EFFECTS OF CULTIVAR AND ENVIRONMENT ON QUALITY CHARACTERISTICS OF YELLOW ALKALINE NOODLES

By

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

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ABSTRACT

Canada Western Red Spring (CWRS) wheat is the most widely cultivated class of wheat in western Canada. The Asian market accounted for an average of over 50 % of the total CWRS wheat exported from 1989-1999. Currently, about 20-25 % of the CWRS wheat exported to Asia is used for noodle production, mainly for blending purposes to improve the processing, cooking or eating requirements of noodles, especially yellow alkaline noodles (YAN) (Bin Xiao Fu, personal communication; Chen, 1993). There is a growing interest from Asian clients in variety specific information as it relates to noodle production, but this information is not available. Therefore, a study was undertaken to determine the relative contribution of cultivar, environment, and their interaction on the quality of YAN made from four registered CWRS wheat cultivars grown at six environments (location and year) across western Canada. A second objective was to quantitate the differences among cultivars and among environments with regard to the characteristics of YAN. The relationship between flour and noodle properties was also investigated.

Although the variability of noodle characteristics among the cultivars was small, differences among them could still be observed for all the textural, color and speck characteristics examined, except for the L* values (brightness) of raw noodle sheets measured between 0 and 2 hr after processing and L* and b* (yellowness) values of cooked noodles. The cultivar AC Barrie demonstrated the poorest overall noodle making quality and was shown to be more responsive to changes in the environment for many of the noodle properties studied. The

CWRS composite sample from the year 2000 harvest was shown to have better noodle making quality than the individual cultivars, especially for maximum cutting stress (MCS), resistance to compression, gumminess, and speck characteristics. This might be due to the better grain quality and more optimum flour characteristics for the composite CWRS sample compared to the individual cultivars.

Cultivars grown in Melfort in 1999 produced YAN with higher MCS values than those grown in Swift Current in 1999 and Melfort in 2000 likely due to the higher protein and gluten contents and lower Rapid Visco Analyzer (RVA) pasting properties (except breakdown) found for their flour samples. Higher wet gluten content were associated with higher resistance to compression and gumminess values as was shown with noodles made from samples grown in Melfort in 1999 and Swift Current in 2000. Gumminess tended to increase with lower breakdown and higher final viscosity (SFV) and setback (SSB) values of flour pastes measured in silver nitrate solution. YAN produced from cultivars grown in Swift Current for both years had higher relaxation time values which were found to be related to the pasting properties of their flours, especially to SSF and SSB. Unlike the noodles made from the cultivars grown in Melfort in 1999 and in particular Glenlea in 2000, those made from Melfort in 2000 and Swift Current, especially for the year 1999, generally had better color and speck characteristics. Lower flour protein content and enzyme activities, especially peroxidase activity corresponded to better overall appearance of noodles. Flour

Agtron color was shown to be a good indicator of color and speck characteristics of noodles.

Location was the predominate effect influencing the quality of YAN. Cultivar by environment interaction effects were important to many of the noodle characteristics investigated as confirmed by the rank correlation results probably due to the small variations observed among the cultivars studied. Samples composited over growing environments may be suitable for screening breeding lines which possess greater genetic variations for some of the characteristics of YAN.

There appeared to be no advantage to use individual CWRS cultivars over the composite CWRS sample for the production of YAN. The quality of the composite sample for noodle production might be improved by eliminating cultivars such as AC Barrie and samples grown in Glenlea in 2000. Nevertheless, selection of cultivars by environment may be appropriate to meet specific needs of the customers. Environmental factors that affect noodle quality should be studied in future research. The effects of other starch properties, such as amylose content, flavones and phenolic compounds on the quality of noodles should also be examined as well as the relationship between instrumental and sensory measurements of noodle quality.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BD	Breakdown
CV	Coefficient of variation
CWRS	Canada Western Red Spring
FN	Falling number
FV	Final viscosity
GAA	Grain Amylase Analyzer
GRL	Grain Research Laboratory
HS	Holding strength
HVK	Hard vitreous kernels
MCS	Maximum cutting stress
MS	Minimum size threshold
PPO	Polyphenol oxidase
PSI	Particle Size Index
PV	Peak viscosity
REML	Restricted maximum likelihood
RTC	Resistance to compression
RVA	Rapid Visco Analyzer
SAS	Statistical Analysis System
SB	Setback
SBD	Breakdown measured in silver nitrate solution
SDS	Sodium dodecyl sulfate
SFV	Final viscosity measured in silver nitrate solution
SHS	Holding strength measured in silver nitrate solution
SPV	Peak viscosity measured in silver nitrate solution
SSB	Setback measured in silver nitrate solution
TPA	Texture Profile Analysis
WSN	White salted noodles
YAN	Yellow alkaline noodles

CHAPTER 1

INTRODUCTION

Noodles are traditional staple foods in many Asian countries. In Asia, more than 40 % of total wheat consumed is in the form of noodles (Chen, 1993). In particular, yellow alkaline noodles (YAN) are popular foods in Southeast Asia, Southern China, and Japan (Ross et al., 1997). The important quality characteristics of YAN determining their acceptability are texture, appearance and cooking properties. Regardless of differences in regional preference, good quality YAN should have a firm, chewy and elastic texture. It is not uncommon for raw YAN to be consumed 24 hr after production (Hatcher and Symons, 2000a), therefore in addition to a bright yellow color, raw YAN should develop minimal discoloration and specks during storage.

Previous work has found that both protein quantity and quality are important to the texture of YAN. Although not as extensively studied as the white salted noodles (WSN), the role of starch in relation to the eating quality of YAN has also been recognized by some researchers. In terms of color, protein content has been shown to affect the color of noodles, but the effect of enzymes, including polyphenol oxidase (PPO) and peroxidase activity on noodle color and speckiness remains unclear.

Hard-grained wheat varieties with potential for noodle production in specific Asian markets are being developed in Australia (Panozzo and Eagles, 1998) and the United States is testing wheat varieties grown in the Pacific Northwest for the Asian market. In Canada, hard white wheat varieties are under development to target the Asian market. However, these varieties are still in experimental stages and their production will not be able to meet the market demand for several years (Dave Hatcher, personal communication).

Among the seven classes of Canadian wheat, Canada Western Red Spring (CWRS) wheat is the most widely cultivated class of wheat in western Canada. CWRS is a hard wheat and is known globally for its superior breadmaking and milling quality. The 10-year (1989-1999) average of CWRS wheat exports has shown that Asia accounted for greater than 50 % of the market (Canadian Grain Commission, 1989/1990 to 1998/1999). Currently, about 20-25 % of the CWRS wheat exported to Asia is used for noodle production (Bin Xiao Fu, personal communication). Because of its strength but less bright color, CWRS wheat flour is mainly used for blending purposes to improve the processing, cooking or eating requirements of noodles, especially YAN (Bin Xiao Fu, personal communication; Chen, 1993). For example, in Japan, about 20-30 % of CWRS wheat flour is blended with the flour milled from the U.S. Hard Red Winter wheat and the Australian Prime Hard wheat for the production of YAN. Countries in Southeast Asia, such as Malaysia, Singapore, and Thailand also use CWRS wheat for blending purposes for the manufacturing of YAN.

Currently, most Canadian wheat is exported by class, which is composed of registered varieties or cultivars grown across western Canada. However, there is growing interest from Asian clients in variety specific information as it relates to noodle production. This information is currently not available.

Therefore, in order to remain competitive on the international market, it would be beneficial to examine the variety specific attributes of the CWRS wheat cultivars for their alkaline noodle making properties.

Evaluation of wheat varieties using samples composited over replicates and growing environments would lead to erroneous conclusions if there were a large cultivar by environment interaction effect. Therefore, the effects of cultivar, environment, and their interactions must be characterized and quantified in order to determine if cultivars vary in their noodle making properties. Previous studies have looked at the effects of cultivar, environment and their interactions on some of the flour characteristics that are related to noodle quality (Crosbie, 1989, 1991; Crosbie et al., 1992; Konik et al., 1994; Morris et al, 1997; Moss and Miskelly, 1984; Panozzo and Eagles, 1998; Park et al., 1997; Vazquez, 2000; Wang and Seib, 1996) and on other wheat characteristics, such as milling, physiochemical and breadmaking quality (Baenziger et al., 1985; Baker and Kosmolak, 1977; Fowler and de la Roche, 1975; Lukow and McVetty, 1991; Zhu and Khan, 2001). However, very few studies (Ames et al., 2000; Moss, 1971; Vazquez, 2000) have looked at the relative importance of cultivar, environment and their interactions on the visual characteristics of YAN and no studies have been done on the cooking and textural properties of YAN. The objectives of this study, therefore, were:

1) To determine the relative contribution of cultivar, environment and their interactions to the quality characteristics (cooking, texture, color and

appearance) of YAN prepared from CWRS wheat cultivars grown across western Canada.

2) To quantitate the differences among cultivars and among environments with regard to the quality characteristics of YAN made from five CWRS wheat cultivars grown in six environments across western Canada.
3) To investigate the relationship between grain and/or flour characteristics and the quality attributes of YAN.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

Common wheat (*Triticum aestivum* L.) is preferred to durum wheat (*Triticum turgidum* L.) for the production of Asian noodles. There are two major types of Asian noodles, WSN and YAN (Miskelly, 1983). The flour quality requirements, processing procedures, and desirable end-product quality characteristics, vary depending on the type of noodles being produced. Wheat flour components and characteristics play a major role in determining the quality of noodles. Studies that have been conducted with regard to noodles have recognized the relationship between flour components, both starch and non-starch (protein, enzymes, and pigments) and the texture and appearance of noodles.

Many major wheat exporting countries have been testing and developing wheat varieties that can produce noodles with desirable quality characteristics for the Asian market. It is well recognized that the characteristics of flour or wheat is influenced by the genetic made-up of the variety and its growing environment. However, very limited information exists on the contribution of genotype, environment and their interactions to noodle quality.

2.2 NOODLE TYPES AND FLOUR REQUIREMENTS

The basic ingredients of noodles are wheat flour, water and salt(s). There are two major types of wheat flour noodles, WSN and YAN (Miskelly, 1993). In Japan, WSN are usually made from soft wheat flour with medium protein content

(Nagao, 1996), whereas in other Asian countries, WSN are made from hard wheat with higher protein content. The salt used in WSN is sodium chloride. In contrast, YAN are made with hard wheat flour and a mixture of alkaline salts, such as sodium carbonate, potassium carbonate and sodium hydroxide (Nagao, 1996). Traditional Japanese WSN are made with flour milled at 60 % extraction rate, while 70 % is preferred for Chinese WSN (Huang and Morrison, 1988). The flour extraction rate used for making fresh YAN can range from 40 % in Japan to 75 % (straight run) in other Asian countries depending on the market (Bin Xiao Fu, personal communication). Most research studies on YAN use a 60 % patent flour (Akashi et al., 1999, Baik et al., 1995, Miskelly and Moss, 1985, Hatcher et al., 1999, Ross et al., 1997). Ash content for YAN can be as high as 1.4 % in China (Huang, 1996), whereas a lower ash content of 0.33 % - 0.45 % is more typical in Japan (Nagao, 1996).

2.3 NOODLE PROCESSING

Although traditional handmade noodles are still available, machine-made noodles are widely manufactured and accepted in most countries (Miskelly, 1993). Both machine-made WSN and YAN involve a similar production process which includes: 1) mixing of raw ingredients into a crumbly dough, 2) sheeting and rolling of noodle dough into noodle sheet with appropriate thickness, and finally 3) cutting of noodle sheet into raw noodle strands of desired width (Nagao, 1996).

Noodles can be sold fresh or furthered processed (drying, steaming, steaming and frying, or steaming and drying). YAN are mainly sold fresh to retail shops and restaurants and can be stored for up to one day before use (Kruger et al., 1994a; Miskelly and Moss, 1985). The most popular form of WSN is dried but fresh noodles are also sold in Japan (Crosbie et al., 1990).

2.4 CHARACTERISTICS OF HIGH QUALITY NOODLES

High quality noodles should have good cooking properties and more importantly, have good end-product appearance and eating quality. Good cooking properties of noodles include short cooking time, high tolerance to over-cooking, retention of size and shape, high cooking yield and low cooking loss (Chen, 1993). Good end-product quality characteristics for both WSN and YAN refer to their color, surface appearance and texture. Surface smoothness in terms of both visual and mouthfeel characteristics is important for both WSN and YAN. A creamy white color, and soft but elastic texture is preferred for boiled Japanese WSN, but a firmer texture is preferred in Northern China (Huang and Morrison, 1988). For YAN, a bright yellow color with minimum specks or discolored spots and a firmer and more elastic texture than WSN is favored (Crosbie et al., 1990; Nagao, 1996).

2.5 EFFECTS OF ALKALINE SALTS ON COLOR OF YAN

The effect of different combination of salts (all at 1 % level) on the yellow color of YAN made from Canadian Western Red Winter wheat was studied by

Kruger et al. (1992). Their results showed that when compared to other kansui (alkaline solution) formulations, NaOH solution produced YAN with a higher intensity of yellowness as measured by the HunterLab colorimeter and the color was the slowest to degrade over time. On the other hand, the greatest decrease in yellowness at 24 hour after production was observed with YAN made from kansui solution at the 1:1 ratio of sodium to potassium hydroxides. Moss et al. (1986) noted that increased potassium in the formulation resulted in raw YAN with a greenish tinge which is undesirable. This might explain why most researchers use a higher percentage of sodium carbonates than potassium carbonates (most commonly at a ratio of 9 to 1) for preparation of YAN (Baik et al.,1994, 1995; Huang and Morrison, 1988; Miskelly, 1984; Kruger et al., 1992).

2.6 FLOUR COMPONENTS INFLUENCING NOODLE QUALITY

2.6.1 Starch

Starch is the major component of wheat flour, comprising 70-80 % of the dry matter (Batey et al., 1991). Amylose and amylopectin are the two major carbohydrates of starch. The absorbance value per 20 mg of sample (dry basis) at 625 nm was used to express the amylose content of starch fractions in a fractionation and reconstitution study by Toyokawa et al. (1989). Their data showed that increasing levels of amylose content increased the firmness, but decreased the elasticity of cooked Japanese WSN. Starches with high amylose content, indicated by the absorbance values of 0.7 and 0.9 at 625 nm, corresponded to poorer texture of WSN due to their tight and rigid structure. In contrast, low amylose starches with an absorbance value of 0.1 at 625 nm (thus approximately 100% amylopectin) resulted in noodles that were very viscous and sticky. The data suggested that an optimum amylose/amylopectin ratio was necessary for good noodle quality.

Upon heating with water, starch granules expand and a paste with increasing viscosity is formed. Upon cooling, the paste is set and a gel is formed (Batey et al., 1991). Studying the change in weight (swelling power), volume (swelling volume) or viscosity (amylograph or Rapid Visco Analyzer (RVA) parameters) of a starch, flour, or wholemeal paste with heat has revealed the importance of starch on the eating quality of noodles. In general, fewer studies have been done to determine the role of starch in YAN than in WSN.

Swelling tests using starch, flour or wholemeal have been extensively correlated with the eating quality of WSN (Baik et al., 1994; Crosbie, 1991; Crosbie et al., 1992; Konik et al., 1990, 1993; McCormick et al., 1991; Toyokawa et al., 1989; Yun et al., 1996) and YAN (Baik et al., 1994; Crosbie et al., 1999; Konik et al., 1994; Ross et al., 1997) as determined by sensory evaluation. For YAN, the swelling power of starch, flour or wholemeal, and the swelling volume of flour have been significantly negatively correlated with firmness and positively with smoothness (Konik et al., 1994; Ross et al., 1997). Ross et al. (1997) found that the relationships of flour swelling volume with firmness and smoothness of YAN improved when flour swelling volume was measured in sodium carbonate solution, an alkaline medium, instead of water alone. Similarly, Crosbie et al. (1999) also found stronger relationship between the total texture scores of YAN (the balance between springiness, firmness, smoothness, and cutting feel) and flour swelling volume when measured in 0.5 mM $AgNO_3$. Unlike firmness and smoothness, only wholemeal swelling power ($r = -0.47$, $P < 0.05$, Konik et al., 1994) and flour swelling volume ($r = -0.78$ without alkaline salt and $r = -0.81$ with alkaline salt, $P < 0.001$, Ross et al., 1997) have been found to be significantly related to the elasticity of YAN.

The amylograph is traditionally used to study starch pasting properties in relation to noodle characteristics, especially for WSN (Baik et al., 1994; Crosbie, 1991; Konik et al., 1992; Konik and Moss, 1993; Miskelly and Moss, 1985; Oda et al., 1980; Panozzo and McCormick, 1993). Amylograph peak viscosity of starch and flour pastes have been shown to be positively correlated with softness, elasticity and total eating quality of WSN (Crosbie, 1991; Konik et al., 1992; Konik and Moss, 1993; Panozzo and McCormick, 1993). These textural characteristics of WSN were also found to be correlated with amylograph pasting temperature, holding strength, breakdown, final viscosity, and setback (Konik et al., 1992; Konik and Moss, 1993). With regard to YAN, Miskelly and Moss (1985) found that the amylograph peak viscosity time of the starch slurry to be correlated with eating quality ($r = 0.36$, $P = 0.01$), but only for one of the four groups of wheat samples which were grown in different seasons. In general, a relatively lower starch paste viscosity value, but not as a result of high alpha-amylase activity, is preferred for YAN as opposed to WSN (Miskelly and Moss, 1985; Panozzo and Eagles, 1998). Baik et al. (1994) reported that unlike protein, starch properties assessed by swelling power and amylograph had little relationship with the textural properties of noodles determined by the texture profile analysis (TPA) using a Instron Universal Testing Machine. They suggested the starch characteristics may be less important to YAN than WSN.

Although the RVA was originally developed to evaluate the degree of sprout damage in wheat (Ross et al., 1987), it has been adopted to assess the pasting viscosity of starch, flour or wholemeal in relation to noodle quality. A RVA plot illustrating its parameters is shown in Figure 2.1. The parameters obtained from a RVA curve are similar to those of the amylograph and they are: peak viscosity (PV), highest viscosity during 95 °C heating stage; holding strength (HS), lowest viscosity at end of 95 °C heating stage; breakdown (BD), difference between PV and HS; final viscosity (FV), highest viscosity at the 50 °C cooling stage; and setback (SB), difference between FV and HS (Konik et al., 1994).

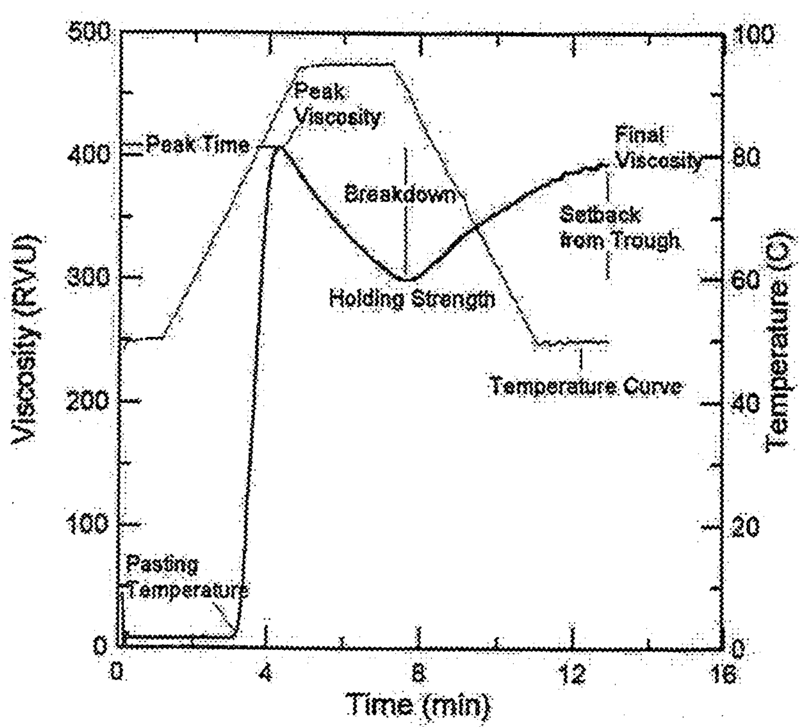

Figure 2.1. Rapid Visco Analyzer pasting curve and parameters.

Panozzo and McCormick (1993) found that the peak viscosity values obtained from RVA and amylograph were highly correlated. Similarly, several studies have shown that most RVA parameters are highly correlated with the swelling test results for both WSN (Konik et al., 1990; McCormick et al., 1991; Yun et al., 1996) and YAN (Ross et al., 1997). Important advantages of the RVA over the amylograph are that it requires a much smaller sample size and shorter analysis time. Compared to the swelling tests, the RVA method is an easier test to perform and it produces more parameters and information (Konik et al., 1990,1993; Panozzo and McCormick, 1993).

Many workers have used RVA to determine the pasting properties of starch or flour and their relationships with the textural properties of YAN. Konik et al. (1994) found that except for PV, all other RVA parameters, especially FV (flour) were significantly ($P < 0.001$) correlated with the smoothness ($r = -0.66$) and firmness ($r = 0.66$) of YAN. They found that the corresponding RVA parameters of flour, starch and wholemeal were all correlated with each other, except for the PV of starch with flour or wholemeal. Ross et al. (1997) also found FV (flour) to be the best predictor of smoothness and firmness of YAN. Unlike the results of Konik et al. (1994), Ross et al. (1997) observed significant relationships between elasticity of YAN and RVA parameters, especially FV ($r = 0.59$, $P < 0.001$). They also found that when RVA parameters were measured in an alkaline condition (3.125 % sodium carbonate solution, w/v) to inactivate alpha-amylase instead of distilled water, better relationships were found between PV and textural characteristics. However, most workers have used $AgNO_3$ as the treatment to inactivate alpha-amylase (Batey et al., 1997; Bhattacharya and Corke, 1996; Crosbie and Lambe, 1993). Similar to Ross et al. (1997), Crosbie et al. (1999) using 1 mM $AgNO_3$ solution to examine flour RVA parameters also observed improved correlations with the total noodle score (sensory) compared with RVA parameters measured in distilled water alone. They found that in the presence of $AgNO_3$, PV ($r = -0.71$) and BD ($r = -0.78$) were the best predictors of total noodle score ($P \leq 0.01$). Therefore, the authors concluded that in order to determine the inherent pasting properties of flour, the effects of alpha-amylase should be inactivated.

2.6.2 Protein

2.6.2.1 Protein and noodle texture

The quantity and quality of protein have been shown by many researchers to be the major factors influencing the texture of YAN. Sensory firmness and hardness of YAN and maximum cutting stress (MCS) measured using the Instron have been positively correlated with both protein content (Miskelly and Moss, 1985, Moss et al., 1987, Shelke et al., 1990; Ross et al., 1997) and protein quality as measured by dough strength and sodium dodecyl sulfate (SDS) sedimentation volume (Baik et al., 1994; Huang and Morrison, 1988; Miskelly and Moss, 1985; Ross et al., 1997). Protein content and dough strength have also been found to be positively related to the elasticity of YAN as assessed by trained sensory panels (Miskelly and Moss, 1985; Ross et al., 1997). However, noodle surface smoothness (sensory) has been negatively associated with protein content (Moss et al., 1987; Ross et al., 1997) and protein quality (Ross et al., 1997). This phenomenon can be explained by the fact that a longer cooking time is required for noodles made from high protein content flour due to slower water penetration into the core of noodles. Oh et al. (1985b), through the use of scanning electron microscopy, showed that noodle sheets with high protein content had a tighter structure, presumably due to stronger adherence between starch and protein. Thus, while increased protein can improve the firmness and elasticity of YAN, the smoothness of the noodles will be compromised.

The relative importance of protein quantity and quality on noodle textural characteristics has been addressed by some researchers. Moss (1971) found that the varietal differences of protein quality (farinograph and mixograph) were slight when compared with the effect of protein content. While both Huang and Morrison (1988) and Baik et al. (1994) have shown that protein quality as measured by SDS sedimentation volume had a stronger relationship with noodle texture (MCS and TPA, respectively) than protein content, the opposite has been observed by Ross et al (1997) who measured noodle texture by sensory evaluation. This could be due to the fact that a much wider range of SDS sedimentation volumes were observed in the samples from Huang and Morrison and Baik and colleagues' studies leading to a greater emphasis of protein quality. Huang and Morrison (1988) reported that protein content is likely to have a large influence on noodle quality when the noodles are prepared from flour samples with similar protein quality.

2.6.2.2 Protein and noodle color

Brightness of raw noodle sheets is known to be inversely related to protein content and flour-grade color (Kent-Jones and Martin Colour Grader) (Baik et al., 1995; Konik et al., 1993; Miskelly, 1984; Miskelly and Moss, 1985; Moss, 1971). However, the relationship between protein content and noodle brightness has been shown to be insignificant after the noodles had been boiled, presumably due to the melanins and pigments dissolved in the cooking water, which was nevertheless undesirable (Miskelly, 1984). Baik et al. (1995) also found that a* value (red or green discoloration) of alkaline noodle sheets measured at 75 hr after preparation was positively related to protein content.

2.6.3 Enzymes

2.6.3.1 Alpha-amylase

Alpha-amylase attacks the 1,4-linkages along the chains of amylose and amylopectin, except on or adjacent to the 1,6-linked glucose units. The composition of the alpha-amylase digestion products may alter the starch paste viscosity (Batey et al., 1991). Therefore, sprout damaged wheat which has an elevated level of alpha-amylase will change the suitability of the flour for noodle production. Wheat starches with a high paste viscosity, which is associated with good noodle making quality for WSN, usually have relatively small amounts of oligosaccharides of degree of polymerization of 5 or greater in their alpha-amylase digest (Batey et al., 1991).

The falling number (FN), amylograph, and RVA apparatus are commonly used to evaluate the amount of sprout damage in wheats based on the viscosity of the starch or flour slurry during heating. The more viscous the gelatinized starch paste or flour paste, the less alpha-amylase activity presents in the grain indicating grain soundness.

Edwards et al. (1989) found that noodles, both WSN and YAN, made from sprout damaged wheat flour (FN values ranged from 68 to 169 sec) were darker than those made from their sound controls (FN values ranged from 203 to 282 sec). On the other hand, Kruger and Hatcher (1995) using CWRS wheat samples observed that flour with FNs as low as 85 sec did not adversely affect FY sedimentation volumes, which are influenced by flour protein content and dough stability. Since noodle texture is affected by flour protein characteristics, the results of the latter study suggested that unlike color, the texture of noodles made from sprout damaged wheat should be comparable to that of the sound wheat.

The Grain Amylase Analyzer (GAA) is a nephelometric method for determining alpha-amylase activity. It measures the change in light scattering of a beta-limit dextrin substrate as its turbidity decreases when degraded by the alpha-amylase extracted from flour or wholemeal sample (Asp, 1990; Kruger and Tipples, 1981). Unlike the other methods mentioned, the GAA method can differentiate very small amounts of alpha-amylase activity.

2.6.3.2 Polyphenol oxidase

PPO is an enzyme that occur widely in plants and is responsible for browning reactions in many food systems. PPO exists in the forms of diphenolase (1.10.3.1) or monophenolase (1.14.18.1) (International Union of Biochemistry and Molecular Biology, Nomenclature Committee, 1992). PPO activity depends on the availability of phenolic compounds. While diphenolase oxidizes both mono- or di- phenols, monophenolase only oxidizes monophenols. Both types of PPO activity oxidize phenolic compounds to the corresponding di-benzo quinones (International Union of Biochemistry and Molecular Biology, Nomenclature Committee, 1992) which through polymerization and interaction with protein produces the dark colored melanins (Miskelly, 1984). Therefore, PPO activity is believed to be responsible for the undesirable darkening of many wheat products, including Asian noodles.

Both PPO and phenolic acids are mainly located in the aleurone and bran layers (Marsh and Galliard, 1986). Therefore, as expected, wheat bran has the highest PPO activity followed by wholemeal and white flour which contains relatively low levels (Marsh and Galliard, 1986). Higher extraction rate flour which contains more bran materials produces noodle sheets with lower degree of brightness (Miskelly, 1984; Oh et al., 1985b) and more specks or discolored spots (Kruger et al., 1994a). Hatcher and Kruger (1993) observed that extraction rates higher than 70% led to a dramatic rise in PPO activity. Therefore, noodles should be made from flours with extraction rate no greater than 70%.

McCallum and Walker (1990) found that PPO level correlated with estimated total soluble phenolics in New Zealand wheat millstreams using the Folin-Denis assay. Hatcher and Kruger (1997), through the use of the reversed-phase high performance liquid chromatograph identified the major phenolic acids in pooled millstreams of the five classes of Canadian wheat. Their results showed that insoluble bound ferulic acid, individual soluble esterified acids, and most free phenolic acids were positively correlated to PPO activity.

Hatcher and Kruger (1997) using pooled millstreams from five classes of Canadian wheat milled to varying extraction rates found that ash content (except for Canada Western Extra Strong wheat class) and Kent-Jones flour color grade were positively related to PPO activity. Ash content and Kent-Jones flour color grade were also found to be correlated with the individual insoluble, soluble esterified, or free phenolic acids presented in the individual wheat class flours. In addition, insoluble ferulic acid, the only detectable insoluble phenolic component in all five wheat classes, was found to have a negative relationship with Agtron readings. Thus, flour ash content and color grade determined by the Kent-Jones or Agtron methods appear to be the relative indicators of PPO activity and should be taken into the account when studying the quality of noodles.

PPO activity can be determined by spectrophotometric method which measures the colored products formed from various diphenol substrates using aqueous extracts of plant material (Marsh and Galliard, 1986). However, this method only detects enzyme activities that are readily extractable into an aqueous media. Unlike the spectrophotometric assay which requires the use of optically clear enzyme extracts, the oxygen-electrode method uses suspensions of plant materials, such as wholemeal or flour, thereby allowing both the extractable and particulate PPO activity to be detected (Marsh and Galliard, 1986). Marsh and Galliard (1986) found that catechol, a diphenol, is the most suitable substrate for the oxygen-consumption method. Since oxygen is required for PPO activity, the rate of oxygen consumed measured by the oxygen-electrode method, will be proportional to the amount of enzyme (Kruger et al., 1994b; Marsh and Galliard, 1986). Thus, this method is very useful for comparing the relative PPO activities of wheat samples, such as wholemeal, flour, or wheat milling fractions.

The effect of PPO activity on the color of noodles has been examined. Kruger et al. (1994b) found that PPO activity in both wheat and flour had a strong positive relationship with the rate of change in brightness (L*) and yellowness (b*) of alkaline noodle sheets. Sprout damaged wheat which has elevated level of PPO (Kruger, 1976) has been reported to produce both YAN and WSN with decreased L* and increased a* (red-green scale) values as measured by the Minolta colorimeter and sensory evaluation (Edwards et al., 1989). Similarly, Baik et al. (1995) found that the a* value of alkaline noodle dough measured at 75 hr after preparation was positively related to PPO activity. However, Baik et al. (1995) reported that the relationship between PPO activity (flour or grain) and brightness of raw YAN was inconclusive depending on the population or class of wheats studied. The study of Hatcher et al. (1999) involving two cultivars from the Canadian Prairie Spring White wheat class found that the differences in brightness (L*), redness (a*) and mean darkness of specks of the alkaline noodle sheets made from the two cultivars were not attributed to their differences in flour PPO activity. They concluded that the time-dependent darkening of the discolored spots in noodle sheets were likely originated from bran contamination in the flour but were not entirely enzyme-dependent.

2.6.3.3 Peroxidase

Peroxidase is also believed to be involved in the time-dependent darkening of raw noodles. Similar to PPO, peroxidase oxidizes phenolic compounds to quinones. However, peroxidase activity only occurs in the presence of hydrogen peroxide. Peroxidase has been found to be more heat stable than PPO (Bucheli and Robinson, 1994). Kruger and LaBerge (1974b) demonstrated that only 50 % of the peroxidase activity in wheat extracts was lost after the heat treatment at 70 ^{o}C for 15 minutes.

Like PPO, peroxidase is higher in wheat bran than in flour (Kruger and Reed, 1988) even though peroxidase levels decrease in the bran layer and increase in the aleurone, endosperm, scutellum, and embryo as the wheat kernel matures (Kruger and LaBerge, 1974a). Germinated wheat kernels also show increased peroxidase activity (Kruger and LaBerge, 1974b).

Very few researchers have examined the role of peroxidase on wheat and wheat end products. Kobrehel et al. (1972) obtained a high correlation between macaroni brownness and peroxidase activity for various durum semolinas. Edwards et al. (1989) determined the peroxidase activity of some Australian wheat flour samples which were made into wheat based products, including noodles, but the effect of peroxidase activity on the quality of those products were not discussed. More research is required in this area to elucidate the effects of peroxidase activity on noodle quality.

2.6.4 Pigments

The major naturally occurring pigments present in wheat that are responsible for the yellow color of noodles are carotenoids, principally xanthophylls, and flavonoids. The creamy-yellow color of flour is attributed to xanthophylls which are located in the endosperm and germ tissue of wheat (Hoseney, 1994). Flavones are also linked to the germ and endosperm. However, they only develop yellowness in alkaline conditions. In contrast to flavonoids, xanthophylls are water insoluble pigments which can be extracted with organic solvents (Kruger and Reed, 1988). Wang (1998) has isolated the major pigments of flours from some Australian wheat cultivars. He reported that the creamy-yellow color of WSN is mainly attributed to xanthophylls, whereas flavonoids were the major contributor to the yellow color of YAN.

Miskelly and Moss (1985) found that straight-grade flours produced raw noodles that were more yellow, but duller than those prepared from patent flours. Some researchers did not find brightness and yellowness of YAN to be related (Moss, 1971), a later study found the opposite (Miskelly and Moss, 1985).

2.7 METHODS FOR MEASURING NOODLE QUALITY

2.7.1 Instrumental Texture Methods

The Instron Universal Testing Machine has been used extensively by many researchers to measure the textural characteristics of cooked noodles. Oh et al. (1983) used the Instron to test the cooked texture of WSN using a series of cutting and compression tests. Three strands of cooked noodles were cut or compressed across their long dimensions. They found that MCS (peak height divided by the blade contact area, g/mm^2) obtained from the cutting curve was significantly correlated with sensory scores for firmness ($r = 0.89$). As well, both resistance to compression (RTC, retained thickness divided by the difference between initial thickness and the compressed distance times 100, %) and recovery (distance recovered divided by the distance of compression times 100 %) obtained from the compression curve were found to be significantly ($r = 0.85$, 0.88, respectively, $P < 0.01$) correlated with sensory scores for chewiness. Based on the fact that RTC was more convenient to determine than recovery and that MCS and RTC correlated well with firmness and chewiness, respectively, the author recommended the use of MCS and RTC as the preferred instrumental measures of noodle texture.

Baik et al. (1994) used the TPA (a force-time curve) test to measure the textural properties of WSN, YAN and instant noodles made from both soft and hard white spring wheats from the US. The TPA test involves a two-cycle compression which determines a number of textural parameters including hardness (peak height), springiness (recovered height after first compression), adhesive force (negative force between the first and second peak), cohesiveness (the area of the second peak divided by the area of the first peak), gumminess (hardness times cohesiveness) and chewiness (gumminess times springiness). The results were reproducible among replicates, except for adhesiveness due to variability in surface conditions of the test fixture and the cooked noodles. TPA parameters were found to vary considerably among the cultivars tested. Noodles made from higher protein (13-14 %) cultivars had higher scores for hardness, cohesiveness, gumminess, and chewiness than those made from lower protein (10-11%) cultivars. However, the starch properties assessed by swelling power and amylograph appeared to have little relationship with the TPA parameters. The authors concluded that compared to WSN, the role of starch on the texture of YAN may be less important. It should be mentioned that the relationship between TPA parameters and sensory properties of cooked noodles were not determined thereby limiting the validity of using the TPA test to describe the textural properties of noodles.

Sopiwnyk (1999) assessed the texture of cooked spaghetti made from durum wheat cultivars varying in gluten strength using the Lloyd Texture Testing Instrument. Stress relaxation tests were performed on nine strands of cooked spaghetti placed on a grooved plexiglas baseplate. The strands were compressed using a flat plexiglas plunger to a fixed load of 8.0 N. They were then allowed to relax at constant deformation until 85 % of the maximum load was reached (6.8 N). Relaxation time, the time (sec) required to reduce the load from 8.0 N to 6.8 N was obtained from the relaxation curve. Results showed no significant differences among cultivars for relaxation time. However, overcooking resulted in decreased values for relaxation time. There were no significant relationships between relaxation time and any of the sensory parameters measured, including springiness, firmness, chewiness, breakdown, and adhesiveness to teeth. The author explained that this lack of relationships between instrumental and sensory measurements of cooked pasta texture was most likely due to the narrow range in cooking quality present in the spaghetti samples. On the other hand, Malcolmson (1991) studying the effects of drying temperature, durum protein level and farina blending on spaghetti quality found that relaxation time was correlated with sensory elasticity ($r = 0.84$) and sensory chewiness ($r = 0.84$).

2.7.2 Assessment of Color

The Hunterlab and the Minolta colorimeters have been used to measure the color of noodles. Both instruments measure color based on an opponent color system of the CIE-Lab L^*, a^* and b^* which denote the white-black (brightness), red-green, and yellow-blue color scales, respectively. L^* value ranges from 0 to 100 with increasing value indicating brighter color. Positive a^* and b^* values indicates redness and yellowness, respectively and a zero a^* value indicates a gray color (Baik et al., 1995; Hatcher et al., 1999).

2.7.3 Assessment of Specks

The major limitation of the CIE-Lab L*, a* and b* values for assessing noodle color is that it only measures the color of the overall matrix of a noodle surface. Discolored spots or specks localized throughout the noodle which are often observed and are deleterious to noodle quality cannot be identified using the this method. As a result, Hatcher et al. (1999) adapted the image analysis systems originally designed to detect bran specks in flour (Evers, 1993) to detect, quantitate and characterize (size, darkness and darkness distribution profile) the localized discolored spots on or below the noodle sheet surface over time. In their experiments, raw noodle sheet images which were captured using a color camera, or currently a scanner, interfaced to a computer were analyzed using two variables: Δ gray and minimum size threshold (MS). A Δ gray value is the minimum darkness that a discolored spot or speck must exceed from the background noodle matrix to be identified. A MS value is the minimum size of a speck to be detected. These two variables are used to determine the number and the area density (darkness) of discolored spots or specks of raw YAN sheets over time. The spots are measured on a 0-255 gray level scale with a higher number indicating the speck is less dark (Hatcher and Symons, 2000c).

Using the imaging systems, Hatcher et al. (1999) found that the discolored spots of the raw noodle sheets made from the two cultivars, AC Karma and AC Vista from the Canadian Prairie Spring White wheat class followed a similar darkening pattern. The most rapid darkening was observed within the first hour, possibly as a result of changes in water distribution within the noodle matrix

(Kruger et al., 1992). This was followed by a relatively stable period before a further significant increase by 24 hr. Also, there were significant differences in the number and size of discolored spots between the two cultivars but only after and at 24 hr, respectively. As well, in accordance with their noodle brightness (L*) values, differences between the two cultivars were found in the darkness distribution profiles of their discolored spots. Thus, image analysis systems appear to be a promising tool in studying the differences in noodle appearance, in particular speckiness among cultivars within the same class. Other studies involving image analysis systems have looked at the effect of flour refinement, sprout damage and noodle type on the discolored spots of noodle sheets made from both white and red seed coat Canadian wheats (Hatcher and Symons, 2000a, b, c).

2.7.4 Sensory Methods

The most important and common parameters for assessing the quality of noodles appear to be softness/firmness, elasticity and smoothness (Miskelly and Moss, 1985; Moss et al., 1987; Ross et al., 1997; Yun et al., 1996). Chewiness is also important for YAN. Overall eating quality is determined by adding the scores of individual textural parameters. As well, total noodle score which is the sum of the overall eating quality and color (brightness and yellowness) scores as measured by sensory panels has also been used by many researchers as an index of overall noodle quality (Konik et al., 1990, 1993, 1994; Yun et al., 1996).

