EVALUATION OF HULL-LESS BARLEY FLOUR AND FIBER-RICH-FRACTIONS IN ASIAN NOODLES

BY

Shelley Lynn Lagassé

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

Department of Food Science
University of Manitoba
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FACULTY OF GRADUATE STUDIES

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DEDICATION

To my family, for their love and support, and for teaching me the importance of a sense of humor and for always giving me a forum in which to make use of it.

To Salah-Eddin, for his love and encouragement, and for teaching me that fulfillment comes from never setting limits on personal achievements.

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LIST OF ABBREVIATIONS

WSN	white salted noodle(s)
YAN	yellow alkaline noodle(s)
HB	hull-less barley
BG	β-glucan(s)
AX	arabinoxylan(s)
NSP	non-starch polysaccharide(s)
FRF	fiber-rich fractions
ZAW	zero amylose waxy
HA	high amylose
PPO	polyphenol oxidase
POD	peroxidase
MCS	maximum cutting stress
RTC	resistance to compression
TPA	texture profile analysis

ABSTRACT

Hull-less barley has been traditionally used for animal feed and to a lesser extent for human food. This grain, grown largely in Canada, has many proven nutritional benefits that include lowering blood cholesterol, reducing the risk of coronary heart disease and reducing the risk of certain forms of cancer. Due to its variable starch amylose content, hull-less barley (HB) has the potential for texture modification in food applications. Recently, research has been aimed at incorporating this functional grain into both traditional and non-traditional food products.

To evaluate the suitability of barley in white salted (WSN) and yellow alkaline noodles (YAN), flours from 8 HB lines with variable starch characteristics (normal, waxy, zero amylose waxy and high amylose) and elevated levels of β-glucans and arabinoxylans were incorporated (20% and 40% w/w) into a Canada Prairie Spring-white (cv. AC Vista) wheat flour. RVA starch pasting characteristics of wheat flour were significantly affected by addition of barley flour with high and low amylose content. Barley flours had elevated polyphenol oxidase and peroxidase enzyme activity relative to wheat. The quality of white salted and yellow alkaline noodles was evaluated in terms of appearance, cooking characteristics, and textural properties. Addition of barley flour had a slightly negative effect on the colour (L*a*b*) of the raw and cooked noodles while increasing speckiness, most noticeable at 24h. Colour changes were more pronounced in the YAN, suggesting that high oxidative enzyme levels were not the primary cause of noodle discolouration. Cooking loss and water uptake were influenced by barley starch type. Cooked noodle texture (i.e. maximum cutting stress and resistance to compression) was influenced by barley starch type. Amylose content of the barley

flour was directly related to firmness and chewiness of white salted noodles whereas additional components, such as phenolics and non-starch polysaccharides, may have had an effect on the texture of the yellow alkaline noodles.

A fiber-rich fraction derived from the milling of HB, which contained concentrated levels of β-glucans and arabinoxylans, was added to AC Vista flour for preparation of yellow alkaline and white salted noodles at a level of 25%. The resulting noodle colour was significantly darker and speckier than the control. Addition of HB fiber-rich fractions reduced cooking time, water uptake, and cooking loss compared to noodles from barley flour admixtures. Addition of fiber-rich fractions to both fresh and dry WSN decreased firmness and chewiness of cooked noodles, while increased firmness and chewiness was seen when the fractions were incorporated into YAN due to the effect of the alkaline condition on the starch and the non-starch polysaccharides. The quality and texture of the fiber-rich fraction blend noodles was influenced largely by the elevated levels of non-starch polysaccharides in the fiber-rich fractions.

INTRODUCTION

Pasta and noodles are considered good sources of complex starch polysaccharides and protein, but are low in dietary fiber. The nutritive value of these types of wheat-based products can be improved upon by the addition of novel ingredients. Studies have been conducted on enriching Asian noodles using additives or substituting some portion of the wheat flour with other grains (Cheigh et al 1976, Baik and Czuchajowska 1997). The addition of non-traditional ingredients to noodle products have been undertaken to improve functional properties, to enhance nutritional composition, to alter texture or appearance and/or for cost considerations.

The use of barley flour and/or enriched fractions in the production of pasta and noodles has been considered as a means of improving the dietary fiber component of these types of food products. Incorporation of barley components to food products has the potential to increase both total and soluble dietary fiber, as well as other bioactive compounds, resulting in food products that have a healthful advantage. Barley with variable starch characteristics may also modify the textural properties of food items. This type of research is needed for the development of new barley lines intended for specific food applications. As the criterion for specific food applications becomes clear, the potential for a new class of barley intended primarily for human food uses will emerge. As research continues with the investigation of specific food applications for HB, valuable information will be gained with regard to the characteristics that new genotypes of barley must possess to be suitable for human food applications, and how processing conditions should be altered to optimize food properties. The opportunity exists to develop novel, attractive and healthy barley-based products that will gain acceptance among consumers.

Asian countries are aware of the health benefits of functional foods from cereal crops, providing Canada with an excellent opportunity to develop value-added food products incorporating Canadian HB and its fractions for the export market. The objective of the present study was, therefore, to evaluate the addition of HB milling fractions, with variable starch amylose content and elevated levels of soluble dietary fiber, to white salted and yellow alkaline noodles. Quality attributes, including appearance, cooking characteristics and texture, of the resulting noodles were evaluated.

LITERATURE REVIEW

Introduction

Barley (*Hordeum vulgare)* is an ancient cereal crop that has been regaining interest in human food applications as people are becoming increasingly aware of the link between diet and health. Barley is among the most widely cultivated crops as it is able to grow under a variety of different environmental conditions. It has a relatively short growing season making it particularly suitable for Canada's limited growing period. Barley is the fourth largest cereal crop grown worldwide after wheat, rice and corn and is currently under-utilised in terms of human food since only approximately 10% of world production is used in human food applications (Bhatty 1993, Czuchajowska et al 1998). Recent research has been aimed at increasing food uses of barley by incorporating this naturally healthy cereal grain and its components into various food applications.

Barley has traditionally been used in the malting, brewing, and animal feed industries. Good quality malting barley obtains a premium price and is characterized by having high levels of hydrolytic enzymes and low levels of protein, β-glucans and arabinoxylans. A good quality feed barley is characterized by having high protein and energy values while having low levels of both β-glucans and arabinoxylans. Quality characteristics of food barley have not yet been clearly defined. Common end uses of food barley include soups, stews, rice extenders, baked goods and breakfast cereals (Bhatty 1993).

Both hulled and HB genotypes exist. Annual production of barley in Canada is estimated at 12 million acres, which includes barley for malt, forage, feed and food uses. Annual production of HB in Canada is estimated at 400 thousand acres (Rossnagel 2003, personal communication). Canada is the main producer and supplier of HB (Bhatty 1999). Although hulled barley is preferable for malting where the husk acts as a natural filter bed during the clarifying process, HB is better suited for feed and human food applications. Since the husk is not fused to the grain, it is easily removed during threshing and harvesting of the grain. The inevitable processing step to remove the husk is, therefore, eliminated. Hull-less barley, like hulled barley, exists in both a 2- and a 6-row form. Bhatty (1995) reported that 2-row genotypes are more desirable for food applications since they tend to have a plump kernel, white aleurone, soft endosperm, and a generally high β-glucan content.

Composition of Barley Grain

Barley is primarily composed of carbohydrates, proteins and lipids with average values of 80%, 10% and 2.5%, respectively (Table 1.1). Barley is known for its high content of total dietary fiber (10-20%), including β-glucans, arabinoxylans, cellulose, fructans, galactomannans, and arabinogalactans, which has been shown to lower plasma cholesterol, reduce glycaemic index and reduce the risk of colon cancer (Anderson et al 1990, Jadhav et al 1998, Slavin et al 2000). Tocopherols and tocotrienols (tocols) constitute other barley components with potential nutraceutical properties. Benefits of tocols include antioxidant activity and reduction of serum LDL-cholesterol (Burton and Traber 1990, Qureshi et al 1991, Peterson 1994). Barley is one of the best sources of total tocols and contains a good distribution of the most biologically active tocol isomers (Peterson and Qureshi 1993, Peterson 1994). Barley hulls, aleurone layer, and the germ are rich in tocopherols and tocotrienols compared to the whole kernel (Bhatty 1995). Wang et al (1993) found that tocols were concentrated in the pearling by-products and suggests that this fraction can be used as a nutrient-rich, health promoting food ingredient.

Table 1.1. Barley Composition (adapted from MacGregor and Fincher, 1993)

Component	Content %, dry weight
Carbohydrates	78-83
Starch	60-65
Arabinoxylans	4.4-7.8
β-Glucans	3.6-6.1
Cellulose	1.4-5.0
Simple carbohydrates (glucose, fructose, sucrose, maltose)	0.41-2.9
Oligosaccharides (raffinose, fructosans)	0.16-1.8
Lipids	2-3
Proteins	8-15
Albumins and globulins	3.5-4.5
Hordeins	3-5
Glutelins	3-5
Minerals	2-3
Others*	5-6

*Barley also contains small quantities of B-complex vitamins, including thiamine (B_1), riboflavin (B_2), nicotinic acid, pyridoxine, (B_6), and panthotheic acid, biotin, folic acid, and vitamin E.

Minor components of barley, including phenolic acids, phytin, B-complex vitamins, vitamin E, proanthocyanidins, and catechins, have also received some attention due to their potential health benefits (MacGregor and Fincher 1993). Barley is an excellent source of B-complex vitamins, especially thiamine, pyridoxine, pantotheic acid, niacin as well as biotin and folacin. Elemental minerals in barley include phosphorus, potassium, calcium, chlorine, magnesium, sulphur, and sodium (MacGregor and Fincher 1993).

The chemical composition of barley, which ultimately determines the nutritional and functional qualities of the grain, is determined by both genotype and environmental growing conditions (Newman and Newman 1991). Barley type (hulled or hull-less) and the nature of the starch (amylose-amylopectin ratio) also influence the composition and the functionality of the cereal grain as a potential food ingredient. Differences have been found to exist in the chemical composition of hulled and HB, with HB showing a better potential for incorporation into human foods. Xue et al (1997) found that HB had greater concentrations of digestible nutrients than hulled barley. Hull-less barley genotypes have also been found to contain less ash and dietary fiber and more starch, protein and fat than hulled barley (Aman and Newman 1986, Oscarsson et al 1996, Andersson et al 1999b, Andersson et al 2000).

The major component of barley is starch, making up about 65% of the kernel by weight (Andersson et al 1999b). Starch is composed of two structurally different glucose polymers, amylose and amylopectin. Amylose is an essentially linear molecule linked by α-1,4 bonds while amylopectin is a highly branched polymer with branch points linked by α-1,6 bonds. The amylose and amylopectin content in normal barley starch is about 25% and 75%, respectively. Two single gene mutations can alter the amylose and amylopectin ratio of barley starch. When the genetic trait of waxy starch is present, starch contains 95-100% amylopectin. The other mutation increases the starch amylose content up to 40%.

The two most nutritionally significant non-starch polysaccharides abundant in barley are β-glucans (BG) and arabinoxylans (AX). While BG are found largely in the endosperm cell walls, they can also be found in smaller quantities in the aleurone layers (Fincher 1975, Bacic and Stone 1981, Izydorczyk et al 1998). Contrarily, AX are located primarily in the aleurone cell walls and to a lesser extent in the endosperm cell walls (Figure 1.1). Environmental conditions such as rainfall, temperature, light and soil fertility as well as genetic factors affect the levels of BG in the grain (Xue et al 1997). BG content is higher in waxy and high amylose genotypes when compared with normal varieties (Fastnaught et al 1996, Oscarsson et al 1996, Andersson et al 1999a, Zheng et al 2000). Waxy genotypes were found to be 2.7% - 4.0% higher in BG content than were the normal starch genotypes (Yoon et al 1995). Izydorczyk et al (2000) found a range of BG content of 3.3–8.23% for 29 Canadian HB genotypes.

Barley β-glucans have been shown to lower plasma cholesterol, reduce glycaemic index, and reduce the risk of colon cancer (Newman and Newman 1991, Jenkins et al 1995, Yokoyama et al 1997). Several mechanisms for the hypocholesterolemic effect of soluble fiber have been proposed: binding of bile acids, which results in reduced serum cholesterol; fermentation of soluble fiber by colonic bacteria and the production of short-chain fatty acids, which may inhibit cholesterol synthesis; increased breakdown of low-density lipoprotein cholesterol; and indirect effects as fiber replaces some dietary saturated fat and cholesterol (Bhatty 1995). Nutritional guidelines specify total dietary fiber consumption of 25-35g per day, of which about one-fourth should be soluble (Newman et al 1998, Canadian Sugar Institute 2003). Others have reported that a maximum effect of BG on cholesterol lowering is achieved by 12g per day, which may only be feasible to achieve with fortification of foods with BG from a concentrated source (Davidson et al 1991).

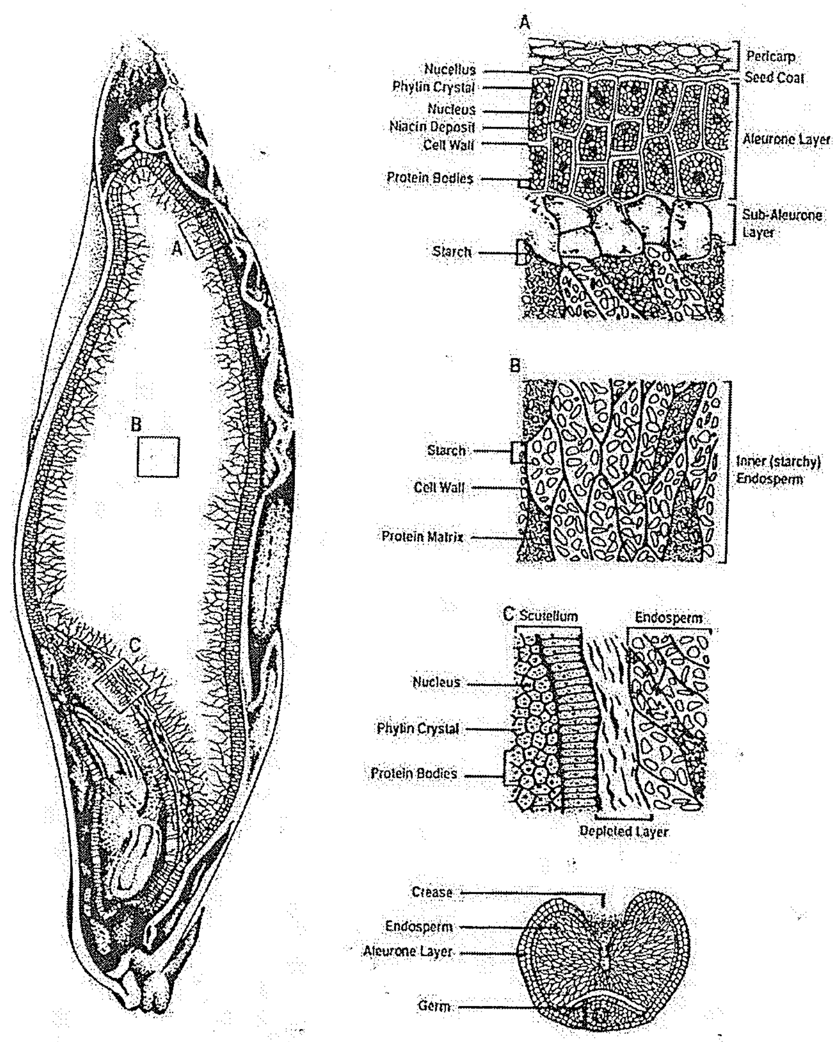


Figure 1.1 Structure of the barley kernel sectioned longitudinally (left) and transversely (right), with detailed bran layer (A), starchy endosperm (B), and embryo (C). From Izydorczyk et al 2002.

Human health benefits of barley BG rely on both content and solubility. Gaosong and Vasanthan (2000) found that extrusion cooking increased the solubility of BG for certain genotypes of barley. Further research is needed to determine what effect processing has on the level and bio-availability of barley components (i.e. soluble fiber) in various food products.

The nutritive value of other dietary fiber components in barley, such as arabinoxylans, cellulose, fructans, galactomannans, and arabinogalactans, has not yet been investigated to the same degree as β-glucans, however may be significant.

Processing and Incorporation of Barley in Food Products

Barley has been gaining interest as a food ingredient because it has the potential to add nutrition and modify texture and flavour of food products. There are many traditional and novel processing methods available for barley that aim at producing versatile ingredients for a variety of food applications (Figure 1.2). Pearling is a process of abrasive scouring that gradually removes the hull, pericarp, see coat, aleurone and sub-aleurone layers, and the embryo. Depending on the degree of pearling, the result is blocked (dehulled) barley, pot or pearled barley. Blocking removes only the husk, removal of the next layer, the pericarp, produces pot barley. Further abrasion, leading to formation of pearled barley, removes the seed coat, aleurone, and sub-aleurone layers (Bhatty 1993). Pearling by-products (outer layers of the barley kernel) are nutrient-rich, health promoting food ingredients. Utilization of pearling-by products for making pasta (by substituting 50% of standard durum wheat semolina) resulted in product that was darker than durum pasta but had good cooking characteristics (Marconi et al 2000).

Blocked or pot barley is usually subjected to further processing, such as milling, grinding, or flaking, before incorporation into food products, even though pot and pearled barley are used directly in various soup, stew, and porridge recipes. Pearling of hulled and HB to 45% and 40%, respectively, results in a barley product that can be used as a rice extender, which after cooking resembles white rice in colour, shape and texture (Edney et al 2002).

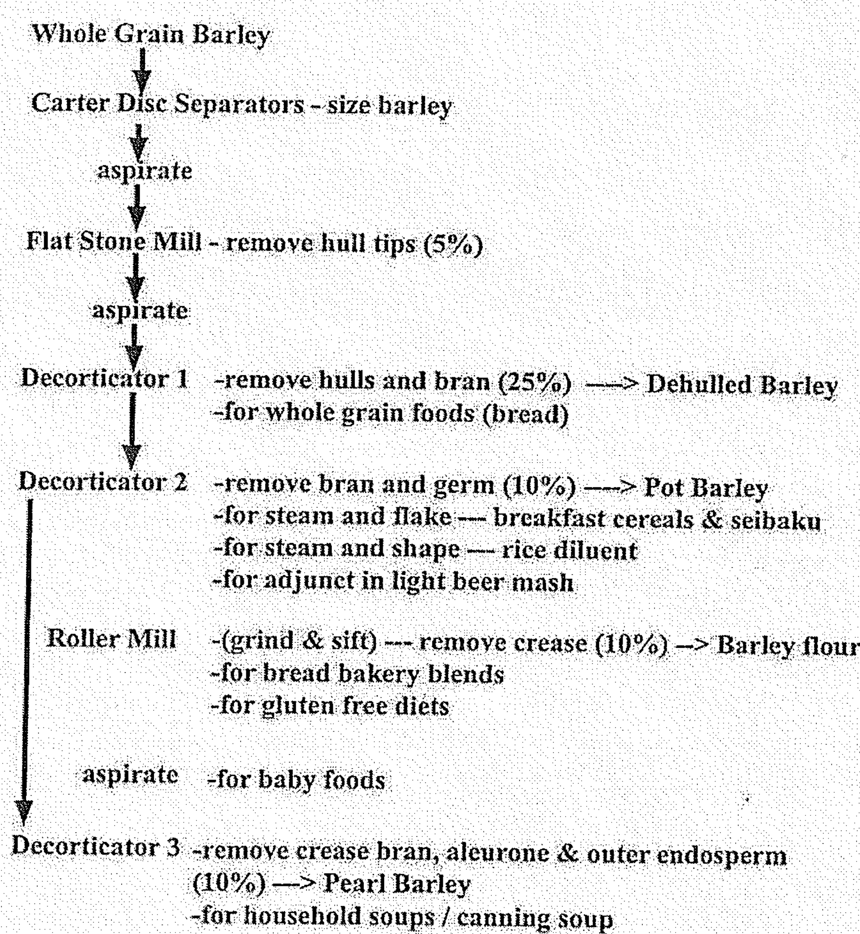


Figure 1.2. Diagrammatic representation of the processing of barley into various fractions. From Bhatty 1993.

Milling, air classifying and sieving of barley have the potential to fractionate the grain into various streams with unique composition and functionality. Non-traditional uses of HB in North American food applications have been investigated and include bread, granola bars, muffins, pasta, noodles, and chapatis. Products of roller milling (flour, shorts and bran) are the most convenient way by which to include HB into these food products (Bhatty, 1999). Research has shown that replacement of 20% wheat flour by barley flour or bran resulted in softer bread without decreasing the loaf volume (Klamczynski and Czuchajowska 1999). Knuckles et al (1997) found that breads and pasta containing 20% dry milled/sieved β-glucan-enriched barley fraction had acceptable eating quality, increased fiber and reduced calories per serving compared to their non-substituted counterparts. Bhatty (1986) found that a maximum of 5-10% barley flour could be added to wheat flour in the production of bread without seriously affecting loaf volume and appearance. Higher levels brought about dilution of wheat gluten and impairment of the dough's gas retention capacity. Consequently, Swanson and Penfield (1988) found that the incorporation of 20% HB into whole-grain variety bread was successful with the addition of 2.0% salt into the formulation. Barley flour has also been investigated in chapatis, where levels of 25% did not adversely affect the quality (Sidhu et al 1990). Sensory analysis of cereal based products with the addition of barley fractions has resulted in acceptable, and in some cases, improved flavour (Berglund et al 1992, Newman et al 1998).

Other forms of processing of whole or ground barley have also been developed and include simple cooking and drying of whole grain, to hydrothermal treatments, to even more sophisticated extrusion cooking or infrared heating (Fasina et al 1999 and Koksel et al 1999). Dudgeon-Bollinger et al (1997) found that the production of a high-fiber snack product using waxy HB is possible through extrusion. They concluded that waxy HB can be utilized to provide important nutritional benefits not currently available in extruded snacks and cereals, thus demonstrating the potential market for these product types.

Barley as a Potential Component of Asian Noodles

Canada exports a large portion of its wheat to Asian countries for noodle production. Asian noodles differ from pasta, which is made from durum semolina and extruded to form a variety of different shaped and sized products. Asian noodles are generally made with common wheat flour and are processed by sheeting and cutting. Important quality attributes of noodles include appearance (colour, brightness and speckiness), cooking quality (optimum cook time, water uptake, cooking loss and resistance to overcooking), and eating quality (texture and flavour). Noodles have also been made with the addition of other grains, such as buckwheat, with success, albeit for a niche market.

Asian noodle products differ depending on ingredients (i.e. wheat and buckwheat flour, rice and mungbean starch), mode of preparation, colour, and texture. Wheat based noodles are the most popular type of Asian noodle, with a wide variety of different products falling within this subclass. Yellow alkaline (YAN) and white salted noodles (WSN) are two popular types of wheat-based noodles (Akashi et al 1999).

Since wheat flour is the major ingredient in both YAN and WSN, its physical and chemical components will have an effect on the quality attributes of the end product. Milling practices influence the quality of flour thus impacting quality of the resulting noodle product. Extraction rate, bran contamination, ash content, particle size and starch damage will affect the quality attributes of noodles (Baik et al 1994a, Kruger et al 1994a). A high flour yield at a specified degree of refinement (ash, colour, specks) is preferable.

The typical formulation of both YAN and WSN include flour, water and salt (sodium chloride) and/or kansui (alkali salts). Kansui can be composed of one or a combination of the following alkali salts: sodium or potassium carbonates, bicarbonates, phosphates and even sodium hydroxide (Morris et al 2000). The alkali salts used in the production of YAN is important for controlling microbial growth during storage, developing the characteristic yellow colour, improving noodle texture, developing aroma and flavour, and modifying dough, starch pasting and cooking characteristics (Morris et al 2000). The salt used in the formulation of WSN serves many of the same functions while maintaining the pH of the noodles near the neutral or slightly acidic range and thus the naturally occurring flavonoids remain colourless. The salt also serves an important function during drying, which is common practice for this noodle type. The salt aids in drying by pulling moisture from the centre of the noodle strand to the exterior for rapid and even drying.

The characteristic yellow colour of YAN is a result of naturally occurring flavonoid compounds found in the flour, which are detached from starch and become yellow under the alkaline conditions of noodle production (Miskelly 1996). Addition of the alkaline kansui reagent generates a strong desirable yellow colour through its reaction with flour flavonoids. Prolonged exposure to the alkaline environment results in a more intense yellow colour being developed. Although a bright colour (high L^* value) is desirable and associated with a high quality noodle product, the yellowness value (b^*)

is another important quality parameter for this noodle type since a bright yellow colour is desirable. Brightness (L* values approaching 100) is preferred in a white salted noodle with a moderate yellowness value. The redness value (a*) of the sample indicates contamination with bran, which leads inevitably to discoloration of noodles due to enzyme activity.

The process of noodle making for both WSN and YAN is very similar. The process begins by mixing the raw material (flour, water and salt and/or kansui). Normal water absorption is in the range of 30-35%. Mixing distributes the ingredients uniformly and allows for hydration of the flour particles with the salt-water solution (Kruger 1996). A noodle sheet is formed by passing the crumb, obtained during the mixing process, through a set of rollers. The noodle sheet is then repeatedly passed through the rollers and the gap between the rollers becomes successively smaller, during which time the gluten protein is developed. The noodle sheet is cut into strands and can be packaged and sold as fresh noodles or can undergo further processing such as drying, steaming, or frying to obtain a variety of end products which are subsequently packaged and sold (Kruger 1996).

YAN are usually eaten fresh, within 2 to 24 hours of production. These noodles tend to have a limited shelf life due to their high water activity. WSN are generally dried to reduce water activity of the food system, prolonging shelf life and thus facilitating distribution and exporting (Kruger 1996).

Quality Attributes of Asian Noodles

Appearance, cooking quality and eating quality are important attributes of Asian noodles. They are measurable parameters either by sensory or instrumental methods with some correlation between the two (Oh et al 1983, Yun et al 1997). Colour, brightness and speckiness are three criteria of appearance. Reduced brightness and discoloration in noodle products are thought to involve the enzymes polyphenol oxidase and peroxidase as well as phenolic compounds, and subsequent auto-oxidation products (Hatcher and Symons 2000a). High protein content in wheat flour has also been correlated with a darker noodle colour (Miskelly and Moss 1985). The desired colour of a noodle product will depend on the product type and consumer preferences, however, a bright colour with minimum speckiness is desired since specks tend to be associated with a less refined product (Shelke et al 1990). WSN should be a bright creamy white colour whereas the preference for YAN is a clear yellow product. Flavonoid pigments are important for the yellow colour development in YAN noodles. Flavonoid pigments, which arise mostly from bran contamination in flour, are stable and show no colour at acidic pH values, but at alkaline pH, flavonoid pigments develop a bright yellow colour (Miskelly 1996).

Wheat noodle colour originates from two main sources; fragments of bran and enzymatic browning products that accumulate during processing (Oh et al 1985b). Minimum bran contamination in the flour is, therefore, desirable and generally WSN are made from flours of 0.36-0.4% ash content. By contrast, YAN are made from flours of lower ash content, 0.33-0.38% (Akashi et al 1999). In the wheat kernel, enzymes are located near the bran, therefore, bran contamination of flour increases the enzyme level

(Hatcher and Kruger 1993). The browning or darkening reaction of fresh noodles is due in part to the presence of polyphenol oxidase, an enzyme that oxidizes tyrosine and phenol containing substances to produce dark pigments (Kruger et al 1992, Baik et al 1995, Vadlamani and Seib 1996).

Noodle colour is usually assessed with a colourimeter, which measures the overall brightness, redness and yellowness of the noodle sheet. Considering the importance of fresh noodle appearance to consumers, this method is insufficient for total noodle appearance characterization. Bran contamination in the flour leads to discoloration in the form of brown specks in the product. Specks are a concern especially in fresh noodles where the water activity and bran specks result in increased speckiness and size of specks over time. Even though the number of specks may remain the same over a 24-hour period, their size increases and therefore have a deleterious effect on noodle appearance. Alkaline noodles may be most affected since it is customary to eat these noodles fresh, 2 – 24 hours after production. Although alkaline noodles tend to have more specks than salted noodles, specks in salted noodles are more apparent due to the contrast between the noodle colour and speck (Hatcher and Symons 2000a).

Specks are thought to be a result of loci of contaminating bran particles in the flour that are involved in a complex phenomenon that involves the enzyme polyphenol oxidase (PPO), phenolics components, alkaline oxidation and their subsequent auto-oxidation products (Hatcher et al 1999b). As the PPO activity increases, the rate of change in brightness (L*) and yellowness (b*) correspondingly increases (Kruger et al 1994b). Higher ash content in the flour, which is generally indicative of less flour refinement, also is associated with increased speckiness. Enzyme levels generally increase with increasing ash, which is consistent with the known location of these enzymes in the aleurone and bran layers where they are bound to particulate material (Marsh and Galliard 1986, Hatcher and Kruger 1993, Kruger et al 1994a).

Cooking quality of noodles include such parameters as optimum cooking time, water uptake, cooking loss and resistance to overcooking. The time required to cook the noodle is an important consideration since a shorter cooking time is associated with a more convenient product. The starch in instant noodles is pre-gelatinized so that they have a shorter cooking time.

Water uptake during cooking will influence the eating quality of the product. A noodle should absorb and hold a sufficient quantity of water during cooking, however, the product should be resistant to overcooking, retain its original shape, have a smooth surface and its cooking loss (the solids lost to the cook water) should be minimal (Kruger 1996).

Texture is often considered the most important parameter when determining quality of cooked noodles (Toyokawa et al 1989). Textural attributes are numerous and the desired texture is dependent on noodle type and consumer preferences. Texture can be measured either by sensory or instrumental methods. In general, the desirable textural characteristics of WSN are a soft, elastic texture whereas a firm, springy texture is preferable in a YAN (Kruger 1996). Therefore, YAN are often made with higher protein, stronger gluten wheat to obtain this firm texture (Morris et al 2000).

Instrumental methods were developed to obtain objective textural measurements of food products that compliment sensory analysis. Oh and co-workers (1983; 1985a) developed a method for measuring textural parameters (cutting and compression) of noodles that correlate with sensory measurements using the Instron Universal testing machine.

A research team at the General Foods Corporation Technical Center (Bourne 1976) developed the texture profile analysis (TPA) test for a detailed instrumental analysis of food texture. This test was created to imitate the chewing action of the mouth by compressing a sample twice. Hardness, fracturability, cohesiveness, adhesiveness, springiness, gumminess, and chewiness are some of the parameters that can be measured from the resulting curve. Many of the textural parameters obtained with the TPA test were correlated with the results of a sensory panel (Bourne 1968, 1976 and 1978; Breene 1975; and Bourne et al 1978).

Research on wheat flour components contributing to noodle quality has indicated that protein content and starch characteristics are the major factors influencing cooked noodle texture. Flour protein has been found to affect resistance to overcooking, water absorption, sheeting characteristics and cooking quality (Miskelly and Moss 1985, Oh et al 1985b, Baik et al 1994b, Crosbie et al 1999). While higher flour protein content has been associated with a firmer bite and more elastic texture, protein content has been negatively correlated to both noodle surface smoothness and colour of noodles (Baik et al 1995). YAN are commonly made from flours with protein content in the range of 10.5 to 12% while WSN are made from flours with protein content in the range of 8 to 10% (Akashi et al 1999).

The role of starch in the textural quality of cooked noodles has been investigated (Nagao et al 1977, Moss 1980, Oda et al 1980, Batey et al 1997a and Batey et al 1997b).

Starch pasting characteristics, as determined by the RVA, have been used to predict Asian noodle quality (Panozzo and McCormick 1993, Batey et al 1997a, Yun and Quail 1999). Peak viscosity and breakdown have been associated with cooked noodle texture (Toyokawa et al 1989, Bhattacharya and Corke 1996, Jun et al 1998b, Crosbie et al 1999). Wheat starches that confer high peak viscosity, high rate of breakdown and low setback have been associated with the desirable soft and elastic eating quality of WSN (Jun et al 1998b). Starch with low paste viscosity is preferred for YAN to allow for the substantial increase in the viscosity in the alkaline medium, whereas the alkali salts function to toughen the dough, alter starch pasting characteristics, colour and flavour (Miskelly and Moss 1985, Bhattacharya and Corke 1996). Starch composition, specifically amylose content, will influence the starch pasting properties and thus can also be considered a determining factor in noodle texture (Toyokawa et al 1989, Baik and Lee 2003, Guo et al 2003).

The role of lipids in noodle production is not well known. Lipids and surfactants are usually added in the production of pasta and noodles to improve cooking texture, to prevent over drying of the surface by preventing dough strands form adhering, and to provide unique flavours (Jun et al 1998a). Removal of free lipids from the flour resulted in increased amounts of amylose in the cooking water and led to greater stickiness.

To date, incorporation of barley components have been investigated in some cereal based products, but to the best of our knowledge, extensive studies have not been conducted on barley milling fractions in noodles.

MANUSCRIPT 1
Hull-less Barley Flour Addition to Fresh and Dry White Salted Noodles

ABSTRACT

Hull-less barley (HB) has the potential for texture modification and health implications in food products. To evaluate the suitability of barley in fresh and dry white salted noodles, roller milled flour from 8 HB genotypes with variable starch characteristics (normal, waxy, zero amylose waxy and high amylose) and elevated levels of β-glucans and arabinoxylans were incorporated (20% and 40% w/w) into a Canada Prairie Spring-white (cv. AC Vista) wheat flour.

The quality of WSN was evaluated in terms of appearance, cooking characteristics, and textural properties. Addition of barley flour had an effect on the colour (L*,a*,b*) of the raw and cooked noodles where a decreased brightness and yellowness while an increased redness was seen. As well, an increase in the speckiness of the noodle sheet was detected with image analysis, most noticeable at 24h.

