A COMPARATIVE STUDY OF CANADIAN AND INTERNATIONAL SOFT WHEATS

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Lisa Joan Nemeth

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BY

LISA JOAN NEMETH

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

TO MY PARENTS

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ABSTRACT

Although considerable research has been done on soft wheats, there are few publications covering comparisons of international soft wheats, and none containing Canadian soft wheats. The purpose of this study was to compare the composition and technological characteristics of representative Canadian soft wheat varieties with wheats from Canada's two main export competitors, Australia and the United States.

Three Canadian varieties, three Australian varieties and five American varieties were analyzed for purity, milling quality, protein content and related tests, starch content and related tests, enzyme activity and related tests and for functionality by technological tests. Correlation analysis was used to determine if a particular test correlated with a milling or baking quality parameter.

The Canadian soft wheats studied were found to be comparable in quality (for cookies) with the American soft wheats and the Australian soft wheat variety Tincurrin. Australian standard white (ASW) varieties were harder and had a medium dough strength which differentiated this class from the others. ASW wheat also had good starch pasting characteristics which is thought to enhance noodle quality. The statistical correlation data showed the alveograph, farinograph, AWRC, starch damage and hardness parameters corresponded with resulting cookie quality.

I. INTRODUCTION

Soft wheat is differentiated from hard wheat by its kernel texture. "Hard" is defined by the Oxford dictionary as "difficult to penetrate or separate into fragments" while soft is described as "easily disintegrated under stress". The endosperm cell contents of hard wheats are firmly bound to each other and to the cell walls even at low protein levels so that complete cells do not separate easily when subjected to stress (Pomeranz and Williams, 1990). This is evident in milling where the starch of hard wheat does not separate readily from the protein. This results in hard wheat flour containing pieces or chunks of endosperm of a larger particle size than soft wheat flour, in which there is a high proportion of free starch granules. Flours from soft wheat have properties different from those of hard wheat due partly to this difference, thus soft wheats are functionally suitable for different end-use products.

In Canada, soft winter wheat is grown mainly in Ontario and Quebec while soft spring wheat is grown in Alberta and south-western Saskatchewan. Both of these wheats have a white pericarp. In 1991, approximately 32.5 million tonnes of wheat were produced in Canada of which 1.2 million tonnes is made up of soft wheat (Harri, 1992). Soft wheat production in Canada is therefore small relative to hard wheat production. It is also important to note that in 1990/91, approximately 980,000 tonnes of soft wheat was exported which would account for approximately 84% of Canada's soft wheat from 1991 if exporting continued at the same level (Harri, 1992). Thus, Canadian breeders and producers of soft wheat must focus on quality of soft wheat not only for Canadian consumption but quality desired abroad.

Soft wheat flour is used in Canada and other countries in a wide variety of product types. In Canada, soft wheat production has developed primarily and traditionally in response to consumer demands for traditional North American items such as cookies, biscuits, cakes, pies, crackers, prepared mixes and ready-to-eat cereals. More recently, new products such as pretzels, cones, wafers, some types of oriental noodles, soup thickeners, European bread, flat breads and steamed breads have made their way into the North American market. Canadian soft wheat is now used for production of these products in Canada as well as overseas.

In the export market for soft wheat, Canada's main competitors are Australia, the United States, Argentina and France (Pomeranz and Williams, 1990). There are few traditional export markets for Canadian soft wheat. In 1984, Canada only provided approximately 3-4% of soft wheat traded on a worldwide basis (Fulcher, 1986). Currently, Canada exports soft wheat to Turkey, Iran, Pakistan and Egypt. Other countries where there is potential to market Canadian soft wheat include Japan, China, Malaysia, Commonwealth of Independent States, Morocco, Bangladesh, Iran, Poland, Indonesia and Syria (Fulcher, 1986; Canada Grains Council, 1991).

In order for Canada to expand its export market for soft wheat, Canadian soft wheat quality must at least meet, or exceed that of its export competitors. It is therefore important to know how our soft wheats compare in quality with those of our competitors. Accordingly, a study was carried out to determine the comparative composition and technological characteristics of representative soft wheat varieties from Canada and its two main export competitors, the United States and Australia. In terms of end-use, the research was focused on the desired quality characteristics for two soft wheat products, sugar snap cookies and Japanese white salted noodles. Results were also examined by statistical correlation to determine if a particular test correlated with a milling or baking quality parameter of the wheat. From this study it may then be possible

to determine if Canadian soft wheat has the quality characteristics needed to challenge the export markets of the United States and Australia.

II. LITERATURE REVIEW

A. Introduction

Research on soft wheat quality has focused on characteristics of soft wheat for use in particular products and their improvement by breeding (Finney and Yamazaki, 1967); (Yamazaki and Greenwood, 1981; Fulcher, 1986; Hoseney, 1986). In Canada, evaluation of the quality of new cultivars of soft wheat emphasizes characteristics that are most appropriate to domestic cookie quality. These characteristics are low protein, low flour viscosity, and high cookie spread (Fulcher, 1986). Very few studies have examined quality characteristics of Canadian soft wheats for products other than cookies. There is also no published information on the comparative quality of Canadian and other soft wheats.

The literature on milling quality of soft wheats will be reviewed first. Review of the literature on chemical composition will focus on protein, carbohydrate and lipid constituents and their individual components. Enzymes (α and ß amylase) are also reviewed because of their negative effect on baking quality. The functional properties that will be considered include farinograph parameters, alveograph parameters, and water binding, pasting, swelling and gelling characteristics.

B. Soft Wheat Milling

The purpose of milling wheat is to break open the grain, remove as much of the endosperm from the bran as possible and reduce the endosperm material, by grinding, into flour

(Brennan, 1982). Soft wheat milling is different from hard wheat milling due to the ease of separation between endosperm particles and the bran in soft wheats. Soft wheat is tempered for a shorter time compared to hard wheat because it takes less time to soften the bran and mellow the endosperm. A higher percentage of soft wheat flour is produced in the breaking of the kernel than with hard wheat. This leads to a shorter reduction system in the further grinding of the endosperm to flour. The ease of breaking and reducing soft wheat kernels to flours greatly decreases starch damage. This will affect the functionality of the resulting flour due to decreased water absorption.

The milling quality of a wheat is usually expressed in the flour yield (%). Measurements of the kernel test weight and thousand kernel weight are usually done before milling and will give an indication of soundness and flour yield. Colour of flour is measured right after milling and is a measure of branny contaminants and therefore milling efficiency. Hardness is measured by the particle size of wholemeal and starch is damaged as a result of the milling process. These two properties are also reviewed in this section.

1. Flour Yield

Flour yield is a measure of the amount of flour in percentage obtained by a particular mill and milling method. It is an important measure because bran is sold for considerably less than the price of flour therefore a high flour yield is preferred. For five soft white winter wheats grown in Canada, flour yield was found to average 72.5% and 15 U.S. soft white spring wheats yielded an average 69.5% flour (Kaldy and Rubenthaler, 1987). In a study of 83 soft red and white winter wheats, Gaines (1985) attained flour yields in the range from 74.1 to 78.0%. This range of variation in the flour yield of soft wheats is economically significant.

2. Test Weight

Test weight is the weight of a specific volume of grain, usually expressed in kilograms per hectolitre (kg per hL). This test gives an index of soundness and flour yield of the grain, and is based on two factors: the degree of packing (shape and uniformity) and density. Shrunken or immature kernels have lower test weight than compact, hard kernels. A higher test weight has been found to correlate with a higher milling yield (Cordeiro and Williams, 1992).

3. Thousand Kernel Weight

In this test the number of kernels in a 20-g sample of wheat is counted and the results converted into weight for 1000 kernels. The test is a measure of average kernel size and mainly reflects kernel size, but also density. For some classes of wheat, thousand kernel weight is related to milling quality as expressed by flour yield because a larger kernel has a higher ratio of endosperm to bran (Matsuo and Dexter, 1980). Kernel size is not uniform in all wheat samples, and thousand kernel weight may be misleading because it is an average value (Matsuo, 1982).

4. Colour

The colour of the flour is important, especially for a product such as white Japanese noodles where a very white colour is desirable (Nagao et al, 1976). A very white flour colour is not as important in a product such as cookies or crackers where a golden colour is expected upon baking (Hoseney et al., 1988). Colour of low-extraction flour reflects the intrinsic colour of the endosperm whereas colour of high-extraction reflects the degree of contamination by bran. Colour is measured by comparing the amount of light reflected from a flour surface to that reflected from a standard white surface.

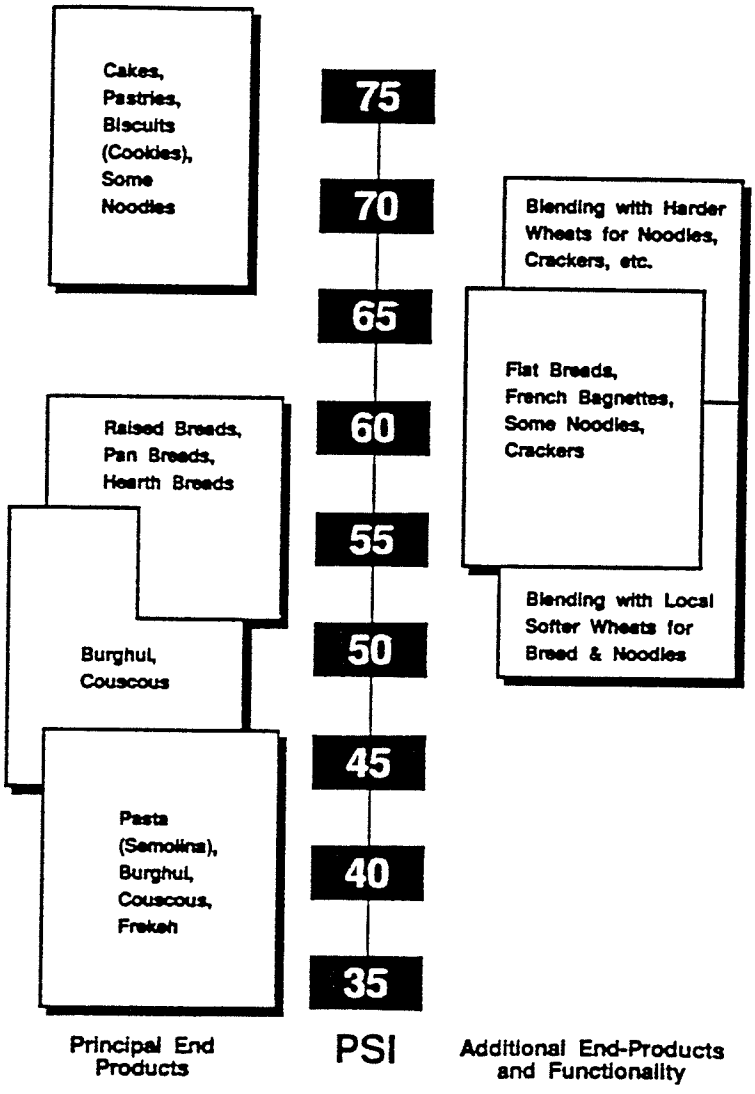
5. Hardness

Wheat hardness is under genetic control to a high degree, but up to a point it can be affected by growing conditions. A hard wheat will never vary in hardness to the extent of becoming soft, and vice versa (Pomeranz and Williams, 1990) Particle size index (PSI) is an indication of the relative kernel texture (hardness or softness) of the wheat. As previously described, soft wheat fractures into a finer particle size than hard wheat and therefore more particles from soft wheat meal will pass through a standard sieve as measured by PSI. A high PSI score (68-75%) is indicative of a soft wheat, and wheats of this type are suited for use in soft wheat products such as cookies, crackers and cakes. Noodles require a lower PSI, that which is found in medium hardness wheat (Fig. 1).

6. Starch Damage

Starch damage occurs during milling where starch granules may be cracked, chipped or flattened by the grinding action of the rolls. This is an important flour parameter because amylase breaks down damaged starch more readily than undamaged granules (Minor, 1984). Starch damage can also increase water absorption from about 90% of the weight of the undamaged starch granules to over five times the weight for damaged granules (Williams, 1970). This increase in absorption is undesirable in soft wheat technology, as it will increase the viscosity of the cookie dough and limit cookie spread. Soft wheat flours generally have less starch damage because, during milling, the protein and starch separate easily relative to hard wheats. Quality studies of Canadian wheat illustrate this difference. In 1992, No. 1 Canadian Eastern Soft White Winter Wheat had an average starch damage of 6 Farrand units, while No. 1 Canada Western Hard Red Spring Wheat flour (at 13.5% minimum protein) had starch damage of 30 Farrand units (Canadian Grain Commission, 1992).

FIGURE 1. Wheat Hardness Scale (Williams, 1993b.)


Cakes, Pastries, Biscuits (Cookies), Some Noodles
75
70
65
60
55
50
45
40
35
Blending with Harder Wheats for Noodles, Crackers, etc.
Flat Breads, French Bagnettes, Some Noodles, Crackers
Blending with Local Softer Wheats for Bread & Noodles
Raised Breads, Pan Breads, Hearth Breads
Burghul, Couscous
Pasta (Semolina), Burghul, Couscous, Freke
Principal End Products
PSI
Additional End-Products and Functionality

C. Soft Wheat Composition

1. Protein

a. Protein Content. Soft wheats vary widely in protein content. Fulcher (1986), reported that Canada Western Soft White Spring (CWSW) and Canada Eastern Soft White Winter (CEWW) wheats routinely contain protein levels in the 9-10.5% range. For 83 American soft red and white wheats, Gaines (1985) reported protein contents in the range of 8.0-12.7%. In Australia, Crosbie (1991) found that Australian Soft (A. soft) wheat contained 9.0% protein on average, while the stronger soft wheat, Australian Standard White (ASW), had protein levels in the 9-11.5% range.

b. Osborne Fractions. Studies on the Osborne fractions of wheat proteins (Osborne, 1907) have focused on hard wheats because of the implication of these fractions in breadmaking quality (Orth and Bushuk, 1972). In this fractionation, the proteins of flours are divided into five groups according to their solubility in water (albumins), 0.5M sodium chloride (globulins), 70% ethanol (gliadins) and 0.05M acetic acid (glutenins) and insolubility in 0.05M acetic acid (residue). A straight grade flour from hard red spring wheat, which is a typical high quality breadmaking wheat, was found to have 16.4% of its protein soluble in water, 3.4% soluble in 0.5N sodium chloride, 33.7% soluble in 70% ethanol, 13.6% soluble in 0.05N acetic acid and 33.4% insoluble protein (Bushuk, 1982). Recovery of % total protein using this type of fractionation has been found to range from 86.8-97.3% (Orth, 1971). The loss of protein is thought to be due to loss of low molecular weight materials during dialysis used to separate salt solubles from water solubles and the cumulative effect of incomplete recoveries of protein due to normal experimental error (Orth, 1971). Orth (1971) also examined the effect of environment (location) on protein solubility distribution and found it to be quite small. He concluded that protein solubility

distribution is largely a genotypic characteristic. Chen and Bushuk (1970) also concluded that the high quality of bread from hard red spring wheat may be due to high amounts of insoluble residue proteins and low content of soluble proteins relative to other cereal species. A higher content of acetic acid insoluble and lower content of acetic acid soluble proteins are required in flour of good breadmaking quality (Orth and Bushuk, 1972). Tsen (1967) stated that the difference in solubility in acetic acid may be due to soft wheats having smaller protein aggregates than hard wheat flours, or that the structure of the soft wheat large protein aggregates may be more liable to disaggregation than that of hard wheats.

c. Wet Gluten. Gluten proteins are those reputed to give a dough the viscoelastic properties necessary for breadmaking. Quantification of gluten proteins is (ostensibly) a method of studying the quality of protein in a particular wheat. In a study of 26 wheats of poor to good breadmaking quality grown in Western Canada, Ng (1987) found the wet gluten content to range from 32.2 to 41.6%. These values were significantly correlated with flour protein content but not with bread baking quality. Wet gluten content may not always necessarily be a predictor of breadmaking quality but soft wheats, which do not have good breadmaking quality, generally have a lower gluten content than hard wheats. The lower gluten content in soft wheat doughs is well suited to cookies and cakes as excessive gluten will result in a tougher, undesirable product.

d. Friabilin. Friabilin is a 15 kilodalton protein associated with starch granules. It is thought to have potential as a biochemical marker for hardness in wheat because there appears to be a very good correlation between friabilin content on starch isolated from wheat and the particle size index (PSI) of the wheat (Greenwell and Schofield, 1989). SDS-PAGE (sodium dodecyl sulphate-polyacrylamide gel electrophoresis) is carried out to detect the presence of friabilin but is not used

as a quantitative method.

e. Alkaline Water Retention Capacity (AWRC). AWRC is used specifically to predict flour quality for cookie baking. A good quality cookie flour binds water poorly; alkaline conditions such as those found in cookie dough (Finney and Yamazaki, 1953) are used to test the ability of a flour to bind water under such conditions. Low AWRC values are considered a necessary prerequisite for good soft wheat flour quality (Finney, 1989). Kaldy and Rubenthaler (1987), in a study of Canadian soft wheats, found that winter wheat flours had significantly lower AWRC than did flours from spring wheats. The values for winter wheat flours ranged from 53.5-55.8% with a mean of 54.8% while those for spring wheat flours ranged from 58.5-63.7% with a mean of 60.3%.

f. MacMicheal Viscosity. MacMicheal viscosity is a measure of the water binding of flour under acidic conditions and is therefore more applicable to products which are acidic in nature such as crackers or bread. The increase in viscosity is dependent upon swelling of gluten and starch and probably reflects both starch and protein properties. Mechanically damaged starch causes higher viscosity due to increased absorption of water by the starch. This causes a change in the value measured by MacMicheal viscosity test. In an evaluation of soft wheats from the United States, Australia, France and Japan, Nagao et al. (1977) found MacMicheal viscosity values ranging from 32 to 87 units. The lower the reading, the better the soft wheat flour quality for cookies as water remaining is available to increase cookie spread which is desirable (Kaldy and Rubenthaler, 1987). Values for cookies should fall between 40-65 units, for layer cakes between 35-65 units, while bread requires higher values (Mailhot and Patton, 1988).

