Effects of Gluten Strength on the Rheological and Textural Properties of Spaghetti Made from Durum Wheat

by

Elaine Janice Sopiwnyk

A thesis
submitted to the Faculty of Graduate Studies,
University of Manitoba, in partial fulfilment
of the requirements for the degree of

Master of Science

Department of Foods and Nutrition,
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

Durum wheat cultivars with extra strong gluten properties are claimed by pasta manufacturers to result in pasta superior cooking quality. However, very few studies have been published which have examined the effect of extra strong gluten cultivars on pasta cooking quality. A study was undertaken to determine the rheological, starch characteristics and pasta cooking quality of a set of seven durum wheat samples varying in gluten strength properties, but with comparable protein content. The effect of drying temperature on the cooking quality of pasta made from durum wheat samples varying in gluten strength was also investigated.

Samples with higher gluten index values (Durex, AC Pathfinder, AC Navigator and AC Melita) were found to have higher sodium dodecyl sulfate sedimentation values and higher gluten extensibility peak breaking force values than samples with lower gluten index values (DT 662, Kyle, Plenty). Samples with stronger gluten strength properties had longer mixograph times to peak, higher curve heights at peak and wider curve band widths at peak. Alveograph parameters usually associated with strong doughs (high *P/L* ratios and high *W*) were observed in samples with stronger gluten strength. No differences among samples were observed in total starch or amylose contents. Differences between samples were observed for all Rapid Visco Analyzer pasting properties

(peak viscosity, peak time, breakdown viscosity, breakdown, setback viscosity and total setback), except breakdown viscosity time. However, these differences were not related to gluten strength.

The textural properties of cooked pasta were assessed using instrumental and sensory methods. Using the Lloyd, differences between samples in shear force and firmness values were observed. No differences were observed between samples in compression values, relaxation times, stickiness, energy or adhesiveness values when summed over all cooking times and drying temperatures. Pasta dried at 90°C had increased shear force, firmness, and compression values and decreased stickiness, energy and adhesiveness values than pasta dried at 70°C when summed over all samples and cooking times. Overcooking resulted in decreased pasta cooking quality for all textural properties when summed over all samples and drying temperatures. Results from the viscoelastograph revealed that samples with weaker gluten strength had higher relative recovery values than samples with stronger gluten strength when summed over all drying temperatures for all three weights used. Using a trained panel, differences between samples were observed in sensory firmness, chewiness, breakdown and strand to strand adherence but not springiness or adhesiveness to teeth when summed over all drying temperatures. Pasta dried at 90°C had lower strand to strand adherence scores than pasta dried at 70°C.

Overall, differences in rheological properties of semolina were related to gluten strength. Although differences were observed in starch pasting properties these differences were not related to gluten strength properties. Cooked pasta texture assessed using the Lloyd, viscoelastograph and sensory evaluation revealed that pasta made from samples with weaker gluten strength did not necessarily result in pasta with poorer cooking quality than pasta made from samples with stronger gluten strength.

Recommendations for future research include; the examination of pasta cooking quality made from blends of cultivars with extra strong gluten properties and cultivars with weaker gluten strength; use of commercial pasta processing equipment and drying cycles.

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CHAPTER 1

INTRODUCTION

Pasta is the term commonly used to describe products made from semolina and water and then extruded under pressure into various shapes. Pasta, as we know it, was thought to be developed in China approximately 800 years ago. It is believed that Marco Polo brought pasta to Italy upon his return from China, however earlier records indicate that some type of wheat and water mixture was consumed in prehistoric Mesopotamia. Currently, pasta consumption is increasing worldwide and is expected to reach 8 kg per person per year in Canada (as cited in Marchylo et al., 1998)

Some of the earliest research into pasta quality defined color and cooking quality as important quality characteristics (Binnington, 1939). While color is relatively easy to evaluate, evaluation of cooking quality has proved to be more difficult. Pasta cooking quality primarily includes the textural parameters of firmness, stickiness (Larmond and Voisey, 1973) and compression/elasticity (Malcolmson, 1991).

Research into quality characteristics affecting pasta cooking quality has revealed that both protein quantity and protein quality are important. Satisfactory pasta can be made from semolina with a protein content between 11.5 to 13.0%

(Irvine, 1971). Protein quality can be defined as gluten strength properties, which can range from weak to strong. There are some American (desert durums) and Australian cultivars available that have gluten strength properties that can be classified as extra strong. These cultivars have high gluten index and alveograph *P/L* and *W* values.

North American and European pasta manufacturers have indicated a preference for durum wheat cultivars with extra strong gluten properties (Marchylo et al., 1998). However, little research has been done to assess the pasta making quality of durum wheat with increased gluten strength. Manufacturers have indicated minimum quality requirements of semolina defined in terms of gluten strength measurements, such as alveograph *P/L* and *W* values as well as gluten index values (Marchylo et al., 1998). The majority of currently registered Canadian Western Amber Durum (CWAD) varieties, however, do not meet these strength requirements. In order for Canada to remain competitive in both foreign and domestic markets, the Canadian durum wheat development program has begun to focus on the development of cultivars with increased gluten strength.

Although the majority of durum wheat research has focused on protein quality and quantity, the role of starch has not been investigated as closely. Starch comprises approximately 73% of pasta, and of that approximately 25% is

amylose (Dexter and Matsuo, 1979b; Morrison et al., 1984).

Recent developments in pasta drying technology, specifically the use of high and ultra high temperature drying cycles, has resulted in the manufacture of pasta with acceptable quality produced from poorer quality raw material (Malcolmson et al., 1993). However, it is not known what benefits can be derived when pasta made from cultivars with increased gluten strength are dried at high temperatures.

Very little information exists in the scientific literature on the cooking quality of pasta made from durum wheat varieties with extra strong gluten properties. If cultivars with increased gluten strength are to remain the focus of the Canadian durum wheat development program, research in this area is imperative. Thus, it was the objectives of this research:

1. To investigate the rheological properties of semolina from durum wheat samples varying in gluten strength.
2. To characterize the starch properties of semolina from durum wheat samples varying in gluten strength.
3. To examine the effects of gluten strength on the textural properties of cooked spaghetti.
4. To investigate the effect of drying temperature on the cooking quality of

pasta made from durum wheat samples with varying gluten strength.

5. To examine the relationship between instrumental and sensory measurements of cooked pasta texture.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

Durum wheat (*Triticum turgidum* L) is the preferred class of wheat used for the production of pasta products (Walsh and Gilles, 1971; Dexter et al., 1981a). Durum wheat has several advantages over other wheat classes that result in its superior pasta making quality. These include amber colored kernels, high test weights, very hard kernels (Matsuo, 1988) and reduced levels of oxidative enzymes (Kim et al., 1986). Cooked pasta made from durum wheats is more resilient, less sticky (Kim et al., 1986), more tolerant to overcooking than hard red spring wheats (Dexter et al., 1981a) and is more resistant to surface disintegration (Autran et al., 1986). High quality pasta made from durum wheat should have a surface that is bright yellow and smooth, with no white spots, streaks, specks or checks. In addition, the texture of high quality cooked pasta should be firm, elastic, and not sticky (Dexter et al., 1983a; Kovacs et al., 1995a).

The hardness of durum wheat enables millers to produce high yields of semolina (Dick and Matsuo, 1988). Typical yields of semolina can be as high as 60 to 68% in commercial mills (Matsuo and Dexter, 1980; Banasik, 1981). The objective of durum milling is to produce semolina with bright yellow color, low

speck count and uniform granulation (Matsuo and Dexter, 1980; Dick and Matsuo, 1988; Matsuo, 1993). In quality tests performed by the Grain Research Laboratory (GRL, Winnipeg, MB), semolina is evaluated on the basis of protein content, wet gluten content, dry gluten content, ash content, yellow pigment content, AGTRON color, speck count and falling number. Other characteristics such as moisture content, granulation, grit content, gluten quality (mixograph), amylase activity, lipoxygenase activity and wheat class purity have been used by other researchers in the evaluation of semolina quality (Dexter and Matsuo, 1977a; Dick and Matsuo, 1988).