Non-starch polysaccharides, in particular β-glucans and arabinoxylans, may have decreased susceptibility to cooking loss and provided strength to the cooked noodle structure, therefore, contributing to its texture. The role of other possible contributing factors, such as phenolics, have yet to be investigated. Results indicate that the amylose-amylopectin ratio of the starch is also a factor in cooked noodle texture. Generally, the addition of HB flour with low amylose content decreased noodle firmness and chewiness while HB flour with increased amylose content increased noodle firmness and chewiness of white salted noodles. Therefore, HB flour with different starch characteristics can be used to produce noodles with tailored textural characteristics.

INTRODUCTION

Consumers are becoming increasingly aware of the link between diet and health. As people continue to look for healthy, alternative food sources, barley has been regaining interest. Barley, which has been traditionally used in the malting, brewing and animal feed industries, is a healthy grain since it contains low levels of fat and high levels of complex carbohydrates, dietary fiber and antioxidants. Moreover, barley has been of interest to food scientists because its varying starch amylose content and elevated levels of non-starch polysaccharides have the potential for texture modification in food applications.

Studies have been conducted on enriching, using additives or substituting some portion of wheat flour with other ingredients in the production of cereal-based foods. Barley has been incorporated into several food products such as pasta, bread and noodles with varying success (Bhatty 1986, Swanson and Penfield 1988, Sidhu et al 1990, Knuckles et al 1997, Klamczynski and Czuchajowska 1999, and Gill et al 2002a, 2002b). The addition of barley in these studies have been undertaken with varying objectives in mind, such as improvement of functional properties, nutritional enhancement, textural or appearance alterations or for cost considerations. Few systematic studies have been conducted to examine the effects of amount, type and composition of barley on the end use quality of Asian noodles.

The objective of the present study was, therefore, to evaluate the quality of white salted noodles with the addition of 20 and 40% HB flour with variable starch amylose content. The quality attributes (appearance, cooking characteristics and texture) of the resulting noodles were evaluated.

MATERIALS AND METHODS

Material

A 60% extraction patent AC Vista (Canada Prairie Spring-white) flour milled on the GRL (Grain Research Laboratory) pilot mill (Black 1980) was used as the control and as the base wheat flour in noodle production. Canadian hull-less barley (HB) samples were obtained from field trails grown in western Canada. Falcon, a 6-row normal starch HB genotype obtained from James Farms Ltd. (Winnipeg, Manitoba), was grown in 1998 in Manitoba, Canada. The remaining 7 HB genotypes used in the study were obtained from the Crop Development Center (CDC), University of Saskatchewan, Saskatoon, Saskatchewan. SB90354 is an unregistered 2-row normal starch genotype. CDC Candle is a 2-row waxy genotype derived from "Waxy Betzes". SR93135 is an unregistered 2-row waxy genotype. SB94792 is an unregistered 2-row zero amylose waxy genotype. CDC Alamo is a 2-row zero amylose waxy starch genotype derived from a cross of a 2-row waxy CDC breeding line with the variety Azhul from the University of Arizona. The high amylose sister lines CDC-92-55-06-48 and CDC-92-55-06-54 are 6-row genotypes derived from "High Amylose Glacier".

HB was tempered to 14.5% moisture and rested for 65 hour period prior to pearling (20%) and milling. Milling was performed with a five-stand mill equipped with 25-cm diameter rolls in conjunction with a rotary box sifter and a Buhler laboratory shorts duster according to the long milling flow described by Izydorczyk et al (2003). The procedure included 4 break passages, 3 sizing passages, 2 reduction passages and 4 shorts duster passages.

Sample Characterization

Protein content (%N x 6.25 for barley and %N x 5.7 for wheat) was determined by combustion nitrogen analysis (model FP-248 Leco Dumas CAN analyzer) calibrated with ethylenediaminetetraacetic acid (EDTA) according to AACC (2000) Approved Method 46-30. Ash and starch damage were determined using AACC (2000) Approved Methods 08-01, and 76-31, respectively. Colour of straight grade barley flour was evaluated using a Minolta Chroma CR-200 Meter with a CR-231 head (Minolta, Mississauga, Ontario). Starch pasting characteristics of barley flour were determined with a 13-minute pasting profile using a Rapid-Visco Analyser (RVA, Foss Food Technology). A 3.5g sample size (14% moisture basis) was suspended in 25 ml of a 0.05M solution of silver nitrate, to inactivate the α-amylase present in the sample. A 30-minute RVA pasting profile was also investigated (Appendix 1-3) and these results were used for correlation analysis. Amylose content of the isolated, defatted starch samples was determined by potentiometric titration (Schoch 1964, Izydorczyk et al 2001).

Polyphenol oxidase (PPO), a measure of oxygen consumption as determined with a biological oxygen monitor using catechol (0.8M) as the substrate solution, was determined according to the method of Hatcher and Kruger (1993). Peroxidase (POD) was determined using 1-Step ABTS (2, 2'-azine-di [3-ethylbenzthiazoline sulfonate]) (Pierce) as the substrate. A 0.05g sample was suspended in 5.0ml of 0.1M sodium acetate buffer (pH 4.2) and extracted by gentle rotation 30 min at 4°C. The samples were centrifuged (14,000 rpm, 10 min) at 4°C. Filtered supernatant was held at 4°C for 30 min and then diluted with 10M sodium acetate buffer (1:10 dilution, pH 4.2). To 25μl of the diluted extract, 150μl of the commercially prepared substrate 1-Step ™ ABTS (Pierce, Rockford, Illinois) was added in the Microplate well and the reaction was halted after 1 min. with 100 μl of H_2SO_4. The absorbance (λ405) was read in the Microplate reader (Thermomax, Molecular Devices Corp., Sunnyvale, California) at a constant temperature of 20°C. The end point result was determined by SOFTmax® PRO Computer Software (Molecular Devices Corp., Sunnyvale, California).

Chemical Composition

Total starch and β-glucan (BG) content of the flour was determined enzymatically using Megazyme kits (Megazyme International Ireland, LTD., AACC (2000) Approved Methods 76-13 and 32-33). Total arabinoxylan (AX) content of the flour was determined colorimetrically by the phloroglucinol reaction method of Douglas (1981). BG and AX were solubilized by shaking a suspension of 1g flour in 10 ml of 40°C distilled deionized water. The samples were shaken (2 h) with a Burrell wrist action shaker (Burrell Corp., Pittsburgh, PA) in a temperature controlled chamber (40°C). The samples were then centrifuged (5,000 rpm) for 20 min. An aliquot of the centrifuged solution (0.5ml made up to 2.0 ml with distilled, deionized water) was obtained for analysis of the soluble components as previously described.

All results of chemical analyses are reported on a dry matter basis as an average of at least three measurements, unless otherwise indicated.

Noodle Preparation

HB straight grade flour was added to WSN at a 20% and 40% level of addition. These levels were chosen since research has shown that acceptable cereal based products can be made with 20% substitution of wheat flour with barley components (Cheigh et al 1976, Prentice et al 1979, Berglund et al 1992). Moreover, a substantial replacement of wheat flour with barley flour was desired for the study.

The handling and the visual properties of the noodle dough as described by Oh and co-workers (1983) determined water absorption levels (Table 2.1). Insufficient water in the system resulted in dough that was not properly or evenly hydrated and difficult to sheet. Excess water resulted in noodle dough that was too extensible and stuck to the rollers during sheeting. Optimum absorption of 35% for WSN made from 100% AC Vista flour was determined based on particle size by the mixograph method (GRL Internal Method). Preliminary investigations found that the mixograph method did not accurately predict the optimum absorption of noodles once HB was added to the system. This is due in part to the large quantity of non-starch polysaccharides that are found in HB, in particular BG and AX, which are highly hygroscopic in nature. Since there was insufficient sample to thoroughly investigate the optimum water absorption for each individual sample, a constant absorption was used to directly compare the samples. The 20% HB flour blend noodles were made at the optimum absorption of the 100% AC Vista noodle since the low level of HB flour addition did not require extra water. Higher water absorption levels were employed upon addition of 40% HB flour to the noodles since the elevated levels of the non-starch polysaccharides in the system compete with the starch and protein for the free water.

Table 2.1. Water Absorption Levels in White Salted Noodles

Hull-less Barley Flour Addition Levels	Water Absorption, %
100% AC Vista flour	35
80% AC Vista + 20% HB flour	35
60% AC Vista + 40% HB flour	42

AC Vista patent flour and HB straight grade flour, water and 1% salt (sodium chloride) were mixed in a Hobart mixer (N50, Hobart Canada, North York, ON) and made into noodles as per Kruger et al (1994a) using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan). Initially, the dry flour was mixed for 30 seconds on setting 1 prior to addition of a salt solution. The solution was slowly added over a 30-second period with mixing continued for an additional 30 seconds. The resulting crumb was mixed at high speed (setting 2) for 1 minute followed by a final 3 minutes of mixing on the slow setting #1. The crumb was rolled between a set of rollers (temperature controlled water bath, 28°C) with an initial gap setting of 3mm. The resulting sheet was folded once and was passed through the rollers, loose ends first, to simulate the industrial noodle sheet compounding or laminating step. WSN were rolled onto a plastic rolling pin, sealed in a polyethylene bag, and allowed to rest for 30 min.

The noodle sheet was then cut into a representative 25-cm long section and was sheeted (roll speed of 3.75 rpm) with a 15% reduction for each consecutive pass (3.00, 2.55, 2.15, 1.85, 1.57, 1.33, 1.10 mm) over a period of 4.5 minutes. Force measurements were captured on an analog-digital board (Labmaster DMA, Scientific Solutions, Solon, OH) interfaced to a personal computer using commercial software (Labtech Notebook, Laboratories Technologies, Wilmington, MA) as described by Hatcher and co-workers (1999a).

The resulting noodle sheet was cut into thirds; two portions were held, at ambient temperature, in sealed plastic bags and containers for colour and image analysis, respectively. The remaining noodle sheet was cut into strands (B 22 cutters) and held in sealed plastic containers, at ambient temperature, until further analysis.

Noodle Quality Analysis

Appearance

Raw, cooked, and dry noodle colour was evaluated with a spectrocolorimeter (Labscan II, HunterLab, Reston, VA) equipped with a D65 illuminant using the L*, a*, and b* colour scale at 0, 1, 2 and 24 hours after processing. The noodle sheet was folded twice to provide three layers of thickness for measurement. Three measurements were taken at 2 different locations and the readings were averaged.

Cooked noodles were held in an Agtron cup (Agtron, Reno, NV) for colour determination after being rinsed and drained. The container was rotated between readings, for an average of 6 measurements, to ensure a representative sampling area. Dry noodle colour was obtained by placing a sufficient quantity of long noodle strands to fully cover the 2.5cm porthole of the Labscan II. All samples were covered with a black plastic container to maintain a consistent background colour and to avoid excess light entering the porthole.

Images of the raw noodle sheets (25 cm^2) were captured at 0, 1, 2 and 24 hours after processing using a commercial scanner (Model 3, Microteck, Canada) and analyzed using in-house developed software established by KS-400 (Carl Zeiss Vision, Echting, Germany) as per Hatcher et al (1999b) and Hatcher and Symons (2000a, 2000b and 2000c). Images captured at 0 time were not included in the statistical analysis due to the incomplete and uneven hydration of the noodle sheet at this time. Delta-grey and speck size were the two imaging variables used during noodle analysis. Delta-grey (0-255) represents a threshold value of darkness that must be exceeded for a discoloured region to be identified (Hatcher et al 1999b). It is the minimum difference in darkness between the specks and the noodle surface. Speck size is an imaging parameter used for selecting discoloured spots based on a defined minimum size. The specks were analyzed with a Δ grey of 5 and a speck size of $6000\mu^2$ to obtain speck count and size.

Optimum Cook Time

Optimum cook time of the noodles was determined by cooking the sample in boiling, distilled water, removing sub-samples at intervals and placing them in temperature controlled (20°C) water. Five noodle strands from each time interval were placed between plexi-glass sheets and their inner core observed by lightly squeezing the plates together. The noodles were deemed to be cooked to optimum once the white inner core of at least four out of the five noodle sub-samples disappeared, indicating that cooking water had fully penetrated to the core.

Texture

Noodles (25g in 400ml boiling distilled water) were cooked to optimum time exactly one hour after completion of processing. The cooked noodles were drained, rinsed for one minute with distilled water (20°C) and placed in sealed plastic containers for 10 min. The compression, texture profile analysis (TPA) and stress relaxation tests were performed 8, 16, and 24 minutes after the commencement of the cutting test, respectively, using the TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK).

A 1mm thick Lexan cutting blade (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) was used in the cutting test while a compression blade (10mm thick) was used for the compression, TPA and relaxation tests as per Oh et al (1983, 1985a). Each test was performed on five sets of 3 noodles. The combined width of 3 noodle strands was measured using digital calipers. The cutting test was performed at a cross speed of 0.4 mm/s. Maximum cutting stress was determined from the force-distance curves. Maximum cutting stress, which is expressed in units of grams per millimeter square, was calculated by dividing the peak height by the initial blade contact area (Oh et al 1983).

Cooked noodles were compressed cross-wise to a load of 1500g. Resistance to compression was obtained from the compression-recovery curves. Resistance to compression (%) is defined as 100 times the ratio of the retained thickness (initial thickness minus the compressed distance) to the initial thickness of the cooked noodle (Oh et al 1983).

The TPA test consists of a series of compressions to the cooked noodles, imitating the chewing action of the jaw. Noodles were compressed to 50% of their initial thickness; the force was removed and held at the position of initial contact for 5 seconds before the compression action (50%) was repeated. Resilience and chewiness were calculated from the resulting force time curves. Chewiness is defined as the product of gumminess and springiness (Bourne et al 1978). Resilience is the area during the withdrawal of the first compression, divided by the area of the first compression (Bourne 1976 and 1978).

The stress relaxation test measures the force exerted by compressed noodles during relaxation (Sopiwnyk 1999). The noodles were compressed once at a cross speed of 0.10 mm/s to a load of 250g and were held at this force for 45 seconds. Relaxation time is defined as the time required for the noodles to relax to 85% of the initial load force.

Water uptake was calculated by subtracting the initial sample weight (25g) from the cooked sample weight and dividing by the initial sample weight. Cooking loss was calculated by dividing the weight of solids left in the beaker after cooking by the initial sample weight.

Dry White Salted Noodles

Drying

Fresh WSN, placed on wooden dowels, were dried over a 16-h period in a drying cabinet (Conviron, Winnipeg, Canada) with the following temperature/ humidity profile: 25°C/55 %RH (1 h), 25°C/90 %RH (7.5 h), 35°C/90 %RH (5.5 h), 25°C/70 %RH (2 h). Dried noodles were placed in non-sealed plastic bags and allowed to cure and equilibrate to atmospheric conditions for a minimum of 2 weeks at room temperature prior to further analysis.

Breaking Strength

The thickness and width were measured at two different locations on 10 dry noodle strands using digital callipers prior to being analyzed for breaking strength.

Breaking strength was evaluated with a TA-XT2i Texture Analyser according to the method described by Oh et al (1985b). A mean value of 20 noodles per sample was determined.

Statistical Analysis

The textural characteristics (cutting, compression, TPA and stress relaxation, as previously described) of cooked Futomaru noodles, a standard dry WSN, were measured each day of testing to ensure equipment was functioning within acceptable limits (results not shown).

All statistical analyses were performed using SAS statistical software version 8 (SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) and Proc GLM were performed to determine significant differences. Experiments were carried out at least in duplicate. Replicated results are reported as means. A completely randomized block design was used, with noodle type and flour addition level being blocked. In all bar graphs, different letters indicate significant differences between means. All values were considered significant at $p \leq 0.05$ unless otherwise stated. The coefficient of variation was less than 5% for all tests.

RESULTS AND DISCUSSION

Composition and Physicochemical Properties of Hull-less Barley and Wheat Flours

Straight grade flour from eight genotypes of hull-less barley (HB) and a 60% patent flour from AC Vista, a registered variety in the Canada Prairie Spring-white (CPS-W) wheat class were used in this study to make Asian type noodles. The eight HB genotypes represented four different starch types: normal, waxy, zero amylose waxy and high amylose with amylose contents ranging from 0%-41.8% (Table 2.2). AC Vista flour contained more starch (75.5%) than the HB flour samples (64.4%-74.6%). Among the HB flours, normal samples had the highest starch contents followed by waxy, zero amylose waxy (ZAW) and high amylose (HA) (Table 2.2). Less starch damage was observed in the HB samples than in the AC Vista flour, possibly because of different milling regimes applied to barley and wheat samples. Variability in starch damage was observed between HB samples of the same starch type as well as among genotypes.

All HB flour samples displayed higher Minolta brightness (L*) values than AC Vista flour (Table 2.2). The high amylose samples consistently displayed the lowest brightness values among HB flours. Brightness values among HB flour samples ranged from 92.80 to 93.40. Redness (a*) values were higher in HB flour samples than in the AC Vista flour sample. AC Vista flour displayed the highest yellowness (b*) value (9.01) overall while the two HA samples had the lowest values, 5.32 and 4.81.

Table 2.2. Sample Characterization of Hull-less Barley and Wheat Flour[a]

Hull-less Barley type/variety	Yield[b] %	Colour L*	Colour a*	Colour b*	Starch Content %	Starch Damage %	Starch Amylose Content %	Protein[c] %	Ash %
Normal									
Falcon	60.2	93.17	-0.47	6.79	74.4	2.8	23.8	13.1	0.76
SB90354	57.6	93.22	-0.22	5.83	74.6	4.9	24.3	12.1	0.79
Waxy									
CDC Candle	52.7	93.33	-0.45	5.72	73.4	4.3	4.3	11.6	0.83
SR93135	50.4	93.29	-0.69	7.26	72.9	4.8	4.8	11.9	0.86
Zero Amylose Waxy									
SB94792	50.3	93.40	-0.59	6.89	71.7	4.0	0	12.8	0.86
CDC Alamo	51.4	93.12	-0.39	6.45	70.8	5.2	0	13.1	0.88
High Amylose									
CDC-92-55-06-54	51.6	92.80	-0.28	5.32	69.9	4.1	41.4	13.0	0.79
CDC-92-55-06-48	48.2	92.82	-0.14	4.81	64.4	3.3	41.8	14.0	0.78
Wheat									
AC Vista		92.66	-0.72	9.01	75.5	6.9		12.3	0.44

[a] Values are expressed on a dry matter basis.
[b] Yield is expressed on an as is moisture and on a whole barley basis.
[c] % N x 5.7 for wheat; % N x 6.25 for barley

Protein content of HB flours ranged from 11.6% to 14.0% with a general trend as follows: high amylose > zero amylose waxy > normal > waxy. AC Vista flour had a protein content of 12.3% (Table 2.2). HB flour displayed consistently higher levels of ash than AC Vista flour, with the ZAW samples having the highest levels, 0.86% and 0.88%, overall (Table 2.2). In contrast, Czuchajowska et al (1998) found that the ash content in high-amylose HB was significantly higher than in waxy and normal HB, which may be due to different growing conditions. Although higher ash content in flour has been related to increased enzyme levels, higher ash content is not necessarily synonymous with lower degree of refinement. Bhatty (1995) reported milled barley flour as having higher ash contents than wheat due to the brittleness of the barley bran and indicated that the darker colour of HB bran is due to anthocyanin pigments present in the pericarp.

All HB flour samples contained significantly higher BG content (2.97% - 4.37%) than wheat flour (0.72%) (Table 2.3). Some differences between barley genotypes and types were also observed. In general, the amount of BG in barley flours was significantly lower compared to that of the whole grain (Izydorczyk et al 2000). Since BG are found largely in the endosperm cell walls, they are concentrated in the shorts fractions, and not in the flour, which is composed primarily of starch. Total BG, and more importantly, soluble levels of BG in barley are an important consideration since it is this component of the grain that has many proven human health benefits. Soluble BG in the HB flour ranged from 1.57% to 2.63%. All classes of HB, with the exception of the normal starch genotypes, had higher levels of soluble BG in the flour, although only the HA genotypes were significantly higher than the normal starch samples.

Arabinoxylans (AX) are located largely in the aleurone layer and to a lesser extent in the cell wall material of the starchy endosperm (MacGregor and Fincher 1993). Pearling of HB before milling reduced the amount of AX in flour compared to the whole barley grain (Izydorczyk et al 2003). AC Vista flour had significantly higher levels of total and soluble AX than HB flours with waxy and zero amylose waxy starch (Table 2.3). High amylose samples displayed the highest levels of AX among the HB flour samples, although not significantly higher than normal samples. No significant differences were detected between HB samples of the same starch type.

Table 2.3. Non-Starch Polysaccharide Content in Hull-less Barley and Wheat Flour*

	β-glucans		Arabinoxylans	
HB type/variety	**Total, %**	**Soluble, %**	**Total, %**	**Soluble, %**
Normal				
Falcon	3.48 bc	1.63 c	1.38 ab	0.28 bc
SB90354	3.94 ab	1.57 c	1.37 ab	0.30 b
Waxy				
CDC Candle	3.16 c	1.71 bc	0.90 bc	0.16 bcd
SR93135	4.37 a	1.99 abc	0.81 c	0.18 bcd
Zero Amylose Waxy				
SB94792	2.97 c	1.98 abc	1.00 bc	0.13 d
CDC Alamo	4.23 a	2.18 abc	1.10 bc	0.15 cd
High Amylose				
CDC-92-55-06-54	3.93 ab	2.47 ab	1.60 a	0.49 a
CDC-92-55-06-48	4.06 ab	2.63 a	1.82 a	0.50 a
Wheat flour				
AC Vista	0.72 d	0.35 d	1.69 a	0.45 a

*Means followed by different letters in columns are significantly different at $p \leq 0.05$.

Two enzymes that have been reported as having deleterious effects on noodle colour are polyphenol oxidase (PPO) and peroxidase (POD) (Kruger et al 1994b, Hatcher and Symons 2000a). Hull-less barley straight grade flours contained higher levels of PPO enzyme activity compared to the levels found in the AC Vista patent flour (Table 2.4). This is not surprising considering AC Vista is a low extraction patent flour, which is almost pure starchy endosperm, while the HB samples are straight grade flours which would be expected to contain more aleurone and pericarp. The bran of barley does not fully separate from the endosperm as it does for wheat. Even when pearled, there is bran left in the crease of the barley kernel, which ends up in the flour. Some differences were seen among HB flour samples. High amylose samples had the lowest PPO activity among the HB flours.

Table 2.4. Polyphenol Oxidase (PPO) and Peroxidase (POD) Enzyme Activity in Wheat and Hull-less Barley Flour*

	PPO[a]	POD[b]
Wheat		
AC Vista	17d	171e
HB Type / Variety		
Normal		
Falcon	84abcd	387abc
SB90354	94abc	489a
Waxy		
CDC Candle	118ab	307cd
SR93135	64bcd	263ed
Zero Amylose Waxy		
SB94792	50bcd	433ab
CDC Alamo	138a	358bcd
High Amylose		
CDC-92-55-06-54	36cd	306cd
CDC-92-55-06-48	19d	257de

*Means followed by different letters in columns are significantly different at $p \leq 0.05$
[a] PPO expressed in nmol/g/min
[b] POD expressed in pyrogallol units/mg

HB flours also contained higher levels of POD than AC Vista flour. No significant differences were detected between HB of the same starch type and minimal differences were detected among HB genotypes. Higher levels of PPO and POD in barley may be associated with higher levels of phenolics in barley compared to wheat. Since enzyme levels were significantly higher in barley, it is expected that they will have an affect on the noodle appearance.

Starch Pasting Characteristics

Peak and breakdown viscosity are starch pasting characteristics of wheat flour that have been related to the texture of cooked WSN (Batey et al 1997a, Crosbie et al 1999). High values of peak and breakdown viscosity have been associated with a soft, elastic noodle texture. RVA curves of HB flour, in the presence of $AgNO_3$, showed that normal barley flour had a similar pasting curve to AC Vista flour (Fig 2.1) although Falcon displayed a higher peak viscosity than AC Vista. The high amylose sample had a substantially lower peak viscosity. Both waxy and zero amylose waxy HB displayed higher peak viscosity than AC Vista, however, their peak times were shorter, 3.5 minutes rather than 6 minutes.

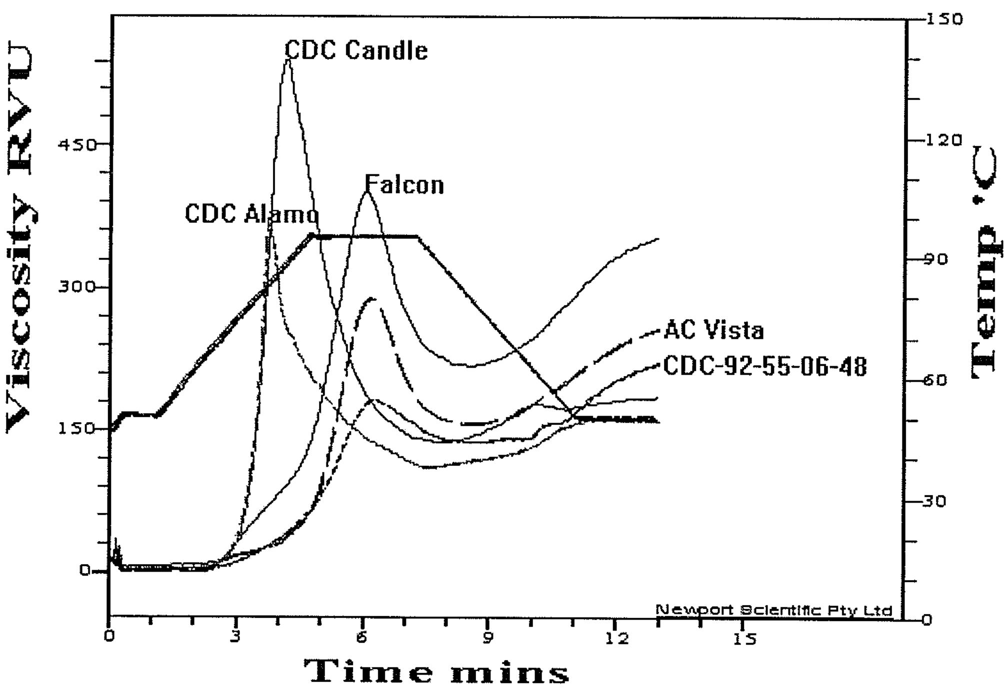
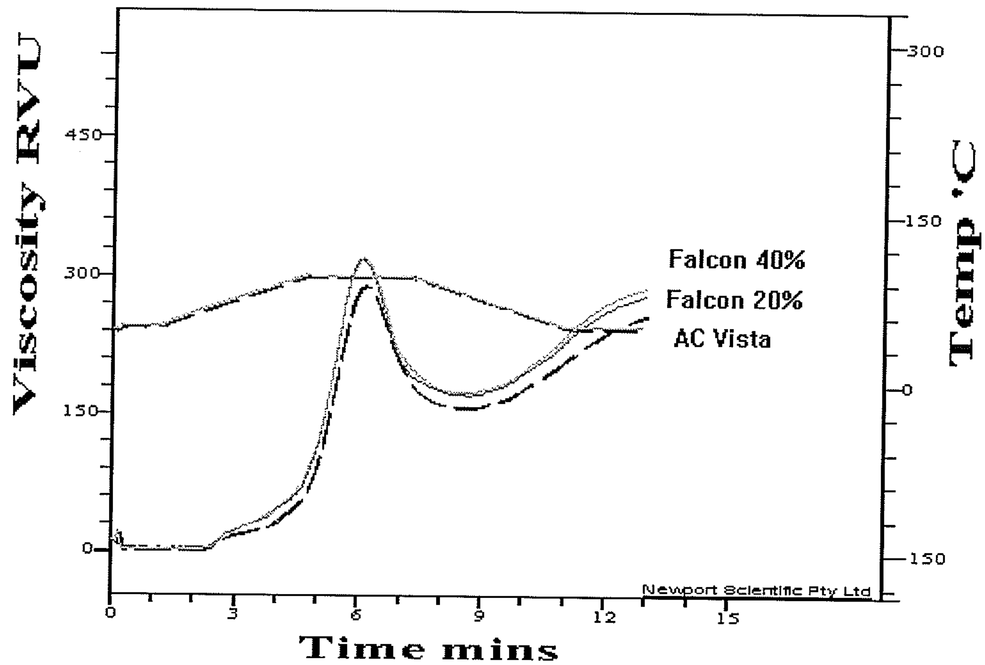


Figure 2.1. RVA starch pasting characteristics of hull-less barley flour and AC Vista flour in the presence of $AgNO_3$.

The starch pasting characteristics of AC Vista flour supplemented with HB flour at both a 20% and 40% addition level were also investigated. Starch pasting characteristics of AC Vista flour were altered with the addition of HB flour at levels of 20% and 40%. Samples containing normal HB flour showed increased peak viscosity while the remaining samples had decreased peak viscosity of the blends (Fig 2.2-2.5).

Peak viscosity of samples containing waxy HB was slightly decreased while peak times were shorter (Fig 2.3). The addition of zero amylose waxy HB flour had the most pronounced effect on the starch pasting characteristics of the flour blends (Fig 2.4). A decrease in peak viscosity, a shorter peak time and two distinct peaks were detected. Samples containing normal and high amylose HB affected peak viscosity, although their starch pasting curves were similar to that of the control (Fig 2.5).

Research has shown that waxy barley produces larger viscosity at peak than non-waxy barley (greater swelling) (Bhatty1997, Bhatty and Rossnagel 1998, Klamczynski and Czuchajowska 1999, Sasaki et al 2000). Zheng et al (1998) found that zero amylose HB starch granules showed easier swelling and higher fragility as indicated by lower pasting temperature and higher peak viscosity when compared with waxy genotypes. Very low granule swelling and viscosity were attributed to high amylose and the presence of amylose-lipid complexes. Amylopectin is primarily responsible for granule swelling and the starch can swell more freely and develop large peak viscosity at a low pasting temperature (Song and Jane 2000).



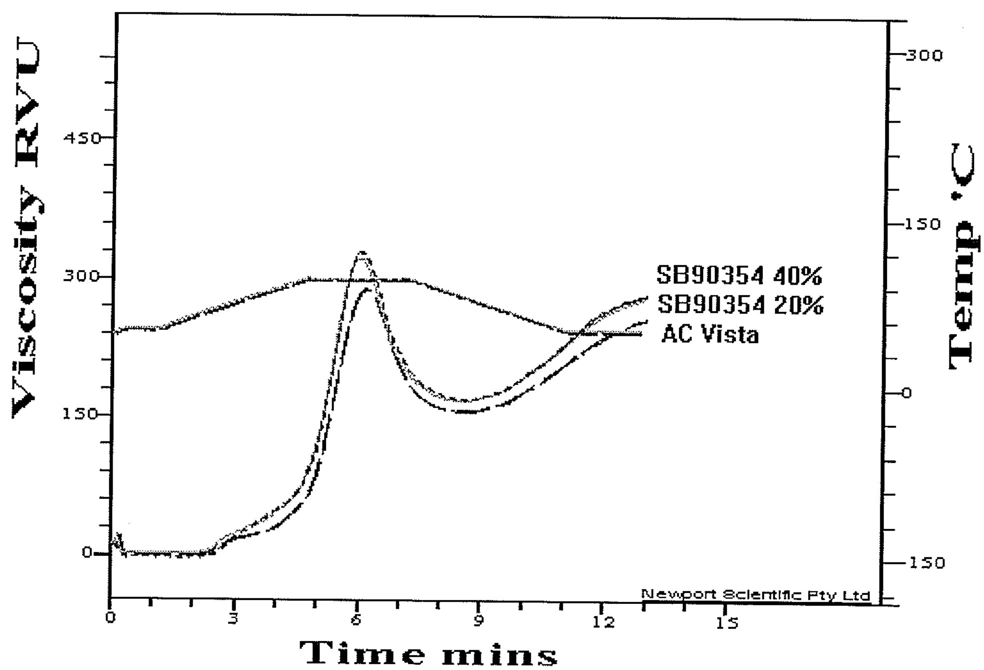
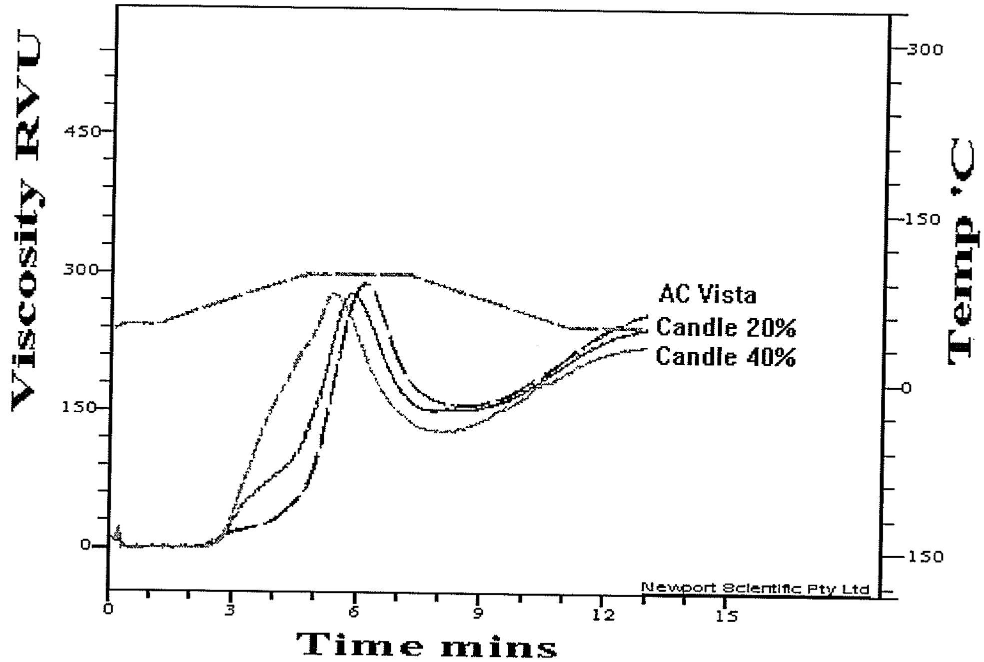


Figure 2.2. RVA starch pasting characteristics of normal hull-less barley flour/AC Vista blends in the presence of $AgNO_3$.