2. Carbohydrates

a. Starch. Wheat stores energy in the form of starch granules. The starch content of wheat has

been reported to be in the 63-72% range (Lineback and Rasper, 1988). Soft wheat varieties generally have a higher percentage of starch (69%) than hard wheat varieties (64%) because of their lower protein content (Miller, 1974). Starch in wheat flour is most important because of its functional properties (gelling, thickening and pasting). Starch granules contain two carbohydrate polymers: amylose - an essentially linear polymer of α (1,4) glucose with limited branching, and amylopectin - a branched α (1,4) and α (1,6) polymer of glucose. The ratio of amylose to amylopectin is under genetic control and has been found in wheat to have little variation (Hoseney et al., 1983). Small differences in amylose content between cultivars have been found to cause appreciable differences in corresponding starch paste viscosity and eating quality of noodles (Crosbie, 1991; Moss and Miskelly, 1984). Amylose content may vary from 19-26% in wheat starch and paste viscosity is inversely proportional to amylose content (Chen, 1993).

b. Starch Properties. Some soft wheats, such as Australian Standard White (ASW) from Western Australia, have been found to be highly suitable for the production of Japanese white salted noodles. Because these noodles are made up of a very simple formula comprising flour, salt and water, the influence of flour quality is greater than in other flour products where other ingredients are included (Endo et al., 1989). Superiority of Western Australian ASW wheat for noodles is thought to be due mainly to its starch characteristics (Crosbie, 1991). It is therefore important that starch properties are examined to distinguish flours with potentially good noodle quality.

i. Pasting. The Brabender Visco-Amylograph is used for determination of flour and starch pasting. Pasting is the phenomenon of starch granule swelling, exudation of some granule constituents and eventually total disruption of granules to form a viscous paste (Atwell et al.,

1988). The maximum paste viscosity (peak viscosity) is attributed to water being taken up by the starch as crystalline structure is lost and the granule swells (Hoseney et al., 1983). The amylograph measures the continuous increase in viscosity of a starch or flour slurry as a function of temperature and time. Amylograph gelatinization temperatures are lower for starch of flours found to be of good quality for noodle making (Oda et al., 1980). These flours have also been found to have a high starch paste peak viscosity (Oda et al., 1980). The measurement of paste peak viscosity has been the most widely accepted means of selecting flours for Japanese noodles (Oda et al., 1980). The only negative aspect of this test is the large quantity of starch that is required. This limits the application of the amylograph test to the later generation in breeding programs. Unique properties of ASW wheat starch were summarized by Konik et al. (1992) to include a high starch peak viscosity, low gelatinization temperature, short time to peak and high breakdown when compared to starches from flours of other wheat varieties used to make noodles.

ii. Swelling Properties. There are two measures of the swelling properties of starch, swelling power and swelling volume (Crosbie, 1991). Swelling power is the weight of sedimented starch gel relative to its dry weight obtained after gelatinization of a sample of starch in water at a given temperature and time followed by centrifugation. Swelling volume is the volume of this sedimented gel. These values (swelling power and volume) have been found to correlate with starch paste peak viscosity as well as noodle eating quality parameters such as softness and elasticity (Crosbie, 1991). In a study of 13 cultivars grown in Australia at two different sites, Crosbie (1991) obtained swelling power values in the range of 17.0-21.9 g/g. Swelling volume values ranged from 7.3-9.2 ml grown at one location in 1987. In 1988, at a second location, swelling power values ranged from 14.9-20.6 g/g and swelling volumes from 6.6-8.8 ml. It is hoped that these two parameters will be an alternative for predicting the eating

quality of noodles in early stages of breeding because of the smaller sample required for the tests.

iii. Starch Gel Strength. This test is an attempt to remove some of the subjectivity involved in using a sensory panel for assessment of noodle textural quality. An Ottawa Texture Measuring System (OTMS) can be used to evaluate starch gel texture which may be related to noodle texture and therefore noodle quality. The energy and amount of deformation required to break the starch gels of different wheat varieties are compared. Nagao et al. (1986) believe it is not possible to replace sensory tests by machine methods due to regional preference of noodles; hence developing a standard method to evaluate noodle texture quality becomes a problem.

iv. Differential Scanning Calorimetry (DSC). DSC measures the heat energy required for starch gelatinization. In surplus water, this process exhibits a single thermal transition endotherm which facilitates measurement of peak temperature (°C) and enthalpy (J/g) of starch gelatinization. Four factors affect starch gelatinization: the environment, which will control the starch granule structure, and the amylose/amylopectin ratio, lipid content and solvent effects which can cause annealing and in turn increase the time to peak (Biliaderis, 1993). The efficiency of this technique to measure soft wheat quality has not been evaluated. A low starch gelatinization temperature is thought to be a characteristic of soft wheat flour which is associated with superior noodle quality (Konik et al., 1992). The amylograph has been used to detect gelatinization temperature (Nagao et al., 1977). There are problems using this method to characterize gelatinization temperature because early stages of starch gelatinization are not detected by the amylograph. This is due to sensitivity of the equipment where, by the time the amylograph detects an increase in viscosity, an appreciable amount of swelling has already taken place. The temperature at which there is a detected change in viscosity (gelatinization temperature) is always higher than the actual temperature of granule swelling (Rasper, 1988).

The sensitivity of DSC is much greater than the amylograph, and may therefore overcome some of these problems.

c. Nonstarch Polysaccharides. The cell wall material of the wheat kernel is composed primarily of nonstarch polysaccharides. Cellulose is the major structural polysaccharide of plants and is located in the bran of the wheat kernel. It is classified as insoluble fibre because it is composed of ß (1,4) glucose units which are not broken down by enzymes in the human digestive tract. This type of fibre is important for its role in treatment of constipation and diverticulitis and may have other health advantages (Bread Research Institute, 1989). Wheat endosperm contains approximately 0.3% cellulose while the cellulose in the bran cell walls accounts for approximately 29% of the total nonstarch polysaccharides (Lineback and Rasper, 1988). Other non-starch polysaccharides found in wheat are the pentosans. Pentosans are heterogenous and can occur in cell walls of the kernel and in stems and green parts as well (Izydorczyk, 1989). Approximately 75% of total pentosans are water insoluble (sometimes referred to as hemicelluloses); the other 25% is water soluble (Mares and Stone, 1973). A typical wheat flour contains 2-3% total pentosans. Although this is a small fraction of the flour this does not preclude the functional properties of pentosans. Pentosans contribute to the breadmaking value of wheat due to their very high water absorbing capacity (Bushuk, 1966) and their consequent ability to affect rheological properties of wheat flour doughs and bread (Lineback and Rasper, 1988).

3. Lipids

Wheat flour contains about 2% of lipids (Pomeranz and Chung, 1978). Total wheat flour lipids contain approximately equal amounts of nonpolar and polar lipids. Starch lipids are often not included in literature values because they are not extracted under normal extraction procedures (ie. petroleum ether) (Chung and Pomeranz, 1981). Although lipids are present in

such a small quantity in the flour, they have important functional properties. Native flour lipids, particularly polar lipids, are essential for obtaining the beneficial effects of shortening on loaf volume and crumb grain in breadmaking (Pomeranz, 1988). Cookies baked from flours that had been extracted with hexane had lower spread and poorer top grain appearance when compared with cookies from untreated flours (Clements and Donelson, 1981). Cakes made from defatted flours had a smaller cake volume and finer cell size than those from normal flours (Seguchi and Matsuki, 1977).

4. Enzymes

α-Amylase is an endoenzyme that breaks α (1,4) glucosidic bonds of starch on a random basis. This results in a breakdown of the starch to dextrins and sugars during breadmaking (Kruger and Reed, 1988). At low temperatures, mainly damaged starch is degraded. However, when starch gelatinizes at higher temperatures, it too becomes accessible to enzyme attack. α-Amylase is present naturally in wheat but at a very low level. When there is a wet harvest and pre-harvest sprouting occurs, α-amylase levels escalate. Excessive α-amylase affects the quality of yeast leavened products such as bread and crackers by causing a stickiness in doughs and crumbs (Kruger and Reed, 1988). Noodle quality is also affected by excessive α-amylase which causes darker, unattractive noodles (Edwards et al., 1989).

ß-Amylase is an exoenzyme that attacks starch from the nonreducing ends of the polymer and yields maltose units. It has practically no action on intact starch granules, but the degrading action of α and ß amylase in combination is faster and more complete than either enzyme alone (Hoseney, 1986).

α-Amylase activity in flour is measured in a number of ways. The Falling Number test is the time, in seconds, for a plunger to fall a fixed distance through a hot aqueous flour

suspension which may be liquified to various degrees by α-amylase. Dextrins and sugars are less viscous than gelatinized starch, therefore, α-amylase decreases viscosity so that the plunger falls through the slurry at a quicker rate. The lower the falling number the greater the amount of α-amylase present. A Falling Number value of 250 sec (minimum) is required for cookies and cakes (Mailhot and Patton, 1988). The activity of α-amylase is also measured with the use of a grain amylase analyzer. The breakdown of a starch-like solution called ß-limit dextrin (which is resistant to breakdown by ß-amylase) by α-amylase is measured. Maltose value is a measure of the amount of starch in a 10 g flour sample broken down to maltose by α-amylase over a certain time (usually one hour). Flour used for home baking should have a maltose value of 290-320 mg (Mailhot and Patton, 1988). Gassing power measures the effect of a combination of enzyme activity and degree of starch damaged in the flour by quantifying the amount of carbon dioxide produced from 10 g of a yeasted flour dough under controlled time and temperature. It is valuable to the baker because it indicates whether a bakery flour has adequate gas production for breadmaking. The gassing power requirement for flour used in home baking is 400-450 mm Hg using a five hour fermentation (Mailhot and Patton, 1988). Another popular method for detection of α-amylase activity quantification is the previously mentioned amylograph test. As starch gelatinizes, the viscosity increases but the α-amylase activity counteracts this effect. Maximum viscosity obtained is affected by the amount of enzyme present. Flour that is used for home baking should have an amylograph peak viscosity of 450-600 BU (Mailhot and Patton, 1988). In Japan, millers recognize that a minimum amylograph viscosity of 400 BU (65 g flour + 450 ml water) is necessary for the production of good quality noodles (Tipples, 1988). This test is especially useful to bakers who want to know not only the α-amylase level but its interaction with starch that may or may not be damaged.

D. Soft Wheat Functionality

1. Farinograph

The Brabender farinograph evaluates the physical properties of dough to provide some indication of how it may perform during mixing to produce a particular end product. The farinograph uses two Z-shaped mixing blades rotating in opposite directions and measures the power needed to mix a dough at constant speed. Properties measured are water absorption (amount water absorbed at a maximum consistency of 500 BU), development time (time to reach maximum consistency), mixing tolerance index (MTI) (difference in BU between the middle of the curve at the peak and the middle of the curve measured five minutes after peak viscosity is reached), degree of softening (change in consistency after 12 minutes from peak) and stability (time between reaching 500 BU and dropping below 500 BU). The farinograph is capable of differentiating potential breadbaking performance of flours of the same variety but with different protein contents and also flour of different varieties at a constant protein content (Bushuk et al., 1969). Farinograms from flours of weak and medium strengths, which are suitable for cookies and noodles respectively, have been described. Weak flours have low absorption (less than 55%), DDT less then 2.5 min. and MTI of greater than 100 BU. Medium strength flours have a water absorbance of 54-60%, DDT of 2.5-4.0 min. and MTI of 60-100 BU (Preston and Kilborn, 1990). Medium strength flours have stabilities of 4-8 minutes (Williams, 1993a.). The farinograph test is not used extensively in the evaluation of functional properties of soft wheats.

2. Alveograph

The Chopin alveograph measures the extent to which a properly formed dough can be extended as a bubble under pressure. The instrument uses air pressure to blow a bubble from a disc of dough which allows for extension of dough in all directions. The Brabender

extensigraph (not used for soft wheats) stretches the dough only in one direction. The pressure of the air in the dough bubble as a function of time is recorded as a curve. The height x 1.1 (termed overpressure (P)) and length (L) of the curve are used as measures of resistance to deformation and of extensibility of the dough respectively. The area under the curve is proportional to the work involved in deformation until rupture and is represented by W. This variable has been found to correlate to loaf volume and flour strength. Dough stability is measured by overpressure/length (P/L). Swelling index (G) is found through calculation (manipulation) of the L value and is dependent upon properties described as springiness and shortness of dough. Several studies have found the W value of the alveogram curve to provide the highest correlation to baking properties of bread (Faridi and Rasper, 1987). For 43 soft white winter wheats grown in Ontario, Rasper et al. (1986) obtained alveograph values ranging from 16.1 to 27.3 mm for P, 86-201 mm for L, 0.11 to 0.30 for P/L, 17.0 to 28.8 ml for G and 21.0 to 71.7 (10^{-4} x J) for W. The alveograph test is used extensively, especially in Europe to measure soft wheat quality.

3. Sodium Dodecyl Sulphate (SDS) Sedimentation Volume

SDS-sedimentation is an estimate of dough strength and baking quality of bread of a very small sample of wholemeal and is therefore useful in early generation screening in wheat breeding programs. SDS-sedimentation is the measurement of sedimentation of ground wheat in a solution of SDS and dilute lactic acid. The sediment consists of a mass of swollen gluten particles in which are imbedded most of the other insoluble wheat constituents. Sedimentation test value depends upon both the quantity and quality of flour gluten and for this reason is considered to be a good estimate of potential bread loaf volume (Zeleny, 1947). A smaller volume represents a weaker flour which would be more desirable for cookies. Preston et al. (1982) found Canadian

SWS wheat to have a sedimentation volume of 25 ml, CEWW a volume of 38 ml and No. 1 CWRS (at 13.5% protein) a volume of 62 ml.

4. Pelshenke Test

The Pelshenke test or wheatmeal fermentation time test, is another measure of the strength of ground wheat ground. A doughball made of ground wheatmeal and yeast suspension is dropped into water. As CO_2 is produced, the doughball rises to the surface. The time from commencement of the test until the doughball falls to the bottom of a beaker is taken as the Pelshenke time. A strong wheat will have a Pelshenke time of greater than 200 min or longer; a weaker wheat will fall in 50 min or less (Williams, 1993a.). A good soft wheat will have a Pelshenke time of less than 20 min, while any wheat with a Pelshenke time of above 25 min is considered too high for this class (Williams, 1993a.). The Pelshenke time is dependent on both quantity and quality of gluten and is fairly widely used as an estimate of potential bread baking strength.

5. End Products

Not withstanding the various test methods enumerated above, the most reliable way of testing a flour for end product suitability is to test it as the end product. This is particularily true in soft wheat quality analysis where most of the quality testing was designed for predicting potential breadmaking quality. Cookies from a standard formula are evaluated by measurement of characteristics such as width (spread), thickness, spread/thickness, appearance (cracks), colour and uniformity. Excellent quality cookies have a greater spread than poor quality cookies. Cookies baked from 14 samples of soft white winter wheat cultivars grown in Ontario in 1983 and 7 cultivars grown in 1984 had a range in spread of 8.6-9.2 cms (Rasper et al., 1986).