2.8 EFFECTS OF GENOTYPE, ENVIRONMENT, AND THEIR INTERACTIONS

Different wheat varieties or cultivars may vary in their properties due to differences in their genetic made-up (genotypic or cultivar effects) and growing environments (location and year effects). Quality evaluation of wheat properties often involves a large number of samples and tests that are time-consuming and expensive. The number of samples to be evaluated may be reduced by compositing over replicates, locations, or years. However, this practice would reduce the precision of the results and lead to inaccurate conclusions if there were large interactions between cultivar and environment for the quality parameters measured (Lukow and McVetty, 1991). As a result, the relative effect of genotype, environment and genotype by environment interaction should be studied to ensure the quality characteristics of different cultivars are adequately assessed. Previous workers have studied the influence of genotype, environment and their interactions on some of the flour characteristics of wheats. Moss and Miskelly (1984) using several Australian cultivars grown across several regions of Australia over three years found significant cultivar and environment (location and season) effects on amylograph peak starch paste viscosity but the interaction effects between cultivar and location or season were not significant. In contrast, Panozzo and Eagles (1998) studying both soft and hard-grained Australian wheats grown in nine environments over 2 years observed that genotype, environment and their interaction effects were all significant for PV of starch paste measured using the RVA. The authors also reported that the environmental variation was not related to the high temperature of the growing environment. Significant genotype and environment effects also have been observed for various swelling tests (Crosbie, 1989, 1991; Konik et al., 1994; Wang and Seib, 1996). Flour swelling volumes of some of the Australian and U.S. wheat cultivars have been found to have high genotype and crop years effects, slight location effect and small genotype by location interactions (Crosbie et al., 1992; Morris et al., 1997). Thus, these results suggest that genotype by environment interactions on starch properties are relatively unimportant in Australian and U.S. wheat cultivars.

Previous studies have looked at the milling and baking quality of U.S. wheat cultivars. Baenziger et al. (1985) examined the quality of soft red winter wheats grown in southeast U.S. Cultivar, environment and their interaction effects were highly significant for all the parameters measured (flour yield, grain protein content, particle size index (PSI) and alkaline water retention capacity). Variance components revealed that while environment was the main effect influencing grain protein percent and alkaline water retention capacity, cultivar was the main effect influencing PSI. The authors also found that except for grain protein percent, the cultivar means of other characteristics from an environment were highly correlated ($r = 0.82$ to 0.95) with the regional cultivar means. Therefore, they concluded that single environment testing should be sufficient for preliminary evaluation of these quality parameters. A recent study by Zhu and Khan (2001) involving the U.S. hard red spring wheats grown in several locations within North Dakota studied the effects of cultivar and environment on glutenin polymeric proteins and breadmaking quality. Significant cultivar, environment and cultivar by environment effects were observed for all of the characteristics examined. They also found that environment had a greater contribution to flour protein content and SDS-soluble glutenin content than cultivar, while the opposite trend was observed for SDS-insoluble glutenin content. As well, the contribution of the cultivar by environment interaction effect was relatively small compared to the cultivar effect for flour protein content and SDS-insoluble glutenin which were also found to be highly correlated with bread loaf volume.

Several studies have looked at the effect of cultivar, environment and their interactions on the characteristics of Canadian wheats. Fowler and de la Roche (1975) examined physical, chemical and rheological characteristics of Canadian spring and winter wheats grown in Eastern Canada. They found significant cultivar variability for most of the characteristics measured and that environment had a large effect on yield, protein and protein related parameters. They also reported that more genetic variability was found in the spring wheat trials than the winter wheat trials. The cultivar by environment (year or location) interaction effects were relatively unimportant for kernel hardness, dough development and protein content which are the basic parameters related to baking quality of wheat (De La Roche and Fowler, 1975). Another study by Baker and Kosmolak (1977) studied the milling and baking quality in hard red spring wheats that had been composed from different geographic areas within western Canada. The important findings were that genotype by environment interactions were important for mixograph development time, falling number and remix loaf volume, less important for farinograph absorption, and least important for flour protein and sedimentation value. However, the use of composites would have obscured the genotype by environment interactions if they existed. Lukow and McVetty (1991) also evaluated milling, physiochemical (such as protein content, sedimentation value and starch damage) and baking qualities (such as mixograph development time, farinograph dough development time and remix loaf volume) of some spring wheat cultivars of both Canada and U.S. origins grown in locations within Manitoba. Their results indicated that cultivar (the dominant effect) and environment effects (except for flour yield and farinograph dough development time) were significant for all of the parameters studied. Also, the cultivar by environment effects were significant but the variance components and rank correlations results indicated that the interaction effects were relatively small in magnitude and unimportant for most of the parameters except for test weight and thousand kernel weight.

Similar studies have also been done on grain and flour PPO activity. Park et al. (1997) studied the PPO activity in two sets of wheat samples which included several populations of hard white winter lines and ten hard red winter cultivars. They found that growing location had a greater effect than genotype on grain PPO activity for the hard white winter lines and on flour PPO activities for both sets of samples. The authors also observed significant interactions between population and location on both grain and flour PPO activities in the hard white experimental lines studied. However, genotype by location interaction ($P > 0.01$) was found to be not significant for both sets of wheats. A similar study done by Vazquez (2000) involving 17 breeding lines (double haploid lines including red and white kernel genotypes) grown in several locations across western Canada over 2 years found that for the genotypes examined, two distinct populations of PPO activity could be observed. The genotype effects were divided into two main categories, namely kernel color and PPO group. For grain PPO activity, though all of the effects were significant, the predominant effect was genotype (mainly due to PPO group) which accounted for 80 % of the total variation. Unlike grain PPO activity, environmental influence was slightly higher than genotypic influence and that genotype by environment interactions were not significant on flour PPO activity.

Very little information is available on the relative effects of genotype, environment and their interactions on the quality of noodles. An early attempt to investigate this issue was done by Moss (1971) regarding the brightness and yellowness (visually ranked shortly after preparation) of raw YAN prepared from flour samples of six Australian wheat cultivars grown in two locations. The author observed that while environment effects were significant for both the brightness and yellowness of YAN, cultivar effect was only significant for yellowness and that cultivar effect ($P < 0.01$) was more significant than location effect ($P < 0.05$) for yellowness. Moss also found significant cultivar by location effect on yellowness of raw YAN but not on brightness. The study by Vazquez (2000) described previously also investigated the discoloration (change in brightness or L^* from 0 to 24 hr) of white salted and alkaline noodle sheets. His results indicated that although both genotype and environment effects were significant, the environment effects were much greater than that of the genotype effects on discoloration for both noodle types. Genotype by environment interactions on discoloration were significant for alkaline noodle sheets only but in a small magnitude compared to the environment effect. Ames et al. (2000) examined the brightness (L*) and yellowness (b*) of both white salted and alkaline noodle sheets made from both Canadian and Australian wheat genotypes grown in several locations within western Canada. They reported that cultivar, environment, and cultivar by environment effects were significant for all of the color parameters measured (at 0 and 24 hr and stability). For alkaline noodle sheets, environment had a greater influence on L* and b* values than cultivar at 0 hr but their contribution became similar by 24 hr. For white salted noodle sheets, environment contributed mostly to all the L* and b* measurements. Cultivar by environment effects were also relatively small compared to either the cultivar or environment effect.

CHAPTER 3

EFFECTS OF CULTIVAR, ENVIRONMENT AND THEIR INTERACTIONS ON COOKING AND TEXTURAL PROPERTIES OF YELLOW ALKALINE NOODLES

3.1 INTRODUCTION

In Asia, more than 40 % of total wheat is consumed in the form of noodles (Chen, 1993). In particular, YAN are popular foods in Southeast Asia, Southern China, and Japan (Ross et al., 1997). High quality noodles should have good cooking properties such as low cooking loss, high cooking yield, and high tolerance to over-cooking (Chen, 1993) and a firm, chewy and springy texture (Huang and Morrison, 1988; Nagao, 1996).

The quantity and quality of protein have been shown to be the major factor influencing the texture of YAN. Both protein content and quality (dough strength and/or SDS sedimentation volume) have been positively associated with firmness and elasticity of YAN (Miskelly and Moss, 1985; Moss et al., 1987; Shelke et al., 1990; Ross et al., 1997) but negatively associated with smoothness (Moss et al., 1987; Ross et al., 1997). While Ross et al. (1997) observed stronger relationship between protein content and texture of YAN, Huang and Morrison (1988) and Baik et al. (1994) found stronger relationship with protein quality (SDS volume).

The role of starch in relation to the eating quality of YAN have been recognized by some workers. Low swelling power and volume of flour or starch pastes (Konik et al., 1994; Ross et al., 1997) and low starch paste viscosity (Miskelly and Moss, 1985; Panozzo and Eagles, 1998) have been associated with desirable texture of YAN. Baik et al. (1994) however, reported that unlike WSN, starch properties may be less important in other types of noodles, including YAN.

Many workers have used the RVA to determine the pasting properties of starch or flour and their relationships with the texture of YAN. Both Konik et al. (1994) and Ross et al. (1997) reported that the FV of the RVA flour pasting curve was the best predictor of smoothness (negatively linked) and firmness (positively linked). However, only the latter study observed significant relationships between RVA parameters and elasticity. Also, while Batey et al. (1997) found relationships between flour paste PV and BD and noodle textural properties to be highly significant, Konik et al. (1994) found the relationships to be lower and non-significant. Ross et al. (1997) and Crosbie et al. (1999) observed improved correlations between RVA parameters, especially peak viscosity and texture characteristics of YAN when they were measured in 3.125 % sodium carbonate and 1 mM $AgNO_3$, respectively, instead of water alone. Crosbie et al. (1999) therefore concluded that in order to determine the inherent pasting properties of flour, the effects of alpha-amylase should be inactivated by an alkaline treatment.

Many major wheat exporting countries such as Australia, the U.S. and Canada have been developing hard-grained wheat varieties targeted at the Asian market. Although CWRS wheat is specifically designed for breadmaking purposes, its flour is often used for blending purposes in Asia to improve the processing, cooking or eating requirements of noodles, especially YAN (Bin Xiao Fu, personal communication; Chen, 1993). Currently, most Canadian wheat is exported by class, which is composed of registered varieties or cultivars grown across western Canada. However, there is growing interest from Asian clients in variety specific information as it relates to noodle production. This information is currently not available. Therefore, studying the noodle making quality of CWRS wheat cultivars appears to be beneficial to the Canadian grain industry. Evaluation of wheat varieties using samples blended over replicates and growing environments would lead to erroneous conclusions if there were a large cultivar by environment interaction effect. Therefore, the effect of cultivar, environment, and their interactions must be characterized in order to determine whether differences exist among CWRS wheat cultivars in their noodle making properties.

Genotypic (cultivar) and environmental variations for starch properties have been recognized by many researchers. The studies of Moss and Miskelly (1984) and Panozzo and Eagles (1998), both involving Australian wheats found significant cultivar and environment effects on peak starch paste viscosity but only the latter study observed significant interaction between cultivar and environment. Significant genotype and environmental effects have also been observed for various swelling properties of starch and flour pastes (Crosbie, 1989, 1991; Konik et al, 1994; Wang and Seib, 1996). Flour swelling volumes of some of the Australian and U.S. wheat cultivars have been found to have high genotype and crop years effects, slight location effect and small genotype by location interactions (Crosbie et al, 1992; Morris et al., 1997). Thus, these results suggest that genotype by environment interactions on starch properties are relatively unimportant in Australian and U.S. wheat cultivars.

The effects of cultivar, environment and their interactions on milling and baking characteristics of both U.S. and Canadian wheats have been investigated. Baenziger et al. (1985), Fowler and de la Roche (1975), and Zhu and Khan (2001) found large environmental effects on grain and flour protein and other protein related characteristics. Lukow and McVetty (1991) found that although environment effects were significant as well, all the milling, physiochemical (including protein content and sedimentation value) and baking qualities (such as mixograph dough development time and remix loaf volume) of the sample set which included both Canada and U.S. spring wheat cultivars were predominantly influenced by the cultivar effects. The results of the above studies agreed on the fact that although significant, the cultivar by environment effects on those characteristics related to baking quality of wheats were relatively unimportant. Baker and Kosmolak (1977) also found that the interaction effects were the least important for flour protein and sedimentation value of Canada hard red spring wheats but were more important in other characteristics, such as remix loaf volume. No studies have been undertaken to examine cultivar and environment effects on the quality of YAN. Therefore, the objectives of this study were:

1) To determine the relative contribution of cultivar, environment and their interactions to the cooking and textural properties of YAN prepared from CWRS wheat cultivars grown across western Canada.
2) To quantitate the differences among cultivars and among environments with regard to their cooking and textural properties of YAN made from five CWRS wheat cultivars grown in six environments across western Canada.

3) To investigate the relationship between grain and/or flour characteristics and textural properties of YAN.

3.2 MATERIALS AND METHODS

3.2.1 Wheat Samples

Four registered CWRS wheat cultivars were selected for the study based on a number of criteria. The variety Katepwa, was selected since it represents the CWRS class standard. AC Barrie was selected since it is the predominant variety grown in the class with an average acreage of 46 % in the 1999 and 2000 crop seasons. AC Domain and CDC Teal were selected due to their relatively weak and strong dough strength, respectively when compared to the other CWRS cultivars. Pedigrees of these cultivars are given in Table 3.1. The cultivars were grown in three locations within western Canada over two years (1999 and 2000). They were grown in a randomized complete block design and two out of the four field plots of each cultivar were used in the study. Only sound grains that qualified for the No. 1 or No. 2 grade in the Canadian grain grading system were included in the study. All four cultivars grown in Melfort (SK) and Swift Current (SK) for both years; Beaverlodge (AB) in 1999 and Glenlea (MB) in 2000 qualified as being sound. For comparative purposes, another CWRS cultivar AC Majestic (known for better flour color and yield) grown in year 2000's locations and a No.1 grade (13.5 % protein) composite CWRS wheat sample from the 2000 crop year harvest were included in the study. Over half of the grains of the year 2000 composite CWRS sample were represented by AC Barrie (44.8 %) and CDC Teal (12.6 %). AC Domain (4.0 %), Katepwa (3.7 %), and AC Majestic (1.9 %) represented a small percentage of the total acreage in the 2000 crop season.

Table 3.1. Pedigree of the Canada Western Red Spring wheat cultivars studied.

Cultivar	Pedigree
AC Barrie	Neepawa/Columbus//BW 90
AC Domain	BW 83/ND 585
Katepwa	Neepawa*6/CT244/3/Neepawa*6Cl188154/2*Froccor
CDC Teal	BW 514/Benito//BW 38
AC Majestic	Columbus*2//Saric 70/Neepawa/3/Clms*5//Saric 70/Np

Information regarding the growing conditions could be retrieved for some of the environments. The tests at Melfort were grown on well-drained Black Chernozem silty clay loam soil, Beaverlodge on grey wooded soil, and Glenlea on poorly drained Scanterbery clay soil. At Melfort in 1999, precipitation during the growing season was near normal, but below normal temperatures delayed maturity in crops. In 2000, the moisture conditions in Melfort were poor in the spring but improved considerably at the end of May. However, the average growing season precipitation in June and July was 150 % of the normal. Temperatures were below normal early in the growing season but improved to near normal levels later in the season. With regard to Beaverlodge in 1999, the average growing season was extremely dry. Glenlea in 2000 had higher than normal precipitation in early growing season, but below normal moisture and above normal temperature at post-anthesis.

3.2.2 Milling and Storage of Samples

Wheat samples were held at room temperature for approximately five months after harvesting before milling. All samples were tempered to 16.0-16.5 % moisture, depending on the specific moisture level. Separate millings were carried out for the two field plots and years using a Tandem Buhler experimental mill (Martin and Dexter, 1991) at the Grain Research Laboratory (GRL, Winnipeg, Manitoba). A check sample was milled after every four to eight samples to ensure similar milling conditions were being applied. Flour streams were combined on the basis of increasing ash content to make up 65 % patent flours. In commercial practice, the flour extraction rate used for making YAN can range from 40 % in Japan (Crosbie et al., 1999) to 75 % (straight run flour) in other countries depending on the market (Bin Xiao Fu, personal communication). A 65 % was chosen for this study since it would give us some insight into the quality of YAN made from a higher extraction rate flour and most other research studies on YAN used a similar extraction rate of 60 % (Akashi et al., 1999; Baik et al., 1995; Miskelly and Moss, 1985; Hatcher et al., 1999; Ross et al., 1997). About 20 g of flours were sub-sampled into 40-mL covered plastic containers placed inside Ziploc bags filled with nitrogen gas and stored at -20±5 °C before determining alpha-amylase activities of flour samples to confirm their levels of sprout damage. The rest of the flour samples and grain residues were placed in plastic bags and kept at 4 °C inside covered 20-L plastic pails.

3.2.3 Flour Alpha-amylase Activity

The soundness of grain samples was confirmed by testing their alpha-amylase activity with the Model 191 GAA (Perkin-Elmer Corp., Coleman Instruments Div., Oak Brook, IL) attached to a NGI Servogor 124 recorder according to the procedure described by Kruger and Tipples (1981) with minor modifications. The working waxy maize β-limit dextrin substrate was centrifuged at 2,000 rpm at 20 °C for 10 min instead of 15 min. Flour suspension (1 g / 5 mL 0.2 M sodium acetate buffer, pH 5.5 containing 1×10^{-3} $CaCl_2$) was rotated for 1 hour, centrifuged at 15,000 rpm at 4 °C for 20 min and then filtered through glass wool. Results were reported as the average of two analyses from one extraction and expressed as mg maltose $\times 10^{-3}$/g sample/min on an as is basis.

3.2.4 Flour Moisture and Ash

Flour moisture and ash were determined according to AACC methods 44-15A and 08-01, respectively (AACC, 1995). Due to the limited amount of flour sample, 1 g and 3 g were used for determining moisture and ash content, respectively, each with two determinations.

3.2.5 Protein Characteristics

Flour protein content (N × 5.7) was determined by combustion with a nitrogen determinator (Leco Corporation, St. Joseph, MI). Wheat protein quality was determined according to the procedure of Kovacs (1985) using the SDS-sedimentation test on ground grain samples obtained by a Udy Cyclone mill with a 0.5 mm mesh. Wet gluten and gluten index of flour were determined by AACC method 38-12 (AACC, 1995) with a double chamber Glutomatic System Model 2200 and Centrifuge Model 2015 (Perten Instrument, Huddinge, Sweden). All measurements were carried out in duplicate.

3.2.6 Flour Pasting Properties

The pasting properties of flour samples were determined in duplicate using a model 3D RVA (Newport Scientific, Warriewood, Australia) connected to a computer controlled by Thermocline for Windows software, Version 1.1 (Newport Scientific, Warriewood, Australia). Flour (3.5 g on a 14 % moisture basis) was weighed into a disposable aluminum canister where 25 mL distilled water or 0.05 M silver nitrate ($AgNO_3$) solution was added. Flour aggregates were broken down with a fine metal pick before inserting the paddle into the canister. While stirring, the suspension was heated to 50 °C within the first minute before heating up to 95 °C at 12 °C/min and held at 95 °C for a further 2.5 min. The temperature was then reduced at 12 °C/min to a final temperature of 50 °C and held at that temperature for another 2 min to complete the 13-min run. RVA parameters measured in distilled water were PV, the highest viscosity during 95 °C heating stage, HS, the lowest viscosity at end of 95 °C heating stage, BD, the difference between PV and HS, FV, the highest viscosity at the 50 °C cooling stage, and SB, the difference between FV and HS (Konik et al., 1994). The same parameters were measured in silver nitrate and expressed as SPV, SHS, SBD, SFV and SSB, respectively. All values were expressed in RVA viscosity units (RVU).

3.2.7 Noodle Preparation

All flour samples, including four mill checks per year were processed into YAN according to the method of Kruger et al. (1994a) in a randomized order with the two plots and two processing replicates being blocked. A 200 g (on a 14 % moisture basis) flour sample was mixed in a Hobart N50 mixer (Hobart Canada, North York, ON) at slow speed (setting 1) for 30 sec followed by an introduction of a 1 % kansui solution (9:1 sodium and potassium carbonates) over the next 30 sec to attain a final absorption of 32 %. Further mixing was done at slow speed for one min, then at high speed (setting 2) for another min and finally at slow speed for three min. Sheeting was done using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan) with the rollers maintained at 28 °C. A representative 25 cm long dough sheet obtained by sheeting the dough twice (folded once after the fist passage) at the 3.00 mm clearance was used for the seven subsequent passages at reducing gap width (3.00, 2.55, 2.15, 1.85, 1.57, 1.33 and 1.10 mm) over a 4.5-min period. A No. 12 cutter was used to cut the noodle sheet into noodles which were then cut into approximately 3 cm long noodle strands.

3.2.8 Noodle Cooking and Cooking Loss

Optimal cooking time, defined as the time required for the white core of the noodle strand to disappear, was determined by pressing noodle strands (5) against two plexiglas plates. One hour after processing, 25.0 g of noodles were cooked in boiling distilled water (~400 mL) in a 500-mL glass beaker heated by a ceramic hot plate. Table 3.2 presents the optimal cooking times for noodles prepared from the cultivars grown in each environment. The cooked noodles were drained into a sieve and then rinsed and cooled for 1 min with a constant stream of distilled water (20 °C). The retained cooking water was collected and poured back into the original cooking beaker (with known weight) which was then oven dried at 150 °F for 2 days, cooled to room temperature and weighed to determine percent cooking loss (total solid loss during cooking divided by the uncooked noodle weight times 100).

Table 3.2. Optimal cooking time[a] of yellow alkaline noodles made from five Canada Western Red Spring wheat cultivars grown in six western Canada environments.

Cultivars	Environments[b]						
	B9	M9	SC9	G0	M0	SC0	Cultivar Mean
AC Barrie	8.5	9	9	9	8	9.5	8.8
AC Domain	9	9	8.5	9.5	8	10.5	9.1
Katepwa	8	9	10	10	8	10	9.2
Teal	9	9	10	10	8	10.5	9.4
Majestic	-	-	-	10	8	10	9.3
Environment mean	8.6	9	9.4	9.7	8	10	9.2

[a] values were time in minute required to cook noodle sample to optimum averaged over two processing replications per plot duplicate (n=4).
[b] B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, M0 = Melfort 2000, SC0 = Swift Current 2000.

3.2.9 Cooked Noodle Texture

The cooked noodles were assessed for textural properties using the TA-XT2*i* Texture Analyser (Stable Micro Systems, Godalming, Surrey, England). Four tests including cutting, compression, TPA and stress relaxation were performed at 10, 15, 20, and 25 min, respectively after rinsing. Each test was carried out 5 times on 3 noodle strands within a 5-min period. For the cutting test, a 1 mm wide plexiglas cutting blade was used and was performed according to the method of Oh et al. (1983). The crosshead traveled at a speed of 0.4 mm/s and stopped when the cutting surface of the blade was 0.1 mm away from the platform. Hardness expressed as maximum cutting force (g) and firmness expressed as MCS (g/mm^2) were determined from the force-distance curve (Oh et al., 1983). RTC, the preferred parameter over recovery as the instrumental measure of chewiness of noodles (Oh et al., 1983), was determined according to the method of Oh et al. (1983) using a 1 cm wide plexiglas blade. TPA was determined using the 1 cm wide plexiglas blade and noodles were compressed twice to 50 % of their original thickness. Springiness, gumminess and chewiness were calculated from the TPA force-distance curve according to Baik et al. (1994). The stress relaxation test was adopted from the study of Sopiwnyk (1999) and was performed by compressing the noodles at a speed of 0.1 mm/s to a peak force of 250 g (force 1). The time when the noodles relaxed to 85 % of the peak force (force 2) was recorded. Relaxation time was recorded as the difference in time between force 1 and force 2. Relaxation area was the area under the curve between force 1 and force 2. Relaxation slope was calculated as force 2 minus force 1 divided by relaxation time.

3.2.10 Statistical Analysis

All statistical analyses were performed with the Statistical Analysis System (SAS) software (version 8.01, SAS Institute, Cary, NC, USA). PROC CORR was used to determine the Pearson correlation coefficients for the RVA and textural parameters, and between textural parameters and grain or flour characteristics.

Originally, PROC MIXED using the restricted maximum likelihood (REML) method was used to determine the significance of the fixed effects for the cooking and textural parameters. The fixed effects were cultivar, year, location (nested within year) and their interactions while the random effects were processing replications (nested within year) and field plot (nested within genotype, location, and year). However, PROC GLM using the analysis of variance (ANOVA) method was used in the end since it gave similar results to PROC MIXED especially when the random effects were taken into the account using a random /test q statement in the ANOVA model. Pairwise comparisons of the least squares means of the cultivar and environment (defined as each location at each year) were performed using Tukey's studentized range test at 95 % significance level. Since AC Majestic was only grown in year 2000, a separate analysis was done to compare the least squares means of the five cultivars using the year 2000 data. Estimates of the relative contribution (or variance components) as a percentage of all the main and interaction effects to the textural characteristics were also determined by PROC MIXED (using REML). PROC CORR SPEARMAN was used to determine the rank correlation coefficients for cultivars in all environments (Lukow and McVetty, 1991). For each textural parameter, the mean of the rank correlations which was the average of all the rank correlations from the 15 environment comparisons was used. PROC REG was used to estimate the relative stability (responsiveness of cultivars to changes in environment) of each cultivar for each parameter (Moll et al., 1978).

3.3 RESULTS AND DISCUSSION

3.3.1 Grading Results

Grading results of samples from year 1999 and 2000 are presented in Table 3.3 and Table 3.4, respectively. In 1999, samples that were graded as No. 1 CWRS were AC Domain and CDC Teal from Beaverlodge, Katepwa from Melfort, and all samples from Swift Current. AC Barrie from Beaverlodge was downgraded to No. 3 CWRS since it had about 2.9 % immature green kernels. However, this sample was still included in the study after most of the green kernels were manually removed to achieve a better quality sample. Katepwa from Beaverlodge was downgraded to No. 2 CWRS also due to the presence of immature green kernels. For Melfort, AC Barrie, AC Domain and CDC Teal samples were downgraded to No. 2 CWRS as a result of frosted green kernels. In 2000, all grain samples were graded as No. 2 CWRS. Immature green kernels was the determinant factor for the downgrading of the grain samples from Melfort in 2000, except for plot #2 of AC Barrie which was downgraded as a result of failing to meet the minimum requirement for having 65 % of hard vitreous kernels (HVK). Bleached kernels, mildewed kernels, and percent HVK (48 to 51 %) were the grading determinants which resulted in the downgrading of samples from Glenlea. Grains from Swift Current were also downgraded due to bleached kernels or low levels of HVK (48 to 57 %).

Table 3.3. Summary of grading results of year 1999 grain samples[a].

Year 1999 Location	Cultivar	Grade	Comments
Beaverlodge	AC Barrie	3 CWRS[b]	2.9 % immature green kernels
	AC Domain	1 CWRS	-
	Katepwa	2 CWRS	immature green kernels
	CDC Teal	1 CWRS	-
Melfort	AC Barrie	2 CWRS	green caused by frost
	AC Domain	2 CWRS	green caused by frost
	Katepwa	1 CWRS	-
	CDC Teal	2 CWRS	green caused by frost
Swift Current	AC Barrie	1 CWRS	-
	AC Domain	1 CWRS	-
	Katepwa	1 CWRS	-
	CDC Teal	1 CWRS	-

[a]only one field plot per cultivar was evaluated.
[b]most green kernels were manually removed to improve sample quality.

Table 3.4. Summary of grading results of year 2000 grain samples.

Year 2000 Location	Cultivar	Plot #	Grade	Comments[a]
Glenlea	AC Barrie	10	2 CWRS	bleached
		19	2 CWRS	50 % HVK
	AC Domain	2	2 CWRS	mildewed, 51 % HVK
		17	2 CWRS	mildewed, 48 % HVK
	Katepwa	5	2 CWRS	bleached
		13	2 CWRS	mildewed, bleached
	CDC Teal	9	2 CWRS	mildewed
		15	2 CWRS	mildewed
	AC Majestic	8	2 CWRS	mildewed, HVK
		16	2 CWRS	mildewed, 51 % HVK
Melfort	AC Barrie	2	2 CWRS	47 % HVK
		13	2 CWRS	immature green
	AC Domain	3	2 CWRS	immature green
		20	2 CWRS	immature green
	Katepwa	4	2 CWRS	immature green
		7	2 CWRS	immature green
	CDC Teal	9	2 CWRS	immature green
		18	2 CWRS	immature green
	AC Majestic	10	2 CWRS	immature green
		14	2 CWRS	immature green
Swift Current	AC Barrie	5	2 CWRS	57 % HVK
		7	2 CWRS	bleached
	AC Domain	2	2 CWRS	48 % HVK
		22	2 CWRS	51 % HVK
	Katepwa	4	2 CWRS	bleached
		11	2 CWRS	bleached
	CDC Teal	8	2 CWRS	51 % HVK
		24	2 CWRS	bleached
	AC Majestic	1	2 CWRS	bleached
		10	2 CWRS	bleached

[a]HVK = hard vitreous kernels.

3.3.2 Flour Alpha-amylase Results

Alpha-amylase activity of flour samples is presented in Table 3.5. Sound flour should have an alpha-amylase activity of less than 5 mg maltose x 10^{-3} /g of flour/min (unit) which is equivalent to approximately 500 Brabender Units of amylograph viscosity. As shown, all of the flour samples had very low alpha-amylase activities (< 5 or ~5 units), thereby indicating sound flour.

Table 3.5. Alpha-amylase activity of flour samples[a].

Year	Location	Genotype	Alpha-Amylase Activity[b] (mg maltose x 10^{-3}/g sample/min.)
1999	Beaverlodge	AC Barrie	0.1
		AC Domain	0.1
		Katepwa	0.4
		CDC Teal	0.5
	Melfort	AC Barrie	1.4
		AC Domain	0.7
		Katepwa	2.7
		CDC Teal	6.6
	Swift Current	AC Barrie	0
		AC Domain	0
		Katepwa	0
		CDC Teal	0
2000	Glenlea	AC Barrie	1.2
		AC Domain	0.8
		Katepwa	2.0
		CDC Teal	3.1
		AC Majestic	0.7
	Melfort	AC Barrie	0.1
		AC Domain	0.3
		Katepwa	0.4
		CDC Teal	0.6
		AC Majestic	0.1
	Swift Current	AC Barrie	0
		AC Domain	0
		Katepwa	0.4
		CDC Teal	0.8
		AC Majestic	0
2000	Composite[c]		0.7

[a] values are mean of two determinations per plot duplicate.
[b] results are based on as is flour moistures.
[c] composite = No.1CWRS sample obtained from the year 2000 harvest.

3.3.3 Ash and Protein Characteristics Results

Cultivar and environment means of ash content and protein-related characteristics (protein content, wet gluten content, gluten index and SDS sedimentation tests) can be found in Table 3.6 to Table 3.8. In order to compare AC Majestic which was grown in year 2000 only with the other four cultivars, the cultivar means averaged over the three locations in year 2000 were used (Table 3.7). The raw data for ash content and protein-related characteristics is provided in Appendix I, Table AI.1. The variability of ash and protein characteristics among environments (8.6 to 14.7 % coefficient of variation (CV), Table 3.8) was found to be higher than the variability among cultivars (1.5 to 5.2 % CV among the four cultivars grown in both years, Table 3.6, and 1.0 to 6.6 % CV among the five cultivars grown in year 2000, Table 3.7).

Table 3.6. Cultivar means[a] and standard deviations (SD) for ash and protein-related characteristics of samples grown in both year 1999 and 2000.

Cultivar	Ash and Protein Characteristics[b]				
	Ash[c] (%)	Protein[c] (%)	Wet Gluten[c] (%)	Gluten Index[c] (%)	SDS-SED[d] (mL)
AC Barrie	0.36 (0.04)	13.1 (1.2)	36.4 (3.7)	94.3 (5.4)	61.2 (8.9)
AC Domain	0.35 (0.06)	13.3 (1.5)	37.8 (4.8)	89.7 (8.8)	61.5 (8.0)
Katepwa	0.37 (0.06)	13.0 (1.2)	36.5 (3.9)	88.5 (8.2)	62.5 (8.6)
CDC Teal	0.36 (0.05)	13.4 (1.1)	37.0 (3.4)	91.5 (9.2)	68.3 (10.9)
Mean	0.36	13.2	36.9	91.0	63.4
C.V.	2.22	1.5	1.6	2.7	5.2

[a]means are average value of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD) with coefficient of variation (CV) for cultivar.
[c]determined using flour samples.
[d]determined using wholemeal samples.

Table 3.7. Cultivar means[a] and standard deviations (SD) for ash and protein related characteristics of samples grown in year 2000.

Cultivar	Ash and Protein Characteristics[b]				
	Ash[c] (%)	Protein[c] (%)	Wet Gluten[c] (%)	Gluten Index[c] (%)	SDS-SED[d] (mL)
AC Barrie	0.39 (0.02)	13.1 (1.3)	35.9 (2.4)	93.7 (6.4)	59.9 (12.3)
AC Domain	0.39 (0.05)	13.6 (1.4)	38.4 (3.2)	88.4 (9.0)	61.9 (9.1)
Katepwa	0.40 (0.05)	12.9 (1.1)	35.7 (2.3)	89.4 (7.8)	62.6 (12.2)
CDC Teal	0.39 (0.04)	13.3 (1.4)	36.3 (2.2)	91.6 (10.6)	70.4 (15.1)
AC Majestic	0.39 (0.02)	13.2 (1.4)	38.3 (2.9)	86.2 (13.1)	61.1 (13.6)
Mean	0.39	13.2	36.9	89.9	63.2
C.V.	1.03	2.3	3.5	3.2	6.6

[a]means are average value of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD) with coefficient of variation (CV) for cultivar.
[c]determined using flour samples.
[d]determined using wholemeal samples.

Table 3.8. Environment means[a] and standard deviations (SD) for ash and protein related characteristics of samples grown in year 1999 and 2000.

Environment[c]	Ash and Protein Characteristics[b]				
	Ash[d] (%)	Protein[d] (%)	Wet Gluten[d] (%)	Gluten Index[d] (%)	SDS-SED[e] (mL)
B9	0.31 (0.02)	13.0 (0.3)	35.4 (1.3)	98.8 (1.4)	67.8 (2.6)
M9	0.37 (0.03)	14.7 (0.2)	43.4 (0.9)	82.4 (5.9)	60.6 (2.2)
SC9	0.31 (0.02)	11.9 (0.8)	32.9 (2.8)	92.5 (4.1)	60.8 (4.3)
G0	0.42 (0.03)	14.2 (0.4)	38.8 (2.0)	96.7 (3.4)	71.9 (6.1)
M0	0.41 (0.02)	11.6 (0.3)	33.6 (0.9)	80.2 (5.7)	47.5 (3.6)
SC0	0.35 (0.02)	13.9 (0.6)	37.5 (1.5)	95.4 (2.4)	71.7 (5.4)
Mean	0.36	13.2	36.9	91.0	63.4
C.V.	13.89	9.8	10.6	8.6	14.7
Composite[f]	0.36	12.7	36.5	95.5	62.5

[a]means are average value of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean and (SD) with coefficient of variation (CV) for environment.
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.
[d]determined using flour samples.
[e]determined using wholemeal samples.
[f]composite = No.1CWRS composite sample from the year 2000 crop harvest.

3.3.4 Flour Pasting Properties Results

Detailed results for RVA parameters measured in distilled water (Table AI.2) and 0.05 M $AgNO_3$ (Table AI.3) of each cultivar grown in each environment are presented in Appendix I. Crosbie et al. (1999) observed improved correlations between sensory evaluation of the total texture scores of YAN and RVA parameters measured in 1 mM of silver nitrate solution instead of water. In the present experiment, a 0.05 M silver nitrate solution or distilled water used for measuring RVA parameters gave comparable correlations (performed using cultivar means of each environment, n =27) with the texture parameters measured (Appendix II, Table AII.1). This could be due to the fact that unlike the study by Crosbie et al. (1999), the majority of the samples in this study were sound. The relationships between the RVA parameters measured in distilled water and 0.05 M silver nitrate solution are shown in Table 3.9. Results revealed that, except for holding strength, RVA parameters measured in silver nitrate were highly correlated with those measured in distilled water. For example, SSB and SB were correlated with each other with a correlation coefficient of 0.86 ($P < 0.001$). Given this finding it was decided to use the flour RVA parameters measured in silver nitrate solution for further analysis in this study. Cultivar and environment means of flour RVA parameters in silver nitrate are reported in Table 3.10 to Table 3.12. Similar to the protein characteristics, a separate analysis was performed on the year 2000 data in order to compare AC Majestic with other cultivars. Higher CV's for the RVA parameters were found among environments (3.0 to 7.3 % CV, Table 3.12) than among cultivars (1.4 to 3.4 %

Table 3.9. Matrix of Pearson correlation coefficients[a,b] for Rapid Visco Analyzer (RVA) parameters[c] of flour samples in water and 0.05 M silver nitrate.

	SPV	SHS	SBD	SFV	SSB	PV	HS	BD	FV	SB
SPV		0.21	0.77***	0.10	-0.02	**0.76*****	0.51**	0.73***	-0.0009	-0.07
SHS	0.21		-0.47*	0.97***	0.87***	0.08	**0.28**	-0.35	0.66***	0.78***
SBD	0.77**	-0.47*		-0.54**	-0.58**	0.64***	0.28	**0.90*****	-0.43*	-0.58**
SFV	0.10	0.97***	-0.54**		0.96***	0.02	0.25	-0.44*	**0.70*****	0.85***
SSB	-0.02	0.87***	-0.58**	0.96***		-0.05	0.21	-0.50**	0.69***	**0.86*****
PV	**0.76*****	0.08	0.64***	0.02	-0.05		0.76***	0.81***	0.20	0.07
HS	0.51**	**0.28**	0.28	0.25	0.21	0.76***		0.50**	0.14	0.29
BD	0.73***	-0.35	**0.90*****	-0.44*	-0.50**	0.81***	0.50**		-0.38*	-0.50**
FV	-0.0009	0.66***	-0.43*	**0.70*****	0.69***	0.20	0.14	-0.38*		0.88***
SB	-0.07	0.78***	-0.58**	0.85***	**0.86*****	0.07	0.29	-0.50**	0.88***	

[a] correlation coefficients were determined using values of cultivars grown at each environment (n=27).
[b] *, **, ***, significant at P < 0.05, P < 0.01, P < 0.001, respectively.
[c] SPV = peak viscosity in silver nitrate, SHS = holding strength in silver nitrate, SBD = breakdown in silver nitrate, SFV = final viscosity in silver nitrate, SSB = setback in silver nitrate, PV = peak viscosity in distilled water, HS = holding strength in distilled water, BD = breakdown in distilled water, FV = final viscosity in distilled water, SB = setback in distilled water.

Table 3.10. Cultivar means[a] and standard deviations (SD) for flour Rapid Visco Analyzer (RVA) parameters in silver nitrate of samples grown in 1999 and 2000.

Cultivar	RVA Parameter[b]				
	Peak Viscosity	Holding Strength	Breakdown	Final Viscosity	Setback
AC Barrie	244.7 (10.5)	103.4 (8.5)	141.3 (8.1)	180.3 (14.9)	76.9 (7.0)
AC Domain	251.2 (10.1)	106.0 (4.8)	145.2 (10.7)	184.9 (9.3)	78.9 (5.5)
Katepwa	253.0 (7.2)	112.0 (5.5)	141.0 (8.2)	193.9 (10.8)	81.8 (6.0)
CDC Teal	251.1 (6.3)	108.1 (6.0)	143.1 (6.8)	188.5 (11.8)	80.4 (6.2)
Mean	250.0	107.4	142.6	186.9	79.5
C.V.	1.5	3.4	1.3	3.1	2.7

[a]means are average value of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD) in RVA viscosity units (RVU) with coefficient of variation (CV) for cultivar.