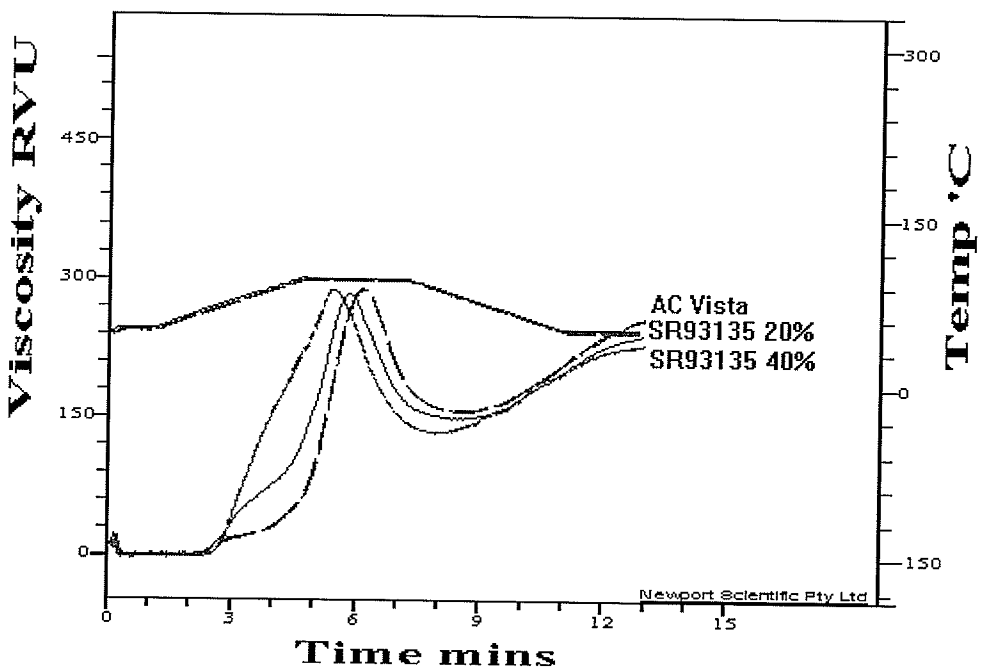
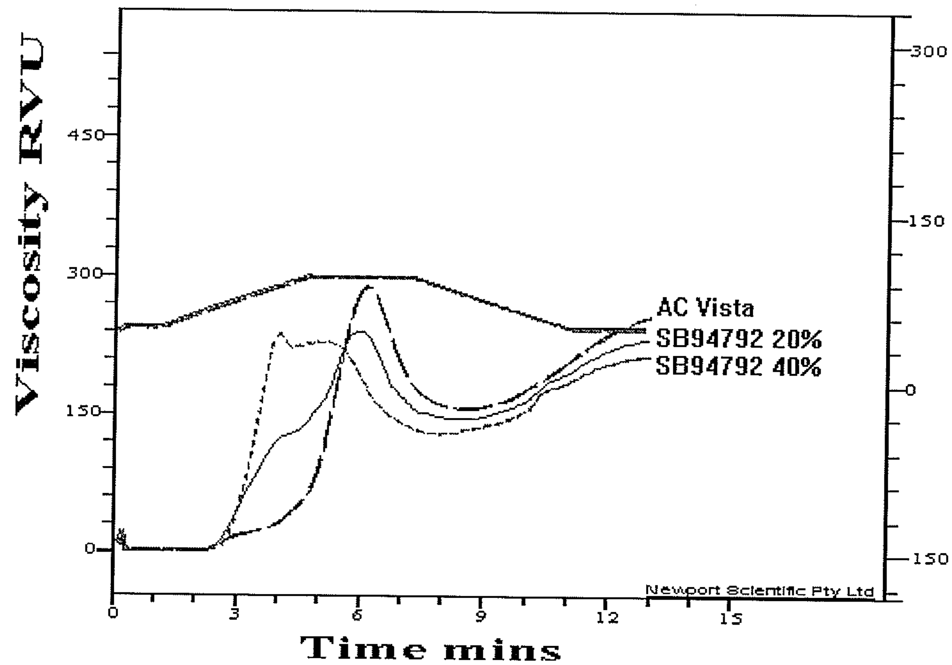


Figure 2.3. RVA starch pasting characteristics of waxy hull-less barley flour/AC Vista blends in the presence of $AgNO_3$.



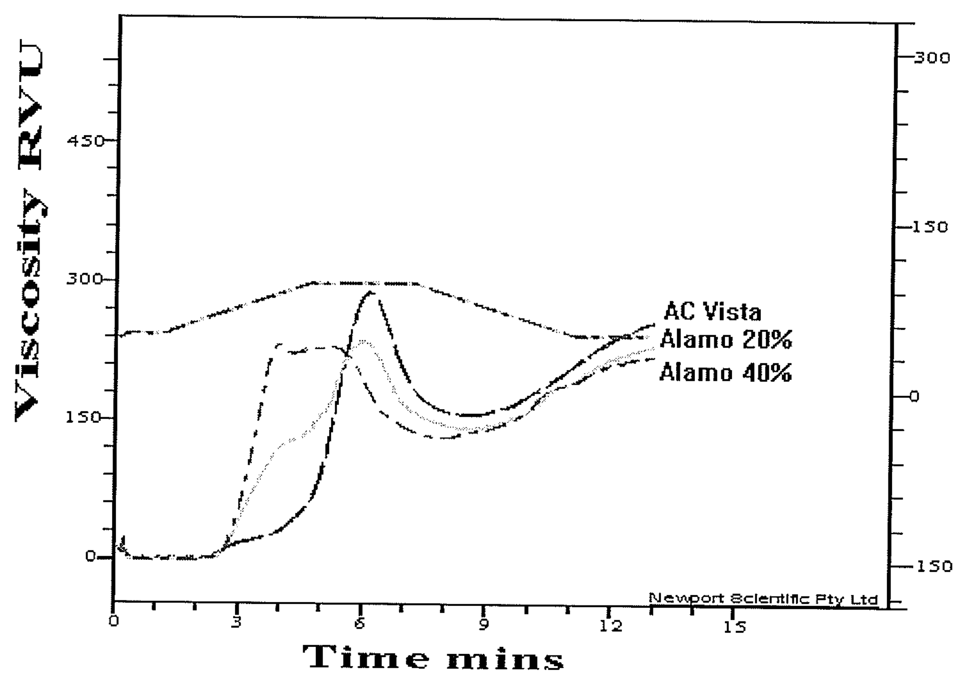
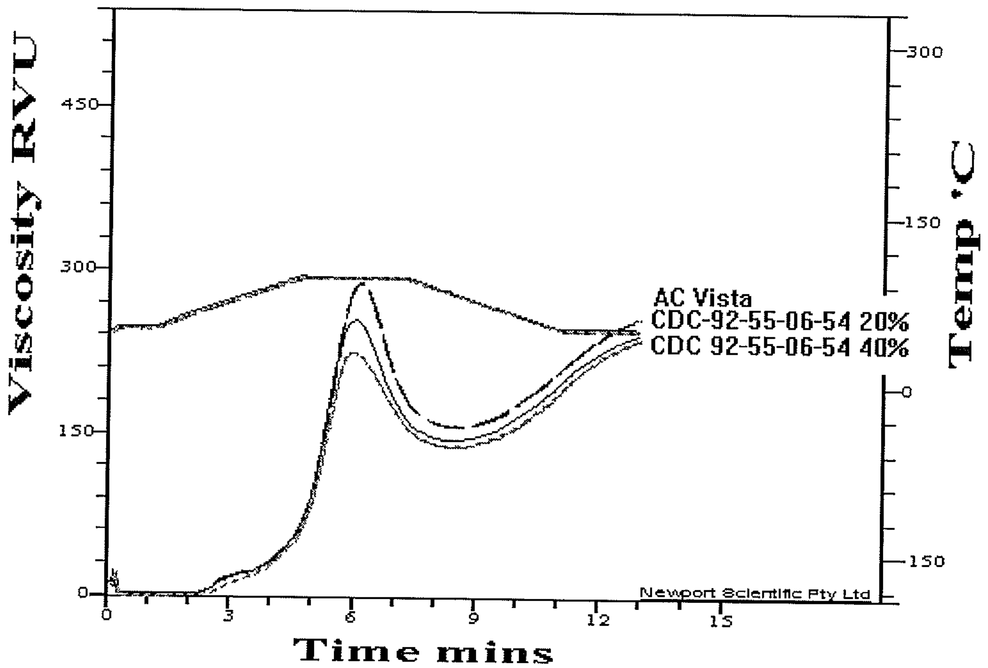


Figure 2.4. RVA starch pasting characteristics of zero amylose waxy hull-less barley flour/AC Vista blends in the presence of $AgNO_3$.



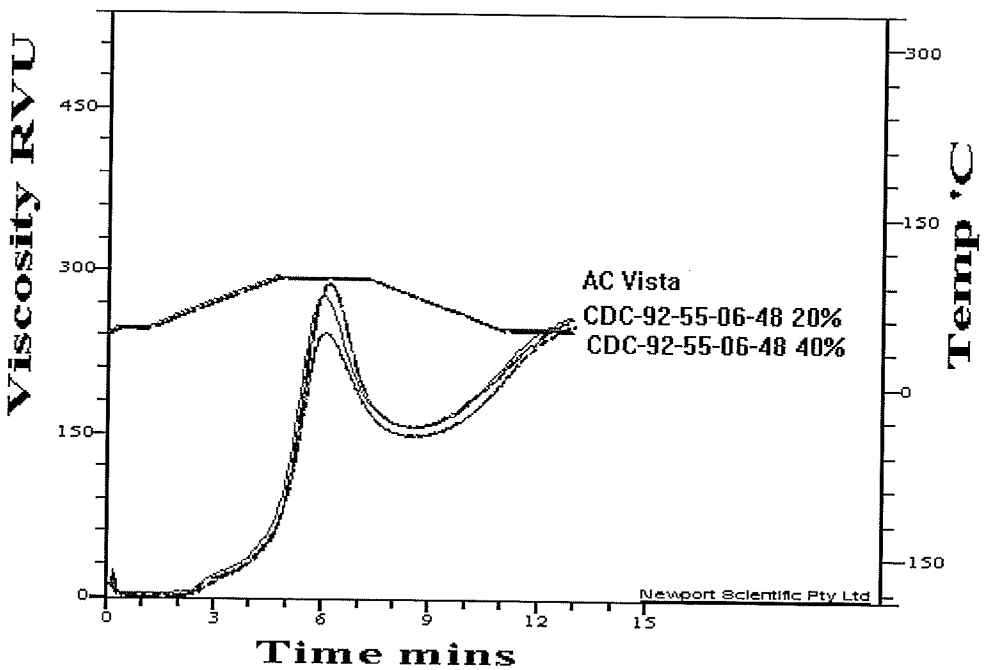


Figure 2.5. RVA starch pasting characteristics of high amylose hull-less barley flour/AC Vista blends in the presence of $AgNO_3$.

Processing and Quality Characteristics of Fresh and Dry WSN Containing Hull-less Barley Flour

Power Requirements

The force required to roll the crumbly dough into a noodle sheet was recorded in order to determine if the addition of HB flour affected work input requirements. Energy requirement is an important economical consideration since energy is one of the most expensive inputs in many production processes. Work input is influenced by water absorption level, with higher water absorption levels resulting in less work input (Hatcher et al 1999a). The addition of 20% HB flour to WSN significantly increased the amount of energy required to make the noodles. High amylose blend noodles required the highest work input overall (Fig 2.6). No significant differences in work input were detected between noodles containing the same types of barley flour. Contrarily, the addition of 40% HB flour significantly decreased the work input with the exception of the high amylose blend noodles, which did not differ considerably from the control. At the 40% addition level, noodles containing normal HB flour displayed the lowest work input values. The 40% HB blend noodles had higher water absorption levels than AC Vista and the 20% HB blend noodles, which would have contributed in part to these differences. Another contributing factor may have been the increased dilution of the vital wheat protein gluten at the elevated level of HB flour addition.

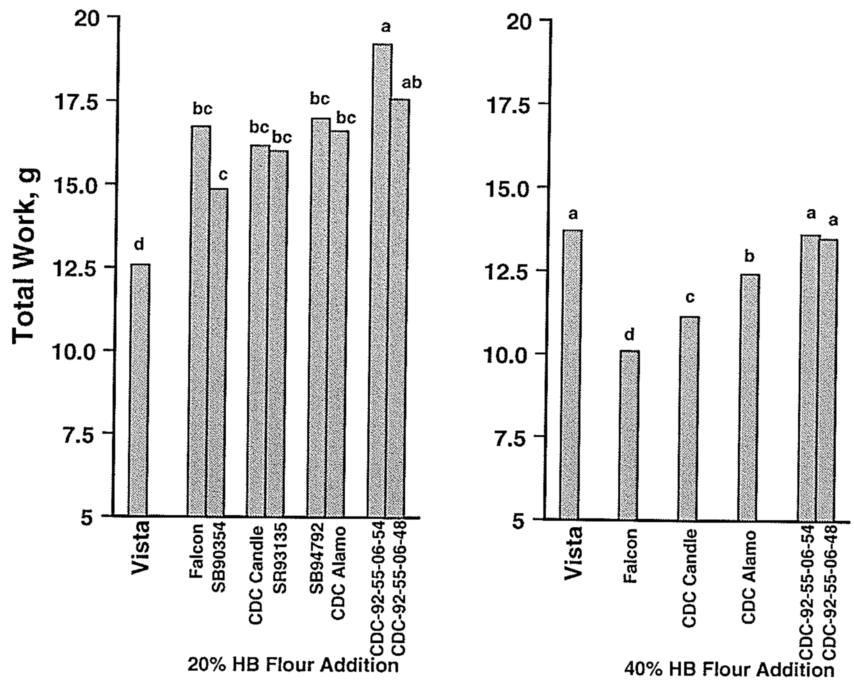


Figure 2.6. Energy requirements during processing of white salted noodles with the addition of hull-less barley flour.

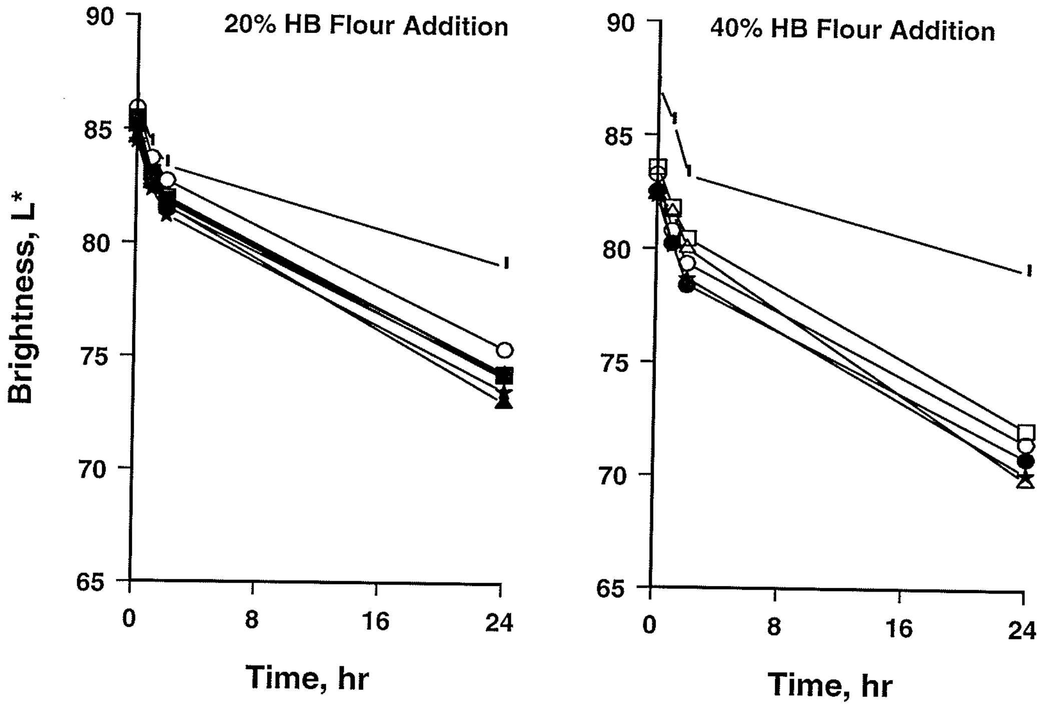
Raw Noodle Colour

Preferences for noodle appearance differ among individual consumers and depend largely on noodle type. Morris et al (2000) stated that although a high brightness (L*) and a moderate yellowness (b*) is desired in a white salted noodle, there is no set preference for redness (a*). Hatcher et al (1999b) indicated that extremes on either side of the a* scale are considered deleterious and can be indicative of bran contamination.

Noodle colour was measured over a 24-hour period at 0, 1, 2 and 24 hours after processing. The addition of 20% HB flour to fresh WSN decreased brightness (L*) and yellowness (b*) while increasing redness (a*) of the fresh noodle sheet in comparison with the AC Vista control over a 24-hour period (Fig 2.7). As the level of

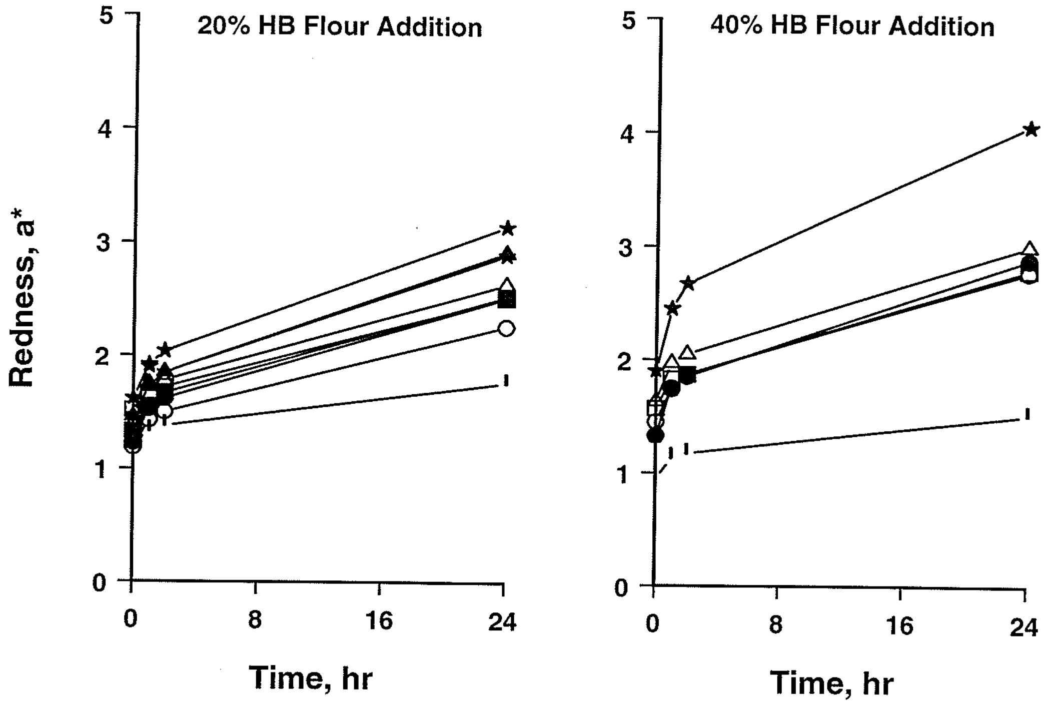
HB flour addition increased from 20% to 40%, these changes became more pronounced and differences among HB samples were more apparent. CDC Alamo, a zero amylose waxy sample, had the most pronounced effect on brightness and redness of the white salted noodles at both levels of addition, while the high amylose samples consistently displayed the biggest effect on yellowness. At time 0, no major differences among HB genotypes were seen, but differences were detected over time. Noodle colour is influenced in part by flour protein content, where higher protein is correlated with a darker noodle colour (Miskelly and Moss 1985, Hatcher et al 1999b). The higher content of protein in high amylose HB flour could have contributed to the higher overall protein content of the barley/wheat blend and consequently to the darker colour of noodles containing HB flour. Other physicochemical properties of flour such as the naturally occurring pigments, enzyme activity, mineral concentration, ash content, and particle size are also known to contribute to noodle colour.

a.



| Vista, □ Falcon, ■ SB90354, △ CDC Candle, ▲ SR93135, (open star) SB94792, (solid star) CDC Alamo, ○ CDC 92-55-06-54 , ● CDC 92-55-06-48

b.



| Vista, □ Falcon, ■ SB90354, △ CDC Candle, ▲ SR93135, (open star) SB94792, (solid star) CDC Alamo, ○ CDC 92-55-06-54 , ● CDC 92-55-06-48

c.

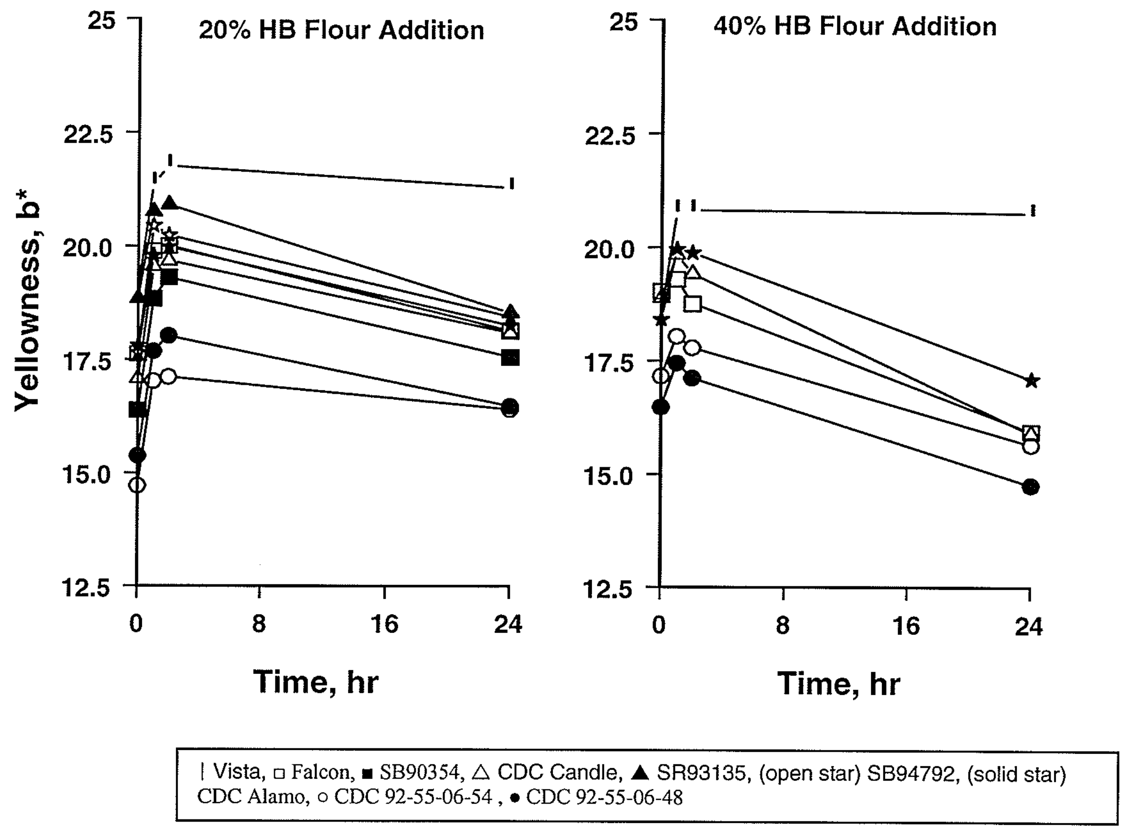


Figure 2.7. Fresh white salted noodle colour over time with the addition of hull-less barley flour (a. brightness, b. redness, c. yellowness).

Enzymes such as polyphenol oxidase (PPO) and peroxidase (POD) have been associated with the colour deterioration of fresh Asian noodles (Hatcher and Symons 2000a). All HB flours contained higher levels of both PPO and POD compared with the wheat flour (Table 2.4). Correlations between noodle colour (L*, a*, b*) and enzyme content (PPO and POD) were investigated. No significant trends were seen (results not shown). The darker colour of barley/wheat noodles can be partially associated with elevated levels of those enzymes. Other factors influencing noodle colour is the ash content. All HB flour contained higher ash content than the wheat flour. Phenolic compounds in barley flour were not measured in this study, but their contribution to noodle colour darkening should be further explored. It is not only the intrinsic factors of the flour that impact noodle appearance but also processing conditions, such as water absorption level, that have been correlated with noodle appearance. Hatcher et al (1999a) found a significant decrease in noodle brightness with increasing water absorption. At 40% addition of barley flour the water absorption of the barley/wheat flour blends was especially high (Table 2.1) and could have contributed to the darker colour of the noodles.

Image Analysis

Hatcher and Symons (2000a, b and c) introduced a means of quantifying noodle specks using image analysis because traditional instrumental methods to measure noodle appearance are based on an overall assessment of the noodle sheet in terms of brightness, redness and yellowness and do not quantify individual discolourations. Minimum speckiness is desired, as noodle speckiness is associated with a less refined product. Speck size and darkness, in addition to speck count, are important parameters of a noodle sheet since they characterize the discolourations and will ultimately affect noodle appearance.

In the present study, at a Δ grey value of 5 and a minimum speck size of $6000\mu^2$, two noodle image variables were obtained: speck count and speck size. Speck count generally increased over time as the fresh noodles began to age and the enzymes associated with the bran contamination in the flour produced discolourations (Fig. 2.8). At 2 hours after noodle processing, certain samples (e.g. SB90354, SR93135, SB94792) displayed a very slight decrease in speck count in relation to their initial reading. A possible explanation for this outcome could be that not all specks were detected at the set parameters as the overall background colour of the noodle sheet began to darken with time. All HB blend noodles had a significantly larger number of specks detected on the raw noodle sheet in comparison with the AC Vista control, but the most significant differences were seen at 24 hours after processing. Surprisingly, noodles containing SB94792 had significantly lower speck counts than the remaining HB samples but was not characterised by significantly lower ash and enzyme content. On the other hand, noodles containing CDC Candle had significantly higher speck counts than the remaining HB samples, but again no significantly higher ash and enzyme content were observed in this sample. The 40% HB blend noodles had more specks initially and over time than their 20% counterparts. Blends containing the waxy HB flour CDC Candle consistently displayed the highest speck count at both levels of addition at 24 hours after processing.

A dramatic contrast between the noodle sheet background colour and the discolouration leads to the specks appearing darker. Since white salted noodles are light in appearance, the specks are usually more apparent. As the overall colour of the noodle darkens, there is less contrast between the background and the actual speck, which could lead to a decreased speck size or fewer specks being detected. The addition of HB flour significantly increased speck size compared to the control at one hour after processing (Fig. 2.9). Size of the specks on the control wheat noodle increased over time, while speck size for noodles containing HB flour remained relatively constant.

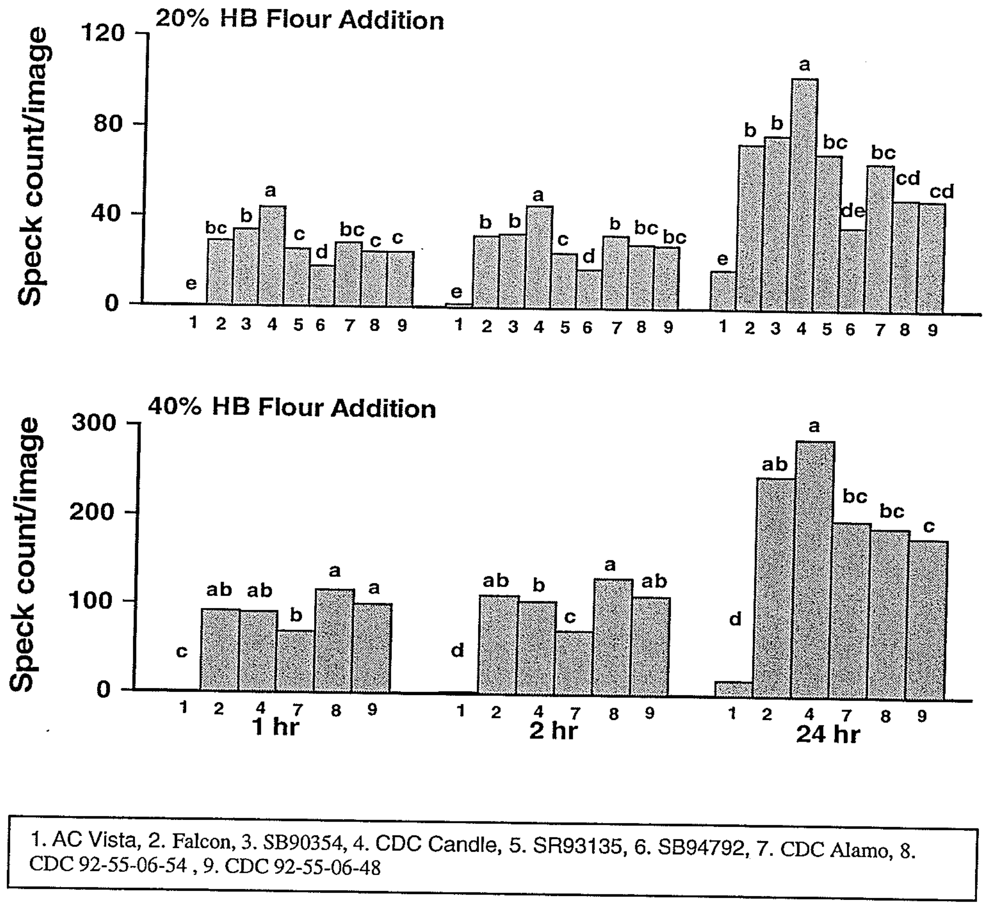


Figure 2.8. Image analysis speck count of fresh white salted noodles over time with the addition of hull-less barley flour.

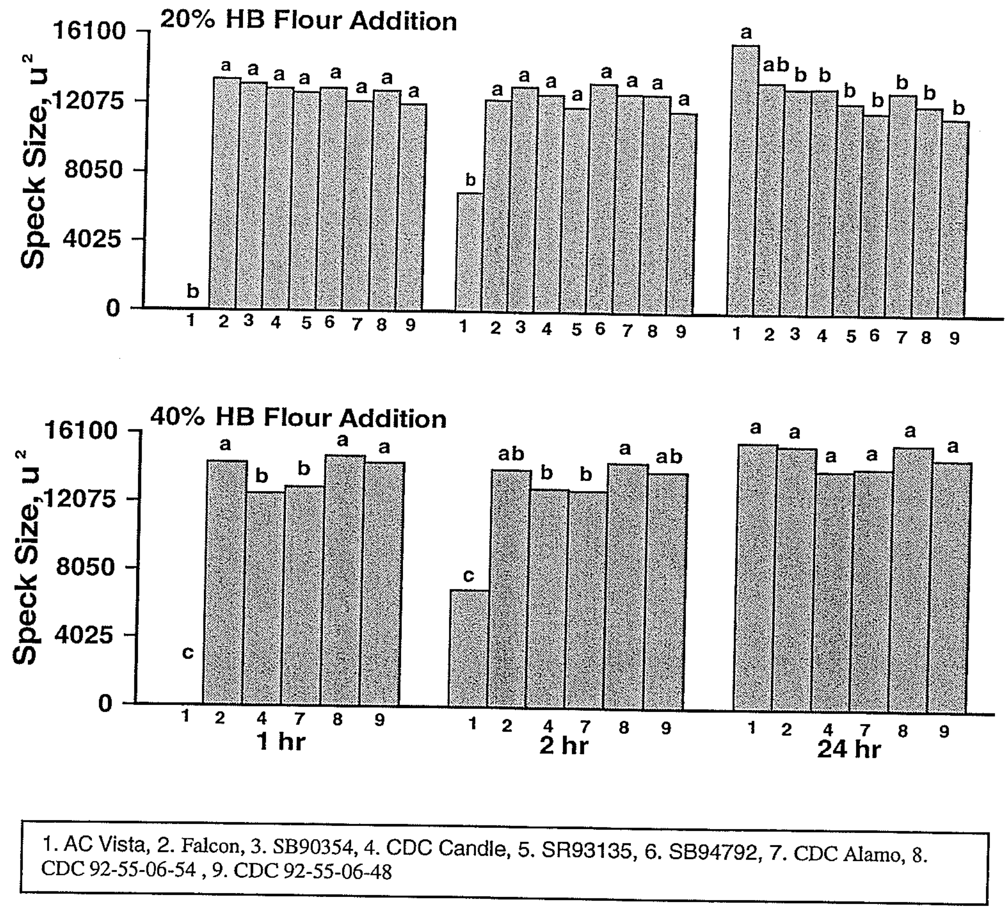


Figure 2.9. Image analysis speck size of fresh white salted noodles over time with the addition of hull-less barley flour.

Cooking Characteristics

Optimum cook time. Convenience is an important aspect of a food product and continues to be a major consideration for consumers. The convenience aspect, whether relating to ease of use, preparation or cooking time, is often a selling feature for a new food product. Cook times of fresh WSN, with the addition of 20% HB flour, ranged from 8.5 to 11 minutes (Fig 2.10). Samples containing Falcon and both the high amylose flours had cook times of 11 minutes, which was equal to the cook time of the AC Vista wheat noodles. Other samples containing HB flour had shorter cook times than the control sample. As the level of HB flour addition increased to 40%, cooking time decreased for each HB blend noodles, with cook times ranging from 5.5 to 7 minutes. The higher water absorption level used in the 40% HB blend noodles is the main factor believed to be responsible for this effect. The dilution of the vital wheat gluten may also have played a role.