Another end product frequently used to evaluate soft wheat flour is high-ratio white layer

cake (Gaines, 1985). Cakes are evaluated for overall volume and internal characteristics such as cell structure, grain, texture, colour and flavour.

Soft wheat flour is also used in the production of some noodles or blended with harder wheat flour in the production of other noodles. Countries such as Australia and Japan which produce large quantities of soft wheat to be used for noodles have developed a standard formula for noodle quality evaluation. Noodles are evaluated for colour (whiteness), smoothness, softness and elasticity by a control taste panel (Konik et al., 1992). ASW wheat from Western Australia is preferred in the production of Japanese white salted noodles due to its moderately high dough strength and starch pasting properties (Konik et al., 1992).

E. Concluding Statement

The above review of the literature indicates that while some research has been done on national soft wheats, only a few of the publications covered comparisons of international wheats and only two of those (Rasper et al., 1986; Kaldy and Rubenthaler, 1987) included Canadian wheats. Accordingly, the proposed comparative study of Canadian, Australian and American soft wheats is definitely warranted in the context of the potential export market for these wheats.

III. MATERIALS

A. Wheat Samples

Eleven wheat samples were used in this study. The samples are described by pedigree and/or wheat class in Table 1. Harus and Augusta were provided by Dr. L. Sugar of W.G. Thompson & Sons Limited, Hensall, Ontario. Fielder was supplied by Dr. P. Sadasivaiah of the Agriculture Canada Research Station, Lethbridge, Alberta. Stephens was provided by Oregon State University, Cardinal by Diener Brothers of Reynolds Indiana and the Club wheat sample by Dr. C. Morris of the Western Quality Wheat Laboratory, Pullman, Washington. The variety name of the Club wheat sample is unknown. Caldwell and Florida-302 were supplied by Dr. P.C. Williams of the Grain Research Laboratory (GRL), Winnipeg, Manitoba. The Australian samples Tincurrin, Eradu and Rosella were provided by Dr. G. McMaster of the Bread Research Institute, North Ryde, Australia.

B. Reagents and Chemicals

Coomassie Brilliant Blue G250, Coomassie Brilliant Blue R250, glycine, glycerol, and TRIS (tris hydroxylmethyl amino methane) were purchased from Sigma Chemical Company, St. Louis, MO, USA. SDS (sodium dodecyl sulphate) and PDA (piperizine diacrylamide) were of electrophoretic grade and were obtained from BioRad, Richmond, CA. Acrylamide, bisacrylamide (N,N'-methylene-bis acrylamide) and the electrophoresis calibration kit for molecular weight determination of polypeptides were also electrophoretic grade and obtained from

TABLE 1. Pedigree, Class and Origin of Wheat Varieties.

No.	Variety	Pedigree, Class and Origin
1	Stephens	Nord Desprez/CI13438, SWW[1], USA
2	Tincurrin	Gluclub/3/Chile 1B//Insignia/Falcon, Soft, Australia
3	Fielder	Complex Pedigree, SWS, Canada
4	Eradu	Ciano/Gamenya, ASW, Australia
5	Harus	Fredrick/Yorkstar, SWW, Canada
6	Augusta	Genesee/Redcoat,x B2747//Yorkstar, SWW, Canada
7	Rosella	Farrolunga/Heron//2*Condor/3/Quarrion sib, ASW, Australia
8	Cardinal	Virginia 635212 x Logan//Blueboy x (Logan x2), SRW, USA
9	Club	Unknown, Club, USA
10	Caldwell	Purdue 5724 B3-5P-8-2*2/Siele Cerros, SRW, USA
11	Florida-302	Coker 65-20//Purdue 4946 A4-18-2-10-1/Hadden/3/Vogel 5/Anderson//Purdue 4946 A4-18-2-10-1/Hadden, SRW, USA

[1] SWW = Soft white winter
SWS = Soft white spring
ASW = Australian standard white
SRW = Soft red winter

Pharmacia AB, Uppsala, Sweden. Amyloglucosidase from "Aspergillus niger" and hexokinase/glucose-6-phosphate dehydrogenase were purchased from Boehringer Mannheim Canada Dorval, Que. Thermal α-amylase was provided by Dr. A.W. MacGregor, GRL, Winnipeg, Manitoba. All other chemicals were of analytical grade. Distilled deionized water was used in all experiments. All experiments were carried out at least in duplicate or with the use of a check sample. Duplicate results are reported as averages. Results are calculated using a constant moisture basis (13.5% wheat, 14% flour), on a dry basis or on an "as is" basis, as reported.

IV. METHODS

A. Sample Preparation and Milling

All wheat samples were cleaned, scoured and tempered overnight at room temperature to a moisture content of 14.5%. Samples were then milled using a modified Allis-Chalmers laboratory mill using the GRL sifter flow as described by Black et al. (1980).

1. Flour Yield

Flour yield was expressed as percent of flour yielded by the cleaned grain.

2. Test Weight

Test weight was determined using a 1 L Schopper chondrometer. The weight in grams of the measured litre of wheat is divided by 10 and the result was reported on an "as is" moisture content basis in Kg/hl.

3. 1000 Kernel Weight

1000 kernel weight was determined by electronically counting the number of seeds in a 20 g sample with a Seedburo counter. The weight of 1000 kernels is calculated and reported on a 13.5% moisture basis.

4. Colour

Flour colour values were determined using a Simon Series IV Flour Colour Grader which gives the relative reflectance of a flour-water slurry. Results are reported numerically as arbitrary scale units; the lower the number, the brighter the colour. Negative values indicate very

bright colour.

5. Starch Damage

Starch damage was determined according to the method of Farrand (1964) with 5g flour (14% moisture basis) using α-amylase (ß subtilis) in extracting solution. 10990 α-amylase (ß subtilis) is supplied by the United States Biochemical Corp. Cleveland, Ohio.

6. Hardness

The wheat hardness was determined by particle size index (PSI) which is an indirect measure of grain hardness. Wholemeal was used and sieved according to the AACC standard method (method 55-30, AACC 1989) and by NIR according to the AACC standard method (method 39-70, AACC 1987). NIR values were determined using a DICKEY-john Instalab 600 NIR product analyzer.

B. Varietal Purity Assessment

1. Sample Preparation

Four single seeds and one 5g sample of each variety were analyzed for homogeneity of high molecular weight glutenin subunits by sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) and gliadin components were analyzed by PAGE. Extracts for PAGE and SDS-PAGE were prepared from the same single seeds or bulk samples by the methods of Sapirstein and Bushuk (1985) and Ng and Bushuk (1988), respectively. If the electrophoregram of the bulk sample matched that of the single seed samples, the varietal sample was considered to be homogeneous (pure). If, however, the bulk and single seed electrophoregrams did not match, further single seeds were tested to estimate the degree of contamination. Single seeds were pulverized and extracted by 70% ethanol. A 10 μl aliquot of

placed into another microcentrifuge tube where 10 μl PAGE extract dilution solution was added. This extract was ready for analysis by PAGE. The remaining supernatant and residue from the ethanol extraction were combined with 250 μl SDS-PAGE extracting buffer solution. The grain-buffer mixture was allowed to stand for 2 hours at room temperature with occasional mixing. The mixture was then heated in a boiling water bath for three minutes, removed and allowed to cool. The mixture was centrifuged and the resulting supernatant used as the protein extract for SDS-PAGE.

2. Electrophoresis

PAGE was carried out on a vertical apparatus described by Sapirstein (1984). The acrylamide concentration was 6%. During electrophoresis, the gels were cooled by circulating water at 21 °C. A constant currant of 50 Ma was used for approximately four hours.

SDS-PAGE in the presence of mercaptoethanol was performed according to the method of Ng and Bushuk (1987). Proteins were electrophoresed on an LKB 2001 vertical electrophoresis unit with a stacking gel of 3.03% acrylamide and bisacrylamide and a separating gel of 17.33% (acrylamide and bisacrylamide). The current used was 5 mA (per gel) for the first 2 hours, followed by 18 hours at 10 mA and a final 2 hours at 15 mA. The wheat variety Neepawa (official standard of the Canada Western Red Spring class) was run with PAGE and SDS-PAGE gels as a molecular weight standard.

C. Chemical Analyses

1. Moisture Content of Grain and Flour

The moisture content of whole grain samples and flour samples was determined according to the AACC standard methods (method 44-15A and 44-18, AACC 1983).

2. Ash Content of Flour

Ash content of flour (14% moisture basis) was determined according to the AACC standard method (method 08-01,AACC 1983).

3. Protein Content of Grain and Flour and Related Analysis

a. Protein Content. Total nitrogen of flour (14% moisture basis) and whole wheat meal (13.5% moisture basis) was determined by the Kjeldahl method as modified by Williams (1973). Protein content was obtained by multiplying the nitrogen content by the conversion factor 5.7 according to Tkachuk (1969). The protein in flour was also determined by NIR spectroscopy using a DICKEY-john Instalab 600 product analyzer.

b. Osborne Fractionation. Flour proteins were fractionated into residue (0.05*M* acetic acid insoluble), glutenin (0.05*M* acetic acid soluble), gliadin (70% ethanol soluble), globulin (0.5*M* NaCl soluble) and albumin (water soluble) by the method of Chen and Bushuk (1970). A 12-14 kDa molecular weight cut-off membrane tubing was used in the dialysis in water of the salt solubles to yield a precipitate of globulins. All fractions were freeze dried and stored in sealed containers at 4 °C. Protein content was determined as total nitrogen by the micro-Kjeldahl method (AACC method 46-13, 1988). Total nitrogen was then multiplied by the conversion factor of 5.7 (Tkachuk, 1969). The protein contents of each fraction were expressed as percent of total recovered protein to facilitate comparison between samples. All fractionations were carried out in duplicate.

c. Wet Gluten Content. Flour wet gluten content was determined according to the ICC standard method (method 137 ICC, 1982) using 10 g flour (14% moisture basis) using a Glutomatic 2100. Samples were dried twice by the centrifugation method before weighing.

d. Friabilin. The presence of the protein friabilin was detected using SDS-PAGE according to

the method of Bettge (1992) and Bettge et al. (1992). Friabilin was extracted from 30 mg flour by using 0.5 ml 0.1 *M* NaCl for one hour with mixing. After this time, a microfuge pestle was used to grind the precipitate and form a gluten ball, leaving the starch in solution. The gluten ball was allowed to settle and the supernatant (with starch) was transferred to a separate microfuge tube and centrifuged three minutes at 11000 X g. The supernatant was discarded and the pellet washed with 1 ml water, centrifuged and the supernatant discarded . This water washing step was repeated two times. The same washing procedure was carried out one more time using 1 ml acetone, discarding the supernatant, and allowing all remaining acetone to evaporate before proceeding. The washed dried starch pellet was then extracted with 100 μl 50% isopropanol/50% 0.1*M* NaCl at room temperature for 30 minutes and centrifuged 3 minutes at 11000g. The supernatant was transferred to another microfuge tube, 60 μl acetone added, mixed and placed in a -20 °C freezer overnight. The next day, the extract was removed from the freezer, centrifuged at 11000 X g for 3 minutes, the supernatant transferred to another microfuge tube, 200 μl acetone added, the mixture mixed, and again placed in the freezer overnight. On the final day of extraction, the extracts were removed from the freezer, spun for 3 minutes at 11000g and dried until no discernable odour of acetone was present. A 100 μl aliquot of sample buffer (standard recipe, with ß-mercaptoethanol) was added and mixed. Extracts were heated for 15 minutes at 70 C, spun 3 minutes at 11000 X g and were ready for electrophoresis.

SDS-PAGE in presence of mercaptoethanol was performed on Bio-Rad mini-protean II Dual Slab Cell System with a stacking gel of 4% acrylamide and piperizine diacrylamide (PDA) and a separating gel of 13.5% (acrylamide and PDA). The power used was 200 volts for approximately 45 minutes. Six standards from a low molecular weight electrophoresis calibration kit (Pharmacia) were used. These standards ranged from 1700-17000 Da and were extracted

using the standard method. Gels were stained for at least 1/2 hour with 0.1% Coomassie Blue R-250 in fixative (40% MeOH, 10% HOAc) and then destained with 40% MeOH/10% HOAc for 1-3 hours.

e. Alkaline Water Retention Capacity. Alkaline water retention capacity (AWRC) was determined using 1 g flour (14% moisture basis) according to the AACC standard method (method 56-10, AACC 1983).

f. MacMicheal Viscosity. MacMicheal viscosity was determined using 20 g flour (14% moisture basis) according to the AACC standard method (method 56-80, AACC 1983).

4. Starch Content and Related Analyses

a. Starch Content. Total starch content of wheat was determined based on the method of Kim and Williams (1990). Duplicate 0.25 g samples of ground wheat were weighed (on a dry weight basis) into 50 ml plastic centrifuge tubes. Ten ml of 0.20*M* NaAcetate/1 μM $CaCl_2$ (pH 5.5) was added, vortexed and placed in a 100°C waterbath for 5 minutes. A 200 μl portion of thermostable α-amylase was added, the sample vortexed and then incubated at 100°C for another 30 minutes in a shaking waterbath. The samples were removed from the heat, cooled below 60°C and 100 μl amyloglucosidase solution added. Samples were vortexed and placed in a 35°C shaking waterbath overnight. After this incubation, test tubes were centrifuged at 2000 X g for 10 min at 17°C. Supernatant was removed into a 25 ml volumetric flask. Remaining sample was washed with 10 ml distilled water, vortexed and centrifuged again at 2000 X g at 17°C. Supernatant was removed into the 25 ml volumetric flask and the flask filled to the mark with distilled water and mixed. Duplicate samples were diluted for spectroscopy by transferring 100 μl of each sample to 25 ml test tubes and adding 10 ml distilled water. A 1 ml aliquot of diluted sample was added to 4 ml of hexokinase reagent and vortexed. Samples were allowed to sit for

at least 5 min and not longer than 30 min then absorbance read at 340 nm. A calibration curve was obtained from standard solutions of glucose (0,25,50,75,100 μg/ml) and the amount of glucose determined from this curve. The glucose content was multiplied by the factor 0.9 to convert to starch content.

b. Starch Isolation. Gluten was first isolated from flour according to the method of Doguchi and Hlynka (1967) using a GRL mixer and 0.001 M NaCl solution. The remaining starch solution was centrifuged at 1500 X g for 15 min. The top layer of starch tailings (sludge) was scraped off, the starch resuspended in distilled water and the centrifugation process repeated. Starch was then resuspended in 95% ethanol (to facilitate rapid drying) and vacuum air dried on a Buchner funnel. Dry starch was sieved with a 100 mesh sieve.

c. Starch Purity. Starch purity was determined according to the percentage of starch found in each isolated starch fraction. This was determined following the procedure outlined in section IV C 4a.

d. Amylose Content. Iodometric determination of the amylose content of defatted starch was determined according to the method of Schoch (1964). Starches were defatted by Soxhlet extraction overnight (16h) using 85% methanol then dried under vacuum (60°C, 200 kPa). Results are reported on a dry basis.

e. Starch Pasting. Determination of starch paste peak viscosity was carried out using a Brabender Visco-Amylograph according to the method of Oda et al. (1980) but using 47.5g (dry basis) and 450 ml water. Parameters measured were peak viscosity (BU) and time to peak (min).

f. Differential Scanning Calorimetry (DSC). DSC of the defatted starch used for analysis for amylose content was carried out using a DuPont 9900 thermal analyzer according to the method of Biliaderis and Tonogai (1991). Slurries containing 30% (w/w) concentrations of starch (dry

basis) were analyzed; the low concentration ensured a single gelatinization endotherm which allows for the measurement of peak temperature (°C) and enthalpy (J/g).

g. Starch Gel Strength. Starch gels with 15% starch (dry basis) were prepared by initially forming a starch paste. The starch slurry was heated at 70 °C for approximately 15 minutes. The hot paste was then transferred into dishes (70x30 mm muffin tins). The depth of each dish was increased approximately 5mm by taping aluminum foil around its rim. The gels were layered with glycerine to prevent drying and boiled for 45 minutes in a hot waterbath. After storing the gels overnight at 5 °C, the aluminum foil was removed and an even surface was obtained by removing the excess gel above the rim with a wire cheese cutter.