2.2 BIOCHEMICAL BASIS OF PASTA COOKING QUALITY

The cooking quality of pasta is thought to depend on the chemical composition and structure of durum wheat components, primarily protein, starch and to a lesser extent, lipids. The role of both protein quality and quantity has been the primary focus of researchers, while research on starch properties has been limited.

2.2.1 Protein Quantity

The protein content of durum wheat can range from 9-18% depending on cultivar and environmental conditions (Feillet, 1984). The protein composition of durum wheats, including quantity and quality of protein and characteristics of the individual protein subunits, plays an important role in the quality of the

final pasta products (Walsh and Gilles, 1971; Dexter and Matsuo, 1979a; Grzybowski and Donnelly, 1979; Pagani et al., 1986; Novaro et al., 1993). Pasta with satisfactory cooking quality can be obtained from semolina with a protein content between 11.5-13.0% (Irvine, 1971). In pasta, the protein forms an insoluble fibrillar network around the swollen and gelatinized starch granules and prevents their leaching into the cooking water (D'Egidio et al., 1983; Feillet, 1984; Pagani et al., 1986). Removal of protein from pasta has been found to negatively affect amylose retention (Dahle and Muenchow, 1968) and also resulted in higher cooking losses, greater stickiness and a loss of firmness (Cubadda, 1989). Protein content has been found to correlate strongly to cooked pasta recovery and compressibility (Dexter and Matsuo, 1977b). As protein content increased, recovery increased ($r=0.98$, $p=0.01$) and compressibility decreased ($r=0.88$, $p=0.01$) when pasta was cooked to optimum (Dexter and Matsuo, 1977b).

The protein content of durum wheat is affected by environmental conditions. Protein content has been found to increase when high amounts of nitrogen fertilizer (ammonium nitrate 34-0-0) are applied, however, no effect was seen on gluten strength (Dexter et al., 1982). It was also found that as the level of nitrogen fertilization increased, the solids lost from the pasta to the cooking water decreased. This was attributed to the increased protein content which

resulted in a stronger protein network thereby increasing the resistance of the spaghetti to breakdown during cooking.

2.2.2 Protein Quality

Protein quality is synonymous with gluten properties. Gluten is the viscoelastic complex made up of gliadins and glutenins. Gliadins are low to medium weight proteins that give extensibility to doughs (Feillet, 1988). Pasta quality is affected by the presence of certain gliadin bands, specifically γ-gliadin 42 and γ-gliadin 45. Poor gluten quality, resulting in poor elastic recovery and poor pasta cooking quality, has been found in durum cultivars with γ-gliadin 42 (Damidaux et al., 1980). Strong gluten properties, strong elastic recovery and superior cooking quality has been found in durum wheat varieties possessing γ-gliadin 45 (Kosmolak et al., 1980; Autran and Galterio, 1989). Glutenins are high molecular weight proteins that give dough its elasticity (Feillet, 1988). Two types of low molecular weight glutenin (LMW) subunits, LMW 2 and LMW 2-, have been associated with γ-gliadin 45 (Kovacs et al., 1995a) while LMW 1 and LMW 1- are associated with γ-gliadin 42 (Pogna et al., 1988; Carrillo et al., 1990).

The ratio of glutenins to gliadins has been found to affect pasta cooking quality. A high ratio of glutenins to gliadins is preferred (Walsh and Gilles, 1971; Dexter

and Matsuo, 1977c; Dick and Matsuo, 1988) since durum varieties with high amounts of gliadin result in pasta with good color but high cooking losses and low cooked firmness values (Walsh and Gilles, 1971). Whereas, high amounts of glutenin result in pasta with low cooking loss, high cooked firmness values but poor color (Walsh and Gilles, 1971).

Durum wheat cultivars with extra strong gluten properties grown in the southwestern United States are referred to as "desert durums". These desert durum cultivars have been found to have stronger gluten strength properties than CWAD durum cultivars (Marchylo et al., 1998). Pasta manufacturers claim that the extra strong gluten strength properties of desert durums result in cooked pasta with increased firmness, decreased stickiness and increased tolerance to overcooking (Marchylo et al., 1998). However, little work has been published in the scientific literature on the pasta making quality of desert durums (Ames et al., 1999).

2.2.3 Characterization of Gluten Strength

Many tests have been developed and used to assess gluten strength. Gluten quality has an effect on the rheological properties of pasta doughs. Rheological properties of the dough as it is being mixed have been primarily characterized using the farinograph and the mixograph. The two types of mixers have very

different types of mixing actions. The mixing action of the farinograph is the result of two sigma-type blades which rotate at a differential speed of 3:2 resulting in a gentle mixing action (Shuey, 1990). In contrast, the mixing action of the mixograph is the result of four vertical pins rotating in planetary motion around three stationary pins in the bottom of the mixing bowl. The pull, fold and repull action of the mixograph is more severe than the farinograph (Kunerth and D'Appolonia, 1985). Both mixers produce curves that provide information about the rheological changes that occur in the dough during mixing. Curves from both mixers consist of a ascending portion, indicating an increase in resistance to mixing, which is followed by a descending portion, indicating a decrease in resistance to mixing or the breakdown of the dough (Bloksma and Bushuk, 1988). Examples of typical farinograph and mixograph curves with some of the parameters commonly measured are presented in Figures 2.1 and 2.2, respectively.

2.2.3.1 Farinograph

Using the farinograph, durum cultivars with strong gluten properties show long dough development times (DDT) along with very low mixing tolerance indices (MTI), whereas cultivars with weak gluten properties have short DDT and high MTI (Matsuo and Irvine, 1979; Dexter and Matsuo, 1980). A strong correlation between farinograph bandwidth and pasta cooking quality has been established

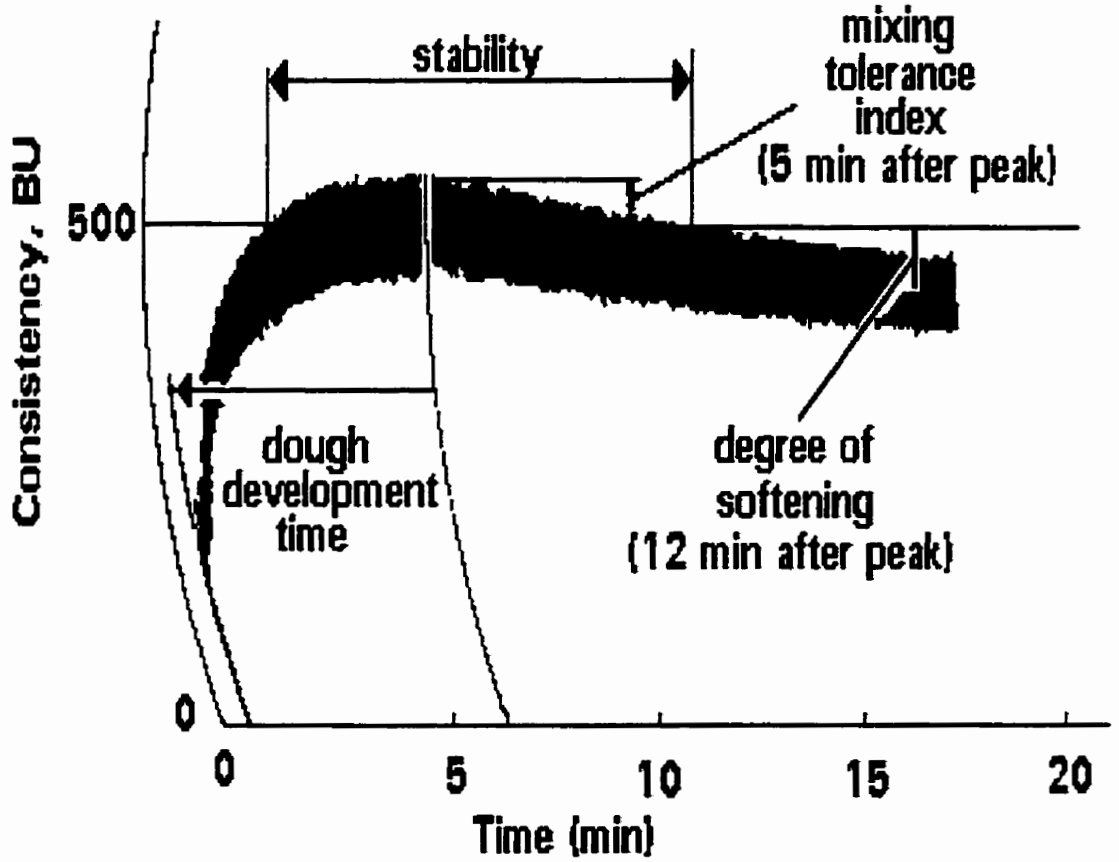

Figure 2.1: A Typical Farinograph Curve With Some Commonly Measured Parameters. Adapted from Bloksma and Bushuk, 1988.

