranks were random among locations (Appendix C, Table 25) and there was no indication of a superior cultivar within these lines.

As in 1982 Butte and Alex displayed significantly lower protein percentages than the standard in 1983 (Table 6). They again ranked below the average, and showed no ability to respond to the environment. Glenlea had the lowest protein percentage in four of six locations (Appendix C, Table 25) and was on the average 1.2% below the standard in 1983 (Table 6).

The combined analysis (Table 6) shows less distinct contrast between cultivars than the individual years. The exceptionally high values obtained for Benito in 1983 make its mean significantly greater than the standard. This apparent advantage cannot be considered absolute, as in 1982 it was not significantly greater than the mean. Chris, Columbus, and Coteau are the other cultivars which regularly displayed protein contents greater than the standard. Neepawa, Manitou and Waldron also had high protein percentages in some locations, however, their variability between locations was high (Appendix C, Table 25) showing a lack of stability.

The variability in the protein content rankings (Table 6)indicate that the cultivars with the highest protein percentages are also highly variable across environments. Within Columbus, Coteau, Benito, and Chris there is as much variability between cultivars, as between locations. These four cultivars most frequently produce top protein percentages but no single cultivar consistently ranks the highest.

The group of cultivars with slightly lower protein content including; Manitou, Neepawa, and Waldron, all vary in rank between locations and years. They have the potential to produce high protein contents, but they appear to react differently to environmental influences, that reduce their consistency.

Alex and Butte produced protein percentages significantly below the standard in virtually every test (Appendix C). The result was very consistent between years and there is no reason to suspect that they have the potential to equal any of the high protein cultivars. Butte,Alex and Glenlea all have protein contents below that required for #1 or #2 C.W. grades and would require special marketing considerations.

4.4 YIELD AND PROTEIN RELATIONSHIPS

To accurately assess the cultivars tested, yield and protein content must be considered simultaneously. The tendency for high yielding lines to express low protein content, and high protein lines low yield, has been an area of major controversy for some time (Kibite 1980).

In 1982 when there was ample time and moisture for good kernel filling, all cultivars were given the opportunity to display potential yield and protein content.

In 1983 suppressed yields due to a shortened filling period increased protein percentages. The overall yield reduction was inconsistent, indicating potential drought tolerance in some cultivars. When considering yield and protein content together the cultivars tested fall into four distinct groups. Columbus, Benito, and Coteau are all high protein cultivars that consistently produce good yields. The variability that exists between years and locations, among these similar cultivars is large. Coteau displayed excellent yield potential under the dry conditions in 1983, while displaying only average yield in 1982. Benito had a protein content highly significantly above the standard in 1983 and displayed only average content in 1982. Columbus was more consistent between years but it displayed variability among locations in both years. This indicates that at a particular location any of these cultivars can perform better than the other two, but is equally likely to perform worse. The effect of different environments is greater than the genotypic differences between these three cultivars.

Waldron, Manitou, Chris, and Neepawa, comprise a group of medium protein cultivars, with generally low yield. These cultivars were all released prior to 1970 and can no longer be considered optimal. They produce high protein percentages (Tables 24 and 25) but these values are variable (Appendix C). The major problem is their inability to produce a consistently high yield (Appendix B). These four cultivars have been replaced by cultivars that can consistently out yield them and maintain high quality.

Alex and Butte belong in a class separate from the previous cultivars. They do not approach the protein contents of the top quality bread wheats, but they hold a substantial yield advantage. These genotypes vary a great deal from the other cultivars, and are very stable between years and locations (Appendices B and C). Clearly the effect of the genotype is greater than the environment in determining their yield and protein content.

Glenlea consistently produced the lowest protein contents and the highest yields.

4.5 MILLING TEST RESULTS

The suitability of a cultivar for milling into flour and the eventual production of bread is dependent on an extremely complex package of characteristics. The efficient production of flour from grain is the initial step in bread production, and a high percentage of flour extracted from the grain is obviously desirable in that it is directly proportional to the miller's profit margin. The most reliable indicators of milling quality are; test weight, MKWT, protein loss and percent ash content, with percent flour yield being the most accurate indicator if ash content is acceptable.

The maximum yield of flour obtainable from wheat in milling is ultimately dependent upon the endosperm content and is affected by the size and shape of the grain, and the thickness of the bran (Kent 1983). Test weight is an indicator of shape and density, and cultivars with a high test weight usually have better milling characteristics and yield more flour (Kent 1983). The kernel size is not only a critical yield component, but is also a determining factor in the milling value, being closely related to the flour yield. In 1982 there was a very strong relationship between MKWT and flour yield (Table 7). In 1983 the drought conditions caused a shortened filling period and reduced MKWT,resulting in shriveled kernels, and conflicting results.

In 1983 the shortened filling period caused yield reductions from 1982 for every cultivar except Coteau. These yield reductions are clearly seen when the MKWTs of 1982 and 1983 are compared (Table 9). Every cultivar including Coteau had a significant drop in the MKWT which is most likely due to the effect of temperature on carbohydrate accumulation late in the year (Partridge and Shaykewich 1972).

In 1982 Butte had a highly significant flour yield advantage over the standard (Table 7). The test weight appears responsible for this advantage. The significantly lower ash content and high percent loss of protein would normally indicate a low flour yield, however, Butte maintained the highest yield and purest flour extract,indicated by its low ash content.

Benito, Columbus, Coteau, Glenlea, and Manitou all had acceptable flour yields in 1982. Glenlea displayed a high ash content, indicative of a thick bran and low flour yield. The exceptional MKWT (Table 7) indicating a high endosperm to bran ratio, compensates for this loss.

Chris, Alex and the standard Neepawa, had low flour yields in 1982. The low flour yield of Waldron in 1982 appeared to be related to it's exceptionally low test weight.

In 1983 the milling results were similar to 1982. The obvious effects of the shortened filling period were decreased MKWTs, (table 8) an increase in percent protein loss and a subsequent drop in flour yield. The decreased carbohydrate accumulation resulted in decreased dilution of the accumulated protein, smaller kernels, and lower endosperm to bran ratio reflected in protein loss (Table 8), all resulting in a decreased flour yield.

In 1983 Butte had the only significant advantage in the test weight resulting in the highest flour yield. The significantly lower ash content also indicates high milling quality. The high average protein percentages in 1983 increased the flour yield rankings of Alex, Chris, Columbus, Coteau, and Glenlea, but decreased the absolute yields. Low test weights, and increased bran to endosperm ratios caused by small seed, caused larger drops in flour yield for Benito, Manitou, Neepawa, and Waldron in 1983. These large losses would decrease the profit realised by the miller and desirability of these cultivars.

The combined 1982-83 analysis removes some of the climatic effects, and gives the best indication of overall milling quality. Kernel size combined with high endosperm separability, result in Butte having the highest percent flour extraction. The high kernel density indicated by test weight, and low flour ash content indicating high percent bran separation are the factors that contributed to this advantage. The lower protein content of the flour produced (Table 9) may decrease the value of Butte's flour, but the excellent flour yield indicates superior milling characteristics.

Columbus, Coteau, and Glenlea also had very high flour yields in the combined 1982-83 analysis. Glenlea exploits its exceptional kernel size, resulting in a much higher endosperm to bran ratio, to produce its high flour yield. Percent protein loss and the high ash content, indicative of a thick bran and poor separation, are compensated for by this size difference. The lower protein content of the flour produced would also decrease its value.

Columbus and Coteau combine high flour extraction with high protein content to produce virtually equivalent milling properties, and potential value. The low percent protein loss in 1982 appears to be related to the low flour yield,however this is contradictory to accepted theory (Kent 1983). The combined results show a significant advantage over Neepawa, but its advantage is variable and dependent on the growing conditions experienced. Manitou had a consistently superior flour yield throughout the test. There is no clear reason for this advantage over Neepawa, but it is stable across years and locations.

Chris, Benito, and Waldron all had low test weights in 1982 resulting in reduced flour yields. In 1983 the shortened filling period clustered the test weights, resulting in smaller differences between cultivars (Table 7-9). The combined analysis indicates that low test weight and MKWT is the major reason for the poor flour yields of these cultivars.

Neepawa,the milling stnadard in this test had the second lowest flour yield in the combined analysis. This result indicates that Neepawa is outdated as a milling standard and should be replaced by one of the newer cultivars.

TABLE 7

Milling quality indicators 1982.

Cultivar	Test Wt. kg/hl	MKWT[1] (g)	Flour % Protein Loss	Flour % Ash	Flour % Yield
Alex	80.3	37 CD	.57	.42	72.9
Benito	78.6-*	34 E	.80	.41	73.3*
Butte	81.3*	38 C	1.0	.38*	74.9**
Chris	78.7-*	33 EF	.77	.40	73.0
Columbus	80.3	40 B	.77	.40	74.2*
Coteau	79.4	36 D	.83	.43	74.6*
Glenlea	79.0	47 A	.87	.44-*	74.6*
Manitou	78.4	32 F	.93	.41	74.3*
Neepawa	79.7	36 D	1.0	.41	73.3
Waldron	77.7-**	37 CD	1.1	.42	71.8-*

* Mean is significantly greater than standard.
-* Mean is significantly less than standard.
** Mean is highly significantly greater than standard (Tipples 1977).
[1] Duncan 2 = 0.05. Means followed by the same letter are not significantly different.

TABLE 8

Milling quality indicators 1983.