Table 3.11. Cultivar means[a] and standard deviations (SD) for flour Rapid Visco Analyzer (RVA) parameters in silver nitrate of samples grown in 2000.

Cultivar	RVA Parameter[b]				
	Peak Viscosity	Holding Strength	Breakdown	Final Viscosity	Setback
AC Barrie	250.5 (5.9)	103.6 (3.7)	146.9 (5.6)	182.6 (9.0)	79.0 (5.4)
AC Domain	259.0 (4.9)	106.6 (2.1)	152.4 (4.8)	184.9 (4.8)	78.3 (4.4)
Katepwa	258.0 (3.6)	112.4 (3.1)	145.6 (5.7)	193.9 (7.5)	81.2 (5.2)
CDC Teal	254.9 (2.5)	109.0 (4.4)	145.9 (4.9)	190.1 (8.6)	81.1 (4.8)
AC Majestic	263.0 (6.3)	100.9 (4.0)	162.1 (5.5)	173.5 (5.8)	72.6 (2.8)
Mean	257.1	106.5	150.6	185.0	78.4
C.V.	1.8	4.2	4.6	4.2	4.5

[a]means are average value of two processing replications per plot duplicate over three locations from year 2000 (n = 12).
[b]values are mean and (SD) in RVA viscosity units (RVU) with coefficient of variation (CV) for cultivar.

Table 3.12. Environment means[a] and standard deviations (SD) for flour Rapid Visco Analyzer (RVA) parameters in silver nitrate of samples grown in 1999 and 2000.

Environment[c]	RVA parameter[b]				
	Peak Viscosity	Holding Strength	Breakdown	Final Viscosity	Setback
B9	250.9 (5.2)	106.5 (4.4)	144.4 (3.2)	181.6 (7.3)	75.1 (3.1)
M9	238.7 (7.1)	98.4 (5.2)	140.4 (3.5)	172.3 (9.7)	74.0 (4.8)
SC9	243.6 (9.1)	115.6 (6.0)	128.0 (4.5)	203.9 (8.9)	88.3 (3.7)
G0	258.4 (3.6)	106.6 (2.8)	151.8 (2.8)	184.3 (4.0)	77.7 (3.0)
M0	254.0 (7.2)	106.3 (4.5)	147.7 (5.6)	183.2 (6.7)	76.7 (3.1)
SC0	254.4 (3.8)	110.9 (5.0)	143.5 (5.5)	196.1 (8.0)	85.2 (3.6)
Mean	250.0	107.4	142.6	186.9	79.5
C.V.	3.0	5.3	5.7	6.0	7.3
Composite[d]	236.0	114.3	121.7	187.2	72.9

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD) in RVA viscosity units (RVU) with coefficient of variation (CV) for environment.
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.
[d]composite = No.1CWRS composite sample from the year 2000 crop harvest.

CV among the four cultivars grown in both years, Table 3.10, and 1.8 to 4.6 % CV among the five cultivars grown in year 2000, Table 3.11).

3.3.5 Selected Textural Parameters

In this experiment, ten textural parameters were measured and therefore correlations were done to select the key parameters that measure different textural characteristics of noodles. Some textural parameters were highly correlated with each other ($P < 0.001$) and were therefore eliminated from further analyses (Appendix II, Table AII.2.). High correlations ($P < 0.001$) were found between MCS and hardness ($r = 0.98$) and between gumminess and chewiness ($r = 0.96$). Similarly, values obtained from the relaxation tests (relaxation time, area, and slope) were strongly correlated with each other ($r \cong 1.00$, $P < 0.0001$). In addition, gumminess was originally defined as applicable to semisolids and chewiness to solids (Friedman et al., 1963). Since noodles are semisolids, gumminess is preferred over chewiness as a measure of noodle texture. Given these findings, it was decided to select one parameter from each set of relationship, namely, MCS, gumminess and relaxation time for further analyses. The remaining parameters (RTC and springiness) were not found to strongly correlate with other parameters and were therefore selected for further analyses. The texture scores of each cultivar grown at each environment are presented in Appendix III, Table AIII.1 and AIII.2.

3.3.6 Cultivar Comparisons

In general, a narrow range was found among cultivars for cooking loss and all textural parameters as shown by the small CV's ranging from 0.2 % for springiness to 6.1 % for relaxation time (Table 3.13). As indicated by the results of the ANOVA shown in Table 3.16, cultivar effects were significant for cooking loss and all the textural parameters, except springiness. A comparison of cultivar means using Tukey's multiple range test ($P \leq 0.05$, Table 3.13) showed that on average, AC Barrie was significantly higher in cooking loss than the other cultivars. YAN made from Katepwa and CDC Teal displayed significantly higher MCS than AC Barrie and AC Domain. Katepwa and AC Domain produced YAN higher in RTC than AC Barrie and higher in gumminess and relaxation time than the other two cultivars. It should be noted that MCS and RTC have been found to be highly correlated with sensory firmness and chewiness, respectively (Oh et al., 1983), and relaxation time (of cooked spaghetti) with both chewiness and elasticity (Malcolmson, 1991). Therefore, we can concluded that AC Barrie appeared to produce YAN with less desirable cooking and textural properties when compared to the other cultivars studied, especially Katepwa and AC Domain.

The noodle making properties of AC Majestic in comparison to the other four cultivars grown in the year 2000 are presented in Table 3.14. The CV's of the cultivar means for the textural parameters ranged from 0.97 % for springiness to 7.8 % for relaxation time. In general, YAN made with AC Majestic had low cooking loss and RTC values but high MCS values. Significantly higher

Table 3.13. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for textural parameters of optimally cooked yellow alkaline noodles made from Canada Western Red Spring Wheat cultivars.

Cultivar	Textural Parameters[b]					
	Cooking Loss (%)	MCS[c] (g/mm^2)	RTC[c] (%)	Springiness	Gumminess (g)	Relaxation Time (sec)
AC Barrie	11.8 (0.8) b	24.9 (1.9) a	23.0 (1.1) a	0.90 (0.01) a	372.8 (9.9) a	3.40 (0.42) a
AC Domain	11.3 (0.8) a	24.5 (1.6) a	24.1 (1.0) b	0.90 (0.01) a	389.9 (11.7) c	3.84 (0.34) b
Katepwa	11.2 (1.0) a	26.0 (1.8) b	24.2 (1.0) b	0.89 (0.02) a	389.0 (9.7) c	3.69 (0.40) b
CDC Teal	11.3 (0.9) a	25.6 (1.4) b	23.5 (1.0) ab	0.89 (0.01) a	379.7 (11.7) b	3.41 (0.33) a
Mean	11.4	25.3	23.7	0.90	382.8	3.58
CV	2.6	2.8	2.1	0.22	2.1	6.1

[a]means are average of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]MCS = maximum cutting stress, RTC = resistance to compression.

Table 3.14. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for textural parameters of optimally cooked yellow alkaline noodles made from Canada Western Red Spring Wheat cultivars grown in year 2000.

Cultivar	Textural Parameters[b]					
	Cooking Loss (%)	MCS[c] (g/mm^2)	RTC[c] (%)	Gumminess (g)	Springiness	Relaxation Time (sec)
AC Barrie	12.2 (0.6) c	24.2 (0.8) a	22.9 (0.6) a	374.1 (11.2) b	0.90 (0.01) a	3.35 (0.34) b
AC Domain	11.5 (0.6) ab	23.8 (0.6) a	24.2 (0.9) c	388.6 (11.4) d	0.89 (0.01) a	3.78 (0.38) c
Katepwa	11.5 (0.9) ab	25.2 (1.0) b	23.9 (0.6) bc	383.0 (6.9) cd	0.90 (0.01) a	3.70 (0.22) c
CDC Teal	11.6 (0.7) b	25.2 (0.7) b	23.5 (0.8) a	375.3 (6.2) bc	0.89 (0.02) a	3.35 (0.26) b
AC Majestic	11.3 (0.8) a	25.4 (0.8) b	22.9 (0.6) a	346.2 (7.8) a	0.91 (0.01) b	3.13 (0.09) a
Mean	11.6	24.8	23.5	373.4	0.90	3.46
CV	2.6	2.8	2.6	4.4	0.97	7.80

[a]means are average of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]MCS = maximum cutting stress, RTC = resistance to compression.

springiness values and lower gumminess and relaxation time values were found for noodles made with AC Majestic than all other noodles.

Due to the low variability among cultivars observed in this study, studying the relationships between flour characteristics and noodle quality properties using cultivar means was not realistic. In contrast, studying the relationships between flour and noodle properties was possible using environment means since wider variations for flour and noodle characteristics were observed among environments.

3.3.7. Environment Comparisons

The environment means for cooking loss and textural parameters are shown in Table 3.15. Relatively larger CV's were observed among environments (Table 3.15) than among cultivars (Table 3.13).

YAN made from wheat grown in Melfort for both years had low cooking loss and relaxation time values. While cultivars grown in Melfort in 1999 generally gave noodles with high MCS, RTC, and gumminess values but low springiness values, the opposite was observed for noodles made from cultivars grown in Melfort in 2000. YAN prepared from cultivars grown in Swift Current for both years were relatively higher in cooking loss, gumminess and relaxation time, but lower in MCS. Cultivars grown in Glenlea in 2000 produced YAN with relatively higher cooking losses and moderate textural properties. Noodles made from cultivars grown in Beaverlodge in 1999 produced YAN with moderate cooking losses and MCS, but generally low in other textural properties.

Table 3.15. Environment means[a], standard deviations (SD), and coefficient of variation (CV) for textural parameters of optimally cooked yellow alkaline noodles made from Canada Western Red Spring Wheat cultivars.

Environment[d]	Textural Parameters[b]					
	Cooking Loss (%)	MCS[c] (g/mm^2)	RTC[c] (%)	Gumminess (g)	Springiness	Relaxation Time (sec)
B9	11.3 (0.3) c	26.2 (0.5) c	23.3 (1.16) a	374.1 (3.2) a	0.91 (0.02) c	3.30 (0.21) a
M9	10.0 (0.4) a	28.0 (1.3) d	24.8 (1.35) b	393.4 (3.7) c	0.89 (0.01) ab	3.42 (0.37) a
SC9	12.0 (0.5) d	23.5 (1.0) a	23.3 (0.94) a	388.8 (1.9) bc	0.90 (0.01) bc	4.14 (0.25) c
G0	12.2 (0.3) d	25.0 (0.7) b	23.2 (0.70) a	382.8 (2.0) b	0.89 (0.01)abc	3.46 (0.26) a
M0	10.9 (0.5) b	24.6 (1.3) ab	23.5 (0.88) a	371.6 (2.7) a	0.91 (0.01) c	3.29 (0.23) a
SC0	12.1 (0.4) d	24.2 (0.7) ab	24.1 (0.83) ab	386.3 (2.2) bc	0.88 (0.01) a	3.89 (0.28) b
Mean	11.4	25.3	23.7	382.8	0.896	3.58
SD	0.9	1.6	0.6	8.5	0.009	0.35
CV	7.9	6.3	2.5	2.2	1.00	9.78
Composite[e]	12.2 (0.5)	27.1 (0.6)	24.5 (0.4)	419.8 (1.3)	0.903 (0)	3.79 (0.06)

[a]means are average of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]MCS = maximum cutting stress, RTC = resistance to compression.
[d]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.
[e]composite = No. 1 CWRS sample obtained from the year 2000 harvest.

With regard to the noodles made from the composite CWRS sample from the 2000 crop year, it is interesting to note that higher textural scores were found (Table 3.15), especially for MCS and gumminess when compared to individual cultivar grown in year 2000 (Table 3.14). This could be explained by the fact that the composite sample was a blend of wheat cultivars from a large number of growing locations some of which likely had favorable growing conditions leading to better wheat quality which in turn resulted in higher firmness and chewiness (RTC and TPA gumminess) (Table 3.15).

3.3.8 Environmental Differences in Relation to Flour Characteristics

Previous studies have found that both protein quality and quantity were positively related to firmness of YAN (Huang and Morrison, 1988; Miskelly and Moss, 1985; Ross et al., 1997). In the present study, Melfort in 1999 produced cultivars with higher protein quantity (flour protein and wet gluten content) (Table 3.7) which in turn produced YAN with a firmer texture (higher MCS) (Table 3.15). The opposite trend was observed for cultivars grown in Swift Current in 1999 and Melfort in 2000. The positive associations of flour protein ($r = 0.60$) and wet gluten content ($r = 0.79$) with MCS were illustrated in Figure 3.1 and Figure 3.2, respectively. Similar correlation coefficients were also obtained between MCS and flour protein ($r = 0.50$, $P < 0.01$) and between MCS and gluten content ($r = 0.64$, $P < 0.01$) using individual data points of all the cultivars grown at each environment ($n = 27$). The relationship between protein quality parameters (SDS sedimentation volume and gluten index) and MCS were inconsistent.

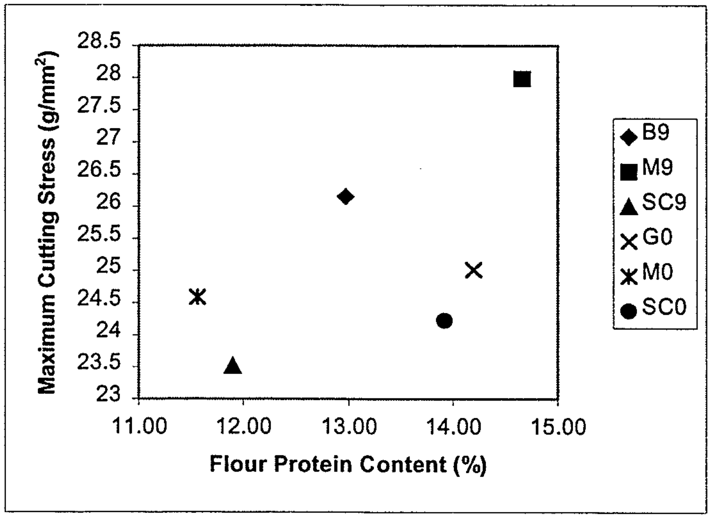

Figure 3.1. The relationship between flour protein content and maximum cutting stress of cooked yellow alkaline noodles illustrated using the means (n = 16) of the environments where B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, and SC0 = Swift Current 2000.

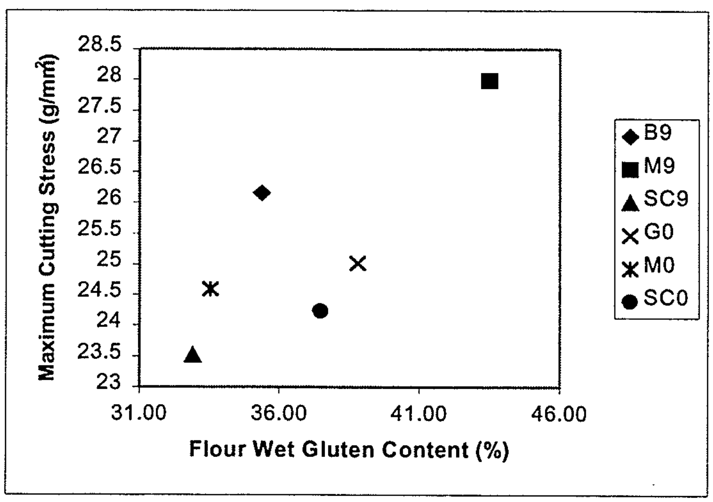

Figure 3.2. The relationship between flour wet gluten content and maximum cutting stress of cooked yellow alkaline noodles illustrated using the means (n = 16) of the environments where B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, and SC0 = Swift Current 2000.

It should be mentioned that although protein and wet gluten content of cultivars grown in Glenlea and Swift Current grown in 2000 were higher than those grown in Swift Current in 1999 and Melfort in 2000 (Table 3.7), their MCS values were very similar (Table 3.15). This observation could be explained by the differences in their flour pasting properties (Table 3.11). Results showed that MCS (firmness) of YAN was negatively correlated with SHS ($r = -0.92$), SFV ($r = -0.89$) and SSB ($r = -0.81$). The relationships between MCS and SHS ($r = -0.52$), SFV ($r = -0.55$), and SSB ($r = -0.55$) were also significant ($P < 0.01$) but weaker when determined by the values of all the cultivars and environments ($n = 27$). Figure 3.3 shows the relationship of MCS with one of the RVA parameter, SFV. As shown, cultivars from Swift Current for both 1999 and 2000 with lower SFV were lower in MCS regardless of the differences in their protein properties. Thus, starch properties also appears to affect the firmness of YAN. However, previous works on Australian cultivars and breeding lines with both high and low swelling starch properties have found the relationships of sensory firmness (Ross et al., 1997) and total texture scores (Crosbie et al., 1999) of YAN with SHS and SFV to be positive. This discrepancy could be explained by the inherent differences in the flour pasting properties of the cultivars examined and/or the different RVA temperature profile used in the present study. The rationale for this statement are: 1) while Crosbie et al. and Ross et al. found that the mean values of all the RVA parameters were higher when measured in alkaline conditions, the present study found increased values for PV and BD but decreased values for HS, SB, and FV when they were measured in alkali and 2) unlike their findings, cultivar

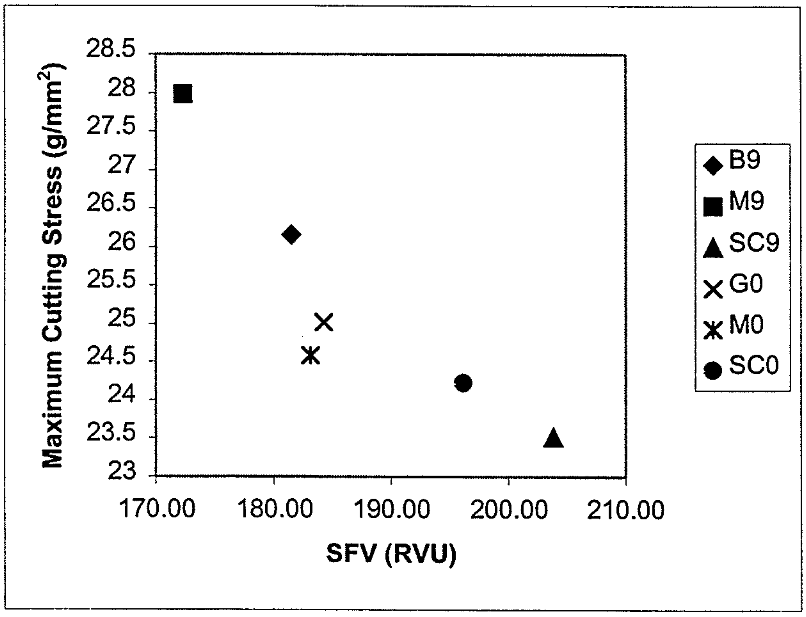

Figure 3.3. The relationship between final viscosity of flour samples measured in 0.05 M silver nitrate solution (SFV) using Rapid Visco Analyzer and maximum cutting stress of cooked yellow alkaline noodles illustrated using the means (n = 16) of the environments where B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, and SC0 = Swift Current 2000.

grown in environments with lower SPV were not necessary higher in SHS, SSB, and SFV in the present study (Table 3.11). Ross and colleagues (1997) also reported that significant relationship between SFV and noodle firmness could only be observed when the data from the high and low starch swelling lines were analyzed together, whereas significant correlations between flour swelling volume and noodle firmness were found for both populations even when calculated separately. It should also be noted that noodles made from cultivars grown in Swift Current in both 1999 and 2000 and in Glenlea in 2000 were noticeably wetter at the 32 % absorption level used. Thus, lower MCS of YAN produced from those samples could have been attributed to excess moistures during noodle processing. Oh et al. (1985a) observed that MCS tended to decrease with increased water absorption (hence, wetter noodle dough). One of the limitations of this study was that water absorption level was not optimized for each flour sample.

Similar to firmness, RTC ($r = 0.75$) and gumminess ($r = 0.59$) were found to be positively related to wet gluten content. Figure 3.4 shows the relationship between RTC and wet gluten content. This relationship was also found to be significant ($r = 0.50$, $P < 0.01$) when the correlation was performed on individual data points of all the cultivars grown at each environment ($n = 27$). Cultivars grown in Melfort in 1999 with higher wet gluten content produced YAN higher in RTC and gumminess, while the opposite was observed for Swift Current and Melfort in 2000 and Beaverlodge in 1999. Baik et al. (1994) observed a positive relationship between protein content and TPA gumminess and chewiness of YAN when the analysis was done on samples (both soft and hard wheats) with a wider range of protein content (10.1 to 13.9 %). However, they also found that when protein range was narrower, SDS sedimentation volume (constant flour protein basis) was a better predictor of chewiness than flour protein content. In the present study however, the relationships between gumminess and SDS sedimentation value (constant weight basis of wholemeal) and gluten index were inconsistent probably due to the differences in our testing materials and methods.

The relationships between gumminess and SBD ($r = -0.53$, $P < 0.01$), SFV ($r = 0.44$, $P < 0.05$), and SSB ($r = 0.49$, $P < 0.01$) were signficant but not very strong when the analysis was performed on the cultivars grown at each

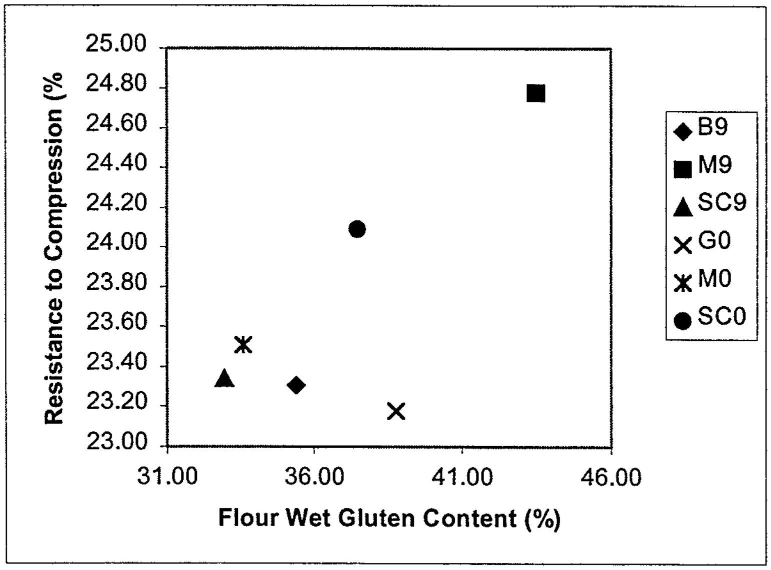

Figure 3.4. The relationship between flour wet gluten content and resistance to compression of cooked yellow alkaline noodles illustrated using the means (n = 16) of the environments where B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, and SC0 = Swift Current 2000.

environment (n = 27). Samples with lower SBD but higher SFV and SSB values (Swift Current in 1999, Table 3.12) appeared to produce noodles with higher gumminess values (Table 3.15) than those with higher SBD and lower SFV and SSB values (Beaverlodge in 1999 and Melfort in 2000). However, samples grown in Melfort in 1999 which had relatively low SFV and SSB values produced noodles that displayed high gumminess. High protein and wet gluten content (Table 3.8) of the samples grown in Melfort in 1999 might have contributed to the higher gumminess values of their noodles (Table 3.15). Thus, gumminess appears to be determined by both protein and starch properties. Baik et al. (1994) reported that compared with protein characteristics, starch properties (amylograph parameters and swelling power) appeared to play a less critical role governing the textural properties (TPA hardness, gumminess, chewiness, springiness and cohesiveness) of YAN and instant noodles.

With regard to springiness, environments with lower protein characteristics (Melfort in 2000 and Swift Current and Beaverlodge in 1999) (Table 3.7) gave rise to noodles with higher TPA springiness (Table 3.15) than those with higher protein properties (Melfort in 1999, Swift Current and Glenlea in 2000). In fact, protein content ($r = -0.56$) and SDS sedimentation value ($r = -0.51$) were found to be negatively correlated to TPA springiness ($P < 0.01$, $n = 27$). On the other hand, Ross et al. (1997) found positive relationships between sensory elasticity (springiness) and protein characteristics (content and SDS sedimentation values). However, in a fractionation and reconstitution study, Akashi et al. (1999) found that the higher elasticity (sensory) of YAN made from Australian prime hard wheat which had a lower protein content than the U.S. hard red winter wheat was related to its primary starch fraction.

No trends were observed between RVA parameters and TPA springiness in the present study. In contrast, Ross et al. (1997) observed significant relationships between elasticity (springiness) of YAN measured by a trained sensory panel and RVA parameters measured with flour samples in alkali (3.125% (w/v) sodium carbonate solution). This lack of agreement could be because their samples consisted of both normal (low swelling starches) and waxy (high swelling starches) wheat cultivars and experimental lines which had a much larger variability in their pasting properties. It might also be explained by the different methods used for measuring springiness in the present study. Thus, TPA springiness might not have been able to differentiate the elasticity of noodles in the present study. This likely accounted for why TPA springiness did not differ consistently between the hard and soft wheat samples used in the study of Baik et al. (1994).

In terms of relaxation time, RVA flour pasting properties seemed to relate better than protein characteristics. All RVA parameters except for SPV showed evidence of linear relationship with relaxation time. In general, cultivars grown in environments with higher SHS (r = 0.78), SFV (r = 0.89), and SSB (r = 0.96), but lower SBD (r = -0.74) produced YAN higher in relaxation time. The relationships between relaxation time and SHS (r = 0.65), SFV (r = 0.74), SSB (r = 0.78), and SBD (r = -0.57) were also found to be significant (P < 0.01) when using data of individual cultivars grown at each environment (n = 27). Relaxation time appears to be best characterized by SFV (Figure 3.5) and SSB.

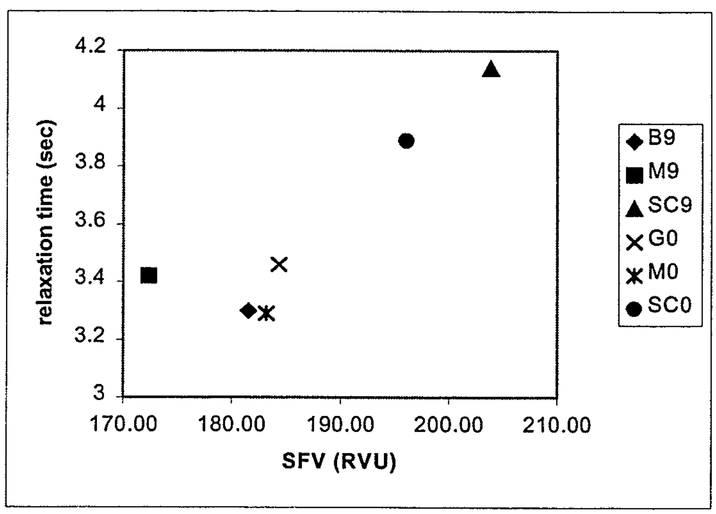

Figure 3.5. The relationship between final viscosity of flour samples measured in 0.05 M silver nitrate solution (SFV) using Rapid Visco Analyzer and relaxation time of cooked yellow alkaline noodles illustrated using the means (n = 16) of the environments where B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, and SC0 = Swift Current 2000.

As mentioned previously, noodles made from the composite CWRS sample had higher MCS values, thus firmer than those made from the individual cultivars. This findings could not simply be explained by the positive relationship between MCS and protein content reported earlier since the protein content of the composite sample (12.7 %) was lower than the individual cultivars (Table 3.7). However, this observation suggests that the flour characteristics of the composite sample might be more optimal for the production of YAN in terms of noodle firmness. The rationale for this statement is first, YAN is commonly made from flour with 10.5 – 12 % protein content (Nagao, 1996). The fact that the Australian Prime Hard wheat and the U.S. Red Winter wheat are favorably used in Japan for the production of YAN is because they have optimum protein range (10 – 12 %) with a mellow gluten quality (Akashi et al., 1999). Similarly, Miskelly and Moss (1985) observed that YAN that had poor eating quality (soft and inelastic) were prepared from flour with < 10 % or > 14.7 % protein content which had high starch paste breakdown values (amylograph). Moss (1982) also found that samples with lower starch paste breakdown values produced firmer YAN. Also, as previously discussed, MCS tends to decrease with SSB. Thus, higher MCS observed for the composite sample might have been attributed to its flour protein content (12.7 %) which was similar to the optimum range reported by other researchers and its relatively lower SBD and SSB values when compared to that of the individual cultivar (Table 3.11) and environment (Table 3.12) means. Thus, the fact that the composite sample produced firmer YAN than the individual cultivars was due to more optimum protein and starch properties of its flour. However, a remark should be made that while the composite sample was a No. 1 CWRS, the majority of the samples were No. 2. Thus, better grain quality of the composite sample might have led to more optimal flour quality which in turn produced firmer noodles, thus more desirable eating quality for YAN. It should also be noted that in agreement with Miskelly and Moss (1985), none of the flour components or properties was shown to have strong linear relationship with noodle eating quality characteristics, but rather that there seems to be an optimum value for best quality in each case.

3.3.9 Effects of Cultivar, Environment and their Interaction

The effects of cultivar, year and location and their interactions on the textural parameters of YAN were determined by ANOVA (Table 3.16). Cultivar effect was observed for all the parameters examined ($P < 0.01$), except for springiness. Location effect was significant for all the parameters examined ($P < 0.01$), whereas year effect was only significant for cooking loss ($P < 0.05$), MCS ($P < 0.01$) and gumminess ($P < 0.01$). Significant interactions between cultivar and year were only found for gumminess ($P < 0.05$). Significant cultivar by location effects were observed for cooking loss ($P < 0.05$), RTC ($P < 0.05$), gumminess ($P < 0.05$) and relaxation time ($P < 0.01$). Other researchers have also found significant cultivar by environment interactions for milling, physicochemical (including protein quantity and quality parameters), dough mixing and baking properties of both hard and soft wheats (Baenziger et al., 1985; Baker and Kosmolak, 1977; Lukow and McVetty, 1991; Peterson et al.,

Table 3.16. Mean squares for the analysis of variance of cooking and textural parameters of optimally cooked yellow alkaline noodles made from Canada Western Red Spring wheat cultivars[a].

Source of Variation	df	Cooking and Texture Parameters[b]					
		Cooking Loss	MCS	RTC	Gumminess	Springiness	Relaxation Time
Year[c]	1	10.2182*	39.3760**	1.1329NS	652.7317**	0.1660×10^{-3}NS	0.1321NS
Location(year)[d]	4	12.7314**	41.6588**	7.3912**	1290.7606**	1.6350×10^{-3}**	2.3916**
Cultivar[d]	3	1.8251**	12.2642**	6.8087**	1603.3793**	0.1550×10^{-3}NS	1.1404**
Cultivar × year[d]	3	0.1098NS	0.7416NS	0.6187NS	253.4143*	0.2700×10^{-3}NS	0.0177NS
Cultivar × location(year)[d]	12	0.2171*	1.3530NS	1.6865*	137.0166*	0.1090×10^{-3}NS	0.1289**
Plot (cultivar × location × year)	24	0.0945	0.8242	0.7408	56.1270	0.1550×10^{-3}	0.0328
Rep(year)	2	0.1857	0.8106	0.4393	14.8438	0.0809×10^{-3}	0.0237
Error	46	0.0975	0.1944	0.6292	24.1699	0.1550×10^{-3}	0.0148

[a]*, $0.01 < P \leq 0.05$; ** $P \leq 0.01$; NS = not significant ($P > 0.05$).
[b]df = degrees of freedom, MCS = maximum cutting stress, RTC = resistance to compression.
[c]The error term for year effect was [MS(rep(year)) + MS(plot(cultivar×location×year)) – MS(Error)] where MS is mean square.
[d]The error term used was MS(plot(cultivar×location×year)) where MS is mean square.

1986; Zhu and Khan, 2001). Morris et al. (1997) however, using eight different data sets varying in number and combination of wheat varieties and environments (location or year) found that in most cases interactions between cultivar and environment (location or year) for flour swelling volume (related to eating quality of WSN) were not significant.

The relative contribution of each effect to the total variation for cooking loss and cooked noodle texture is presented in Table 3.17. Year effect did not show any contribution to the parameters examined. Location effect contributed predominately to cooking loss (79.6 %) and all the textural parameters, ranging from 21.2 % for RTC to 69.5 % for MCS. The total variation attributed to cultivar and cultivar by year or location effects were relatively small compared to the location. Contribution of cultivar to cooking loss was 7.2 % and to texture ranged from 0 % for springiness to 29.8 % for gumminess. Cultivar by year interactions only contributed to gumminess (4.8 %) and springiness (2.8 %). Cultivar by location interactions contributed to all the parameters except springiness and its contribution ranged from 2.6 % for cooking loss to 13.3 % for RTC.

ANOVA results generally coincided with the variance component results. Cultivar effect was significant for all the textural characteristics investigated (except for springiness), yet the magnitude of its contribution was relatively small compared to location, especially for cooking loss, MCS, springiness, and relaxation time. Opposite to our findings, Lukow and McVetty (1991) found that cultivar contributed most of the total variations on milling, physiochemical and breadmaking quality parameters of spring wheats. This lack of agreement could

Table 3.17. Relative contribution of cultivar, year, location and their interactions to the textural parameters of optimally cooked yellow alkaline noodles made from Canada Western Red Spring wheat cultivars.

Effect	Relative Contribution (%)[b]					
	Cooking Loss	MCS	RTC	Gumminess	Springiness	Relaxation Time
Year	0	0	0	0	0	0
Location(year)	79.6	69.5	21.2	33.7	37.9	57.2
Cultivar	7.2	12.8	16.1	29.8	0	21.5
Cultivar × year	0	0	0	4.8	2.8	0
Cultivar × location(year)	2.6	2.8	13.3	10.7	0	9.2
Plot (cultivar × location × year)	0	8.8	4.3	8.5	10.5	4.5
Processing Rep(year)	0.4	0.7	0	0	0	0.2
Residual	10.2	5.4	45.1	12.5	48.8	7.4

[a]refers to the total variations contributed by cultivar × year and cultivar × location(year) effects.

[b]MCS = maximum cutting stress, RTC = resistance to compression.

be due to the fact that in Lukow and McVetty's study, different parameters were measured and/or much broader cultivar range (involving different classes of both Canada and U.S. wheats) but narrower environmental range (all locations were within the province of Manitoba) were used increasing the likelihood of higher variations due to cultivar relative to environment. Morris et al. (1997) also reported that flour swelling volume was mostly attributed to variations among cultivars followed by environment with crop year more so than location within a year. Baenziger et al. (1985) observed that the relative contribution of cultivar, environment and their interaction varied among the quality parameters measured. Similar to our findings, Zhu and Khan (2001) using U.S. Hard Red Spring wheats found that environment accounted for greater variability than cultivar on protein-related characteristics such as flour protein content and % insoluble glutenin which were found to be positively correlated to loaf volume of bread. A large environment effect on protein-related parameters of hard and soft spring wheats grown in eastern Canada was also observed by Fowler and De La Roche (1975).

For most of the parameters studied, the contribution of the cultivar by location effect was very small when compared to that of the location effect but was comparable to the cultivar effect. Unlike our results, very small cultivar by environment interactions relative to cultivar effect have been observed by others (Baenziger et al., 1985; Lukow and McVetty, 1991; Morris et al., 1997) for the wheat and breadmaking quality characteristics investigated such as flour protein content, sedimentation values, mixograph and farinograph parameters and remix loaf volume. In contrast, Baker and Kosmolak (1977) concluded that the importance of the cultivar by environment effect varied among the parameters with mixograph development time and remix loaf volume more affected by the interaction effect than parameters such as flour protein and sedimentation value. It should be mentioned that the low variability among the cultivars in the present study probably increased the likelihood of having a larger cultivar by environment interactions.

3.3.10 Spearman Rank Correlation

Quality evaluation of wheat properties often involves a large number of samples and tests that are time-consuming and expensive. Ideally, testing of wheat properties using samples composited over growing environments would be desirable since time and resources would be reduced. This practice would give accurate results even if the cultivar by environment interactions were significant as long as the rankings of the cultivars remain consistent across environments. As discussed previously, for some of the parameters examined, the cultivar by environment interactions were significant and their relative contributions were comparable to that of the cultivar effect. Therefore, in order to confirm whether cultivar by environment interactions were due not only to changes in magnitude but reversal of rank, Spearman rank correlation which correlates the rankings of different cultivars among the environments was performed for each of the parameter examined. An example of the matrix of the Spearman correlation coefficients for all the environment comparisons can be found in Table 3.18. The means of the rank correlations averaged over the 15 environment comparisons are presented in Table 3.19. For the number of cultivars involved, a reversal of one rank gave a correlation value of 0.80 which is considered to be high. A high mean rank correlation coefficient signifies that rankings of cultivars are similar among environments and vice versa. As shown in Table 3.19, the mean rank correlation values were moderate to high for MCS and relaxation time, moderate to low for RTC, cooking loss and gumminess, and extremely low for springiness. Lukow and McVetty (1991) found that for the majority of the parameters measured (flour protein content, mixograph development time, farinograph mixing tolerance index, and remix loaf volume, etc.), moderate or high mean rank correlations were observed except for test weight and thousand-kernel weight. It should be mentioned that low correlations observed for the parameters investigated in the present study were probably due to low cultivar (genetic) variability (Baker and Kosmolak, 1977).

Table 3.18. Matrix of Spearman correlation coefficients for maximum cutting stress of optimally cooked yellow alkaline noodles[a].

	B9	M9	S9	G0	M0	S0	Mean
B9		0.00	0.60	0.60	0.60	0.80	0.52
M9	0.00		0.80	0.80	0.80	0.40	0.56
S9	0.60	0.80		1.00	1.00	0.80	0.84
G0	0.60	0.80	1.00		1.00	0.80	0.84
M0	0.60	0.80	1.00	1.00		0.80	0.84
S0	0.80	0.40	0.80	0.80	0.80		0.72
Mean	0.52	0.56	0.84	0.84	0.84	0.72	0.72

[a] B9 = Beaverlodge 1999, M9 = Melfort 1999, S9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, S0 = Swift Current 2000.

Table 3.19. Means of the Spearman rank correlation coefficients of cooking loss and textural parameters of yellow alkaline noodles.

Parameters	Mean Rank Correlation[a]
Cooking Loss	0.56
MCS[b]	0.72
RTC[b]	0.43
Gumminess	0.64
Springiness	0.08
Relaxation Time	0.77

[a] means are averaged over 15 environment comparisons.
[b] MCS = maximum cutting stress, RTC = resistance to compression.

As indicated by the rank correlation results, cultivar by environment interactions were due not only to changes in magnitude but reversals of rank, especially for cooking loss, RTC, and gumminess. Thus, multiple environments appeared to be required to accurately assess the cultivars for those parameters. Regarding springiness, the remarkably low rank correlations observed can be attributed to the extremely low variability among the four cultivars studied. Since location was the only significant effect found for springiness, some effort might be made in the future to identify environments which will produce YAN with higher springiness. However, variability for springiness within the CWRS wheat class is still likely present as suggested by the results for AC Majestic which showed higher springiness than the other four cultivars examined.

3.3.11 Stability Analyses

As discussed, the cultivar by environment effects observed for the parameters investigated were due to changes in magnitude and reversals of rank, however, the rank correlation values can be greatly reduced if one or two cultivars are very responsive to changes in environment. Although only four cultivars were involved in the present study, stability analyses could further investigate the nature of the cultivar by environment interaction by identifying which cultivar(s) was most likely to be involved in the interaction effect. For each cultivar and parameter, stability analysis was performed by regressing the mean of a given cultivar on the environment mean of all other cultivars in each environment. The slope (b) of the regression was defined as the stability of the cultivar for that parameter. Table 3.20 presents the b values for each cultivar and parameter examined. Cultivar with a higher slope (b > 1) were considered more responsive to environmental variations than cultivar with a lower slope (b < 1) (Lukow and McVetty, 1991). In general, AC Barrie which on average had the least favorable cooking and noodle textural properties was overall the most responsive (b > 1) to changes in environment (Table 3.20). Katepwa was also quite responsive to environmental variations (b > 1) for a number of parameters. AC Domain and CDC Teal appeared to be more stable across the environments (b < 1 or ~ 1).