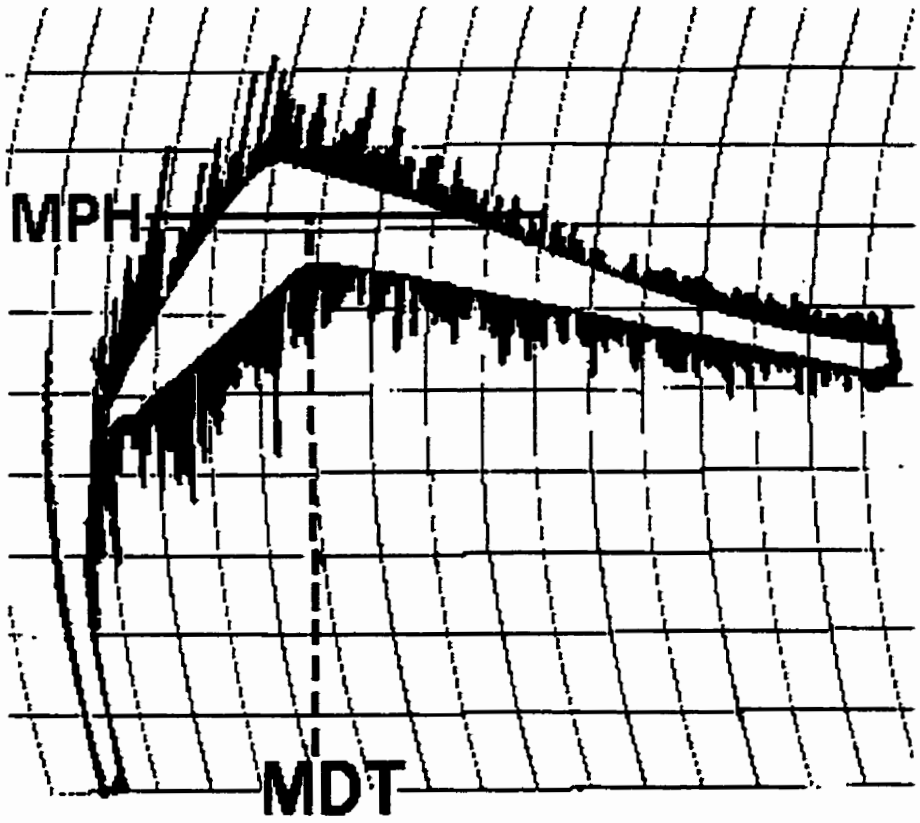

Figure 2.2: A Typical Mixograph Curve With Some Commonly Measured Parameters. Adapted from Kunerth and D'Appolonia, 1985. The following abbreviations have been used; MPH is mixograph peak height, MDT is mixograph development time.

(Dexter and Matsuo, 1980). Farinograph bandwidth has been shown to be a better indicator of pasta cooking quality than DDT, TI or maximum consistency since it is less dependent on protein content (Dexter and Matsuo, 1980). Pasta doughs (31.5% absorption) with wide farinograph bandwidths have been found to exhibit nonsticky doughs (Dexter and Matsuo, 1980). Grzybowski and Donnelly (1979) found that the farinogram score, an indicator of gluten strength, was somewhat correlated with cooked pasta firmness ($r=0.44$, $p=0.01$). Farinograph properties have also been shown to be affected by the amounts of gliadins and glutenins. Increased amounts of gliadins, with a corresponding decrease in glutenins, results in decreased farinograph mixing times (Dexter and Matsuo, 1978). A high glutenin to gliadin ratio has been correlated to long farinograph mixing times (Wasik and Bushuk, 1975).

2.2.3.2 Mixograph

The mixograph has been found to be a reliable method for discriminating semolina samples of differing gluten strength (Bendelow, 1967). Durum cultivars with strong gluten properties exhibit long DDT, small MTI and also larger areas under the curve compared to durum cultivars with weak gluten properties. Dexter et al. (1980) and Matsuo et al. (1982a) found poor correlations between mixograph development time (MDT) and cooking quality of optimal cooked and overcooked pasta. Strong correlations between pasta

disc viscoelasticity and mixograph parameters of MDT, mixograph peak height and mixograph total energy (MTE) have been reported (Kovacs et al., 1995b). Comparison between durum wheat varieties grown over a two year period found significant correlations between protein content and mixograph peak height ($r=0.59$, $p=0.001$) and MTE ($r=0.59$, $p=0.001$) for the 1992 growing season, while correlations between the same variables were not significant for durum varieties grown in 1993 (Kovacs et al., 1995a). Boggini et al. (1996) examined the correlation between several mixograph parameters and cooked pasta scores over two growing years for Italian durum varieties. Mixograph mixing time ($r=-0.50$, $p=0.01$) and mixograph peak height ($r=0.49$, $p=0.01$) were found to be correlated with cooked pasta score over both growing seasons.

In the U.S., mixograms are typically compared to a set of standard mixograms and assigned a score from 1 to 8, with higher scores being related to stronger mixing characteristics (Dick, 1985). A study by Dick and Quick (1983) found a poor correlation between mixogram score and firmness of cooked pasta ($r^2=0.365$). However, when wheat protein content was also considered, 64.9% of the variation in cooked pasta firmness could be accounted for. The development of the 2 g micromixograph has allowed for the assessment of rheological properties in early generations to be performed with as little as 3-5

g of seed (Gras and O'Brien, 1992). Correlations between the 35 g and 2 g mixographs have been established (Rath et al., 1990).

2.2.3.3 Alveograph

Another method to determine the rheological properties of pasta doughs is the alveograph which is more commonly used in Europe. The alveograph measures the resistance of a dough to biaxial extension by inflating it into a bubble. A typical alveogram and some commonly measured parameters is shown in Figure 2.3. The alveograph parameter *W* (deformation energy of the dough) has been found to be closely related to flour strength (Boyacioğlu and D'Appolonia, 1994). Durum flours have been found to have very high tenacity (*P*) compared to elasticity/extensibility (*L*) suggesting that durum wheat gluten is very tenacious but not very elastic (Quaglia, 1988). D'Egidio et al. (1990) have found strong relationships between alveograph *P* and *W* values and pasta cooking quality evaluated using a sensory panel ($r=0.37$ and $r=0.38$, $p=0.01$, respectively). Matsuo and Irvine (1970) found a strong negative correlation between alveograph maximum pressure (*P*) of gluten discs and the tenderness index of cooked pasta in durum wheats ($r=-0.94$, $p=0.01$). Alveograph extensibility (*L*) has been found to be positively associated with protein content (Dexter et al., 1994). In a study of Italian durum varieties, Boggini et al. (1996) found that *W* and *P/L* values were strongly influenced by variety and not by year