Optimum cook times of dry WSN were longer than those of corresponding fresh noodle samples (Fig 2.11). Since hydration is a prerequisite for gelatinisation and a longer period of time is required for water to penetrate to the core of a dry noodle, cooking time is prolonged in relation to a fresh noodle. The addition of 20% HB flour, regardless of starch amylose type, did not significantly change the cooking time of dry noodles compared with the control. Selected genotypes used to prepare the 40% HB flour blend noodles had lower cooking times than the control and noodles containing Falcon.

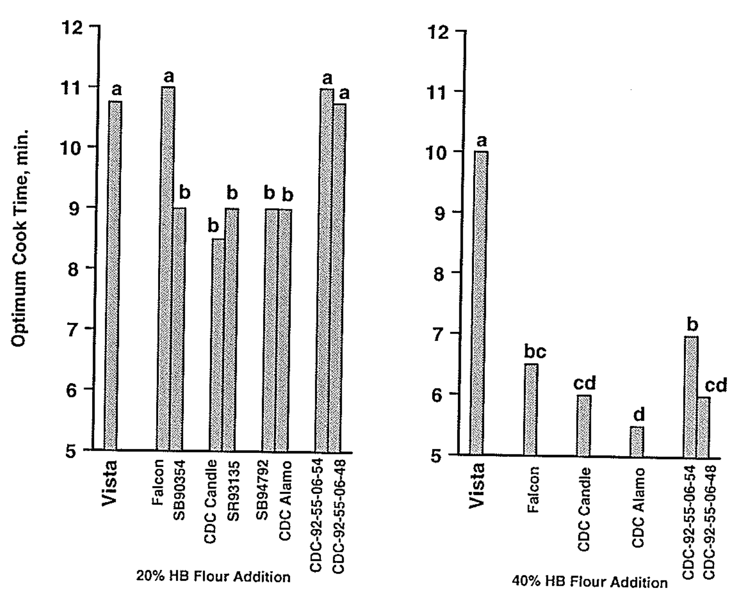


Figure 2.10. Optimum cooking time of fresh white salted noodles with the addition of hull-less barley flour.

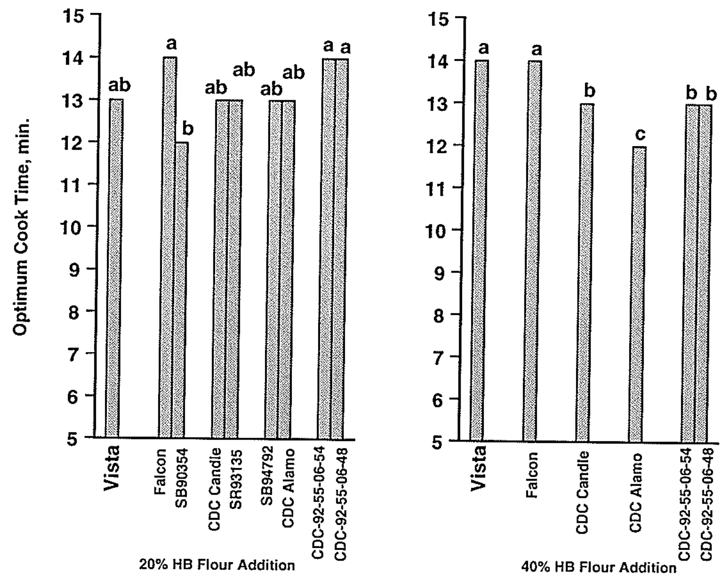


Figure 2.11. Optimum cooking time of dry white salted noodles with the addition of hull-less barley flour.

Water uptake. Water uptake during cooking influences eating quality of noodle products. Ideally, cooked noodles should retain their original shape and maintain a smooth surface. Water uptake during cooking of fresh WSN decreased with the addition of 20% and 40% HB flour, with a greater reduction seen as more HB flour was added to the system (Fig 2.12). Water absorption level during dough making as well as length of cook time will influence water uptake and solids lost during the cooking process.

Dry WSN displayed a higher degree of water uptake during cooking than the corresponding fresh WSN, likely because they were subjected to longer cooking times. No significant differences were detected between AC Vista and the blend noodles at the 20% addition level. Whereas, at the 40% addition level, the waxy blend noodle displayed significantly higher water uptake while the ZAW and the HA blend noodles displayed significantly less water uptake than the AC Vista noodles (Fig 2.13).

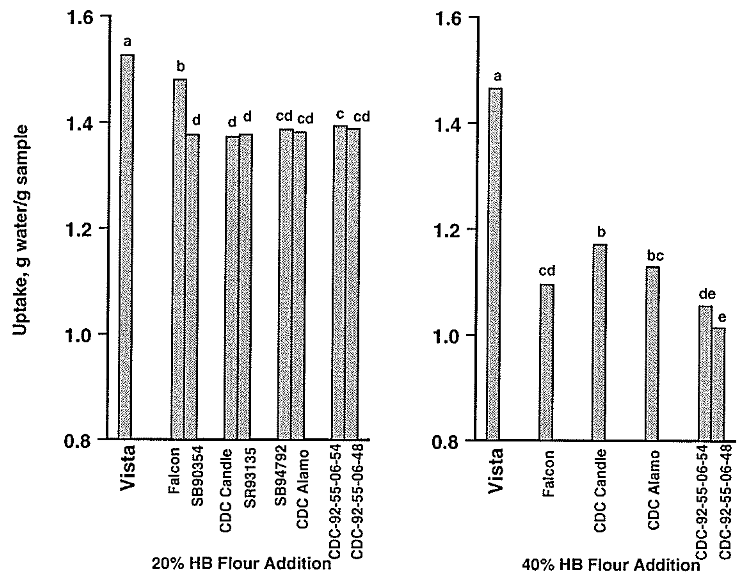


Figure 2.12. Water uptake during cooking of fresh white salted noodles with the addition of hull-less barley flour.

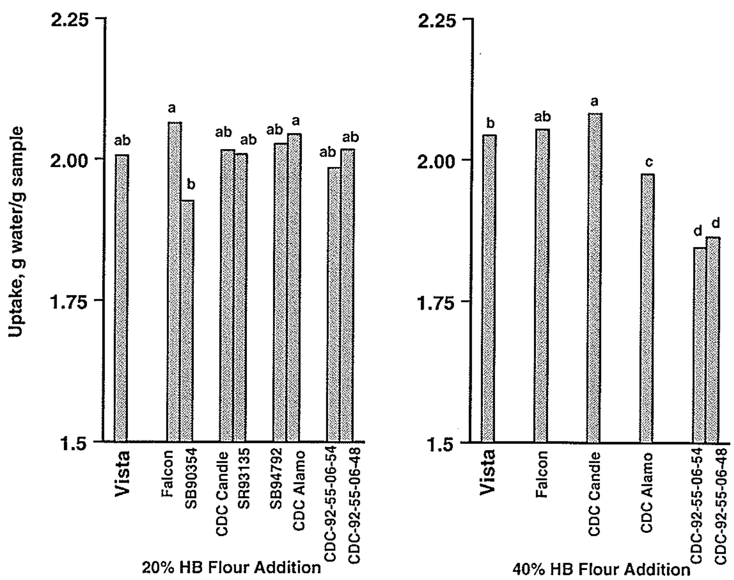


Figure 2.13. Water uptake during cooking of dry white salted noodles with the addition of hull-less barley flour.

Solid loss. It is recommended that solid loss during cooking of noodles be minimal and the product should be resistant to overcooking. Fresh noodles containing CDC Candle (waxy) and zero amylose waxy HB flour displayed lower solid loss during cooking than the noodles containing AC Vista flour, while those with high amylose HB flour displayed a higher degree of solid loss (Fig 2.14). No significant differences were detected between noodles containing normal HB flour and AC Vista flour. Solid loss was further decreased as the level of HB flour addition increased to 40%, even though these noodles had longer optimum cook times. A possible explanation for this observation could be the higher content of non-starch polysaccharides in the HB flours. It is possible that the non-starch polysaccharides form networks that entrap polymers preventing them from leaching out into solution. Significantly higher solid losses for noodles containing high amylose HB flour were likely due to higher amounts of amylose leaching out during cooking.

No significant differences were detected between the solid loss of the dry WSN HB blends at a 20% addition level, although the high amylose samples exhibited significantly higher solid loss than the remaining HB blend noodles (Fig 2.15). Solid loss was affected relatively little as the addition of HB flour to dry WSN increased to 40%. These results indicate that HB blend noodles may be resistant to overcooking, which should be further explored.

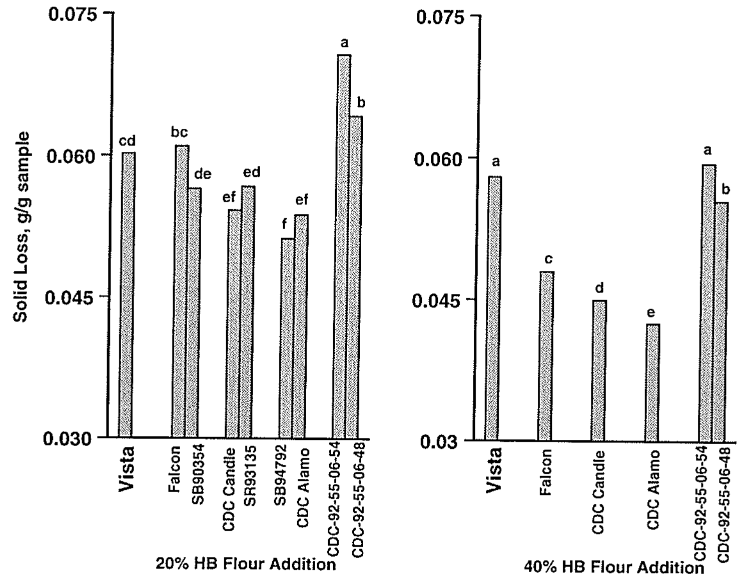


Figure 2.14. Solid loss during cooking of fresh white salted noodles with the addition of hull-less barley flour.

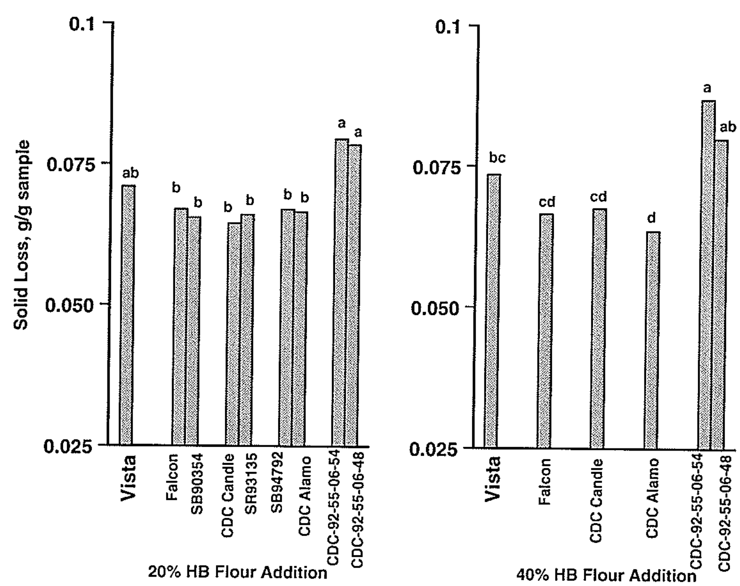


Figure 2.15. Solid loss during cooking of dry white salted noodles with the addition of hull-less barley flour.

Noodle Appearance

Colour of cooked fresh white salted noodles. Consumer preference for WSN is a clean, bright product, free of specks and discoloration (Hatcher and Symons 2000a). Cooked noodle brightness (L*) decreased with the addition of 20% HB flour (Table 2.5). All HB blend noodles were significantly darker than the control AC Vista noodles. Little distinction was made between noodle products containing the same starch type of HB flour with the exception of noodles containing high amylose HB flour. Noodles containing the high amylose HB genotype CDC-95-55-06-48 were significantly darker than those containing CDC-92-55-06-54. Redness (a*) values of the cooked noodles increased with the addition of HB, noodles became redder and less green, approaching positive values. Yellowness (b*) values decreased upon the addition of HB with significant differences detected among noodles containing AC Vista, normal and high amylose flour.

Table 2.5. Colour of Cooked 20% Hull-less Barley/Wheat Flour Blend White Salted Noodles*

	L*	a*	b*
AC Vista Noodles	77.94a	-1.01f	14.53a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	75.26b	-0.55e	13.51cd
SB90354	75.32b	-0.45de	13.33de
Waxy			
CDC Candle	74.95bcd	-0.31abc	14.32ab
SR93135	74.74bcd	-0.39bcd	14.42ab
Zero Amylose Waxy			
SB94792	74.69bcd	-0.28ab	14.69a
CDC Alamo	74.06cd	-0.20a	14.00bc
High Amylose			
CDC-92-55-06-54	75.16bc	-0.43cde	12.99e
CDC-92-55-06-48	73.98d	-0.31abc	12.87e

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

The addition of 40% HB flour to fresh WSN resulted in the cooked noodles being significantly darker than the AC Vista noodle although there were no significant differences detected among noodles containing flour from different HB genotypes (Table 2.6). Redness increased to positive values with a more pronounced difference than that seen with the 20% blend noodles. Yellowness values were decreased significantly in relation to the AC Vista noodle with the exception of the ZAW sample. The high amylose samples had the most significant effect on the yellowness values at a 40% addition level, which was consistent with the observations made for the raw noodle colour.

Table 2.6. Colour of Cooked 40% Hull-less Barley/Wheat Flour Blend White Salted Noodles*

	L*	a*	b*
AC Vista Noodles	78.37a	-1.00e	14.77a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	71.42b	0.09d	13.97b
Waxy			
CDC Candle	72.85b	0.25cd	13.86b
Zero Amylose Waxy			
CDC Alamo	70.95b	0.84a	14.69a
High Amylose			
CDC-92-55-06-54	69.98b	0.44b	12.99c
CDC-92-55-06-48	70.50b	0.38bc	12.55c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

No significant decrease in cooked noodle brightness over time was found (results not shown) suggesting that colour deleterious enzymes are involved only in raw noodle colour deterioration. Heat from the cooking process inactivates these enzymes, therefore, the darkening process is arrested in cooked noodles and the colour remains stable for a considerably longer period of time.

Colour of uncooked dry white salted noodles. The appearance of dry WSN is an important quality criterion since it is in this form that WSN are commonly sold to consumers. The addition of 20% HB flour had a slight effect on the brightness of the uncooked dry noodles, although they were not significantly different from each other or from the AC Vista control (Table 2.7). Few significant differences in redness were detected among the uncooked dry noodles. Noodles containing CDC Candle and CDC-92-55-06-48 had significantly lower a* values than AC Vista. Yellowness values significantly decreased with the addition of HB, with the most significant reduction in yellowness resulting from samples of the high amylose starch class. A similar trend was observed upon the addition of 40% HB, although, at this level the differences were more pronounced and the reduction in brightness was very significant (Table 2.8). The increased redness values for normal, waxy, and ZAW samples was also significantly increased in the 40% blend noodles. Similarly to the 20% addition, noodles with 40% high amylose HB flour addition had significantly lower yellowness values.

Table 2.7. Colour of Uncooked Dry 20% Hull-less Barley/Wheat Flour Blend White Salted Noodles*

	L*	a*	b*
AC Vista Noodles	81.85a	2.57ab	19.62a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	81.03a	2.52abc	16.87c
SB90354	80.42a	2.65a	17.90b
Waxy			
CDC Candle	81.70a	2.34c	16.77c
SR93135	80.30a	2.64a	17.63b
Zero Amylose Waxy			
SB94792	80.65a	2.66a	16.96c
CDC Alamo	80.63a	2.64a	16.16d
High Amylose			
CDC-92-55-06-54	80.21a	2.37bc	15.45e
CDC-92-55-06-48	81.10a	2.35c	15.51e

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Table 2.8. Colour of Uncooked Dry 40% Hull-less Barley/Wheat Flour Blend White Salted Noodles*

	L*	a*	b*
AC Vista Noodles	80.21a	2.56b	20.54a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	75.82bc	3.24a	19.44ab
Waxy			
CDC Candle	75.17c	3.11a	18.79b
Zero Amylose Waxy			
CDC Alamo	78.44ab	3.09a	16.94c
High Amylose			
CDC-92-55-06-54	76.65bc	2.47b	15.81c
CDC-92-55-06-48	76.90bc	2.77ab	16.42c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Colour of cooked dry white salted noodles. A majority of the HB blend dry cooked noodles were significantly darker than the AC Vista noodle, similar to observations made for uncooked noodles. No significant differences were detected between samples containing the same type of HB flour at the moderate level of addition

(Table 2.9). Redness values, like those in uncooked noodles containing normal, waxy and ZAW samples, increased in relation to AC Vista with no significant differences seen within HB of the same starch type. Yellowness of the blend noodles decreased in relation to AC Vista with minimal differences seen between HB blend noodles of the same starch type and among HB samples although the high amylose starch class did display the lowest yellowness values.

Upon the addition of 40% HB, brightness of the normal and waxy blend dry cooked noodles decreased in relation to AC Vista with a further decrease observed in the ZAW and high amylose samples (Table 2.10). All samples were significantly redder than AC Vista. All HB blend noodles had positive a* values (red) whereas the AC Vista noodle had a negative a* value (green). Yellowness of the noodles decreased with the addition of HB flour, the high amylose samples displaying the lowest yellowness values overall. These changes were more pronounced as the level of HB flour addition increased to 40%. AC Vista had significantly higher brightness and yellowness values while having significantly lower redness values overall.

Table 2.9. Colour of Cooked Dry 20% Hull-less Barley/Wheat Flour Blend White Salted Noodles*

	L*	a*	b*
AC Vista Noodles	75.74a	-0.58c	15.66a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	74.07b	-0.19b	13.52c
SB90354	74.36ab	-0.21b	13.53c
Waxy			
CDC Candle	73.98bc	-0.06ab	13.71bc
SR93135	72.93bcd	-0.11ab	14.16b
Zero Amylose Waxy			
SB94792	72.49cd	-0.08ab	14.22b
CDC Alamo	72.93bcd	0.06a	13.46c
High Amylose			
CDC-92-55-06-54	72.38d	-0.02ab	13.31cd
CDC-92-55-06-48	73.27bcd	0.04a	12.82d

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Table 2.10. Colour of Cooked Dry 40% Hull-less Barley/Wheat Flour Blend White Salted Noodles*

	L*	a*	b*
AC Vista Noodles	76.57a	-0.82d	14.68a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	71.65b	0.18c	12.80bc
Waxy			
CDC Candle	71.79b	0.37b	13.18b
Zero Amylose Waxy			
CDC Alamo	70.23c	0.82a	13.53b
High Amylose			
CDC-92-55-06-54	70.09c	0.52b	12.25cd
CDC-92-55-06-48	69.44c	0.52b	11.91d

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Texture

Fresh and dried cooked noodle texture. The acceptability of noodles, like most other food products, is collectively based on their appearance, texture and flavour. Although some work has been done incorporating barley flour or other barley components into pasta and noodles, the majority of this work has focused on the nutritional and sensory aspects of the product and little work has been done to instrumentally characterize their textural attributes (Cheigh et al 1976, Berglund et al 1992, Sood et al 1992, Baik and Czuchajowska 1997, Yokoyama et al 1997, Basman and Koksel 1999, and Marconi et al 2000).

The addition of HB flour substantially affected several texture parameters of the fresh and dried cooked WSN. Greater effects were seen with higher amounts of HB flour addition to the noodles. Noodles containing waxy and zero amylose waxy HB flour were less firm than the other samples as indicated by lower maximum cutting stress (MCS) values (Fig. 2.16 and 2.17).

Noodles containing normal and high amylose HB flour were chewier than the other samples as indicated by higher resistance to compression (RTC) and chewiness (TPA parameter) values (Fig. 2.18, 2.19, 2.20 and 2.21). The addition of waxy and zero amylose waxy HB flour decreased chewiness of the noodles compared to the control.

In general, a reduction in resilience was seen with the addition of waxy, ZAW and high amylose HB flour samples to fresh WSN (Fig. 2.22). These differences were not observed to be significant in the dry WSN (Fig. 2.23). The addition of Falcon (normal) HB flour significantly increased resilience of the cooked dry WSN compared to the remaining samples.

Stress relaxation, a modification of the texture profile analysis (TPA) test, is an instrumental texture test that has been investigated as a means of predicting dough stickiness in bread making (Wang et al 1996). Sopiwnyk (1999) used the stress relaxation test to measure texture of pasta, but to our knowledge, it has not been reported in the literature in relation to cooked noodles. The parameters obtained from the stress relaxation curve have, therefore, not been correlated with sensory parameters. In the present study, relaxation time was found to correlate well with the textural parameters MCS, RTC, and chewiness for both the 20% and 40% level of HB flour addition to WSN (Appendix 4 and 5).

Noodles containing 20% of normal and high amylose HB flour displayed a significantly higher relaxation time when compared to AC Vista, while the remaining samples significantly decreased relaxation time (Fig 2.24 and 2.25). As the level of HB addition increased to 40%, the high amylose samples displayed a reduction in relaxation time, while the waxy and zero amylose waxy samples showed a further reduction.

In general, the texture of the WSN made from various wheat/barley blends was significantly affected by the type and characteristics of starch in barley flour. The addition of barley flour containing waxy and zero amylose waxy starch significantly decreased the firmness and chewiness of noodles compared to the control sample. The results were not unexpected since it is know that in contrast to amylose, amylopectin requires much longer time and concentration of the polymer to develop strong and rigid gels (Biliaderis 1992). Waxy barley starches have also been reported to have very slow retrogradation kinetics (Czuchajowska et al 1998 and You and Izydorczyk 2002). Seib (2000) reported that increased flours swelling ability, decreased paste gel rigidity, and enhanced deformation of gelatinized starch granules caused by reducing amylose content contributed to softer texture and higher springiness of cooked noodles. These particular starch characteristics combined with decreased gluten content due to replacement of 20-40% of wheat flour in the blends significantly decreased firmness and chewiness of noodles containing waxy and zero amylose waxy barley flour.

In contrast, the addition of HB flour containing higher amylose content increased firmness and chewiness of the noodles. This is most likely due to the strong gelation properties of amylose (Biliaderis 1992). Despite the dilution of gluten in the blends, noodles containing HB flour with amylose levels of 25% and above significantly increased firmness and chewiness compared to the control sample.

Correlations between textural parameters and RVA starch pasting characteristics were investigated. No significant trends were seen (Appendix 6). Correlations between textural parameters and protein content as well as between textural parameters and amylose content of the starch were also investigated. Again, no clear trends were seen (Appendix 7).

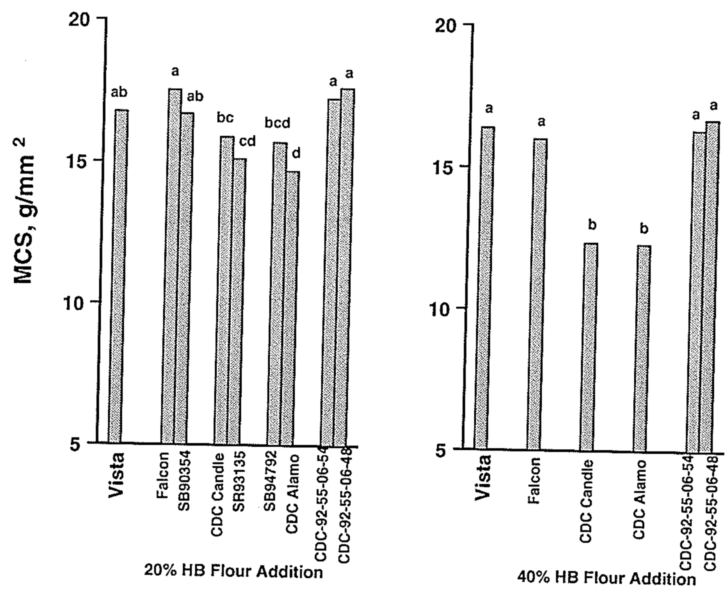


Figure 2.16. Maximum cutting stress of fresh white salted noodles with the addition of hull-less barley flour.

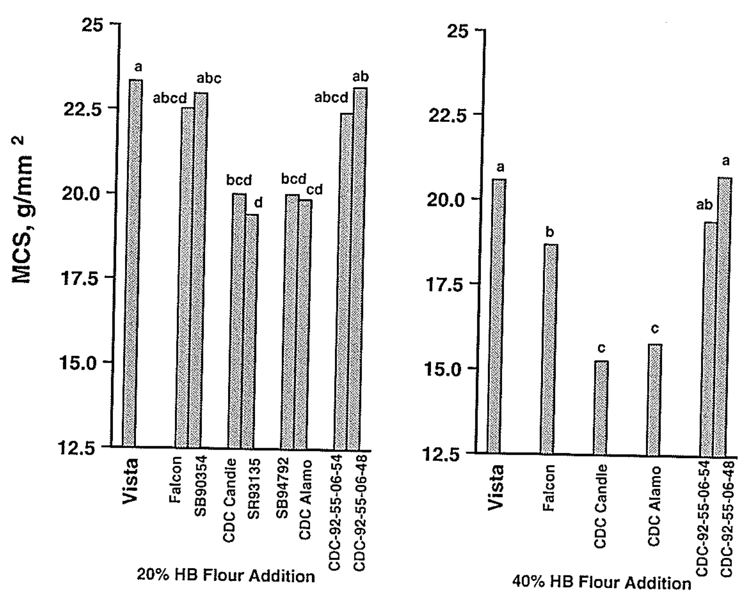


Figure 2.17. Maximum cutting stress of dry white salted noodles with the addition of hull-less barley flour.

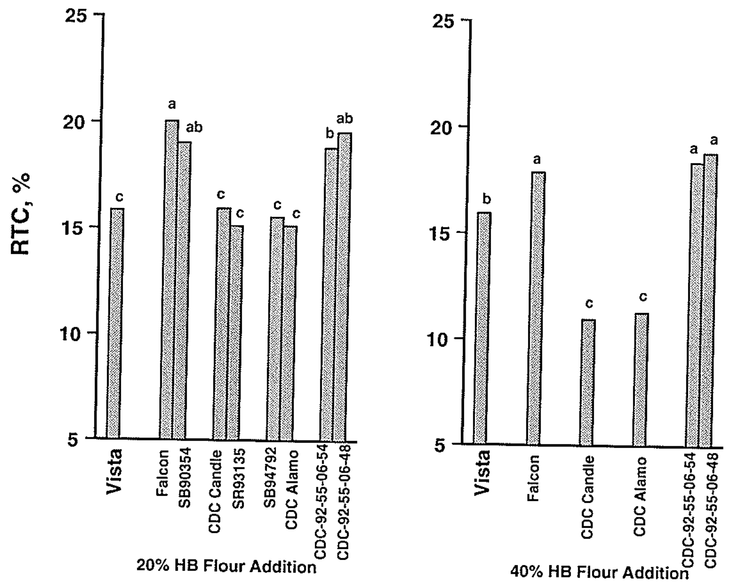


Figure 2.18. Resistance to compression of fresh white salted noodles with the addition of hull-less barley flour.

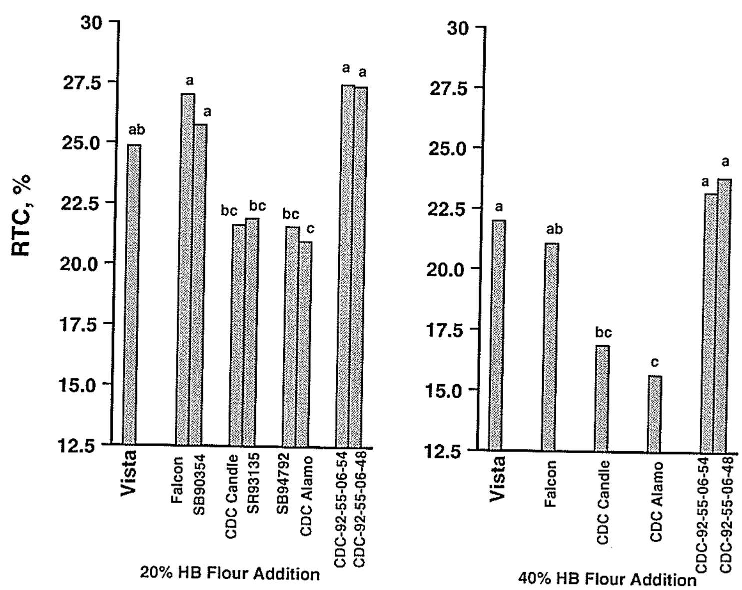


Figure 2.19. Resistance to compression of dry white salted noodles with the addition of hull-less barley flour.

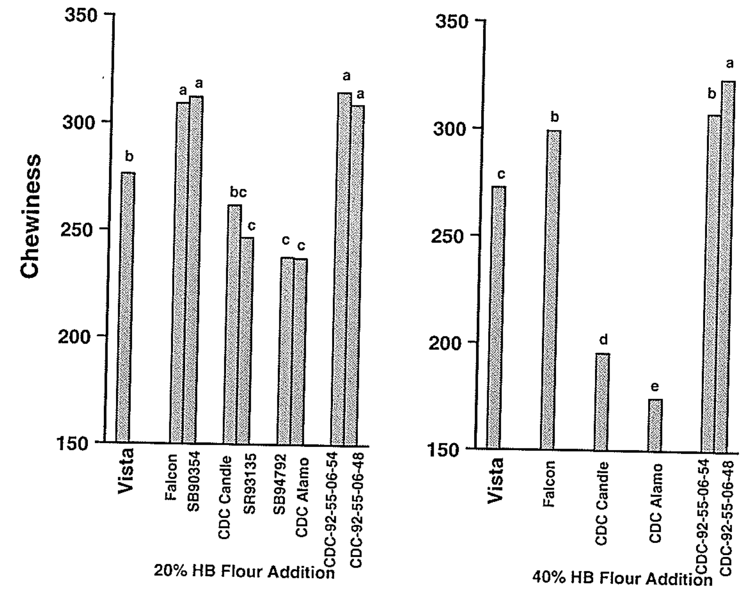


Figure 2.20. Chewiness of fresh white salted noodles with the addition of hull-less barley flour.

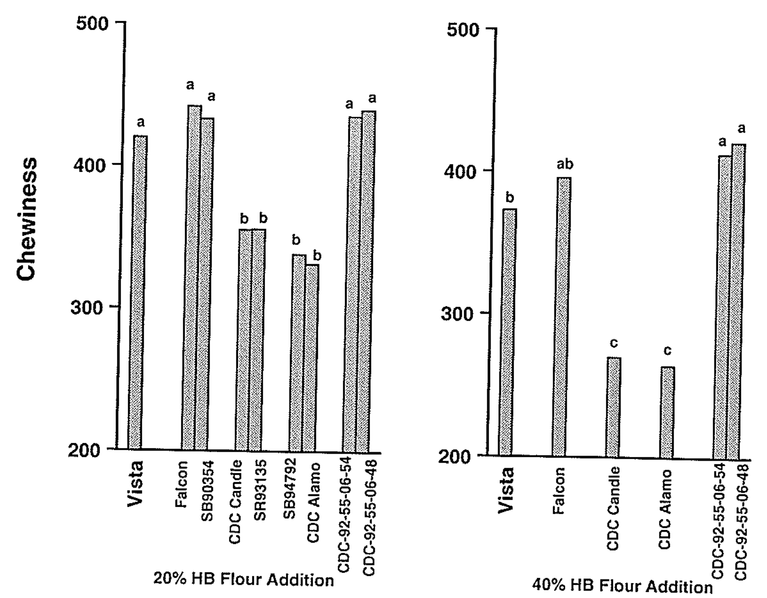


Figure 2.21. Chewiness of dry white salted noodles with the addition of hull-less barley flour.

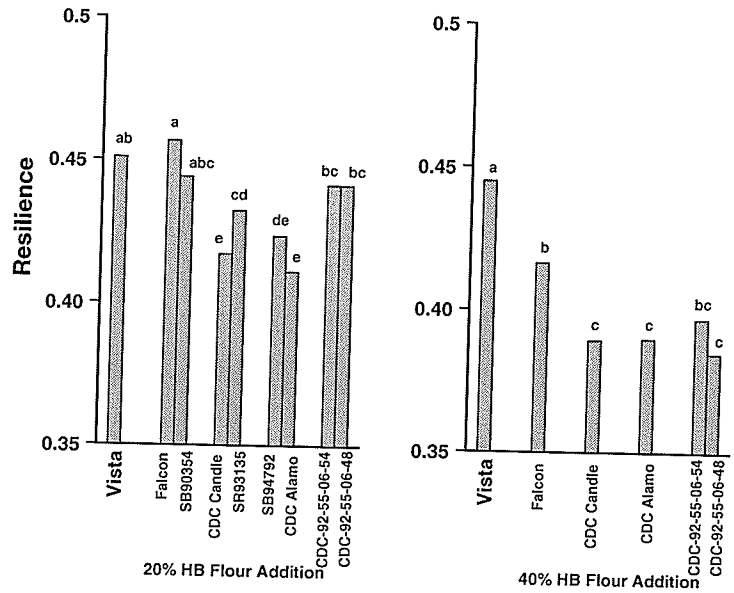


Figure 2.22. Resilience of fresh white salted noodles with the addition of hull-less barley flour.