It should be noted that although the present study only involved a few numbers of cultivars, the findings as discussed below, suggest that in early generation of breeding lines where greater genetic differences exist among lines, screening for lines with good cooking and noodle textural properties could be done adequately in any environment even for those parameters with significant interaction effects as indicated by the low rank correlations. The rationale for this statement is that for a number of the parameters studied, reversals of rank only occurred within the two distinct groups of cultivars. For example, for cooking loss,

Table 3.20. Cultivar stability on cooking and textural properties of yellow alkaline noodles made from Canada Western Red Spring Wheat cultivars grown in six western Canada environments.

Cultivar	Parameter	Slope of Regression (b)
AC Barrie	Cooking Loss	0.84
	MCS	1.21
	RTC	1.63
	Springiness	1.09
	Gumminess	0.54
	Relaxation Time	1.28
AC Domain	Cooking Loss	0.77
	MCS	0.82
	RTC	0.65
	Springiness	0.80
	Gumminess	0.96
	Relaxation Time	0.61
Katepwa	Cooking Loss	1.34
	MCS	1.11
	RTC	1.18
	Springiness	0.63
	Gumminess	0.83
	Relaxation Time	1.01
CDC Teal	Cooking Loss	1.07
	MCS	0.77
	RTC	0.08
	Springiness	1.01
	Gumminess	1.04
	Relaxation Time	0.92

although CDC Teal and Katepwa were relatively less stable (b > 1) thereby resulted in reversal of their rankings with AC Domain across the environments, AC Barrie which consistently had the highest cooking losses over all the environmental ranges investigated could easily be distinguished from the other three cultivars (Figure 3.6). This indicates that in early stages of a breeding program, single environment testing might be adequate enough for identifying and screening out lines with high cooking losses, thereby reducing the amount of time and resources in the selection process. Similarly, reversals of rank occurred within the two distinct groups of cultivars for gumminess and relaxation time. Figure 3.7 and 3.8 show that Katepwa and AC Domain consistently had higher gumminess and relaxation time values than CDC Teal and AC Barrie over the environmental ranges examined. Thus, it is reasonable to speculate that selection for lines with higher gumminess and relaxation time values can also be done in any environment since cultivar by environment interactions only occur within the group.

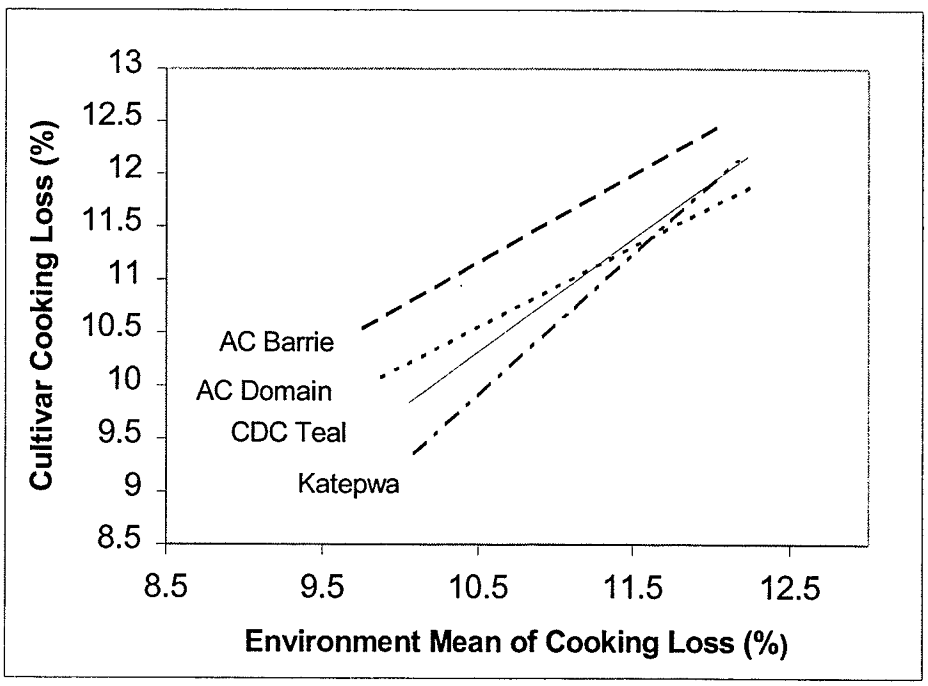

Figure 3.6. Cultivar stability on cooking loss. The slope (b) of AC Barrie, AC Domain, Katepwa, and CDC Teal were 0.84, 0.77, 1.34, and 1.07, respectively.

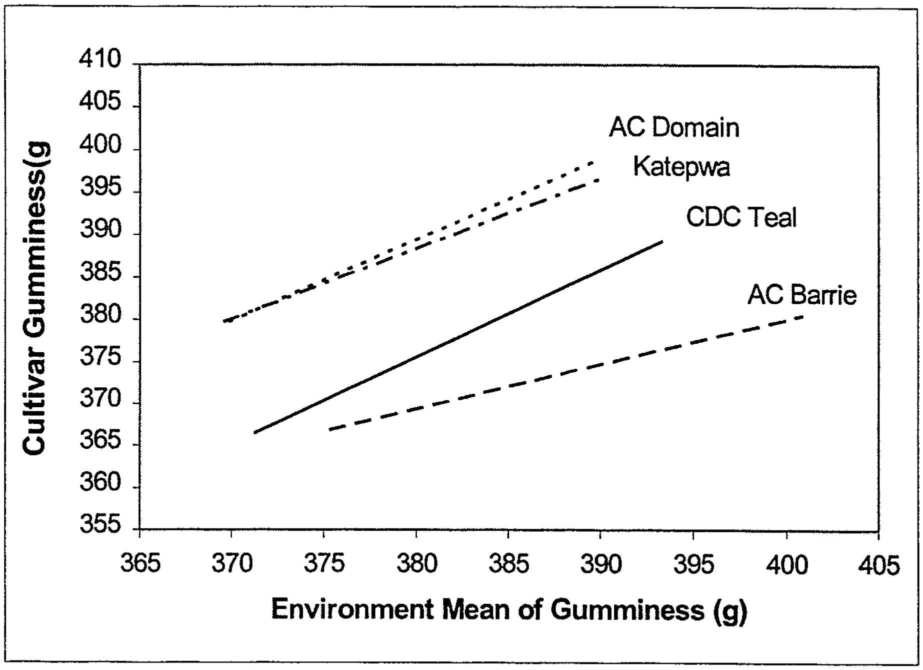

Figure 3.7. Cultivar stability on gumminess. The slope of AC Barrie, AC Domain, Katepwa, and CDC Teal were 0.54, 0.96, 0.83, and 1.04, respectively.

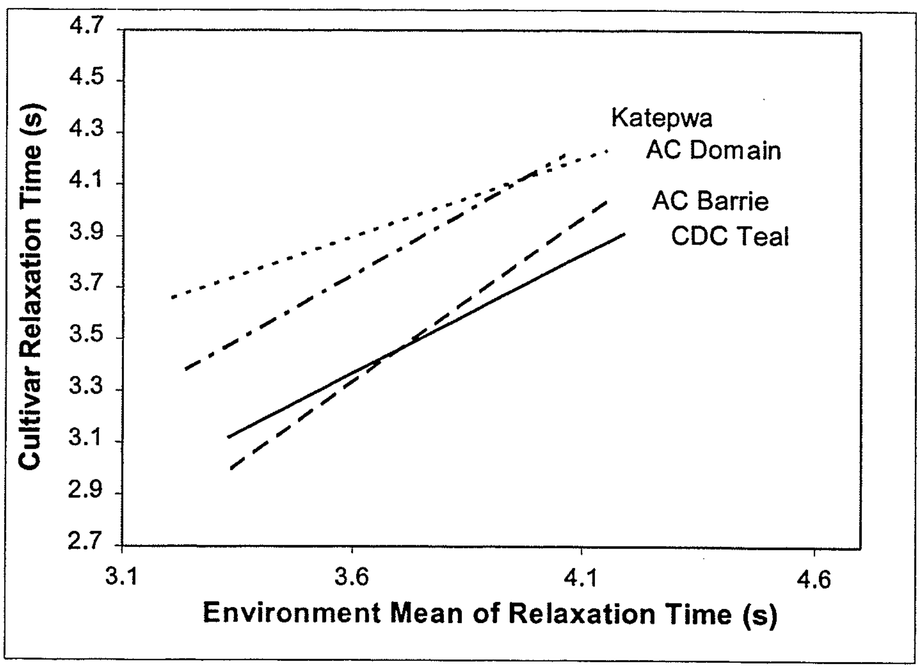

Figure 3.8. Cultivar stability on relaxation time. The slope of AC Barrie, AC Domain, Katepwa, and CDC Teal were 1.28, 0.61, 1.01, and 0.92, respectively.

3.4 CONCLUSIONS

For the CWRS wheat cultivars and growing environments involved in this study, the variance for environment was much greater than for cultivar for the flour characteristics and noodle cooking properties investigated. Alkaline noodle texture was influenced by both the protein and starch characteristics of flour. MCS and gumminess were related to protein and gluten contents as well as RVA parameters of flour paste. RTC was found to be positively related to wet gluten content. Among the RVA parameters, SFV and SSB appeared to better characterize MCS and relaxation time. Gumminess was found to be negatively related to SBD and positively to SFV and SSB.

Both cultivar and environment had significant effects on the cooking and textural properties of YAN, yet location was the predominant effect. Interactions between cultivar and environment were significant for most of the parameters studied and were due to reversals of rank. Results from the stability test revealed that while AC Barrie was overall the least stable cultivar across environments, AC Domain and CDC Teal were relatively more stable. From a plant breeder's point of view, it is reasonable to speculate that in early generation of breeding lines where greater genetic differences exist among lines, screening for lines with good cooking and noodle textural properties could be done adequately using samples composited over growing environments. However, for cultivars within the CWRS wheat class, multiple environment testing appeared to be important to accurately evaluate their cooking and textural properties in noodles. This practice might not be necessary since the Canadian grain handling system involves co-mingling of varieties grown in different locations to ensure customers of consistent high quality as being reflected in the present study since the composite CWRS sample was found to produce firmer noodles than individual cultivars. This could be due to the better grain quality and more optimum protein and starch characteristics that the composite sample possessed. The composite sample can be improved by eliminating cultivars such as AC Barrie, which produce YAN with less desirable cooking and textural properties. Nevertheless, since location had such a great influence on noodle eating properties, selection of CWRS wheat cultivars by location may be appropriate to meet specific needs of the customer. More research is required to elucidate what the important environmental factors are in affecting the quality of wheats for noodle production. As well, more work should be done to verify the relationships between instrumental measurements and sensory perception of noodle textural properties, especially for springiness or elasticity.

CHAPTER 4

EFFECTS OF CULTIVAR, ENVIRONMENT AND THEIR INTERACTIONS ON COLOR AND SPECKINESS OF YELLOW ALKALINE NOODLES

4.1 INTRODUCTION

Color and appearance are important quality criteria for YAN. Ideally, YAN should have a bright yellow color with minimal level of specks or discolored spots. YAN with a dull brown or greenish color is undesirable (Kruger et al., 1992). It is not uncommon for raw YAN to be used one day after processing thereby allowing the development of discoloration and specks. Therefore, the stability of color and specks over storage are important to the overall appearance of YAN.

It is known that the yellow color of YAN is attributed to the naturally occurring flour pigment flavones which develop yellowness in alkaline conditions. Moss (1971) suggested that the yellow color might also be partly governed by the presence of germ particles in the flour.

Protein content and flour-grade color are known to be inversely related to noodle brightness (Baik et al., 1995; Konik et al., 1993; Miskelly, 1984; Miskelly and Moss, 1985; Moss, 1971). Baik et al. (1995) also found that a* (red and green discoloration) value of alkaline noodle dough measured at 75 hr after preparation was highly positively related to protein content.

PPO and peroxidase activities are believed to be responsible for the time-dependent darkening effect of noodles. Though not fully understood, the appearance of discolored spots in noodles might originate from the loci of contaminating bran particles in the flour since PPO (and peroxidase) is mainly located in the bran layers (Hatcher et al., 1999; Hatcher and Kruger, 1993). Consideration of color is more important with raw than with boiled noodles. This is because raw YAN can be stored for up to one day before use allowing the development of gray discoloration, whereas during boiling, PPO is inactivated and the darkening components may leach out of the noodle (Miskelly, 1984; Kruger et al., 1992). Some studies have found that PPO activity was positively linked to L*, a*, and b* values (Baik et al., 1995; Kruger et al., 1994b). However, Baik et al. (1995) could not find a significant relationship between PPO activity and L* using another set of samples of a different wheat class. Hatcher et al. (1999) also showed that PPO activity was not responsible for the differences in the L* and a* values, and the darkness of specks of the raw alkaline noodle sheets prepared from the two Canadian cultivars. Although the relationship between peroxidase activity and brownness of macaroni has been recognized (Kobrehel et al., 1972), the role of peroxidase which oxidizes similar phenolic compounds and produces similar quinones as PPO on the time-dependent darkening effect of noodles remains uncertain.

Many major wheat exporting countries such as Australia, the U.S. and Canada have been developing hard-grained wheat varieties targeted at the Asian market. Although CWRS wheat is specifically designed for breadmaking purposes, its flour is often used for blending purposes in Asia to improve the processing, cooking or eating requirements of noodles, especially YAN (Bin Xiao Fu, personal communication; Chen, 1993). Currently, most Canadian wheat is exported by class, which is composed of registered varieties or cultivars grown across western Canada. However, there is growing interest from Asian clients in variety specific information as it relates to noodle production. This information is currently not available. Therefore, studying the noodle making quality of CWRS wheat cultivars appears to be beneficial to the Canadian grain industry. Evaluation of wheat varieties using samples blended over replicates and growing environments would lead to erroneous conclusions if there were a large cultivar by environment interaction effect. Therefore, the effect of cultivar, environment, and their interactions must be characterized in order to determine whether differences exist among CWRS wheat cultivars in their noodle making properties.

There is very little information regarding the relative effects of cultivar, environment and their interactions on the color and appearance of noodles. Moss (1971) studied the difference in brightness and yellowness of YAN among six Australian wheat cultivars grown in two locations. The author found that environment effects were significant for both brightness and yellowness but cultivar effects and culitvar by location interactions were significant for yellowness only. The study of Vazquez (2000) involved 17 breeding lines grown in eight western Canadian environments (location and year) and found that although both cultivar and environment effects were significant, environment played a much greater role than cultivar on the stability of L* for both white salted and alkaline noodle sheets. Genotype by environment interactions were only significant for the stability of L* for alkaline noodle sheets but in a small magnitude compared to the environment effect. Ames et al. (2000) studied the color stability of white salted and alkaline noodle sheets prepared from some Canadian and Australian wheat genotypes grown in several locations within western Canada. Unlike the two studies discussed previously, they observed significant cultivar by environment effects for all color measurements for both noodle types. Similar to the results of Vazquez (2000), Ames et al. found that the contribution of the interaction effects was relatively small compared to the cultivar or environment main effects. As well, they observed a greater influence by the environment than the cultivar on both L* and b* measurements of white salted noodle sheets. Similar observations were found for alkaline noodle sheets, except that the contribution of environment and cultivar on L* and b* became similar by 24 hr. Thus, in general, environment appears to play a major role on determining the brightness and yellowness of noodles and cultivar by environment effects are relatively unimportant.

In short, studying the color and appearance of YAN made from CWRS wheat cultivars will be beneficial to the Canadian grain industry. To adequately evaluate these cultivars for their noodle characteristics, the growing environment should also be considered. However, only a few studies have looked at the relative effects of genotype, environment, and their interactions on noodle color characteristics, and none on speckiness. Therefore, the objectives of this study were:

1) To determine the relative contribution of cultivar, environment and their interactions to the color and speck characteristics of YAN prepared from CWRS wheat cultivars grown across western Canada.
2) To quantitate the differences among cultivars and among environments with regard to the color and speck characteristics of YAN made from five CWRS wheat cultivars grown in six environments across western Canada.
3) To investigate the relationship between grain and/or flour characteristics and color and speck characteristics of YAN.

4.2. MATERIALS AND METHODS

4.2.1 Wheat Samples

Four registered CWRS wheat cultivars were selected for the study based on a number of criteria. The variety Katepwa, was selected since it represents the CWRS class standard. AC Barrie was selected since it is the predominant variety grown in the class with an average acreage of 46 % in the 1999 and 2000 crop seasons. AC Domain and CDC Teal were selected due to their relatively weak and strong dough strength, respectively when compared to the other CWRS cultivars. Pedigrees of these cultivars are given in Table 4.1. The cultivars were grown in three locations within western Canada over two years (1999 and 2000). They were grown in a randomized complete block design and two out of the four field plots of each cultivar were used in the study. Only sound grains that qualified for the No. 1 or No. 2 grade in the Canadian grain grading system were included in the study. All four cultivars grown in Melfort (SK) and Swift Current (SK) for both years; Beaverlodge (AB) in 1999 and Glenlea (MB) in 2000 qualified as being sound. For comparative purposes, another CWRS cultivar AC Majestic (known for better flour color and yield) grown in year 2000's locations and a No.1 grade (13.5 % protein) composite CWRS wheat sample from the 2000 crop year harvest were included in the study. Over half of the grains of the year 2000 composite CWRS sample were represented by AC Barrie (44.8 %) and CDC Teal (12.6 %). AC Domain (4.0 %), Katepwa (3.7 %), and AC Majestic (1.9 %) represented a small percentage of the total acreage in the 2000 crop season.

Table 4.1. Pedigree of the Canada Western Red Spring wheat cultivars studied.

Cultivar	**Pedigree**
AC Barrie	Neepawa/Columbus//BW 90
AC Domain	BW 83/ND 585
Katepwa	Neepawa*6/CT244/3/Neepawa*6CI188154/2*Froccor
CDC Teal	BW 514/Benito//BW 38
AC Majestic	Columbus*2//Saric 70/Neepawa/3/Clms*5//Saric 70/Np

Information regarding the growing conditions could be retrieved for some of the environments. The tests at Melfort were grown on well-drained Black Chernozem silty clay loam soil, Beaverlodge on grey wooded soil, and Glenlea on poorly drained Scanterbery clay soil. At Melfort in 1999, precipitation during the growing season was near normal, but below normal temperatures delayed maturity in crops. In 2000, the moisture conditions in Melfort were poor in the spring but improved considerably at the end of May. However, the average growing season precipitation in June and July was 150 % of the normal. Temperatures were below normal early in the growing season but improved to near normal levels later in the season. With regard to Beaverlodge in 1999, the average growing season was extremely dry. Glenlea in 2000 had higher than normal precipitation in early growing season, but below normal moisture and above normal temperature at post-anthesis.

4.2.2 Milling and Storage of Samples

Wheat samples were held at room temperature for approximately five months after harvesting before milling. All samples were tempered to 16.0-16.5 % moisture, depending on the specific moisture level. Separate millings were carried out for the two field plots and years using a Tandem Buhler experimental mill (Martin and Dexter, 1991) at the GRL (Winnipeg, Manitoba). A check sample was milled after every four to eight samples to ensure similar milling conditions were being applied. Flour streams were combined on the basis of increasing ash content to make up 65 % patent flours. In commercial practice, the flour extraction rate used for making YAN can range from 40 % in Japan (Crosbie et al., 1999) to 75 % (straight run flour) in other countries depending on the market (Bin Xiao Fu, personal communication). A 65 % was chosen for this study since it would give us some insight into the quality of YAN made from a higher extraction rate flour and most other research studies on YAN used a similar extraction rate of 60 % (Akashi et al., 1999; Baik et al., 1995; Miskelly and Moss, 1985; Hatcher et al., 1999; Ross et al., 1997). About 20 g of flours were sub-sampled into 40-mL covered plastic containers placed inside Ziploc bags filled with nitrogen gas and stored at -20±5 °C before determining enzyme activities of flour samples. The rest of the flour samples and grain residues were placed in plastic bags and kept at 4 °C inside covered 20-L plastic pails.

4.2.3 Flour Alpha-amylase Activity

The soundness of grain samples was confirmed by testing their alpha-amylase activity with the Model 191 GAA (Perkin-Elmer Corp., Coleman Instruments Div., Oak Brook, IL) attached to a NGI Servogor 124 recorder according to the procedure described by Kruger and Tipples (1981) with minor modifications. The working waxy maize β-limit dextrin substrate was centrifuged at 2,000 rpm at 20 °C for 10 min instead of 15 min. Flour suspension (1 g / 5 mL 0.2 M sodium acetate buffer, pH 5.5 containing 1×10^{-3} $CaCl_2$) was rotated for 1 hour, centrifuged at 15,000 rpm at 4 °C for 20 min and then filtered through glass wool. Results were reported as the average of two analyses from one extraction and expressed as mg maltose $\times 10^{-3}$/g sample/min on an as is basis.

4.2.4 Flour Characteristics

Flour moisture, ash and Agtron color were determined according to AACC methods 44-15A, 08-01 and 14-30, respectively (AACC, 1995) with minor modifications. Due to the limited amount of flour sample, 1 g and 3 g were used for determining moisture and ash content, respectively. Similarly, sample size was decreased in half (10 g of flour and 12.5 mL of distilled water) for determining Agtron color. Flour protein content (N $\times$ 5.7) was determined by combustion with a nitrogen determinator (Leco Corporation, St. Joseph, MI). All measurements were carried out in duplicate except for Agtron color with only one determination.

4.2.5 Polyphenol Oxidase Activity

Flour and ground grain PPO activities were determined using a YSI model 5300 biological oxygen monitor (Yellow Spring Instrument Co., Yellow Spring, OH, USA) according to the method of Hatcher and Kruger (1993). The assay was carried out at 37.0 °C. The flour (200 mg) or ground grain (25 mg) sample was added to 4 mL air-saturated 0.01M McIlvaine's buffer, pH 6.8, and monitored for 5-8 min to establish endogenous oxygen consumption. The substrate, 0.1 mL of 0.8 M catechol, was then added and the oxygen consumption was traced for 3-5 min. Results were corrected for auto-oxidation of catechol. Assay was performed in duplicate and the results are expressed as nanomoles of O_2 consumed per minute per gram at 37.0 °C.

4.2.6. Peroxidase Activity

Peroxidase activities were determined spectrophotometrically using commercially prepared substrate, 1-Step ABTS (Pierce 1-Step ABTS, Product No. 37615), a stopping reagent (2 M H_2SO_4) and a Molecular Devices ThermoMax Microplate Reader (Molecular Devices Corporation, Sunnyvale, CA). The stock peroxidase solution was prepared by dissolving an amount equivalent to 400 purpurogallin units of horseradish peroxidase (Sigma Product #P-8375, Sigma-Aldrick, MO, USA) in 100 mL of peroxidase stabilizing buffer (Sigma Product #P-9209, Sigma-Aldrick, MO, USA). It was protected from light by covering the volumetric flask with aluminum foil and was stored at 4 ° C.

Seven standards, ranging from 1×10^{-3} units to 7×10^{-3} units, were made fresh daily from the stock peroxidase solution and cold 0.1 M sodium acetate buffer, pH 4.2. The standards were made up in amber plastic microcentrifuge tubes, vortexed, and stored in a holder on ice in a Styrofoam box throughout the entire assay. The Styrofoam box was kept refrigerated at 4 °C when not in use.

Two extractions were performed per flour sample. Samples from both crop years were analyzed together with the two plots and extractions being blocked. Flour samples of 500±2 mg were weighed into 12-mL centrifuge tubes. Extraction buffer was made daily by combining five parts of cold 0.1 M sodium acetate buffer, pH 4.2, and 1 part of peroxidase stabilizing buffer. A maximum of 24 sample extracts were prepared per assay. Extraction buffer (5.0 mL) was pipetted to each tube. The tubes were immediately capped and vortexed followed by a 30-min mixing with a LabQuake rotating mixer (Barnstead|Thermolyne, Dubuque, IA) in a 4 °C cold room. After centrifugation at 14,000 rpm and 4 °C for 10 min, the supernatants were filtered through 0.45 μm syringe filters into glass tubes placed on a holder on ice in the Styrofoam box. Thirty minutes after centrifugation, the first eight sample extracts were diluted by adding 100 μl of extract to 900 μl of cold 0.1 M sodium acetate buffer, pH 4.2, and vortexed thoroughly. The diluted extracts were kept on ice in the same Styrofoam box.

Molecular Devices ThermoMax microplate reader connected to a computer using SoftMax Pro for Windows software, version 3.0 was used to collect the data. Immediately after the dilutions, 25 μl of each standard was added into each well of a 96-well (8 rows x 12 columns) microplate in duplicate by an electronic pipette. The two wells at the bottom row were then filled with a blank (each 25 μl) which was the sample extraction buffer. Then, 25 μl of each of the eight diluted sample extract was pipetted into 2 empty wells. Thus, each sample extract was analyzed in duplicate where the standards (or blanks) and samples were placed in alternating columns on the plate. Each of these 32 wells (8 rows x 4 columns) were then pipetted with 150 μL of ABTS substrate by an eight-channel electronic pipetter. The reactions were allowed for 1 min and then stopped immediately by adding 100 µL of 2 M sulfuric acid to each well with another eight-channel electronic pipetter. The plate was then placed into the microplate reader. Samples were automixed once and the optical density at a wavelength of 405 nm was measured. The software adjusted the readings by subtracting the blank values to produce the standard curve with linear regression values for calculating the sample peroxidase activity. Another set of eight samples was then diluted and analyzed in the same manner. All assays were completed within a week.

4.2.7 Noodle Preparation

All flour samples, including four mill checks per year were processed into YAN according to the method of Kruger et al. (1994a) in a randomized order with the two plots and two processing replicates being blocked. A 200 g (on a 14 % moisture basis) flour sample was mixed in a Hobart N50 mixer (Hobart Canada, North York, ON) at slow speed (setting 1) for 30 sec followed by an introduction of a 1 % kansui solution (9:1 sodium and potassium carbonates) over the next 30 sec to attain a final absorption of 32 %. Further mixing was done at slow speed for one min, then at high speed (setting 2) for another min and finally at slow speed for three min. Sheeting was done using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan) with the rollers maintained at 28 °C. A representative 25 cm long dough sheet obtained by sheeting the dough twice (folded once after the fist passage) at the 3.00 mm clearance was used for the seven subsequent passages at reducing gap width (3.00, 2.55, 2.15, 1.85, 1.57, 1.33 and 1.10 mm) over a 4.5-min period. After the last pass in processing, two pieces of noodle sheets were set aside for measuring raw noodle sheet color (3 layers) and specks (single layer), respectively. The rest of the noodle sheets were cut into noodles using a No. 12 cutter, then cut into approximately 3-cm long noodle strands.

4.2.8 Raw Noodle Sheet Color and Specks

Color of raw noodle sheets was measured with a Labscan II spectrocolorimeter (Hunterlab, Reston, VA, US) with a D65 illuminant using the CIE 1976 L*, a*, and b* color scale. Measurements were taken in triplicate at two locations (each represented about 7 cm^2 of the noodle sheet surface) near the center at 0, 1, 2, and 24 hr after processing. Noodle sheets were stored in sealed plastic containers at room temperature in between readings (Kruger et al., 1994a).

Image analysis of raw noodle sheets was performed as described by Hatcher et al. (1999) except a scanner (Microtek Scanmaker 4700) was used to capture the noodle sheet images. Each image represented a 5 × 5-cm section of the noodle surface for a total of 25 $cm^{2.}$ Each noodle sheet was scanned at 0, 1, 2, and 24 hr after preparation and was stored in a covered plastic container at room temperature between readings. Each image was analyzed by software designed at the GRL, which was developed in KS400 software (version 3.0, Carl Zeiss Vision, Hallbergmoos, Germany). Two imaging analysis variables, a Δ gray value, the minimum darkness that a discolored spots or specks must exceed from the background matrix to be identified and a MS were used to determine the number and the area density (darkness) of discolored spots or specks of raw YAN sheets during storage. A Δ gray value of 5 (the gray scale ranged from 0-225) and a MS value correspond to an actual size of 6000 μm^2 were used in this study.

4.2.9 Noodle Cooking and Cooked Color

Optimal cooking time, defined as the time required for the white core of the noodle strand to disappear, was determined by pressing noodle strands (5) against two plexiglas plates. One hour after processing, 25.0 g of noodles were cooked in boiling distilled water (~400 mL) in a 500-mL glass beaker heated by a ceramic hot plate. Table 4.2 presents the optimal cooking time for noodles prepared from the cultivars grown in each environment. The cooked noodles were drained into a sieve and then rinsed and cooled for 1 min with a constant stream of distilled water (20 °C). Excess water was then wiped off from the bottom of the sieve and the noodles were then placed into a plexiglas sample cup for color measurements. Results of the color measurements, the average of 6 readings was obtained using the Hunterlab (Labscan II, CIE 1976 L*, a*, and b* color scale) spectrocolorimeter with a D65 illuminant.

Table 4.2. Optimal cooking time[a] of yellow alkaline noodles made from five Canada Western Red Spring wheat cultivars grown in six western Canada environments.

Cultivars	Environments[b]						
	B9	M9	SC9	G0	M0	SC0	Cultivar Mean
AC Barrie	8.5	9	9	9	8	9.5	8.8
AC Domain	9	9	8.5	9.5	8	10.5	9.1
Katepwa	8	9	10	10	8	10	9.2
Teal	9	9	10	10	8	10.5	9.4
Majestic	-	-	-	10	8	10	9.3
Environment mean	8.6	9	9.4	9.7	8	10	9.2

[a] values were time in minute required to cook noodle sample to optimum averaged over two processing replications per plot duplicate (n=4).
[b] B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, M0 = Melfort 2000, SC0 = Swift Current 2000.

4.2.10 Statistical Analysis

All statistical analyses were performed with the SAS software (version 8.01, SAS Institute, Cary, NC, USA). PROC CORR was used to determine the Pearson correlation coefficients between the flour characteristics and color and specks parameters. Originally, PROC MIXED using the REML method was used to determine the significance of the fixed effects for the cooking and textural parameters. The fixed effects were cultivar, year, location (nested within year) and their interactions while the random effects were processing replications (nested within year) and field plot (nested within genotype, location, and year). However, PROC GLM using the ANOVA method was used in the end since it gave similar results to PROC MIXED especially when the random effects were taken into the account using a random /test q statement in the ANOVA model.

Pairwise comparisons of the least squares means of the cultivar and environment (defined as each location at each year) were performed using Tukey's studentized range test at 95 % significance level. Since AC Majestic was only grown in year 2000, a separate analysis was done to compare the least squares means of the five cultivars using the year 2000 data. Estimates of the relative contribution (or variance components) as a percentage of all the main and interaction effects to the color and specks characteristics were also determined by PROC MIXED (using REML). PROC CORR SPEARMAN was used to determine the rank correlation coefficients for cultivars in all environments (Lukow and McVetty, 1991). For each parameter, the mean of the rank correlations which was the average of all the rank correlations from the 15 environment comparisons was used.

4.3 RESULTS AND DISCUSSION

4.3.1 Grading Results

Grading results of samples from year 1999 and 2000 are presented in Table 4.3 and Table 4.4, respectively. In 1999, samples that were graded as No. 1 CWRS were AC Domain and CDC Teal from Beaverlodge, Katepwa from Melfort, and all samples from Swift Current. AC Barrie from Beaverlodge was downgraded to No. 3 CWRS since it had about 2.9 % immature green kernels. However, this sample was still included in the study after most of the green kernels were manually removed to achieve a better quality sample. Katepwa from Beaverlodge was downgraded to No. 2 CWRS also due to the presence of immature green kernels. For Melfort, AC Barrie, AC Domain and CDC Teal samples were downgraded to No. 2 CWRS as a result of frosted green kernels. In 2000, all grain samples were graded as No. 2 CWRS. Immature green kernel was the determinant factor for the downgrading of the grain samples from Melfort in 2000, except for plot #2 of AC Barrie which was downgraded as a result of failing to meet the minimum requirement for having 65 % of HVK. Bleached kernels, mildewed kernels, and percent HVK (48 to 51 %) were the grading determinants which resulted in the downgrading of samples from Glenlea. Grains from Swift Current were also downgraded due to bleached kernels or low levels of HVK (48 to 57 %).

Table 4.3. Summary of grading results of year 1999 grain samples[a].

Year 1999 Location	Cultivar	Grade	Comments
Beaverlodge	AC Barrie	3 CWRS[b]	2.9 % immature green kernels
	AC Domain	1 CWRS	-
	Katepwa	2 CWRS	immature green kernels
	CDC Teal	1 CWRS	-
Melfort	AC Barrie	2 CWRS	green caused by frost
	AC Domain	2 CWRS	green caused by frost
	Katepwa	1 CWRS	-
	CDC Teal	2 CWRS	green caused by frost
Swift Current	AC Barrie	1 CWRS	-
	AC Domain	1 CWRS	-
	Katepwa	1 CWRS	-
	CDC Teal	1 CWRS	-

[a]only one field plot per cultivar was evaluated.
[b]most green kernels were manually removed to improve sample quality.

Table 4.4. Summary of grading results of year 2000 grain samples.

Year 2000 Location	Cultivar	Plot #	Grade	Comments[a]
Glenlea	AC Barrie	10	2 CWRS	bleached
		19	2 CWRS	50 % HVK
	AC Domain	2	2 CWRS	mildewed, 51 % HVK
		17	2 CWRS	mildewed, 48 % HVK
	Katepwa	5	2 CWRS	bleached
		13	2 CWRS	mildewed, bleached
	CDC Teal	9	2 CWRS	mildewed
		15	2 CWRS	mildewed
	AC Majestic	8	2 CWRS	mildewed, HVK
		16	2 CWRS	mildewed, 51 % HVK
Melfort	AC Barrie	2	2 CWRS	47 % HVK
		13	2 CWRS	immature green
	AC Domain	3	2 CWRS	immature green
		20	2 CWRS	immature green
	Katepwa	4	2 CWRS	immature green
		7	2 CWRS	immature green
	CDC Teal	9	2 CWRS	immature green
		18	2 CWRS	immature green
	AC Majestic	10	2 CWRS	immature green
		14	2 CWRS	immature green
Swift Current	AC Barrie	5	2 CWRS	57 % HVK
		7	2 CWRS	bleached
	AC Domain	2	2 CWRS	48 % HVK
		22	2 CWRS	51 % HVK
	Katepwa	4	2 CWRS	bleached
		11	2 CWRS	bleached
	CDC Teal	8	2 CWRS	51 % HVK
		24	2 CWRS	bleached
	AC Majestic	1	2 CWRS	bleached
		10	2 CWRS	bleached

[a]HVK = hard vitreous kernels.

4.3.2 Flour Alpha-amylase Results

Alpha-amylase activity of flour samples is presented in Table 4.5. Sound flour should have an alpha-amylase activity of less than 5 mg maltose x 10^{-3} /g of flour/min (unit) which is equivalent to approximately 500 Brabender Units of amylograph viscosity. As shown, most of the flour samples had very low alpha-amylase activities (< 5 or ~ 5 units), thereby indicating sound flour.

Table 4.5. Alpha-amylase activity of flour samples[a].

Year	Location	Genotype	Alpha-Amylase Activity[b] (mg maltose x 10^{-3}/g sample/min.)
1999	Beaverlodge	AC Barrie	0.1
		AC Domain	0.1
		Katepwa	0.4
		CDC Teal	0.5
	Melfort	AC Barrie	1.4
		AC Domain	0.7
		Katepwa	2.7
		CDC Teal	6.6
	Swift Current	AC Barrie	0
		AC Domain	0
		Katepwa	0
		CDC Teal	0
2000	Glenlea	AC Barrie	1.2
		AC Domain	0.8
		Katepwa	2.0
		CDC Teal	3.1
		AC Majestic	0.7
	Melfort	AC Barrie	0.1
		AC Domain	0.3
		Katepwa	0.4
		CDC Teal	0.6
		AC Majestic	0.1
	Swift Current	AC Barrie	0
		AC Domain	0
		Katepwa	0.4
		CDC Teal	0.8
		AC Majestic	0
2000	Composite[c]		0.7

[a] values are means of two determinations per plot duplicate.
[b] results are based on as is flour moistures.
[c] composite = No.1CWRS sample obtained from the year 2000 harvest.

4.3.3 Flour and Wheat Characteristics Results

The ash and protein contents (Table AI.1), Agtron color, peroxidase, and PPO activities (Table AI.4) of each cultivar grown at each environment are shown in Appendix I. Cultivar and environment means of these characteristics are presented in Tables 4.6 to Table 4.8. It should be noted that since no PPO activity was detected in the flour samples, only wholemeal PPO activity is reported. In order to compare AC Majestic which was grown in year 2000 only with the other four cultivars, the cultivar means averaged over the three locations in year 2000 were used (Table 4.7). As revealed by the CV's, the variability of these characteristics were much higher among environments than among cultivars. The ash content, Agtron color, protein content, peroxidase and PPO activities of the four cultivars grown over two years ranged from 0.35 to 0.37 % (2.8 % CV), 82.8 to 86.7 (1.9 % CV), 13.0 to 13.4 % (1.5% CV), 324 to 374 optical density at 405 nm (6.7 % CV) and 1002 to 1241 nmoles O_2/min/g (8.9 % CV), respectively. Although slightly wider ranges (except for ash content) were observed among the five cultivars grown in year 2000 (Table 4.7), they were still much narrower than that among the environments (Table 4.8). For the environments, the ash content, Agtron color, protein content, peroxidase and PPO activities ranged from 0.31 to 0.42 % (13.9 % CV), 68.7 to 93.1 (10.4 % CV), 11.6 to 14.7 % (9.8 % CV), 265 to 399 optical density at 405 nm (13.7 % CV), and 618 to 2508 nmoles O_2/min/g (60.8 % CV), respectively (Table 4.7). Except for Agtron color, the values of all the characteristics of the CWRS composite sample from the year 2000 harvest were lower than that of the overall cultivar means (Table 4.7).

Table 4.6. Cultivar means[a] and standard deviations (SD) for flour and wheat characteristics of samples grown in 1999 and 2000.

	Flour Characteristics[b]				
Cultivar	Ash[c] (%)	Agtron[c]	Protein[c] (%)	Peroxidase Activity[c]	PPO Activity[d]
AC Barrie	0.36 (0.04)	86.7 (6.7)	13.1 (1.2)	374 (68)	1185 (724)
AC Domain	0.35 (0.06)	82.8 (12.1)	13.3 (1.5)	345 (46)	1166 (591)
Katepwa	0.37 (0.06)	84.5 (7.7)	13.0 (1.2)	324 (52)	1241 (872)
CDC Teal	0.36 (0.05)	83.9 (10.1)	13.4 (1.1)	327 (28)	1002 (458)
Mean	0.36	84.5	13.2	342.5	1148.5
SD	0.01	1.6	0.2	23.0	102.7
C.V.	2.78	1.9	1.5	6.7	8.9

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD).
[c]determined using flour samples, peroxidase unit = optical density at 405 nm.
[d]PPO = polyphenol oxidase, determined using ground grain samples, unit = nmoles oxygen/min/g of sample.

Table 4.7. Cultivar means[a] and standard deviations (SD) for flour and wheat characteristics of samples grown in 2000.