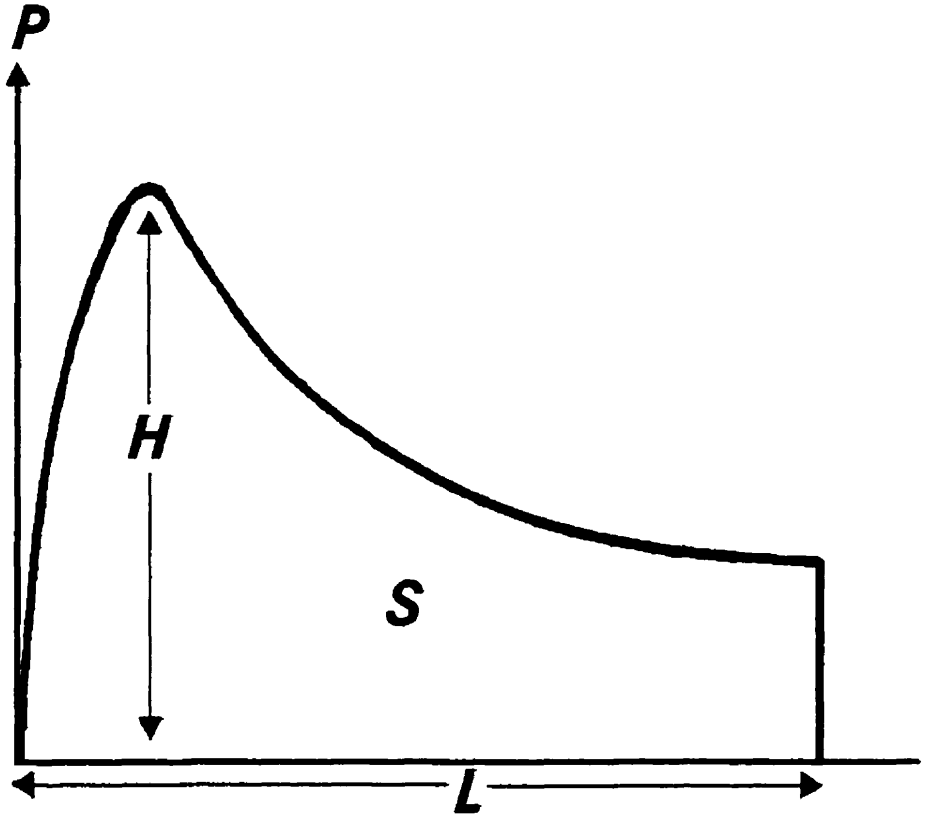

Figure 2.3: **A Typical Alveograph Curve With Some Commonly Measured Parameters. Adapted from Rasper et al., 1985. The following abbreviations have been used; *P* is the maximum over pressure (*P*=1.1*H*); *L* is a measure of extensibility; *H* is the height of the curve; *S* is the area under the curve.**

and growing conditions. *W* and *P/L* values were found to be poorly correlated to pasta score ($r=-0.22$ and $r=-0.28$, respectively).

2.2.3.4 Viscoelastograph

The rheological properties of cooked gluten have been characterized using the viscoelastograph. Evaluation of a sample consists of extracting gluten from a semolina dough, cooking it between two plates and then cutting a disc. The disc of gluten is then placed under a constant load, applied perpendicularly, for a set period of time after which the load is removed (D'Egidio and Nardi, 1996). A typical curve obtained from the viscoelastograph is presented in Figure 2.4. The absolute recovery of the cooked gluten can be determined from the creep and recovery curves. Damidaux and Feillet (1978) found the absolute recovery values to be correlated to the rheological properties of the gluten as well as the pasta cooking quality. Cultivars with strong gluten properties were found to have higher relative recovery ($R_r\%$) and absolute recovery ($A_r\%$) values than cultivars with weaker gluten properties (Kovacs et al., 1994). Strong correlations have been found between cooked gluten viscoelasticity (CGV) and mixograph development time ($r=0.77$, $p=0.01$) and sodium dodecyl sulfate (SDS) sedimentation volume ($r=0.89$, $p=0.001$), but not protein ($r=-0.16$) or wet gluten ($r=-0.46$) contents (Kovacs et al., 1994). A Relationship between CGV and gluten firmness and SDS sedimentation volumes has also been found

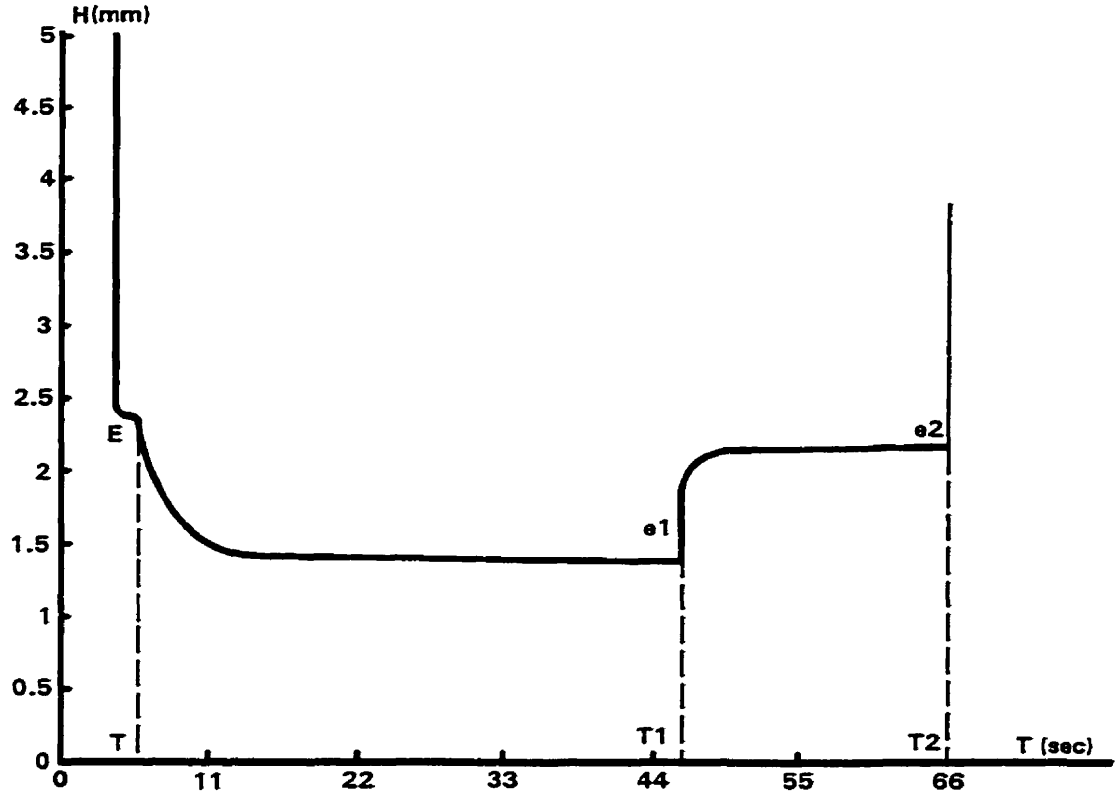

Figure 2.4: A Typical Viscoelastograph Curve. Adapted from D'Egidio and Nardi (1996) The following abbreviations have been used; E = initial spaghetti thickness, e1 = thickness after load applied, e2 = final thickness after load removed.

by Autran et al. (1986). Low, but significant correlations between cooked gluten elastic recovery and the surface conditions of overcooked pasta ($r=0.35$, $p=0.01$) have also been reported (Autran et al. 1986).

2.2.3.5 Extensograph

The resistance of noodle doughs to extension has been measured using the extensograph. Inferior noodle quality was found to result from noodle doughs having a maximum resistance value of less than 300 Brabender Units (Moss, 1982, in Dick, 1985). The extensograph has not however been commonly used to evaluate durum wheat. Matsuo (1978) developed a modified extensibility test to directly measure the gluten strength by measuring the force required to break a strand of wet gluten. Gluten breaking strength was found to be significantly correlated with SDS sedimentation volume ($r=0.70$, $p=0.01$) and pasta cooking quality ($r=0.49$, $p=0.01$) (Matsuo et al., 1982a). The development of a micro extensibility test using the 2 g micromixograph and the Kieffer rig for the TA.XT2 has been used to evaluated evaluate bread wheat doughs (Ingelin and Lukow, 1998). Parameters obtained using this method may be useful in evaluating the dough strength properties of durum wheats. The Kieffer rig has also been used to evaluate wet gluten extensibility (Anonymous, 1995). Measurement of dough or gluten extensibility may provide an alternate, and possibly more reliable method to assess strength properties of durum cultivars.

2.2.3.6 Gluten Index

Gluten strength can also be assessed using the gluten index (GI) method. Traditionally, gluten quality has been evaluated by using a manual method which involves washing out the gluten from a dough by hand and then evaluating its elasticity and extensibility by stretching it between the fingers (Landi, 1988). However, this method is highly subjective. An alternative method to this is the GI method in which wet gluten is washed out from a dough using the Glutomatic system. The wet gluten is then centrifuged on a special screen and the amount of gluten that remains on the screen is expressed as a percentage of the total amount of wet gluten. GI values close to 100 indicates a strong gluten whereas values close to 0 indicates a weak gluten (Perten, 1990). Cubadda et al. (1992) found both whole meal and semolina GI values to be related to SDS sedimentation volumes ($r=0.78$ and $r=0.80$, $p=0.01$ respectively).