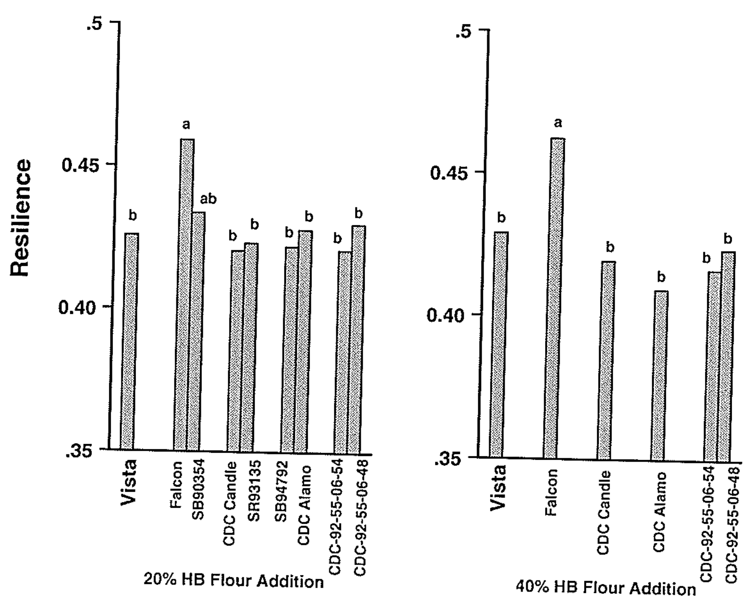


Figure 2.23. Resilience of dry white salted noodles with the addition of hull-less barley flour.

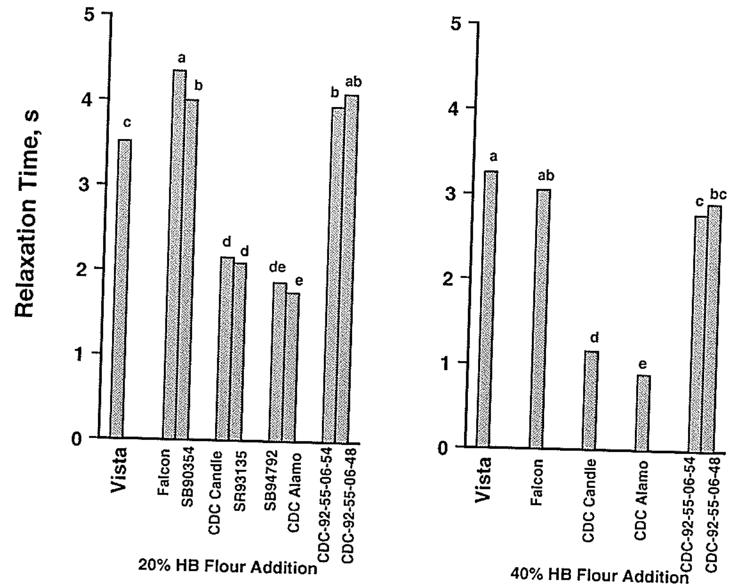


Figure 2.24. Relaxation time of fresh white salted noodles with the addition of hull-less barley flour.

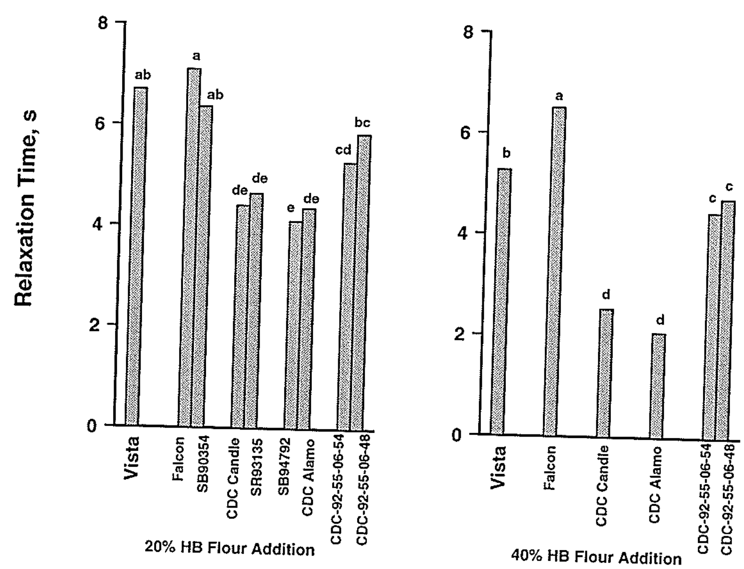


Figure 2.25. Relaxation time of dry white salted noodles with the addition of hull-less barley flour.

Breaking strength. Breaking strength is an important textural parameter of dry noodles to consider in transportation logistics. A noodle should be resistant to breakage under conditions of packaging and transportation. No significant differences in breaking strength were detected between the control and the noodles containing 20% HB flour (Fig 2.26). As the level of HB introduced into the formula increased, less force was required to break the dry WSN. HB blend noodles at the 40% level of addition were all significantly more susceptible to breakage than the AC Vista control, which is most likely due to the dilution of the gluten protein. Minimal differences were detected among HB genotypes.

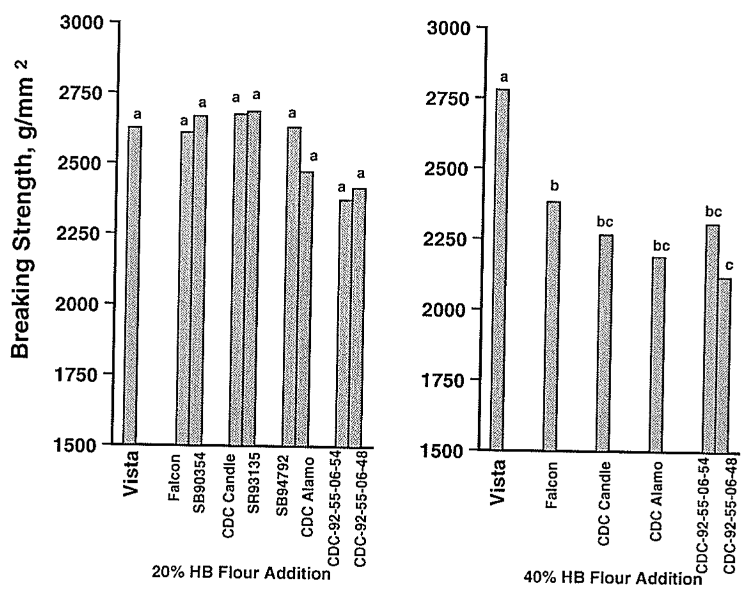


Figure 2.26. Breaking strength of dry white salted noodles with the addition of hull-less barley flour.

CONCLUSIONS

Hull-less barley flour can be added to fresh and dry WSN at a 20% and a 40% level of addition with some adjustments to the processing conditions being necessary. HB flour addition to white salted noodles decreased noodle brightness and yellowness while increasing redness. As well, a dramatic increase in the speckiness of the noodle sheet was detected with image analysis. Some changes in the colour of noodles may not necessarily affect the acceptability of barley/wheat noodles as the health conscious consumers may be willing to accept products that are different from the traditional white noodles. Sensory analysis and consumer acceptability testing should be conducted to assess the effect that HB flour had on the flavour of these products.

It is evident that cooked noodle texture is not solely a function of protein; other factors such as starch and non-starch polysaccharides contribute to the firmness and chewiness of cooked noodles. Results indicate that the amylose-amylopectin ratio of the starch is also a factor to cooked noodle texture. Generally, the addition of HB with low amylose content decreased noodle firmness and chewiness while HB with increased amylose content increased noodle firmness and chewiness of white salted noodles. Therefore, barley with different starch characteristics can be used to produce noodles with tailored textural characteristics.

In addition to the decreased susceptibility to cooking loss that non-starch polysaccharides provide, the capacity of the BG and AX to form a net-like structure that holds starch during the cooking procedure is also thought to provide strength to the cooked noodle structure and contribute to its texture. The role of other contributing factors such as phenolics have yet to be investigated. Cooked noodle texture is a complex phenomenon that involves many intrinsic factors of flour and their interactions.

Increasing the food uses of HB by introducing it into both traditional and non-traditional products may add value to this versatile crop. Additional research is required to assess the attributes of HB that will make each variety particularly suitable for a specific food application, thus increasing the production and export of Canadian hull-less barley.

MANUSCRIPT 2
Hull-less Barley Flour Addition to Yellow Alkaline Noodles

ABSTRACT

Hull-less barley, traditionally used in the animal feed industry, has the potential for nutritional enhancement and texture modification in products for human consumption. To evaluate the suitability of HB in yellow alkaline noodles, roller milled flour from eight HB genotypes with variable starch characteristics (normal, waxy, zero amylose waxy and high amylose) and elevated levels of β-glucans and arabinoxylans were incorporated (20% and 40% w/w) into a Canada Prairie Spring-white (cv. AC Vista) wheat flour.

The addition of HB flour to yellow alkaline noodles resulted in products with decreased brightness and yellowness values, increased redness values and significantly higher speck counts. Texture of the noodles was also affected with addition of HB flour. Starch amylose content was not the primary factor contributing to the texture of yellow alkaline noodles, as demonstrated by the results of the texture evaluation. Other factors, such as phenolics and non-starch polysaccharides, may have been affected by the alkaline medium and, consequently, affected the textural characteristics of the cooked noodles. Hull-less barley flour can successfully be added to yellow alkaline noodles at levels of 20-40% thereby enhancing nutritional properties and altering textural parameters.

INTRODUCTION

Hull-less barley (HB) has the potential for texture modification and nutritional enhancement of food products due to its variable starch amylose content and elevated levels of non-starch polysaccharides, in particular β-glucans (BG) and arabinoxylans (AX). Functional components in HB are known to have positive health implications, which include lowering plasma cholesterol, reducing glycaemic index and reducing the risk of cardio-vascular disease and certain forms of cancer (Anderson et al 1990; Jadhav et al 1998; Slavin et al 2000).

Yellow alkaline noodles (YAN) are a popular type of wheat based noodle with distinct quality attributes resulting from the alkaline reagent used in the formulation. The alkali salts used in the production of YAN are important for developing the characteristic yellow colour, improving noodle texture, developing aroma and flavour, and modifying dough, starch pasting and cooking characteristics (Morris et al 2000). Barley has been added to Asian noodle products (Baik and Czuchajowska 1997), but to our knowledge, no research is available on the effect of HB addition specifically to YAN. The objective of this study was to evaluate the suitability of straight grade flour derived from roller milling of 20% pearled HB genotypes with varying levels of starch amylose, BG and arabinoxylans (AX) in YAN. Eight HB genotypes were investigated having a range in starch amylose content from 0 to 40%. Noodle quality was evaluated at both a 20% and a 40% level of addition of barley flour to a patent flour of Canada Prairie Spring-white wheat (cv. AC Vista).

MATERIALS AND METHODS

A 60% extraction patent AC Vista (Canada Prairie Spring-white) flour milled on the GRL (Grain Research Laboratory) pilot mill (Black 1980) was used as the control and as the base wheat flour in noodle production. Eight Canadian hull-less barley (HB) genotypes, representing 4 starch classes, were used in the study and included Falcon, SB90354, CDC Candle, SR93135, SB94792, CDC Alamo, CDC-92-55-06-48 and CDC-92-55-06-54 (Manuscript 1, page 23). HB was tempered to 14.5% moisture and rested for 65 hour period prior to pearling (20%) and milling. Milling was performed with a five-stand mill equipped with 25-cm diameter rolls in conjunction with a rotary box sifter and a Buhler laboratory shorts duster according to the long milling flow described by Izydorczyk et al (2003). The procedure included 4 break passages, 3 sizing passages, 2 reduction passages and 4 shorts duster passages.

Noodle Preparation

Hull-less barley straight grade flour was added to yellow alkaline noodles (YAN) at a 20% and 40% level of addition. The handling and the visual properties of the noodle dough as described by Oh and co-workers (1983 and 1986) determined water absorption levels (Manuscript 1, page 26). Optimum absorption of 37% for YAN made from 100% AC Vista flour was determined based on particle size by the mixograph method (GRL Internal Method). The 20% HB flour blend noodles were made at the optimum absorption of the 100% AC Vista noodle since the low level of HB flour addition did not require extra water. Higher water absorption levels were employed upon addition of 40% HB flour to the noodles (Table 3.1).

Table 3.1. Water Absorption Levels in Yellow Alkaline Noodles

	Water Absorption, %
100% AC Vista flour	37
80% AC Vista + 20% Hull-less Barley flour	37
60% AC Vista + 40% Hull-less Barley flour	42

AC Vista patent flour and HB straight grade flour, water and 1% kansui (9:1 sodium and potassium carbonates) were mixed in a Hobart mixer (N50, Hobart Canada, North York, ON) and made into noodles as per Kruger et al (1994a) using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan). Initially, the dry flour was mixed for 30 seconds on setting 1 prior to addition of an alkaline solution. The solution was slowly added over a 30-second period with mixing continued for an additional 30 seconds. The resulting crumb was mixed at high speed (setting #2) for 1 minute followed by a final 3 minutes of mixing on the slow setting #1. The crumb was rolled between a set of rollers (temperature controlled water bath, 28°C) with an initial gap setting of 3mm. The resulting sheet was folded once and was passed through the rollers, loose ends first, to simulate the industrial noodle sheet compounding or laminating step.

The noodle sheet was then cut into a representative 25-cm long section and was sheeted (roll speed of 3.75 rpm) with a 15% reduction for each consecutive pass (3.00, 2.55, 2.15, 1.85, 1.57, 1.33, 1.10 mm) over a period of 4.5 minutes. Force measurements were captured on an analog-digital board (Labmaster DMA, Scientific Solutions, Solon, OH) interfaced to a personal computer using commercial software (Labtech Notebook, Laboratories Technologies, Wilmington, MA) as described by Hatcher and co-workers (1999a). The resulting noodle sheet was cut into thirds; two portions were held, at ambient temperature, in sealed plastic bags and containers for colour and image analysis, respectively. The remaining noodle sheet was cut into strands (B 22 cutters) and held in sealed plastic containers, at ambient temperature, until further analysis.

Noodle quality parameters (appearance, optimum cook time, texture, water uptake and cooking loss) were determined according to previously described methods and procedures (Manuscript 1, pages 27-30).

Statistical Analysis

The textural characteristics (cutting, compression, TPA and stress relaxation, as previously described) of cooked Futomaru noodles, a standard dry WSN, were measured each day of testing to ensure equipment was functioning within acceptable limits (results not shown).

All statistical analyses were performed using SAS statistical software version 8 (SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) and Proc GLM were performed to determine significant differences. Experiments were carried out at least in duplicate. Replicated results are reported as means. A completely randomized block design was used, with noodle type and flour addition level being blocked. In all bar graphs, different letters indicate significant differences between means. All values were considered significant at $p \leq 0.05$ unless otherwise stated. The coefficient of variation was less than 5% for all tests.

RESULTS AND DISCUSSION

Processing and Quality Characteristics of Yellow Alkaline Noodles

Power Requirements

Hull-less barley (HB) flour, having different starch characteristics, were added to yellow alkaline noodles (YAN) at 20% and 40% levels and were evaluated for their effect on the quality characteristics of the resulting noodles. Addition of HB flour (20%) to wheat flour had variable effects on the energy requirements during sheeting of the resulting noodle crumb. Noodles containing zero amylose waxy (ZAW) barley flour and normal barley flour (SB90354) significantly increased work requirements during sheeting compared to the AC Vista control sample, the remaining samples had no significant effect (Fig. 3.1). At 40% addition only Falcon displayed a significant reduction in work requirements. Noodles containing 40% HB flour required less work input than their corresponding 20% blend noodles, which is thought to be due primarily to the higher water absorption at the elevated level of HB flour addition. The observed trend was similar to that of the WSN containing HB flour, although the YAN did require more work input, demonstrating that the alkaline medium toughens the dough, thus affecting noodle texture (Morris et al 2000).

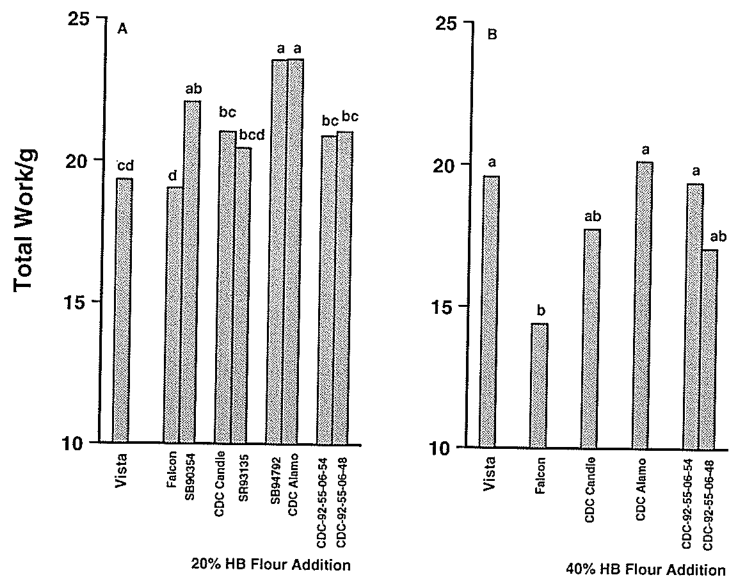


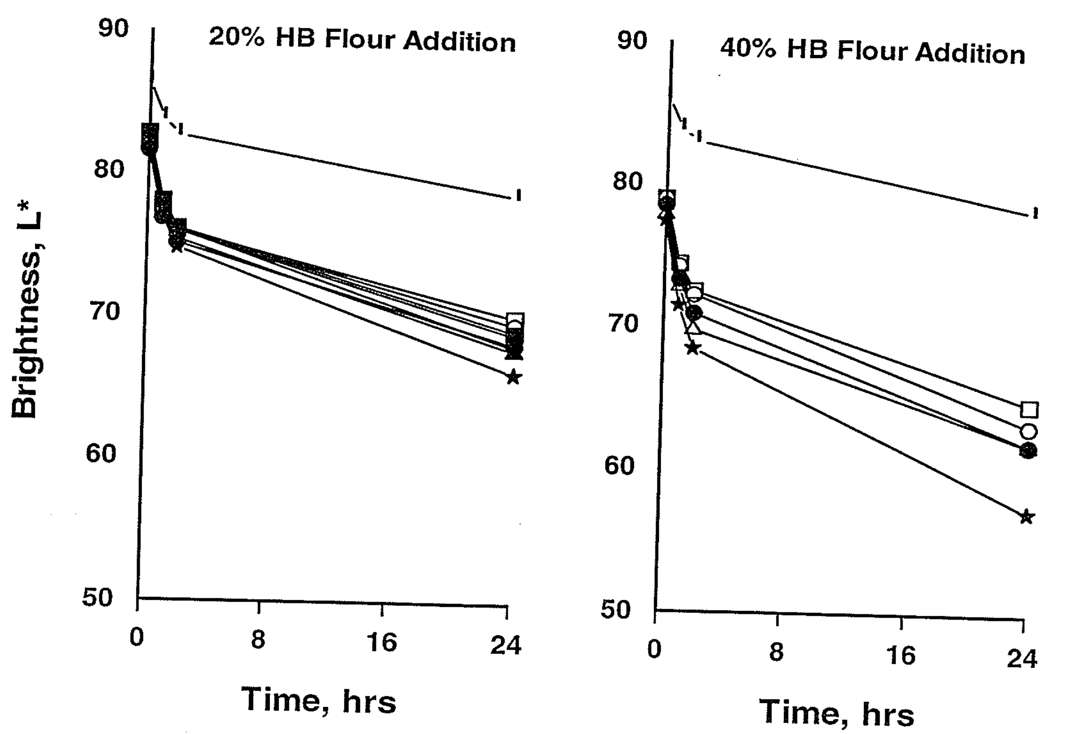
Figure 3.1. Energy requirements during processing of yellow alkaline noodles with the addition of hull-less barley flour.

Raw Noodle Appearance

Colour is an important parameter affecting noodle quality since it is the initial criteria by which consumers judge the product. A high brightness and a moderate yellowness are desired characteristics of WSN appearance, whereas clear, bright yellow noodles, free of any darkening or discolourations are preferable for YAN (Miskelly and Moss 1985, Morris et al 2000). The yellow colour of alkaline noodles is attributed to the presence of naturally occurring flavones in flour that become yellow under alkaline conditions (Morris et al 2000). While there is no set preference for the redness (a*) of a noodle product, formation of off-coloured pigments can be detected on the red-green scale (Hatcher et al 1999b). Appearance is a major consideration for YAN since these noodles are usually eaten fresh, within 24 hours of production (Hatcher et al 1999b).

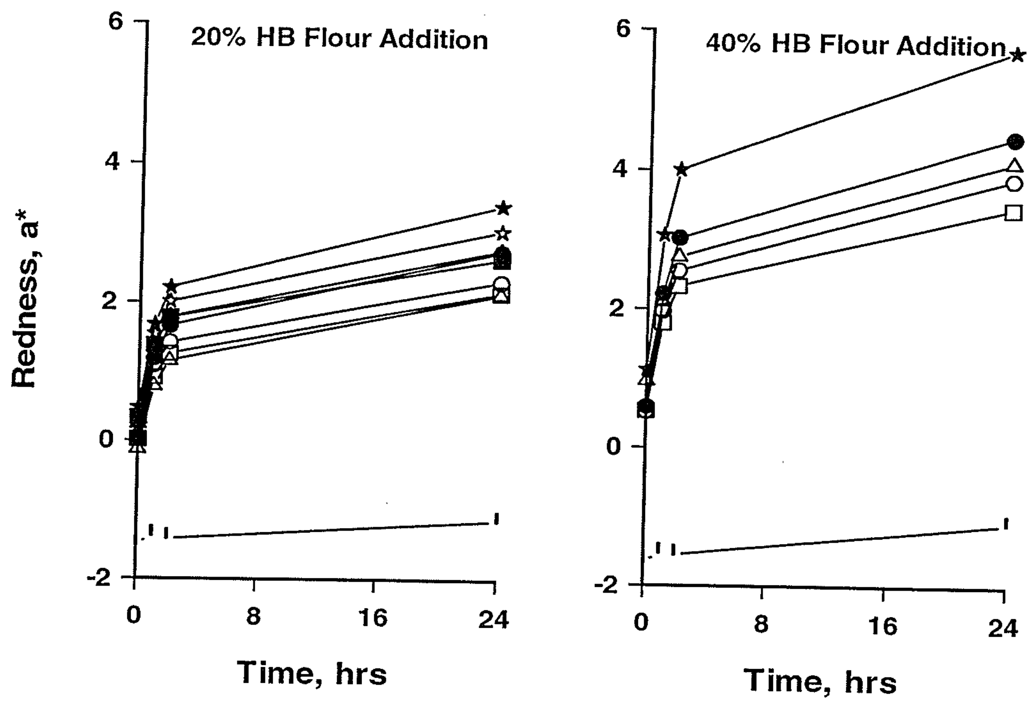
The addition of HB flour to YAN resulted in a decrease in brightness and yellowness of the product while redness values increased in comparison to the AC Vista noodle (Fig. 3.2). These effects were most pronounced at the 40% HB flour addition level. More differences in the colour parameters among HB genotypes were observed at 2 hours after processing compared to the 20% blend noodles. Noodles containing CDC Alamo had the most pronounced effect on brightness and redness values at both levels of addition whereas noodles containing CDC-92-55-06-54 had the most pronounced effect on yellowness values.

a.



| AC Vista, □ Falcon, ■ SB90354, △ CDC Candle, ▲ SR93135, (open star) SB94792, (solid star) CDC Alamo, o CDC 92-55-06-54 , ● CDC 92-55-06-48

b.



| AC Vista, □ Falcon, ■ SB90354, △ CDC Candle, ▲ SR93135, (open star) SB94792, (solid star) CDC Alamo, ○ CDC 92-55-06-54 , ● CDC 92-55-06-48

c.

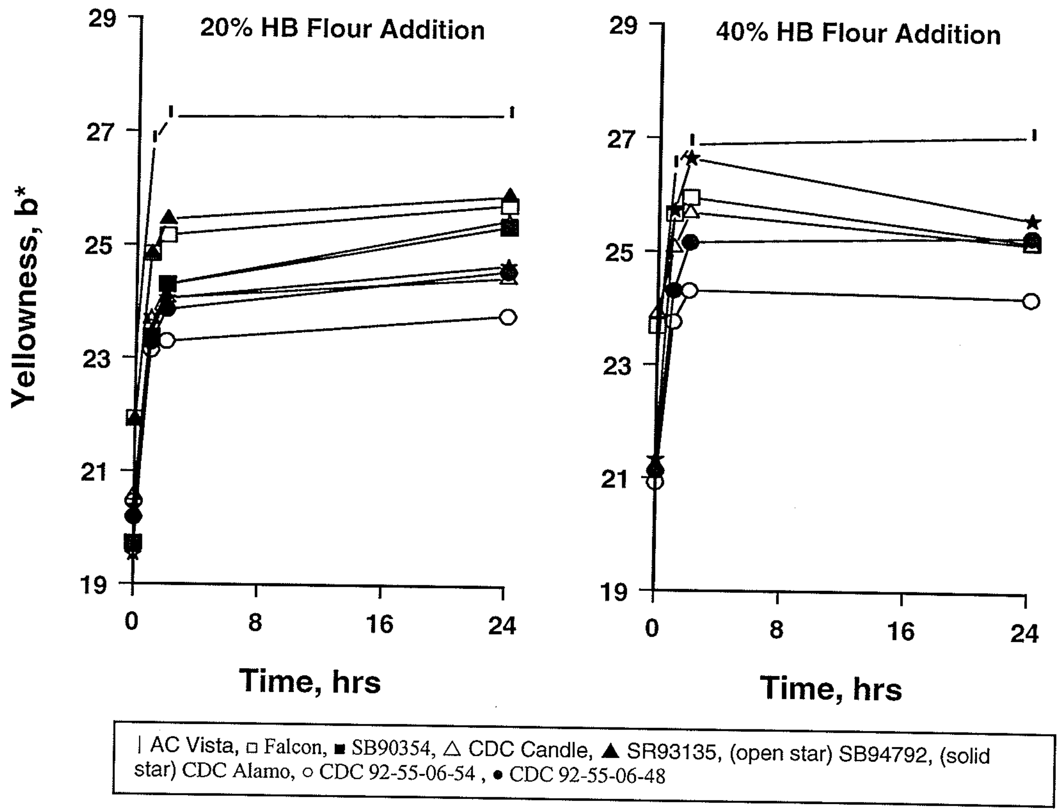
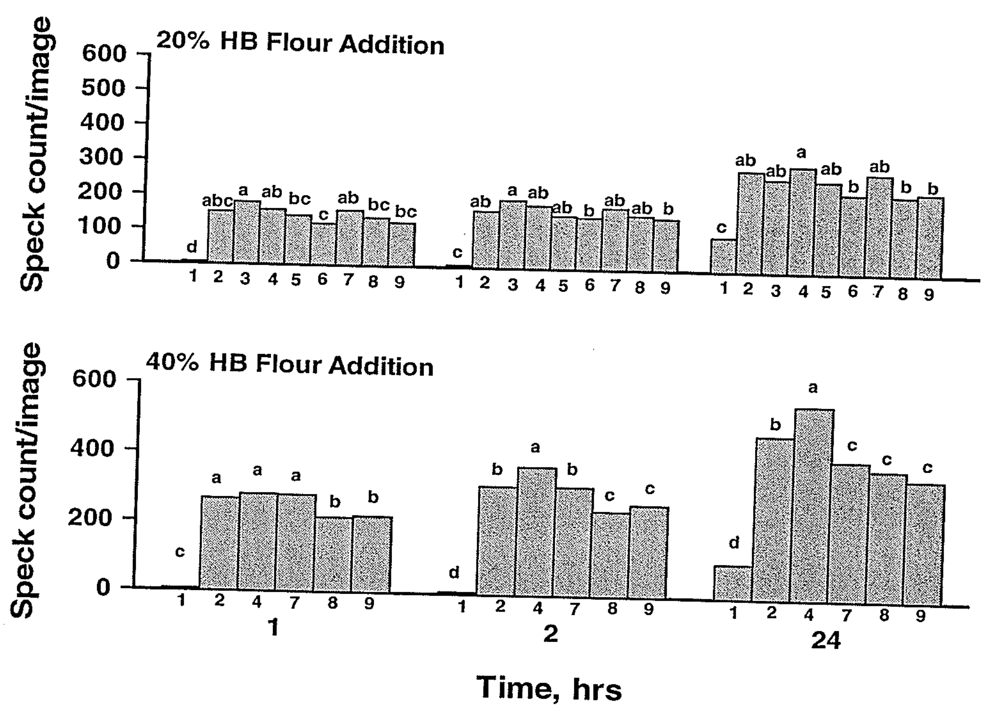


Figure 3.2. Fresh yellow alkaline noodle colour over time with the addition of hull-less barley flour (a. brightness, b. redness, c. yellowness).

Image Analysis

Image analysis was used in the present study to determine the number and size of specks on a fresh noodle sheet (Hatcher and Symons 2000a, b and c). The addition of HB flour to YAN at both the moderate and elevated level of addition dramatically increased the number of specks on the noodle sheet in comparison with the control, both initially and over time (Fig. 3.3). As the level of HB addition increased, so did the number of specks on the noodle sheet. Minimal differences were detected between HB samples of the same starch type. At the elevated level of addition, noodles containing high amylose flour displayed significantly lower speck counts than the remaining noodles containing HB flour. The average speck size detected on noodles containing HB flour was larger than that found on AC Vista control (Fig. 3.4). Small differences in speck size were detected among HB genotypes. The level of HB flour addition did not have a significant effect on the average speck size of the resulting YAN.



1. AC Vista, 2. Falcon, 3. SB90354, 4. CDC Candle, 5. SR93135, 6. SB94792, 7. CDC Alamo, 8. CDC 92-55-06-54 , 9. CDC 92-55-06-48

Figure 3.3. Image analysis speck count of fresh yellow alkaline noodles over time with the addition of hull-less barley flour.

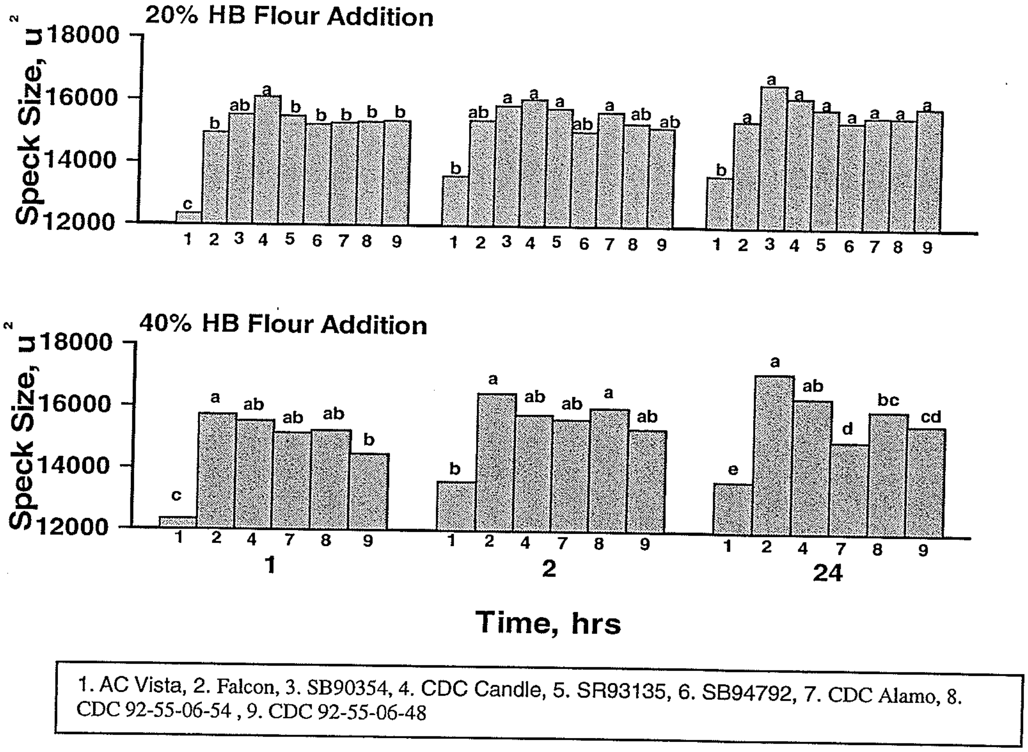


Figure 3.4. Image analysis speck size of fresh yellow alkaline noodles over time with the addition of hull-less barley flour.

Addition of HB flour to YAN not only increased the total number of specks detected on the noodle sheet but also increased their average size, thus having a considerable impact on the noodles appearance.

Cooking Characteristics

Optimum cook time. While the AC Vista noodle had an optimum cook time of 7 minutes, noodles containing a 20% addition level of normal HB flour and high amylose HB flour (CDC-92-55-06-54) increased cook time to 8 min. (Fig. 3.5). Noodles containing waxy and ZAW flour had equal or lower cook times compared with the control. The range of cook times for noodles containing 20% HB flour was relatively small, from 6 to 8 minutes.

The addition of 40% HB flour to YAN decreased cook times in all cases, with cook times ranging from 3 to 6.5 minutes. Only noodles containing normal HB flour did not significantly reduce optimum cook time compared to the control. Noodles containing waxy and ZAW flour had the lowest optimum cook times overall. The decreased cooking times are thought to be due largely to the increased water absorption at this level of HB addition.

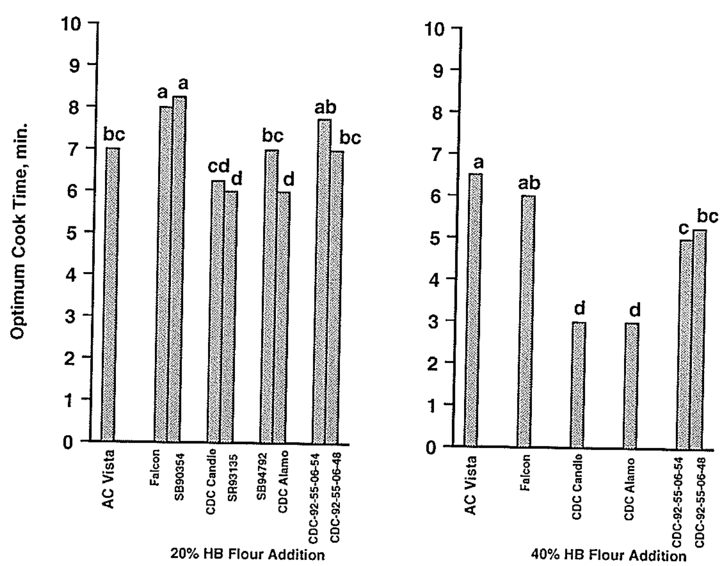


Figure 3.5. Optimum cooking time of yellow alkaline noodles with the addition of hull-less barley flour.