Cultivar	Test Wt. kg/hl	MKWT[1](g)		Flour % Protein Loss	Flour % Ash	Flour % Yield
Alex	80.2	34	BC	.97	.40	72.3**
Benito	78.1	31	E	1.12	.41	70.4
Butte	80.5*	34	BC	1.17	.38*	73.6**
Chris	79.0	31	E	1.01	.39	71.7**
Columbus	79.4	32	DE	1.04	.42	72.8**
Coteau	79.0	33	CD	1.23	.41	73.2**
Glenlea	78.3	46	A	1.11	.43	72.2**
Manitou	78.1	29	F	1.02	.40	70.8*
Neepawa	78.6	32	DE	1.13	.41	70.0
Waldron	78.2	35	B	1.31	.41	70.4

* Mean is significantly greater than standard.
** Mean is highly significantly greater than standard (Tipples 1977).
[1] Duncan 2 = 0.05. Means followed by the same letter are not significantly different.

TABLE 9

Milling quality indicators 1982-83 combined.

Cultivar	Test Wt. kg/hl	MKWT[1](g)	Flour % Protein Loss	Flour % Ash	Flour % Yield
Alex	80.2	36 BC	.76	.41	72.6*
Benito	78.4	32 DE	.93	.41	71.9
Butte	80.9*	36 B	1.11	.38	74.3**
Chris	78.9	32 EF	.90	.40	72.3
Columbus	79.9	37 B	.88	.41	73.5**
Coteau	79.2	34 BC	1.03	.42	73.9**
Glenlea	78.7	47 A	1.03	.43-*	73.4**
Manitou	78.3	31 F	.98	.41	72.6*
Neepawa	79.2	34 CD	1.07	.40	71.7
Waldron	78.0-*	36 B	1.18	.41	71.1
Means	79.1	35	.98	.41	72.7

* Means are significantly greater than standard.
** Means are highly significantly greater than standard.
-* Means are significantly less than standard (Tipples 1977). Standard = Neepawa.
[1] Duncan 2 = 0.05. Means followed by the same letter are not significantly different.

4.6 FLOUR TESTS

The purpose of the baking test is to determine the particular characteristics of the flour and the treatment, lack of treatment, or combination of treatments necessary to render it suitable for the wheat industry (Blish and Sandstedt 1935). After milling was completed, the next step involves analysis of the flour for mixing and baking characteristics.

4.6.1 Enzyme Activity

The initial tests; falling number and amylograph viscosity were conducted on whole milled grain. The diastatic activity of a flour is related to the interaction of many enzyme-substrate systems, including the breakdown of starch by alpha (α) amylase (Kent 1983). The reduction of viscosity of the flour-water slurry is therefore directly related to the αamylase activity but the reverse is not necessarily true. The similarity of the falling number test to the amylograph test (i.e., being the change in viscosity of a flour-water slurry and not a direct test of enzyme activity) should strengthen the relationship between the two tests. The amylograph viscosity test allows significantly more starch gelatinization to occur and gives better opportunity for enzymes to act on the starch molecules.

The Hagberg falling number is used as a screening test for alpha amylase activity and the level of post harvest sprouting. The amylograph viscosity measures the activity of starch hydrolysing enzymes in the flour (including αamylase) (Brabender and Pagenstedt 1957). and is a direct measure of the diastatic activity in the flour.

In 1982 Neepawa (table 10) had an amylograph viscosity of 680 (B. U.). Using the guidelines set out by Tipples (1977) for significant differences from the standard, Chris and Columbus both had significantly greater viscosities. Coteau, Glenlea and Waldron all had significantly lower viscosities, indicating a high diastatic activity in the flour.

In 1982 Glenlea was the only cultivar that had a low amylograph viscosity that was accompanied by a low falling number (Table 10). Both Coteau and Waldron have falling numbers near the 400 level, (Table 10) considered acceptable, yet their amylograph viscosities are significantly below the standard. This indicates that the low amylograph viscosity is not due to a high level of αamylase, but rather some inherent characteristics, that increases the hydrolysing activity in the flour-water slurry. Glenlea had a falling number of 355 sec (Table 10) which was significantly below, the standard, coupled with a low amylograph viscosity. The high level of alpha amylase would cause the increase in hydrolysing activity, displayed by the low amylograph viscosity. When Coteau, Waldron, and Glenlea are compared, the interaction of amylograph viscosity and

αamylase (falling #) shows that falling number can often predict the amylograph viscosity, but amylograph viscosity

TABLE 10

1982 Sedimentation value, amylograph viscosity and falling number.

Cultivar	Sed. cc	Falling # sec.	Amyl V. B. U.[1]
Alex	71.3	467	507
Benito	65.6	457	743
Butte	63.7	403	603
Chris	67.7	472	837*
Columbus	69.7	457	843*
Coteau	70.0	435	490-*
Glenlea	62.0	355-*	490-*
Manitou	62.7	425	727
Neepawa	65.3	438	680
Waldron	70.7	397	470-*

[1] B. U. = Brabender Units.
* Mean is significantly greater than standard.
1977) Standard = Neepawa.

can vary independently of falling number.

In 1982 Chris and Columbus both had amylograph viscosities (a. v.) significantly above the standard (Table 10). This exceptionally low activity of hydrolysing enzymes, would necessitate the addition of malt (Kent 1983). The low activity of hydrolysing enzymes in Columbus is not suprising, because it was selected, specifically for its sprouting resistance (Campbell and Czarnecki 1980). The low level of enzyme activity in Chris is surprising, because Chris suffered from severe lodging problems and was harvested after severe lodging at three locations in 1982.

TABLE 11

1983 Sedimentation value, amylograph viscosity and falling number.

Cultivar	Sed. cc	Falling # sec.	Amyl V. B. U.[1]
Alex	65.0	400	753
Benito	53.3	448	700
Butte	60.0	390-*	747
Chris	61.3	422	907*
Columbus	59.7	437	910*
Coteau	65.3	387-*	720
Glenlea	61.3	310-**	493-*
Manitou	57.0	422	773
Neepawa	54.0	457	650
Waldron	64.3	380-*	677

[1] B. U. = Brabender Units.
* Mean is significantly greater than standard.
-* Mean is significantly less than standard.
-** Mean is highly significantly less than standard (Tipples 1977). Standard = Neepawa.

TABLE 12

1982-83 Average sedimentation value, amylograph viscosity and falling number.

Cultivar	Sed. cc	Falling # sec.	Amyl V. B. U.[1]
Alex	68.2	408	630
Benito	59.5	452	722
Butte	61.8	397	675
Chris	64.5	447	872*
Columbus	64.7	447	877*
Coteau	67.7	411	605
Glenlea	61.7	333-**	492-*
Manitou	59.8	423	760
Neepawa	59.7	448	665
Waldron	67.5	388-*	573
Mean	63.5	415	687

[1] B. U. = Brabender Units.
* Mean is significantly greater than standard.
-* Mean is significantly less than standard.
-** Mean is highly significantly less than standard

(Tipples 1977) Standard = Neepawa.

In 1983 the extremely hot and dry conditions, conducive to low levels of alpha amylase (Baker and Kosmolak 1976) worked in the opposite direction, with four cultivars having falling numbers significantly below the standard (Table 11). It should be noted that falling numbers of approximately 400 or greater are often considered to be virtually equivalent (Zillman 1984 - personal communication). Three of the cultivars; Butte, Coteau and Waldron, had falling numbers close to 400 sec., so the significance of the difference is reduced (Table 11). Glenlea had a falling number of 310 sec. which was highly significantly below the standard,and an exceptionally low amylograph viscosity.

As in 1982, Chris and Columbus had amylograph viscosities significantly above the standard, proving that their low level of enzyme activity is stable across years and locations.

The combined 1982-83 analysis (Table 12) gives the clearest indication of cultivar differences in falling number and amylograph viscosity. Glenlea had a high level of starch hydrolysing enzyme activity that resulted in a low falling number and a low amylograph viscosity. Chris and Coteau consistently produced very low levels of starch hydrolysing enzymes and had amylograph viscosities significantly greater than the standard.

Waldron was a marginal cultivar, with a low falling number, but the standard had a low amylograph viscosity, resulting in nonsignificant differences in the combined analysis.

The major purpose of these experiments was to discover the level of starch hydrolysing enzyme activity in these cultivars (including alpha amylase). This determination is critical to the baker, because it is essential that he has a "predictable" flour. If the level of enzyme activity is high the amount of gas production by yeast will be unpredictable and the baker will have to adjust his baking procedures. For this reason, the high amylograph viscosity values improve the baking quality of that flour. The baker can achieve the exact level of activity he wishes through malt addition, and end up with a "predictable" product. In the combined analysis the majority of the cultivars tested had acceptable amylograph viscosities, this result may be deceiving, because, the dry harvest conditions in both 1982 and 1983 resulted in very high falling numbers. The effect of weathering on the falling number and amylograph viscosity values could be great, radically altering these values (Baker and Kosmolak 1976).

4.6.2 Zeleny Sedimentation

The other baking quality test normally performed on flour is the Zeleny Sedimentation which is an indicator of bread-making quality and dough mixing strength. Gluten proteins are generally defined as the proteins left in the gluten ball after the starch and water solubles have been washed out (Huebner 1977). Huebner (1977) went on to point out that the percentages of each protein fraction can be different among different cultivars, long mixing "strong" flours having high quantities of high molecular weight proteins in the gluten, and weak flours having the least of this fraction. Sedimentation values can be expected to range from 20 or less for low-protein wheat of inferior bread-baking strength to as high as 70 or more for high protein wheat of superior bread-baking strength (Pickney et al. 1957).

In 1982 all of the cultivars tested had high sedimentation values (Table 10), however, little differentiation can be made from these values. Sedimentation value is often used as a screening method for baking strength, and any cultivar having a sedimentation value of 55-60 or greater is generally considered equal and to have "potentially" high baking strength (Zillman 1983 - personal communication).