2.2.3.7 Chemical Tests to Characterize Gluten Strength

In addition to instrumental measurements of gluten quality, chemical tests such as the Berliner test and SDS sedimentation test have also been used to measure gluten quality. Durum wheats with strong gluten, when assessed using the Berliner test, have higher Q_0-values indicating superior cooking quality ($r=0.71$, $p=0.01$) (Dexter and Matsuo, 1977b). Despite the strong correlation between

the results from the Berliner test and cooking quality it has not seen extensive use (Cole, 1991). The SDS sedimentation test has been used in the Canadian durum breeding program to assess the pasta making quality of developing durum lines. The SDS sedimentation test was found to be a suitable method to predict gluten strength, although the correlation between SDS sedimentation and cooking quality was poor ($r=0.24$, $p=0.05$) (Dexter et al., 1980). Durum wheats have been found to have weaker gluten properties than common wheats based on results from the SDS sedimentation test (Dexter et al., 1981a).

2.2.4 Starch

The role of starch in pasta quality has received little attention, even though it constitutes the major component of durum semolina. Of the approximately 73% of starch present in pasta, amylose makes up approximately 25% (Dexter and Matsuo, 1979b; Feillet, 1984). Durum wheat has been found to have a slightly higher amylose content than wheats from other classes (Berry et al., 1971; Klassen and Hill, 1971). Dexter and Matsuo (1979b) found that as the proportion of amylomaize in reconstituted semolina-amylomaize starch (51.9% amylose) spaghetti samples increased so did cooked pasta firmness. The amylose fraction of starch is primarily responsible for the gelling properties of starch while the amylopectin fraction is nongelling.

The pasting properties of durum wheat starch have been investigated by several researchers using the amylograph (Shuey and Gilles, 1964; Medcalf and Gilles, 1965; Lintas and D'Appolonia, 1973; Marshall, 1974; Lii and Lineback, 1977; Dexter and Matsuo, 1979b; Meredith and Pomeranz, 1982). A typical pasting curve can be found in Figure 2.5. Researchers have found that starch from durum wheat begins to swell at lower temperatures than starch from other wheat classes (Lii and Lineback, 1977) which may be related to the less compact granular structure of starch from durum wheat (Medcalf and Gilles, 1965). Starch paste viscosity measurements, using the Rapid Visco Analyzer (RVA), have been found to be related to the eating quality of udon noodles (Konik et al., 1994). However very little research has been done relating the pasting properties of starch from durum wheat to textural properties of cooked pasta. Marshall (1974) found that peak height during gelatinization was directly related to cooked spaghetti recovery suggesting that starch has a role in this textural parameter. Durum starches have also been found to have the lowest initial and final birefringent end point temperatures when compared to other cereal starches (Medcalf and Gilles, 1965; Lii and Lineback, 1977).

Gelatinization of starch during the cooking of pasta proceeds in an inward direction (Grzybowski and Donnelly, 1977). The rate of gelatinization is also affected by the level of protein, where higher protein samples result in longer

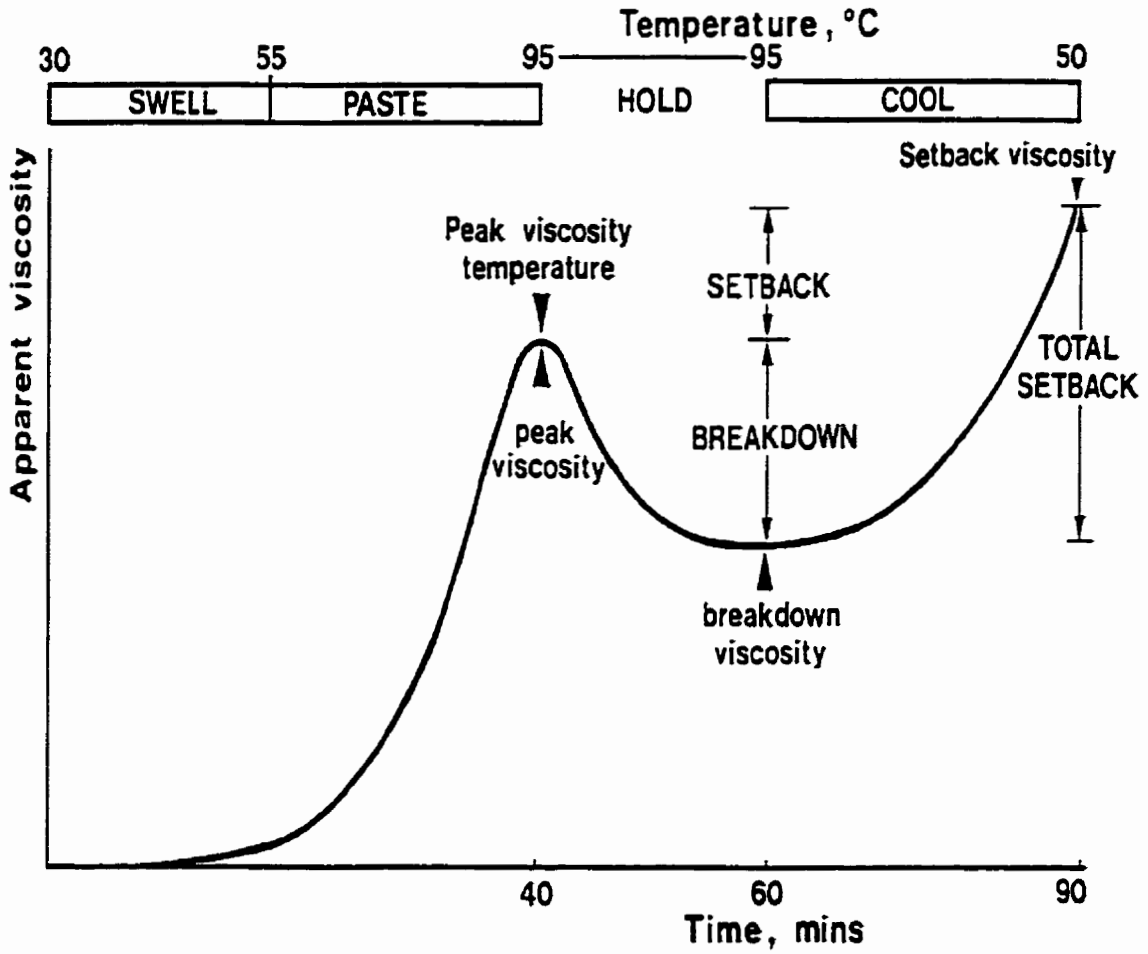

Figure 2.5: A Typical Pasting Curve with Some Commonly Measured Parameters. Adapted from Dengate, 1988.

gelatinization times since it becomes more difficult for water to penetrate the protein network (Marshall and Wasik, 1974; Grzybowski and Donnelly, 1977). The presence of higher amounts of protein in pasta, results in greater competition between starch and protein for available water (Eliasson, 1983). Higher protein pasta samples have also been found to have several distinct zones of gelatinization, unlike lower protein pasta samples where only two zones were present (Marshall and Wasik, 1974). The swelling of starch during cooking can result in a loss of the integrity of the protein network, thereby allowing the leaching of starch into the cooking water (Dexter et al., 1979). On the surface of the pasta, swollen starch granules may lose their shape (Cunin et al., 1995), rupture and release their contents (Voisey et al., 1978a) influencing the stickiness of cooked pasta (Dexter et al., 1985a). Pasta made from poorer quality raw materials yields pasta with increased stickiness and decreased firmness caused by gelatinization of starch granules before the protein network has been established (Pagani et al., 1986).