	Flour Characteristics[b]				
Cultivar	Ash[c] (%)	Agtron[c]	Protein[c] (%)	Peroxidase Activity[c]	PPO Activity[d]
AC Barrie	0.39 (0.02)	85.3 (8.1)	13.1 (1.3)	394 (47)	1485 (939)
AC Domain	0.39 (0.05)	79.5 (14.7)	13.6 (1.4)	353 (21)	1426 (746)
Katepwa	0.40 (0.05)	83.4 (9.7)	12.9 (1.1)	318 (29)	1647 (1107)
CDC Teal	0.39 (0.04)	80.5 (13.5)	13.3 (1.4)	337 (24)	1250 (547)
AC Majestic	0.39 (0.02)	81.4 (10.5)	13.2 (1.4)	365 (34)	1828 (1080)
Mean	0.39	82.0	13.2	353	1527
SD	0.004	2.3	0.3	29	220
C.V.	1.0	2.8	2.3	8	14
Composite[e]	0.36 (0.01)	85.9 (0.2)	12.9 (0)	345 (7)	1206 (54)

[a]means are averages of two processing replications per plot duplicate over three locations (n=12).
[b]values are mean (SD).
[c]determined using flour samples, peroxidase unit = optical density at 405 nm.
[d]PPO = polyphenol oxidase, determined using wholemeal samples, unit = nmoles oxygen/min/g of sample.
[e]composite = No.1CWRS composite sample from the year 2000 crop harvest.

Table 4.8. Environment means[a] and standard deviations (SD) for flour and wheat characteristics.

	Flour Characteristics[b]				
Environment[c]	Ash[d] (%)	Agtron[d]	Protein[d] (%)	Peroxidase Activity[d]	PPO Activity[e]
B9	0.31 (0.02)	86.7 (1.8)	13.0 (0.3)	341 (23)	787 (85)
M9	0.37 (0.03)	80.5 (4.2)	14.7 (0.2)	399 (35)	974 (107)
SC9	0.31 (0.02)	93.1 (1.7)	11.9 (0.8)	265 (30)	772 (70)
G0	0.42 (0.03)	68.7 (9.1)	14.2 (0.4)	382 (42)	2508 (486)
M0	0.41 (0.02)	90.7 (2.2)	11.6 (0.3)	329 (19)	618 (49)
SC0	0.35 (0.02)	87.1 (3.4)	13.9 (0.6)	341 (42)	1230 (124)
Mean	0.36	84.5	13.2	342.5	1148.5
SD	0.05	8.8	1.3	46.8	698.45
C.V.	13.89	10.4	9.8	13.7	60.8

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.
[d]determined using flour samples, peroxidase unit = optical density at 405 nm.
[e]PPO = polyphenol oxidase, determined using ground grain samples, unit = nmoles oxygen/min/g of sample.

4.3.4 Cultivar Comparisons

4.3.4.1 Color measurement

Ideally, raw YAN should have a bright yellow color with little discoloration during storage. The time-dependent discoloration is perceived as the development of reddish-brown spots on noodle surface attributed to the reaction of labile quinones (phenolic oxidation products) with the free amines, and sulfhydryls of proteins (Hatcher and Symons, 2000b). YAN with high L* (brighter) and b* (more yellow) values and a neutral a* value (positive value indicates increased redness and negative values indicates increased greenness) is preferred.

The brightness (L*), redness (a*), and yellowness (b*) values of raw noodle sheets prepared from each cultivar grown at each environment are presented in Appendix IV, Tables AIV.1 to AIV.3. Cultivar means of brightness (L*), redness (a*), and yellowness (b*) of raw noodle sheets over time are illustrated in Figures 4.1 to 4.3. Figure 4.1 shows that brightness (L* values) of raw noodle sheets continuously decreased over time for all the cultivars. The a* values of the raw noodle sheets made from the four cultivars increased with time, however, only the raw noodle sheets made from AC Barrie had positive a* values (indicating redness) over the entire storage period (Figure 4.2). Yellowness (b* values) of the raw noodle sheets increased rapidly during the first hour and then increased more gradually thereafter (Figure 4.3). A similar observation was made by Kruger et al. (1992) except that a decrease of b* values from 2 to 24 hr of storage was found in their study.

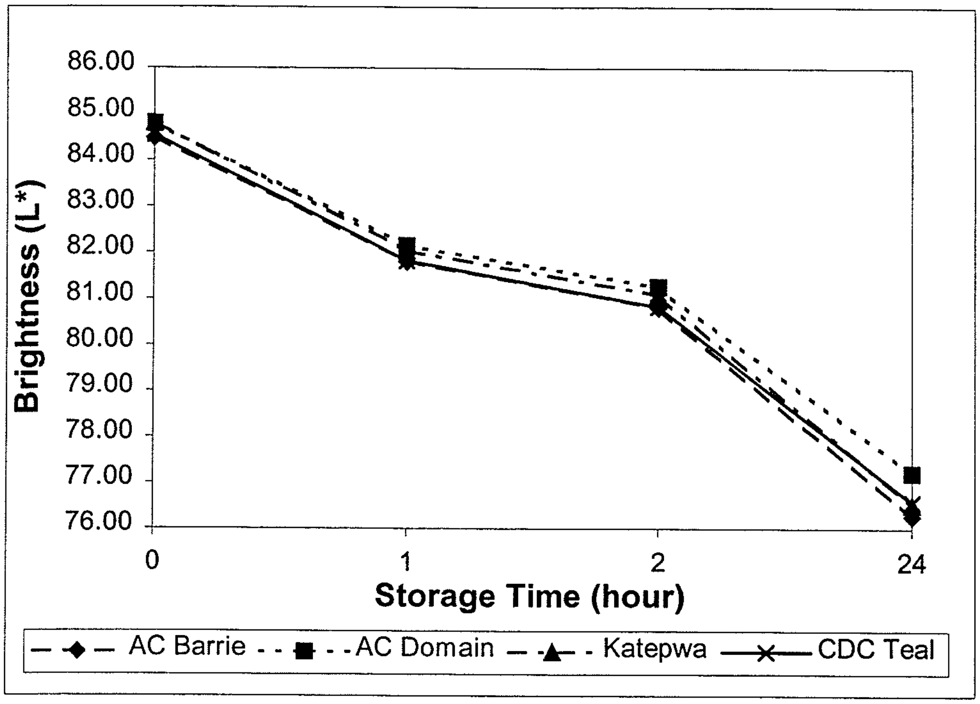

Figure 4.1. Cultivar means of brightness (L*) of raw yellow alkaline noodle sheets changed over time. Results are the average value of two processing replications per plot duplicate over six environments (n=24).

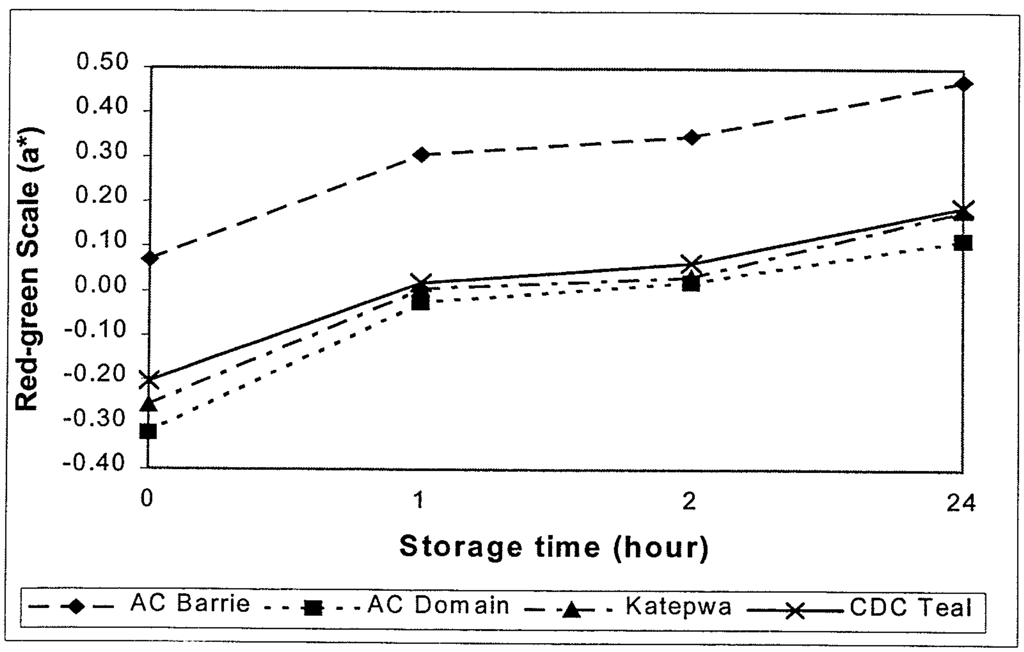

Figure 4.2. Cultivar means of redness and greenness (a*) of raw yellow alkaline noodle sheets over time. Results are the average value of two processing replications per plot duplicate over six environments (n=24).

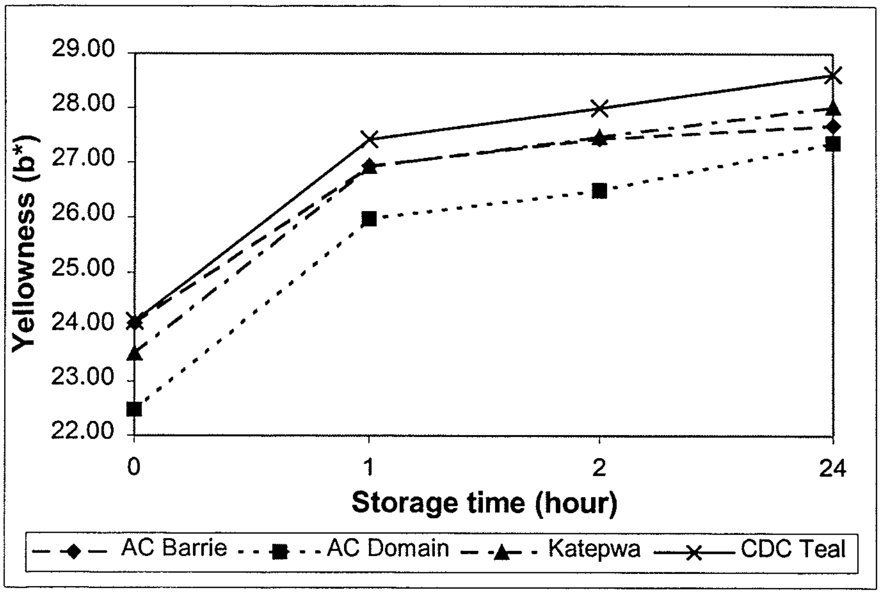

Figure 4.3. Cultivar means of yellowness (b*) of raw yellow alkaline noodle sheets over time. Results are the average value of two processing replications per plot duplicate over six environments (n=24).

The same data with regard to cultivar means of L* (brightness), a* (redness) and b* (yellowness) values of the raw noodle sheets during a 24-hr storage period is shown in Appendix V, Tables AV.1 to AV.3. The color (L*, a*, b* values) characteristics of the optimally cooked noodles is presented in Table 4.9. In general, narrow ranges among cultivars were found for the color values as indicated by their CV's (Appendix V and Table 4.9). Note that the CV's of a* values were not determined since the a* values involved small and negative numbers, therefore their CV's would become very large and non-meaningful.

As indicated by the ANOVA results shown in a later section (Table 4.15 to Table 4.18), cultivar effects were significant for all the color parameters measured except for the L* values of raw noodle sheets at 0, 1, and 2 hr of storage and L* and b* values of the optimally cooked YAN. Comparison of

Table 4.9. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for color parameters of optimally cooked yellow alkaline noodles (YAN) made from Canada Western Red Spring Wheat cultivars.

	Cooked YAN Color[b]		
Cultivar	L*	a*	b*
AC Barrie	66.63 (1.16) a	-1.88 (0.27) ab	26.76 (1.55) a
AC Domain	66.41 (1.43) a	-1.99 (0.33) bc	26.42 (2.33) a
Katepwa	66.43 (0.97) a	-2.05 (0.38) c	26.86 (1.59) a
CDC Teal	66.46 (1.79) a	-1.74 (0.32) a	27.04 (1.67) a
Mean	66.48	-1.91	26.77
SD	0.10	0.14	0.26
CV	0.15		0.97

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).

cultivar means using Tukey's multiple range test ($P \leq 0.05$) indicated no differences among the cultivars for the L* values except for those measured at 24 hr after processing. At that time, noodle sheets made from AC Barrie were found to be significantly less bright than those made from AC Domain (Appendix V, Table AV.1). AC Barrie displayed significantly higher a* values than all other cultivars over the entire 24-hr storage period (Appendix V, Table AV.2), thus indicating a less desirable color. During storage (0 to 2 hr), noodle sheets prepared from AC Domain were significantly lower in b* values than those made from the other cultivars. At 24 hr, the b* values of noodle sheets made from AC Domain and AC Barrie were lower than that of CDC Teal (Appendix V, Table AV.3).

Examination of optimally cooked YAN indicated cultivar color differences were only significant for a* values. Cooked YAN made from all cultivars displayed negative a* values with Katepwa having the lowest value indicating its noodles had a greener tinge than those of AC Barrie and CDC Teal (Table 4.9). The color characteristics of cooked YAN made from each cultivar grown at each environment are shown in Appendix IV, Table AIV.4.

In order to compare AC Majestic and the year 2000 CWRS composite sample with the other four cultivars, only the year 2000 data were used to calculate the cultivar means of the L*, a*, and b* values for analyses. No significant differences were found among the five cultivars for the brightness of the raw noodle sheets at any time interval (Table 4.10). Also, the brightness of the raw noodle sheets prepared with the composite sample was similar to that of the individual cultivar means (Table 4.10).

Table 4.10. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for L* (brightness) of raw yellow alkaline noodle sheets made from five Canada Western Red Spring Wheat cultivars averaged over three locations in year 2000.

	L* (brightness)[b]			
Cultivar	0 hr	1 hr	2 hr	24 hr
AC Barrie	84.65 (1.35) a	81.83 (1.35) a	80.81 (1.45) a	76.30 (1.34) a
AC Domain	84.60 (1.77) a	81.74 (2.28) a	80.81 (2.41) a	76.78 (2.61) a
Katepwa	84.80 (1.17) a	81.96 (1.49) a	81.01 (1.57) a	76.57 (1.91) a
CDC Teal	84.30 (1.77) a	81.51 (2.09) a	80.47 (2.16) a	76.40 (2.07) a
AC Majestic	84.92 (1.43) a	81.95 (1.76) a	80.90 (1.71) a	76.37 (1.96) a
Mean	84.65	81.80	80.80	76.48
SD	0.23	0.18	0.20	0.19
CV	0.27	0.22	0.25	0.25
Composite[c]	84.72	81.77	80.72	75.90

[a]means are averages of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]composite = No.1CWRS composite sample from the year 2000 crop harvest.

AC Barrie displayed significantly higher a* values in raw noodle sheets than all other cultivars, including AC Majestic (Table 4.11). The a* value of the raw noodle sheets made from the composite sample was lower than that made from AC Barrie but higher than that made from the other four cultivars (Table 4.11).

Table 4.11. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for a* (red-green scale) of raw yellow alkaline noodle sheets made from five Canada Western Red Spring Wheat cultivars averaged over three locations in year 2000.

	a* (red-green)[b]			
Cultivar	0 hr	1 hr	2 hr	24 hr
AC Barrie	0.16 (0.33) b	0.43 (0.28) b	0.49 (0.25) b	0.60 (0.31) b
AC Domain	-0.29 (0.23) a	0.01 (0.22) a	0.08 (0.23) a	0.21 (0.36) a
Katepwa	-0.26 (0.18) a	0.03 (0.21) a	0.07 (0.25) a	0.27 (0.35) a
CDC Teal	-0.21 (0.24) a	0.02 (0.21) a	0.07 (0.19) a	0.24 (0.28) a
AC Majestic	-0.21 (0.29) a	0.06 (0.30) a	0.10 (0.26) a	0.19 (0.34) a
Mean	-0.16	0.11	0.16	0.30
SD	0.18	0.18	0.18	0.17
Composite[c]	0.05	0.27	0.29	0.31

[a]means are averages of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]composite = No.1CWRS composite sample from the year 2000 crop harvest.

In terms of the yellowness of the raw noodle sheets, AC Majestic and AC Domain were significantly lower than AC Barrie and CDC Teal at 0 hr and were significantly lower than CDC Teal at 24 hr (Table 4.12). The yellowness of the composite sample noodle sheets were slightly higher than those of the individual cultivar noodle sheets at 1 and 2 hr but were slightly lower than those of the noodle sheets made from AC Barrie and CDC Teal at 0 and 24 hr, respectively (Table 4.12).

Table 4.12. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for b* (yellowness) of raw yellow alkaline noodle sheets made from five Canada Western Red Spring Wheat cultivars averaged over three locations in year 2000.

	b* (yellowness)[b]			
Cultivar	0 hr	1 hr	2 hr	24 hr
AC Barrie	23.81 (0.83) b	26.83 (0.83) a	27.37 (0.87) a	27.47 (1.00)ab
AC Domain	21.80 (2.06) a	25.36 (2.22) a	25.87 (2.11) a	26.83 (1.97) a
Katepwa	22.98 (2.15)ab	26.28 (1.87) a	26.90 (1.79) a	27.52 (1.46)ab
CDC Teal	23.51 (2.11) b	26.78 (1.93) a	27.40 (1.88) a	28.23 (1.59) b
AC Majestic	21.89 (1.87) a	25.41 (1.69) a	25.91 (1.62) a	26.38 (1.20) a
Mean	22.80	26.13	26.69	27.29
SD	0.92	0.72	0.76	0.71
CV	4.04	2.76	2.85	2.60
Composite[c]	23.71	27.63	28.10	27.85

[a]means are averages of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]composite = No.1CWRS composite sample from the year 2000 crop harvest.

No significant differences were found for cooked noodle brightness or yellowness among the five cultivars. CDC Teal however, displayed significantly higher a* values (less green) than the other four cultivars (Table 4.13). Compared with most cultivar means, slightly higher L*, a* and b* values in cooked YAN were found for the composite sample (Table 4.13). These results indicated that raw noodle sheets prepared with the CWRS composite sample displayed a similar degree of brightness but slightly higher degree of redness and yellowness than most of the individual CWRS cultivars studied. However, whether the differences were great enough to be perceived visually remain unclear. An advantage of using individual cultivars (except for AC Barrie) over the composite sample to prepare YAN might be less discoloration during storage.

Table 4.13. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for color parameters of optimally cooked yellow alkaline noodles (YAN) made from five Canada Western Red Spring Wheat cultivars averaged over three locations in year 2000.

	Cooked YAN Color[b]		
Cultivar	L*	a*	b*
AC Barrie	66.33 (1.03) a	-2.07 (0.13) a	26.68 (1.10) a
AC Domain	66.04 (1.78) a	-2.15 (0.36) a	25.99 (2.65) a
Katepwa	66.10 (1.05) a	-2.22 (0.25) a	26.69 (1.71) a
CDC Teal	65.34 (1.86) a	-1.79 (0.35) b	26.68 (1.97) a
AC Majestic	65.88 (1.30) a	-2.27 (0.28) a	26.53 (1.62) a
Mean	65.94	-2.10	26.51
SD	0.37	0.19	0.30
CV	0.56		1.13
Composite[c]	66.19	-1.86	27.88

[a]means are averages of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]composite = No.1CWRS composite sample from the year 2000 crop harvest.

4.3.4.2 Speck measurement

Discolored spots or specks on noodle surface are undesirable. The limitation of using the colorimetric method for measuring noodle color is that they only describe the overall color of the noodle surface. Image analysis however, can be used to quantitate the number of specks and the darkness (area density) of the individual specks.

Speck measurements done at 0 hr were not analyzed since uneven hydration of flour particles immediately after processing (0 hr) caused exaggerated readings (Hatcher et al., 2000a). Figures 4.4 and 4.5 illustrate the changes in the number and mean area density of specks per image over time for each cultivar averaged over the six environments at a Δ gray level of 5 and a MS (the minimum size for a speck to be identified) equivalent to 6000 μm^2. The detailed data for each cultivar grown at each environment is shown in Appendix IV, Tables AIV.5 and AIV.6.

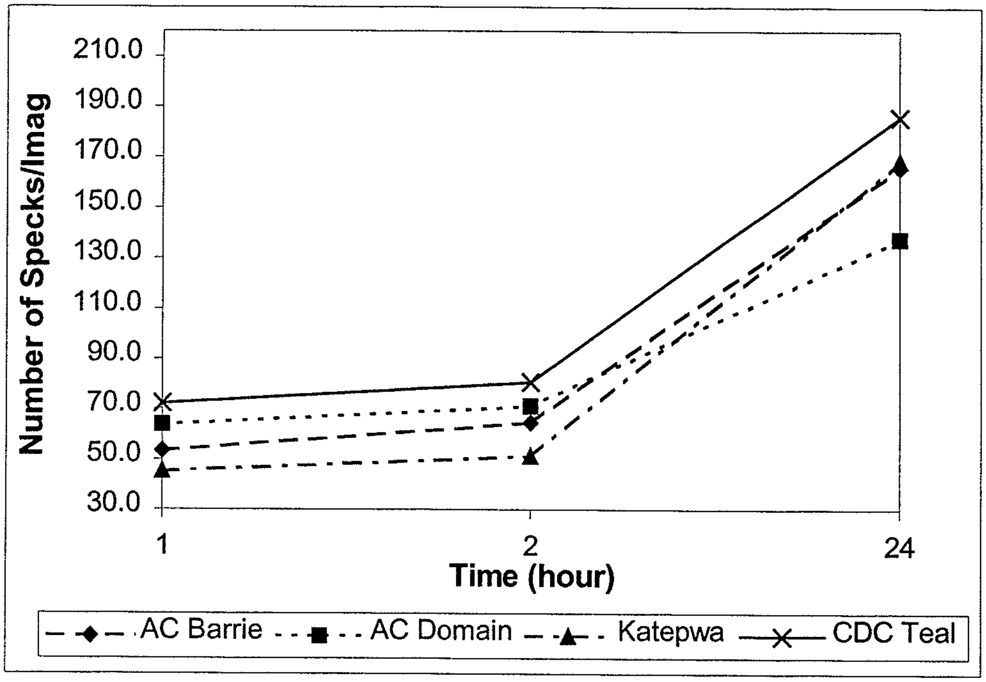

Figure 4.4. Cultivar means of number of specks per image of raw yellow alkaline noodle sheets over time. Δ gray value of 5 and minimum size threshold equivalent to 6000 μm^2 were used in the analysis. Results are the average value of two processing replications per plot duplicate over six environments (n=24).

Results indicated that the number of specks per image for each cultivar increased with time at a different rate (Figure 4.4). In agreement with the ANOVA results that will be discussed later, differences in the number of specks per image among cultivars were significant by 24 hr where noodle sheets prepared with AC Domain (138 specks/image) were found to have fewer number of specks than those made from CDC Teal (186 specks/image) (Figure 4.4 and Appendix V, Table AV.4). For the year 2000 data where AC Majestic was also included, no significant differences were observed at any time for the number of specks per image among the five cultivars studied (Appendix V, Table AV.5). The number of specks per image for the year 2000 CWRS composite sample at 1, 2 and 24 hr were 34, 41, and 146, respectively which were fewer than that of the individual cultivar means obtained in year 2000 (Appendix V, Table AV.5).

The mean area density of specks per image decreased with time (Figure 4.5, Appendix V, Table AV.6). Since the specks were measured on a 0-225 gray level scale with a low value indicating a darker speck, it can be seen that overall, the darkness of specks increased with time. At 1 and 2 hr, the mean area densities of noodle sheets prepared with AC Domain (177 and 173, respectively) were significantly higher (thus the specks were less dark) than that of AC Barrie (174 and 170, respectively) and CDC Teal (175 and 170, respectively) (Appendix V, Table AV.6). The specks of noodle sheets made from Katepwa (172) was also significantly less dark than that made from AC Barrie at 2 hr. At 24 hr, the specks of the AC Domain's noodle sheets (159) were overall less dark than the specks of the AC Barrie's noodle sheets (156). It should be mentioned that although statistical differences were found among cultivars for the mean speck darkness of noodle sheets, the variations among the cultivars were still very small (0.8 to 0.9 % CV as shown in Appendix V, Table AV.6). Regardless, these findings were consistent with the observed differences in brightness, particularly at 24 hr for the raw noodle sheets. Similar observations were reported by Hatcher et al. (1999). In the present study, the overall noodle sheet color (at 24 hr) and specks of AC Barrie were found to be relatively less bright. In contrast, AC Domain's noodle sheets which were on average the brightest at 24 hr were also found to have fewer number of specks that appeared less dark than AC Barrie's noodle sheets.

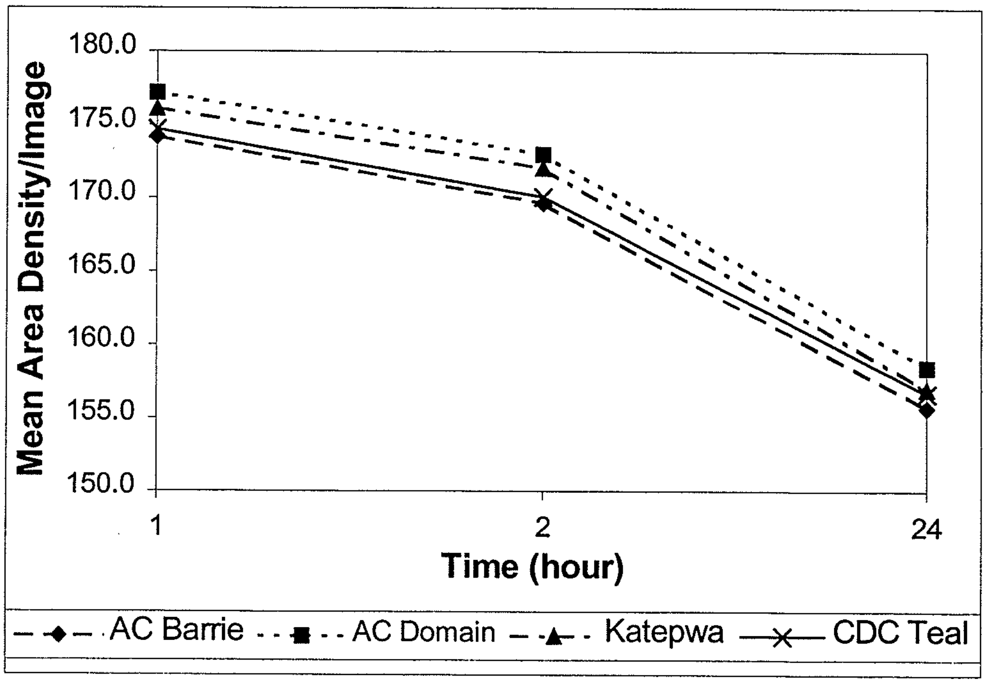

Figure 4.5. Cultivar means of mean area density per image of raw yellow alkaline noodle sheets over time. Δ gray value of 5 and minimum size threshold equivalent to 6000 μm^2 were used in the analysis. Results are the average value of two processing replications per plot duplicate over six environments (n=24).

Similar to the number of specks, no significant differences were observed among the cultivars (including AC Majestic) for the mean area density of noodle sheets (Appendix V, Table AV.7). The mean area densities per image for the year 2000 CWRS composite sample at 1, 2 and 24 hr were 181, 176, and 160, respectively which were similar to that of the individual cultivar means observed from the year 2000 data of this study (Appendix V, Table AV.7).

Although the actual differences in the mean darkness of specks were small among the cultivars and the composite sample, the darkness intensity profiles of the specks highlighted their dissimilarities (Figures 4.6a to 4.6c). The darkness distributions included seven equally divided gray levels from 120 to 189 plus two additional divisions (< 120 and > 189) to ensure the specks were fully characterized. The relative distribution in the darkness intensities of specks for the composite sample noodle sheet was different from that of the individual cultivar noodle sheets. When aged for 1 hr, over half of the specks (63 %) of the noodle sheets for the composite sample fell into the lighter region of the darkness profile at ≥ 180 whereas only 16 to 23 % of the specks for the noodle sheets of the cultivars were located in this region (Figure 4.6a). A similar trend was observed at 2 hr (Figure 4.6b) but it became less obvious by 24 hr (Figure 4.6c). Another difference was that the composite sample noodle sheets had a narrower darkness distribution of specks (within 4 divisions of gray levels) than the individual cultivars (ranged from 5-7 divisions) at each of the time periods measured. Hence, the specks of the noodle sheets for the composite sample were more uniform in darkness than that of the noodle sheets for the cultivars examined.

Among the cultivars, the specks of noodle sheets made from AC Domain were more evenly distributed within its darkness profile. For example, at 24 hr (Figure 4.6c), the majority of specks that fell into one gray level division was only

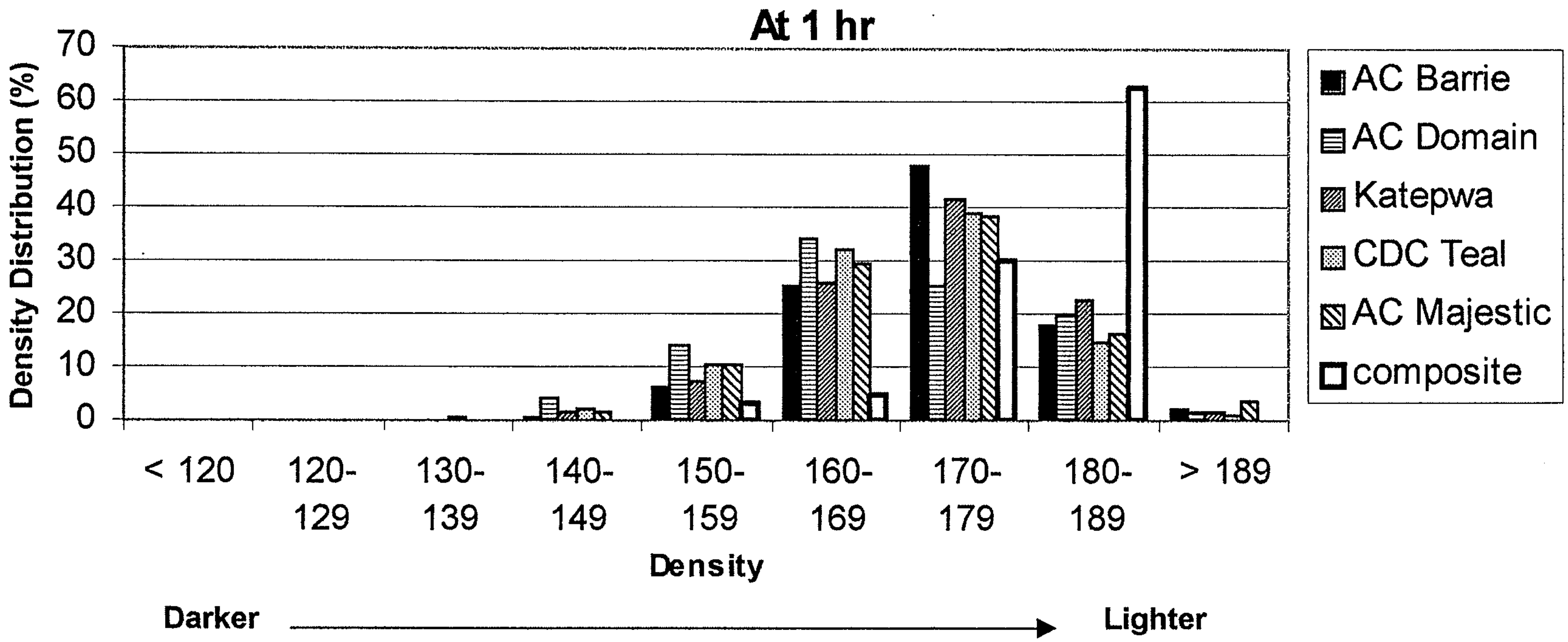

Figure 4.6a. Profiles of darkness distribution of specks for cultivars and NO.1CWRS composite samples from year 2000 at 1 hr using Δ gray value of 5 and minimum size threshold equivalent to 6000 μm^2. Results for cultivars are the average value of two processing replications per plot duplicate over three locations (n=12).

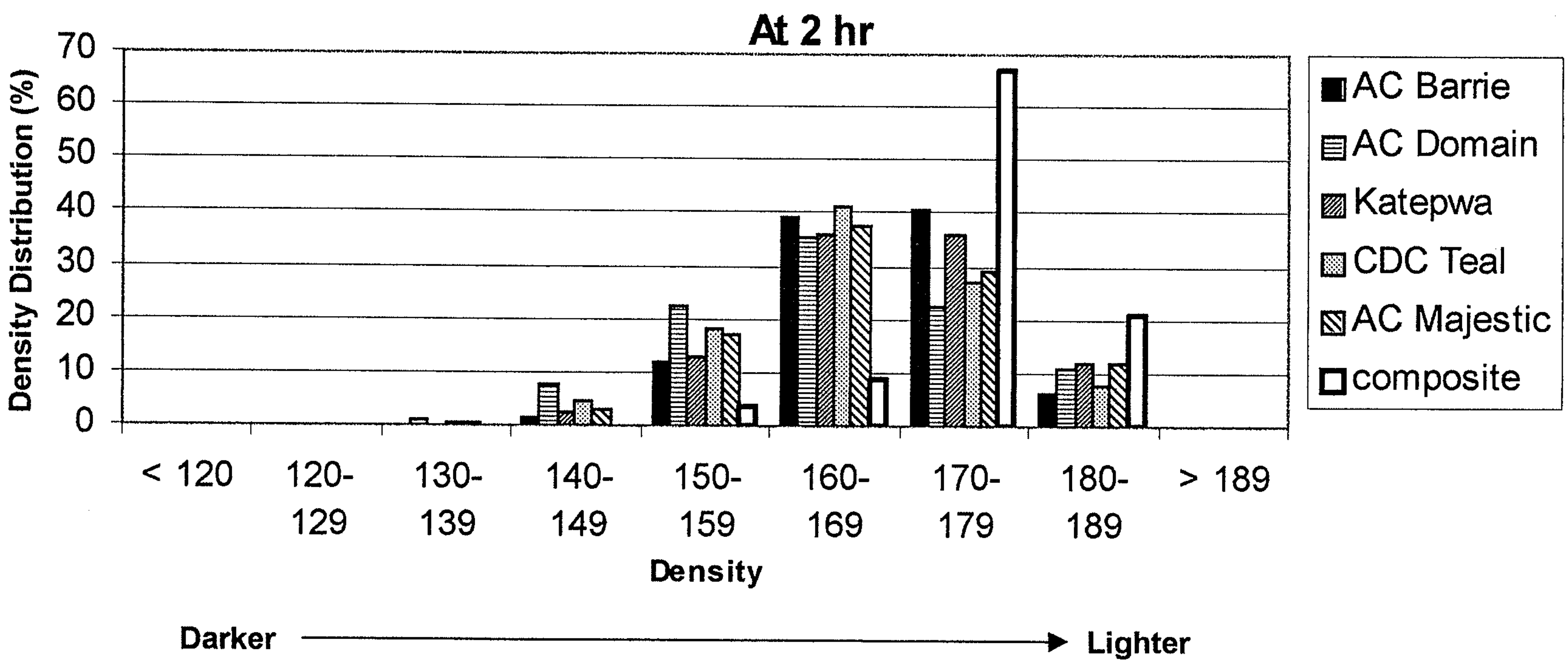

Figure 4.6b. Profiles of darkness distribution of specks for cultivars and NO.1CWRS composite samples from year 2000 at 2 hr using Δ gray value of 5 and minimum size threshold equivalent to 6000 μm^2. Results for cultivars are the average value of two processing replications per plot duplicate over three locations (n=12).

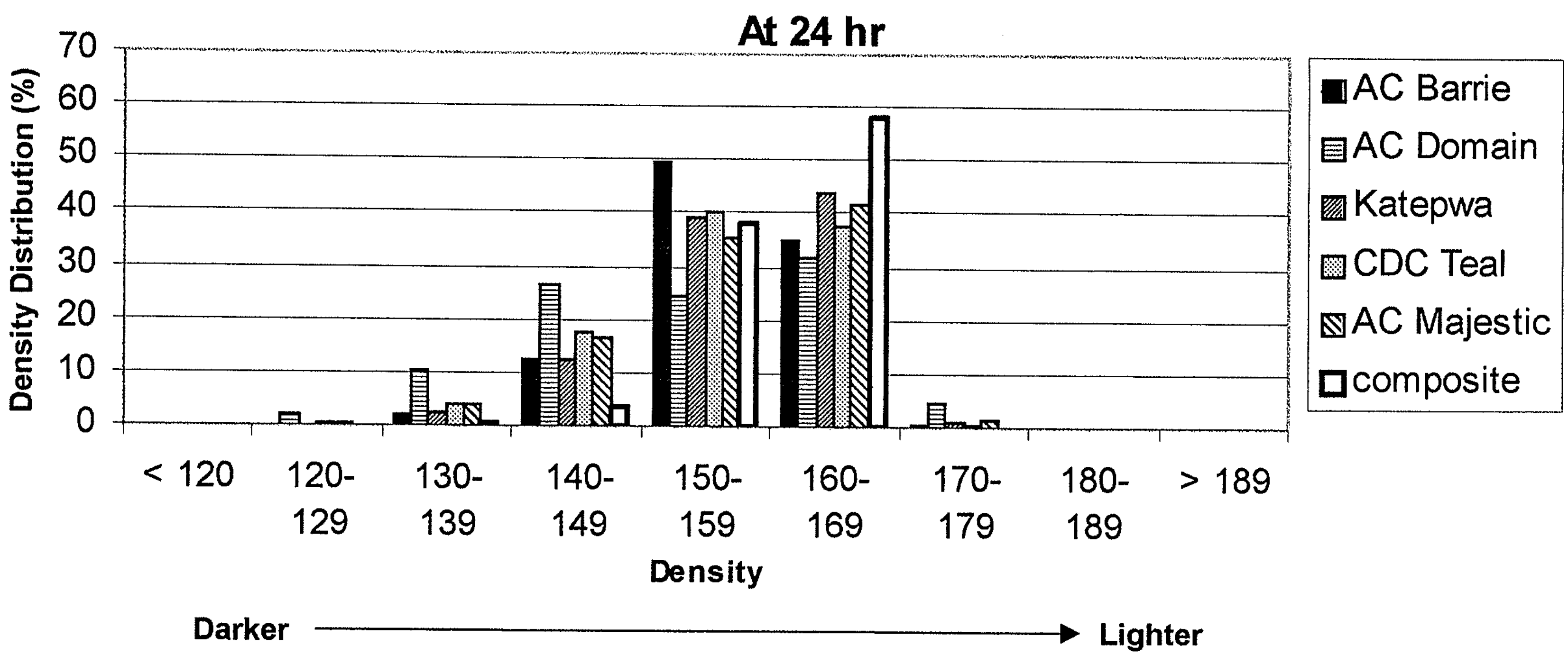

Figure 4.6c. Profiles of darkness distribution of specks for cultivars and NO.1CWRS composite samples from year 2000 at 24 hr using Δ gray value of 5 and minimum size threshold equivalent to 6000 μm^2. Results for cultivars are the average value of two processing replications per plot duplicate over three locations (n=12).

32 % for AC Domain, whereas for the other cultivars a range from 40 to 50 % was observed. Thus, the specks of noodle sheets prepared from AC Domain were more varied in darkness than the other cultivars. These results suggest that YAN prepared with the composite sample rather than the individual cultivars would be more desirable to consumers since the it displayed fewer specks which were not as less dark in color.