The strength of the starch gels was determined using a Ottawa Texture Measuring System (OTMS) fitted with a Apple II computer based texture data acquisition and analysis system. The gels were compressed at a speed of 2.5 cm/min. (0.4166 mm/s) using a cylindrical plunger (12 mm diameter) and a 25 lb capacity load cell. The recording cart speed was 100 mm/min. Gel strength was determined by measuring the energy required to fracture the gel surface (energy to peak, J) and the distance on the chart from the time of contact of the plunger on the gel surface to gel fracture (deformation to peak, mm).

h. Starch Swelling Properties. Swelling power and volume measurements of starch were determined (on a dry basis) according to the method of Crosbie (1991). Swelling power was calculated as the weight of sedimented gel divided by the original dry weight of starch less the soluble dry matter. The swelling volume value was calculted as the height of sedimented gel (mm) in the tube.

D. Alpha-Amylase Activity Tests

1. Falling Number

The Falling Number value was determined using 7 g flour sample (14% moisture basis) according to the AACC standard method (method 56-81B, AACC 1983).

2. α-Amylase Activity

α-Amylase activity of 1 g wheat, flour and starch (13.5% moisture basis for wheat, 14% moisture basis for flour, "as is" moisture basis for starch) was determined according to the method of Kruger and Tipples (1981).

3. Maltose Value

Maltose value of flours (14% moisture basis) was determined according to the AACC standard method (method 22-15, AACC 1983).

4. Gassing Power

Gassing power was determined according to the AACC standard method (method 22-11, 1983). Values were expressed in mm Hg pressure after six hours of fermentation.

5. Amylograph Test

Pasting curves from the Brabender Visco-Amylograph were obtained using 65 g flour (14% moisture basis) and 450 ml water according to the AACC standard method (method 22-10, AACC 1983). Peak viscosity was considered the highest viscosity achieved during initial heating.

E. Functional Analyses

1. Farinograph Test

Farinogram values were derived from a 15 minute mixing of 50 g of flour (14% moisture

content basis) with sufficient distilled water to give a maximum dough consistency centred on the 500 BU line. A 50 g stainless steel farinograph bowl (63 rpm drive) was used according to the AACC standard method (method 54-21, AACC 1983).

2. Alveograph Test

Alveogram values were determined according to the ICC standard method No. 121 using the constant pressure Model MA82 instrument.

3. SDS-Sedimentation Value

SDS-sedimentation values were determined according to the AACC standard method (method 56-70, AACC 1983) except that the wheats were ground on a UDY cyclone grinder and a 4.5g sample (14% moisture basis) was used with 2% SDS solution. Samples were run in duplicate and were repeated if replicates differed by more than 2 ml.

4. Pelshenke Test

The Pelshenke test (wheat meal fermentation time) was performed according to the AACC standard method (method 56-50, AACC 1983).

5. Cookies

The baking quality of cookie flour was determined according to the AACC standard method (method 10-50D, AACC 1983).

F. Statistical Analyses

All statistical analyses were performed on a HP 9000/380 microcomputer using SAS 6.0 statistical analysis software program package (SAS Institute, 1990). Correlation analysis between all data was carried out using the procedure corr (correlation analysis).

V. RESULTS AND DISCUSSION

A. Varietal Purity of Wheat Samples

National or regional commercial classes of wheat are usually mixtures of several varieties which may differ in individual overall end-use quality. For this study, grain of pure varieties representative of these classes was selected. Because some of the samples were of commercial origin, there is always a possibility that they comprised grain of several varieties. Accordingly, as the first step in the study, all samples were checked for varietal purity by two biochemical fingerprinting techniques, PAGE and SDS-PAGE (Ng et al., 1988).

Electrophoretic results for the 11 samples are presented in Appendix I and II. All samples were found to be homogeneous by PAGE and SDS-PAGE except for Eradu which showed a mixture of an unknown variety of approximately 27% (7/26 seeds were different). Eradu was therefore treated as a mixed sample.

High molecular weight (HMW) subunits of each variety were also identified and are shown in Appendix III. HMW subunits of glutenin are related to breadmaking quality (Ng and Bushuk, 1988). The presence of subunits 5 and 10 have been found in previous studies to be significantly correlated with dough strength and subunits 2 and 12 associated with poor breadmaking quality.

B. Milling Quality Data

The milling quality data for the 11 samples is given in Table 2. The results will be

TABLE 2. Milling Quality Data.

Wheat Variety	Wheat					Flour				
	Test Weight (Kg/hl)	1000 Kernel Weight (g)	Moisture (%)	PSI (%)	NIR-PSI (%)	Yield (%)	Colour	Starch damage (%)	Moisture (%)	Ash (%)
Canadian										
Augusta	74.3	29.4	13.7	71.2	67.5	72.0	-1.2	6	14.0	0.41
Fielder	82.4	35.3	13.0	69.3	63.9	71.9	-1.4	10	14.0	0.42
Harus	75.0	31.5	15.5	70.3	68.0	70.9	1.6	9	14.1	0.40
Australian										
Eradu	84.2	42.7	11.6	61.9	60.1	73.6	-2.2	23	14.1	0.40
Rosella	85.1	37.0	11.2	67.1	61.0	74.3	-3.2	9	14.0	0.42
Tincurrin	82.8	34.2	12.2	63.3	67.0	70.3	-3.3	13	14.0	0.39
American										
Caldwell	82.6	28.0	9.4	70.5	62.2	77.4	0.0	2	13.4	0.45
Cardinal	80.2	37.7	14.3	70.8	64.7	75.0	-0.6	8	13.6	0.43
Club	80.1	32.7	9.8	67.6	62.9	74.8	-2.0	8	13.9	0.40
Florida-302	75.9	31.9	9.3	74.2	67.8	75.1	0.3	0	13.4	0.41
Stephens	81.5	63.5	13.8	62.5	59.3	75.3	-2.1	15	14.2	0.40

discussed in the order of the columns in the table.

1. Test Weight

Test weight values ranged from 74.3 to 85.1 Kg/hl. Canadian varieties Harus and Augusta had the lowest test weights which was indicative of visually shrunken kernels. Florida-302 also had a low test weight but did not appear to be shrunken suggesting that this variety was less compact compared with the other varieties.

2. Thousand Kernel Weight

Thousand kernel weights for all varieties except for Stephens ranged from 28.0 to 42.7 g. The variety Stephens had a much higher weight (63.5 g) than the other samples. This high value reflected a very large kernel size for this variety. The remaining varieties fell close to the normal range for soft wheats of 30 to 40 g per 1000 kernels (Halverson and Zeleny, 1988).

3. Wheat and Flour Moisture Content

The moisture content of wheats ranged from 9.3 to 15.5% and the moisture content of flours ranged from 13.4 to 14.2%. Canadian wheats had the highest moisture and American wheats had the highest range. Wheat moisture content has great economic importance because it is inversely related to dry matter. A wheat of lower moisture is of greater value because a buyer would be purchasing less water. Keeping quality is also affected by moisture as excessive moisture in storage will permit the growth of fungi which is detrimental to quality. Dry, sound wheat can be stored safely for several years (Halverson and Zeleny, 1988). Flour moisture content was found to have a narrow range due to tempering to constant moisture content of the grain before milling.

4. Hardness

Particle size index values measured by sieving range from 61.9 to 74.2% and those

measured by NIR range from 59.3 to 68.0% (Table 2). Measurements of PSI by NIR were consistently lower except for variety Tincurrin which was higher. Australian varieties were the hardest overall, followed by American and then Canadian varieties. The two Australian varieties which are used for making noodles (Eradu and Rosella) would be considered to be of medium hardness according to the scheme proposed by Williams (1993a.).

5. Flour Yield

Flour yield values ranged from 70.3 to 77.4%. These values are comparable to flour yields obtained in other soft wheat quality studies (Kaldy and Rubenthaler, 1987; Gaines, 1985). Canadian wheat varieties yielded lower amounts of flour when compared with Australian (except Tincurrin) and American (U.S.) varieties. The American varieties yielded the most flour overall with the American soft red winter varieties yielding the most flour of all varieties.

6. Flour Colour

Flour colour values ranged from 1.6 to -3.3. Australian varieties had brighter colour values illustrating their superior whiteness which is an essential feature in Japanese noodles. Red wheat varieties Florida-302, Cardinal and Caldwell displayed a darker flour colour which is expected due to pieces of dark seed coat in the flour. Variety Harus exhibited the darkest flour colour.

7. Starch Damage

Starch damage values ranged from 0 to 23%. Starch damage was very high for varieties Eradu and Stephens (23% and 15% respectively) which also had a low PSI. This is expected because a harder wheat will be harder to mill and suffer more damage to the starch.

8. Flour Ash

Flour ash results were found in a narrow range of 0.39 to 0.43% (Table 2). No

differences were noted due to origin of wheat. Ash content requirements for cookies is 0.42-0.50%, layer cakes 0.34-0.40% and crackers or pastry 0.40-0.48% (Mailhot and Patton, 1988).

C. Protein Content and Related Tests

1. Protein Content

Protein content was determined in wheat (13.5% moisture basis) using both the Kjeldahl method and near infrared reflectance spectroscopy (NIR). The Kjeldahl results ranged from 7.9 to 11.9% and the NIR values ranged from 8.2-11.6% (Table 3). Protein content of flour (14% moisture basis) was determined using the Kjeldahl method and values ranged from 7.0-10.2% (Table 3). Flour protein content was approximately 1% lower than that of wheat. This is caused by the removal of the aleurone layer and germ portion of the wheat kernel. Canadian varieties had higher protein contents than Australian and American varieties. A flour of low protein content (8.5-9%) is often specified for cookie flours (Hoseney et al., 1988). However, the quality of the protein in soft wheat flour has been suggested to be more important than a specific protein content (Abboud et al., 1985).

2. Osborne Fractionation

Flour proteins were fractionated on the basis of solubility by the modified Osborne procedure. The water soluble fraction (albumins) of total protein varied between 13.1 and 17.9% with an average of 14.8% (Table 4). The salt soluble fraction (globulins) contributed the least to the total protein extracted, varying between 3.5 and 6.2% with an average of 4.6%. The proportion of alcohol soluble protein (gliadin) was the highest and varied from 31.9 to 40.0% with an average of 35.4%. The acetic acid soluble fraction (glutenins) varied from 11.8 to 22.7% with an average of 15.9%. The acetic acid insoluble fraction (residue) varied from 21.0

TABLE 3. Protein Content (%) of Wheat and Flour.

	Wheat Protein (%)		Flour Protein (%)
Wheat Variety	Kjeldahl	NIR	Kjeldahl
Canadian			
Augusta	10.2	10.1	8.9
Fielder	10.6	10.4	9.1
Harus	11.9	11.6	10.2
Australian			
Eradu	9.8	9.9	8.8
Rosella	9.2	9.4	8.1
Tincurrin	7.9	8.2	7.0
American			
Caldwell	9.8	9.6	8.8
Cardinal	9.9	9.9	8.7
Club	10.0	10.1	9.3
Florida-302	9.0	8.7	7.5
Stephens	9.5	9.4	8.5

TABLE 4. Osborne Fractionation - Fractionation of Total Protein Extracted (%).

Wheat Variety	Water Sol	0.5 M NaCl Sol	70% ETOH Sol	0.05M AA Sol	0.05M AA Insol	Total Extracted
Canadian						
Augusta	14.4	4.3	35.3	15.8	30.3	84.2
Fielder	16.0	4.4	36.0	22.7	21.0	83.1
Harus	13.1	3.5	37.7	15.8	30.0	86.8
Australian						
Eradu	13.4	4.1	33.5	14.4	34.4	87.5
Rosella	14.8	4.9	31.9	12.5	36.0	89.3
Tincurrin	17.9	4.7	35.6	12.7	29.2	87.7
American						
Caldwell	14.5	6.2	33.0	11.8	34.7	89.4
Cardinal	14.2	4.4	35.8	18.2	27.6	88.9
Club	13.6	4.4	39.0	18.9	24.3	87.4
Florida-302	16.5	6.0	32.0	15.9	29.6	90.5
Stephens	14.6	3.6	40.0	15.9	26.0	85.8
Mean	14.8	4.6	35.4	15.9	29.3	87.3

to 36.0% with an average of 29.3%. It is interesting to compare the mean values of protein fractions for these soft wheats with those from hard red spring wheat. The soft wheats in this study had a lower average acetic acid insoluble fraction (29.3% versus 33.4%) and a higher acetic acid soluble fraction (15.9% versus 13.6%) (Bushuk, 1982). These results support findings that soft wheat flour has a higher percentage of acetic acid soluble proteins compared to hard wheats (Tsen, 1967). This is especially notable in in the present study for the variety Fielder where the acetic acid soluble fraction actually exceeds the acetic acid insoluble fraction (Table 4). Australian standard white wheats, such as Eradu and Rosella, require gluten strength to have a good noodle texture. These two varieties along with Caldwell had higher amounts of acetic acid insoluble proteins and lower amounts of acetic acid soluble compared with the other varieties. The recovery of % total protein from flours ranges from 83.1 to 90.5% with an average of 87.3% (Table 4). The recovery of these soft wheat flour proteins is low when compared to recovery of proteins from hard wheats of good breadmaking quality which have been reported by Orth (1971) to be 87 to 97%. The lower protein recovery is thought to be due to loss of low molecular weight proteins. Albumin proteins have molecular weights about 20000 (Meredith and Wren, 1966) but may contain components with molecular weights as low as 9000 (Bietz, 1984). The same authors detected proteins of molecular weight of 11000 and suggested that these proteins may be albumins or globulins. Low molecular weight proteins (2000 Da) have been detected in the gliadin fraction (Bietz, 1984).

3. Wet Gluten Content

Wet gluten content of flour ranged from 20.2 to 34.1% (Table 5). Two varieties of Canadian origin (Fielder and Harus) appear to have slightly higher wet gluten levels than varieties of American and Australian origin. In 1992, wet gluten content of CEWW, CWSWS,

TABLE 5. Wet Gluten content, MacMicheal Viscosity and AWRC results.

Wheat Variety	Wet Gluten (%)	AWRC (%)	MacMicheal (units)
Canadian			
Augusta	24.8	64	40
Fielder	34.1	71	31
Harus	30.1	71	70
Australian			
Eradu	25.5	73	80
Rosella	23.4	69	45
Tincurrin	20.2	69	20
American			
Caldwell	24.1	67	24
Cardinal	27.2	67	33
Club	26.4	69	42
Florida-302	21.1	65	7
Stephens	25.4	72	33

and CWRS wheats were found to be 27.9, 32.1 and 39.9%, respectively (Canadian Grain Commission, 1992). The Canadian variety Fielder is a CWSWS wheat and was found to have the highest gluten content. This is consistent with the fact that the CWSWS wheat had a higher gluten level than CEWW production in Canada over the past two years (Canadian Grains Commission, 1992).

4. Presence of Friabilin

The soft wheat protein friabilin was found by SDS-PAGE to be present in all varieties used in this study. Samples of Canadian hard spring wheats Katepawa and Neepawa and utility wheat Glenlea were also examined in the same manner; the intensity of their friabilin band was less, in most cases, but the band was not absent. This suggests a lower quantity of friabilin but as the method used was not quantitative no conclusions may be drawn.

5. Alkaline Water Retention Capacity

AWRC results ranged from 64 to 73% (Table 5). The AWRC values were high overall when compared with other studies of soft wheat which may be due to a difference in methodology (Kaldy and Rubenthaler, 1987; Abboud et al., 1985). Other AWRC results on soft wheats using the same methodology as used in this study were also higher compared to the results of these other studies (Canadian Grains Commission, 1992). The American SRW wheats and Augusta all had low AWRC values relative to the other varieties in this study.

6. MacMicheal Viscosity

MacMicheal viscosity results ranged from 7 to 80 MacMicheal units (Table 5). Varieties with low MacMicheal viscosity (ie. Florida-302) also had low wet gluten content and low starch damage. Conversely, samples with high MacMicheal viscosity (ie. Eradu and Harus) had higher wet gluten content and starch damage.

D. Starch Content and Related Tests

1. Starch Content

Starch content of wheat ranged from 53.2 to 63.5% (Table 6). These are low compared to starch content of flour due to the extra protein, lipid and cellulose found in the germ and bran of wheat. There were no differences due to origin or variety.

2. Starch Purity

The purity of isolated starch fractions ranged from 90.4 to 97.4% (Table 6). The non-starch portion is thought to be moisture, non-starch polysaccharides and protein. The purity of the starches met requirements for analysis by DSC.