Cooking water residue (cooking loss) is thought to be composed primarily of starch. Cooking losses are higher during the period of optimum cooking than overcooking since most of the cooking losses occur during the period of optimum cooking (Colonna et al., 1990). Increased swelling of starch granules as a result of increased water absorption occurs during the period of

overcooking (Colonna et al., 1990). Several methods have been established to quantify the amount of solids lost during cooking. The method used previously by the GRL involves freeze-drying the cooking water and weighing the residue (Dexter and Matsuo, 1979a). The amount of solids lost are expressed as a proportion of uncooked pasta on a constant moisture basis. A colorimetric method has also been used by the GRL to determine the amount of amylose present in the residue (Matsuo et al., 1992).

The principle starch component found in the cooking water residue has been determined to be amylose (D'Egidio et al., 1983; Colonna et al., 1990; Matsuo et al., 1992). Amylose has also been found on the surface of cooked pasta but it has not yet been established as the primary cause of stickiness in cooked pasta, although researchers do believe that it does play a role (Dexter et al., 1985a). The determination of materials rinsed from the surface of drained cooked pasta was found to be a better predictor of pasta cooking quality than cooking loss (Dexter et al., 1985a). Materials rinsed from the surface of cooked pasta consists of amylose and other reducing sugars and this is thought to contributes to stickiness in cooked pasta (Dexter et al., 1985a). Matsuo et al. (1986) found a strong correlation between the absorbance of an amylose-iodine complex rinsed from the surface of cooked pasta and cooked pasta stickiness ($r=0.89$, $p<0.01$). Higher amylose contents in the cooking water are

associated with longer cooking times (Dahle and Muenchow, 1968).

During the milling of durum wheat, starch damage can occur resulting in poorer quality pasta (Feillet, 1984). The production of millstreams with finer granulation results in greater starch damage than millstreams with coarser granulation (Fernandes et al., 1978; Matsuo and Dexter, 1980). Durum wheats have been found to have greater levels of starch damage than common wheats due to their harder kernels (Fernandes et al., 1978). A strong correlation was found between increased starch damage and increased cooking loss for both optimum and overcooked pasta ($r=0.87$ and $r=0.84$, respectively, $p=0.01$) (Matsuo and Dexter, 1980).

Starch damage can also occur during pasta processing resulting in poorer quality pasta (Lintas and D'Appolonia, 1973; D'Egidio et al., 1983; Feillet, 1984; Quaglia, 1988). Lower peak viscosity in starch extracted from pasta compared to starch extracted from semolina indicates that starch damage occurs during processing (Lintas and D'Appolonia, 1973). Starch isolated from pasta was found to have higher water-binding capacities than starch isolated from semolina (Lintas and D'Appolonia, 1973) indicating that starch damage had occurred (Quaglia, 1988). Mechanical stresses endured by the pasta during mixing and extrusion contribute to starch damage (Lintas and D'Appolonia,

1973).

Starch damage allows for the increase in susceptibility to amylolytic enzymes. Amylolytic enzymes are additional causes of starch damage. When low temperature drying conditions are employed, enzymes such as α-amylase, may not be destroyed and can therefore degrade starch (Lintas and D'Appolonia, 1973). The use of high temperature drying results in the reduction of amylolytic activity (Dexter et al., 1981a; Dexter et al., 1990a). When high levels of amylolytic enzymes were present in pasta made from sprouted durum wheat, increased cooking losses occurred (Kruger and Matsuo, 1994) and a softer texture was found (Dexter et al., 1981b), likely due to the breakdown in structure of the starch gel (Matsuo et al., 1982b). Durum wheat damaged by sprouting has been found to have an adverse effect on pasta dough elasticity and cooked pasta firmness (Maier, 1980). Damaged starch can also affect rheological measurements. In rheological methods where the absorption is constant, increased damaged starch results in less available water for absorption, therefore, affecting rheological parameters (Boyacioğlu and D'Appolonia, 1994; Dexter et al., 1994).

2.2.5 Lipids

Although lipids constitute a minor part of durum semolina (less than 3%) they

appear to play a role in the quality of cooked pasta (Youngs, 1998). Lipids present in durum semolina have been found to complex with amylose (Dahle and Muenchow, 1968). The presence of an amylose-lipid complex has been found to affect the cooking quality of pasta. The removal of lipids from semolina has been shown to increase stickiness of cooked pasta (Matsuo et al., 1986) and increase amylose concentration in the cooking water (Dahle and Muenchow, 1968). Addition of monoglycerides has been shown to decrease surface stickiness and increase tolerance to overcooking (Matsuo et al., 1986). Monoglycerides form water-insoluble complexes with amylose resulting in decreased stickiness in cooked pasta (Eliasson and Krog, 1985). The possible formation of a starch-glycolipid-protein network may result in increased cooking quality of pasta (Feillet, 1984). While protein has been determined to be an integral structural component of pasta, the role of lipids has been to complement the functions of protein and minimize the consequences of cooking (Dahle and Muenchow, 1968).

2.3 EFFECT OF DRYING TEMPERATURE ON PASTA COOKING QUALITY

The most important improvement in pasta manufacturing in recent years has been the development of high-temperature (HT) and very high-temperature (VHT) drying processes (Cubadda, 1989). These developments have allowed the drying process to be significantly shortened, therefore allowing manufacturers

to increase their productivity (Mondelli, 1989).

The drying of pasta products is one of the most critical steps in the manufacturing of dried pasta goods (Banasik, 1981). The primary objective of the drying process is to lower the moisture content of the pasta from approximately 31% to 12.5% so that the pasta will retain its shape and store without spoiling or shattering. If the removal of moisture occurs too slowly, the pasta can become mouldy and spoil, whereas, if the removal of water is too rapid, checking and cracking can occur.

The drying process can be divided into two stages; the pre-drying and final drying stages. Of the two drying stages, the pre-drying stage is the most critical (Baroni, 1988). During this stage, the moisture content is rapidly lowered from 31% to 25% (Banasik, 1981). In the final drying stage, the moisture content is reduced to 12.5% through a combination of alternating ventilation and resting periods of different temperatures and relative humidities (Baroni, 1988). High temperatures can be applied during the pre-drying or final drying stages.

2.3.1 High Temperature Drying

Drying temperatures between 60°C and 90°C are generally referred to as HT drying (Manser, 1980), while temperatures above 90°C are referred to as VHT

or trés haute temperature (THT) drying (Mondelli, 1989). The advantages of HT and VHT drying include reduced drying times, increased output, decreased microbiological activity, increased yellow color due to inactivation of enzymes (Mondelli, 1989) and improved cooking quality, by decreasing stickiness and increasing firmness in the cooked pasta (Manser, 1980). HT and VHT drying also allow for the production of good quality pasta from low quality semolina (Donnelly, 1991). It has been reported, however, that HT and VHT drying can result in undesirable browning in pasta due to the occurrence of Maillard-type reactions (Manser, 1980; Abecassis et al., 1989a).

Dexter et al. (1981b) compared two HT (70°C) drying cycles. For the drying cycle that used HT in the final drying stages (HT-B) rather than HT in the pre-drying stage (HT-A), improved strand strength, as measured by a breaking test, and increased pasta cooking quality resulted. The pasta cooking quality of the HT-A pasta was found to be similar to pasta dried at low temperature (LT 39°C) dried pasta. Application of HT during the final drying stages results in a less sticky pasta possibly due to the avoidance of premature denaturation of the gluten network (Manser, 1980).

DeStefanis and Sgrulletta (1990) found that HT (90°C) dried pasta was less sticky than LT dried pasta as measured by sensory evaluation. HT dried pasta

was also found to have improved cooking quality over LT dried pasta. The improvement in cooking quality of HT dried pasta was thought to be associated with a considerable decrease in gluten solubility. Also, a highly significant correlation between the amount of insoluble protein and the cooking quality scores of HT dried pasta was found ($r=0.99$, $p=0.01$). Aktan and Khan (1992) also found an increase in insoluble proteins with increased drying temperature indicating greater degrees of denaturation that enhance cooking quality.

Wyland and D'Appolonia (1982) compared three HT drying cycles to a LT drying cycle. The HT drying cycles (60, 70 and 80°C) were applied after a LT (40°C) pre-drying cycle. Results indicated that HT drying resulted in increased color scores and increased firmness, regardless of the HT drying treatment. The 80°C HT drying treatment resulted in the lowest cooking losses of the three HT drying treatments evaluated, while the LT drying treatment resulted in the highest cooking losses. The decrease in cooking loss at the highest HT (80°C) drying treatment was attributed to the heat strengthened protein network which retains greater amounts of starch.