4.3.5 Environment Comparisons

4.3.5.1 Color measurement

Environment means of brightness (L*), redness (a*), and yellowness (b*) of raw noodle sheets over time are shown in Figures 4.7-4.9, respectively. Brightness of raw noodle sheets declined continually with time and at a similar rate among the six environments. Thus, the relative ranking of the environments for brightness appeared to be consistent over the 24-hr storage period (Figure 4.7). The a* values ascended quickly during the first hour for all the environments examined. After the first hour of storage, the a* values of noodle sheets made from cultivars grown in Glenlea in year 2000 and Melfort for both years continued to rise gradually, whereas that made from Beaverlodge in 1999 and Swift Current for both years leveled off (Figure 4.8). Yellowness of raw noodle sheets also rose rapidly during the first hour then increased at a slower rate between 1 to 2 hr. From 2 to 24 hr, yellowness of noodle sheets prepared from cultivars grown in Swift Current for both years decreased slightly while that made from other environments continued to rise gradually (Figure 4.9). Due to differences among the environments in their rates for a* and b* values over time, particularly from 2 to 24 hr, the relative ranking of the environments over time changed as well.

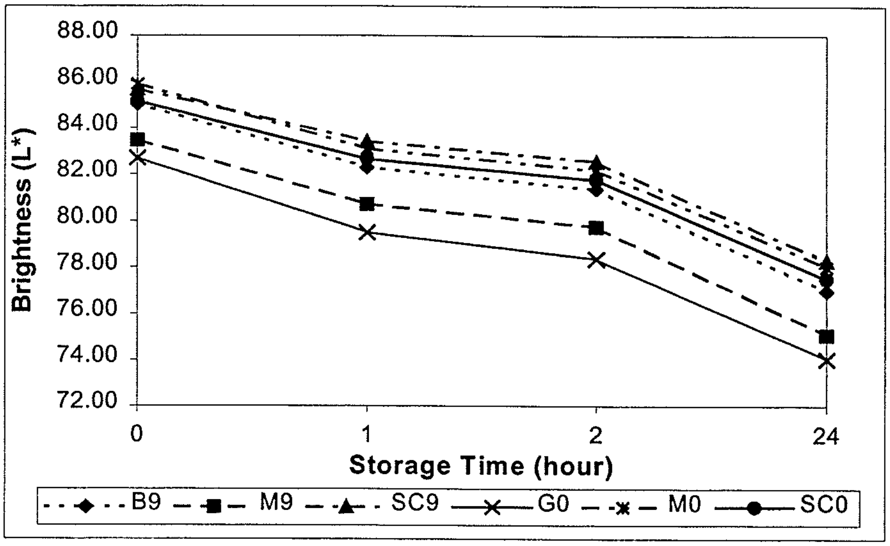

Figure 4.7. Environment means of brightness (L*) of raw yellow alkaline noodle sheets over time. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

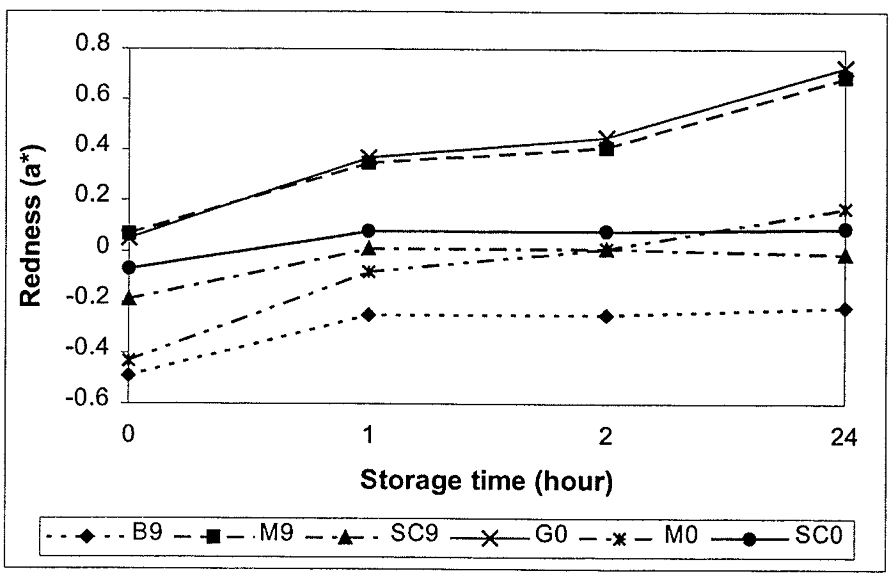

Figure 4.8. Environment means of redness (a*) of raw yellow alkaline noodle sheets over time. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

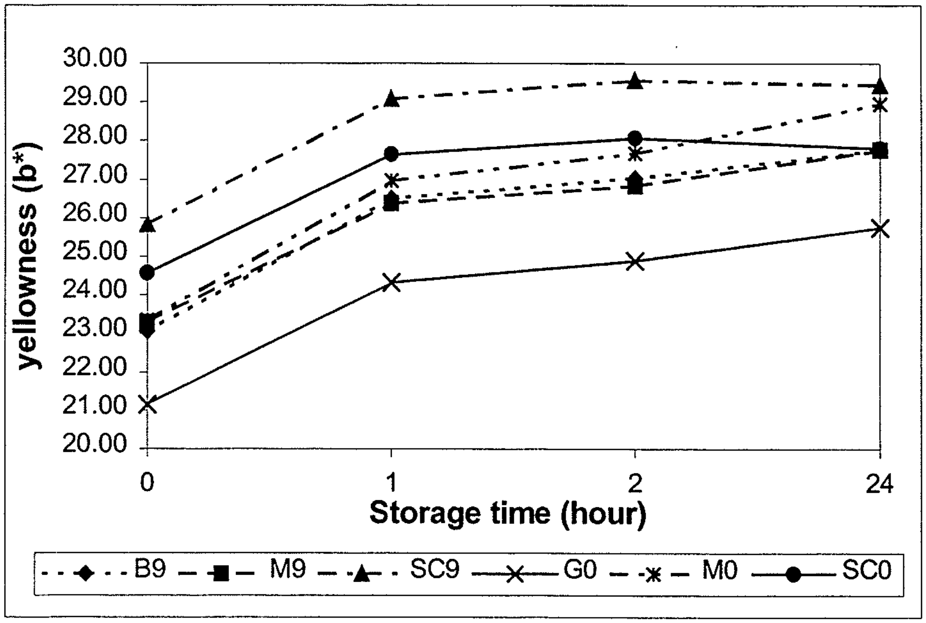

Figure 4.9. Environment means of yellowness (b*) of raw yellow alkaline noodle sheets over time. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

The environment means, standard deviations, and CV's of L*, a*, and b* values of raw noodle sheets over time are shown in Appendix V, Tables AV.8-10, and that of the cooked noodles is presented in Table 4.14. Overall, larger variations for color parameters were observed among environments than among cultivars (Appendix V, Tables AV.1-3 and Table 4.9) as revealed by their CV's.

Tukey's multiple range test results showed that Glenlea in 2000 produced raw noodle sheets that were the darkest among the environments studied but no significance differences were observed between Glenlea in 2000 and Melfort in 1999 at 0 and 24 hr after processing. Raw noodle sheets made from cultivars grown in Swift Current for both years and Melfort for year 2000 were generally brighter than those prepared from cultivars grown in the other environments (Appendix V, Table AV.8).

Differences in noodle brightness among the environments could be predicated by their differences in flour Agtron color since noodle brightness has been shown to have a strong positive relationship (r = 0.95-0.98 during storage) with Agtron color (Figure 4.10). Similar correlation coefficients (r = 0.90-0.95, P < 0.0001) between brightness and Agtron color were also obtained when using data from each cultivar grown at each environment (n =27). Note that these relationships hold for all of the time periods measured and therefore only one of the time period (at 2 or 24 hr) was used to illustrate the relationships.

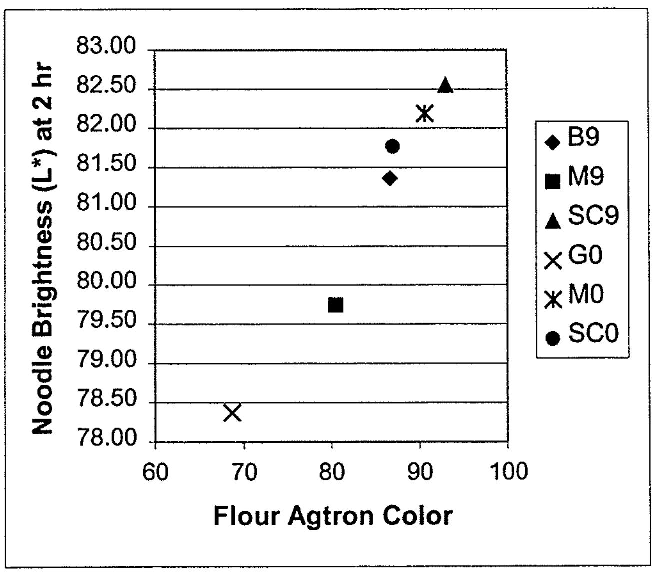

Figure 4.10. Relationship between the brightness (L*) of raw yellow alkaline noodle sheets (at 2 hr) and flour Agtron color (r = 0.98). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

In agreement with the work by Baik et al. (1995), Miskelly (1984), Miskelly and Moss (1985) and Moss (1971), raw alkaline noodle sheets made from flour with higher protein content were lower in brightness as indicated by the correlation coefficients obtained using the environment means (r = -0.79 to -0.85 during storage, Figure 4.11) and the data of the cultivars at each environment (r = -0.74 to -0.79, P < 0.0001, n = 27).

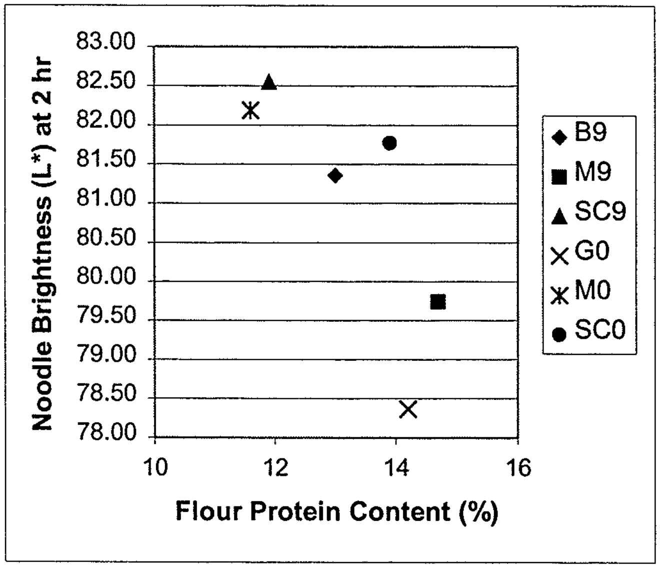

Figure 4.11. Relationship between the brightness (L*) of raw yellow alkaline noodle sheets (at 2 hr) and flour protein content (r = - 0.79). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

Environments with higher level of wholemeal PPO activity appeared to produce darker raw alkaline noodle sheets (Figure 4.12). The correlation coefficients between wholemeal PPO activity and raw noodle sheet brightness obtained using the environment means (r = -0.78 to –0.81, n = 6) and the data of the cultivars at each environment (r = -0.68 to –0.72, P < 0.0001, n = 27) were very similar. Baik et al. (1995) and Hatcher et al. (1999) found that the relationship between flour or grain PPO activity and brightness of raw noodle sheets was not conclusive depending on the population or class of wheat studied. It should be mentioned that the average flour PPO activity is only about

3 % the wheat PPO activity (Baik et al., 1995). However, PPO activity could not be detected in the flour samples of the present study. Thus, either the method employed was not sensitive enough or in fact PPO activities were extremely low in the flour samples. This might explain why the relationship between wholemeal PPO activity and brightness was not that strong as shown in Figure 4.12.

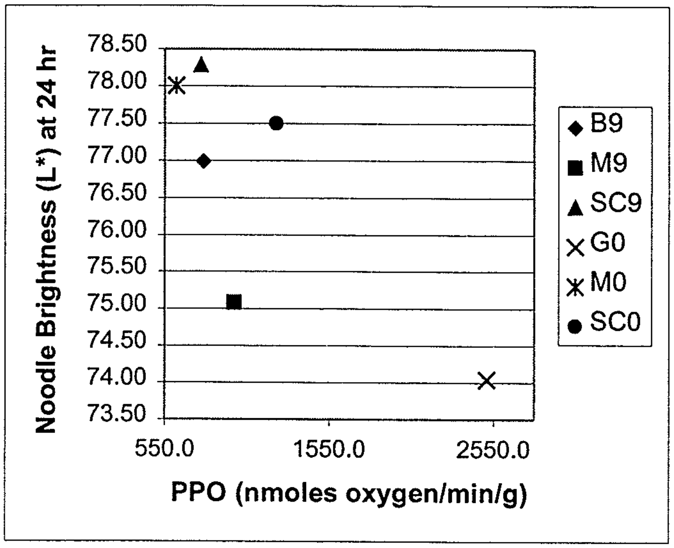

Figure 4.12. Relationship between the brightness (L*) of raw yellow alkaline noodle sheets (at 24 hr) and grain polyphenol oxidase (PPO) activity (r = - 0.78). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

Raw Noodle sheets made from cultivars with lower flour peroxidase activities tended to be brighter (Figure 4.13). The correlation coefficients for this relationship obtained using the environment means (r = -0.81 to –0.85 during storage) and individual data points (r = -0.68 to -0.73, P < 0.0001, n = 27) were comparable.

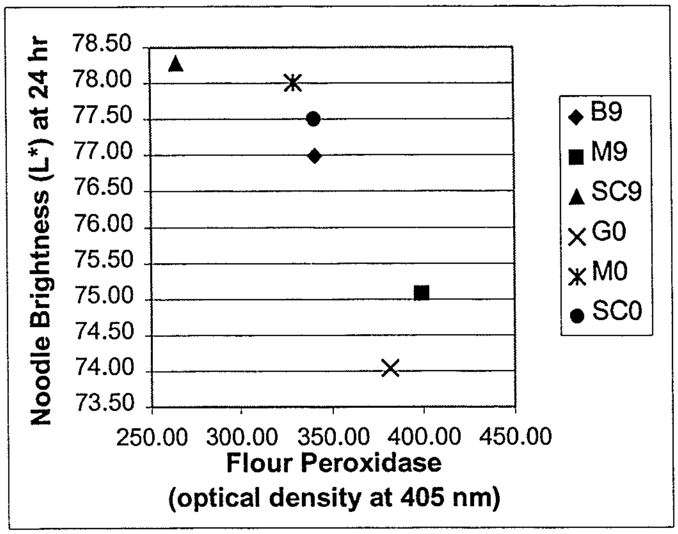

Figure 4.13. Relationship between the brightness (L*) of raw yellow alkaline noodle sheets (at 24 hr) and flour peroxidase activity (r = - 0.85). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

For the a* values, raw noodle sheets prepared with cultivars grown in Glenlea in 2000 and Melfort in 1999 displayed a red color throughout the 24-hr storage period as indicated by the positive a* values. The raw noodle sheets made from cultivars grown in these environments were significantly redder than those made from cultivars grown in the other environments at any time period except for 0 time where no differences were found among them and those prepared with cultivars grown in Swift Current in 2000 (Appendix V, Table AV.9). In contrast, Beaverlodge in 1999 produced raw noodle sheets with negative a* values throughout the 24-hr storage period and their a* values were significantly lower than those prepared from cultivars grown in all other environments at the 2 and 24 hr time periods (Appendix V, Table AV.9). No significant differences were observed among the a* values of noodle sheets produced from samples grown in Beaverlodge in 1999 and Melfort in 2000 at 0 and 1 hr time periods (Appendix V,

Table AV.9). Raw noodle sheets for Swift Current from both years generally displayed neutral a* values (close to zero) during storage, indicating less discoloration and therefore an overall more desirable color (Appendix V, Table AV.9).

Baik et al. (1995) found that a* values of alkaline noodle doughs measured at 75 hr after preparation were positively related to wheat or flour protein content and PPO activity. In the present study, the relationships between a* values and wholemeal PPO activity ($r = 0.48$ to 0.56, $P < 0.01$, $n = 27$) and protein content ($r = 0.57$ to 0.65, $P < 0.01$, $n = 27$) were not as strong probably due to the smaller sample size and shorter storage period used compared to the study of Baik et al. (1995). Similarly, although a* values of the raw noodle sheets appeared to be positively related to flour peroxidase value ($r = 0.51$ to 0.74, Figure 4.14) and negatively related to Agtron color ($r = -0.63$ to -0.80, Figure 4.15), the relationships were not that linear. Similar r values for the relationship between a* values and peroxidase activity were observed for the individual data points ($n = 27$). They increased from 0.61 at 0 time to 0.73 at 24 hr ($P < 0.001$, $n = 27$). The relationship between a* values and Agtron color was found to be less strong for the individual data points ($r = -0.43$ at $P < 0.01$ to -0.67 at $P = 0.0001$, $n =27$). However, it is clear that environments such as Glenlea in 2000 and Melfort in 1999 both of which produced cultivars with higher protein contents and enzyme activities but lower flour Agtron color also produced raw noodle sheets with more undesirable discoloration.

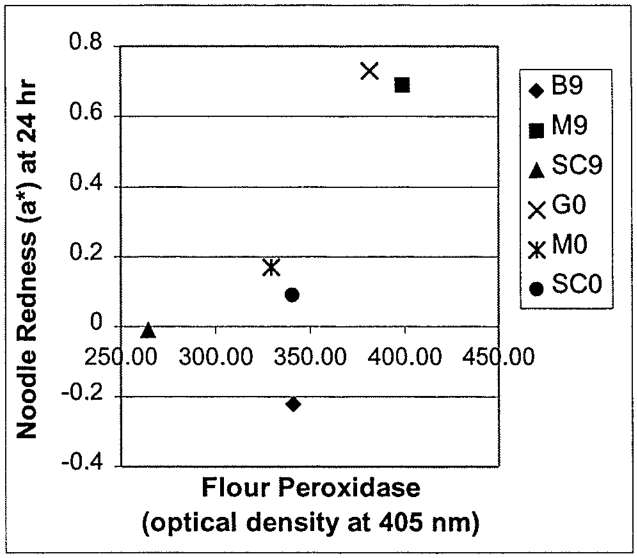

Figure 4.14. Relationship between the redness (a*) of raw yellow alkaline noodle sheets (at 24 hr) and flour peroxidase activity (r = 0.74). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

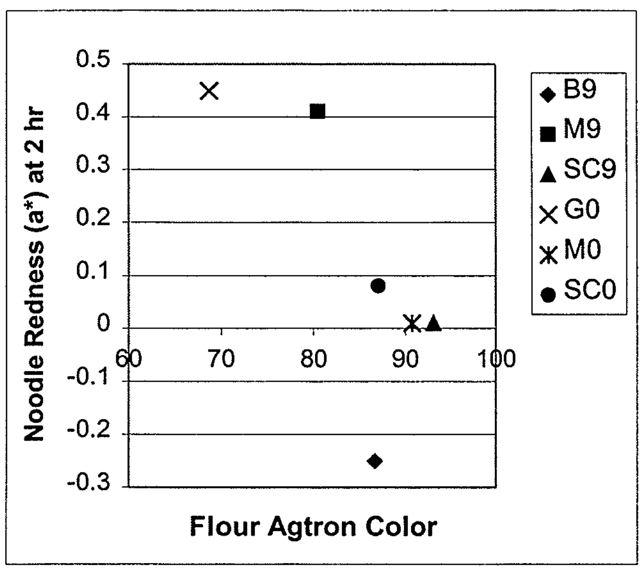

Figure 4.15. Relationship between the redness (a*) of raw yellow alkaline noodle sheets (at 2 hr) and flour Agtron color (r = - 0.76). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

Raw noodle sheets produced from cultivars grown in Glenlea in 2000 were also significantly lower in yellowness than those prepared from cultivars grown in the other environments at any of the time periods measured (Appendix V, Table AV.10). Noodle sheets prepared from samples grown in Swift Current in 1999 were significantly higher in yellowness than those from the other environments during storage except that no significant differences were found when compared with that of Melfort in 2000 at the 24 hr time period (Appendix V, Table AV.10).

It is known that the yellow color of YAN is mainly attributed to flavones which develop yellowness in alkaline conditions (Wang, 1998). This is probably governed in part by the presence of germ components in the flour, as wheat germ is richer in flavone than is the endosperm (Moss, 1971). In the present study, flavones were not measured, however, our results showed that the environments which produced raw noodle sheets with higher yellowness were higher in flour Agtron color ($r = 0.83$-0.95, Figure 4.16). Similar r values (0.73-0.78, $P < 0.0001$) were obtained using data of the cultivars at each environment. As discussed, positive relationship was also observed between brightness and Agtron color. Hence, it is possible to identify environments that will produce raw YAN with high levels of brightness and yellowness as preferred by consumers.

In terms of the color of cooked YAN, no differences were found among the environments for brightness, except for Glenlea in 2000 which was significantly lower than all other environments (Table 4.14). Cooked YAN made from samples grown in all the environments had negative a* values. Cooked noodles made from samples grown in Melfort in 2000 had the lowest a* values while Swift

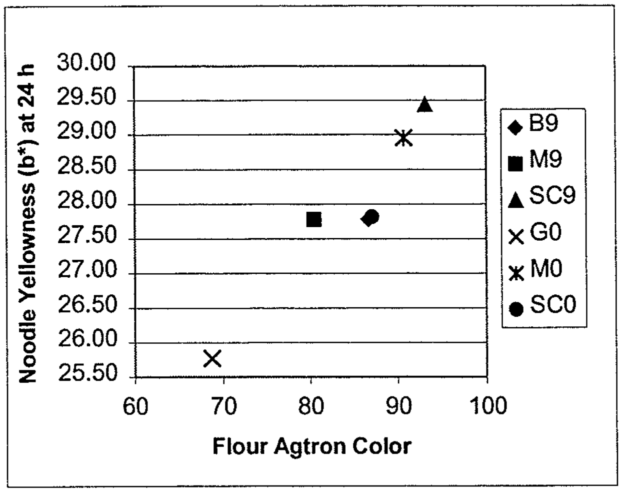

Figure 4.16. Relationship between the yellowness (b*) of raw yellow alkaline noodle sheets (at 24 hr) and flour Agtron color (r = 0.95). Environment means which are the average value of two processing replications per plot duplicate over four cultivars were used (n=16).

Current in 1999 had the highest (Table 4.14). Glenlea in 2000 also produced cooked YAN that were significantly lower in yellowness followed by Melfort in 1999 (Table 4.14). Similar to the results of the raw noodle sheets, cooked YAN prepared from the samples grown in Swift Current in 1999 and Melfort in 2000 were significantly higher in yellowness than all other environments (Table 4.14). The relationships for brightness and yellowness of cooked YAN with flour Agtron color ($r = 0.85$ ($n = 6$) and 0.78 ($P < 0.0001$, $n = 27$) for L*; $r = 0.96$ ($n = 6$) and 0.91 ($P < 0.0001$, $n = 27$) for b*), and PPO activities ($r = -0.91$ ($n = 6$) and -0.70 ($P < 0.0001$, $n = 27$) for L*) were similar to that of the raw noodle sheets.

In short, Glenlea from year 2000 appeared to produce both raw and cooked YAN with inferior color since they were less bright and less yellow with greater discoloration, whereas the opposite was found for Swift Current, especially for the year 1999 and for Melfort from year 2000.

Table 4.14. Environment means[a] , standard deviations (SD), and coefficient of variation (CV) for color parameters of optimally cooked yellow alkaline (YAN) noodles made from Canada Western Red Spring Wheat cultivars.

Environment[c]	Cooked YAN color[b]		
	L*	a*	b*
B9	66.84 (0.88) b	-1.89 (0.28) b	27.13 (0.86) c
M9	66.96 (1.09) b	-1.93 (0.24) b	25.14 (0.47) b
SC9	67.25 (0.92) b	-1.49 (0.17) c	28.83 (0.65) d
G0	64.55 (1.42) a	-2.00 (0.19) b	24.21 (1.31) a
M0	66.49 (0.74) b	-2.33 (0.24) a	28.27 (0.45) d
SC0	66.82 (1.05) b	-1.84 (0.32) b	27.05 (0.45) c
Mean	66.49	-1.91	26.77
SD	0.98	0.27	1.78
CV	1.47		6.65

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.

4.3.5.2 Speck measurement

The changes in number and mean area density (darkness) of specks per image over time for environments are illustrated in Figures 4.17 and 4.18, respectively. The number of specks per image for each environment accelerated at different rates over time resulting in inconsistency in their rankings (Figure 4.17). Tukey's test indicated that at 1 and 2 hr of noodle aging, noodle sheets made from samples grown in Glenlea in 2000 had significantly higher number of specks than all other environments (Appendix V, AV.11). By 24 hr, noodle sheets prepared with samples grown in Glenlea in 2000, Melfort in 1999, and Swift Current in 2000 had significantly higher number of specks than all other environments.

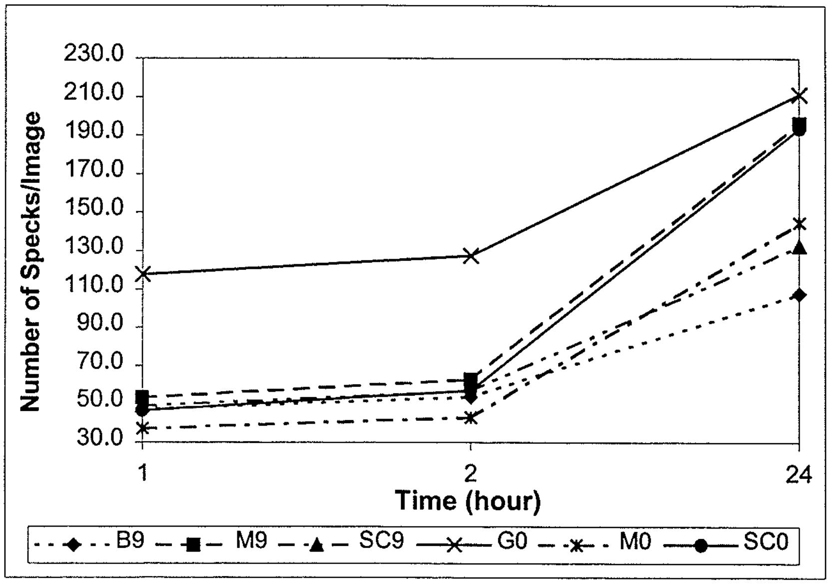

Figure 4.17. Environment means of number of specks per image of raw yellow alkaline noodle sheet over time. Δ gray value of 5 and minimum size threshold equivalent to 6000 μm^2 were used in the analysis. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

Similar to the noodle sheet L* value, the mean area density of specks of the raw noodle sheets darkened continually in a parallel fashion over time for all environments (Figure 4.18). Results of the Tukey's tests comparing the environment means for the mean area density of specks are shown in Appendix V, Table AV.12. The specks for the noodle sheets made from the cultivars grown in Glenlea 2000, followed by Melfort in 1999 were significantly darker than those of all other environments. At 1 and 2 hr, the specks of the noodle sheets made from the samples grown in Melfort in 2000 were overall brighter than all other environments, except Swift Current in 1999. At 24 hr, noodle sheets prepared with samples grown in both Melfort in 2000 and Swift Current in 1999 had brighter specks than all other environments, except Swift Current in 2000.

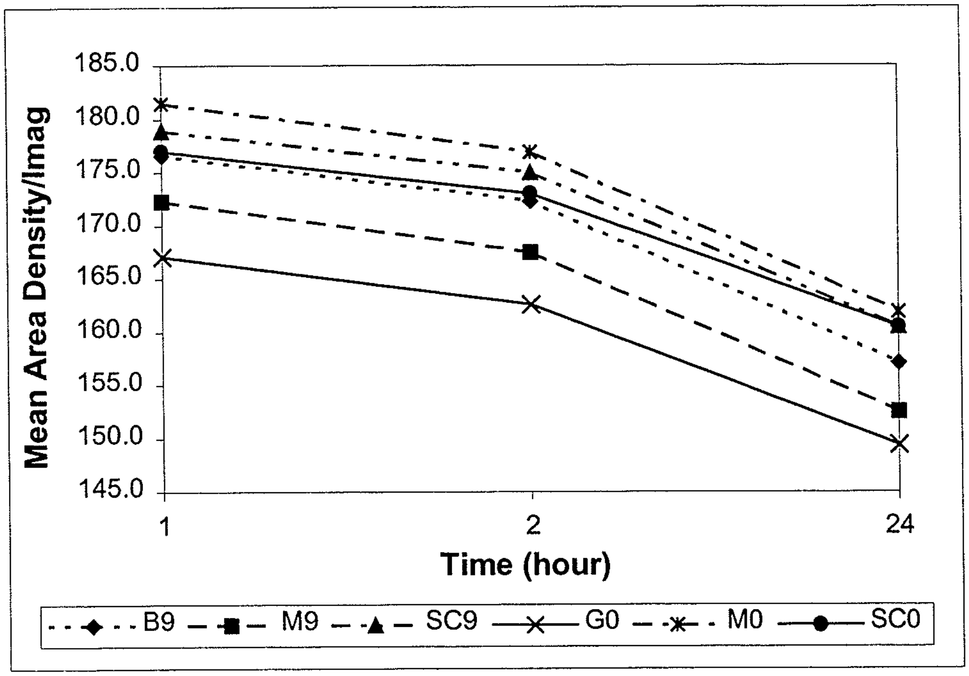

Figure 4.18. Environment means of mean area density per image of raw yellow alkaline noodle sheet over time. Δ gray value of 5 and minimum size threshold equivalent to 6000 μm² were used in the analysis. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

The darkness intensity profiles of specks highlighted the differences in the appearance of the raw noodle sheets among the six environments. As explained previously, the darkness distributions included seven equally divided gray levels from 120 to 189 plus two additional divisions (< 120 and > 189). As shown in Figure 4.19a-c, the differences in the relative distribution in the darkness intensities of the specks among the environments were quite obvious. After 1 hr, only 35 % of the specks found in the noodle sheets made from Glenlea in 2000 were located in the lighter region of the darkness profile (≥ 170) whereas Melfort in 2000 had 92.5 % of the specks in this region (Figure 4.19a). At 2 hr, while Glenlea from year 2000 only had 11.3 % of the specks at the darkness value of ≥

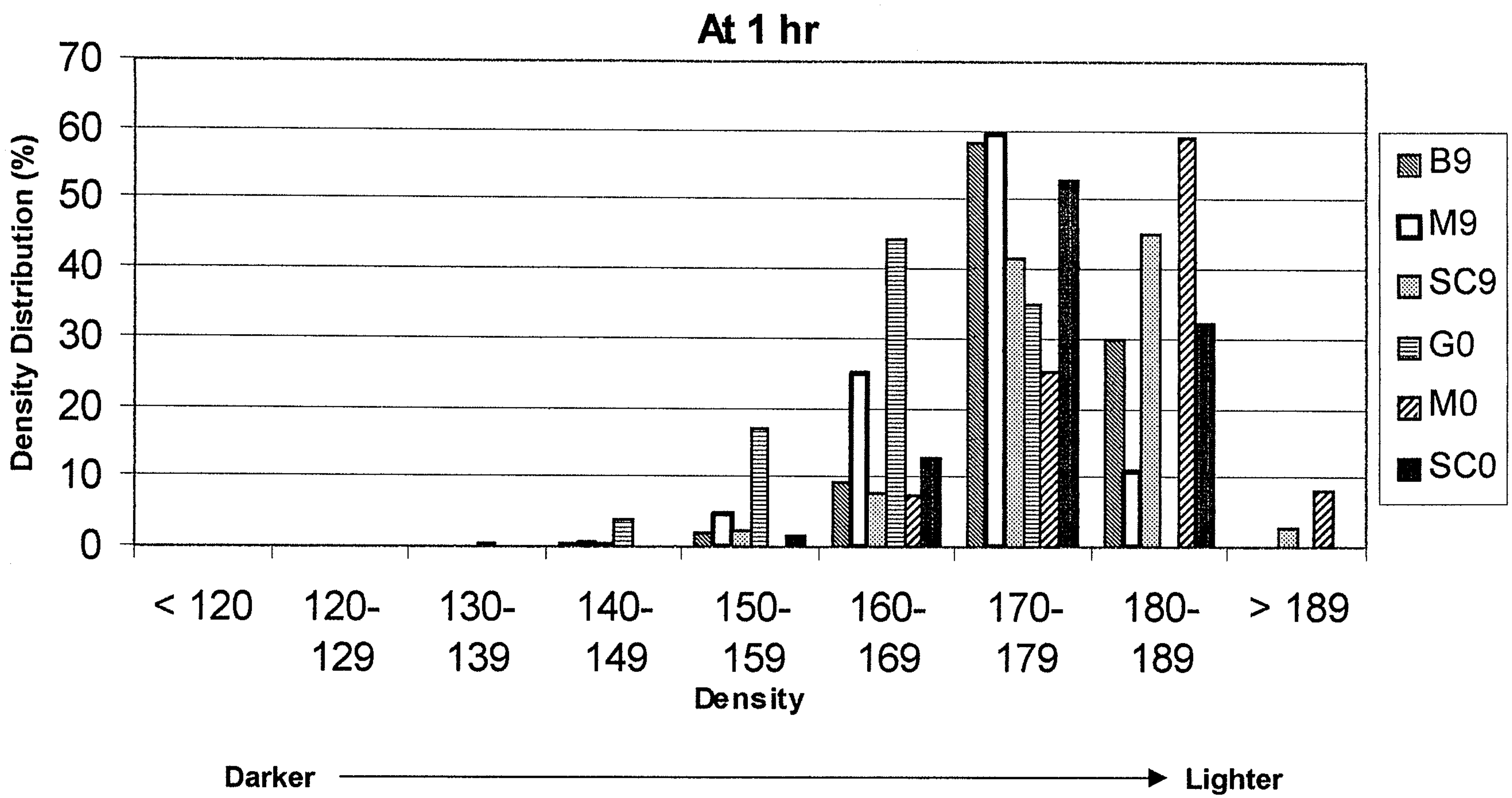

Figure 4.19a. Profiles of darkness distribution of specks for environments at 1 hr at Δ gray level of 5 and minimum size threshold equivalent to 6000 μm^2. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

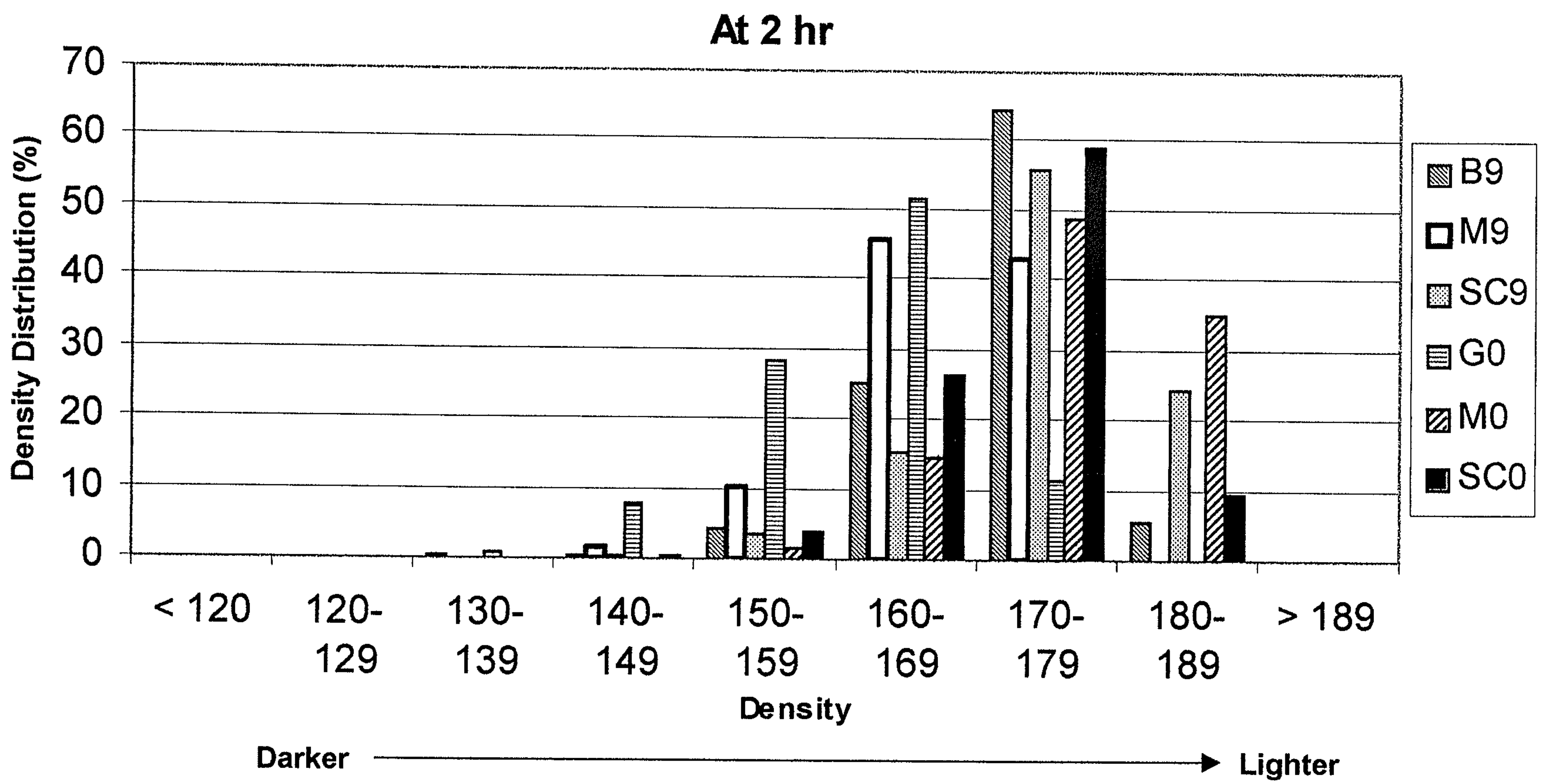

Figure 4.19b. Profiles of darkness distribution of specks for environments at 2 hr at Δ gray level of 5 and minimum size threshold equivalent to 6000 μm^2. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

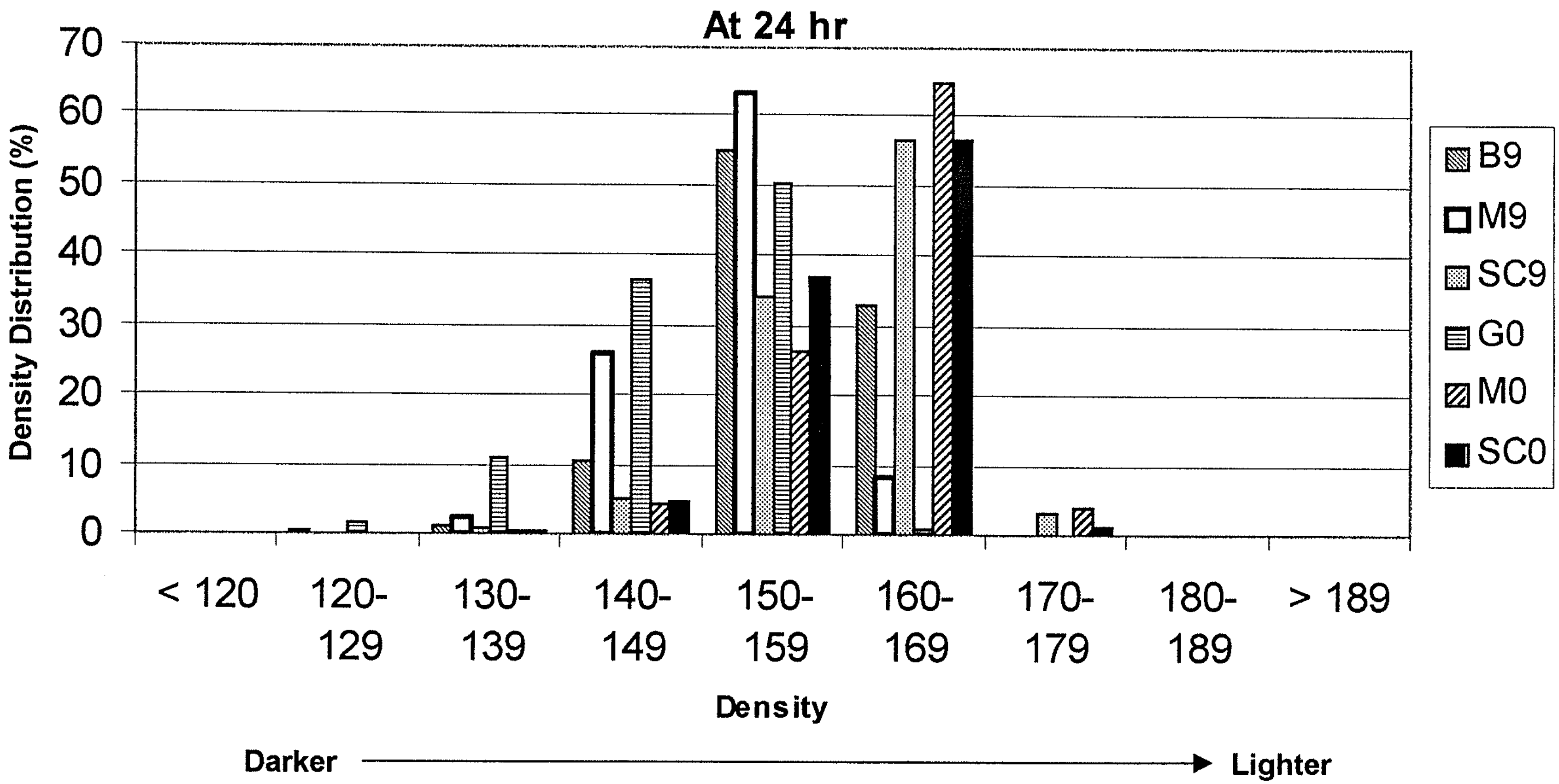

Figure 4.19c. Profiles of darkness distribution of specks for environments at 24 hr at Δ gray level of 5 and minimum size threshold equivalent to 6000 μm^2. Results are the average value of two processing replications per plot duplicate over four cultivars (n=16).