In 1983 all cultivars had a large decrease in sedimentation values, indicating a decrease in protein (gluten) quality (Table 11) (Partridge and Shaykewich 1972). This decrease resulted in Neepawa and Benito having sedimentation values below 55 cc, indicating inferior strength. All of the remaining cultivars should be considered to have good potential strength.

In the combined analysis the sedimentation values indicate adequate gluten quantity and quality,and potential baking strength for all cultivars. Obviously the Zeleny Sedimentation is not capable of descriminating between such similar cultivars. No serious fault can be placed on any cultivar.

4.7 MIXING TESTS

Flour absorption is the amount of water required by a flour sample to produce a dough with a definite consistency, expressed as a percent of flour weight. This value is related to protein quantity and quality,level of starch damage and general baking characteristics (Kent 1983).

Small differences in this value are of particular interest to the baker because it is directly related to the yield of dough and final bread yield.

The flour absorption results of 1982 differentiate between cultivars much better than 1983. The exceptionally high protein percentages in 1983 are responsible for the increase in flour absorption and the clustering of values.

The change in level of starch damage may have also contributed to the change, but was considered to be the same for all cultivars.

Chris, Columbus and Coteau had the highest quantity and quality of protein in 1982, indicated by significantly higher flour absorptions (Table 13). The lower absorption of Glenlea indicates poor protein quantity and/or quality. The remaining cultivars had absorptions equivalent to the standard in 1982.

The hot and dry filling period in 1983 elevated the protein quantity and masked many significant differences attributable to quality. Despite this masking effect the poor protein quality of Benito was evident in the low absorption values. Glenlea also had a low absorption in 1983, proving that the protein quality remains poor under stress conditions. No differentiation can be made between the remaining cultivars in 1983.

The bread wheats in this test combine various protein quantities and qualities and levels of starch damage to produce virtually equivalent farinograph absorptions. Alex and Butte have low protein contents (Table 6) but acceptable absorptions, indicating high protein quality. Benito had the highest protein content in the test, (Table 6) but one of the lowest absorptions, indicating poor protein quality.

Glenlea is not a true bread wheat and has a combination of protein quantity and quality below the bread wheat stan-

TABLE 13

1982 Flour absorption, dough development time, and mixing tolerance index.

Cultivar	F. Abs. %	DDT min	MTI B.U.
Alex	63.7	6.2	35.0
Benito	62.1	5.0	40.0
Butte	63.7	5.2	35.0
Chris	64.7*	5.2	35.0
Columbus	65.3*	5.7	38.3
Coteau	64.4*	6.2	43.3
Glenlea	60.3-*	5.0	10.0
Manitou	62.4	5.3	36.7
Neepawa	62.9	4.8	38.3
Waldron	64.2	6.7	28.3

* Mean is significantly greater than standard.
-* Mean is significantly less than standard
(Tipples 1977). Standard = Neepawa.

TABLE 14

1983 Flour absorption, dough development time, and mixing tolerance index.

Cultivar	F. Abs. %	DDT min	MTI B.U.
Alex	64.5	7.3	30.0
Benito	64.2-*	5.2	30.0
Butte	65.1	5.2	33.0
Chris	66.1	5.2	30.0
Columbus	65.7	5.2	28.3
Coteau	65.1	5.5	33.3
Glenlea	62.2-*	8.7	18.3
Manitou	64.7	4.8	30.0
Neepawa	65.8	4.3	28.3
Waldron	66.5	7.2	23.3

* Mean is significantly greater than standard.
(Tipples 1977). Standard = Neepawa.

TABLE 15

1982-83 Combined flour absorption, dough development time, and mixing tolerance index.

Cultivar	F. Abs. %	DDT min	MTI B.U.
Alex	64.1	6.8	32.5
Benito	63.1	5.1	35.0
Butte	64.1	5.2	34.2
Chris	65.4	5.2	32.5
Columbus	65.5	5.4	33.3
Coteau	64.7	5.8	38.3
Glenlea	61.3-*	6.8	14.2
Manitou	63.6	5.1	33.3
Neepawa	64.4	4.6	33.3
Waldron	65.4	6.9	25.8
Mean	64.1	5.7	31.3

-* Mean is significantly less than standard (Tipples 1977). Standard = Neepawa.

dards.

A flour of good quality for bread making should have a medium to medium long mixing requirement, and a satisfactory mixing tolerance. The best indicator of these properties, is the Brabender Farinogram curve, which measures the resistance to mixing and the plasticity and mobility of a dough when subjected to continuous mixing at a constant temperature (Kent 1983). The farinograph also measures the absorption and general strength of the dough (Brabender and Pagenstedt 1957), which will be discussed later.

A uniform mixing characteristic is essential, especially in large commercial baking operations, where highly mechanised techniques have difficulty adapting to the unique "quirks" of each new wheat shipment (Brabender and Pagenstedt 1957).

In both 1982 and 1983 location composites were made for each cultivar, and then three location composites were made for each year, on the basis of similar test weight and protein percentages.

The three composites reacted very similarly in the dough development time and mixing tolerance index tests.Cultivars will be discussed as averages in this section, however, individual farinograms are included, for each composite (Figures 1 - 6). The dough development time (DDT) and the mixing tolerance index (MTI) are both measures of dough strength, and the baking potential of that flour (Kent 1983). A DDT of 5.0-6.5 min. and a low but not excessively low MTI is desired for optimal baking potential. The farinograms (Figures 1-6) and the specific values taken from the farinograms show considerable similarity between cultivars and across station years.

In 1982 all of the cultivars, except Neepawa, had DDT values within the desirable range (Table 13). Neepawa had a DDT of 4.8 minutes indicating potential weakness.

The MTI values in 1982 are all below the 45 B.U. level that would indicate a weak flour. Glenlea displays excessive strength with a MTI of 10 B.U. below the value acceptable for bread wheat (Table 13).

In 1983 the higher protein percentages resulted in larger DDTs, but only Glenlea is excessively long. The high protein composite (Figure 4) shows the delayed development characteristics of strength. Alex, Glenlea, and Waldron have the longest delays, in Figure 4, but the lower protein composites, figures 5 and 6 have normal development curves.

The MTI values were lower for the bread wheats in 1983. The increased protein percentages reduced the MTI values by 5-10 B.U. but all of the bread wheats maintained optimal strength. Glenlea had a MTI of 18.3 indicative of excessive strength.

The farinograms (Figures 1-6) show considerable similarity between cultivars and across station years. In the 1982-1983 analysis, few differences exist that indicate any superiority. Glenlea does not belong with the other bread wheats. Its excessive strength would require extensive mixing and an increased power requirement. The farinograms of Waldron and Alex tend to show greater strength than the other bread wheats (Figure 1-6). They had long DDTs (Table 15.) and the level and broad curve indicates that these cultivars have the greatest mixing requirement of the bread wheats. The remaining bread wheats have dough mixing characteristics that are virtually identical.

The variability between protein composites and years (Figures 1-6) is greater than the differences between specific cultivars. With small modifications to speed and duration of mixing, all bread wheats in this test show excellent potential breadmaking quality.

Figure 1: Farinogram. High protein composite 1982.
1 = Glenlea
2 = Neepawa
3 = Manitou
4 = Benito
5 = Columbus
6 = Chris
7 = Waldron
8 = Butte
9 = Coteau
10 = Alex

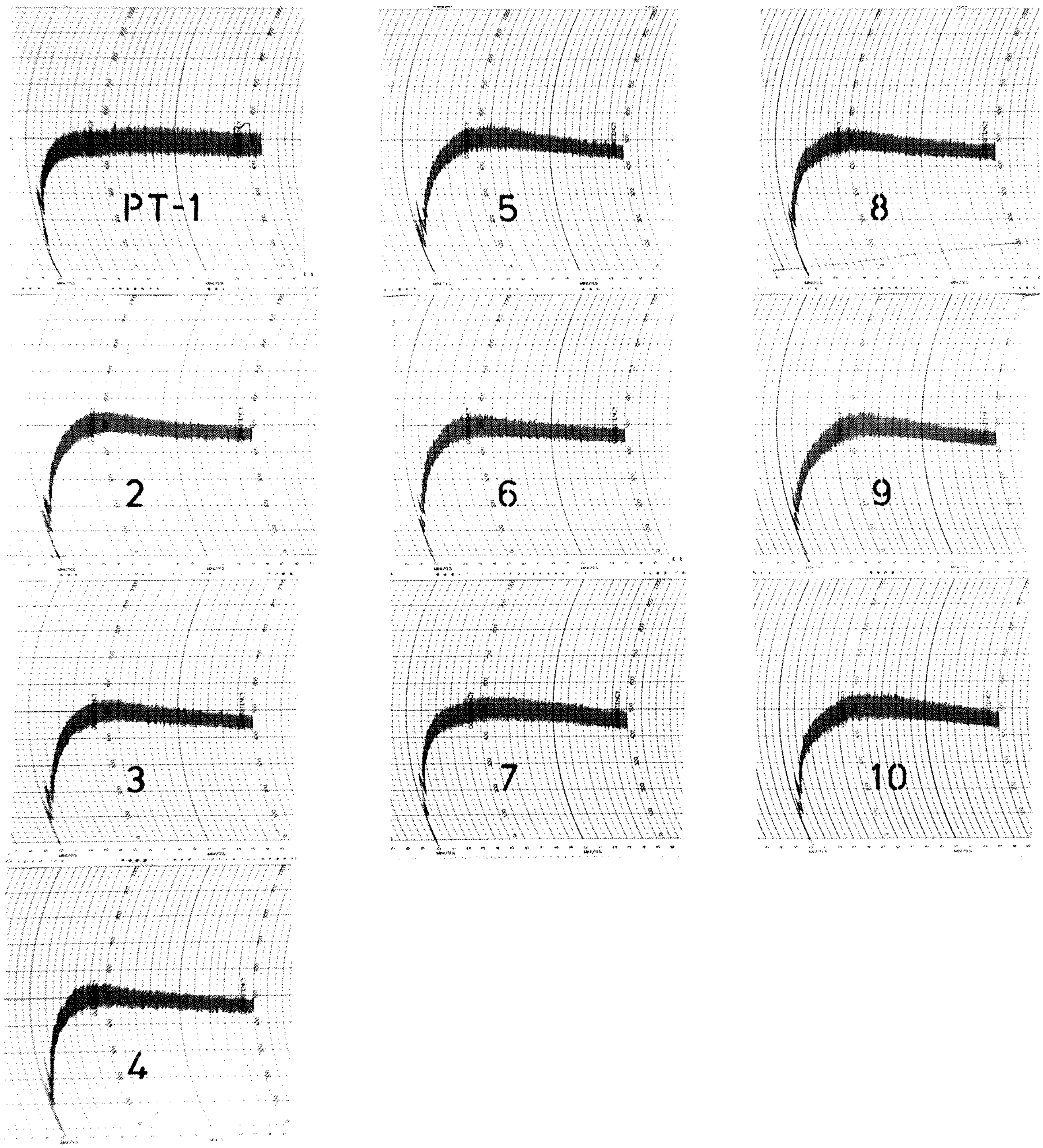
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Figure 2: Farinogram. Medium protein composite 1982.
1 = Glenlea
2 = Neepawa
3 = Manitou
4 = Benito
5 = Columbus
6 = Chris
7 = Waldron
8 = Butte
9 = Coteau
10 = Alex