3. Amylose Content

Amylose content of the starch ranged from 19.2 to 22.5% (Table 6). Australian varieties Eradu and Rosella, and the Canadian variety Fielder had amylose contents lower than the remaining varieties.

4. Starch Pasting

Two pasting parameters of starch were measured by a Brabender Visco-Amylograph. Paste peak height values ranged from 280 to 840 BU and time to peak ranged from 29 to 44 min. (Table 7). The varieties Augusta, Cardinal and Harus had high levels of α-amylase activity. This affected results by causing low times to peak and peak heights for all three varieties thus preventing a true measure of starch properties. Rosella, an ASW wheat, had both a short time to peak and high peak height relative to the other varieties. These are required starch pasting characteristics for ASW wheat which is used for noodles. Varieties Eradu, Fielder and Florida-302 also had high peak height values.

TABLE 6. Starch Content of Wheat, Purity and Amylose Content of Isolated Starch.

	Wheat	Isolated Starch	
Wheat Variety	Starch (%)	Purity (%)	Amylose (%)
Canadian			
Augusta	61.1	92.9	20.9
Fielder	55.2	97.4	19.2
Harus	56.8	96.8	21.2
Australian			
Eradu	58.5	95.7	19.5
Rosella	63.5	90.9	19.8
Tincurrin	53.2	96.7	20.5
American			
Caldwell	62.0	94.4	22.5
Cardinal	55.3	96.3	21.8
Club	60.5	95.3	21.2
Florida-302	60.0	90.4	20.5
Stephens	61.3	96.0	21.8

TABLE 7. Starch Amylograph Pasting Properties and Differential Scanning Calorimetry Results.

	Amylograph		DSC	
Wheat Variety	Time to Peak (min)	Peak Height (BU)	Peak Temp (°C)	Enthalpy (J/g)
Canadian				
Augusta	30.5	300	60.7	11.2
Fielder	44.0	760	58.9	11.6
Harus	29.0	280	60.9	12.0
Australian				
Eradu	39.0	610	57.4	11.4
Rosella	30.5	840	63.7	11.9
Tincurrin	34.5	410	59.2	11.6
American				
Caldwell	44.0	540	61.3	11.6
Cardinal	32.0	365	60.5	11.0
Club	33.5	400	57.6	11.7
Florida-302	32.0	660	61.7	12.3
Stephens	35.0	400	57.0	10.5

5. Differential Scanning Calorimetry

DSC results for peak gelatinization temperatures varied from 57.0 to 63.7°C (Table 7). Enthalpy values varied from 10.5 to 12.3 J/g (Table 7). Peak gelatinization temperatures were lower for varieties Eradu, Stephens and the Club variety than those for the remaining varieties. There was no difference due to origin or variety. Gelatinization enthalpy covered a narrow range and no significant comparisons can be made.

6. Gel Strength

The energy required to break the gel surface (energy to peak) values varied from 0.014 to 0.056 J (Table 8). The deformation to peak varied from 10.3 to 19.5 mm. The mean results of this test showed a high standard deviation. This indicates that greater precision is needed in order to draw conclusions from this experiment. With the exception of enzyme damaged starches from varieties Augusta and Harus (refer to Table 9), the starches showed comparable gel strength. Enzyme damaged starches produced gels of lower strength.

7. Swelling Properties

Swelling power values ranged from 13.6 to 18.2 g/g and swelling volume values from 5.0 to 7.4 ml (Table 8). The Canadian variety Fielder, the ASW varieties Rosella and Eradu and the American variety Stephens had higher swelling volume. Rosella also had a high swelling power. The swelling volume test provided more precise results based on the standard deviations of replications. The swelling values obtained in this study were lower, overall, than those found on a series of Australian flours (Crosbie, 1991). Also, a study in which ASW wheat was compared to a common Japanese variety with good noodle quality showed higher swelling values for the Australian wheat (Endo et al., 1989). The reason for the discrepancy between the results for Australian wheats in this study and the published results is unknown.

TABLE 8. Starch Gel Strength and Swelling Properties.

Wheat Variety	Gel		Swelling	
	Energy to Peak (J)	Deformation to Peak (mm)	Swelling Power (g/g)	Swelling Volume (ml)
Canadian				
Augusta	0.018 ± 0.003*	11.4 ± 1.5	15.4	5.7
Fielder	0.032 ± 0.005	17.2 ± 1.3	14.4	6.9
Harus	0.014 ± 0.002	10.3 ± 0.8	16.2	5.7
Australian				
Eradu	0.037 ± 0.005	16.4 ± 1.0	15.0	6.4
Rosella	0.040 ± 0.003	19.5 ± 0.8	18.2	7.4
Tincurrin	0.037 ± 0.005	16.7 ± 0.9	13.6	5.9
American				
Caldwell	0.045 ± 0.007	14.6 ± 0.7	14.7	5.6
Cardinal	0.037 ± 0.009	14.7 ± 2.2	11.8	5.0
Club	0.056 ± 0.003	19.3 ± 0.8	14.7	6.4
Florida-302	0.044 ± 0.004	16.9 ± 0.8	16.3	6.0
Stephens	0.031 ± 0.008	14.9 ± 1.9	13.7	7.4

* ± Standard deviation

E. Amylase Activity and Related Tests

Results for the α-amylase activity of wheat, flour and starch (Table 9) indicate the Canadian variety Harus had much higher α-amylase activity than those of the other varieties. Canadian variety Augusta and American variety Cardinal also have notably higher levels than the remaining varieties. All other varieties had varying but low levels of α-amylase activity. The American red winter varieties Caldwell and Florida-302 exhibited very low levels of α-amylase.

1. α-Amylase Activity

Wheat α-amylase activity ranged from 0.5 to 616.9 units/g (Table 9). Flour α-amylase activity ranged from 0.1 to 199.5 units/g. Starch α-amylase activity ranged from 0 to 5 units/g. In 1992, a year of wet harvest conditions in Canada, No.1 CEWW wheat and No.2 CEWW wheat had α-amylase activities of 27.5 and 80.5 units/g respectively. The flour from these same composite wheat samples had α-amylase activities of 12.5 units/g for No.1 grade and 37.5 units/g for No.2 grade (Canadian Grains Commission, 1992). Varieties Harus, Augusta and Cardinal had elevated levels of α-amylase. Australian samples displayed very low levels of α-amylase.

2. Falling Number

The falling number values ranged from 65 to 435 sec (Table 10). According to Mailhot and Patton (1988), a minimum falling number of 250 sec is required for cookies and cakes. Accordingly, the varieties Harus, Augusta and Cardinal would not meet this qualification.

3. Maltose Value

Maltose values ranged from 0.60 to 4.30 g/100g (Table 10). The required maltose values for breadbaking are higher than for cookies and noodles (2.9-3.2 versus not significant)(Mailhot and Patton, 1988). This is because in breadbaking the sugars produced by α-amylase are used in fermentation. In cookies or noodles, the lowest possible maltose value is desired. The

TABLE 9. Amount of α-Amylase (units/g) in Wheat, Flour and Starch.

Wheat Variety	Wheat Amylase	Flour Amylase	Starch Amylase
Canadian			
Augusta	125.0	48.9	1.5
Fielder	5.7	0.9	0.2
Harus	616.9	199.5	5.0
Australian			
Eradu	3.9	1.1	0
Rosella	3.5	0.1	0.2
Tincurrin	4.3	0.3	0.3
American			
Caldwell	0.5	0.5	0
Cardinal	49.0	17.5	1.0
Club	2.7	0.8	0.3
Florida-302	0.5	0.5	1.3
Stephens	5.1	1.1	0

TABLE 10. Wheat Falling Number (FN), Maltose Value (MV), Gassing Power (GP) and Flour Amylograph (FA).

Wheat Variety	FN (secs)	MV (g/100g)	GP (mm Hg)	FA (BU)
Canadian				
Augusta	185	1.7	360	55
Fielder	375	2.0	320	985
Harus	65	4.3	400	30
Australian				
Eradu	425	1.6	325	625
Rosella	370	1.0	235	1325
Tincurrin	370	1.3	320	515
American				
Caldwell	435	0.8	175	910
Cardinal	225	1.3	335	95
Club	390	1.0	285	395
Florida-302	370	0.6	175	1010
Stephens	380	1.6	325	450

Canadian variety Harus had the highest maltose value, consistent with the relatively low quality of the grain sample of this variety.

4. Gassing Power

Gassing power values ranged from 175 to 400 mm Hg (Table 10). Gassing power is a measure of the gas produced from fermentation of flour in a yeasted dough. Yeast requires sugars for fermentation. These sugars are available from starch granules that have been damaged and are available for hydrolysis to fermentable sugars by amylases. Gassing power is therefore dependent on both the amount of starch damage and the amylase activity of the flour. Gassing power values were found to be high for the Canadian varieties Harus and Augusta; varieties which were also high in α-amylase. Values were low for American varieties Caldwell and Florida-302; both were low in α-amylase activity.

5. Amylograph Results

The amylograph peak viscosity of the 11 flours ranged from 30 to 1325 BU (Table 10). Values were highest for varieties Rosella, Florida-302, Fielder and Caldwell and lowest for varieties known to contain high levels of α-amylase eg. Harus.

F. Results of Technological Tests

1. Farinograph Data

Water absorption values of the 11 samples ranged from 45.5 to 57.5%; dough development times (DDT) from 0.50 to 3.00 min; mixing tolerance index (MTI) values from 60 to 175 BU and stability values from 1.5 to 5.0 min (Table 11). The Australian variety Eradu exhibited mixing characteristics which place it in the medium strength class of wheat (Preston and Kilborn, 1990). Varieties Rosella, Stephens and Harus also were found to be stronger than the

TABLE 11. Farinograph Test Results.

Wheat Variety	Water Absorption (%)	Dough Development Time (min)	MTI (BU)	Stability (min)
Canadian				
Augusta	50.6	0.75	120	2.50
Fielder	54.0	1.00	175	1.50
Harus	53.3	0.75	100	3.50
Australian				
Eradu	57.5	3.00	60	5.00
Rosella	52.2	1.50	70	4.50
Tincurrin	52.0	1.25	115	2.00
American				
Caldwell	54.1	0.75	95	2.00
Cardinal	51.7	0.75	110	2.00
Club	52.1	1.50	130	2.00
Florida-302	45.5	0.50	170	1.50
Stephens	56.4	1.50	120	2.00

remaining varieties but not strong enough to be classified higher than "weak" wheat. These varieties were also more tolerant to mixing which is reflected by high stability values and lower MTI.

2. Alveograph Data

The alveograph resistance to deformation values (P) ranged from 18.0 to 69.0 mm, the extensibility (L) from 74.0 to 245.0 mm, stability (P/L) from 0.099 to 0.657, work of deformation (W) from 55 to 200 units, and the swelling index (G) from 19.1 to 34.8 (Table 12). The Australian standard white varieties exhibited the strongest dough properties with the variety Eradu reaching levels classified as a medium strength wheat rather than weak wheat (Faridi and Rasper, 1987). The American, Canadian and Australian soft (Tincurrin) varieties exhibited dough forming properties typical of soft wheat flours. The Canadian varieties displayed slightly weaker dough properties than the American.

3. SDS-Sedimentation Data

SDS-sedimentation volumes ranged from 19.5 to 42.5 ml (Table 13). The ASW wheats Rosella and Eradu displayed high SDS-sedimentation volumes but could not be considered strong wheat. Canadian varieties Harus and Augusta and American variety Caldwell also had higher SDS-sedimentation values compared to the remaining varieties.

4. Pelshenke Test Data

Pelshenke values ranged from 28.5 to 181.0 min (Table 13). Varieties which had previously shown characteristics of stronger wheats (Harus, Rosella, Eradu, Augusta, Cardinal) all had higher Pelshenke values. Results obtained at the Grain Research Laboratory, where evaluation of the SWS Plant Breeder's Co-operative Tests have been carried out for 12 years, show correlations of -0.62 between Pelshenke Time and cookie spread, and the Pelshenke Time

TABLE 12. Alveograph Test Results.

Wheat Variety	P (Overpressure)	L (width)	P/L	Work (W)	G (Swelling)
Canadian					
Augusta	20	202	0.099	65	31.6
Fielder	25	160	0.158	55	28.1
Harus	30	245	0.121	133	34.8
Australian					
Eradu	69	109	0.633	200	23.2
Rosella	42	130	0.323	130	25.4
Tincurrin	34	75	0.547	59	19.2
American					
Caldwell	36	127	0.284	137	25.0
Cardinal	24	157	0.154	77	27.8
Club	34	131	0.260	82	25.4
Florida-302	18	144	0.126	60	26.6
Stephens	49	74	0.657	91	19.1

TABLE 13. SDS-Sedimentation and Pelshenke (Whole Wheat Fermentation) Results.

Wheat Variety	Sedimentation Vol. (ml)	Time to Disintegrate (min)
Canadian		
Augusta	34.5	175.5
Fielder	24.0	28.5
Harus	41.0	181.0
Australian		
Eradu	42.5	119.5
Rosella	33.0	103.0
Tincurrin	20.0	58.5
American		
Caldwell	37.0	100.0
Cardinal	28.0	138.5
Club	28.5	37.0
Florida-302	19.5	30.5
Stephens	21.0	50.5

is regarded as a reasonable predictor of cookie baking potential for early generation screening (Williams and Cordeiro, 1993).

5. Cookie Data

The cookie spread values ranged from 72.9 to 83.4 mm, the ratio of spread to thickness from 6.7 to 10.4 and the score from 9 to 23.5 out of 30 (Table 14). There did not appear to be any origin differences in any of these three parameters. The variety Eradu, which showed stronger dough properties, had a poor score while the weaker varieties (Augusta, Harus, Caldwell and Cardinal) all had higher scores. These results support evidence that a weaker strength wheat results in a better quality of cookies as an end-product.

G. Statistical Analyses

1. Introduction

Each quantitative parameter determined in this study was correlated with each other. The data was compiled into a correlation matrix (Appendix VI). Although there are many significant correlations, some of these correlations are between unrelated tests. Only significant correlations ($P \leq 0.05$) with milling (flour yield, flour ash, colour, wheat hardness, starch damage) and baking (cookie spread, spread/thickness, score) quality parameters will be identified as potential predictors of end-use properties.

2. Milling Quality Parameters

Flour yield and flour ash were not significantly correlated with any other parameters (Appendix VI). The results of both of these parameters fell in a small range. This may have prevented potential relationships with other parameters from showing in correlation results. Flour colour (brightness) was significantly correlated with PSI, wheat, flour and starch α-amylase

TABLE 14. Cookie Test Results.

Wheat Variety	Spread (mm)	Spread/Thickness	Score (/30)
Canadian			
Augusta	82.4	9.2	19.5
Fielder	79.9	9.8	16.0
Harus	82.5	9.1	19.0
Australian			
Eradu	72.9	10.4	9.0
Rosella	79.0	9.5	14.5
Tincurrin	72.2	9.8	15.5
American			
Caldwell	83.4	8.8	23.5
Cardinal	82.5	9.2	20.5
Club	78.8	9.7	14.5
Florida-302	76.2	7.4	15.0
Stephens	75.4	6.7	10.0

activity ($P \leq 0.05$) (Table 15). When a wheat becomes damaged due to a wet harvest there is potential for increased α-amylase activity and grains become softer because the absorbed water diffuses throughout the grain. This softening causes the PSI to increase. The softer wheat can also become darker because in milling, small pieces of the softened bran can become detached and enter the flour streams. Two other parameters, wheat hardness (measured by PSI) and starch damage were also significantly correlated with each other as well as AWRC, farinograph parameters (water absorption, DDT, P, P/L, and G) and cookie score (Table 16). PSI was also significantly correlated with alveograph L. Starch damage also correlated significantly with cookie spread. These correlations illustrate that as PSI increased (softer wheat) and starch damage decreased, less water was absorbed by the flour (as illustrated by decreasing farinograph water absorption). The residual water became available to increase cookie spread and hence increase cookie score. The alveograph test is very sensitive to starch damage as it is performed at a constant water absorption. This was why alveograph parameters correlated so well with PSI and starch damage. PSI and starch damage were the tests which significantly correlated with more of the other quality parameters than any of the other individual tests. This emphasizes the importance of these two parameters in quality evaluation of soft wheats.