170, Melfort from year 2000 and Swift Current from year 1999 had 83.9 % and 80.4 %, respectively (Figure 4.19b). Similarly, by 24 hr, the percentage of specks that fell into the lighter range (≥ 160) for Glenlea in 2000 (0.6 %) and Melfort in 1999 (8.3 %) were much lower than that of Melfort in 2000 (68.8 %) and Swift Current in 1999 (59.7 %) (Figure 4.19c).

These findings indicate that on average, samples grown in Melfort in 1999 and in particularly in Glenlea in 2000 produced raw noodle sheets with less bright overall color and with more specks that were darker in color. The opposite results were found for noodle sheets made from samples grown in Melfort in 2000 and Swift Current in 1999. Thus, YAN made samples grown in Melfort in 2000 and Swift Current in 1999 were more appealing and were preferred over those made from the other environments, especially Glenlea in 2000.

The relationships between speck measurements and flour characteristics were similar to that between L* value and flour characteristics. In fact, flour Agtron color ($r = -0.86$ at 1 and 2 hr ($P < 0.0001$) and $r = -0.56$ at 24 hr ($P < 0.01$)) and wholemeal PPO activity, though not very strong ($r = 0.72$ at 1 hr, 0.73 at 2 hr ($P < 0.0001$), and 0.47 at 24 hr ($P < 0.05$)) were found to be related to speck count ($n = 27$). Similarly, flour protein content (r values ranged from –0.73 to –0.78, $P < 0.0001$), Agtron color (r values ranged from 0.88 to 0.89, $P < 0.0001$), peroxidase activity (r values ranged from –0.61 to –0.65, $P < 0.001$) and wholemeal PPO activity (r values ranged from –0.67 to –0.75, $P < 0.0001$) were also found to be correlated with mean darkness of specks.

4.3.6 Effects of Cultivar, Environment and their Interaction

The results of the ANOVA to determine the effects of cultivar, environment, and their interactions for color and speck characteristics are presented in Tables 4.15 to 4.20.

For L* values of raw noodle sheets, cultivar effect ($P < 0.05$) was only observed at 24 hr (Table 4.15). Significant cultivar effects ($P < 0.01$) were found for a* (Table 4.16) and b* values (Table 4.17) of raw noodle sheets at all of the time periods measured. However, only a* values of optimally cooked noodles had a significant cultivar effect ($P < 0.01$, Table 4.18). Similar to L* values, cultivar effect was significant for speck count at 24 hr ($P < 0.01$, Table 4.19), whereas that of the mean area density of specks was significant at 1 hr ($P < 0.01$), 2 hr ($P < 0.01$) and 24 hr ($P < 0.05$) as shown in Table 4.20.

The effect of year was significant for all the parameters studied except for a* value at 0 hr (Table 4.16) and L* values (Table 4.15) and mean area density of specks (Table 4.20) at any of the time periods measured. On the other hand, location effects were significant for all of the color and speck parameters measured at all of the time periods ($P < 0.01$, Tables 4.15 to 4.20).

With regard to the interaction effects, none of the parameters measured had a significant cultivar by year effect ($P > 0.05$). Cultivar by location effects were significant in most cases, except for L* values at 0 and 1 hr (Table 4.15) and speck count at 1 and 2 hr (Table 4.19) for raw noodle sheets, as well as L* values for cooked noodles (Table 4.18).

Table 4.15. Mean squares of the ANOVA of L* (brightness) of raw yellow alkaline noodle sheets [a].

Source of Variation	df	L* (brightness)			
		0 hr	1 hr	2 hr	24 hr
Year [b]	1	0.5017NS	3.7407NS	4.6420NS	1.8150NS
Location(year) [c]	4	32.7047**	46.2363**	51.0554**	57.9562**
Cultivar [c]	3	0.7070NS	0.6785NS	1.1206NS	3.9063*
Cultivar × year [c]	3	0.8256NS	0.9708NS	1.1247NS	1.2292NS
Cultivar × location(year) [c]	12	0.8559NS	1.3792NS	1.6066*	2.2409*
Plot (cultivar × location × year)	24	0.4235	0.6772	0.6611	1.0241
Rep(year)	2	0.7276	0.6221	0.4442	0.3703
Error	46	0.1093	0.0831	0.0831	0.0680

[a]*, $0.01 < p \leq 0.05$; ** $p \leq 0.01$; NS = not significant ($p > 0.05$).
[b]The error term was [MS(rep(year)) + MS(plot(cultivar×location×year)) – MS(Error)] where MS is mean square.
[c]The error term was MS(plot(cultivar×location×year)) where MS is mean square.

Table 4.16. Mean squares of the ANOVA of a* (red-green) of raw yellow alkaline noodle sheets [a].

Source of Variation	df	a* (red-green)			
		0 hr	1 hr	2 hr	24 hr
Year [b]	1	0.0743NS	0.1873*	0.3738**	0.7455**
Location(year) [c]	4	1.1341**	1.1516**	1.3321**	2.8112**
Cultivar [c]	3	0.7004**	0.5664**	0.5827**	0.6011**
Cultivar × year [c]	3	0.0499NS	0.0669NS	0.0781NS	0.0214NS
Cultivar × location(year) [c]	12	0.0980*	0.1160**	0.1198**	0.1429**
Plot (cultivar × location × year)	24	0.0440	0.0315	0.0288	0.0298
Rep(year)	2	0.0092	0.0050	0.0041	0.0039
Error	46	0.0029	0.0022	0.0026	0.0020

[a]*, $0.01 < p \leq 0.05$; ** $p \leq 0.01$; NS = not significant ($p > 0.05$).
[b]The error term was [MS(rep(year)) + MS(plot(cultivar×location×year)) – MS(Error)] where MS is mean square.
[c]The error term was MS(plot(cultivar×location×year)) where MS is mean square.

Table 4.17. Mean squares of the ANOVA of b* (yellowness) of raw yellow alkaline noodle sheets [a].

Source of Variation	df	b* (yellowness)			
		0 hr	1 hr	2 hr	24 hr
Year [b]	1	25.7508*	24.8067**	21.0938**	16.1376**
Location(year) [c]	4	42.9641**	43.5093**	42.4924**	28.2408**
Cultivar [c]	3	13.6997**	8.6976**	9.4197**	6.9634**
Cultivar × year [c]	3	0.7822NS	1.6204NS	1.7392NS	0.4858NS
Cultivar × location(year) [c]	12	2.9784*	2.2996*	2.2299*	1.8934*
Plot (cultivar × location × year)	24	1.1846	0.9992	0.9787	0.8041
Rep(year)	2	1.8194	0.3325	0.1955	0.1090
Error	46	0.5648	0.2241	0.1896	0.0832

[a]*, $0.01 < p \leq 0.05$; ** $p \leq 0.01$; NS = not significant ($p > 0.05$).
[b]The error term was [MS(rep(year)) + MS(plot(cultivar×location×year)) – MS(Error)] where MS is mean square.
[c]The error term was MS(plot(cultivar×location×year)) where MS is mean square.

Table 4.18. Mean squares of the analysis of variance of optimally cooked yellow alkaline noodle color parameters[a].

Source of Variation	df[b]	Color Parameters		
		L*	a*	b*
Year[c]	1	27.0194**	1.9323**	6.6413**
Location(year)[d]	4	12.3907**	0.9617**	61.9600**
Cultivar[d]	3	0.2333NS	0.4552**	1.6217NS
Cultivar × year[d]	3	3.7185NS	0.0962NS	0.6600NS
Cultivar × location(year)[d]	12	2.2641NS	0.1792**	1.9442*
Plot (cultivar × location × year)	24	1.3455	0.0323	0.6580
Rep(year)	2	0.1900	0.0099	0.0431
Error	46	0.5553	0.0194	0.1394

[a]*, $0.01 < p \leq 0.05$; ** $p \leq 0.01$; NS = not significant ($p > 0.05$).
[b]df = degrees of freedom.
[c]The error term for year effect was [MS(rep(year)) + MS(plot(location×genotype×year)) – MS(Error)] where MS is mean square.
[d]The error term used was MS(plot(location×genotype×year)) where MS is mean square.

Table 4.19. Mean squares of the analysis of variance of speck count of raw yellow alkaline noodle sheets[a].

Source of Variation	df[b]	Speck Count		
		1 hr	2 hr	24 hr
Year[c]	1	7193.34*	7902.51*	34088.00**
Location(year)[d]	4	15610.00**	16503.00**	26209.00**
Cultivar[d]	3	3384.09NS	3654.95NS	9574.98**
Cultivar × year[d]	3	847.84NS	808.84NS	3519.87NS
Cultivar × location(year)[d]	12	1078.46NS	1230.07NS	3917.15*
Plot (cultivar × location × year)	24	1553.78	1508.14	1724.49
Rep(year)	2	55.01	3.93	191.76
Error	46	51.75	59.47	309.06

[a]*, $0.01 < p \leq 0.05$; ** $p \leq 0.01$; NS = not significant ($p > 0.05$).
[b]df = degrees of freedom.
[c]The error term for year effect was [MS(rep(year)) + MS(plot(location×genotype×year)) – MS(Error)] where MS is mean square.
[d]The error term used was MS(plot(location×genotype×year)) where MS is mean square.

Table 4.20. Mean squares of the analysis of variance of mean area density of specks of raw yellow alkaline noodle sheets[a].

Source of Variation	df[b]	Mean Area Density		
		1 hr	2 hr	24 hr
Year[c]	1	12.5921NS	15.2496NS	7.5249NS
Location(year)[d]	4	526.1502**	552.7509**	508.5431**
Cultivar[d]	3	45.3216**	60.5807**	33.7818*
Cultivar × year[d]	3	13.1130NS	11.6819NS	26.3680NS
Cultivar × location(year)[d]	12	23.7830**	22.6862**	20.7065*
Plot (cultivar × location × year)	24	7.1015	6.6266	9.0171
Rep(year)	2	12.9081	15.5779	11.1229
Error	46	4.7318	2.9351	3.6562

[a]*, $0.01 < p \leq 0.05$; ** $p \leq 0.01$; NS = not significant ($p > 0.05$).
[b]df = degrees of freedom.
[c]The error term for year effect was [MS(rep(year)) + MS(plot(location×genotype×year)) – MS(Error)] where MS is mean square.
[d]The error term used was MS(plot(location×genotype×year)) where MS is mean square.

The relative contribution of each effect to all the color and speck parameters are shown in Tables 4.21 to 4.26. In general, location effect was the predominant contributor for all of the parameters measured. Cultivar effects were very small in magnitude which were similar to or even less than the cultivar by location interaction effects. The relative contribution for year and its interaction with cultivar were zero in most cases.

With regard to the L* values of raw noodle sheets, the total variation was primarily attributed to the location effect ranging from 76 % (at 24 hr) to 81 % (at 1 and 2 hr). Cultivar by location effect also contributed to the total variation for L* values of raw noodle sheets throughout the 24 hr period with an average value of 5.7 % which was higher than that of cultivar which ranged from 0 % (from 0 to 2 hr) to 2 % (at 24 hr) (Table 4.21). Park et al. (1997) found that growing locations had greater effects than genotypes on grain (several populations of hard white winter advanced experimental lines) and flour PPO activities (ten hard red winter wheat cultivars) which were believed to be related to the time-dependent darkening of raw noodles. They also found that both grain and flour PPO activities were significantly influenced by the interaction effect between population and location.

For a* values of raw noodle sheets, the contribution due to location was found to increase with time (from 46 % at 0 hr to 71 % at 24 hr), whereas the contribution due to cultivar was found to diminish with time (from 23 % at 0 hr to 10 % at 24 hr). In terms of the cultivar by location interaction effect, its contribution was found to be similar to that of the cultivar effect except for 0 time (Table 4.22).

Table 4.21. Relative contribution of cultivar, year, location and their interactions to the brightness (L*) of raw yellow alkaline noodle sheets.

	Relative Contribution (%)			
	L*			
Effect	0 hr	1 hr	2 hr	24 hr
Year	0	0	0	0
Location(year)	80.3	81.2	81.2	75.9
Cultivar	0	0	0	2.1
Cultivar × year	0	0	0	0
Cultivar × location(year)	5.0	4.6	6.3	6.9
Plot (cultivar × location × year)	7.9	10.5	9.3	13.0
Processing Rep(year)	1.3	0.8	0.5	0.3
Residual	5.5	2.9	2.7	1.8

Table 4.22. Relative contribution of cultivar, year, location and their interactions to the red-green color scale (a*) of raw yellow alkaline noodle sheets.

	Relative Contribution (%)			
	a*			
Effect	0 hr	1 hr	2 hr	24 hr
Year	0	0	0	0
Location(year)	46.4	49.3	53.4	71.1
Cultivar	22.7	17.7	16.3	10.0
Cultivar × year	0	0	0	0
Cultivar × location(year)	9.9	17.3	17.1	11.1
Plot (cultivar × location × year)	18.2	13.6	10.9	6.9
Processing Rep(year)	0.2	0.1	0.1	0
Residual	2.6	2.0	2.2	1.0

The relative contribution of each effect for b* values remained roughly the same regardless of the time. The contribution of location (63 % on average) was much higher than all other effects (9 % on average for cultivar and 8 % on average for cultivar by location interaction (Table 4.23).

Table 4.23. Relative contribution of cultivar, year, location and their interactions to the yellowness (b*) of raw yellow alkaline noodle sheets.

	Relative Contribution (%)			
	b*			
Effect	0 hr	1 hr	2 hr	24 hr
Year	0	0	0	0
Location(year)	57.1	66.6	65.7	63.5
Cultivar	11.5	7.7	8.9	9.4
Cultivar × year	0	0	0	0
Cultivar × location(year)	8.4	8.3	8.4	8.5
Plot (cultivar × location × year)	7.7	11.0	11.5	15.1
Processing Rep(year)	1.3	0.1	0	0
Residual	14.0	6.3	5.5	3.5

The relative contribution of location and year were 30 % and 15 % for L* value of cooked noodles, respectively. Cultivar effect was not found to contribute to the L* values of cooked noodles which is in keeping with the ANOVA results. About 50 % of the total variation was due to environment (36 % for location and 14 % for year) for a* values of cooked noodles. Cultivar by location effect contributed 23 % to a* value while only 8.7 % was contributed by cultivar. The b* values of cooked noodles was predominantly influenced by the location effect (83 %) as oppose to the cultivar effect (0 %) and their interaction (7 %) (Table 4.24).

Table 4.24. Relative contribution of cultivar, year, location and their interactions to the color parameters[a] of optimally cooked yellow alkaline noodles.

	Relative Contribution (%)		
Effect	L*	a*	b*
Year	14.6	14.4	0
Location(year)	30.5	35.5	82.6
Cultivar	0	8.7	0
Cultivar × year	0	0	0
Cultivar × location(year)	9.8	23.2	6.8
Plot (cultivar × location × year)	19.3	4.7	7.0
Processing Rep(year)	0	0	0
Residual	25.8	13.5	3.6

[a] L* = brightness, a* = red-green scale, b* = yellowness.

The number of specks of raw noodle sheets was also mainly influenced by location (50 % on average) within the 24-hr time period. As discussed previously, ANOVA showed that cultivar and cultivar by location effects were only significant at 24 hr and Table 4.25 shows that their interaction effect had a higher contribution to speck count than the cultivar effect at 24 hr.

Table 4.25. Relative contribution of cultivar, year, location and their interactions to the speck count of yellow alkaline noodle sheets.

	Relative Contribution (%) to Speck Count		
Effect	1 hr	2 hr	24 hr
Year	0	0	4.9
Location(year)	49.9	50.9	41.8
Cultivar	5.4	5.8	7.2
Cultivar × year	0	0	0
Cultivar × location(year)	0	0	15.8
Plot (cultivar × location × year)	41.4	39.8	21.2
Processing Rep(year)	0	0	0
Residual	3.3	3.5	9.1

Table 4.26. Relative contribution of cultivar, year, location and their interactions to the mean are density of specks of yellow alkaline noodle sheets.

	Relative Contribution (%) to Mean Area Density of Specks		
Effect	1 hr	2 hr	24 hr
Year	0	0	0
Location(year)	69.9	71.9	70.2
Cultivar	2.7	4.5	1.0
Cultivar × year	0	0	1.2
Cultivar × location(year)	10.1	9.3	8.5
Plot (cultivar × location × year)	3.3	5.0	7.7
Processing Rep(year)	0.9	1.4	0.9
Residual	13.1	7.9	10.5

Similar to L* value, the contribution of location to the mean area density of specks of the raw noodle sheets (71 % on average) was much greater than all other effects (Table 4.26). Although both cultivar and cultivar by location effects were found to be significant at all the time periods measured, the contribution of their interaction effect was relatively larger than that of the cultivar.

These findings indicate that location effects were significant and relatively substantial in magnitude for all of the parameters measured at all of the time periods up to 24 hr, particularly for L* value and mean area density of specks for the raw noodle sheets. Moss (1971) using six different Australian wheat cultivars grown at two locations also found location effect to be more significant than the cultivar effect on the brightness of raw YAN (visually ranked shortly after preparation), whereas the opposite trend was observed for yellowness. In the present study, cultivar effects were significant for some of the color and specks measurements but very small in magnitude. The interaction effects between cultivar and location were significant for all of the parameters depending on the time being measured but in a relatively small magnitude compared to that of the location. Moss (1971) also found a significant cultivar by location effect on the yellowness of raw YAN but not for brightness, possibly due to the small number of locations or environments studied. In the present study, the lack of significance or the minor influence of cultivar effects on the color and speck measurements is in keeping with the fact that low variability of flour characteristics were observed among the cultivars examined. The small differences among the cultivars studied with regard to their color and speck characteristics possibly increased the likelihood of having significant interaction effect between the cultivar and environment.

Ames et al. (2000) found significant cultivar, environment and cultivar by environment effects for all the color parameters measured (L* and b* values at 0 and 24 hr and their stability) on raw alkaline noodle sheets. In agreement with the present study, they found that environment had a greater influence on L* and b* than cultivars at 0 hr. Unlike the present study, cultivar and environment were found to be similar in their contribution to the total variation for both L* and b* values at 24 hr and their changes after 24 hr of storage. Also, the contribution of the cultivar by environment interaction was found to be small compared to both the cultivar and environment effects. The greater role played by the cultivar effect in their study can be explained by the fact that they included cultivars with much wider genotypic range (Canadian and Australian genotypes representing several wheat classes) compared to the present study.

4.3.7 Spearman Rank Correlation

Quality evaluation of wheat properties often involves a large number of samples and tests that are time-consuming and expensive. Ideally, testing of wheat properties using samples composited over growing environments would be desirable since time and resources would be reduced. This practice would give accurate results even if the cultivar by environment interactions were significant as long as the rankings of the cultivars remain consistent across environments. Therefore, in order to confirm whether cultivar by environment interactions were due not only to changes in magnitude but reversal of rank, Spearman rank correlation which correlates the rankings of different cultivars among the environments was performed for those parameter examined. The results of the present study showed that selection of cultivars for higher noodle brightness at 0, 1 and 2 hr and lower number of specks at 1 and 2 hr for raw noodle sheets and higher cooked noodle brightness and yellowness were not necessary since differences for those characteristics among the cultivars were not significant and they were predominantly affected by the environment (mainly location effect). For those color and speck measurements which had significant cultivar and cultivar by location effects as revealed by ANOVA, selection can still be accomplished using composite samples as long as the ranking of the cultivars remain consistent across environments. An example of the matrix of the Spearman correlation coefficients for all the environment comparisons can be found in Table 4.27. The means of the rank correlations averaged over the 15 environment comparisons are presented in Table 4.28. For the number of cultivars involved, a reversal of one rank gave a correlation value of 0.80 which was considered to be high in the present study. A high mean rank correlation coefficient signifies that rankings of cultivars are similar among environments and vice versa.

As shown in Table 4.28, the mean rank correlations were low to very low for all of the measurements. It should be mentioned that it is common to store raw YAN up to 24 hr before consumption allowing darkening and discoloration of noodles over time. Therefore, selection for better color and speck characteristics

Table 4.27. Matrix of Spearman correlation coefficients for b* value (yellowness) of raw yellow alkaline noodle sheets at 1 hr after processing[a].

	B9	M9	S9	G0	M0	S0	Mean
B9		0.80	0.40	0.40	0.40	1.0	0.60
M9	0.80		- 0.20	- 0.20	0.20	0.80	0.28
S9	0.40	- 0.20		1.00	0.60	0.40	0.44
G0	0.40	- 0.20	1.00		0.60	0.40	0.44
M0	0.40	0.20	0.60	0.60		0.40	0.44
S0	1.00	0.80	0.40	0.40	0.40		0.60
Mean	0.60	0.28	0.44	0.44	0.44	0.60	0.47

[a] B9 = Beaverlodge 1999, M9 = Melfort 1999, S9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, S0 = Swift Current 2000.

Table 4.28. Means of the Spearman rank correlation coefficients of color and speck parameters of yellow alkaline noodles[a].

Parameters	Time period (hr)	Mean Rank Correlation[a]
L* (brightness)	24	0.17
a* (red-green scale)	0	0.49
	1	0.43
	2	0.39
	24	0.39
	cooked	0.11
b* (yellowness)	0	0.73
	1	0.47
	2	0.56
	24	0.08
Number of specks	24	0.29
Mean area density of specks	1	0
	2	0.16
	24	0.08

[a] only results of those measurements having significant cultivar and cultivar by environment effects were calculated. Means are averaged over 15 environment comparisons.

at the later stage of storage (2 to 24 hr) is more crucial than at the earlier stage (0 hr). However, selection of cultivars for the characteristics studied at the later stage of storage appeared to be even more unfeasible than earlier stage since our results showed that the mean rank correlation coefficients tended to decrease with time. For example, the b* value at 0 hr had the highest mean rank correlation coefficient of 0.73, however, it dropped considerably thereafter reaching a mean rank correlation coefficient of 0.08 at 24 hr. The low correlations observed for the parameters investigated in the present study were probably due to the low cultivar (genetic) variability (Baker and Kosmolak, 1977). Hence, our results indicated that cultivar by environment effects were due not only to changes in magnitude but reversals of rank for the color and speck measurements of YAN. Thus, if selection for those characteristics were to take place, multiple environments would be required to accurately assess the cultivars for those parameters. However, since location was found to be the dominant factor influencing the color and speck characteristics of YAN, effort might focus on identifying environments that would produce YAN with better color and speck properties.

4.4 CONCLUSIONS

For the CWRS wheat cultivars and growing environments involved in this study, the variance for environment was much greater than for cultivar for the flour characteristics and the color and speck properties investigated. Samples with lower flour protein content and enzyme activities, such as those grown in Melfort in 2000 and Swift Current in 1999, generally produced noodles with better color and speck characteristics. Flour Agtron color was shown to be a good indicator of the overall appearance of YAN.

Location effects were significant and contributed predominantly to all of the color and speck properties studied, especially raw noodle sheet brightness and speck darkness. Cultivar effects were significant in some cases depending on the storage time but contributed to a lesser degree than the environment effects. Cultivar by location interactions were statistically significant for most of the parameters studied and were due to reversals of rank. Thus, multiple environment testing appeared to be required to accurately evaluate the CWRS wheat cultivars for their noodle color and speck properties. However, this practice might not be necessary since the Canadian grain handling system involves co-mingling of varieties grown in different locations to ensure customers of consistent high quality wheat as being reflected in the present study. The composite sample could have been improved by eliminating cultivars such as AC Barrie and samples grown in environments such as Glenlea in 2000 that were shown to bring deleterious properties to the appearance of YAN. Nevertheless, since location had such a great influence on the color and speck properties of

YAN, selection of CWRS wheat cultivars by location may be appropriate to meet specific needs of the customer. In fact, there is an increasing trend in the Canadian grain handling system with direct shipment of grains from some areas. However, more research is required to elucidate what environmental factors would favor the production of YAN with desirable color and speck characteristics.

CHAPTER 5

CONCLUSIONS AND LIMITATIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Part of the objectives of this research was to quantitate the differences among cultivars and among environments with regard to the quality characteristics of YAN. Another objective was to investigate the relationship between grain and/or flour characteristics and noodle properties. Overall, the variance for cultivar was much smaller than for environment for both the flour and noodle characteristics.

Differences among the cultivars were observed for all of the characteristics measured regarding the eating quality and appearance of noodles, except for raw noodle sheet brightness measured between 0 and 2 hr, and brightness and yellowness of cooked YAN. Among the cultivars examined, AC Barrie appeared to be the least favorable for noodle production. With regard to raw noodle sheet appearance, AC Barrie were less bright at 24 hr, had more discoloration and more specks that were darker in color. High cooking losses and low textural values were also observed for its cooked noodles. Compared with the individual cultivars, YAN made with the composite sample from the year 2000 harvest appeared to have better quality. Raw noodle sheets prepared with the composite sample had fewer specks that were less dark in color and the cooked noodles had higher textural values, especially for MCS, RTC, and gumminess, thus firmer and chewier texture. This might be due to the more optimum flour quality that the composite sample possessed.

Environmental differences were observed for all of the textural properties measured and they were related to the differences in their flour and wheat characteristics. Compared with the noodles made from the cultivars grown in Swift Current in 1999 and Melfort in 2000, those of Melfort in 1999 were higher in MCS since the flour samples from Melfort in 1999 had higher protein and gluten contents but lower RVA parameter values, except for SBD. Higher RTC and gumminess values observed for noodles prepared from environments such as Melfort in 1999 and Swift Current in 2000 were due to higher wet gluten content. Gumminess also appeared to increase with lower SBD and higher SFV and SSB values. Flour samples that had higher SHS, SFV and SSB but lower SBD values were associated with higher relaxation time values of cooked noodles as in the case of Swift Current for both year.

Differences among the environments were also observed for all of the characteristics related to the color and specks of both raw and cooked YAN. In general, cultivars grown in Glenlea in 2000 produced both raw and cooked noodles with inferior color characteristics, since they were less bright and yellow with greater discoloration and more specks that were darker in color. The opposite trend was found for the noodles made from the cultivars grown in Melfort in 2000 and in Swift Current, especially for the year 1999. Differences among the environments for the color and speck characteristics of YAN were related to the differences in their flour and wheat characteristics. In general, samples with lower flour protein content and lower flour peroxidase and grain PPO activities were found to produce YAN with more favorable color characteristics and less specks that were not as dark in color. Flour Agtron color appears to be a useful indicator of color and speck characteristics of YAN since it was shown to be positively related to brightness and yellowness of raw noodle sheets and cooked noodles and negatively to discoloration, speck count, and speck darkness of raw noodle sheets.

The other objective of this thesis was to determine the relative contribution of cultivar, environment and their interaction to the quality characteristics of YAN prepared from CWRS wheat cultivars grown across western Canada. Our results showed that both cultivar and environment had significant effects on the quality characteristics of YAN, yet location was the predominate effect, especially for the color characteristics and mean darkness of specks of raw noodle sheets, as well as the brightness, discoloration, cooking loss, MCS and relaxation time of the cooked noodles. The relative contribution of the cultivar by location effects were similar to or in some cases greater than that of the cultivar effects for the parameters investigated. The interaction effects between the cultivar and environment were important especially for the color and speck characteristics of raw noodle sheets and for the cooking losses, RTC, gumminess, and springiness of cooked noodles as confirmed by the rank correlation results. Results from the stability test revealed that while AC Barrie was overall the least stable cultivar across environments for the cooking and textural properties of YAN, AC Domain and CDC Teal were relatively more stable. Even though cultivar by environment effects were significant for the majority of the parameters examined, this was likely due to the fact that the variations among the cultivars were small which in turn increased the likelihood of change of rank across the environments. It should be noted that the cultivar by environment effect was not significant for MCS and that the interaction effects were observed within the two groups of cultivars studied with regard to cooking loss, gumminess, and relaxation time. Therefore, it is reasonable to speculate that in early generation of breeding lines where greater genetic variations exist among lines, screening for lines with good cooking and noodle textural properties could be done adequately using samples composited over different growing environments.

5.2 LIMITATIONS AND RECOMMENDATIONS

One of the limitations of this research was that other starch properties, such as amylose content, flavones and phenolic compounds which respectively are known to affect the texture, yellowness and brightness of noodles were not determined. In addition to the flour characteristics investigated in this research, future studies should also consider the characteristics stated above and use samples with wider variability in noodle characteristics in order to have a better understanding of their effects on noodle quality.

Another limitation was that water absorption level was not optimized for each flour sample. Although methods that can predict the optimum water absorption level for noodle production have been developed, the testing procedures are usually time-consuming and/or require large sample sizes. There appears to be a need for a testing procedure that will require smaller sample sizes and less time to determine the optimum water absorption level for individual flour samples with regard to noodle production.

Although a previous study has found that MCS and RTC were correlated with the sensory perception of noodle firmness and chewiness, respectively, whether the other instrumental parameters used in this study could adequately measure the sensory counterparts remained unclear. Similarly, although differences were observed among samples for their speckiness analyzed by image analysis, whether the differences could be perceived visually are not known. Future research is needed to verify the relationships between instrumental measurements and sensory evaluation of noodle characteristics, especially for springiness and speckiness.

The fact that the composite sample examined in this study had better overall noodle making quality than individual cultivars has validated the success of the current Canadian grain handling system which involves co-mingling of registered varieties grown across varying locations to ensure customers of consistent high quality wheat. The composite sample can be improved by eliminating cultivars such as AC Barrie and samples grown in environments such as Glenlea in 2000 that were shown to bring deleterious properties to YAN. Nevertheless, the effects of environment on the quality characteristics of YAN were shown to be very important in this study. Therefore, selection of CWRS wheat cultivars by environment may be appropriate to meet specific needs of the customers. In fact, there is an increasing trend in the Canadian grain handling system with direct shipment of grains from some areas. However, more research is required to elucidate what the important environmental factors are in governing the noodle making quality of wheat cultivars.

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APPENDIX I

Detailed data of wheat and flour characteristics

Table AI.1. Ash content[a] (%), protein content[b] (%), sodium dodecyl sulfate sedimentation volume[c] (mL), wet gluten content[d] (%) and gluten index values[e] (%) of each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	0.32[a]	(0.01)	0.29	(0.01)	0.32	(0.01)	0.31	(0.02)		
	13.1[b]	(0.1)	13.0	(0.0)	12.6	(0.2)	13.2	(0.1)		
	66.5[c]	(1.0)	70.5	(0.6)	64.8	(1.7)	69.3	(1.3)		
	36.0[d]	(1.0)	36.7	(0.5)	34.9	(1.1)	34.0	(0.4)		
	99.4[e]	(1.1)	98.6	(1.5)	97.4	(0.9)	99.9	(0.1)		
Melfort 1999	0.36	(0)	0.33	(0.01)	0.40	(0.01)	0.38	(0.01)		
	14.5	(0.1)	14.8	(0.1)	14.9	(0.1)	14.5	(0.1)		
	60.3	(1.0)	58.3	(1.0)	60.5	(1.7)	63.5	(0.6)		
	42.4	(0.4)	44.5	(0.2)	43.9	(0.5)	43.2	(0.7)		
	89.5	(1.8)	80.8	(6.6)	76.9	(2.9)	82.3	(2.2)		
Swift Current 1999	0.32	(0.01)	0.31	(0.02)	0.30	(0.03)	0.31	(0.01)		
	11.7	(0.6)	11.0	(0.1)	12.1	(0.3)	12.9	(0.2)		
	60.5	(1.3)	54.8	(1.0)	62.3	(2.1)	65.5	(1.7)		
	32.2	(3.0)	30.3	(0.6)	33.2	(1.5)	36.0	(2.0)		
	95.8	(1.1)	93.8	(4.1)	88.7	(0.7)	91.6	(5.2)		
Glenlea 2000	0.39	(0.02)	0.43	(0.05)	0.43	(0.01)	0.42	(0.04)	0.40	(0.02)
	14.0	(0.1)	14.9	(0.3)	13.9	(0.1)	13.9	(0)	14.3	(0.08)
	67.8	(1.0)	67.0	(0)	71.5	(0.6)	81.5	(1.9)	70.0	(1.6)
	37.6	(0.4)	42.0	(1.0)	38.3	(0.2)	37.3	(0.3)	41.4	(0.4)
	99.4	(0.7)	92.1	(2.3)	95.6	(0.7)	99.7	(0.3)	93.6	(1.9)
Melfort 2000	0.40	(0.01)	0.39	(0.01)	0.44	(0.01)	0.41	(0.01)	0.41	(0.01)
	11.4	(0.4)	11.9	(0.1)	11.5	(0.1)	11.5	(0.1)	11.4	(0.1)
	43.5	(3.5)	49.8	(0.5)	46.3	(1.0)	50.5	(3.1)	42.8	(2.1)
	32.9	(1.2)	34.6	(0.1)	33.1	(0.8)	33.5	(0.5)	34.7	(0.8)
	85.4	(1.4)	78.9	(10.1)	79.1	(0.4)	77.4	(2.2)	68.7	(1.3)
Swift Current 2000	0.37	(0.02)	0.36	(0.03)	0.34	(0.02)	0.35	(0.02)	0.36	(0.01)
	13.9	(0.2)	14.1	(0.6)	13.2	(0.4)	14.6	(0.3)	14.0	(0.01)
	68.5	(1.3)	69.0	(2.3)	70.0	(2.5)	79.3	(5.2)	70.5	(1.7)
	37.2	(0.8)	38.7	(1.1)	35.8	(1.0)	38.2	(1.1)	38.8	(0.4)
	96.1	(1.4)	94.1	(2.0)	93.6	(2.6)	97.8	(0.3)	96.3	(1.9)

Values are mean and (standard deviation) of two determinations per plot duplicate. AC Majestic was grown at the year 2000 locations only.

Table AI.2. Peak viscosity[a], holding strength[b], breakdown[c], final viscosity[d], and setback[e] measured in distilled water (Rapid Visco Analyzer viscosity units) of each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	199.1[a]	(2.6)	226.7	(1.8)	202.4	(2.3)	220.9	(4.4)		
	119.4[b]	(1.6)	134.7	(3.1)	124.7	(2.4)	130.0	(3.9)		
	79.8[c]	(1.3)	92.0	(2.1)	77.7	(0.4)	90.8	(0.7)		
	225.0[d]	(3.0)	246.0	(3.8)	234.5	(2.6)	239.5	(6.3)		
	105.6[e]	(1.5)	111.3	(1.1)	109.9	(0.9)	109.5	(2.5)		
Melfort 1999	170.3	(5.9)	182.1	(2.6)	164.4	(4.1)	143.9	(1.5)		
	101.1	(5.3)	122.9	(2.0)	103.9	(4.9)	73.5	(1.0)		
	69.1	(1.8)	59.3	(0.7)	60.4	(1.6)	70.4	(2.0)		
	198.6	(8.5)	239.7	(2.7)	206.0	(5.9)	155.4	(1.1)		
	97.5	(3.3)	116.8	(0.7)	102.1	(1.4)	82.0	(0.1)		
Swift Current 1999	199.7	(11.5)	191.0	(7.3)	194.8	(1.0)	201.1	(13.2)		
	137.7	(6.2)	136.6	(9.6)	144.1	(1.5)	141.4	(7.4)		
	62.0	(5.4)	53.0	(3.7)	50.7	(1.1)	59.7	(5.9)		
	267.7	(9.6)	265.7	(16.0)	278.8	(1.6)	270.8	(11.4)		
	129.9	(3.7)	129.1	(6.6)	134.7	(1.6)	129.3	(4.1)		
Glenlea 2000	219.2	(3.0)	235.6	(3.3)	216.2	(3.2)	213.2	(5.3)	255.9	(3.5)
	126.7	(3.4)	136.0	(4.7)	121.7	(4.1)	164.9	(52.8)	193.7	(71.1)
	92.5	(3.4)	99.6	(2.5)	94.4	(1.7)	105.2	(11.1)	126.2	(3.0)
	242.9	(5.1)	249.2	(4.0)	233.9	(4.8)	162.2	(75.8)	175.8	(56.4)
	116.1	(1.8)	113.2	(0.8)	112.2	(0.7)	107.4	(2.1)	93.8	(3.0)
Melfort 2000	194.2	(1.0)	210.2	(3.5)	199.2	(2.1)	202.4	(1.8)	250.7	(2.9)
	112.3	(1.5)	127.9	(3.4)	122.8	(3.2)	115.6	(1.1)	156.6	(52.3)
	81.9	(1.1)	82.3	(0.5)	76.4	(1.7)	86.9	(0.9)	121.8	(5.7)
	217.6	(2.5)	241.3	(3.2)	233.3	(2.7)	221.5	(1.6)	204.3	(53.4)
	105.3	(1.5)	113.4	(0.6)	110.5	(1.3)	105.9	(2.1)	100.4	(1.5)
Swift Current 2000	212.5	(1.6)	235.5	(3.5)	216.4	(3.7)	224.7	(3.8)	263.5	(5.0)
	135.4	(1.1)	148.0	(7.0)	139.1	(5.1)	135.5	(2.5)	138.7	(2.3)
	77.1	(0.8)	87.5	(4.2)	77.3	(2.7)	89.2	(1.5)	124.8	(3.0)
	258.7	(1.5)	268.5	(7.7)	258.9	(3.8)	255.6	(3.8)	238.0	(1.9)
	123.3	(1.3)	120.5	(2.0)	119.8	(1.5)	120.2	(1.6)	99.2	(1.5)

Values are mean and (standard deviation) of two determinations per plot duplicate. AC Majestic was grown at the year 2000 locations only.