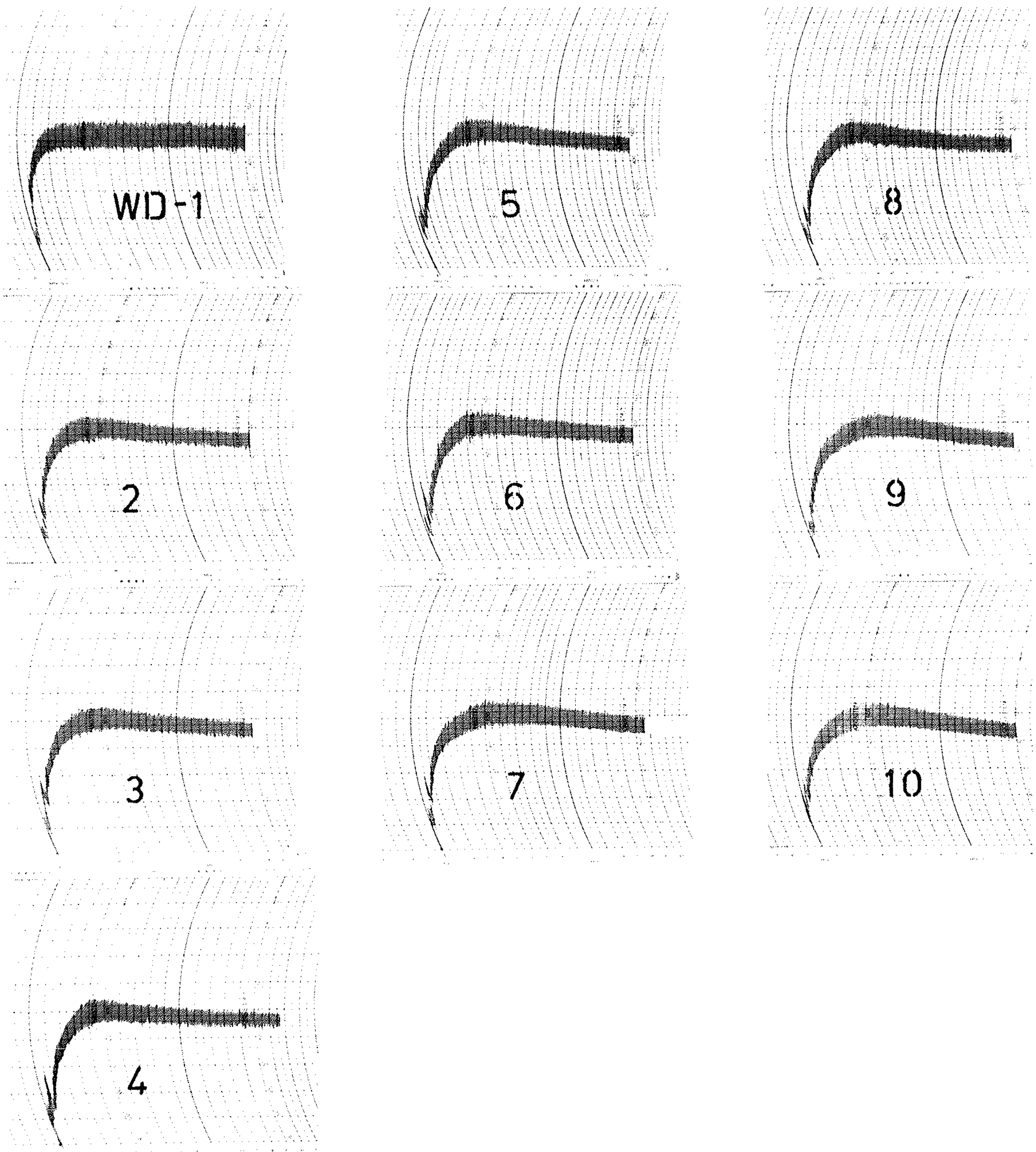
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Figure 3: Farinogram. Low protein composite 1982.

1 = Glenlea
2 = Neepawa
3 = Manitou
4 = Benito
5 = Columbus
6 = Chris
7 = Waldron
8 = Butte
9 = Coteau
10 = Alex

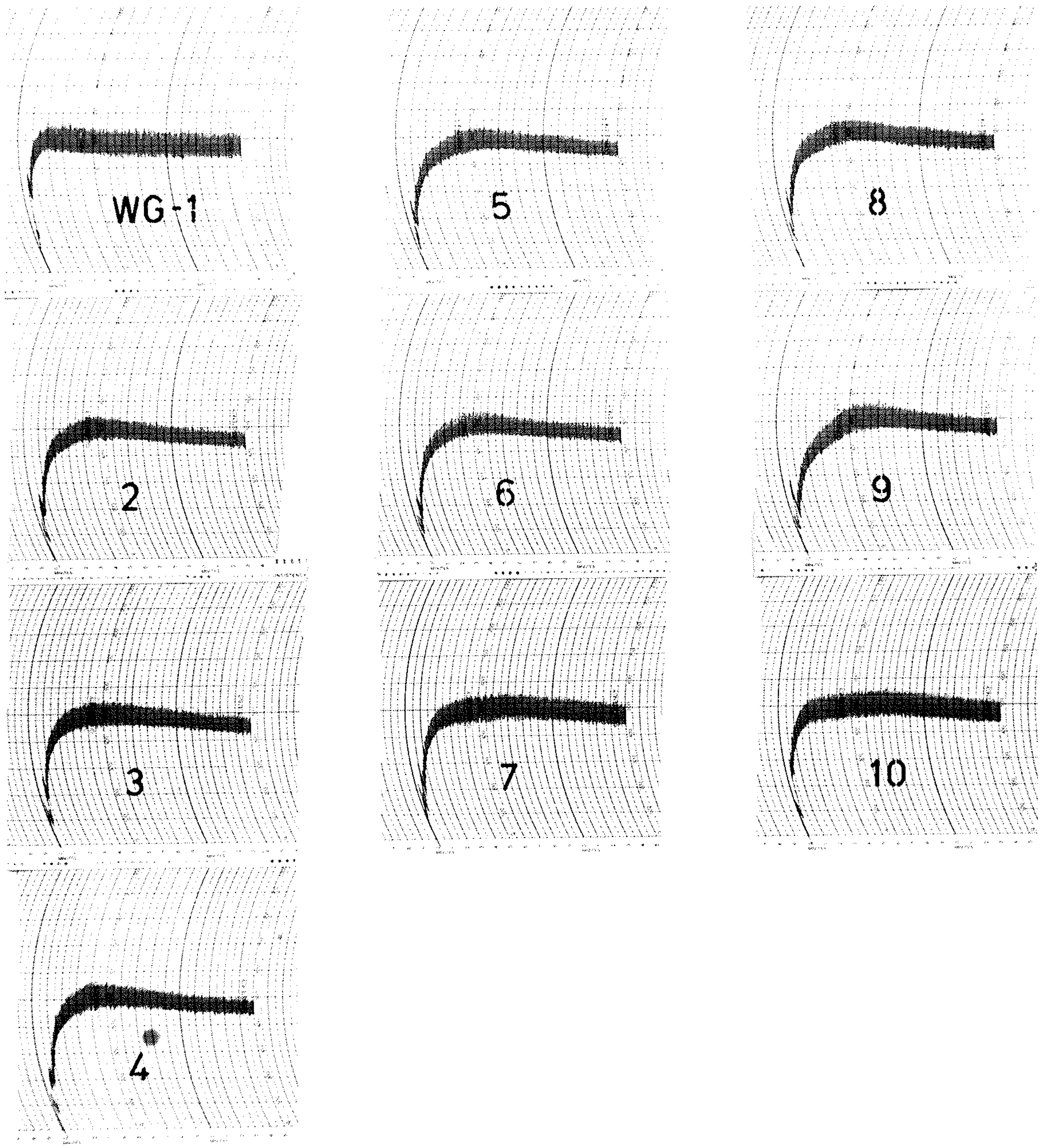
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Figure 4: Farinogram. High protein composite 1983.
1 = Glenlea
2 = Neepawa
3 = Manitou
4 = Benito
5 = Columbus
6 = Chris
7 = Waldron
8 = Butte
9 = Coteau
10 = Alex