Water uptake. Water uptake during cooking of YAN was affected relatively little by the addition of HB at the 20% level, although noodles containing normal starch HB flours displayed significantly larger water uptake values (Fig. 3.6). Noodles containing normal starch HB flours did, however, have the highest cook times, which had an affect on water uptake. At the 40% level of addition, noodles containing Falcon were not significantly different than the control while the remaining noodles containing HB flour displayed significantly lower water uptake values.

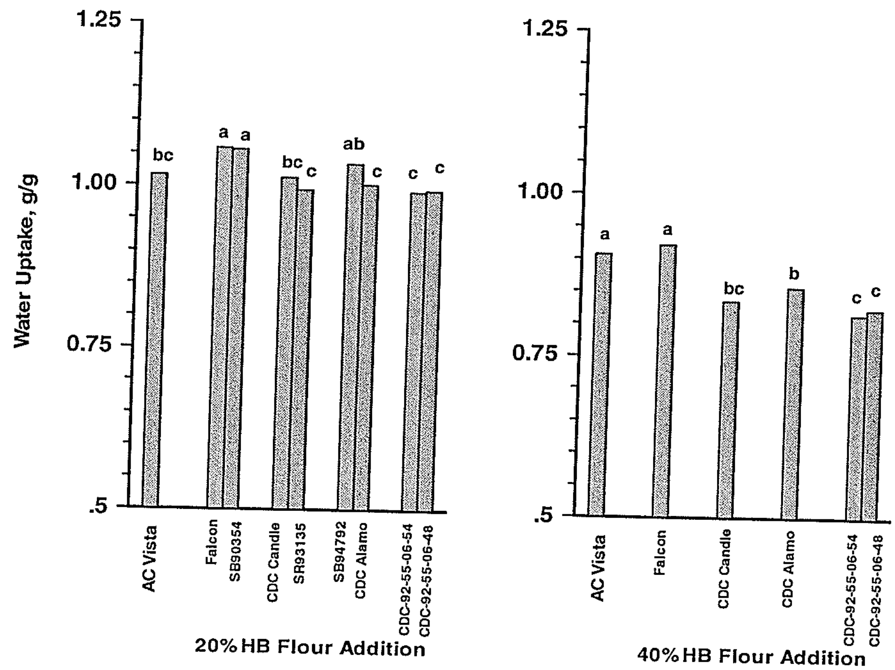


Figure 3.6. Water uptake during cooking of fresh yellow alkaline noodles with the addition of hull-less barley flour.

Solid loss. At the 20% addition level, noodles containing waxy and ZAW HB flour, especially CDC Candle, SR93135 and CDC Alamo, displayed significantly less solid loss than the control sample (Fig. 3.7). No significant differences were detected between noodles containing HB flour of the same starch type and minimal differences were seen among HB classes. At the 40% addition level, all noodles containing HB flour had significantly lower solid loss than the control, with noodles containing waxy and ZAW flour displaying the lowest values overall.

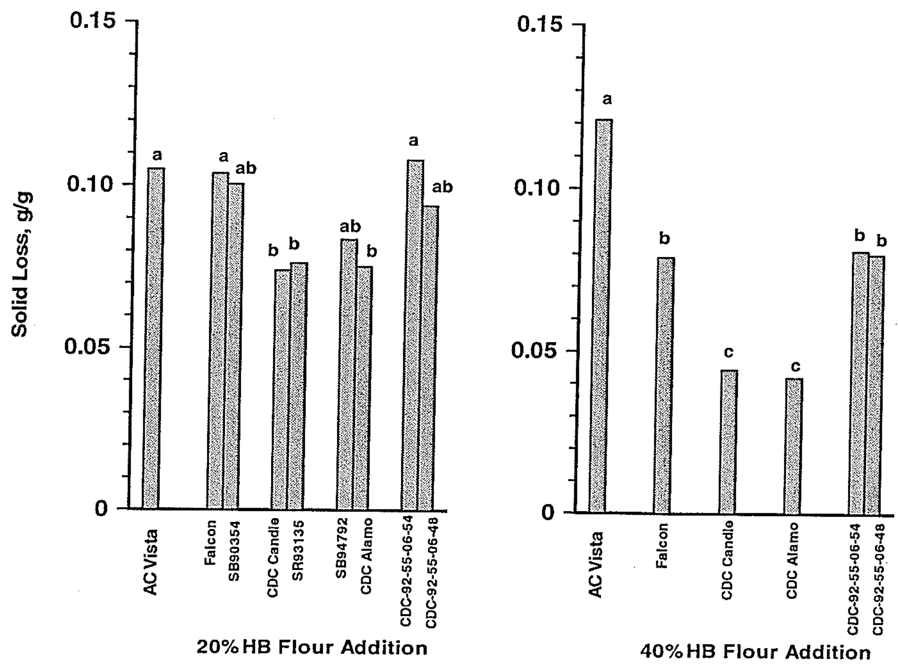


Figure 3.7. Solid loss during cooking of fresh yellow alkaline noodles with the addition of hull-less barley flour.

Cooked Noodle Appearance

Similar preferences exist for cooked YAN appearance as they do for raw YAN appearance, where a bright yellow colour is preferable. Alkaline noodles are generally made with higher protein and stronger gluten wheat than WSN to obtain the firmer texture of this noodle type (Morris et al 2000). The disadvantage is that higher flour protein content is negatively correlated with noodle colour (Miskelly and Moss 1985). Despite this, YAN are commonly made with flours of 10.5-12.0% protein content (Nagao 1996).

The addition of 20% HB flour to YAN decreased cooked noodle brightness (Table 3.2). No significant differences were seen among noodles containing HB flour with different starch characteristics. The control sample had a brightness (L*) value of 67.15 while the HB blend noodles had brightness values ranging from 62.13 to 60.35. Redness (a*) values increased upon addition of HB flour, with noodles containing ZAW and high amylose flour having significantly higher redness values than noodles containing normal and waxy flour. Yellowness (b*) values decreased with the addition of 20% HB flour to YAN. Noodles containing CDC-92-55-06-48 flour were significantly less yellow than noodles containing CDC-92-55-06-48 flour. No other significant differences were detected between noodles containing HB flour of the same starch type.

Table 3.2. Colour of Cooked 20% Hull-less Barley/Wheat Flour Blend Yellow Alkaline Noodles*

	L*	**a***	**b***
AC Vista Noodles	67.15a	-3.37c	26.29a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	61.99b	-0.69b	23.89b
SB90354	61.07bc	-0.52b	23.64b
Waxy			
CDC Candle	61.69bc	-0.71b	23.30bc
SR93135	62.13b	-0.61b	24.13b
Zero Amylose Waxy			
SB94792	61.53bc	-0.05a	23.96b
CDC Alamo	60.35c	0.18a	23.52b
High Amylose			
CDC-92-55-06-54	60.37c	-0.07a	23.69b
CDC-92-55-06-48	60.73bc	0.19a	22.25c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

At the 40% level of addition, brightness values decreased further in relation to the AC Vista control and were less bright than their 20% blend counterparts (Table 3.3). No significant differences in brightness were seen among noodles containing different HB genotypes. Redness values were further increased at the 40% level of addition. Significant differences were detected among noodles containing HB with different starch types, with noodles containing CDC Alamo flour having the highest redness values overall. In all cases, yellowness values decreased upon addition of 40% HB flours, with noodles containing CDC-92-55-06-48 flour displaying the lowest values.

Table 3.3. Colour of Cooked 40% Hull-less Barley/Wheat Flour Blend Yellow Alkaline Noodles*

	L*	a*	b*
AC Vista Noodles	65.54a	-3.41e	26.80a
AC Vista/ HB Blend Noodles			
Normal			
Falcon	58.30b	0.81d	23.76b
Waxy			
CDC Candle	57.74b	1.35c	22.84bc
Zero Amylose Waxy			
CDC Alamo	56.30b	2.40a	22.80bc
High Amylose			
CDC-92-55-06-54	56.76b	1.88b	23.01b
CDC-92-55-06-48	56.37b	2.07ab	21.97c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

In preliminary studies, no significant differences in cooked colour over time were detected (results not shown); suggesting that a majority of the raw noodle colour deterioration is due to enzyme activity, in particular PPO and POD. No clear correlation between colour and enzymes were found, suggesting that enzyme activity alone cannot account for the darkening of raw noodles over time.

Texture

Texture is considered to be among the most important quality attributes of a cooked noodle. Cooked WSN should be soft and elastic in texture whereas firmness, elasticity and smoothness are the most important texture characteristics of YAN (Akashi et al 1999, Crosbie et al 1999, Miskelly and Moss 1985).

The addition of 20% HB to YAN did not significantly affect firmness of the cooked noodles in relation to the AC Vista control as determined by maximum cutting stress (MCS) values (Fig. 3.8). Very small differences were seen between HB samples of the same starch type with the exception of the high amylose class, where noodles containing CDC-92-55-06-54 flour displayed significantly higher MCS values than those containing CDC-92-55-06-48 flour. While small differences in MCS were seen at the 20% addition level, significant differences were detected at the 40% addition level. All noodles containing HB flour had higher MCS values than the control with waxy and ZAW blend noodles having the highest MCS values overall. This is contrary to the results obtained for white salted noodles (WSN). WSN made from blends containing waxy HB flour showed significantly lower MCS values than control wheat noodles. These effects were attributed to slow gelation properties of waxy starches. The results obtained for YAN, however, cannot be explained on the bases of starch characteristics.

Resistance to compression (RTC), the instrumental parameters known to correlate with chewiness of noodles, indicated that YAN containing HB were slightly chewier than the control (Fig.3.9). As the level of HB flour addition increased to 40%, all samples had higher RTC values than the AC Vista noodle. At the elevated level of

HB addition, a significant difference in RTC was detected between noodles containing the high amylose flour. Although most of the noodles containing HB flour displayed higher RTC values than the control at both levels of addition, noodles containing waxy and ZAW flour were generally less chewy than those containing normal and high amylose flour.

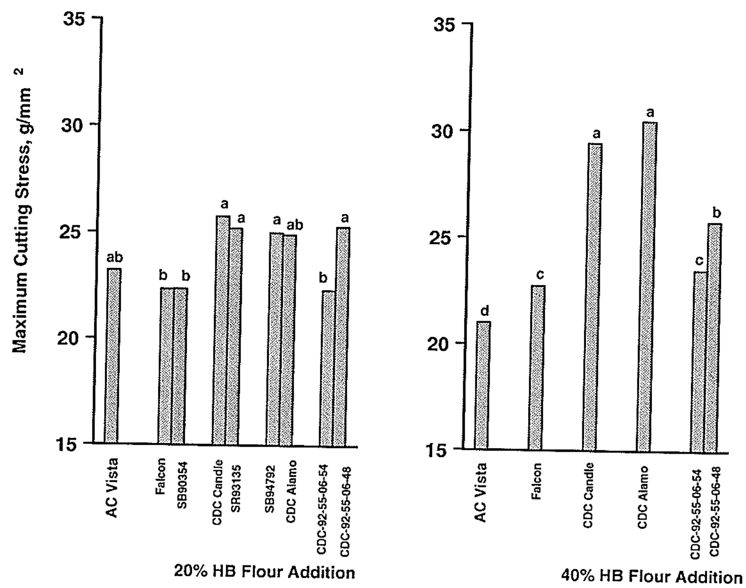


Figure 3.8. Maximum cutting stress of yellow alkaline noodles with the addition of hull-less barley flour.

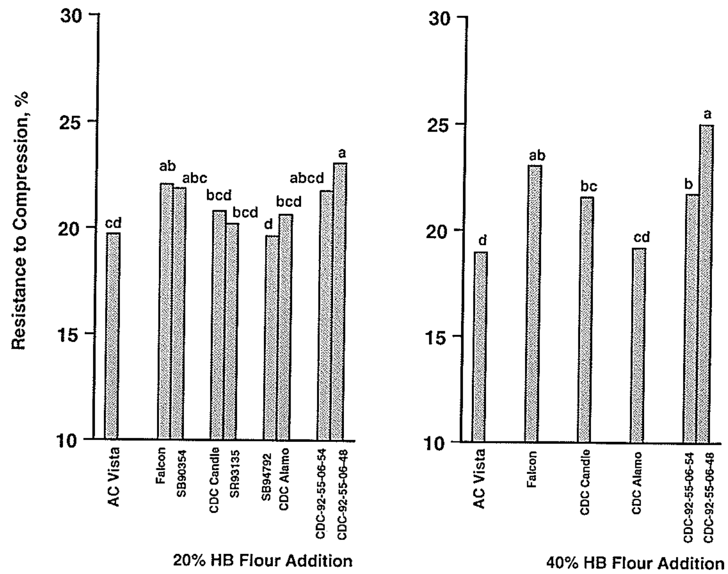


Figure 3.9. Resistance to compression of yellow alkaline noodles with the addition of hull-less barley flour.

It appears that factors other than starch contributed to the texture of YAN. It is known that both BG and AX are partially insoluble. Physical entrapments and/or covalent bonds, via ester linkages, are thought to be responsible for partial insolubility of these polymers. It is possible that the solubility of BG and AX increased during processing in the alkaline medium. Both polymers are capable of formation of three-dimension networks and could contribute to the firmer texture of YAN containing HB flour. There is also a possibility that phenolic compounds are released in the alkaline conditions. There is a potential for formation of phenolic-compounds/starch complexes, however, these types of complexes are not clearly understood and it is difficult to speculate on these effects on the texture of noodles (Tomasik and Schilling 1998). Behaviour of protein in the alkaline medium may also have affected texture of the cooked noodles.

Interestingly, the chewiness parameter obtained from the texture profile analysis (TPA) did not confirm the textural characteristics of YAN as assessed by MCS and RTC. It is possible that starch, non-starch polysaccharides and phenolic compounds, and their interactions, behaved differently under the conditions (force, time and probe) of the various instrumental tests (cutting, compression, texture profile analysis and stress relaxation). At 20% addition of HB, the waxy and the ZAW samples were less chewy (TPA parameter) while the normal and the high amylose samples were more chewy than the control (Fig. 3.10). In general, at the 40% addition level, normal and high amylose starch blend noodles were significantly chewier, while the waxy and the ZAW blend noodles were less chewy than the control.

Only CDC Alamo flour, at the 20% addition level, decreased noodle resilience (TPA parameter) in relation to the control (Fig. 3.11). At the elevated level of addition, the waxy, ZAW and high amylose blend noodles displayed significantly lower resilience values than the AC Vista noodle. No differences were seen between HB blend noodles with the exception of Falcon, which had significantly higher resilience values than the remaining samples.

The addition of 20% normal or high amylose HB flour to YAN increased relaxation time, while the waxy and the ZAW decreased in relation to the control (Fig 3.12). No significant differences were detected between samples of the same starch type. A similar trend was seen at the elevated level of HB flour addition. In the present study, relaxation time was found to correlate well with the textural parameters RTC, chewiness and resilience for both the 20% and 40% level of HB flour addition to YAN (Appendix 8 and 9).

Differences between noodles containing high amylose HB flour were seen with many of the textural parameters. Although they have approximately the same proportions of amylose and amylopectin, the fine structure of the non-starch polysaccharides may be different, resulting in significantly different functionality.

Correlations between textural parameters and RVA starch pasting characteristics were investigated. No significant trends were seen (Appendix 10). Correlations between textural parameters and protein content as well as between textural parameters and amylose content of the starch were also investigated. Again, no clear trends were seen (Appendix 11).

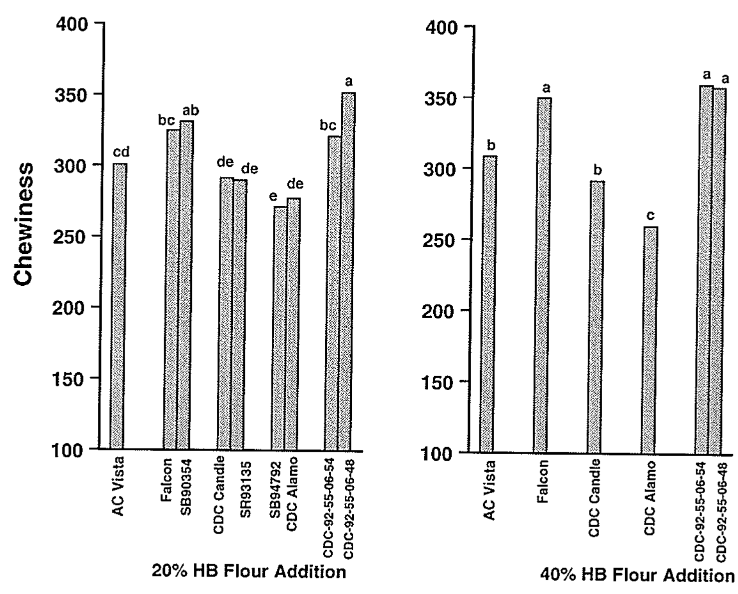


Figure 3.10. Chewiness of yellow alkaline noodles with the addition of hull-less barley flour.

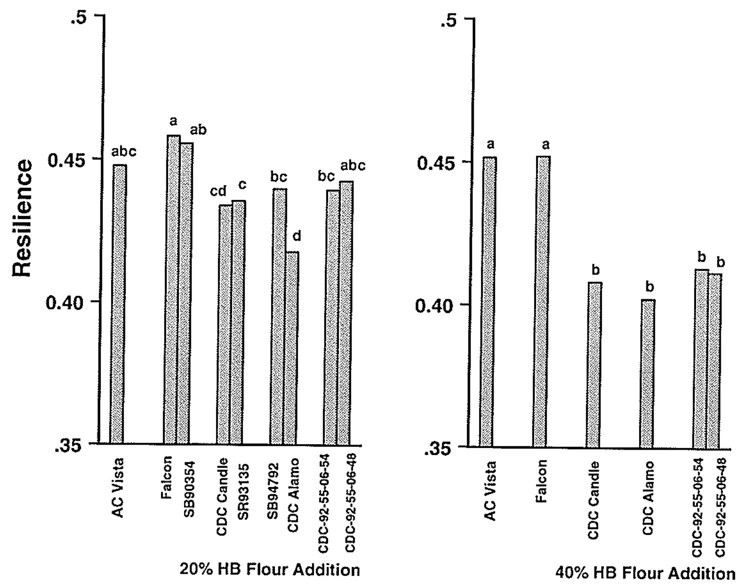


Figure 3.11. Resilience of yellow alkaline noodles with the addition of hull-less barley flour.

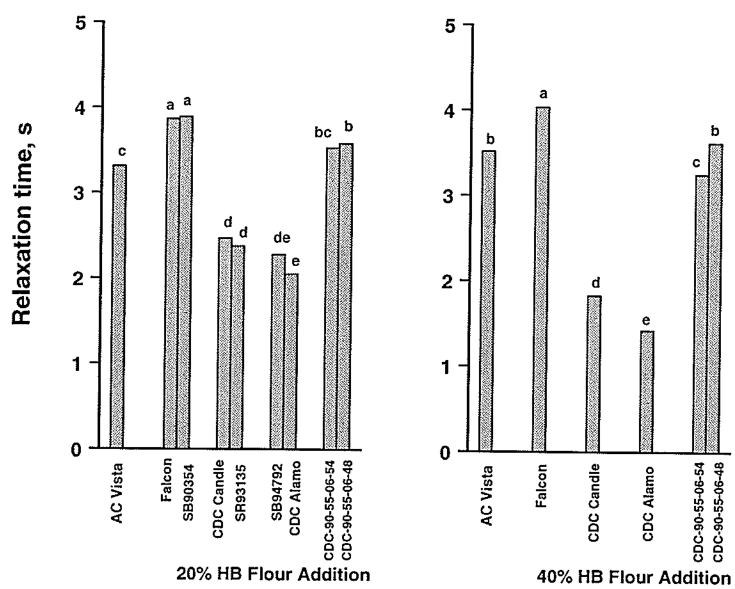


Figure 3.12. Relaxation time of yellow alkaline noodles with the addition of hull-less barley flour.

CONCLUSIONS

Yellow alkaline noodles were made with the addition of both 20% and 40% HB with various starch amylose characteristics and elevated levels of non-starch polysaccharides, with minimal adjustments to the process and formulation. Noodle appearance was significantly affected. A decrease in noodle brightness and yellowness with an increase in redness was observed in conjunction with increased speckiness. Noodle texture was also affected with the addition of HB flour to YAN. Normal and high amylose starch amylose samples increased firmness and chewiness of cooked YAN, with high amylose samples having the most pronounced effect. Waxy and ZAW samples decreased cooked YAN firmness and chewiness, with ZAW samples having the most pronounced effect. Starch amylose content was not the only factor contributing to the texture of YAN. Other factors, such as phenolics and non-starch polysaccharides may have been affected by the alkaline medium and resulted in different textural characteristics. Hull-less barley flour can be added to Asian noodles at levels of 20-40% thereby increasing the resulting products nutritional properties and altering its textural parameters.

MANUSCRIPT 3
The Enrichment of Asian Noodles with a Fiber-Rich Fraction of Hull-less Barley

ABSTRACT

Hull-less barley (HB), traditionally used in the animal feed industry, has the potential for texture modification and healthful enrichment of food products. Due to the elevated levels of healthful soluble dietary fiber and other bio-active components, HB milling fractions, rich in β-glucans (BG), are an economically feasible way to obtain a functional food ingredient. HB fiber-rich fractions (up to > 20% βG) were incorporated (25% w/w) with a Canada Prairie Spring-white (cv. AC Vista) wheat flour to evaluate their suitability as functional ingredients in white salted (WSN) and yellow alkaline (YAN) noodles.

The resulting noodle colour was significantly darker and speckier than the control. Addition of HB fiber-rich fractions reduced cooking time, water uptake, and cooking loss compared to noodles from barley flour admixtures. The addition of fiber-rich fractions increased cooked YAN firmness and chewiness due to the effect of the alkaline condition on the starch and non-starch polysaccharides. In contrast, a decrease in firmness and chewiness was seen when fractions were incorporated into both fresh and dry WSN. The quality and texture of the fiber-rich fraction blend noodles was influenced largely by the elevated levels of non-starch polysaccharides in the fiber-rich fractions.

INTRODUCTION

As awareness is growing about functional foods and their benefits, the link between diet and health is becoming more apparent to consumers. The demand for foods with functional properties is increasing and consequently, so is the research in this area. Functional components in HB are known to have positive health implications, which include lowering blood cholesterol, reducing the risk of coronary heart disease, controlling blood glucose levels, and reducing the risk of colon cancer (Newman and Newman 1991, Jenkins et al 1995, Yokoyama et al 1997). HB with variable starch amylose contents contain elevated levels of soluble fiber. HB fractions such as flour, pearling by-products and enriched milling fractions, have been investigated in a variety of food products (Bhatty 1986, Swanson and Penfield 1988, Sidhu et al 1990, Knuckles et al 1997, Klamczynski and Czuchajowska 1999). The objective of the present study was to evaluate the suitability of a fiber-rich fraction derived from roller milling of 20% pearled HB genotypes (with varying levels of starch amylose, molecular weight, β-glucans and arabinoxylans) in Asian noodles. A 25% addition level of the fiber-rich fractions were added to a Canada Prairie Spring-white wheat (cv. AC Vista) patent flour for the production and evaluation of yellow alkaline noodles (YAN), fresh white salted noodles (WSN) and dry white salted noodles (dry WSN) .

MATERIALS AND METHODS

Material

A 60% extraction patent AC Vista (Canada Prairie Spring-white) flour milled on the GRL (Grain Research Laboratory) pilot mill (Black 1980) was used as the control and as the base wheat flour in noodle production. Canadian hull-less barley (HB) samples were obtained from field trails grown in Western Canada. The two HB samples used in the study were obtained from the Crop Development Center (CDC), University of Saskatchewan, Saskatoon, Saskatchewan. SR93135 is an unregistered 2-row waxy genotype. The high amylose CDC-92-55-06-48 is a 6-row genotypes derived from "High Amylose Glacier".

A fiber-rich fraction (FRF), with concentrated levels of BG and AX, was obtained with the long flow milling procedure of HB as outlined by Izydorczyk et al (2003). The FRF was the coarse discard material coming from SD4, and originated mainly from endosperm cell walls. In wheat milling, this fraction would be referred to as shorts. However, unlike wheat shorts, which are comprised primarily of fine bran, the FRF were composed primarily of endosperm cell wall remnants.

Sample Characterization

Protein, ash, and amylose content, starch damage and colour were analyzed according to the methods and procedures previously described (Manuscript 1, pages 24-25). Starch pasting characteristics (peak viscosity, trough, breakdown, final viscosity, setback and pasting time) were determined with a 30-minute pasting profile using a Rapid-Visco Analyser (RVA, Foss Food Technology). A 3.5g sample size (14%

moisture basis) was suspended in 25 ml of a 0.05M solution of silver nitrate, to inactivate the α-amylase present in the sample. Starch pasting characteristics of the FRF could not be determined independently due to high viscosity of the samples. Pasting curves were obtained of samples blended with AC Vista flour.

Polyphenol oxidase (PPO) and peroxidase (POD) enzymes were determined as per Hatcher and Kruger (1993) and an unpublished method using 1-Step ABTS (2, 2'-Azine-di [3-ethylbenzthiazoline sulfonate]) (Pierce) as the substrate, respectively. The sample size required for PPO analysis of the FRF was 0.05g in 4ml of McIlvaines buffer.

Chemical Composition

Total starch, BG and AX content of the FRF were determined according to the methods and procedures previously described (Manuscript 1, page 25). Total dietary fiber was determined using a Total Dietary Fiber Assay Kit (Sigma) according to the AOAC Official Method 985.29 (1998). Dietary fiber measured by this test includes remnants of plant cells resistant to hydrolysis by the alimentary enzymes of man as well as hemicelluloses, celluloses, lignins, pectins, gums, non-digestible oligosaccharides and waxes in the total dietary fiber measurements. The residues and blanks were analyzed for protein by Kjeldahl nitrogen analysis according to the AOAC Official Method 960.52 (1998). A conversion factor of 6.25 was employed.

Noodle Preparation

The fiber-rich fraction from SR93135 and CDC-92-55-06-48 HB, at a 25% level of addition, were added to yellow alkaline noodles (YAN), fresh and dry white salted noodles (WSN) in order to produce noodles that would contain nutritionally significantly elevated levels of non-starch polysaccharides, β-glucans and arabinoxylans. WSN and YAN (75% AC Vista patent flour: 25% HB fiber-rich fraction) were made at a 50% water absorption level, whereas the control wheat noodle was made at a water absorption level of 35 and 37, respectively (Manuscript 1, page 26). An increased water absorption level was required to form an acceptable noodle since the concentrated levels of non-starch polysaccharides in the FRF have a strong affinity for water.

AC Vista patent flour, HB fiber-rich fractions, water and 1% salt (sodium chloride) or 1% kansui (9:1 sodium and potassium carbonates) were mixed in a Hobart mixer (N50, Hobart Canada, North York, ON) and made into noodles as per Kruger et al (1994a) using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan). Salt was used in the production of WSN whereas kansui was used in the production of YAN to obtain the characteristic colour and flavour desired for this noodle type. Initially, the dry flour was mixed for 30 seconds on setting 1 prior to addition of a salt or alkaline solution. The solution was slowly added over a 30-second period with mixing continued for an additional 30 seconds. The resulting crumb was mixed at high speed (setting 2) for 1 minute followed by a final 3 minutes of mixing on the slow setting #1. The crumb was rolled between a set of rollers (temperature controlled water bath, 28°C) with an initial gap setting of 3mm. The resulting sheet was folded once and was passed through the rollers, loose ends first, to simulate the industrial noodle sheet compounding or laminating step. WSN were rolled onto a plastic rolling pin, sealed in a polyethylene bag, and allowed to rest for 30 min. A resting period is commonly employed in the production of WSN in Asian noodle manufacturing facilities to relax the gluten, and to aid in proper and even hydration of the flour particles. YAN are not traditionally subjected to a rest period prior to sheeting.

The noodle sheet, either YAN or WSN, was then cut into a representative 25-cm long section and was sheeted (roll speed of 3.75 rpm) with a 15% reduction for each consecutive pass (3.00, 2.55, 2.15, 1.85, 1.57, 1.33, 1.10 mm) over a period of 4.5 minutes. Force measurements were captured on an analog-digital board (Labmaster DMA, Scientific Solutions, Solon, OH) interfaced to a personal computer using commercial software (Labtech Notebook, Laboratories Technologies, Wilmington, MA) as described by Hatcher and co-workers (1999a).

The resulting noodle sheet was cut into thirds; two portions were held, at ambient temperature, in sealed plastic bags and containers for colour and image analysis, respectively. The remaining noodle sheet was cut into strands (B 22 cutters) and held in sealed plastic containers, at ambient temperature, until further analysis.

Noodle Quality Analysis

Noodle appearance (raw, cooked, and dry noodle colour), noodle image analysis, optimum cook time, texture parameters, water uptake and cooking loss were evaluated according to the methods and procedures previously described (Manuscript 1, pages 27-30).

The cook water of the noodles containing HB fiber-rich fractions was analyzed in order to determine the portion of the BG being lost during the cooking procedure. After draining the noodles, a portion of the cook water was retained, stored in a sealed plastic container and was frozen. The samples were freeze-dried and the resulting material was ground with a mortar and pestle to ensure a representative sample was taken for BG analysis, by the method described previously.

Dry White Salted Noodles

Noodles containing fiber-rich fractions were processed, dried and analyzed according to methods previously described (Manuscript 1, page 30).

Statistical Analysis

The textural characteristics (cutting, compression, TPA and stress relaxation, as previously described) of cooked Futomaru noodles, a standard dry WSN, were measured each day of testing to ensure equipment was functioning within acceptable limits (results not shown).

All statistical analyses were performed using SAS statistical software version 8 (SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) and Proc GLM were performed to determine significant differences. Experiments were carried out at least in duplicate. Replicated results are reported as means. A completely randomized block design was used, with noodle type being blocked. In all bar graphs, different letters indicate significant differences between means. All values were considered significant at $p \leq 0.05$ unless otherwise stated. The coefficient of variation was less than 5% for all tests.

RESULTS AND DISCUSSION

Addition of a Fiber-Rich Fraction of Hull-less Barley to Yellow Alkaline and White Salted Noodles

With elevated levels of non-starch polysaccharides, comparable Minolta colour values, and relatively low enzyme activity in comparison with wheat flour, a HB fiber-rich fraction (FRF) was tested as a potential functional ingredient in Asian noodles. Due to increasing interest in functional foods, and the well-known health benefits of soluble dietary fiber, of which HB contains elevated levels, the FRF provided a concentrated source of these components that was economically feasible to obtain.

A 25% level of addition was chosen to obtain approximately 5% BG in the resulting noodle sample. Since the serving size of most pasta and noodle products ranges from 85-100g, a resulting 4.25-5g of dietary fiber per serving would be sufficient to claim a high source of dietary fiber as regulated by Health Canada. A fiber-rich fraction from two HB genotypes representing a waxy and a high amylose class (SR93135 and CDC-92-55-06-48, respectively) was incorporated into yellow alkaline noodles (YAN), fresh white salted noodles (WSN) and dry WSN; their effect on noodle quality and, consequently, their potential as a functional food ingredient was investigated.

Sample Characterization

Milling of SR93135 and CDC-92-55-06-48 HB samples yielded 16.5% and 17% of the FRF on a whole barley basis, respectively. The fiber-rich fractions were only slightly less bright than the AC Vista patent flour. SR93135 FRF more closely resembled AC Vista flour than did the CDC-92-55-06-48 FRF, for all colour parameters (brightness, redness and yellowness) as seen in Table 4.1. Unlike HB flour, the fiber-rich fractions did not consist primarily of starch. They were characterized by higher protein, lower starch and considerably higher ash contents than AC Vista flour.

Table 4.1. Physical Characteristics and Composition of Hull-less Barley Fiber-Rich Fractions and Wheat Flour[a]

	Yield[b]	Colour			Starch Content	Starch Damage	Starch Amylose Content	Protein[c]	Ash
Hull-less barley type/variety	%	L*	a*	b*	%	%	%	%	%
Waxy									
SR93135	16.5	90.37	-0.57	9.54	46.3	2.6	4.8	13.3	1.06
High Amylose									
CDC-92-55-06-48	17.0	89.80	0.12	6.28	43.1	1.7	41.8	14.4	0.98
Wheat flour									
AC Vista		92.66	-0.72	9.01	75.5	6.9		12.3	0.44

[a] Values are expressed on a dry matter basis.
[b] Yield is expressed on an as is moisture and on a whole barley basis.
[c] %N x 5.7 for wheat; %N x 6.25 for barley.

The fiber-rich fraction from SR93135 had a total dietary fiber content of 34% while that of CDC-92-55-06-48 was 35% (Table 4.2). Dietary fiber of cereal grain is composed largely of cellulose, BG and AX. While cellulose is highly insoluble, the non-starch polysaccharides, BG and AX, exist in both a soluble and an insoluble form with the soluble fraction being of utmost interest in promoting health benefits.

HB fiber-rich fractions had elevated levels of non-starch polysaccharides. AC Vista flour had less than 1% total BG, whereas the FRF had levels just over 22%. Soluble BG, which have become the main focus in terms of nutrition, were 9.1% and 11.8% for SR93135 and CDC-92-55-06-48 fiber-rich fraction, respectively.