Table AI.3. Peak viscosity[a], holding strength[b], breakdown[c], final viscosity[d], and setback[e] measured in 0.05 M silver nitrate solution (Rapid Visco Analyzer viscosity units) of each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	243.9[a]	(2.0)	250.3	(1.2)	255.4	(4.7)	253.9	(1.7)		
	102.9[b]	(0.6)	102.6	(1.1)	111.6	(3.6)	108.8	(1.3)		
	141.1[c]	(2.3)	147.7	(1.3)	143.7	(3.1)	145.1	(1.8)		
	174.7[d]	(1.0)	175.5	(1.6)	189.6	(5.2)	186.5	(2.0)		
	71.8[e]	(0.7)	72.9	(0.6)	78.0	(1.9)	77.7	(1.3)		
Melfort 1999	227.4	(1.9)	242.2	(2.8)	242.4	(1.6)	242.9	(2.6)		
	90.5	(1.8)	101.3	(1.0)	103.4	(0.6)	98.1	(1.3)		
	136.8	(0.7)	140.9	(3.0)	139.0	(1.1)	144.7	(2.6)		
	157.9	(2.4)	179.8	(2.3)	181.0	(1.1)	170.6	(1.5)		
	67.4	(0.5)	78.5	(1.5)	77.8	(1.1)	72.5	(1.2)		
Swift Current 1999	245.0	(13.4)	237.4	(9.0)	246.6	(3.5)	245.3	(8.5)		
	115.9	(8.1)	112.2	(7.7)	119.9	(0.9)	114.3	(3.6)		
	129.1	(5.7)	125.2	(2.4)	126.7	(3.3)	131.1	(4.9)		
	201.3	(8.3)	199.3	(12.0)	211.5	(2.7)	203.3	(7.4)		
	85.3	(0.7)	87.1	(4.4)	91.6	(1.9)	89.1	(3.9)		
Glenlea 2000	256.7	(2.9)	260.5	(3.4)	261.0	(2.0)	255.4	(2.7)	260.5	(2.5)
	103.1	(1.3)	106.9	(2.4)	109.8	(0.6)	106.6	(0.9)	99.9	(4.5)
	153.6	(1.7)	153.6	(1.3)	151.3	(1.8)	148.7	(2.9)	160.6	(3.8)
	181.6	(1.9)	180.1	(0.8)	189.0	(0.9)	186.6	(2.0)	169.6	(4.7)
	78.5	(1.0)	73.2	(2.0)	79.3	(0.3)	80.0	(1.4)	69.6	(0.7)
Melfort 2000	244.3	(3.5)	261.0	(4.9)	256.8	(3.6)	253.9	(3.1)	270.7	(0.9)
	100.2	(1.1)	107.2	(1.6)	111.6	(1.8)	106.1	(2.2)	102.5	(1.3)
	144.1	(3.9)	153.8	(6.5)	145.2	(2.2)	147.8	(4.7)	168.1	(1.3)
	173.4	(1.1)	187.2	(3.5)	189.3	(0.9)	182.7	(2.9)	175.9	(2.7)
	73.2	(1.2)	80.0	(2.1)	76.9	(3.0)	76.6	(1.8)	73.4	(1.6)
Swift Current 2000	250.7	(2.1)	255.4	(5.1)	256.2	(3.6)	255.4	(1.9)	257.8	(3.9)
	107.7	(3.0)	105.6	(2.5)	115.9	(2.2)	114.4	(2.5)	100.2	(5.6)
	143.0	(2.8)	149.8	(5.0)	140.2	(5.6)	141.0	(3.2)	157.5	(4.0)
	192.9	(6.0)	187.2	(5.3)	203.4	(4.9)	201.2	(2.3)	175.0	(7.9)
	85.2	(3.1)	81.5	(3.0)	87.4	(2.9)	86.8	(2.9)	74.7	(2.8)

Values are mean and (standard deviation) of two determinations per plot duplicate. AC Majestic was grown at the year 2000 locations only.

Table AIII.4. Flour Agtron color[a] (%), flour peroxidase activity[b] (optical density at 405 nm), and wholemeal polyphenol oxidase activity[c] (nmoles oxygen/min/g of sample) of each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	88.5[a]	(0.4)	87.8	(0.9)	86.0	(0.9)	84.4	(1.4)		
	373[b]	(9)	331	(6)	345	(11)	315	(10)		
	753[c]	(54)	915	(16)	761	(24)	720	(50)		
Melfort 1999	81.9	(0.2)	75.4	(0.6)	78.9	(1.6)	86.0	(0.4)		
	435	(19)	411	(14)	402	(1)	348	(6)		
	1044	(23)	1089	(21)	930	(38)	832	(26)		
Swift Current 1999	93.6	(0.9)	95.3	(1.3)	92.0	(0.3)	91.7	(1.3)		
	257	(44)	273	(35)	244	(7)	285	(12)		
	855	(35)	713	(26)	814	(26)	707	(16)		
Glenlea 2000	75.2	(2.6)	63.1	(15.7)	71.1	(0.8)	65.6	(12.1)	68.8	(7.6)
	443	(26)	378	(6)	354	(10)	352	(26)	405	(20)
	2684	(404)	2349	(132)	3087	(56)	1912	(54)	3252	(42)
Melfort 2000	92.2	(1.6)	87.8	(0.9)	90.3	(0.9)	92.5	(0.7)	89.9	(0)
	342	(10)	349	(6)	313	(6)	314	(15)	329	(7)
	625	(66)	642	(32)	574	(47)	633	(24)	837	(28)
Swift Current 2000	88.7	(0.2)	87.7	(4.7)	88.9	(2.4)	83.3	(3.5)	85.4	(1.8)
	397	(24)	331	(7)	288	(4)	346	(8)	360	(5)
	1147	(112)	1287	(206)	1280	(60)	1206	(13)	1394	(106)

[a] Values are mean and (standard deviation) of one determination per plot duplicate.
[b,c] Values are mean and (standard deviation) of two determinations per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

APPENDIX II

Correlations with regard to textural parameters

Table AII.1. Correlation coefficients between Rapid Visco Analyzer parameters measured in distilled water or 0.05 M silver nitrate solution and textural parameters.

	Maximum Cutting Stress	Resistance to Compression	Springiness	Gumminess	Relaxation Time
PV	-0.40*	-0.34	0.26	-0.56**	-0.08
HS	-0.42*	-0.26	0.20	-0.36	0.22
BD	0.006	-0.36	0.37	-0.73**	-0.55**
FV	-0.62**	0.06	-0.25	0.34	0.70**
SB	-0.67**	0.01	-0.29	0.45*	0.83**
SPV	-0.25	-0.24	0.29	-0.33	-0.15
SHS	-0.52**	-0.09	-0.22	0.36	0.65**
SBD	0.12	-0.16	0.41*	-0.53**	-0.57**
SFV	-0.55**	-0.01	-0.33	0.44*	0.74**
SSB	-0.55**	0.07	-0.42*	0.49**	0.78**

[a] correlation coefficients were determined using cultivar means at each environment examined (n=27).

[b] *, **, significant at $P < 0.05$ and $P < 0.01$, respectively.

[c] PV = peak viscosity in distilled water, HS = holding strength in distilled water, BD = breakdown in distilled water, FV = final viscosity in distilled water, SB = setback in distilled water, SPV = peak viscosity in silver nitrate, SHS = holding strength in silver nitrate, SBD = breakdown in silver nitrate, SFV = final viscosity in silver nitrate, SSB = setback in silver nitrate.

Table AII.2. Matrix of Pearson correlation coefficients[a,b] for textural parameters of cooked yellow alkaline noodles.

	Hardness	MCS	RTC	Springiness	Gumminess	Chewiness	RTime	RArea	RSlope
Hardness		0.98***	0.47*	-0.18	0.04	-0.02	-0.47*	-0.47*	-0.46*
MCS	0.98***		0.47*	-0.11	0.07	0.04	-0.48*	-0.47*	-0.46*
RTC	0.47*	0.47*		-0.55**	0.61***	0.52**	0.30	0.30	0.32
Springiness	-0.18	-0.11	-0.55**		-0.59**	-0.34	-0.40*	-0.41*	-0.42*
Gumminess	0.04	0.07	0.61***	-0.59**		0.96***	0.64***	0.65***	0.66***
Chewiness	-0.02	0.04	0.52**	-0.34	-0.34		0.61***	0.61***	0.63***
RTime	-0.47*	-0.48*	0.30	-0.40*	-0.40*	0.61***		> 0.99***	> 0.99***
RArea	-0.47*	-0.47*	0.30	-0.41*	-0.41*	0.61***	> 0.99***		> 0.99***
RSlope	-0.46*	-0.46*	0.32	-0.42*	-0.42*	0.63***	> 0.99***	> 0.99***	

[a] correlation coefficients were determined using textural values of noodles made from cultivars grown at each environment (n=27).
[b] *, **, ***, significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively.
MCS = Maximum cutting stress, RTC = Resistant to compression, RTime = Relaxation time, RArea = Relaxation area, RSlope = Relaxation slope

APPENDIX III

Textural Properties of noodles prepared from each cultivar grown at each environment

Table AIII.1. Cooking loss[a] (%), maximum cutting stress[b] (g/mm^2), and resistance to compression[c] (%) of cooked noodles prepared from each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	11.6[a]	(0.4)	11.2	(0.2)	10.9	(0.1)	11.4	(0.3)		
	25.7[b]	(0.4)	26.1	(0.4)	26.4	(0.4)	26.5	(0.7)		
	22.0[c]	(1.0)	24.3	(0.7)	23.7	(0.7)	23.3	(1.0)		
Melfort 1999	10.5	(0.1)	10.1	(0.2)	9.5	(0.1)	9.6	(0.1)		
	28.1	(1.1)	26.5	(0.9)	29.6	(0.4)	27.8	(0.6)		
	24.9	(0.4)	24.8	(0.9)	25.9	(0.5)	23.5	(2.0)		
Swift Current 1999	12.2	(0.1)	11.8	(1.0)	12.1	(0.0)	11.9	(0.2)		
	22.8	(0.3)	22.8	(0.8)	24.7	(0.8)	23.8	(0.5)		
	22.6	(0.9)	23.0	(1.3)	23.8	(0.5)	23.9	(0.3)		
Glenlea 2000	12.5	(0.1)	12.1	(0.1)	12.1	(0.2)	11.9	(0.3)	11.9	(0.2)
	24.7	(0.2)	24.3	(0.5)	25.9	(0.3)	25.2	(0.6)	26.3	(0.5)
	22.7	(0.7)	23.3	(0.3)	23.9	(0.6)	22.9	(0.7)	23.1	(0.7)
Melfort 2000	11.5	(0.4)	10.7	(0.3)	10.4	(0.3)	10.9	(0.3)	10.2	(0.1)
	23.9	(1.3)	23.4	(0.6)	25.7	(0.5)	25.3	(1.0)	25.2	(0.3)
	22.7	(0.4)	24.0	(0.7)	23.7	(1.0)	23.6	(1.0)	23.0	(0.5)
Swift Current 2000	12.6	(0.3)	11.7	(0.4)	12.1	(0.2)	12.1	(0.4)	11.6	(0.3)
	23.9	(0.3)	23.8	(0.4)	24.1	(0.6)	25.1	(0.5)	24.8	(0.2)
	23.3	(0.7)	25.2	(0.3)	24.0	(0.3)	23.8	(0.6)	22.6	(0.6)

Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

Table AIII.2. Gumminess[a] (g), springiness[b], and relaxation time[c] (sec) of cooked noodles prepared from each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	362.3[a]	(5.0)	381.8	(8.7)	386.2	(4.1)	366.2	(6.8)		
	0.916[b]	(0.007)	0.908	(0.006)	0.897	(0.032)	0.900	(0.010)		
	3.10[c]	(0.04)	3.57	(0.14)	3.33	(0.13)	3.23	(0.10)		
Melfort 1999	371.5	(4.1)	404.8	(8.6)	403.7	(1.2)	393.8	(6.3)		
	0.883	(0.006)	0.898	(0.003)	0.880	(0.011)	0.895	(0.009)		
	3.11	(0.11)	3.98	(0.13)	3.38	(0.15)	3.20	(0.11)		
Swift Current 1999	380.5	(4.4)	387.3	(5.0)	395.3	(5.6)	392.1	(5.1)		
	0.897	(0.007)	0.901	(0.010)	0.892	(0.010)	0.894	(0.009)		
	4.10	(0.17)	4.12	(0.24)	4.37	(0.28)	3.97	(0.16)		
Glenlea 2000	381.5	(2.2)	392.0	(4.1)	383.5	(2.8)	374.3	(8.1)	343.3	(8.7)
	0.898	(0.005)	0.891	(0.012)	0.896	(0.012)	0.893	(0.012)	0.913	(0.014)
	3.16	(0.07)	3.55	(0.20)	3.78	(0.11)	3.36	(0.07)	3.14	(0.11)
Melfort 2000	360.1	(6.0)	376.4	(11.1)	377.3	(8.9)	372.5	(4.4)	353.0	(4.6)
	0.907	(0.005)	0.904	(0.006)	0.904	(0.007)	0.909	(0.001)	0.925	(0.013)
	3.14	(0.19)	3.52	(0.03)	3.44	(0.13)	3.05	(0.03)	3.17	(0.06)
Swift Current 2000	380.7	(5.1)	397.4	(4.6)	388.3	(2.0)	379.0	(5.3)	342.3	(5.7)
	0.888	(0.016)	0.881	(0.012)	0.886	(0.009)	0.874	(0.003)	0.900	(0.013)
	3.76	(0.22)	4.28	(0.09)	3.87	(0.12)	3.64	(0.09)	3.07	(0.07)

Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

APPENDIX IV

Color and speck characteristics of noodle sheets and noodles prepared from each cultivar grown at each environment

Table AIV.1. Brightness (L*) of raw noodle sheets prepared from each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	85.00[a]	(0.45)	85.47	(0.45)	85.10	(0.18)	84.60	(0.31)		
	82.18[b]	(0.10)	82.96	(0.16)	82.37	(0.18)	81.72	(0.33)		
	81.08[c]	(0.26)	82.24	(0.20)	81.41	(0.19)	80.72	(0.23)		
	76.30[d]	(0.33)	78.51	(0.09)	76.91	(0.10)	76.27	(0.62)		
Melfort 1999	82.58	(0.18)	83.33	(0.27)	83.59	(0.71)	84.42	(0.51)		
	79.93	(0.25)	80.61	(0.15)	80.51	(0.43)	81.79	(0.40)		
	78.91	(0.10)	79.62	(0.15)	79.50	(0.44)	80.92	(0.29)		
	74.23	(0.11)	75.38	(0.10)	74.27	(0.44)	76.49	(0.45)		
Swift Current 1999	85.39	(0.45)	86.19	(0.25)	85.79	(0.33)	85.33	(0.17)		
	83.25	(0.31)	84.13	(0.42)	83.48	(0.09)	82.92	(0.21)		
	82.42	(0.39)	83.25	(0.39)	82.59	(0.08)	81.94	(0.23)		
	78.22	(0.58)	79.11	(0.42)	78.27	(0.26)	77.54	(0.11)		
Glenlea 2000	82.93	(0.42)	82.42	(1.17)	83.32	(0.36)	82.13	(1.01)	83.33	(1.02)
	80.08	(0.36)	78.91	(1.57)	80.04	(0.16)	78.94	(1.35)	79.79	(0.72)
	78.95	(0.39)	77.77	(1.46)	78.97	(0.11)	77.81	(1.37)	78.77	(0.78)
	74.59	(0.28)	73.54	(1.55)	74.08	(0.31)	73.95	(1.63)	73.96	(1.09)
Melfort 2000	85.86	(0.43)	86.02	(0.28)	85.74	(0.44)	85.98	(0.26)	86.35	(0.54)
	82.98	(0.37)	83.28	(0.41)	82.84	(0.71)	83.36	(0.24)	83.65	(0.72)
	82.04	(0.44)	82.35	(0.48)	82.03	(0.64)	82.34	(0.30)	82.43	(0.66)
	77.52	(0.45)	78.77	(0.45)	77.67	(0.39)	78.08	(0.12)	78.01	(0.82)
Swift Current 2000	85.15	(0.20)	85.37	(0.45)	85.35	(0.48)	84.79	(0.27)	85.08	(0.29)
	82.43	(0.29)	83.03	(0.61)	82.99	(0.57)	82.21	(0.34)	82.41	(0.12)
	81.45	(0.37)	82.32	(0.57)	82.04	(0.51)	81.27	(0.43)	81.51	(0.23)
	76.81	(0.15)	78.04	(0.99)	77.96	(0.82)	77.18	(0.69)	77.14	(0.33)

[a], [b], [c], [d], values were measured at 0, 1, 2, and 24 hour, respectively, after processing.
Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

Table AIV.2. Redness (a*) of raw noodle sheets prepared from each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	-0.25[a]	(0.04)	-0.63	(0.03)	-0.60	(0.13)	-0.48	(0.11)		
	-0.09[b]	(-0.02)	-0.38	(0.01)	-0.35	(0.07)	-0.20	(-0.06)		
	-0.11[c]	(-0.01)	-0.42	(0.06)	-0.32	(0.05)	-0.16	(-0.08)		
	-0.07[d]	(-0.02)	-0.42	(-0.03)	-0.33	(-0.03)	-0.08	(-0.08)		
Melfort 1999	0.34	(0.07)	-0.04	(0.07)	0.16	(0.02)	-0.17	(0.01)		
	0.63	(0.04)	0.32	(-0.05)	0.43	(-0.02)	0.02	(0.06)		
	0.69	(0.06)	0.41	(-0.04)	0.46	(-0.02)	0.07	(0.04)		
	1.04	(0.03)	0.59	(0.10)	0.81	(0.07)	0.31	(0.04)		
Swift Current 1999	-0.16	(0.41)	-0.37	(0.22)	-0.32	(0.10)	0.07	(0.19)		
	0.03	(0.26)	-0.13	(0.30)	-0.12	(0.17)	0.24	(0.18)		
	0.03	(0.27)	-0.10	(0.27)	-0.16	(0.14)	0.25	(0.18)		
	0.09	(0.23)	-0.10	(-0.29)	-0.21	(-0.10)	0.19	(0.22)		
Glenlea 2000	0.45	(0.04)	-0.07	(0.15)	-0.05	(0.01)	-0.14	(0.04)	0.03	(0.04)
	0.75	(0.05)	0.28	(-0.09)	0.30	(-0.05)	0.16	(0.05)	0.38	(0.03)
	0.82	(0.03)	0.37	(-0.05)	0.38	(-0.04)	0.22	(0.07)	0.40	(0.04)
	1.01	(0.04)	0.67	(0.03)	0.68	(0.05)	0.57	(0.13)	0.64	(0.06)
Melfort 2000	-0.27	(0.10)	-0.50	(0.07)	-0.45	(0.02)	-0.51	(0.10)	-0.58	(0.09)
	0.10	(0.05)	-0.13	(0.04)	-0.05	(0.03)	-0.26	(-0.03)	-0.31	(0.13)
	0.25	(0.07)	-0.03	(0.03)	-0.01	(0.10)	-0.17	(-0.05)	-0.20	(0.11)
	0.37	(0.09)	0.07	(0.02)	0.27	(0.07)	-0.05	(-0.04)	-0.06	(0.11)
Swift Current 2000	0.30	(0.04)	-0.31	(0.19)	-0.28	(0.07)	0.02	(0.06)	-0.09	(0.09)
	0.43	(0.03)	-0.11	(0.15)	-0.16	(0.01)	0.16	(0.09)	0.12	(0.04)
	0.41	(0.04)	-0.11	(0.11)	-0.16	(0.02)	0.17	(0.10)	0.10	(0.04)
	0.40	(0.04)	-0.12	(-0.10)	-0.13	(-0.03)	0.20	(0.06)	0.00	(0.03)

[a], [b], [c], [d], values were measured at 0, 1, 2, and 24 hour, respectively, after processing.
Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

Table AIV.3. Yellowness (b*) of raw noodle sheets prepared from each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic
Beaverlodge 1999	22.42[a]	(0.54)	21.66	(0.77)	23.61	(0.80)	24.53	(0.16)	
	25.80[b]	(0.24)	25.02	(0.22)	26.99	(0.66)	28.28	(0.23)	
	26.19[c]	(0.18)	25.45	(0.40)	27.58	(0.69)	28.92	(0.11)	
	26.70[d]	(0.04)	26.63	(0.32)	28.10	(0.66)	29.70	(0.35)	
Melfort 1999	23.59	(0.41)	22.51	(0.52)	23.07	(1.22)	24.00	(0.90)	
	25.83	(0.31)	26.16	(0.49)	26.71	(0.51)	26.84	(0.51)	
	26.35	(0.27)	26.71	(0.48)	27.01	(0.60)	27.35	(0.38)	
	27.36	(0.47)	27.61	(0.29)	28.04	(0.28)	28.12	(0.15)	
Swift Current 1999	26.99	(0.48)	25.33	(0.39)	25.46	(1.23)	25.55	(0.54)	
	29.58	(0.35)	28.67	(0.28)	29.04	(0.46)	29.07	(0.58)	
	29.96	(0.46)	29.22	(0.37)	29.55	(0.26)	29.58	(0.68)	
	29.65	(0.92)	29.43	(0.68)	29.43	(0.08)	29.25	(0.75)	
Glenlea 2000	23.35	(0.64)	19.62	(2.13)	20.48	(0.97)	21.15	(1.62)	20.04 (0.58)
	25.86	(0.38)	22.87	(2.12)	23.99	(0.51)	24.54	(1.08)	23.59 (0.72)
	26.30	(0.33)	23.51	(1.99)	24.63	(0.46)	25.16	(1.18)	24.02 (0.66)
	26.40	(0.21)	24.76	(1.62)	25.65	(0.31)	26.26	(0.97)	24.96 (0.58)
Melfort 2000	23.75	(1.05)	22.52	(0.71)	23.20	(0.62)	23.95	(0.72)	21.55 (0.97)
	27.05	(0.47)	26.83	(0.97)	26.75	(0.79)	27.24	(0.99)	25.41 (0.89)
	27.75	(0.44)	27.40	(0.79)	27.54	(0.72)	28.05	(0.90)	26.11 (0.65)
	28.65	(0.45)	28.89	(0.40)	28.76	(0.67)	29.55	(0.39)	27.07 (0.85)
Swift Current 2000	24.31	(0.62)	23.26	(0.83)	25.26	(0.54)	25.43	(0.70)	24.07 (0.68)
	27.59	(0.32)	26.37	(0.34)	28.11	(0.38)	28.56	(0.48)	27.23 (0.55)
	28.06	(0.34)	26.71	(0.56)	28.52	(0.34)	28.99	(0.37)	27.60 (0.46)
	27.37	(0.16)	26.86	(0.21)	28.16	(0.21)	28.88	(0.24)	27.11 (0.46)

[a], [b], [c], [d], values were measured at 0, 1, 2, and 24 hour, respectively, after processing.
Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

Table AIV.4. Brightness (L*)[a], redness (a*)[b], and yellowness (b*)[c] of cooked noodles prepared from each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	67.17[a]	(0.99)	66.13	(1.01)	67.15	(0.64)	66.91	(0.69)		
	-1.84[b]	(0.30)	-1.88	(0.13)	-2.24	(0.08)	-1.59	(0.06)		
	26.79[c]	(0.54)	26.09	(0.47)	27.67	(0.49)	27.96	(0.20)		
Melfort 1999	65.90	(1.18)	66.94	(0.83)	66.89	(0.66)	68.09	(0.43)		
	-1.62	(0.21)	-1.98	(0.21)	-2.10	(0.07)	-2.04	(0.12)		
	24.65	(0.24)	25.09	(0.19)	25.08	(0.28)	25.75	(0.33)		
Swift Current 1999	67.73	(0.96)	67.29	(0.52)	66.24	(0.89)	67.73	(0.55)		
	-1.60	(0.19)	-1.60	(0.07)	-1.33	(0.14)	-1.44	(0.15)		
	29.09	(0.62)	29.40	(0.55)	28.35	(0.50)	28.50	(0.48)		
Glenlea 2000	65.87	(0.17)	64.05	(1.50)	64.81	(0.50)	63.47	(1.82)	64.45	(0.90)
	-2.12	(0.07)	-2.05	(0.15)	-2.08	(0.14)	-1.76	(0.14)	-2.12	(0.17)
	25.28	(0.15)	22.80	(1.65)	24.44	(0.39)	24.32	(1.18)	24.45	(0.67)
Melfort 2000	65.85	(0.76)	66.76	(0.70)	66.64	(0.25)	66.70	(0.93)	66.26	(0.89)
	-2.05	(0.03)	-2.59	(0.06)	-2.49	(0.14)	-2.19	(0.11)	-2.55	(0.23)
	27.78	(0.10)	28.51	(0.48)	28.14	(0.27)	28.64	(0.29)	27.87	(0.44)
Swift Current 2000	67.26	(1.23)	67.31	(0.86)	66.86	(0.62)	65.86	(1.02)	66.92	(0.52)
	-2.03	(0.23)	-1.82	(0.17)	-2.09	(0.23)	-1.42	(0.14)	-2.15	(0.21)
	26.99	(0.21)	26.64	(0.53)	27.48	(0.39)	27.08	(0.18)	27.27	(0.20)

Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

Table AIV.5. Number of specks per noodle image for each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	49[a]	(9)	37	(9)	41	(7)	63	(15)		
	57[b]	(6)	42	(7)	44	(6)	71	(15)		
	115[c]	(12)	74	(10)	99	(7)	144	(30)		
Melfort 1999	49	(14)	61	(10)	43	(6)	61	(8)		
	60	(11)	69	(14)	50	(4)	73	(5)		
	147	(36)	183	(15)	238	(19)	219	(20)		
Swift Current 1999	52	(3)	51	(7)	40	(11)	54	(14)		
	67	(4)	57	(5)	45	(12)	59	(13)		
	127	(7)	118	(4)	138	(33)	148	(23)		
Glenlea 2000	80	(21)	157	(91)	86	(7)	149	(53)	115	(48)
	90	(23)	169	(85)	96	(9)	156	(60)	127	(54)
	191	(26)	226	(92)	188	(3)	241	(44)	214	(54)
Melfort 2000	45	(6)	36	(7)	28	(5)	41	(8)	33	(7)
	54	(8)	40	(5)	32	(5)	47	(7)	41	(6)
	164	(14)	109	(22)	150	(20)	158	(16)	188	(13)
Swift Current 2000	45	(1)	43	(6)	33	(4)	66	(16)	44	(8)
	60	(4)	51	(9)	42	(4)	77	(14)	57	(10)
	254	(13)	117	(13)	198	(24)	206	(16)	159	(18)

[a], [b], [c], values were taken at 1, 2, and 24 hour, respectively, after processing.
Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

Table AIV.6. Mean area density of specks per noodle image for each cultivar grown in each environment.

	AC Barrie		AC Domain		Katepwa		CDC Teal		AC Majestic	
Beaverlodge 1999	175.5[a]	(0.6)	178.0	(3.1)	178.4	(0.4)	174.4	(1.3)		
	170.9[b]	(0.4)	174.3	(2.4)	173.9	(0.6)	170.1	(1.9)		
	155.0[c]	(0.7)	160.4	(1.5)	157.7	(0.7)	155.4	(0.5)		
Melfort 1999	167.5	(2.5)	174.0	(1.9)	172.9	(0.6)	175.0	(1.0)		
	162.5	(2.7)	169.4	(1.6)	168.3	(0.4)	170.0	(0.9)		
	148.3	(2.5)	154.7	(1.8)	151.2	(0.5)	155.6	(1.4)		
Swift Current 1999	178.2	(3.3)	183.5	(1.9)	178.6	(2.8)	175.4	(1.6)		
	174.7	(2.6)	179.4	(1.5)	174.8	(3.1)	171.3	(1.5)		
	160.1	(1.6)	164.1	(2.1)	159.7	(4.4)	158.1	(0.5)		
Glenlea 2000	168.6	(1.5)	165.0	(3.7)	168.4	(1.4)	166.4	(2.9)	166.5	(2.8)
	164.0	(1.5)	160.7	(3.8)	164.0	(1.5)	161.6	(3.2)	162.2	(2.9)
	151.5	(1.2)	146.0	(4.8)	150.3	(0.6)	149.6	(3.9)	149.0	(3.0)
Melfort 2000	181.2	(3.7)	182.4	(2.0)	180.4	(5.2)	182.2	(1.0)	185.4	(2.3)
	175.4	(3.4)	178.6	(1.9)	176.3	(3.2)	177.3	(0.9)	180.5	(1.9)
	160.5	(3.6)	163.6	(3.0)	161.1	(3.6)	162.4	(1.1)	163.9	(1.5)
Swift Current 2000	174.6	(1.3)	180.6	(1.9)	178.2	(2.9)	174.8	(2.1)	176.2	(1.3)
	170.5	(0.9)	175.7	(1.6)	175.4	(2.0)	170.4	(2.2)	171.9	(1.2)
	158.5	(0.9)	162.4	(2.7)	162.1	(2.3)	159.0	(2.1)	159.2	(0.6)

[a], [b], [c], values were taken at 1, 2, and 24 hour, respectively, after processing.
Values are mean and (standard deviation) of two processing replications per plot duplicate.
AC Majestic was grown at the year 2000 locations only.

APPENDIX V

Cultivar and Environment means of color and speck characteristics of noodle sheets and noodles

Table AV.1. Cultivar means[a] , standard deviations (SD), and coefficient of variation (CV) for L* (brightness) of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	L* (brightness)[b]			
Cultivar	0 hr	1 hr	2 hr	24 hr
AC Barrie	84.49 (1.32) a	81.81 (1.37) a	80.81 (1.46) a	76.28 (1.52) a
AC Domain	84.80 (1.54) a	82.15 (1.95) a	81.26 (2.06) a	77.22 (2.21) b
Katepwa	84.81 (1.09) a	82.04 (1.37) a	81.09 (1.44) a	76.52 (1.80)ab
CDC Teal	84.54 (1.30) a	81.82 (1.55) a	80.83 (1.59) a	76.58 (1.52)ab
Mean	84.66	81.96	81.22	76.65
SD	0.17	0.17	0.22	0.40
CV	0.20	0.21	0.27	0.52

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).

Table AV.2. Cultivar means[a] , standard deviations (SD), and coefficient of variation (CV) for a* (red-green scale) of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	a* (red-green)[b]			
Cultivar	0 hr	1 hr	2 hr	24 hr
AC Barrie	0.07 (0.34) b	0.31 (0.34) b	0.35 (0.35) b	0.47 (0.44) b
AC Domain	-0.32 (0.25) a	-0.02 (0.28) a	0.02 (0.32) a	0.12 (0.42) a
Katepwa	-0.26 (0.26) a	0.01 (0.28) a	0.03 (0.30) a	0.18 (0.45) a
CDC Teal	-0.20 (0.25) a	0.02 (0.21) a	0.06 (0.20) a	0.19 (0.24) a
Mean	-0.18	0.08	0.12	0.24
SD	0.17	0.15	0.15	0.16

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).

Table AV.3. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for b* (yellowness) of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	b* (yellowness)[b]			
Cultivar	0 hr	1 hr	2 hr	24 hr
AC Barrie	24.07 (1.57) b	26.95 (1.42) b	27.43 (1.41) b	27.69 (1.22) a
AC Domain	22.48 (1.99) a	25.99 (2.01) a	26.50 (1.97) a	27.36 (1.71) a
Katepwa	23.51 (1.88) b	26.93 (1.67) b	27.47 (1.62) b	28.02 (1.25)ab
CDC Teal	24.10 (1.69) b	27.42 (1.65) b	28.00 (1.62) b	28.62 (1.30) b
Mean	23.54	26.82	27.35	27.92
SD	0.76	0.60	0.63	0.54
CV	3.23	2.24	2.30	1.93

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).

Table AV.4. Cultivar means[a], standard deviations (SD), and coefficient of variation (CV) for speck count of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	Speck Count		
Cultivar	1 hr	2 hr	24 hr
AC Barrie	53 (16) a	65 (16) a	166 (51) ab
AC Domain	64 (55) a	71 (56) a	138 (63) a
Katepwa	45 (20) a	51 (22) a	168 (50) ab
CDC Teal	72 (42) a	81 (43) a	186 (45) b
Mean	59	67	165
SD	12	12	20
CV	20	18	12

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).

Table AV.5. Cultivar means[a] , standard deviations (SD), and coefficient of variation (CV) for speck count of raw yellow alkaline noodle sheets made from five Canada Western Red Spring Wheat cultivars grown in three locations in year 2000.

	Speck Count		
Cultivar	1 hr	2 hr	24 hr
AC Barrie	57 (21) a	68 (21) a	203 (43) a
AC Domain	78 (75) a	86 (76) a	150 (75) a
Katepwa	49 (28) a	56 (30) a	179 (27) a
CDC Teal	85 (57) a	93 (58) a	202 (44) a
AC Majestic	64 (46) a	75 (48) a	187 (39) a
Mean	67	76	184
SD	15	15	21
CV	23	19	12
composite[c]	34	41	146

[a]means are averages of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]composite = No.1CWRS composite sample from the year 2000 crop harvest.

Table AV.6. Cultivar means[a] , standard deviations (SD), and coefficient of variation (CV) for mean speck density of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	Mean Speck Density		
Cultivar	1 hr	2 hr	24 hr
AC Barrie	174.2 (5.4) a	169.7 (5.4) a	155.7 (5.0) a
AC Domain	177.2 (6.8) b	173.0 (6.9) c	158.5 (7.0) b
Katepwa	176.1 (4.9) ab	172.1 (4.9) bc	157.0 (5.2) ab
CDC Teal	174.7 (4.9) a	170.1 (5.0) ab	156.7 (4.4) ab
Mean	175.6	171.2	157.0
SD	1.4	1.6	1.2
CV	0.8	0.9	0.8

[a]means are averages of two processing replications per plot duplicate over six environments (n=24).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).

Table AV.7. Cultivar means[a] , standard deviations (SD), and coefficient of variation (CV) for mean speck density of raw yellow alkaline noodle sheets made from five Canada Western Red Spring Wheat cultivars grown in three locations in year 2000.

	Mean Speck Density		
Cultivar	1 hr	2 hr	24 hr
AC Barrie	174.8 (5.8) a	170.0 (5.3) a	156.9 (4.5) a
AC Domain	176.0 (8.5) a	171.6 (8.5) a	157.3 (9.0) a
Katepwa	175.7 (6.3) a	171.9 (6.2) a	157.8 (6.0) a
CDC Teal	174.4 (7.0) a	169.8 (7.0) a	157.0 (6.1) a
AC Majestic	176.0 (8.3) a	171.5 (8.0) a	157.4 (6.8) a
Mean	175.4	171.0	157.3
SD	0.7	1.0	0.4
CV	0.4	0.6	0.3
composite[c]	181	176	160

[a]means are averages of two processing replications per plot duplicate over three locations in year 2000 (n=12).
[b]values are mean and (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]composite = No.1CWRS composite sample from the year 2000 crop harvest.

Table AV.8. Environment means[a] , standard deviations (SD), and coefficient of variation (CV) for L* (brightness) of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	L* (brightness)[b]			
Environment[c]	0 hr	1 hr	2 hr	24 hr
B9	85.04 (0.46) b	82.31 (0.50) c	81.36 (0.62) c	76.99 (0.99) b
M9	83.48 (0.80) a	80.71 (0.76) b	79.74 (0.80) b	75.09 (1.00) a
SC9	85.67 (0.46) bc	83.44 (0.52) d	82.55 (0.56) d	78.28 (0.67) c
G0	82.70 (0.87) a	79.49 (1.11) a	78.37 (1.09) a	74.04 (1.09) a
M0	85.90 (0.34) c	83.12 (0.47) cd	82.19 (0.46) cd	78.01 (0.60) bc
SC0	85.16 (0.41) b	82.67 (0.56) cd	81.77 (0.61) cd	77.50 (0.85) bc
Mean	84.66	81.96	81.00	76.65
SD	1.28	1.54	1.62	1.71
CV	1.51	1.88	2.00	2.23

[a]means are averages of two processing reps per plot duplicate over four cultivars (n=16).
[b]values are mean (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.

Table AV.9. Environment means[a] , standard deviations (SD), and coefficient of variation (CV) for a* (red-green scale) of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

Environment[c]	a* (red-green)[b]			
	0 hr	1 hr	2 hr	24 hr
B9	-0.49 (0.17) a	-0.25 (0.13) a	-0.25 (0.14) a	-0.22 (0.16) a
M9	0.07 (0.21) c	0.35 (0.23) c	0.41 (0.23) c	0.69 (0.28) c
SC9	-0.19 (0.29) b	0.01 (0.26) b	0.01 (0.26) b	-0.01 (0.25) b
G0	0.05 (0.25) c	0.37 (0.24) c	0.45 (0.23) c	0.73 (0.18) c
M0	-0.43 (0.12) a	-0.08 (0.14) ab	0.01 (0.17) b	0.17 (0.18) b
SC0	-0.07 (0.27) bc	0.08 (0.26) b	0.08 (0.25) b	0.09 (0.24) b
Mean	-0.18	0.08	0.12	0.24
SD	0.24	0.24	0.27	0.39

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.

Table AV.10. Environment means[a] , standard deviations (SD), and coefficient of variation (CV) for b* (yellowness) of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

Environment[c]	b* (yellowness)[b]			
	0 hr	1 hr	2 hr	24 hr
B9	23.06 (1.27) b	26.52 (1.32) b	27.04 (1.42) bc	27.78 (1.34) b
M9	23.29 (0.94) bc	26.38 (0.59) b	26.85 (0.55) b	27.78 (0.43) b
SC9	25.83 (0.96) d	29.09 (0.51) d	29.58 (0.50) d	29.44 (0.63) c
G0	21.15 (1.93) a	24.32 (1.57) a	24.90 (1.49) a	25.77 (1.09) a
M0	23.35 (0.91) bc	26.97 (0.77) b	27.69 (0.70) bc	28.96 (0.57) c
SC0	24.57 (1.08) cd	27.66 (0.91) c	28.07 (0.96) c	27.82 (0.82) b
Mean	23.54	26.82	27.36	27.93
SD	1.57	1.58	1.55	1.27
CV	6.67	5.89	5.67	4.55

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.

Table AV.11. Environment means[a] , standard deviations (SD), and coefficient of variation (CV) for speck count of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	Speck Count		
Environment[c]	1 hr	2 hr	24 hr
B9	47.5 (13.8) a	53.6 (14.7) a	107.8 (30.5) a
M9	53.5 (11.9) a	63.0 (12.7) a	196.4 (41.9) b
SC9	49.1 (10.2) a	56.9 (11.8) a	132.8 (21.7) a
G0	117.9 (60.2) b	127.5 (60.1) b	211.4 (52.5) b
M0	37.3 (8.8) a	43.2 (10.1) a	144.9 (27.6) a
SC0	46.8 (14.8) a	57.3 (15.8) a	193.6 (53.1) b
Mean	58.7	66.9	164.5
SD	29.5	30.4	41.6
CV	50.3	45.4	25.3

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.

Table AV.12. Environment means[a], standard deviations (SD), and coefficient of variation (CV) for mean speck density of raw yellow alkaline noodle sheets made from Canada Western Red Spring Wheat cultivars.

	Mean Area Density/Image[b]		
Environment[c]	1 hr	2 hr	24 hr
B9	176.6 (2.3) c	172.3 (2.4) c	157.1 (2.4) b
M9	172.3 (3.3) b	167.5 (3.4) b	152.5 (3.4) a
SC9	178.9 (3.7) cd	175.0 (3.6) cd	160.5 (3.3) c
G0	167.1 (2.8) a	162.6 (2.8) a	149.4 (3.6) a
M0	181.5 (3.2) d	176.9 (2.6) d	161.9 (2.9) c
SC0	177.0 (3.2) c	173.0 (3.1) c	160.5 (2.6) bc
Mean	175.6	171.2	157.0
SD	5.1	5.3	5.0
CV	2.9	3.1	3.2

[a]means are averages of two processing replications per plot duplicate over four cultivars (n=16).
[b]values are mean (SD); means within each column with the same letter are not significantly different ($P \leq 0.05$).
[c]B9 = Beaverlodge 1999, M9 = Melfort 1999, SC9 = Swift Current 1999, G0 = Glenlea 2000, M0 = Melfort 2000, SC0 = Swift Current 2000.