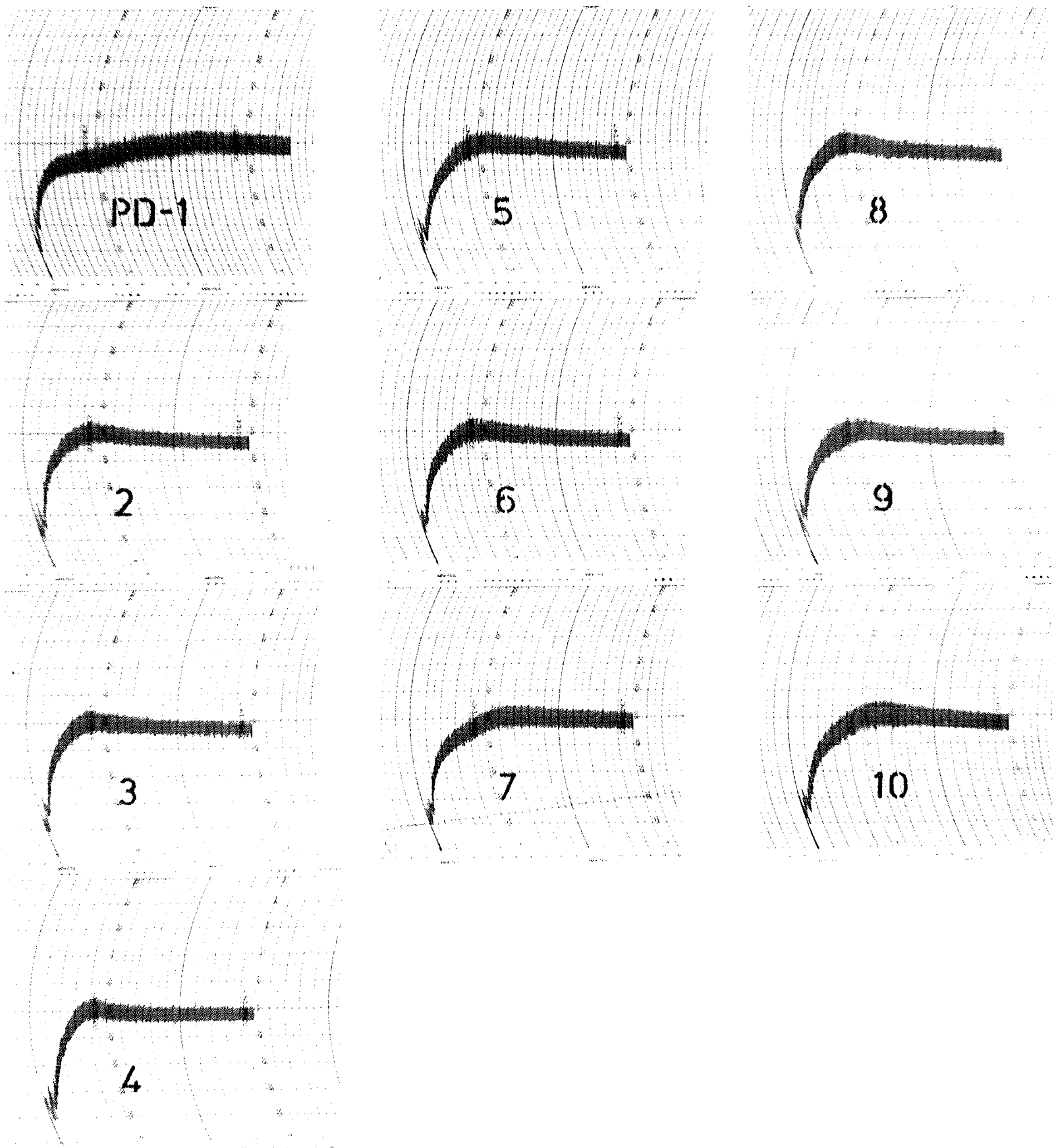
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Figure 5: Farinogram. Medium protein composite 1983.
1 = Glenlea
2 = Neepawa
3 = Manitou
4 = Benito
5 = Columbus
6 = Chris
7 = Waldron
8 = Butte
9 = Coteau
10 = Alex

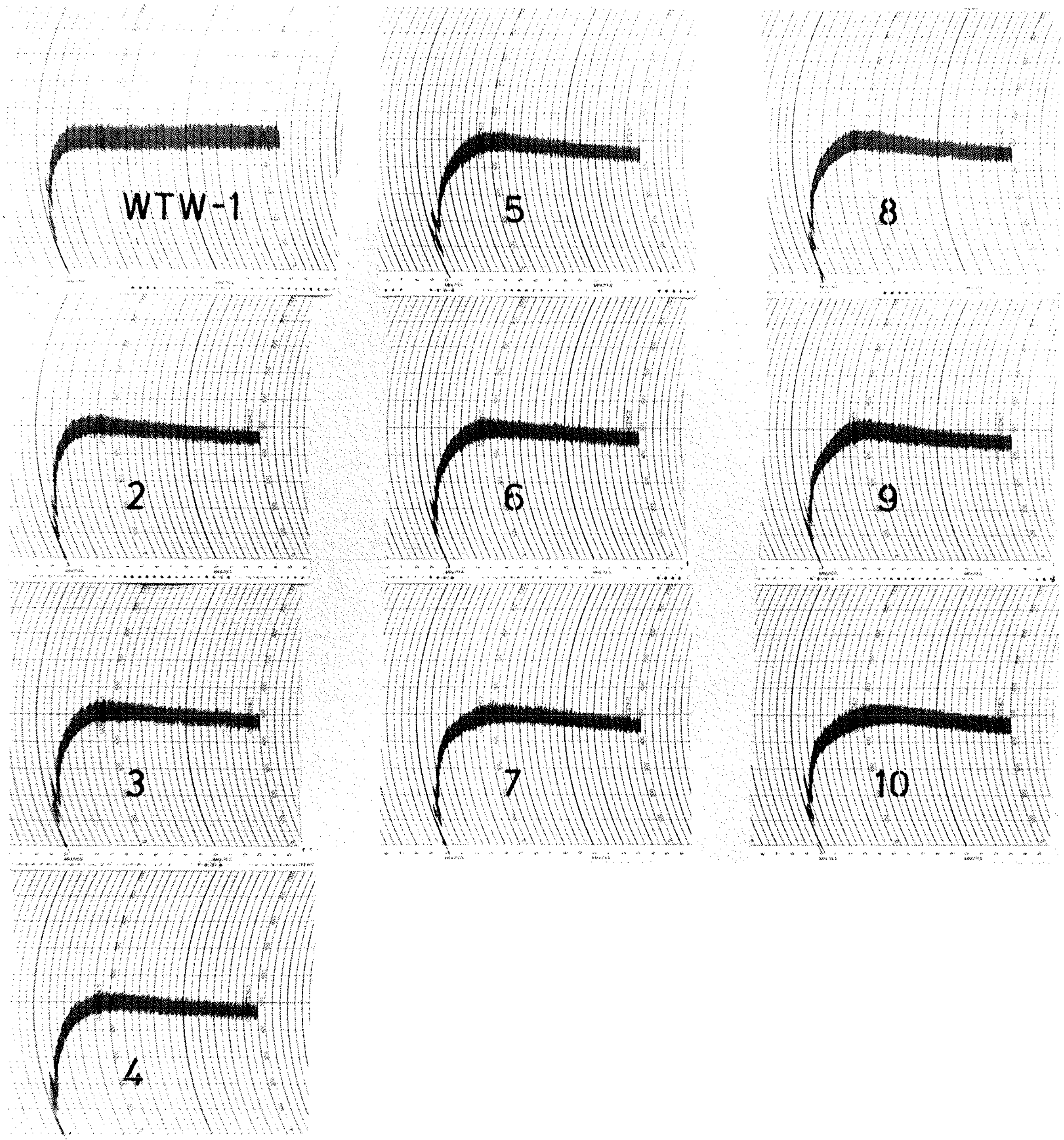
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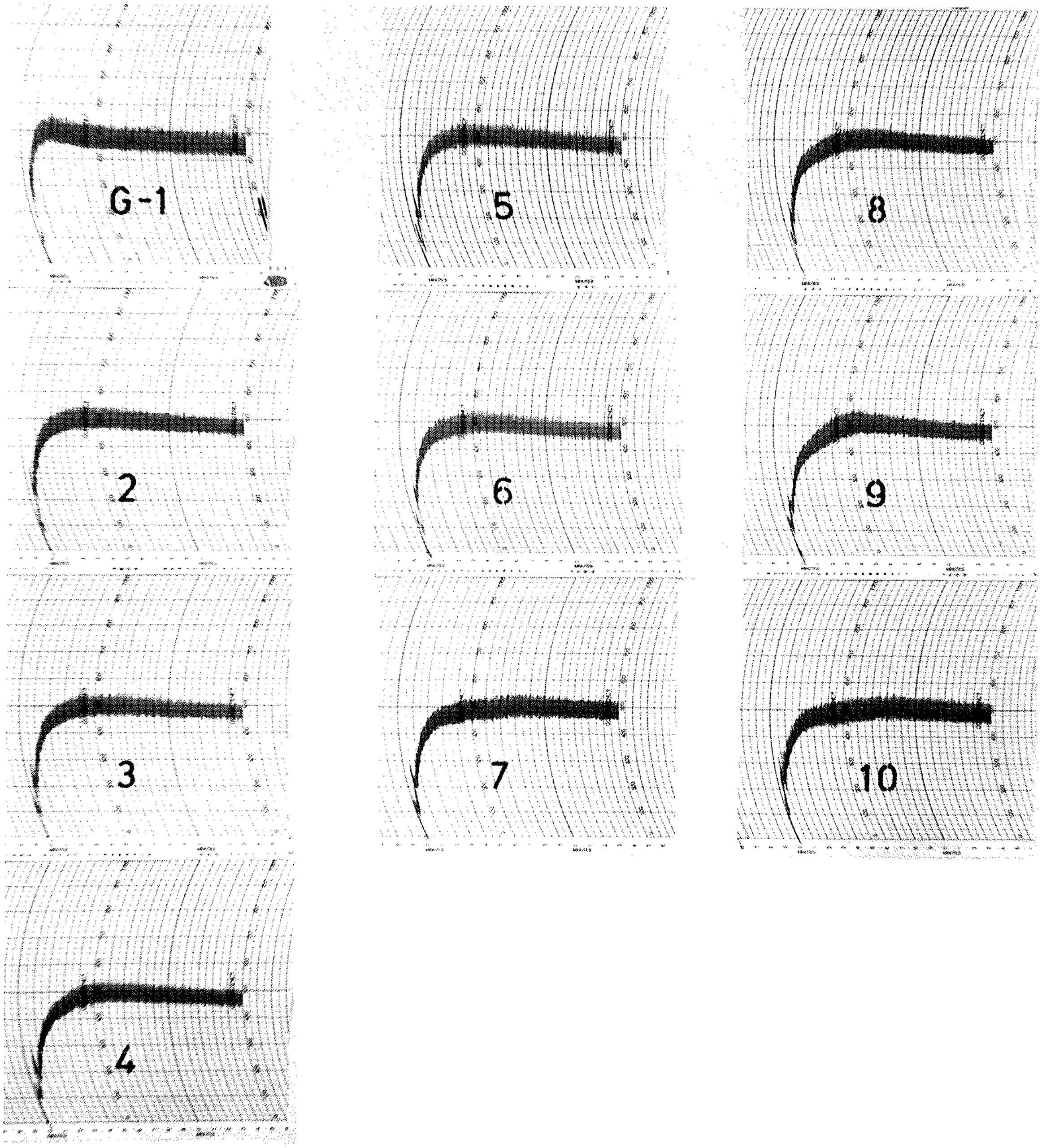
Figure 6: Farinogram. Low protein composite 1983.