3. Baking Quality Parameters

Cookie spread was significantly correlated with alveograph overpressure (P) and dough stability (P/L), farinograph dough development time (DDT) and starch damage ($P \leq 0.05$) (Table 17). The ratio of spread/thickness was not significantly correlated with any other parameters. Cookie score was significantly correlated with P, P/L, AWRC, PSI ($P \leq 0.05$), DDT and starch damage ($P \leq 0.01$) (Table 16). Spread and score values were also significantly correlated ($P \leq 0.01$). The alveograph measurements provided a good prediction of cookie quality as illustrated

TABLE 15. Correlation Coefficients of Flour Colour with Predictors of Flour Quality (Adapted from Appendix VI).

Test Parameter	Colour
PSI[1]	717*
Wamy	649*
Famy	652*
Samy	726*

* significantly correlated at 5%
[1] definition of abbreviations may be found in Appendix V.

TABLE 16. Correlation Coefficients of Wheat Hardness (PSI) and Starch Damage with other Predictors of Flour Quality (Adapted from Appendix VI).

Test Parameter	PSI (%)	Starch Damage (%)
PSI[1]	1	-906**
AWRC	-742**	733**
Abs	-739**	757**
DDT	-814**	807**
P	-835**	806**
L	680*	-589
P/L	-939**	864**
G	718*	-617*
Sprd	589	-682*
Scor	709*	-778**

*,** significantly correlated at 5%, 1% respectively.
[1] definition of abbreviations may be found in Appendix V.

TABLE 17. Correlation Coefficients of Cookie Baking Quality with Predictors of Baking Quality (Adapted from Appendix VI).

Test Parameter	Spread	Spread/Thickness	Score
Sprd[1]	1	153	945**
P	-647*	192	-662*
P/L	-676*	150	-700*
AWRC	-492	192	-623*
DDT	-724*	401	-759**
PSI	589	-191	709*
Sdam	-682*	38	-778**

*,** significantly correlated at 5%, 1% respectively.
[1] definition of abbreviations may be found in Appendix V.

by the correlation of alveograph parameters and cookie spread and score as well as good correlations with starch damage and PSI. The farinograph parameters did not provide as many correlations with cookie score as only one measure, DDT, was found to be inversely related to cookie spread and score. The DDT measure was, however, more significantly correlated with the cookie quality. These correlation results would suggest the alveograph test is better than the farinograph test in predicting soft wheat flour quality for cookies.

VI. GENERAL DISCUSSION

The purpose of this study was to compare the composition and technological characteristics of representative Canadian soft wheat varieties with those of Canada's two main export competitors, Australia and the United States. In soft wheat quality assessment there are certain concerns that must be addressed particularly due to the many different end products which are made from soft wheats. When examining soft wheat quality, desirable characteristics are much different for a cookie product than for a noodle product. Differences in soft wheat quality characteristics became evident in the different soft wheats examined in this study. There appears to be quality differences due to origin of the wheat. Statistical correlation analysis also provided information on relationships between quality test parameters of wheat and its milling and baking quality. Six different wheat classes were studied: soft white winter (SWW) varieties Stephens, Harus and Augusta, soft white spring (SWS) variety Fielder, soft red spring (SRW) varieties Cardinal, Caldwell and Florida-302, Australian standard white (ASW) varieties Eradu and Rosella, Australian Soft (A. Soft) variety Tincurrin and one soft Club variety. The results for the sample Eradu will be affected by the mixture of the unknown variety and this fact should be considered when comparing results. There were not enough varieties in each class to make a valid comparison of classes. Discussion will therefore first focus on wheat quality differences due to origin and then on statistical correlation results.

The origin of wheat was found to have an effect on its milling and end-use quality. This was particularly noticeable in comparison of the Australian varieties with Canadian and with

American varieties. Milling quality, protein quality, starch quality, enzyme quantity and technological test results will be considered in the discussion that follows.

Milling quality of the samples in this study varied with origin. There was a small range in flour yield between varieties (7%), however wheat samples from the U.S. gave the highest flour yield while Canadian varieties gave the lowest yield. Australian wheat flours were generally brighter (whiter) than Canadian and American varieties. This is due to Australian wheat breeding programs which encourage whiteness for products such as noodles. Also, Australian wheats are all white branned. The Australian varieties also had a low amount of weather damage. Excessive weather damage, as previously indicated, can lead to a darker flour. Canadian and American samples produced flours of similar brightness. Ash content, another measure of milling quality, did not differ between groups classified according to origin. Wheat hardness tests found Australian wheats to be hardest and Canadian wheats the softest. Starch damage could not be related to origin.

Protein content and related tests illustrated that although Canadian wheats had slightly higher protein and gluten contents than the American and Australian varieties, the wheats with the best quality of protein (according to Osborne fractionation) were those from Australia. Gluten is developed in the sheeting process of noodle manufacturing therefore some gluten strength is required for good noodle texture. Australian varieties had better protein quality, as indicated by Osborne fractions, which may be another reason Australian varieties generally are of good quality for noodles. Cookies do not require a high gluten strength and since American and Canadian soft wheats have been bred with this end product in mind, they generally have low gluten strength. Neither AWRC or MacMicheal viscosity appears to be affected by origin of soft wheat growth.

Starch content and related parameters revealed some interesting differences in the starch

properties of Australian wheats in comparison with the U.S. and Canadian wheats. First, there was no difference in starch content of wheats due to country of origin. However, the amylose content of isolated starch was lowest for Australian wheats (and in particular ASW wheats) and highest for American varieties. Endo et al. (1989) also noted amylose content of ASW starch to be lower than Japanese varieties commonly used for noodles. These authors predicted that ASW starch was unique in content (and perhaps structure) of amylose and amylopectin. The amylograph pasting properties of separated starch were affected by excessive α-amylase in varieties Harus, Augusta and Cardinal which precludes valid comparison due to origin. The ASW varieties displayed a high amylograph peak viscosity which may be due to their low amylose content as previously suggested by Moss and Miskelly (1984). The Australian soft variety Tincurrin did not have a high peak viscosity but it is used for cookie flour, not noodles, therefore would not be expected to have this starch property which is preferred in wheats for noodles. There was no apparent difference in time to peak of the amylograph curve due to origin. Differential Scanning calorimetry curves, which reflect the gelatinization temperature and enthalpy of gelatinization, did not show any difference due to origin. The starch gel strength test also did not reflect any differences in deformation or energy required to break the gel. Low gel strength is caused by excessive α-amylase; these low values are difficult to measure precisely (ie. high standard deviation of replicates). Swelling power and volume values showed that Australian varieties had slightly higher swelling values. This was especially evident for the ASW varieties. Although these results indicate ASW varieties have unique starch properties, it is not possible to state what affect these properties had on end product quality as noodle quality was not evaluated. A noodle quality test would have greatly assisted in this evaluation.

α-Amylase activity and related tests such as falling number, maltose value, gassing power

and amylograph pasting all indicated that the Australian samples were low in α-amylase activity. Eastern Canadian soft wheats Harus and Augusta had high levels of α-amylase while only one American variety, Cardinal, showed excessive activity.

The functionality of the wheats was tested by the farinograph, alveograph, SDS-sedimentation, Pelshenke test and by processing into cookies. There was variation in the ability of these tests to detect variation in the functional properties of the different wheats. The farinograph was unable to differentiate between wheats of different origin. The alveograph results indicated the Canadian varieties to have the weakest dough properties (low P and P/L values and high L and G values). The Australian varieties had the strongest dough properties. The ASW varieties are known to develop medium strength doughs which are required for good noodle texture (Konik et al., 1992). SDS-sedimentation and Pelshenke tests for wheat strength did not discriminate wheats according to country of origin. These two tests as well as the farinograph, are used extensively in hard wheat quality analysis but to a lesser extent for soft wheats. The alveograph is used widely in Europe for evaluation of soft wheats. The development of the alveograph to analyze soft wheat quality and the different parameters measured may be the reason why it can differentiate between weak dough strengths better than the other technological methods. Finally, the cookie test results (spread, spread/thickness, score) did not differentiate the groups of wheats of different origin.

Test results of this study showed that Canadian and American varieties are of similar softness and are comparable in quality and cookie end product suitability. Australian soft wheat variety Tincurrin also displayed characteristics similar to those of Canadian and American varieties; this is understandable, since it is a variety that was bred for cookie baking. ASW varieties Eradu and Rosella displayed stronger dough strength and stronger starch pasting

characteristics than all other varieties. These are thought to be desirable characteristics for Japanese salted noodles but undesirable for cookies as indicated by the poor cookie quality these varieties displayed. The reason for the unique starch pasting properties of some ASW wheats has yet to be discovered but is thought to be due to the relative amount of amylose present in their starch (Endo et al., 1989).

The statistical correlation data showed the extent to which chemical composition data for wheat or flour can be used as indicators of functionality in milling and processing into end products. The results also showed that the presence of high levels of α-amylase activity can modify and even confound the results of several tests. Flour colour (brightness) was found to be significantly correlated with PSI and α-amylase activity. The alveograph appears to be a good predictor of cookie score and correlated rather better with cookie quality parameters than did the farinograph results. PSI and starch damage were also significantly correlated with cookie quality. These relationships are important in understanding the interrelationship between wheat grain structure and functionality.

Overall results showed Canadian varieties Augusta, Fielder, and Harus to be comparable with American and Australian soft wheats in cookie baking quality. Canadian soft wheats of similar quality to those studied in this research can be competitive with the American and Australian markets for pastry flours. Fielder also showed good starch properties which suggests that further study on the use of this variety for noodle production is warranted. On the basis of the results obtained in this study for Canadian varieties Augusta and Harus (e.g. excessive α-amylase activity) it is not possible to speculate on the potential quality of these wheats for noodles. Isolation of the starch from the flour removed most of this enzyme but analysis showed that sufficient enzyme remained to affect results.

Although this study has made some progress in understanding how the quality of Canadian soft wheat compares to that of Australian and American soft wheats, there is still need for further studies. An examination of more varieties grown over more than one season would be required to elucidate the nature of the year and location interaction. The addition of a noodle test would benefit future studies. While it is possible to predict noodle quality from starch and gluten qualities, the ultimate test is the actual end product. Results of this study indicated the ASW wheats commonly used for noodles are more of a medium strength wheat class. When further research is undertaken, Canadian soft wheat varieties with stronger dough properties (ie. gluten strength) should be examined along with varieties of other classes of medium hardness and medium dough strength such as Canadian Prairie Spring (CPS). Finally, studies should not be limited to flour quality only for products such as cookies and noodles but be expanded to include other products (and therefore markets) such as arabic bread, steam buns, cakes and flat breads.

VII. SUMMARY

1. It is important to know how the quality of Canadian soft wheats compares with that of its export competitors. Accordingly, a study was carried out to determine the comparative composition and technological characteristics of representative soft wheat varieties from Canada and its two main export competitors, Australia and the United States.

2. This study focused on the desired quality characteristics for two soft wheat products, cookies and noodles. Wheats were evaluated by examining the following characteristics; milling quality, protein content and related tests, starch content and related tests, amylase activity and related tests and technological tests. Statistical correlation analysis was also used to determine if a particular test correlated with a functional property of the flour required for a specific application.

3. Australian soft wheat and the American and Canadian varieties were found to be suitable for cookie production. American SRW varieties Caldwell and Cardinal and Canadian SWW varieties Augusta and Harus produced the best quality cookies.

4. ASW varieties were medium strength wheats with good starch pasting properties believed to be necessary for good noodle quality. Canadian variety Fielder had good pasting quality and a weak dough strength. Pasting properties of varieties Augusta and Harus were inhibited by excessive levels of α-amylase which affected all results. These varieties had weak dough strength.

5. Correlation analysis confirmed that tests such as those from the alveograph, farinograph, AWRC, starch damage and PSI correspond with resulting cookie quality. Once a noodle quality test is developed it is hoped that starch pasting quality, starch swelling quality and gluten strength may be used to predict noodle quality in the same way.

6. Canadian soft wheats used in this study were comparable with Australian and American soft wheats in cookie quality. Further research is needed to evaluate noodle quality of Canadian soft wheats as valid results of starch quality (thought to be very important in noodle quality) were not produced due to excessive enzyme activity. The addition of a noodle test to examine colour, smoothness, softness and elasticity by sensory analysis would have greatly benefited evaluation of flour quality for this end product.

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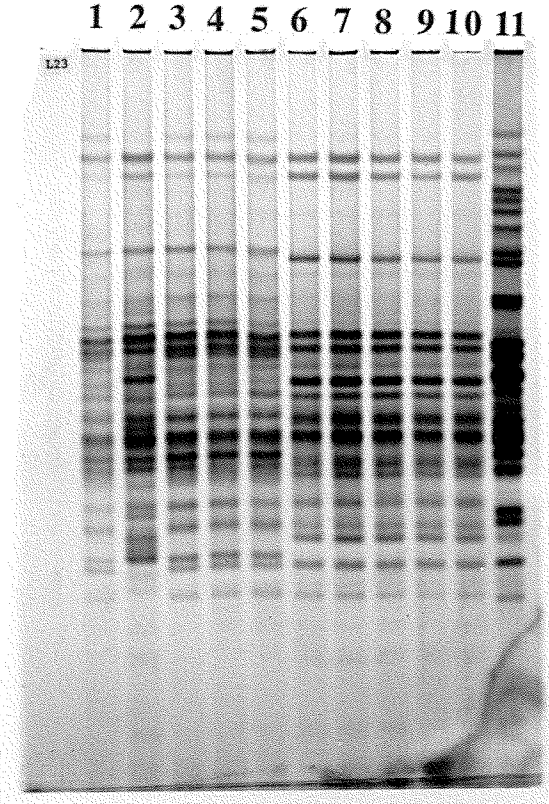
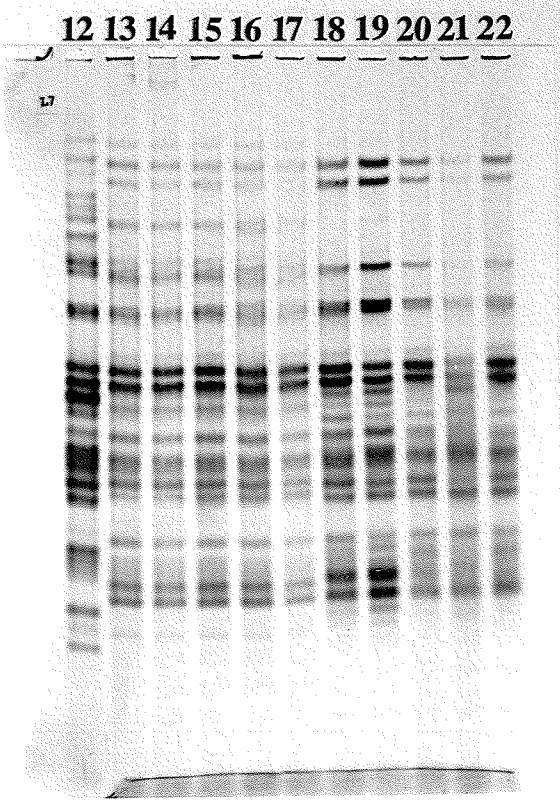
APPENDICES

APPENDIX I. Acid PAGE Electrophoregrams

Figure 2. Acid PAGE electrophoregrams of American varieties: 1-5 = variety Florida-302, 1 = 5g sample, 1-4 = single seed samples; 6-10 variety Caldwell, 6= 5g sample, 7-10 = single seed samples; 13-17 = variety Stephens, 13 = 5g sample 14- 17 = single seed samples; 18-22 = variety Cardinal, 18 = 5g sample, 19-22 = single seed samples; 24-27 = variety Cardinal, 24 = 5g sample, 25-27 = single seed samples; 28-32 = variety Club, 28 = single seed sample, 29-32 = single seed samples; 11,12,23,33 = Neepawa reference sample.