Table 4.2. Non-Starch Polysaccharide Content in Hull-less Barley Fiber-Rich Fractions and in Wheat Flour*

Hull-less barley fiber-rich fractions	Total Dietary Fiber	β-Glucans		Arabinoxylans	
	%	Total, %	Soluble, %	Total, %	Soluble, %
Waxy					
SR93135	33.8	22.02a	9.10b	4.21a	0.71a
High Amylose					
CDC-92-55-06-48	35.3	22.14a	11.81a	5.93a	1.09a
Wheat flour					
AC Vista		0.72b	0.35c	1.69b	0.45a

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Arabinoxylans have also been implicated as having a role in barley's potential for health and texture modification of food products. However its role is understood to a lesser extent than that of BG. Total levels of AX were significantly higher than levels found in the wheat flour, however, the soluble levels of AX were not significantly higher.

Endogenous enzymes. The fiber-rich fraction from CDC-92-55-06-48 had similar polyphenol oxidase (PPO) levels to AC Vista flour whereas the fiber-rich fraction from SR93135 had much higher levels (Table 4.3). Both samples had lower peroxidase (POD) levels than AC Vista flour.

Table 4.3. Endogenous Enzyme Activity in Fiber-Rich Fractions of Hull-less Barley in Comparison with Wheat Flour

Hull-less barley fiber-rich fractions	PPO[a]	POD[b]
Waxy		
SR93135	247	29
High Amylose		
CDC-92-55-06-48	16	63
Wheat flour		
AC Vista	17	171

[a] PPO values expressed in nmol/g/min
[b] POD values expressed in pyrogallol units/mg

Starch pasting characteristics. Unlike HB flour, which is composed primarily of starch, the fiber-rich fraction had much higher levels of dietary fiber components, in particular non-starch polysaccharides (NSP). The addition of 25% fiber-rich fraction to AC Vista flour significantly increased peak viscosity, through, breakdown viscosity, final viscosity and setback viscosity in relation to the control sample while peak time was significantly decreased (Fig 4.1 and Table 4.4). The blend of wheat flour and the fiber-rich fraction from SR93135 displayed significantly higher peak and breakdown viscosity than the blend containing the fiber-rich fraction from CDC-92-55-06-48 while the opposite was seen for through, final and setback viscosity. The presence of NSP influenced viscosity due to their high molecular weight and hygroscopic nature. Additional research is required to investigate whether RVA starch pasting characteristics of HB fiber-rich fractions cans be used to predict noodle texture.

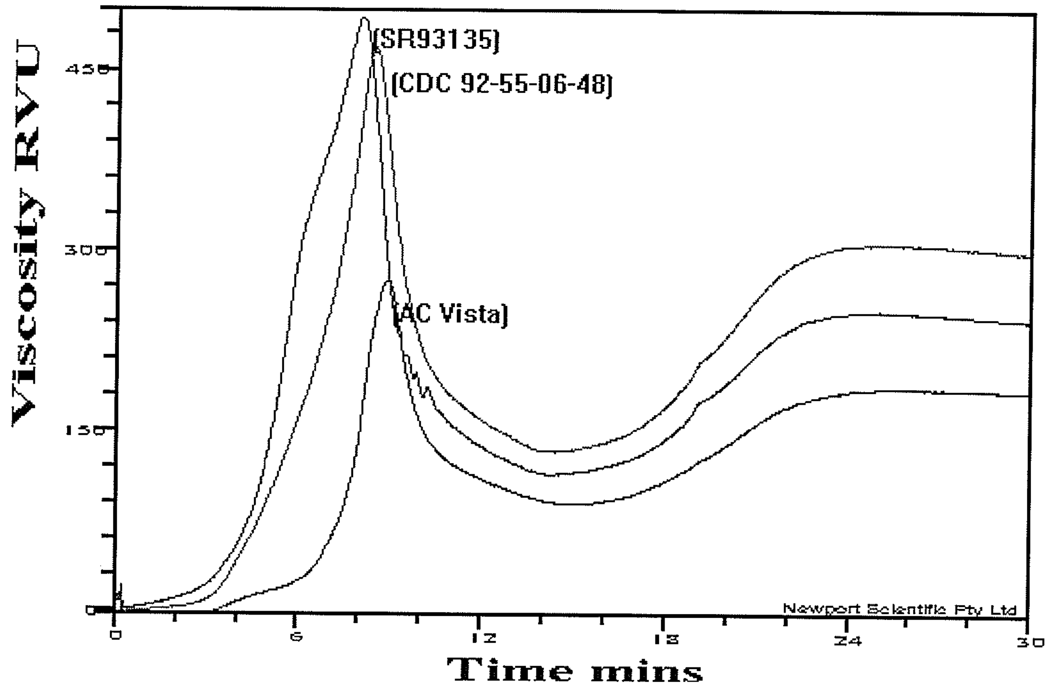


Fig 4.1. RVA starch pasting curve of wheat flour/hull-less barley fiber-rich fractions – 75%/25% in the presence of $AgNO_3$.

Table 4.4. RVA Starch Pasting Characteristics of Wheat Flour/Hull-less Barley Fiber-Rich Fractions – 75%/25%[a,b]

	Peak viscosity	Through	Breakdown	Final viscosity	Setback	Peak time
Wheat Flour						
AC Vista	262.6c	88.2c	174.4c	178.0c	89.9c	8.8a
Wheat flour/ HB FRF blend						
Waxy						
SR93135	494.1a	115.5b	378.6a	245.2b	129.7b	8.1c
High Amylose						
CDC-92-55-06-48	466.3b	133.9a	332.4b	299.0a	165.2a	8.5b

[a] Values are expressed in RVU units where 1 RVU = 12 centipoise

[b] Means followed by different letters in columns are significantly different at $p \leq 0.05$

Noodle Quality Evaluation

Since the HB fiber-rich fractions had elevated levels of NSP, which are hygroscopic in nature and compete with starch and protein during hydration, a higher water absorption level was required to produce a workable noodle sheet. The water absorption level was increased to 50% in comparison with 35% and 37% for the control WSN and YAN.

Force requirements. No significant differences in force requirements to process the noodle sheets were detected between noodles containing HB fiber-rich fractions, nor were they significantly different than the control for both YAN and WSN (Fig. 4.2). Water absorption of noodles containing HB fiber-rich fractions was considerably higher than the control, which has been found to decrease work input (Hatcher et al 1999a). Since the higher water absorption level did not reduce the work input, other factors to consider in the strength and resistance of the noodles during sheeting are the elevated levels of NSP and the gluten development, which may be more complete at the higher water absorption level.

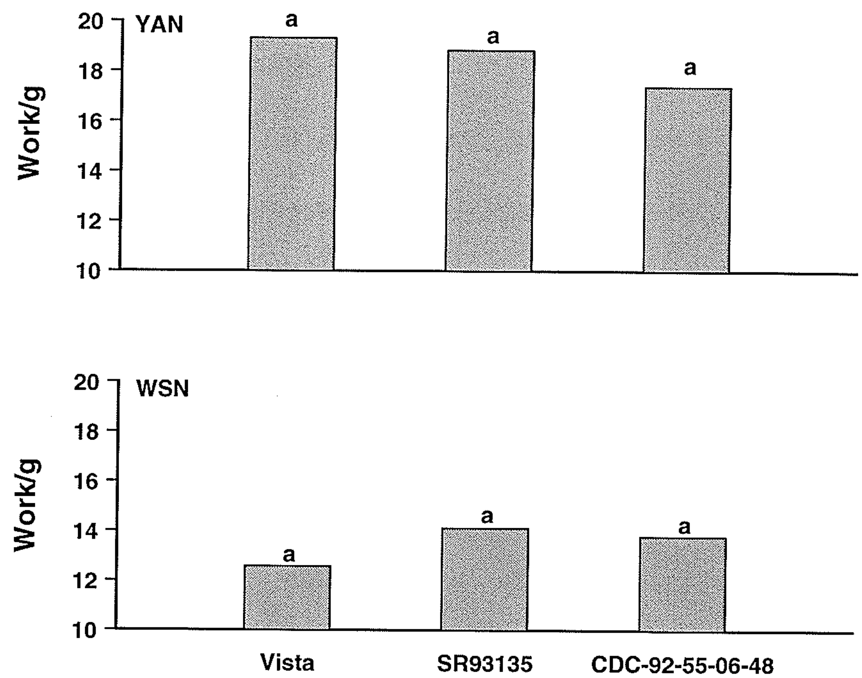
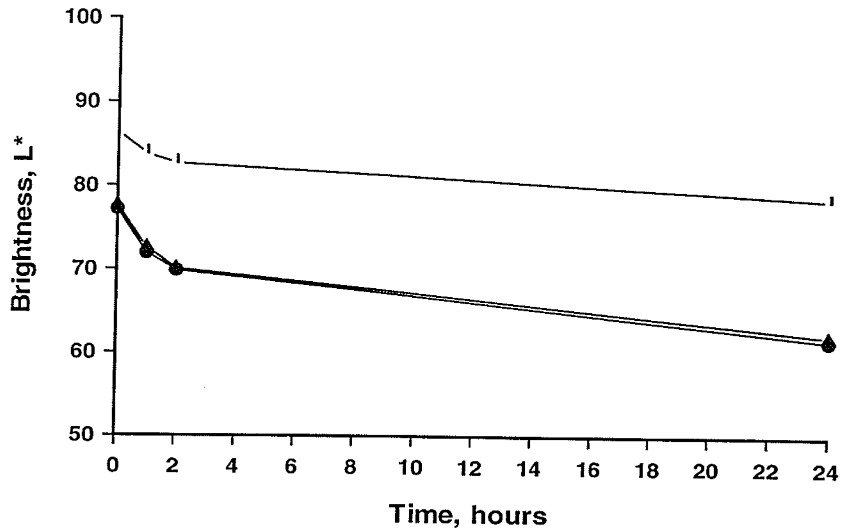


Figure 4.2. Energy requirements during sheeting of yellow alkaline and white salted noodles with the addition of 25% hull-less barley fiber-rich fractions

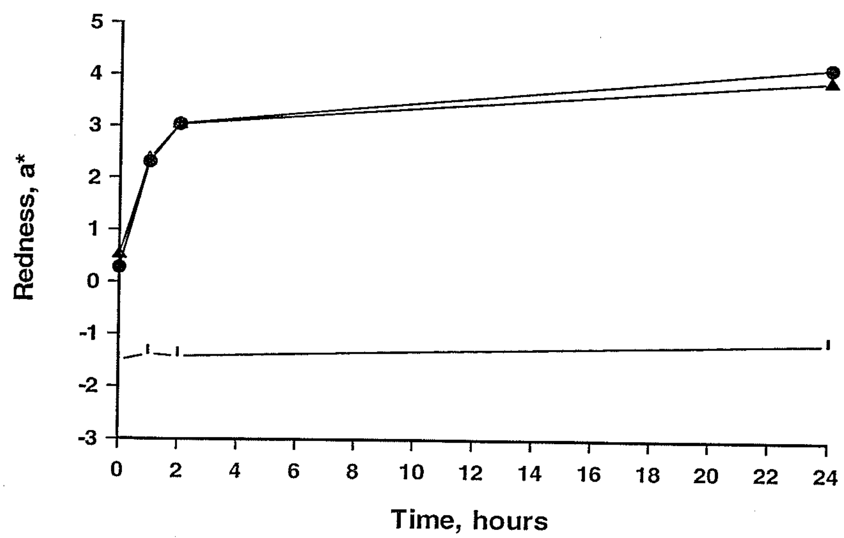
Raw Noodle Appearance

Raw colour. The addition of 25% fiber-rich fractions decreased brightness and yellowness while increasing redness of the YAN (Fig. 4.3). There were considerable differences in yellowness between the fiber-rich fractions, CDC-92-55-06-48 having the lowest yellowness values overall, while the two samples displayed similar values for brightness and redness. Addition of the fractions increased redness values of the noodle from negative (green) to positive (red) values.

a.


Brightness, L*
100
90
80
70
60
50
0
2
4
6
8
10
12
14
16
18
20
22
24
Time, hours

b.


Redness, a*
5
4
3
2
1
0
-1
-2
-3
0
2
4
6
8
10
12
14
16
18
20
22
24
Time, hours

c.

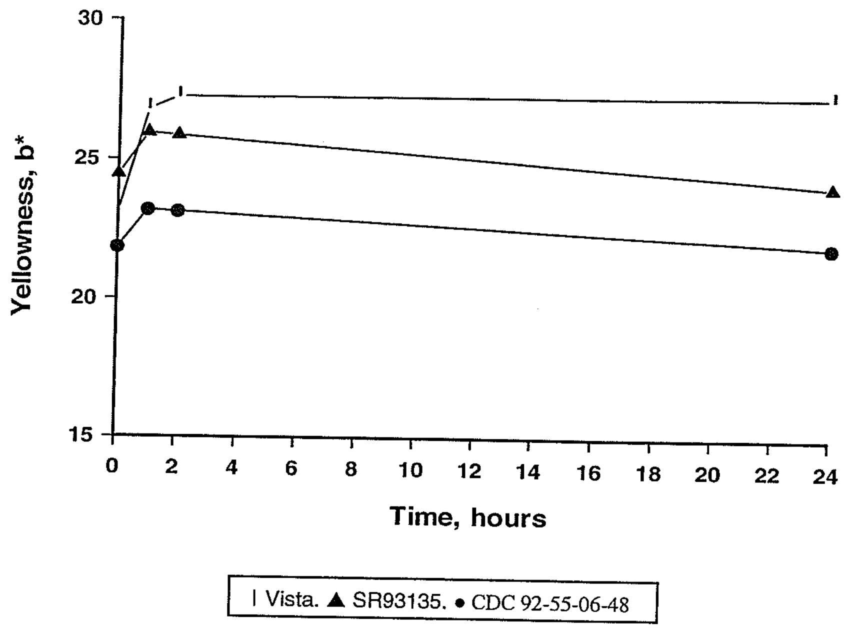
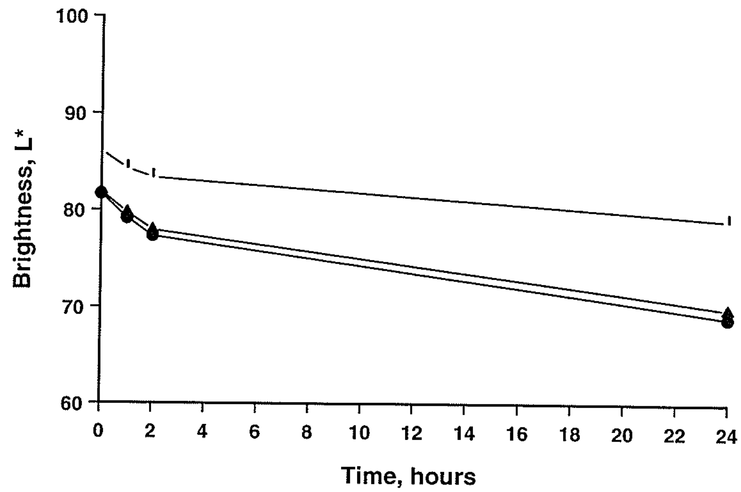


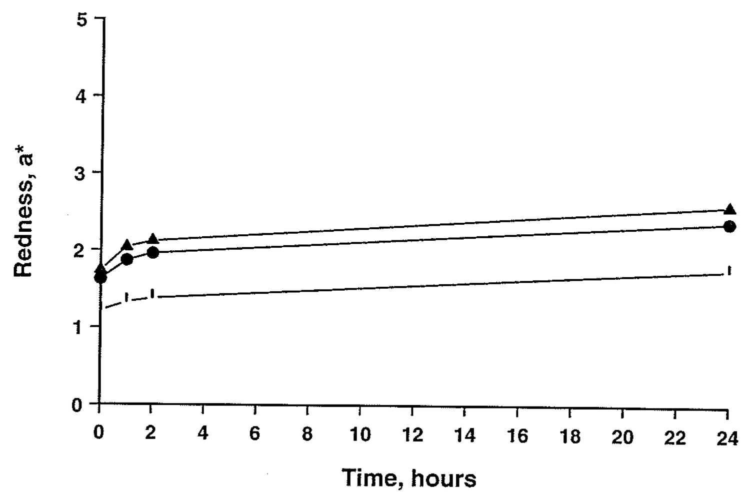
Figure 4.3. Fresh yellow alkaline noodle colour over time with the addition of hull-less barley fiber-rich fractions (a. brightness, b. redness, c. yellowness).

A similar trend was observed when the fractions were added to WSN (Fig. 4.4), where a decrease in brightness and yellowness and an increase in redness were observed over time and in relation to the control.

a.


100
90
80
70
60
Brightness, L*
0
2
4
6
8
10
12
14
16
18
20
22
24
Time, hours

b.


5
4
3
2
1
0
Redness, a*
0
2
4
6
8
10
12
14
16
18
20
22
24
Time, hours

c.

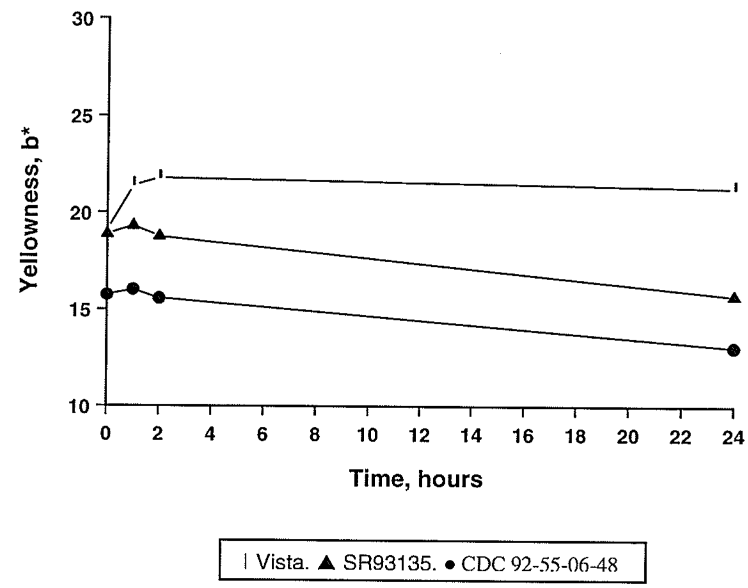


Figure 4.4. Fresh white salted noodle colour over time with the addition of hull-less barley fiber-rich fractions (a. brightness, b. redness, c. yellowness).

Image analysis. The addition of HB fiber-rich fractions to YAN dramatically increased the number of specks on the noodle sheet, initially and over time (Fig. 4.5). While the control YAN had a speck count of 6 at one hour after processing and approximately 100 specks 24 hours after processing, YAN containing fiber-rich fractions had speck counts approaching 1000 initially and approximately 1300 at 24 hours after processing. YAN containing fiber-rich fractions from CDC-92-55-06-48 consistently displayed higher speck counts than the remaining samples at each time interval.

The average speck size of YAN containing fiber-rich fractions was more than double that of the control. Time after processing did not seem to influence the size of the specks as minimal changes in speck size were observed over a 24-hour period. In addition, minimal differences were detected between YAN containing fiber-rich fractions.

WSN containing fiber-rich fractions had fewer specks than the corresponding YAN. Since specks are a result of a complex reaction that involves the enzyme polyphenol oxidase, phenolics, alkaline oxidation and their subsequent auto-oxidation products, the alkaline medium of YAN provides a more suitable environment for these reactions to occur. The control WSN had 0 specks at one hour after processing and 18 specks 24 hours after processing while WSN containing fiber-rich fractions displayed speck counts in excess of 100 initially and in excess of 170 at 24 hours (Fig. 4.6). Noodle speck count generally increases over time as enzymes associated with bran contamination produce discolourations. While the general trend was for increasing speck count over time, WSN containing fiber-rich fractions from CDC-92-55-06-48 displayed a slight decrease in speck count at 2 hours after processing. This is presumably due to the diminishing contrast between the actual speck and the noodle background.

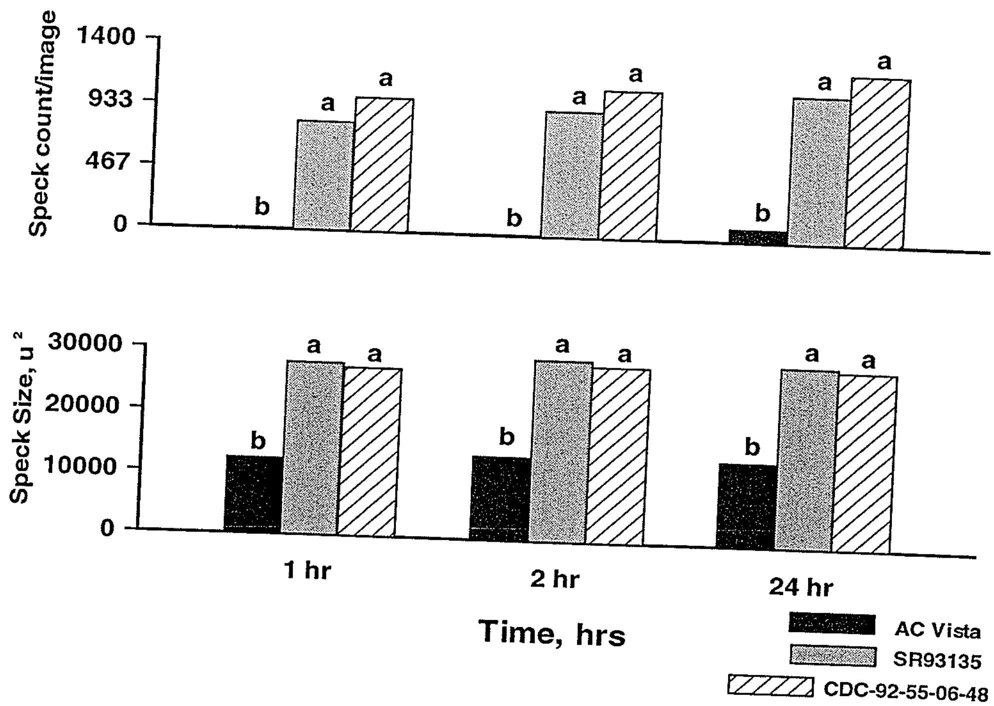


Figure 4.5. Image analysis of yellow alkaline noodles over time with the addition of hull-less barley fiber-rich fractions.

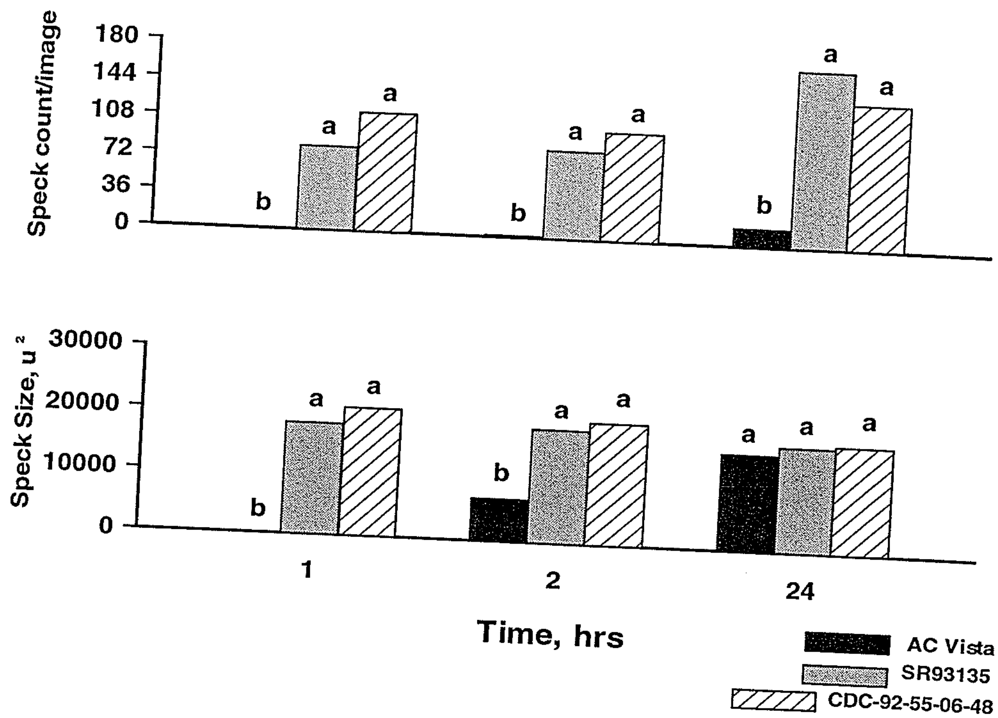


Figure 4.6. Image analysis of white salted noodles over time with the addition of hull-less barley fiber-rich fractions.

Not only was the number of specks in WSN less than that seen in YAN, the average size of the speck was smaller. In the YAN, speck size seemed to remain relatively constant over time, while in the WSN, the average size of the control noodle specks increased while those containing fiber-rich fractions displayed a slight decrease over time. Speck size of the control and of noodles containing fiber-rich fractions approached equal values at 24 hours after processing.

Cooking Quality

Optimum cook time. The addition of fiber-rich fractions from HB dramatically reduced optimum cooking time of YAN from 7 minutes for the AC Vista noodles to 3.0

and 3.5minutes for YAN containing fiber-rich fractions from CDC-92-55-06-48 and SR93135, respectively (Table 4.5). A similar reduction in cooking time was seen with the addition fiber-rich fractions to WSN. The higher water absorption level of the noodles containing fiber-rich fractions is believed to be the primary factor involved in the reduced cooking times.

Table 4.5. Optimum Cook Time of Noodles Containing 25% Hull-less Barley Fiber-Rich Fractions*

HB FRF type/variety		YAN	WSN	Dry WSN
Waxy				
	SR93135	3b	6b	14b
High Amylose				
	CDC-92-55-06-48	3b	5b	16a
Wheat flour				
	AC Vista	7a	11a	13c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

While a reduction in cooking time was seen with the addition of fiber-rich fractions to fresh YAN and WSN, an increased cooking time was required for dry WSN containing fiber-rich fractions, further indicating that the water absorption level was the primary factor involved in reducing cook times. Once the noodles were dry, more time was needed for re-hydration, and consequently, a longer optimum cooking time was required.

Water uptake. The addition of HB fiber-rich fractions to YAN significantly decreased water uptake during cooking with minimal differences detected between HB samples (Fig. 4.7). A similar trend was observed for WSN, although a significant difference was detected between HB samples, with noodles containing fiber-rich fractions from CDC-92-55-06-48 displaying the least amount of water uptake over all. A corresponding decrease in water uptake was seen with the reduced cooking times of the fresh yellow alkaline and white salted noodles containing fiber-rich fractions.

No significant differences were detected in water uptake values of the noodles containing HB fiber-rich fractions and the AC Vista control, although the dry WSN did display considerably higher water uptake values than the fresh YAN and WSN, presumably due to their higher optimum cooking times.

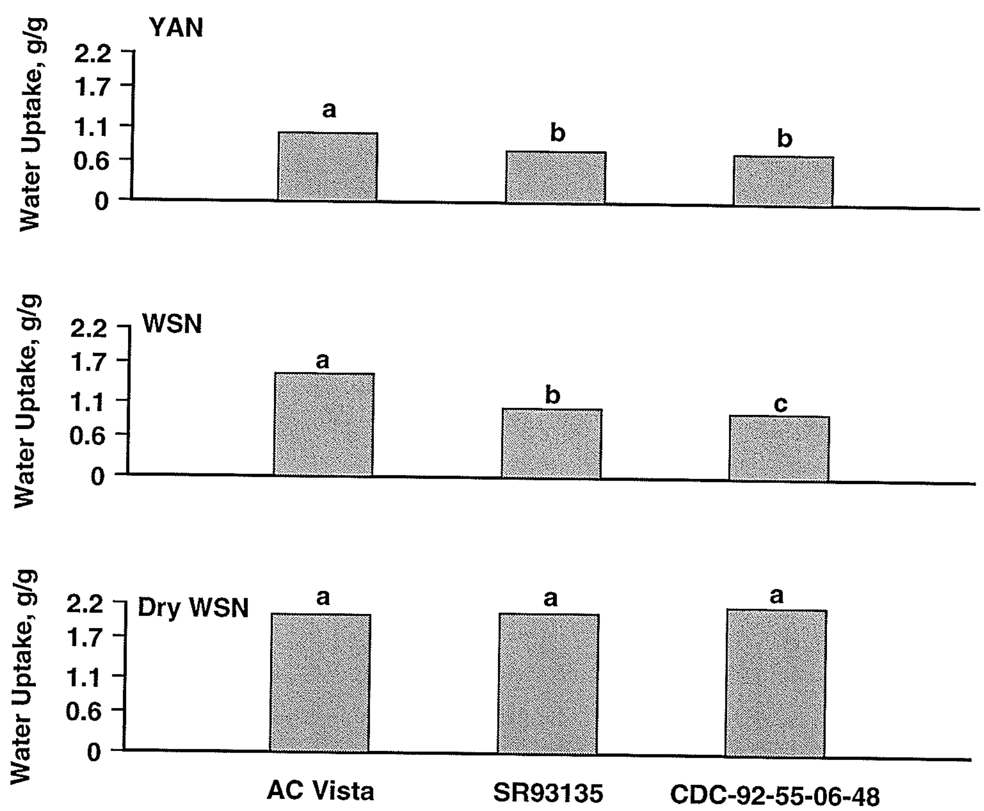


Figure 4.7. Water uptake during cooking of Asian noodles with the addition of hull-less barley fiber-rich fractions.

Solid loss. Similar to the trend observed for water uptake, YAN and WSN containing fiber-rich fractions exhibited significantly decreased solid loss in comparison with the control, due in large part to their decreased cooking time (Fig. 4.8). No significant differences in solid loss were seen between the control and dry WSN containing fiber-rich fractions, with these having similar cook times.

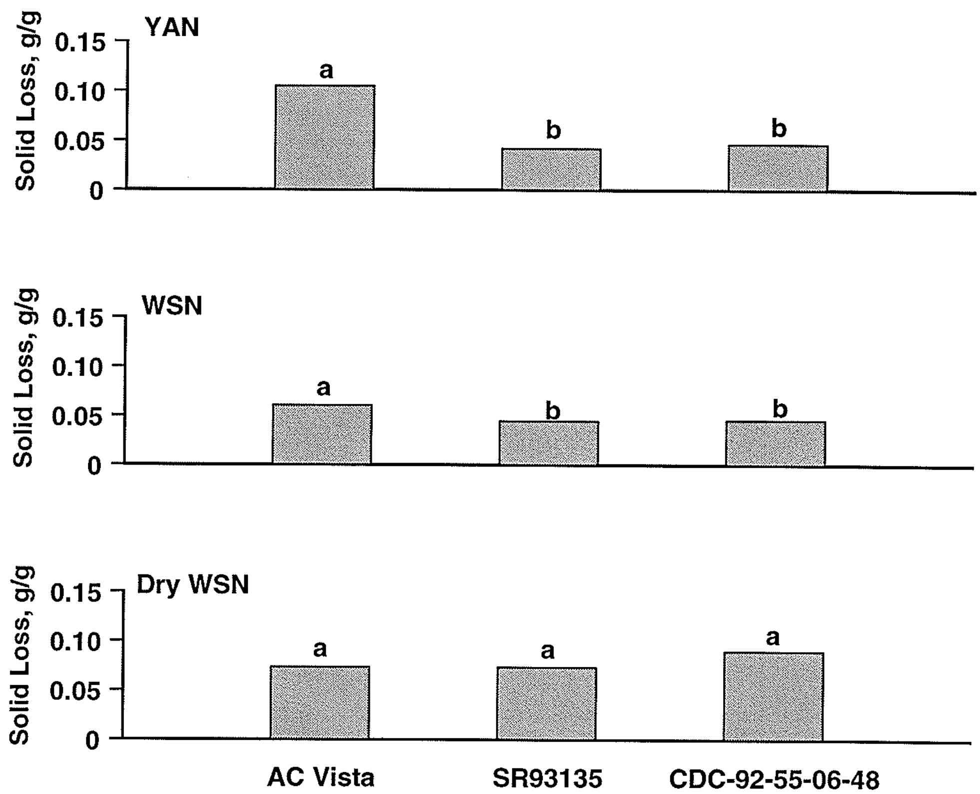


Figure 4.8. Solid loss during cooking of Asian noodles with the addition of hull-less barley fiber-rich fractions.

β-Glucan loss during cooking. Fiber-rich fractions from HB were added to Asian noodles to increase their total and soluble level of dietary fiber. As a result, the solids being lost to the cook water were characterized to ensure that the healthful components were not being completely lost prior to consumption of the product. The level of BG being lost during the cooking procedure were relatively insignificant, with values under 3% for fresh YAN and WSN, and values under 4% for dry WSN (Table 4.6). The slightly higher values seen in the dry WSN presumably correspond to the higher cook times of this noodle type. Since minimal amounts of BG were lost during the cooking procedure it appears that the soluble BG may be held tightly in a protein-starch gel matrix.

Table 4.6. β-Glucan Cooking Loss of Noodles Containing Hull-less Barley Fiber-Rich Fractions

	Total β-glucan, g/25g	Total β-glucan lost, g/25g	% β-glucan lost
YAN			
SR93135	1.38 ±0	0.036 ±0.0036	2.6 ±0.27
CDC-92-55-06-48	1.38 ±0	0.036 ±0.0076	2.6 ±0.55
WSN			
SR93135	1.38 ±0	0.035 ±0.0033	2.5 ±0.22
CDC-92-55-06-48	1.38 ±0	0.030 ±0.0040	2.1 ±0.31
Dry WSN			
SR93135	1.38 ±0	0.047 ±0.0059	3.4 ±0.46
CDC-92-55-06-48	1.38 ±0	0.053 ±0.0085	3.8 ±0.60

Noodle type had a significant effect on the BG lost during the cooking procedure (Table 4.7). This effect was presumably due to the differences between the fresh and the dry WSN. There were no significant differences between noodles containing fiber-rich fractions from different HB genotypes. In addition, there were no significant differences due to interactions of the noodle type and sample.