1 = Glenlea
2 = Neepawa
3 = Manitou
4 = Benito
5 = Columbus
6 = Chris
7 = Waldron
8 = Butte
9 = Coteau
10 = Alex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4.8 BAKING TESTS

Optimum baking absorption, which is normally judged by the handling properties of the dough at panning, is the maximum amount of water that may be used, consistent with a high yield of bread per unit weight of flour, and satifactory bread quality (Holas and Tipples 1978).

In 1982 Chris and Columbus had baking absorptions significantly above, and Glenlea had a baking absorption significantly below the standard (Table 16). These differences are critical to the baker because they are directly related to his profit margin. A baker could realise a 4.35% increase in absorption, and dough yield if he switched from Glenlea to Chris in 1982. There were few differences in the absorptions of the remaining cultivars, and they would yield similar amounts of dough.

The blend baking trials are designed to establish the carrying power of a cultivar and its potential strength and absorption, for use in blending with weaker wheat (Tipples and Kilborn 1974). Importing countries are particularly interested in blend characteristics that allow them to blend imported strong wheats with their locally grown weaker cultivars, and still have an acceptable product.

In 1982 all cultivars had an approximately 4 to 5 percent drop in baking absorption in the blend test (Table 16). The significant advantages of Chris and Columbus in the standard test were not evident in the blend test. Glenlea had a blend baking absorption significantly below the bread wheats and would not improve the absorption in a blend as much as the other cultivars. None of the remaining cultivars had significantly different blend absorptions.

The increased protein percentages in 1983 reduced the number of significant inter cultivar differences (Table 17). Glenlea was the only cultivar that had a significant difference in either the standard remix absorption or the remix blend absorption.

The combined analysis shows that no differentiation can be made between the bread wheats tested. All of these cultivars would produce equivalent amounts of dough in the remix test and have similar carrying powers in the blend test. It appears that Glenlea lacks the protein quantity and/or quality to absorb as much water as the bread wheats. This results in a reduced dough yield in the remix test and poorer carrying power in the blend test.

The loaf volume of the remix baking test gives the most accurate indication of strength and baking quality (Baker et al. 1971). Baker et.al (1971) stated that any increase in protein content will result in a proportional increase in loaf volume and hence baking quality. To detail the relationship between protein percentage and loaf volume, individual protein composites were considered. Tables 20 and 21 (Appendix A) indicate that virtually every increase in protein content is accompanied by an increase in loaf volume. This relationship is stable across a large range of protein percentages, however, differences in inter cultivar quality make inferences of potential loaf volume from protein content, between cultivars highly speculative (Tipples and Kilborn 1974).

Baking strength index (BSI) is a protein quality parameter that expresses loaf volume, as a percentage of the volume normally expected for Canadian hard red spring wheat flours of the same protein percentage (Tipples and Kilborn 1974). Protein percentage and BSI should explain differences in loaf volumes, not solely attributable to protein content. Blend loaf volumes and BSI also give an indication of the carrying power of each cultivar, when blended with a weaker wheat.

In 1982 Chris and Waldron had highly significantly larger loaf volumes than the standard (Table 16). The high volume of Chris is attributable to high protein content (Table 6), while the remix BSI of 105% for Waldron indicates excellent protein quality. Benito, Columbus and Coteau were three cultivars that rely on protein content to produce significantly larger loaf volumes. Alex had a remix BSI of 103%

and a low protein content indicating that protein quality is responsible for its superior loaf volume. Butte had a remix BSI indicating high protein quality, but the low protein quantity (Table 6) reduces the loaf volume. The low protein quality indicated by remix BSI is responsible for the loaf volumes of Neepawa and Manitou (Table 16).

The exceptional strength of Glenlea results in undermixing and the significantly smaller loaf.

The results of the blend tests were contradictory to the standard remix tests. The cultivars with superior strength; Chris, Waldron, Alex, Benito, Columbus and Coteau, all had blend loaf volumes similar to the standard, indicating low carrying power. The high strength of Glenlea results in exceptional carrying power and a much larger loaf in the blend test. The blend BSI indicates a large difference in carrying power between the bread wheats and Glenlea. The bread wheats all had blend BSI values below 100%, and Glenlea had a value of 108% indicating that the blend would perform better than a Canadian hard red spring of equivalent protein content.

The increased protein percentages in 1983 resulted in an increase in loaf volume for most cultivars. Alex, Chris, Columbus and Coteau all had loaf volumes significantly larger and BSI percentages significantly higher than the standard. In 1983 Glenlea had a significantly lower loaf volume indicating that it does not respond to conventional baking methods and would require special consideration (Blish and Sandstedt 1935). The low BSI values would substantiate this finding. The remaining cultivars had equivalent baking potentials and protein qualities in the remix tests.

The blend test results were similar in 1982 and 1983. The increased protein percentages increased the blend loaf volumes by 30-60 cc (Table 17). The blend BSI values were also increased indicating higher carrying power. The strength displayed by Alex in the farinograms (Figures 1-6) appears to improve its carrying power and results in a significantly larger blend loaf volume and high blend BSI (Table 17). The low carrying power of Manitou indicated,by the blend BSI, results in a weak dough and the small blend loaf. As in 1982 Glenlea had a blend loaf volume and blend BSI values much higher than the bread wheats. This repeated superiority in blend tests indicates that the exceptional carrying power is stable across station years. The remainder of the cultivars had blend characteristics equivalent to the standard.

The combined 1982-83 results are the most indicative of the overall baking characteristics of these cultivars. Baking quality is generally correlated with the levels of glutenin and residue proteins in the flour (Orth and Buskuk 1972). Huebner (1977) went on to say that potential dough performance and loaf volume were dependent on a suitable mixture of gliadins, glutenins and residue proteins. The cultivars tested combined various protein quantities and qualities resulting in a wide range of loaf volumes. Chris had the top loaf volume and bread making potential in this test. Its high protein content (Table 6) and high quality, indicated by remix BSI, combined to produce a dough that responded most favourably to the mixing and baking methods used.

The high remix BSI percentages of Alex and Waldron indicate that high quality protein contributed to their superior loaf volumes. Both of these cultivars had protein percentages (Table 6) that indicated inferior baking potentials, but superior strength, evident in farinograms (Figures 1-6) compensates for a low protein percentage.

Benito, Columbus and Coteau had the highest protein percentages in the test (Table 6). They combine this quantity, with acceptable quality, indicated by BSI to produce loaf volumes significantly larger than the standard. Benito, Columbus and Coteau have superior baking potential that is due to protein quantity and are not nearly as reliant on protein quality. Butte and Manitou have loaf volumes equivalent to the standard. Butte has a lower protein percentage (Table 6) but higher quality indicated by BSI. Manitou and the standard Neepawa have medium protein percentages and low protein quality resulting in small loaves.

The combined 1982-83 analysis showed that Glenela has a BSI signficantly lower and a loaf volume highly significantly lower than the standard. Tipples and Kilborn (1974) suggested that Glenlea may give a low BSI in the standard remix test due to undermixing, and may require extended remixing to achieve maximum potential loaf volume. The poor remix tests of Glenlea and the outstanding blend test results, indicate undermixing and excessive strength. Smith and Mullen (1965) suggest that this excessive strength could be due to a higher percentage of glutenin in the gluten fraction. This strength is substantiated by the level and wide farinograms (Figures 1-6). It appears that Glenlea is ideally suited to blending, however, for its strength to be of any value it must be diluted to allow proper dough development.