1 2 3 4 5 6 7 8 9 10 11
L23


12 13 14 15 16 17 18 19 20 21 22
L7

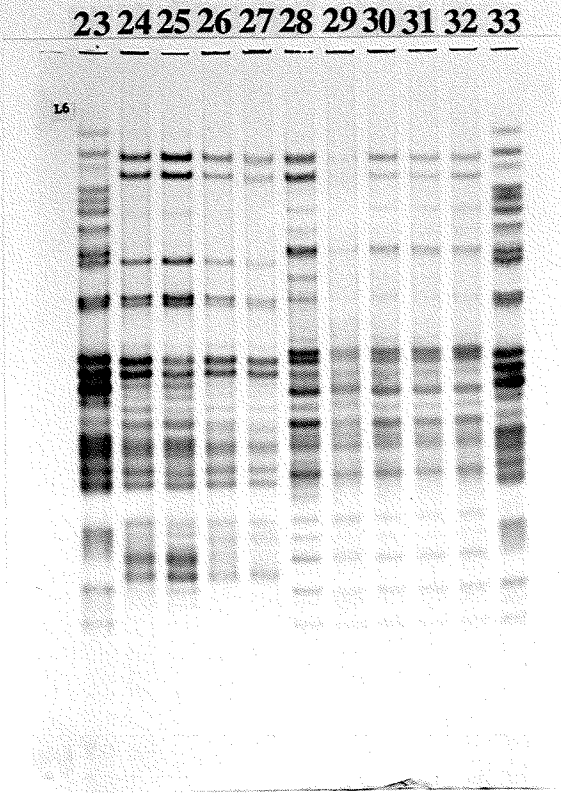

23 24 25 26 27 28 29 30 31 32 33
L6

Figure 3. Acid PAGE electrophoregrams of Australian varieties: 1-5 = variety Rosella, 1 = 5g sample, 2-5 = single seed samples; 6-10 = variety Tincurrin, 6 = 5g sample, 7-10 = single seed samples; 13-22 = variety Eradu, 13 = 5g sample, 14 = 1.5g sample, 15 = 1.25 g sample, 16 = 0.75 g sample, 17 = 5 seed sample, 18-22 = single seed samples; 11,12 = Neepawa reference sample.

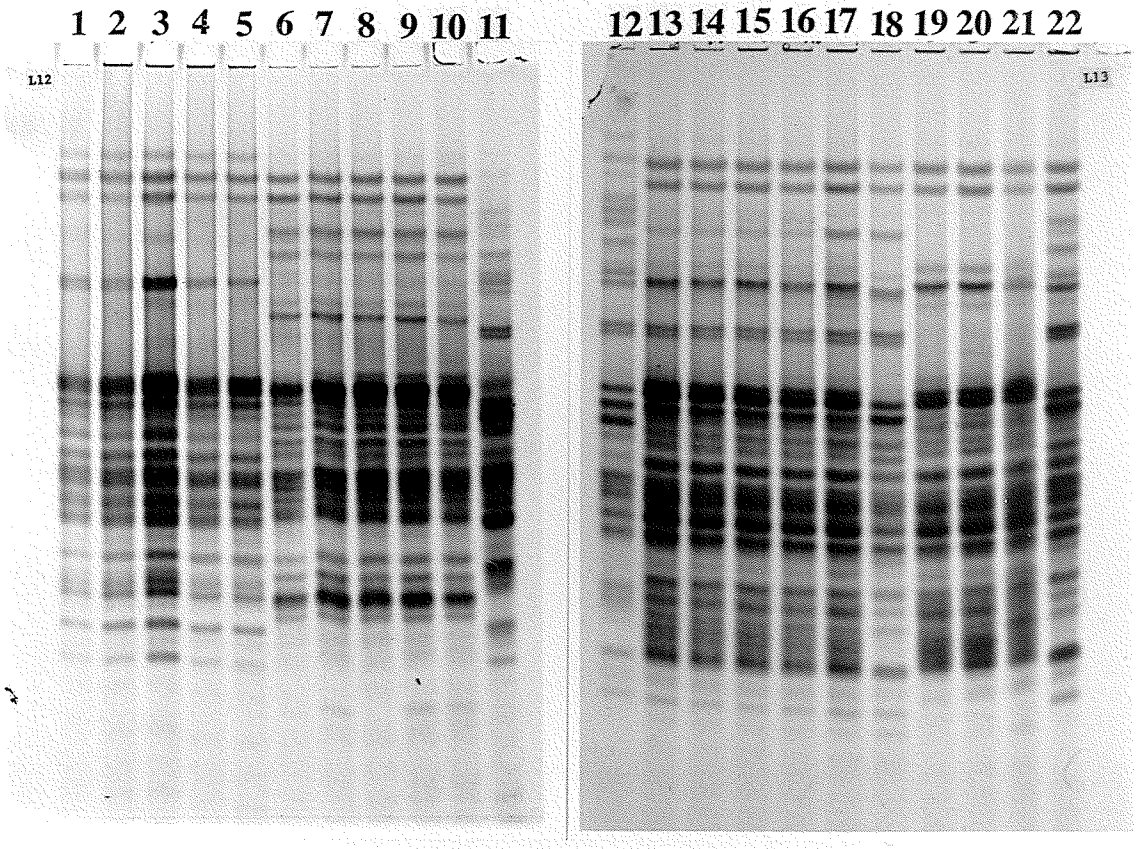
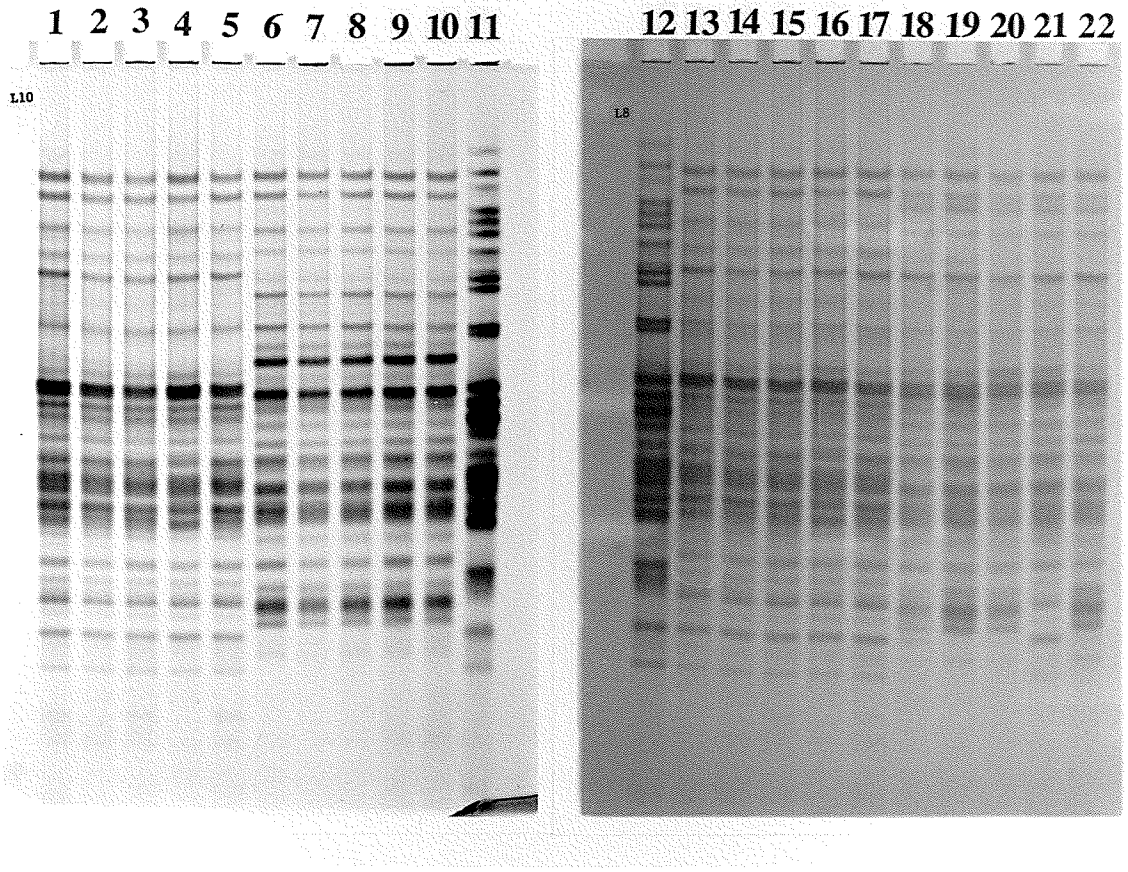

1 2 3 4 5 6 7 8 9 10 11
12 13 14 15 16 17 18 19 20 21 22
L12
L13

Figure 4. Acid PAGE electrophoregrams of Canadian varieties: 1-5,13-17 = variety Fielder, 1,13 = 5g sample, 2-5,14-17 = single seed sample; 6-10 = variety Harus, 6 = 5g sample, 7-10 = single seed samples; 18-22 = variety Augusta, 18 = 5g sample, 19-22 = single seed samples; 11,12 = Neepawa reference sample.


1 2 3 4 5 6 7 8 9 10 11
L10
12 13 14 15 16 17 18 19 20 21 22
L8

APPENDIX II. SDS-PAGE Electrophoregrams

Figure 5. SDS-PAGE electrophoregrams of Australian and American varieties: 3-7 = variety Eradu, 3 = 5g sample, 4-7 = single seed samples; 8-12 = variety Rosella, 8 = 5g sample 9-12 = single seed samples; 13-17 = variety Tincurrin, 13 = 5g sample, 14-17 = single seed sample; 21-25 = variety Stephens, 21 = 5g sample, 22-25 = single seed sample; 26-30 = variety Cardinal, 26 = 5g sample, 27-30 = single seed sample; 31-35 = variety Club, 31 = 5g sample, 32-35 = single seed samples, 1,2,18-20,36 = Neepawa reference sample.

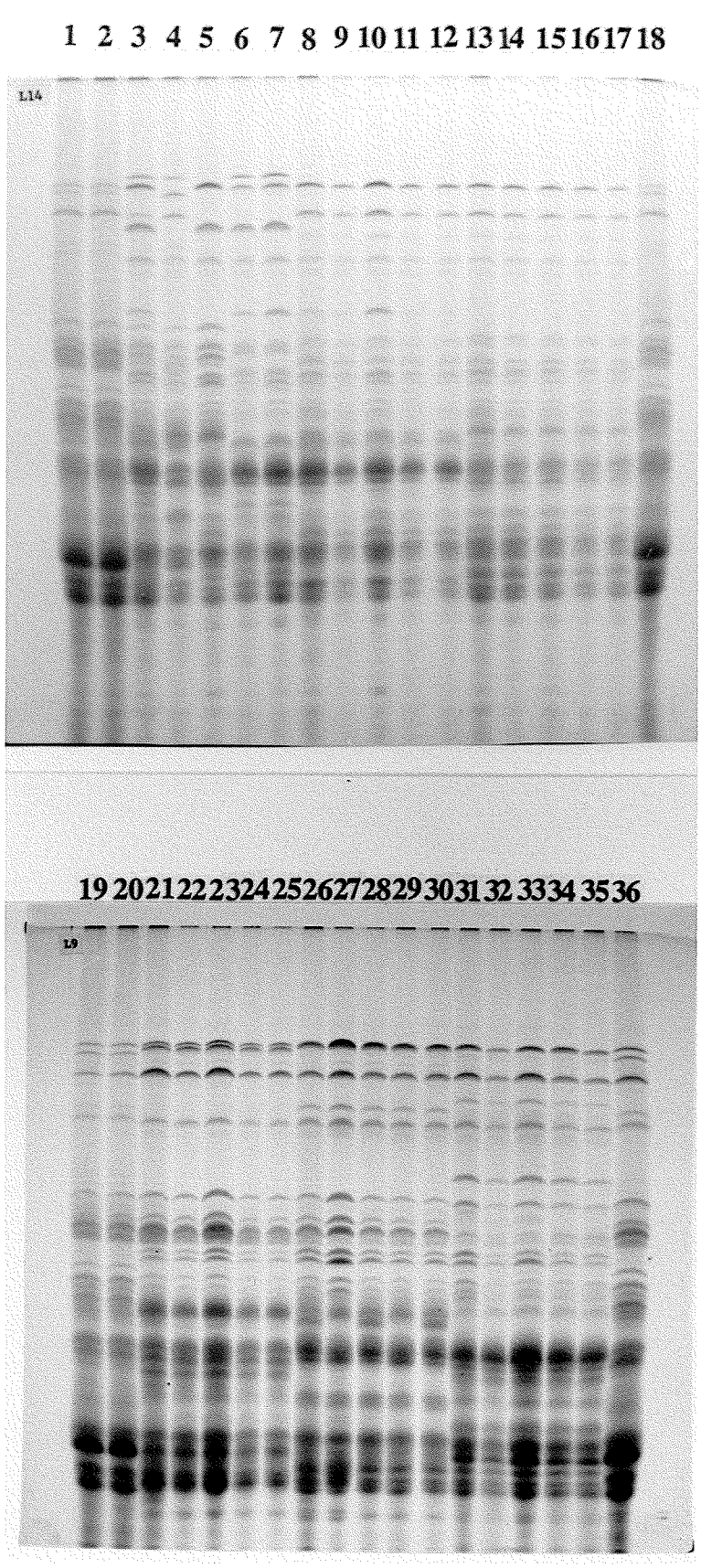
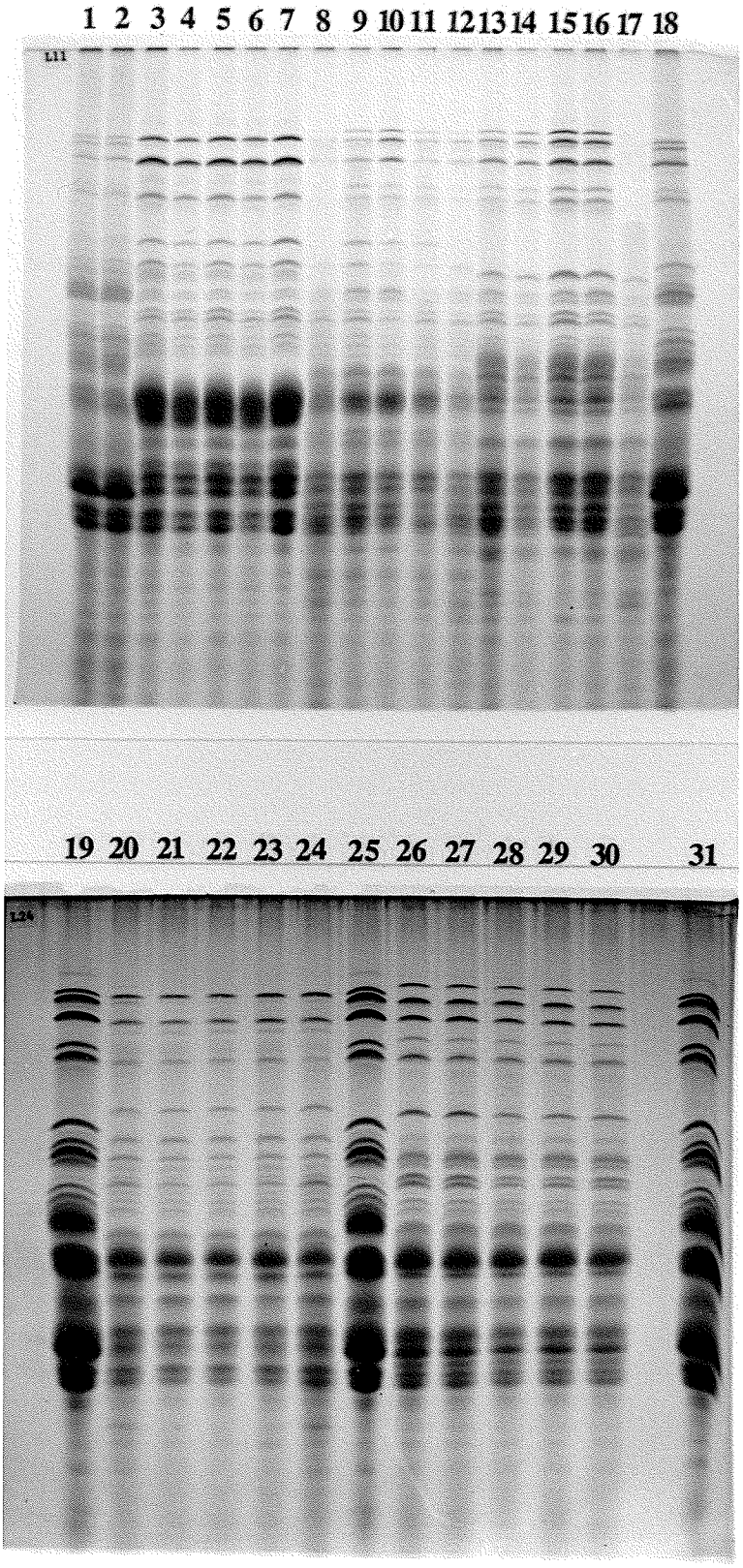

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
L14
19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
L9

Figure 6. SDS-PAGE electrophoregrams of Canadian and American varieties: 3-7 = variety Fielder, 3 = 5g sample, 4-7 = single seed sample; 8-12 = variety Augusta, 8 = 5g sample, 9-13 = single seed sample; 13-17 = variety Harus, 20-24 = variety Florida-302, 20 = 5g sample, 21-24 = single seed sample; 25-30 = variety Caldwell, 25 = 5g sample, 30 = single seed samples; 1,2,18,19,31 = Neepawa reference sample.