Increases in pasta disc viscoelasticity, as measured by relative recovery values, were found when a HT (80°C) drying cycle was used as compared to a LT (40°C) drying cycle (Kovacs et al., 1995b).

The effect of semolina protein level and drying temperature was investigated by Malcolmson et al. (1993). Using response surface methodology, five drying temperatures (40-90°C) and seven protein levels (11-17%) were examined. Firmness of cooked pasta was found to increase primarily with increasing protein level and to a lesser extent with increasing drying temperature. Cooking losses were found to decrease with increasing drying temperature and to a lesser extent, with increasing protein content. In order to produce pasta of comparable commercial quality, drying temperatures greater than 60°C were recommended for low protein samples (11%). Pasta made from semolina with a protein content greater than 14% could be produced using a drying temperature of 50°C.

The effect of HT drying on sprouted durum wheat samples was investigated by Grant et al. (1993). HT (72°C) drying was found to reduce stickiness values in unsprouted samples, whereas it had no effect on sprouted samples. HT drying was also found to result in decreased cooking loss of pasta regardless of sprout damage. The firmness of pasta samples, whether from wheat that was sprouted or not, did not show an improvement with HT. This was attributed to the fact that only two cultivars were investigated. Dexter et al. (1983b) found that sprout damage did not have any detrimental affects on stickiness or any other aspect of cooking quality of pasta dried using HT drying (70°C).

The effect of HT drying on α-amylase levels has been investigated by Dexter et al. (1982). Using a 80°C drying cycle, α-amylase activity was found to be partially inactivated, whereas 39°C and 65°C drying cycles were found to have little effect on α-amylase activity. This suggests that α-amylase activity can be reduced using HT drying.

2.4 EVALUATION OF COOKED PASTA TEXTURE

The texture of cooked pasta is the primary criterion for assessing the overall quality of pasta (D'Egidio and Nardi, 1996). Cooked pasta should have a smooth surface that is free of stickiness (Guan and Seib, 1994). It should also be firm, elastic, resilient and resist surface disintegration during cooking (Dexter et al., 1983a; du Cros, 1987; Kovacs et al., 1995b). The characterization and measurement of cooked pasta texture has been accomplished through the use of sensory panels and instrumental procedures.

Various factors have been found to have an influence on textural measurements. The amount of time between cooking and testing, whether the cooked sample is rinsed, whether the cooked sample is held in water and the temperature of the holding water as well as the composition of cooking water have all been found to be important factors that can influence textural measurements. Researchers have found that cooked pasta becomes stickier as

the length of time between draining and testing is increased (Voisey et al., 1978b; Dexter et al., 1983a). Dexter et al. (1983b) found that type of cooking water had a significant effect on stickiness, as measured by the GRL compression tester. Pasta cooked in tap water (hardness 94.0 mg $CaCO_3$/L) was found to be stickier than when cooked in deionized water (hardness 1.65 mg $CaCO_3$/L) (Malcolmson and Matsuo, 1993).

2.4.1 Instrumental Evaluation

The use of instrumental methods offers several advantages over the use of sensory panels in that instrumental methods require less time and are usually easier to perform, whereas sensory panels require more time to perform and can result in poor reproducibility unless the panel is adequately trained (Malcolmson, 1991; Edwards et al., 1995). Although easier and less time-consuming to perform, instrumental methods must be carefully standardized in order to provide meaningful and reproducible results. Various parameters can be measured using instrumental procedures. These include firmness, tenderness, chewiness, recovery, elasticity and stickiness.

2.4.1.1 Measurement of Firmness/Hardness

Walsh and Gilles (1971) evaluated the firmness of samples using a plexiglass tooth attached to an Instron Universal Testing Instrument. Firmness was

measured by calculating the area of the force-distance curve. Firm samples of cooked pasta gave higher peaks on the force-distance curves than soft samples. High firmness values were associated with high glutenin and low gliadin contents.

Using a bevelled plexiglass tooth attached to the plunger of an Instron Universal Testing Machine, the maximum cutting stress and the work to cut cooked noodle samples were found to have strong correlations ($r=0.39$ and $r=0.82$, respectively, $p=0.01$) with sensory firmness scores (Oh et al., 1983). The AACC accepted method for the evaluation of cooked pasta firmness (Method 16-50, 1989) uses the plexiglass tooth developed by Oh et al. (1983) but uses five strands of cooked pasta instead of three.

A spaghetti tenderness testing apparatus designed to simulate a bite test was developed by Matsuo and Irvine (1969). A piece of cooked pasta is placed in a holding slot and the movement of the cutting edge (tooth) is measured and recorded. The tenderness index was determined from the linear portion of the penetration-time curve which measured the time required for the cutting edge to cut through the sample. The apparatus was modified to also measure parameters of chewing (Matsuo and Irvine, 1971). Results indicated that as pasta cooking time increased recovery scores decreased, while tenderness and

compressibility scores increased. The tenderness index has been found to be significantly correlated to gluten extensibility as measured by the gluten stretching test ($r=0.93$, $p=0.001$) (Matsuo and Irvine, 1970).

Pasta firmness has also been evaluated using compression forces as opposed to shear forces. Binnington et al. (1939) used a plunger to compress cooked pasta samples to a predetermined thickness by increasing the weight applied to the sample. The resulting values from the tenderness test chart were converted to a tenderness score. Tenderness scores were found to decrease as cooking time was increased.

Using the Ottawa Texture Measuring System (OTMS) with a multi-blade shear cell, Voisey and Larmond (1973) found sensory evaluations of chewiness and firmness were more strongly correlated with shear force ($r=0.71$ and $r=0.82$, respectively) than shear stress ($r=0.54$ and $r=0.78$, respectively). The use of a multi-blade shear cell which measures the force required to shear pasta in 100 places was found to be related to consumer response during chewing. This method was also found to account for both inter- and intra-strand variation.

2.4.1.2 Measurement of Compressibility/Recovery

Compressibility and recovery, as measured using the GRL tenderness testing

apparatus, were found to be strongly correlated with Instron shear force ($r=-0.953$, $p=0.01$ and $r=0.832$, $p=0.05$, respectively), and poorly correlated with the OTMS maximum force ($r=-0.150$ and $r=0.153$) (Matsuo and Irvine, 1974).

Methods to measure the compressibility and elasticity has been investigated by several researchers. Using the viscoelastograph, the variation in thickness of cooked pasta as a function of time, during and after the application of pressure can be investigated (Cubadda, 1989). The viscoelastic recovery values of both pasta discs and spaghetti have been investigated by Ames et al. (1998). Spaghetti relative recovery (R_r%) values were found to be related to protein content ($r=0.88$, $p=0.01$), however pasta disc R_r% was related to gluten strength. Kovacs et al. (1995b) also found that higher recovery values were found for pasta discs made from cultivars with strong gluten properties.

2.4.1.3 Measurement of Stickiness/Adhesiveness

Measurements of stickiness in cooked pasta has been investigated using several different instruments. Using the Grain Research Laboratory compression tester, Dexter et al. (1983a) compressed pasta samples and measured the force of adhesion of pasta to the plunger to determine pasta stickiness. Results showed that pasta with the highest instrumental stickiness value was also rated as

being the most sticky by a sensory panel.

Dalbon et al. (1985) examined the stickiness of cooked pasta using an Instron Texture Testing machine. Stickiness was measured as the negative area of the force-distance curve. This method was also used by Malcolmson et al. (1993). Voisey et al. (1978a) used a serrated bottom plate and a smooth top plate to measure pasta stickiness. The use of a serrated plate was thought to enhance the measurement of the adhesive characteristics of pasta perceived during eating. Pasta samples with high starch to protein ratios were found to have increased measurements of instrumental stickiness (Voisey et al., 1978a).

Guan and Seib (1994) designed a multifaced probe, sample restraining device and sample holder to measure stickiness with a TA.XT2 texture analyzer. Stickiness was measured as the peak tensile force and total tensile work required to separate the probe from the strand surface. This method allows for the stickiness of five strands of pasta to be measured and recorded in 5 minutes.