Table 4.7. Proc ANOVA- Effect of noodle type and sample on the level of β-glucan lost in the cooking water

	Mean Square	F Value	Pr > F
Noodle type	3.06871118	17.88	< 0.0001
Sample	0.02161067	0.13	0.7271
Noodle type * sample	0.26651609	1.55	0.2402

Noodle Colour

Cooked colour. Addition of hull-less barley fiber-rich fractions to YAN decreased brightness and yellowness while increasing redness of the cooked noodles (Table 4.8). The only significant difference detected between HB samples were seen with the redness values, where noodles containing fiber-rich fractions from CDC-92-55-06-48 were significantly redder than noodles containing fiber-rich fractions from SR93135. The redness values increased to positive values with the addition of fiber-rich fractions. Similarly, brightness and yellowness decreased while redness increased upon addition of fiber-rich fractions to fresh cooked WSN. The only significant difference detected between HB samples in this case was with the yellowness values, where noodles containing CDC-92-55-06-48 were less yellow than noodles containing SR93135 (Table 4.9).

Table 4.8. Colour of Cooked Fresh Yellow Alkaline Noodles Containing Hull-less Barley Fiber-Rich Fractions*

	L*	a*	b*
AC Vista Noodles	66.90a	-3.00c	25.93a
AC Vista/ HB FRF Blend Noodles			
Waxy			
SR93135	51.57b	3.23b	22.76b
High Amylose			
CDC-92-55-06-48	52.03b	4.10a	21.73b

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

The appearance of noodles containing fiber-rich fractions may be influenced by particle size. The fiber-rich fractions have a larger particle size than flour and contain insoluble material, leading to increased speckiness and discolouration.

Table 4.9. Colour of Cooked Fresh White Salted Noodles Containing Hull-less Barley Fiber-Rich Fractions*

	L*	a*	b*
AC Vista Noodles	77.87a	-1.06b	14.15a
AC Vista/ HB FRF Blend Noodles			
Waxy			
SR93135	65.82b	0.83a	13.49b
High Amylose			
CDC-92-55-06-48	65.38b	0.87a	11.22c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Colour of uncooked and cooked dry white salted noodles. A similar trend was observed for uncooked and cooked dry WSN colour where brightness and yellowness decreased while redness increased (Table 4.10 and Table 4.11). Noodles containing fiber-rich fractions from CDC-92-55-06-48 HB were significantly less yellow than those containing fiber-rich fractions from SR93135 for both dry and dry cooked WSN samples. No other distinctions between samples were made for the remaining colour parameters.

Table 4.10. Colour of Dry White Salted Noodles Containing Hull-less Barley Fiber-Rich Fractions*

	L*	a*	b*
AC Vista Noodles	80.21a	2.56b	20.54a
AC Vista/ HB FRF Blend Noodles			
Waxy			
SR93135	75.26b	3.06a	18.25b
High Amylose			
CDC-92-55-06-48	75.20b	2.62ab	15.65c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Table 4.11. Colour of Cooked Dry White Salted Noodles Containing Hull-less Barley Fiber-Rich Fractions*

	L*	a*	b*
AC Vista Noodles	76.57a	-0.82b	14.68a
AC Vista/ HB FRF Blend Noodles			
Waxy			
SR93135	68.17b	1.08a	13.52b
High Amylose			
CDC-92-55-06-48	66.94b	1.28a	11.69c

*Means followed by different letters in columns are significantly different at $p \leq 0.05$

Texture

The bite or firmness of a cooked noodle on a front tooth can be described by its maximum cutting stress (MCS) while the chewiness of the noodle on the back molars can be estimated by the resistance to compression (RTC) of the noodle (Oh et al 1983; Hatcher and Preston 2003). The addition of CDC-92-55-06-48 HB fiber-rich fraction significantly increased cooked YAN firmness (Fig. 4.9). The addition of fiber-rich fractions to fresh WSN did not affect firmness of the cooked noodles. In the case of the dry WSN, the noodles became less firm upon addition of the fiber-rich fraction with CDC-92-55-06-48 displaying the least firm noodle texture overall.

Addition of fiber-rich fractions increased chewiness of YAN with those containing CDC-92-55-06-48 having the highest chewiness values overall (Fig. 4.10 and 4.11). No significant differences were detected among WSN samples while dry WSN containing HB fiber-rich fractions were significantly less chewy than the control.

Both the YAN and the fresh WSN displayed lower resilience values upon addition of the fiber-rich fractions (Fig. 4.12) with noodles containing CDC-92-55-06-48 consistently displaying the lowest values overall. In contrast, the addition of fiber-rich fractions increased resilience values in the dry WSN, with noodles containing SR93135 being significantly more resilient than the control.

The addition of HB fiber-rich fractions decreased relaxation time for all noodle types (Fig. 4.13).

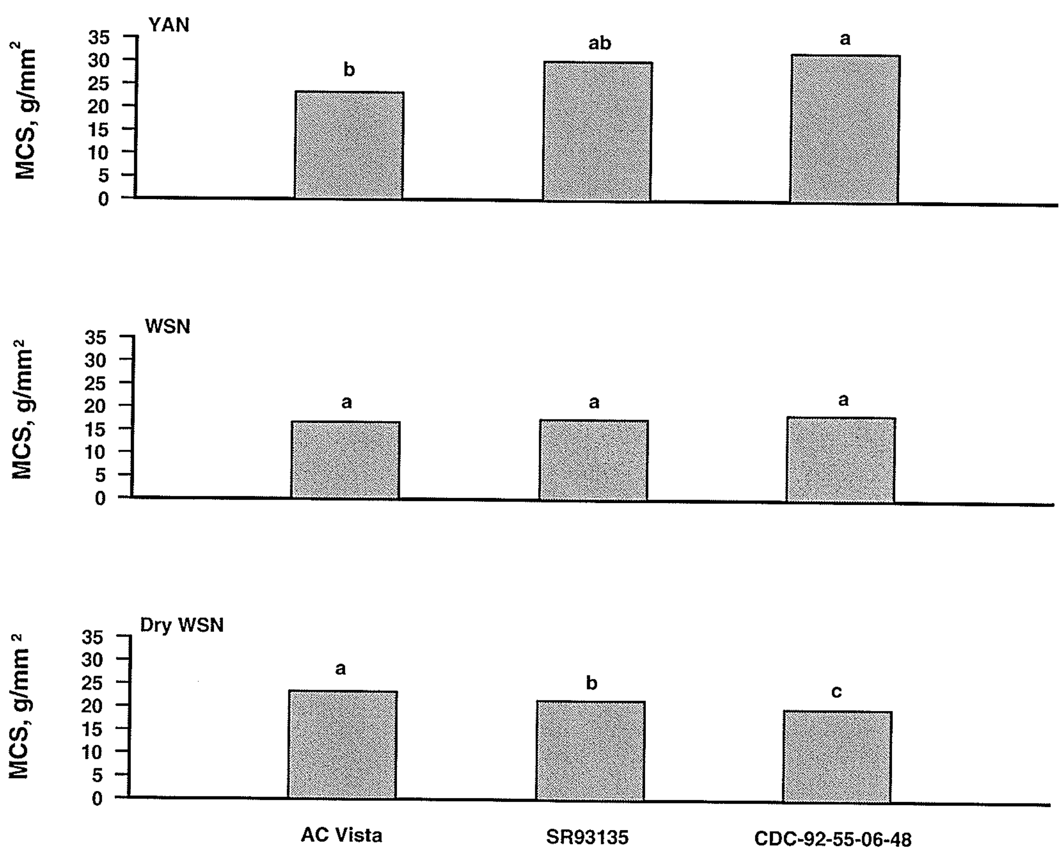


Figure 4.9. Maximum cutting stress of Asian noodles containing hull-less barley fiber-rich fractions.

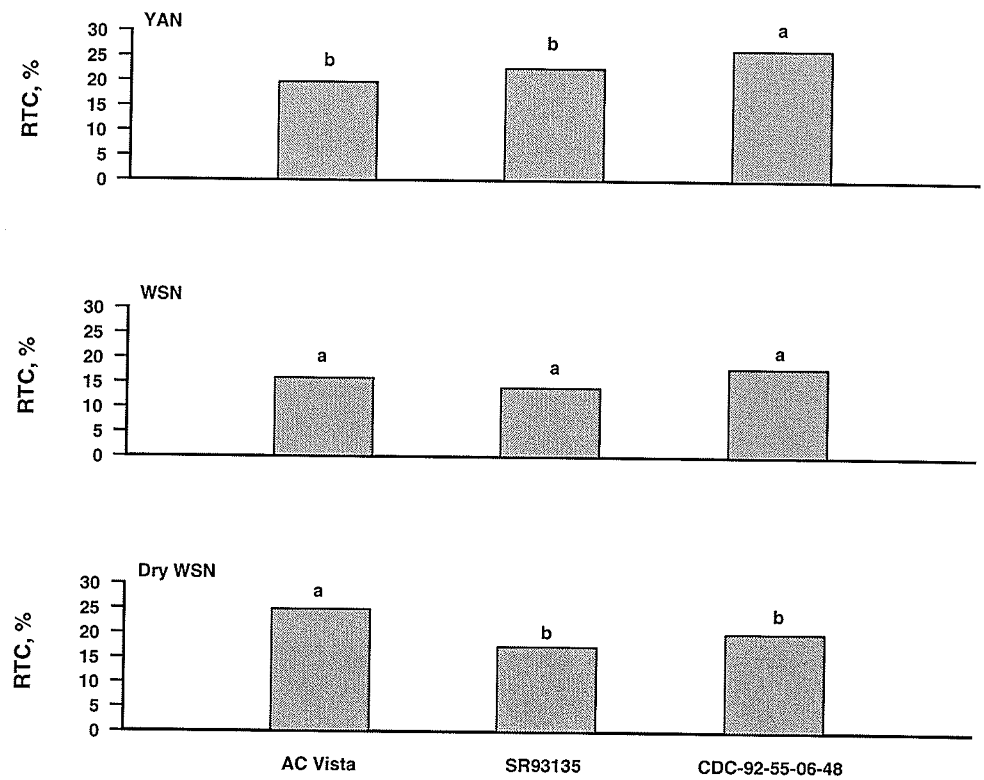


Figure 4.10. Resistance to compression of Asian noodles containing hull-less barley fiber-rich fractions

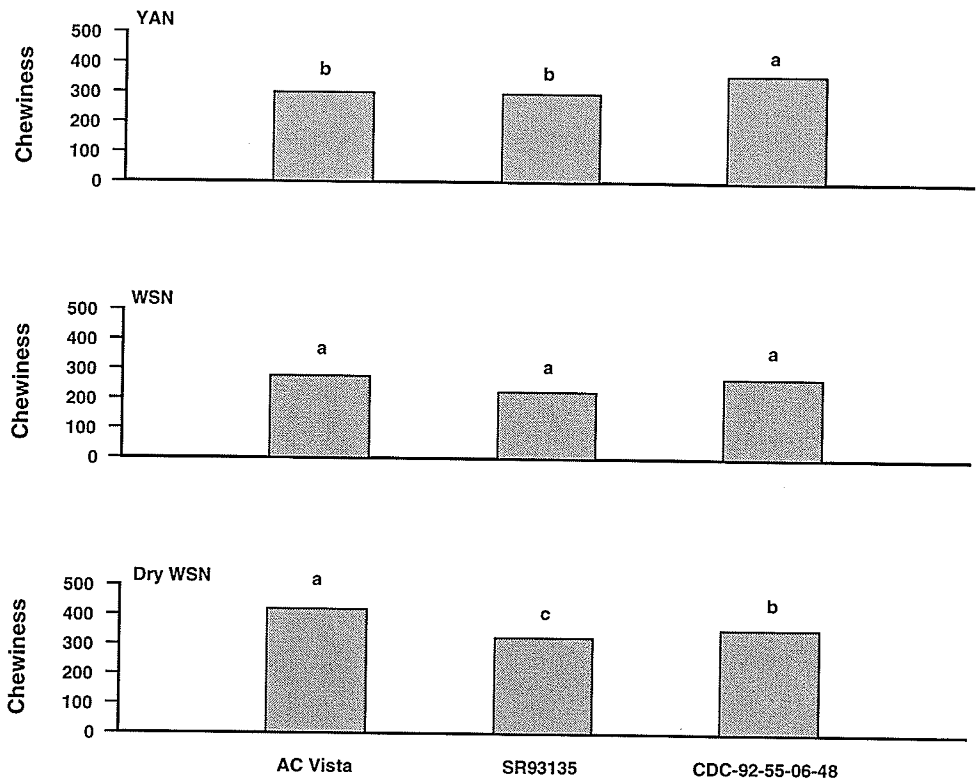


Figure 4.11. Chewiness of Asian noodles containing hull-less barley fiber-rich fractions.

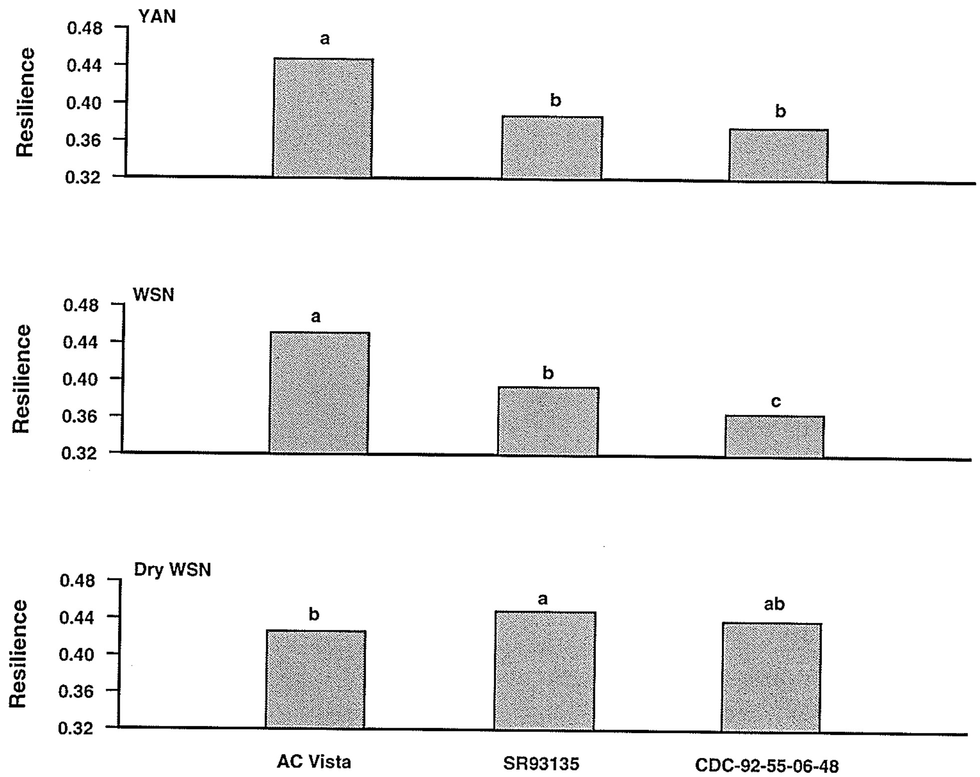


Figure 4.12. Resilience of Asian noodles containing hull-less barley fiber-rich fractions.

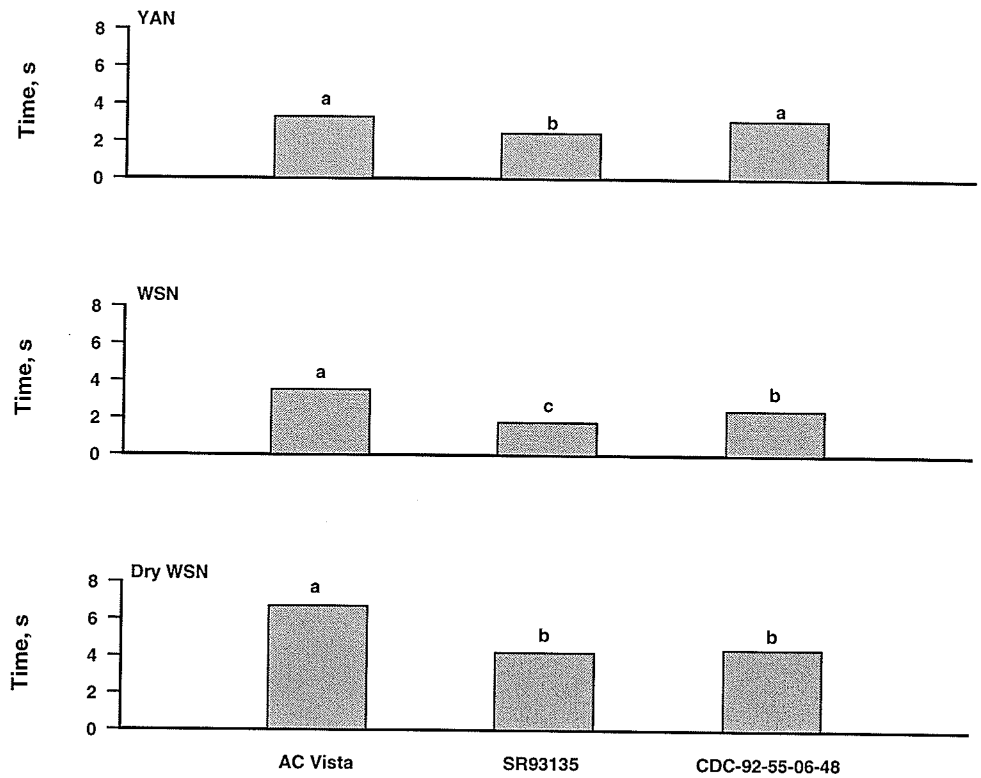


Figure 4.13. Relaxation time of Asian noodles containing hull-less barley fiber-rich fractions.

Although an instrumental or formal sensory surface smoothness test was not carried out, general observations were made regarding the noodles appearance. Due to the large quantity of endosperm cell wall remnants in the fiber-rich fractions, the majority of which are insoluble and of large molecular weight, the resulting noodles did not have a smooth surface appearance.

Dry white salted noodle breaking strength. The addition of HB fiber-rich fractions to dry WSN did not significantly impact dry noodle breaking strength, suggesting that noodles containing fiber-rich fractions are as resistant to breakage under stressful conditions as the control noodle made with wheat flour (Fig. 4.14).

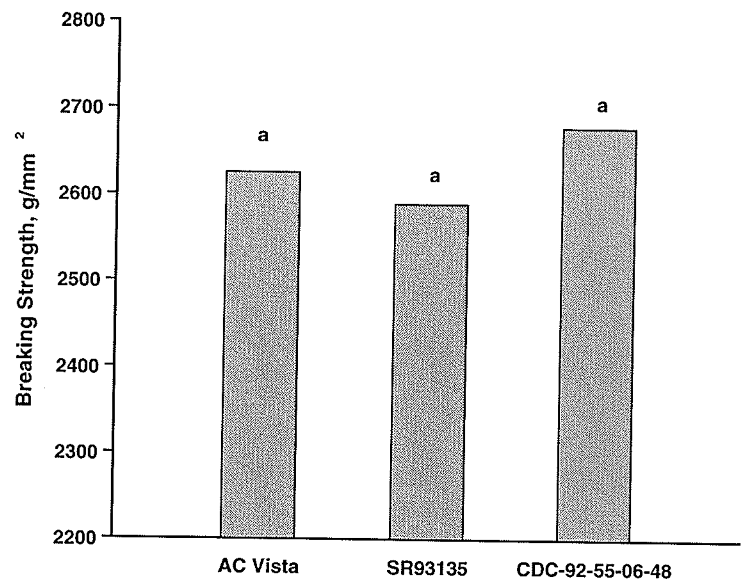


Figure 4.14. Breaking strength of Asian noodles containing hull-less barley fiber-rich fractions.

CONCLUSIONS

Noodles containing HB fiber-rich fractions were significantly darker and speckier than the control wheat noodle. The elevated water absorption level of noodles enriched with the fiber-rich fractions resulted in products with a high water activity that may promote chemical, microbiological and enzymatic reactions that are deleterious to the quality and appearance of the noodle. Drying of the noodles may be required, since drying was seen to arrest the darkening of the noodles. Health conscious consumers may be more accepting of functional foods with altered appearances; however, additional research is required to investigate in detail the causes of noodle colour deterioration due to the addition of fiber-rich fractions and how they may be resolve.

A decrease in firmness and chewiness was seen when the fiber-rich fractions were incorporated into both fresh and dry WSN. YAN firmness and chewiness increased with the addition of the fractions, likely due to the effect of the alkaline condition on the starch and the non-starch polysaccharides. Largely, the elevated levels of non-starch polysaccharides in the fiber-rich fractions influenced water absorption, cooking time and texture of the noodle admixtures. Differences in functionality can also be attributed to varying molecular size and structure of the non-starch polysaccharides.

Ideally, a high level of β-glucan is desired in the fiber-rich fractions material that can be added to noodles without negatively impacting its quality attributes. Both a high content and solubility of the BG in the fraction would be desirable for promoting the health benefits of this non-starch polysaccharide. Since it is not economically feasible at this time to extract β-glucan from barley, the fiber-rich fraction provides a concentrated source of these components in a form that can be incorporated into a variety of different food products. The resulting Asian noodles contained elevated levels of BG and AX. Incorporation of this grain and its components into food products provides a benefit to consumers due to its healthful components that are known to have a low glycaemic index response, reduce cholesterol and reduce the risk of cardiovascular disease and some forms of cancer.

This research provides insight into the increased possibility of using barley fractions in noodles, as a functional food ingredient. It also provides breeders with the information necessary to select for intrinsic quality attributes of HB that would be advantageous for this grain to be used in food applications. HB with variable starch amylose content can contribute to tailored textural properties of noodles while the increased content of BG and AX contribute to the nutritional benefits of the resulting product.

GENERAL DISCUSSION AND CONCLUSIONS

The results of these studies indicate that incorporation of HB milling fractions into white salted and yellow alkaline noodles result in products with altered colour and texture and increased content of dietary fiber. The addition of HB flour to either white salted or yellow alkaline noodles resulted in a decrease of brightness and yellowness of the noodles and an increase in redness. The colour of YAN was affected to a greater extent than the colour of the WSN, due to the effect of the alkaline medium. Barley fiber-rich fractions had a more pronounced effect on the appearance of both yellow alkaline and white salted noodles than the barley flour. Since WSN are commonly dried, and drying was found to arrest noodle darkening, the addition of barley fractions into dry WSN may have the most potential in the market.

Generally, addition of HB flour to Asian noodles decreased cooking time, water uptake and solid loss upon cooking. These phenomena were observed for both barley flour and barley fiber-rich fractions. Addition of waxy barley flour produced softer, less chewy WSN, whereas the addition of high amylose barley flour produced firmer and chewier WSN. Starch composition, more specifically the amylose content, had a significant effect on the texture of WSN. Generally, incorporation of barley flour to YAN, regardless of starch composition, resulted in firmer, and chewier cooked noodle texture. It appears, therefore, that the observed differences in texture between the control wheat noodles and those with the addition of barley cannot be explained solely by the differences in starch composition. Other components in barley, such as non-starch polysaccharides and phenolic compounds, might also affect the overall noodle texture especially under the alkaline conditions of YAN. In addition, a combination of high amounts of non-starch polysaccharides and unusual starch characteristics in HB seems to balance the negative effects associated with gluten dilution caused by addition of barley into wheat flour.

The findings of our studies indicate that HB flour can be incorporated into Asian noodles and results in products with altered appearance and modified textural parameters. Moreover, incorporation of barley fiber-rich fractions into noodles results in a functional product with a very high content of dietary fiber (2.3-3.0 grams of soluble β-glucan per 150 grams of fresh noodles). The fiber-rich milling fraction from HB provided an economically feasible source of concentrated β-glucans and other bio-active components. The fiber-rich fractions were significantly enriched in both arabinoxylans and β-glucans compared to the straight grade flours.

Additional research is needed to determine what intrinsic quality attributes of HB make it particularly suitable for food uses, and how we can accurately predict their functionality in food systems. The nutritional and functional characteristics of HB vary depending on genotype and require further investigation. Since barley addition to food products generally results in favourable or improved flavour, sensory and/or consumer acceptability testing of the noodles containing HB fractions should be evaluated. Further investigation is also required to determine how processing may alter the availability of the bio-active components in food products containing HB milling fractions.

With the growing awareness of beneficial effects of healthy diet on the quality of life and on cost effectiveness of health care, HB may become an attractive food grain grown on the Prairies. Hull-less barley contains many beneficial constituents with both functional and nutritional properties. Wider adoption of barley by food processors will increase the demand for barley and create opportunities for increased production of this grain. It is hoped that the results of this research will provide useful information that will add value to, improve and diversify utilization of Canadian HB. Hull-less barley fractions have promise as functional food ingredients thereby improving the healthful benefits of both non-traditional and traditional food products.

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APPENDIX 1.

RVA Starch Pasting Characteristics of Wheat Flour and of Hull-less Barley Flour[a,b]

	Peak viscosity	Through	Breakdown	Final viscosity	Setback	Peak time
Wheat Flour						
AC Vista	262.6 f	88.2 b	174.4 e	178.0 b	89.9 c	8.8 b
HB Flour Type / Variety						
Normal						
Falcon	374.3 c	116.6 a	257.7 d	246.4 a	129.8 a	8.8 b
SB90354	425.3 b	119.5 a	305.7 b	259.2 a	139.7 a	8.6 c
Waxy						
CDC Candle	503.7 a	70.4 cd	433.4 a	121.0 d	50.7 d	6.0 e
SR93135	496.8 a	73.4 c	423.4 a	129.7 d	56.3 d	6.1 d
Zero Amylose Waxy						
SB94792	359.1 d	77.4 c	281.7 c	125.1 d	47.7 d	6.0 e
CDC Alamo	343.4 e	76.5 c	266.9 d	121.6 d	45.1 d	6.1 de
High Amylose						
CDC-92-55-06-54	120.5 h	61.6 d	59.0 g	154.0 c	92.4 c	8.8 b
CDC-92-55-06-48	156.2 g	75.7 c	80.5 f	185.0 b	109.3 b	9.0 a

[a] Values are expressed in RVU units where 1 RVU = 12 centipose.
[b] Means followed by different letters in columns are significantly different @ $p = 0.05$.

APPENDIX 2.

RVA Starch Pasting Characteristics of 20% Hull-less Barley/Wheat Flour Blends[a,b]

	Peak viscosity	Through	Breakdown	Final viscosity	Setback	Peak time
Wheat Flour						
AC Vista	274.7 d	89.3 b	185.4 d	182.2 bc	92.9 bc	8.8 a
HB Flour Type / Variety						
Normal						
Falcon	302.3 b	98.8 a	203.5 b	198.8 a	100.0 ab	8.8 a
SB90354	313.4 a	101.5 a	211.8 a	203.1 a	101.5 a	8.8 a
Waxy						
CDC Candle	276.8 d	91.1 b	185.7 d	171.5 bcd	80.3 d	8.6 b
SR93135	286.0 c	91.1 b	194.9 c	171.4 bcd	80.3 d	8.6 b
Zero Amylose Waxy						
SB94792	247.0 fg	91.9 b	155.1 g	170.3 cd	78.4 d	8.7 b
CDC Alamo	244.1 g	90.3 b	153.8 g	167.4 d	77.1 d	8.6 b
High Amylose						
CDC-92-55-06-54	255.3 ef	88.8 b	166.5 F	182.9 b	94.0 bc	8.8 a
CDC-92-55-06-48	264.3 e	87.9 b	176.3 e	180.5 bc	92.6 c	8.8 a

[a]Values are expressed in RVU units where 1 RVU = 12 centipose.
[b]Means followed by different letters in columns are significantly different @ p = 0.05.

APPENDIX 3.

RVA Starch Pasting Characteristics of 40% Hull-less Barley/Wheat Flour Blends[a,b]

	Peak viscosity	Through	Breakdown	Final viscosity	Setback	Peak time
Wheat Flour						
AC Vista	278.9 e	95.1 bc	183.8 d	183.7 bc	88.5 b	8.9 ab
HB Flour Type / Variety						
Normal						
Falcon	327.8 b	101.8 ab	226.0 b	206.9 a	105.1 a	8.8 ab
SB90354	343.6 a	105.7 a	238.0 a	217.5 a	111.9 a	8.8 b
Waxy						
CDC Candle	301.8 d	92.5 bcd	209.4 c	159.8 de	67.3 c	8.2 c
SR93135	312.7 c	88.9 cde	223.8 b	158.3 de	69.4 c	8.1 c
Zero Amylose Waxy						
SB94792	232.3 g	82.7 e	149.6 e	144.9 e	62.2 c	8.1 c
CDC Alamo	232.6 g	83.0 de	149.6 e	146.5 e	63.5 c	8.1 c
High Amylose						
CDC-92-55-06-54	220.7 h	80.7 e	140.0 f	168.7 cd	88.0 b	8.8 ab
CDC-92-55-06-48	243.0 f	89.3 cde	153.7 e	190.1 b	100.9 a	8.9 a

[a]Values are expressed in RVU units where 1 RVU = 12 centipose.
[b]Means followed by different letters in columns are significantly different @ $p = 0.05$.

APPENDIX 4.

Correlation Coefficients Among 20% HB Blend Fresh Cooked WSN Textural Parameters

	MCS	RTC	CHEW	RES	R TIME
MCS	1.0000				
RTC	0.8835**	1.0000			
CHEW	0.9148**	0.9409**	1.0000		
RES	0.8184**	0.6972*	0.7727*	1.0000	
R TIME	0.9347**	0.8931**	0.9549**	0.9054**	1.0000

Statistically significant at *p=0.05, **p=0.01

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),
CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,
R TIME = Relaxation Time (s)

APPENDIX 5.

Correlation Coefficients Among 40% HB Blend Fresh Cooked WSN Textural Parameters

	MCS	RTC	CHEW	RES	R TIME
MCS	1.0000				
RTC	0.9747**	1.0000			
CHEW	0.9653**	0.9580**	1.0000		
RES	0.4287	0.4524	0.2212	1.0000	
R TIME	0.9767**	0.9754**	0.9198**	0.5839	1.0000

Statistically significant at *p=0.05, **p=0.01

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),
CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,
R TIME = Relaxation Time (s)

APPENDIX 6.

Correlation Coefficients Among RVA Starch Pasting Characteristics and Textural Parameters of White Salted Noodles Containing Hull-less Barley Flour.

	PV	BD	FV	SB
MCS	0.1018	0.0660	0.7386*	0.8489*
RTC	0.1123	0.0720	0.7811*	0.8910*
CHEW	0.1477	0.1170	0.8077*	0.9312*
RES	0.4141	0.3921	0.5291*	0.4767*
R TIME	0.3146	0.2908	0.8034*	0.8718*

Statistically significant at *p=0.05

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),

CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,

R TIME = Relaxation Time (s)

PV = Peak Viscosity, BD = Breakdown, FV = Final Viscosity, SB = Setback Viscosity

APPENDIX 7.

Correlation Coefficients Among Hull-less Barley Components and Textural Parameters of White Salted Noodles Containing Hull-less Barley Flour.

	Protein	Starch Amylose
MCS	-0.3581	0.5310
RTC	-0.2221	0.6278*
CHEW	-0.0957	0.7399*
RES	-0.7888*	-0.1828
R TIME	-0.3003	0.4954

Statistically significant at *p=0.05

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),

CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,

R TIME = Relaxation Time (s)

APPENDIX 8.

Correlation Coefficients Among 20% HB Blend Fresh Cooked YAN Textural Parameters

	MCS	RTC	CHEW	RES	R TIME
MCS	1.0000				
RTC	-0.2770	1.0000			
CHEW	-0.4462	0.8996**	1.0000		
RES	-0.6674*	0.3484	0.6102	1.0000	
R TIME	-0.7613*	0.6881*	0.8919**	0.8408**	1.0000

Statistically significant at *p=0.05, **p=0.01

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),

CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,

R TIME = Relaxation Time (s)

APPENDIX 9.

Correlation Coefficients Among 40% HB Blend Fresh Cooked YAN Textural Parameters

	MCS	RTC	CHEW	RES	R TIME
MCS	1.0000				
RTC	-0.0809	1.0000			
CHEW	-0.7085	0.7480	1.0000		
RES	-0.5554	0.7834	0.9383**	1.0000	
R TIME	-0.5574	0.8624*	0.9697**	0.9072*	1.0000

Statistically significant at *p=0.05, **p=0.01

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),

CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,

R TIME = Relaxation Time (s)

APPENDIX 10.

Correlation Coefficients Among RVA Starch Pasting Characteristics and Textural Parameters of Yellow Alkaline Noodles Containing Hull-less Barley.

	PV	BD	FV	SB
MCS	-0.2892	-0.2396	-0.7607*	-0.7730*
RTC	0.1445	0.1353	0.5258*	0.6089*
CHEW	0.1423	0.1391	0.6634*	0.8021*
RES	0.6332*	0.5941*	0.7637*	0.6584*
R TIME	0.3735	0.4129	-0.1445*	-0.2590

Statistically significant at *p=0.05

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),

CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,

R TIME = Relaxation Time (s)

PV = Peak Viscosity, BD = Breakdown, FV = Final Viscosity, SB = Setback Viscosity

APPENDIX 11.

Correlation Coefficients Among Hull-less Barley Components and Textural Parameters of Yellow Alkaline Noodles Containing Hull-less Barley Flour.

	Protein	Starch Amylose
MCS	0.3850	-0.3813
RTC	0.3559	0.7975*
CHEW	0.3080	0.9041*
RES	-0.5901*	-0.0579
R TIME	0.2417	-0.0676

Statistically significant at *p=0.05

MCS = Maximum Cutting Stress (g/mm^2), RTC = Resistance to Compression (%),

CHEW = Chewiness , TPA (g/mm), RES = Resilience, TPA,

R TIME = Relaxation Time (s)