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
19 20 21 22 23 24 25 26 27 28 29 30 31

APPENDIX III. High molecular weight subunits of varieties studied.

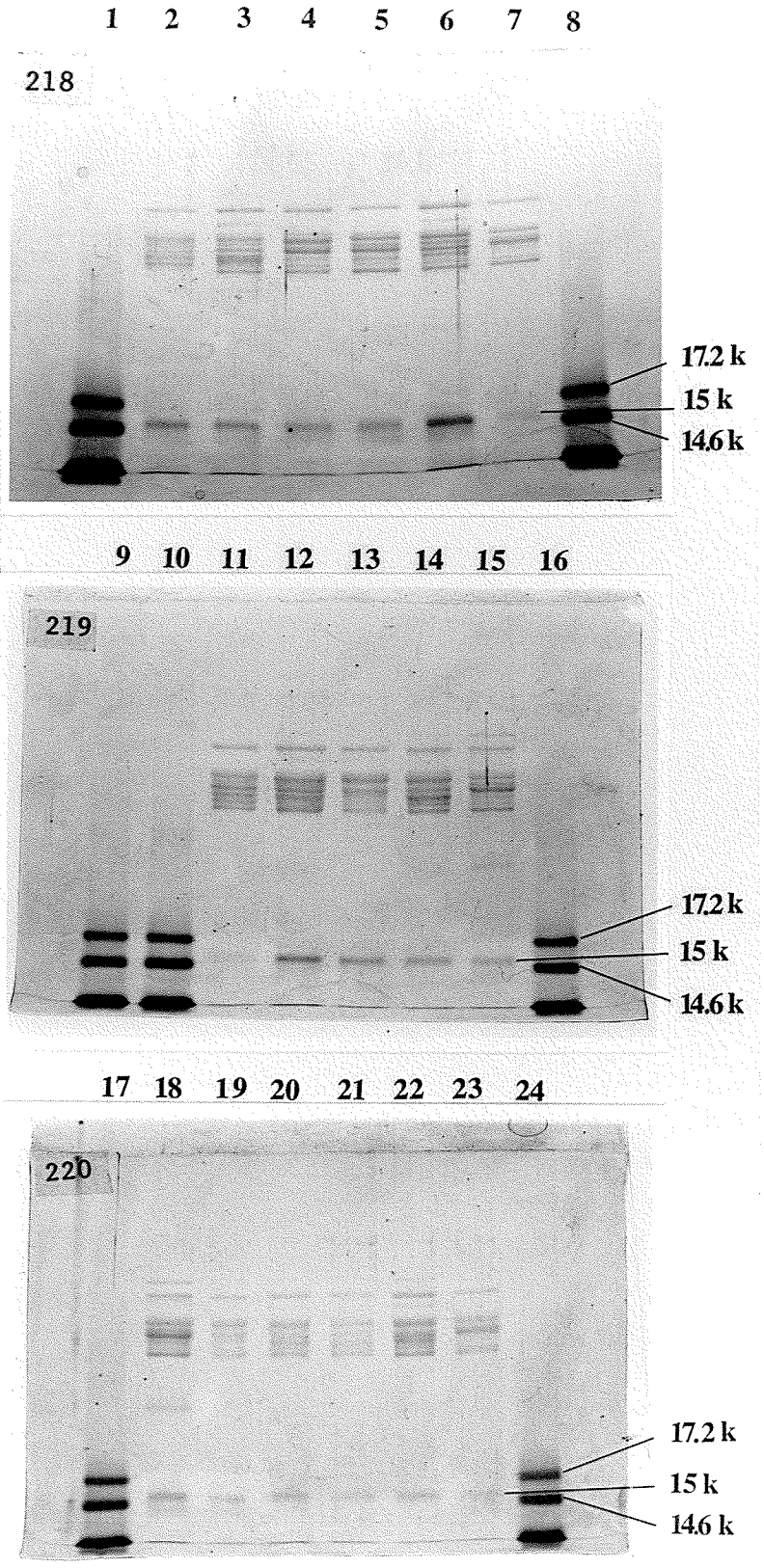
Figure 7. High molecular weight glutenin subunits of varieties studied.

Glu - A1	Glu - B1	Glu - D1	Varieties
2*	7 + 9	5 + 10	Neepawa
1	7 + 9	2 + 12	Augusta, Harus
1	7 + ?[1]	2 + 12	Eradu
1	7 + 8	5 + 10	Caldwell
Null	20	2 + 12	Fielder, Florida-302
Null	7 + 8	2 + 12	Rosella, Tincurrin, Club
Null	7 + 9	2 + 12	Cardinal
Null	7 + ?[2]	2 + 12	Stephens

[1] subunit 17, 18 or 22.
[2] subunit 3 or 4.

APPENDIX IV. SDS-PAGE Electrophoregrams for the detection of Friabilin.

Figure 8. SDS-PAGE electrophoregrams of American, Australian and Canadian varieties: 2 = Stephens, 3 = Cardinal, 4 = Club, 5 = Caldwell, 6 = Florida-302, 7,23 = Katepawa, 11 = Glenlea, 12 = Eradu, 13 = Rosella, 14 = Tincurrin, 15,18 = Neepawa, 19 = Fielder, 20 = Augusta, 21 = Harus, 22 = Genesis, 1,8-10,16,17,24 = standard reference sample.


1 2 3 4 5 6 7 8
218
17.2 k
15 k
14.6 k
9 10 11 12 13 14 15 16
219
17.2 k
15 k
14.6 k
17 18 19 20 21 22 23 24
220
17.2 k
15 k
14.6 k

APPENDIX V. Glossary of Abbreviated Technological Test Names

Term Name	Definition of Term
P	Alveograph resistance to deformation (mm)
L	Alveograph extensibility (mm)
P/L	Alveograph stability
W	Alveograph work of deformation
G	Alveograph swelling
Amlo	Amylose content (%)
Tipk	Starch amylograph time to peak (min)
Pkht	Starch amylograph peak height (BU)
Wtfn	Wheat falling number (s)
Wamy	wheat α-amylase (units/g)
Fpas	Flour amylograph peak height (BU)
Famy	Flour α-amylase (units/g)
Samy	Starch α-amylase (units/g)
Ash	Ash content (%)
AWRC	Alkaline water retention capacity (%)
Sprd	Cookie spread (mm)
Rati	Cookie ratio (spread/thickness)
Scor	Cookie score (/30)
Pktp	DSC peak temperature (°C)
Enth	DSC peak enthalpy (J/g)
Abs	Farinograph water absorbance (%)
DDT	Farinograph dough development time (min)
MTI	Farinograph mixing tolerance index (BU)
STAB	Farinograph stability (min)
GP	Gassing power (mm Hg)
Eng	Energy to fracture gel (J)

Term Name	Definition of Term
Defo	Deformation to peak (mm)
Wmoi	Wheat moisture (%)
Glut	Gluten Content (%)
PSI	Particle size index (%)
PSIN	PSI by Near infrared reflectance spectroscopy (%)
MacM	MacMicheal viscosity (degrees)
Twt	Test weight (Kg/hL)
Yiel	Flour yield (%)
Colo	Flour colour
Thwt	Thousand kernel weight (g)
Fmoi	Flour moisture (%)
Alb	Albumin (%)
Glob	Globulin (%)
Gli	Gliadin (%)
Glu	Glutenin (%)
Res	Residue (%)
Tot	Total protein extracted (%)
Kwht	Wheat protein content (%) (Kjeldhal determination)
Kflr	Flour protein content (%) (Kjeldhal determination)
WNIR	Wheat protein content (%) (NIR determination)
SDSS	SDS-sedimentation (mm)
Star	Starch content (%)
Pow	Swelling power (g/g)
Vol	Swelling volume (mm)
Sdam	Starch damage (Farrand units)
Sdam	Maltose value (g/100g)
Malt	Maltose value (g/100g)

APPENDIX VI. Correlation coefficients of all experimental data.

Figure 9. Correlation Coefficients of all Experimental Data. Letters as defined in Appendix IV; __ , negative correlation; decimals omitted, except for those with perfect correlations (ie. r=1).

VAR	TWT	YIEL	COLO	THWT	WMOI	FMOI	ASH	KWHT	KFLR	WNIR	ALB	GLOB	GLI	GLU	RES	TOT	GLUT	AWRC	MACM	STAR	AMLO	TIPK	PKHT	PKTP	ENTH	ENG	DEFO	POW	VOL	WTFN	WAMY	FPAS	FAMY	SAMY	MALT	SDAM	GP	PSI	PSIN	ABS	DDT	MTI	STAB	P	L	P/L	W	G	SDSS	PELS	SPRD	RATI	SCOR
TWT	1																																																					
YIEL	237	1																																																			
COLO	689	108	1																																																	
THWT	331	181	363	1																																																
WMOI	298	560	179	290	1																																															
FMOI	143	600	443	490	567	1																																													
ASH	51	331	166	154	82	405	1																																												
KWHT	442	162	594	118	554	261	129	1																																										
KFLR	304	44	516	94	413	255	104	973	1																																									
WNIR	354	215	553	137	553	303	181	978	961	1																																								
ALB	143	273	323	85	229	189	106	747	819	736	1																																							
GLOB	101	522	132	495	796	854	230	518	484	524	409	1																																						
GLI	195	202	0	459	506	519	348	430	438	339	258	731	1																																				
GLU	212	169	156	46	273	114	348	418	408	410	68	349	461	1																																		
RES	193	228	24	188	265	173	39	208	191	153	189	361	688	875	1																																	
TOT	151	528	115	187	550	644	77	483	413	442	51	604	532	564	576	1																																
GLUT	71	223	321	22	502	303	336	781	778	814	400	489	416	758	551	635	1																															
AWRC	526	192	261	580	267	665	340	196	285	276	240	590	392	123	138	270	417	1																														
MACM	68	272	26	118	389	603	185	593	635	663	742	636	155	32	273	218	384	592	1																													
STAR	15	628	45	111	441	115	85	18	71	42	380	296	228	367	454	226	288	216	21	1																												
AMLO	273	504	397	39	36	391	35	179	177	33	279	126	332	240	44	261	176	324	255	224	1																											
TIPK	537	267	87	28	331	173	46	45	25	59	150	313	123	146	135	210	287	295	128	90	98	1																										
PKHT	574	223	311	16	504	148	377	406	323	266	294	458	637	0	193	195	1	144	136	238	636	399	1																									
PKTP	167	91	276	544	136	463	497	113	169	34	123	533	688	385	540	474	245	572	229	275	19	327	316	1																								
ENTH	217	158	334	686	439	351	48	93	74	8	200	483	523	125	241	416	127	225	71	12	336	148	379	557	1																							
ENG	478	588	318	121	846	507	53	538	363	530	161	571	236	32	3	559	342	96	364	189	36	300	399	68	202	1																						
DEFO	673	277	652	99	654	87	90	624	463	538	321	315	230	74	79	298	215	167	247	133	423	233	687	71	182	815	1																					
POW	98	60	42	277	291	90	41	1	32	106	97	217	476	335	500	189	161	73	217	571	388	291	472	569	668	68	135	1																				
VOL	507	104	524	312	149	466	32	224	155	95	170	63	204	3	70	213	102	443	136	310	691	173	765	60	137	27	531	578	1																			
WTFN	728	491	561	241	757	191	112	648	502	638	335	479	273	151	65	234	328	195	314	253	195	635	607	268	52	752	776	36	417	1																		
WAMY	587	470	649	219	609	268	176	716	630	738	420	455	281	14	44	157	382	132	497	195	148	444	489	183	268	688	722	230	257	853	1																	
FPAS	574	334	306	32	658	259	223	539	443	429	399	621	629	186	256	321	194	57	315	345	439	421	944	353	416	498	699	491	709	707	533	1																
FAMY	611	473	652	231	616	264	168	724	633	741	425	454	278	15	47	170	377	102	494	186	156	456	507	189	256	703	743	227	273	869	998	553	1															
SAMY	731	449	726	310	541	108	100	627	518	643	317	334	188	56	15	57	288	60	347	210	138	552	477	284	376	639	707	248	336	888	964	522	966	1														
MALT	314	463	113	322	776	678	387	532	451	502	487	817	514	111	76	378	182	354	674	144	149	433	679	296	398	752	686	98	204	649	660	756	670	550	1													
SDAM	528	72	593	822	246	673	332	116	71	110	111	575	350	10	67	322	43	733	409	72	246	211	15	715	663	90	167	300	350	343	279	67	288	428	406	1												
GP	304	609	13	225	835	682	279	509	421	485	384	888	594	132	158	468	287	309	608	395	43	457	708	367	417	669	570	279	278	687	585	842	596	503	923	371	1											
PSI	649	163	717	655	106	681	539	258	180	235	2	478	307	242	64	180	132	742	382	96	219	182	8	624	485	37	280	194	367	408	250	7	266	427	361	906	326	1									
PSIN	759	542	494	641	212	248	51	104	52	79	333	109	74	107	150	21	59	570	267	441	19	429	380	360	486	346	461	49	474	630	486	371	501	648	68	675	186	622	1							
ABS	564	3	284	531	297	583	227	313	389	324	427	520	357	43	45	376	383	806	610	25	20	469	37	563	569	170	57	251	239	197	20	97	7	227	444	757	353	739	709	1						
DDT	601	13	580	444	108	529	349	119	1	57	281	352	10	155	241	53	47	686	632	77	442	210	230	532	249	184	375	38	409	451	273	125	285	411	237	807	196	814	672	668	1					
MTI	407	97	242	117	77	264	132	53	117	110	501	179	210	671	774	301	236	305	652	265	77	127	48	116	163	73	78	192	57	16	135	64	132	12	441	348	290	477	441	530	571	1				
STAB	299	137	216	87	106	448	94	142	194	265	488	292	306	428	675	137	41	428	820	246	396	205	221	139	107	190	16	511	387	74	236	92	231	125	420	357	289	409	351	426	678	833	1			
P	646	152	455	555	85	465	382	93	25	45	337	288	16	364	391	61	98	738	604	198	199	267	188	451	310	118	241	45	375	451	186	158	203	363	294	806	139	835	777	784	923	695	681	1		
L	715	322	717	541	435	32	301	771	672	787	425	184	9	297	38	234	511	279	320	59	24	355	273	404	356	557	625	290	264	829	772	399	788	821	307	589	327	680	593	278	479	112	82	524	1	
P/L	642	59	635	703	71	454	553	430	355	429	96	243	163	402	187	29	342	629	200	20	89	242	60	561	460	142	286	197	303	550	371	124	388	512	228	864	117	938	650	642	753	447	319	843	816	1
W	369	214	28	120	80	178	163	228	324	299	613	96	260	471	682	262	7	501	756	303	74	162	161	20	37	12	54	303	168	122	186	112	174	39	309	349	90	384	520	604	662	825	832	792	26	401	1
G	685	266	706	575	371	88	369	752	664	773	432	125	48	319	28	204	514	313	300	26	1	323	208	432	378	490	565	304	248	781	711	343	727	769	230	617	259	718	566	303	473	122	82	534	994	849	22	1
SDSS	24	3	281	281	135	148	1	600	633	640	760	165	198	289	583	10	233	178	804	248	19	8	105	155	103	275	392	324	77	305	475	199	482	353	439	12	296	9	140	420	330	712	728	390	474	79	807	479	1	
PELS	374	230	365	246	557	148	135	567	470	567	569	315	80	282	481	56	117	150	577	33	215	408	464	329	93	641	739	111	365	744	639	565	660	594	676	136	601	172	251	131	61	577	505	0	639	265	404	613	752	1	
SPRD	340	86	436	601	268	309	368	415	341	373	95	138	28	33	22	78	249	492	175	118	481	82	359	488	76	252	470	112	474	549	400	313	415	401	22	682	94	589	473	222	724	61	304	647	587	676	279	585	201	470	1	
RATI	329	432	298	480	9	224	24	142	191	230	125	140	189	72	120	159	243	192	483	363	476	175	127	32	181	98	193	22	66	8	27	28	27	56	34	38	227	191	25	253	401	355	438	192	150	41	287	176	473	252	153	1
SCOR	360	86	555	689	68	574	398	301	228	248	37	391	179	58	97	117	109	623	290	76	526	20	282	556	179	119	455	117	577	427	296	210	312	340	142	778	107	708	504	337	759	94	356	662	538	700	228	550	200	421	945	79	1