The bread wheats did not perform as well as Glenlea in blends. Alex and Waldron have the strongest doughs and greatest carrying power among the bread wheats. This strength is evident in their high BSI percentages and the shape of their farinograms. The remaining bread wheats have equivalent carrying power and would perform well in a blend with weaker flours.

The baking results indicate that equivalent baking potentials can be achieved with different protein quantities and qualities. All of the bread wheats in this test have the

TABLE 16

Baking trials 1982.

Cultivar	R Abs%	RLV cc	RBSI %
Alex	60.0	932*	103*
Benito	59.0	920*	97
Butte	60.3	882	102*
Chris	61.3*	980**	94
Columbus	62.0*	913*	94
Coteau	60.7	923*	96
Glenlea	57.0-*	777-*	93
Manitou	59.0	880	97
Neepawa	59.3	852	94
Waldron	61.0	942**	105**

Standard = Neepawa.

Cultivar	B Abs%	BLV cc	BBSI %
Alex	55.3	690	95
Benito	54.7	650	88
Butte	55.3	628-*	90
Chris	56.0	695	93
Columbus	56.0	678	90
Coteau	55.7	685	91
Glenlea	53.7-*	745**	108**
Manitou	54.7	657	91
Neepawa	55.3	668	92
Waldron	55.3	688	96

* Mean is significantly greater than standard.
** Mean is highly significantly greater than standard.
-* Mean is highly significantly less than standard (Tipples 1977).
R Abs = Remix absorption
RLV = Remix loaf volume
RBSI = Remix baking strength index
B Abs = Blend absorption
BLV = Blend loaf volume
BBSI = Blend baking strength index

TABLE 17

Baking trials 1983.

Cultivar	R Abs%	RLV cc	RBSI %
Alex	60.7	970*	101*
Benito	60.3	937	93
Butte	61.0	883	96
Chris	62.0	985*	101*
Columbus	62.0	975*	99*
Coteau	61.0	957*	98*
Glenlea	58.3-*	682-**	77-**
Manitou	61.0	910	92
Neepawa	61.7	903	92
Waldron	62.3	918	96

Standard = Neepawa.

Cultivar	B Abs%	BLV cc	BBSI %
Alex	55.0	752*	100
Benito	55.0	697	90
Butte	55.3	718	98
Chris	56.0	710	98
Columbus	56.0	705	95
Coteau	55.3	712	95
Glenlea	54.0-*	772**	108**
Manitou	55.7	682-*	90
Neepawa	56.0	718	95
Waldron	56.3	740	99

* Mean is significantly greater than standard.
** Mean is highly significantly greater than standard.
-* Mean is significantly less than standard.
-** Mean is highly significantly less than standard (Tipples 1977).
R Abs = Remix absorption
RLV = Remix loaf volume
RBSI = Remix baking strength index
B Abs = Blend absoerption
BLV = Blend loaf volume
BBSI = Blend baking strength index

potential to perform well in a commercial baking operation.

TABLE 18

Baking trials 1982-83 combined.

Cultivar	R Abs%	RLV cc	RBSI %
Alex	60.3	951*	102*
Benito	59.7	928*	95
Butte	60.7	883	99*
Chris	61.7	963**	99*
Columbus	62.0	944*	96
Coteau	60.8	940*	97
Glenlea	57.7-*	729-**	85-*
Manitou	60.0	895	95
Neepawa	60.5	878	93
Waldron	61.7	930*	101*
Mean	60.5	904	96

Standard = Neepawa.

Cultivar	B Abs%	BLV cc	BBSI %
Alex	55.2	721	97
Benito	54.8	673	89
Butte	55.3	673	94
Chris	56.0	708	94
Columbus	56.0	692	91
Coteau	55.5	698	93
Glenlea	53.8-*	758**	108**
Manitou	55.2	669	91
Neepawa	55.7	693	94
Waldron	55.8	714	98
Mean	55.3	700	95

* Mean is significantly greater than standard.
** Mean is highly significantly greater than standard.
-* Mean is significantly less than standard.
-** Mean is highly significantly less than standard (Tipples 1977).
R Abs = Remix absorption
RLV = Remix loaf volume
RBSI = Remix baking strength index
B Abs = Blend absorption
BLV = Blend loaf volume
BBSI = Blend baking strength index

Chapter V

CONCLUSIONS

The purposes of this experiment were; to compare the American cultivars: Chris, Waldron, Butte, Coteau and Alex with the major Canadian cultivars: Manitou, Neepawa, Glenlea, Benito and Columbus, and to see if there is not more variability that can be attributed to different environments than among the cultivars themselves. The conclusions to follow will be entirely academic unless the Canadian Grain Commission is willing to relax the licencing requirements for visual distinguishability, and quality being equivalent to Marquis.

For a cultivar to establish its superiority in this test, the most important attribute would be its ability to produce a larger quantity of higher quality bread from a given area of land. The key steps in this ability involve; superior grain yield from the field, a high percentage flour yield,and a large dough yield , all contributing to larger loaves and a higher bread yield per hectare. Each of these requirements involve a complex set of genotype-environment interactions that result in significant inter cultivar differences for some characteristics, and virtually identical results for others. Each of the above parameters was measured along with many other tests conducted in an attempt to explain the differences between cultivars.

From a yield point of view Glenlea is clearly the superior cultivar. Its clear advantage in both 1982 and 1983 and the fact that it had the top yield in eleven out of twelve station years indicates that this yield advantage is stable across environments. The exceptional kernel weight (Table 9), is a major contributor to Glenlea's superior flour yield (Kent 1983). This combination of exceptional grain yield and high flour yield means that Glenlea will produce more flour from a given land area than any of the other cultivars tested. Unfortunately, for any cultivar to succeed as a bread wheat it must have a higher protein content, than Glenlea possesses (Table 6). Glenlea's low protein content is very apparent in the low baking absorption and remix loaf volumes obtained (Table 19). The poor response of Glenlea to conventional mixing techniques removes it from serious consideration as a bread wheat ,however, the exceptional blend carrying power displayed makes it a prime candidate for blending with weak wheats.

Butte and Alex are two cultivars that are very similar in yield and quality. The classical yield-protein percent trade off, gives Butte a slight yield advantage, and Alex a slight protein advantage. Both Butte and Alex have excellent yield potentials, being behind Glenlea by approximately 8 %, but still well above the other Canadian cultivars. The

TABLE 19

General analysis of yield, flour yield, baking absorption and loaf volume.

Cultivar	Yield kg/ha	Fl. Yield %	B. Abs. %	L. V. cc
Alex	3026	72.6	60.3	950*
Benito	2840	71.9	59.7	928*
Butte	3060	74.3**	60.7	883*
Chris	2440	72.3	61.7	963**
Columbus	2740	73.5**	62.0	944*
Coteau	2930	73.9**	60.8	940*
Glenlea	3310	73.4**	57.7-*	729-**
Manitou	2633	72.6*	60.0	895
Neepawa	2723	71.7	60.5	878
Waldron	2603	71.1	61.7	930*

* Mean is significantly greater than standard.
** Mean is highly significantly greater than standard.
-* Mean is significantly less than standard.
-** Mean is highly significantly less than standard (Tipples 1977) Standard = Neepawa.

high flour yield of Alex and exceptional flour yield of Butte indicate that these cultivars have excellent milling characteristics. When protein percentages are compared both Butte and Alex appear near the lowest, however, excellent protein quality indicated by high sedimentation values, high BSI percentages, and most importantly high loaf volumes, indicate that these cultivars have excellent baking potential. To achieve general acceptance as a bread wheat in Canada a cultivar would be expected to have protein percentages above that of Butte and Alex (Canada Grains Council 1981). There is no segregation based on protein quality in our grading system (Tipples and Kilborn 1974) a distinct disadvantage for cultivars like Butte and Alex, however, serious consideration should be given to cultivars with such high yield and baking potential.

Coteau is the one American cultivar that could be accommidated in the Canadian grading system.Coteau is a high yielding cultivar with excellent quality. The small difference between the yield figures for 1982 and 1983 indicated that Coteau was very tolerant of the stress placed on it by the hot dry filling period in 1983. The milling quality of Coteau was also very high, giving a flour yield percentage well above the standard. The protein content of Coteau would facilitate its acceptance in the Canadian grain industry, and the acceptable protein quality indicated by sedimentation values and BSI percentages combine to give Coteau good baking potential. If any of the American cultivars are to be considered for production in Manitoba, Coteau could likely match or exceed the yield and protein content of the top Canadian cultivars, and require the fewest changes to the grading system.

Chris and Waldron are two older American cultivars that have excellent milling and baking characteristics, but cannot be seriously considered because of extremely poor yields. Both had low yields at all locations in both years, and had flour yields that were only acceptable. These two factors combine to give the lowest flour yields per hectare.

The loaf volume of Chris was the highest in this test. It combines one of the top protein percentages (Table 6) with high protein quality to give excellent baking potential. Waldron also has excellent baking quality indicated by the high loaf volume (Table 19).

Both Chris and Waldron have excellent quality that is comparable with the top Canadian cultivars, but their low yields prohibit any consideration of these cultivars.

The remaining cultivars, Benito, Columbus, and Manitou were included in this test for chronological comparison, as well as being useful references for other parameters. Neepawa was included because it is the most widely grown cultivar in western Canada and has established itself as the milling and baking standard (Tipples 1977).

Neepawa was one of the lowest yielding cultivars in the trial, and had some of the poorest milling and baking qualities tested.

Manitou was included in this test because it was the last Canadian cultivar to be grown to any extent in the United States. Like Neepawa, Manitou had a low yield and poor milling and baking quality in comparison with some of the newer cultivars. Its poor performance in comparison with the American cultivars was likely the reason why its production was suspended in the United States. From the yield,milling and baking results,it appears that Manitou has been replaced by superior cultivars.

Benito and Columbus are the two newest Canadian cultivars in this trial and as expected have the top yield and quality characteristics among the Canadian cultivars. Both have very high protein percentages (Table 6) resulting in excellent loaf volume potentials (Table 19). Columbus appears to be the top Canadian cultivar, its comparable yield, and excellent flour yield indicate that it can produce large amounts of flour. Columbus also has the best overall baking absorption (Table 19), ensuring excellent dough production. When combining the milling and baking quality with the agronomic advantages displayed by Columbus (i.e., low alpha amylase levels (Table 12)) it should be considered the best Canadian bread wheat.

In the final assessment Coteau could fit into Canadian production with little trouble, and its apparent yield potential in dry seasons (Table 2) make it a viable consideration.

Butte and Alex would require major changes in the licencing system and marketing strategies before they could be grown in Canada, however, their high yield potential and excellent protein quality (Table 3 and Table 16) make them worthy of further consideration.

Chris and Waldron are both "older" cultivars that have since been replaced by cultivars with equal or superior quality and higher yields, no consideration for production of these cultivars should be considered for Manitoba.

Appendix A

TABLE 20

Composite, protein percentages and loaf volumes 1982.

Cultivar	Composite	Protein %	Loaf Vol. cc
	High	14.9	1020
Alex	Medium	14.1	885
	Low	14.0	890
	H	16.0	1005
Benito	M	15.5	865
	L	13.9	890
	H	14.8	970
Butte	M	14.3	870
	L	13.2	805
	H	16.1	1020
Chris	M	15.1	895
	L	14.6	905
	H	16.2	1015
Columbus	M	15.5	895
	L	14.7	830
	H	15.8	1010
Coteau	M	15.1	890
	L	15.3	870
	H	14.7	950
Glenlea	M	13.5	750
	L	12.7	630
	H	15.7	915
Manitou	M	14.4	900
	L	13.9	825
	H	16.0	920
Neepawa	M	14.8	875
	L	13.7	760
	H	15.4	1030
Waldron	M	14.7	885
	L	14.1	910

TABLE 21

Composite, protein percentages and leaf volumes 1983.

Cultivar	Composite	Protein %	Leaf Vol. cc
	High	16.2	1035
Alex	Medium	15.5	965
	Low	14.8	910
	H	17.5	900
Benito	M	16.5	980
	L	15.1	930
	H	16.1	915
Butte	M	15.1	875
	L	14.4	860
	H	17.0	1010
Chris	M	15.8	1025
	L	14.7	920
	H	17.2	990
Columbus	M	16.1	985
	L	14.7	950
	H	16.6	1025
Coteau	M	15.7	975
	L	15.4	870
	H	15.8	690
Glenlea	M	14.8	750
	L	13.4	605
	H	16.8	890
Manitou	M	15.8	990
	L	15.3	850
	H	17.2	985
Neepawa	M	16.0	940
	L	14.5	785
	H	16.5	925
Waldron	M	15.5	910
	L	15.2	920

Appendix B

TABLE 22

Yield rankings 1982.

a) Winnipeg

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3593	A
Butte	3583	A
Alex	3493	A
Benito	3147	B
Coteau	3037	B C
Waldron	3024	B C
Columbus	2964	B C D
Neepawa	2937	C D
Manitou	2804	D E
Chris	2470	E

b) Glenlea

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3203	A
Butte	3017	B
Alex	2960	B C
Neepawa	2894	B C
Manitou	2887	B C
Benito	2854	C
Chris	2624	D
Columbus	2587	D
Waldron	2557	D
Coteau	2534	D

c) Portage

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	2940	A
Butte	2671	B
Neepawa	2644	B
Columbus	2627	B
Coteau	2597	B
Benito	2561	B
Alex	2534	B
Manitou	2298	C
Waldron	2128	C D
Chris	2005	D

d) Teulon

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3163	A
Alex	2737	B
Neepawa	2727	B
Butte	2711	B C
Benito	2451	B C D
Coteau	2351	B C D
Manitou	2338	C D
Columbus	2298	C D
Waldron	2131	D E
Chris	1765	E

e) Waskada

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3307	A
Benito	3120	A B
Coteau	3087	A B
Alex	3050	A B
Columbus	2837	B C
Manitou	2837	B C
Butte	2810	B C
Waldron	2784	B C
Chris	2731	B C
Neepawa	2494	C

f) Dauphin

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	4146	A
Butte	4139	A
Alex	4099	A B
Columbus	3746	B
Benito	3650	B
Coteau	3636	B
Neepawa	3507	B
Waldron	3363	B
Chris	3000	C
Manitou	2904	C

TABLE 23

Yield rankings 1983.

a) Winnipeg

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3550	A
Butte	3357	A B
Coteau	3270	B C
Alex	3087	C D
Benito	3057	C D
Columbus	3054	C D
Manitou	2960	D
Waldron	2957	D
Neepawa	2957	D
Chris	2604	E

b) Glenlea

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	2774	A
Butte	2488	B
Alex	2474	B
Coteau	2464	B
Benito	2204	C
Waldron	2184	C
Manitou	2128	C
Columbus	2121	C
Chris	2101	C
Neepawa	2088	C

c) Portage

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Butte	3383	A
Glenlea	3330	A B
Coteau	3243	A B
Alex	3143	B
Columbus	2770	C
Neepawa	2714	C D
Manitou	2641	C D
Benito	2614	C D
Waldron	2534	D
Chris	2291	E

d) Teulon

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3330	A
Butte	2977	B
Coteau	2943	B
Benito	2847	B C
Neepawa	2614	C D
Manitou	2511	D E
Alex	2481	D E
Columbus	2364	D E
Chris	2344	D E
Waldron	2218	E

e) Dauphin

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Glenlea	3423	A
Alex	3054	B
Coteau	2914	B C
Columbus	2681	C D
Butte	2594	D E
Chris	2567	D E F
Waldron	2521	D E F
Neepawa	2424	D E F
Benito	2331	E F
Manitou	2271	F

f) Waskada

Cultivar	Mean Yield (kg/ha)	Duncans α = .05*
Alex	3090	A
Coteau	2954	A B
Butte	2867	A B C
Benito	2864	A B C
Glenlea	2863	A B C
Manitou	2764	A B C
Columbus	2714	B C D
Waldron	2707	B C D
Neepawa	2591	C D
Chris	2434	D

Appendix C

TABLE 24

Percent protein (Kjeldahl N x 5.7) 14% M.B. 1982.

Entry	Winnipeg	Glenlea	Portage	Teulon	Waskada	Dauphin	Average
Glenlea	13.1	12.9	14.3	14.2	13.1	13.7	13.6
Neepawa	14.3	13.4	16.1	15.6	15.0	14.6	14.8
Manitou	13.9	13.4	16.0	15.1	14.5	13.8	14.5
Benito	14.4	13.2	16.3	15.7	15.1	16.0	15.1
Columbus	14.9	14.3	16.2	15.7	15.1	15.5	15.3
Chris	14.6	14.8	16.5	16.2	14.8	15.5	15.4
Waldron	14.3	13.9	15.8	15.3	14.4	14.7	14.7
Butte	13.3	12.6	15.0	15.4	13.9	14.1	14.1
Coteau	15.0	15.7	15.7	15.6	15.1	15.0	15.4
Alex	13.9	13.7	15.5	15.0	14.4	14.2	14.5
Average	14.2	13.8	15.8	15.4	14.6	14.7	14.7

TABLE 25

Percent protein (Kjeldahl N x 5.7) 14% M.B. 1983.

Entry	Winnipeg	Glenlea	Portage	Teulon	Waskada	Dauphin	Average
Glenlea	13.8	13.7	15.0	15.0	15.2	15.5	14.7
Neepawa	16.1	14.4	16.1	15.4	15.8	17.0	15.8
Manitou	15.9	15.1	16.3	15.1	15.8	16.6	15.8
Benito	16.3	15.0	17.2	15.7	16.7	17.1	16.3
Columbus	15.7	14.7	17.2	16.2	16.2	17.2	16.2
Chris	15.8	14.6	17.0	15.4	15.9	16.7	15.9
Waldron	15.7	15.5	16.2	15.6	15.6	16.2	15.8
Butte	14.8	14.2	15.4	14.4	15.1	16.2	15.0
Coteau	15.3	15.5	15.8	16.1	15.1	16.8	15.8
Alex	15.3	14.9	16.2	15.2	15.5	16.5	15.6
Average	15.5	14.8	16.2	15.4	15.7	16.6	15.7
Yield Mean	926	694	861	800	837	805	820.5

TABLE 26

Correlation coefficients of flour yield with protein content (with probabilities).

	1982	1983	1982-83
Alex	-.97	-.96	-.70
	.14	.17	.12
Benito	-.47	-.86	-.76
	.68	.33	.08
Butte	-.80	-.94	-.81
	.4	.22	.05
Chris	-.99	-.70	-.82
	.08	.51	.05
Columbus	-.96	.07	-.49
	.17	.95	.32
Coteau	-.81	-.99	-.88
	.39	.03	.02
Glenlea	-.90	-.91	-.84
	.29	.27	.04
Manitou	-.83	.50	-.75
	.37	.67	.09
Neepawa	-.79	-.89	-.65
	.42	.29	.16
Waldron	-.92	-.94	-.92
Overall	-.62		
	.0001		

Probabilities of greater than .05 are not statistically significant

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