2.4.2 Sensory Evaluation

The use of sensory panels to evaluate the texture of cooked pasta are believed to be the most reliable methods to assess the quality of cooked pasta (Matsuo,

1988). Despite this, several disadvantages are associated with the use of sensory panels. Sensory tests require more time to perform and can result in poor reproducibility due individual bias (Matsuo, 1988; Malcolmson, 1991). In order to limit personal biases, and therefore increase reproducibility, it is important to train panelists so that precise and consistent results are achieved (Watts et al., 1989). Whereas sensory panels have the ability to evaluate overall textural characteristics of a sample, instrumental methods are only able to measure limited characteristics which may not relate to sensory judgements (Matsuo, 1988; D'Egidio and Nardi, 1996).

Textural parameters of pasta that have been evaluated by researchers using sensory panels include: cohesiveness, adhesiveness, chewiness, gumminess, firmness, elasticity and stickiness. The assessment of stickiness has been evaluated using both oral and non-oral methods (tactile and visual). A summary of some of the definitions and techniques used to evaluate the texture of cooked pasta using sensory panels are presented in Tables 2.1-2.7.

A study by Larmond and Voisey (1973) used a trained sensory panel to evaluate the firmness, gumminess, adhesiveness and chewiness of optimally cooked pasta samples on an 8-point scale. For all of the textural parameters evaluated, the trained panel was able to distinguish differences between each of the eight

samples. Based on the results, it was determined that consumer acceptability could be predicted on the basis of firmness and gumminess scores of the trained panel.

Voisey et al. (1978b) assessed the firmness, adhesiveness, springiness and rate of breakdown using a trained panel. Significant correlations ($r \geq 0.55$, $p = 0.01$) were found between mean instrumental cutting forces, as measured by the OTMS with a multi-blade cutting cell, and mean sensory evaluations of firmness, springiness and rate of breakdown.

Malcolmson (1991) evaluated firmness, elasticity, chewiness, cohesiveness tooth pack and stickiness using a trained panel. Sensory measurements of firmness, elasticity and chewiness could be predicted from instrumental measurements using the Instron and the GRL tenderness testing apparatus except stickiness determinations. However, none of the instrumental tests were found to be good predictors of sensory cohesiveness, tooth pack or stickiness.

Firmness, chewiness and adhesiveness to teeth of 12 durum wheat varieties were evaluated using a trained panel (Kovacs et al., 1997). Mixograph peak height and mixograph total energy gave strong correlations with chewiness ($r = 0.88$ and $r = 0.89$, $p = 0.01$ respectively) and firmness ($r = 0.81$ and $r = 0.82$,

p=0.01 respectively) for wheat grown in 1991.

Voisey et al. (1978a) evaluated stickiness using oral and non-oral methods. Using a trained panel, the stickiness (adhesiveness) of 20 samples of cooked spaghetti was measured as the force required to remove a chewed sample from the molar teeth. A poor correlation was found to exist between sensory and instrumental readings obtained using the OTMS (r=-0.17). The authors explanation for the poor relationship was that the sensory and instrumental measurements were not related to the same physical characteristics and that saliva may have also had an effect on the sensory measurements. To assess cooked pasta stickiness using non-oral methods, cooked pasta was packed into a 250 mL beaker and refrigerated overnight. Four panelists assessed the stickiness of the samples using four different non-oral methods; the force required to remove the sample from the beaker (ease of removal), the force needed to stir and spread the sample with their index finger (stirring), the force needed to separate adhering strands (separating strands)and the ease of which the sample slides on a flat tilted sheet (sliding angle). Correlations were found between the non-oral methods and instrumental measurements of stickiness in commercial samples (ease of removal r=0.64, stirring r=0.99, separating strands r=0.85, sliding angle r=0.47) but not experimental samples.

Strand-to-strand stickiness, the degree to which cooked pasta sticks to the teeth, and firmness was evaluated by Dalbon et al. (1985) using a six member trained sensory panel. The overall quality of the cooked pasta samples was determined based on the evaluation of the individual textural characteristics. The authors stated that sensory measurements were found to show good correlations with instrumental measurements, however no data was provided.

Using a trained panel, Malcolmson (1991) found strong correlations between instrumental methods and sensory evaluations. Shear force and work to shear values were found to be correlated to sensory firmness scores ($r=0.89$ and $r=0.77$). Relaxation was found to be correlated to sensory elasticity ($r=0.84$) and sensory chewiness ($r=0.84$). A correlation between instrumental stickiness and sensory stickiness scores was also observed ($r=0.56$).

In Italy, researchers and manufacturers use a trained three member sensory panel. Textural characteristics of stickiness, bulkiness and firmness are determined (D'Egidio and Nardi, 1996). Evaluations of stickiness and bulkiness are done both visually and manually, while firmness is evaluated orally. Each textural parameter is rated from 1 to 100, and a score for the overall cooking quality is obtained by calculating the arithmetic mean of each of the three scores and summing. A pasta of excellent quality will have an overall score of

80 or more, while poor quality pasta will score below 40.

Table 2.1: Summary of Sensory Rating Scales Used for the Evaluation of Firmness/Hardness.

Term Used	Definition/Technique	Scales Used	Reference
Hardness/Firmness	Force required to completely bite through 1 strand of pasta placed between the molars.	15 cm line scale 0 = soft 15 = hard	D. Hahn (personal communication)
Firmness	Resistance to cutting between the teeth and to crushing between the tongue and the palate.	9-pt scale 1 = very tender 9 = very firm	ISO (1985)
Firmness	Force required to penetrate a substance with the molar teeth.	8-pt scale 1 = extremely soft 8 = extremely firm	Larmond and Voisey (1973)
Firmness	Break a single strand in 2 pieces. Place 1 piece lengthwise between the molars. Force required to bite through the sample.	15 cm line scale 0 = soft 15 = firm	Malcolmson, (1991)
Hardness/Firmness[1]	Place 1-3 noodles between the molars in a bunch. Measure force required to chew through a mass of 1-3 noodles.	15 cm line scale 0 = soft 7.5 = firm 15 = hard	Noodle Lexicon Development Study
Firmness	Force required to compress the spaghetti between the molar teeth when biting down evenly during the first bite.	15 cm line scale 1.6 = slightly firm 13.6 = very firm	Kovacs et al. (1997)
Firmness	Force required to compress the spaghetti between the molar teeth when biting evenly during the first bite.	15 cm line scale 1.3 = soft 13.7 = firm	Voisey et al. (1978b)

[1] Evaluations were performed using noodles. Definitions were provided during a short course on noodle texture at Oregon State University, August 30, 1995 to September 1, 1995.

Table 2.2: Summary of Sensory Rating Scales Used for the Evaluation of Elasticity/Springiness.

Term Used	Definition/Technique	Scales Used	Reference
Elasticity	Twirl two strands around index finger to form a ball. Remove the ball and place between the molars. Slightly compress the sample between the molars and release. Repeat several times. Measure the degree of elasticity of the sample.	15 cm line 0 = low degree of elasticity 15 = high degree of elasticity	Malcolmson (1991)
Springiness[1]	Place 1-2 noodles between the molars in a bunch. The amount the noodle returns to its original shape and feels resilient (pushing back) against the molars.	15 cm line scale 0 = dead/plastic 15 = resilient/elastic	Noodle Lexicon Development Study
Springiness	Degree to which a product returns to its original shape once it has been partially compressed between the teeth.	15 cm line 1.6 = slightly springy 13.6 = very springy	Kovacs et al. (1997)
Springiness	Resiliency of the spaghetti when a strand of spaghetti is stretched with the fingers.	15 cm line 1.3 = very little 13.7 = very much	Voisey et al. (1978b)

[1] Evaluations were performed using noodles. Definitions were provided during a short course on noodle texture at Oregon State University, August 30, 1995 to September 1, 1995.

Table 2.3: Summary of Sensory Rating Scales Used for the Evaluation of Chewiness/Rate of Breakdown.

Term Used	Definition/Technique	Scales Used	Reference
Chewiness	Length of time required to masticate a sample in order to reduce it to a consistency satisfactory for swallowing.	8-pt scale 1 = extremely tender 8 = extremely chewy	Larmond and Voisey (1973)
Chewiness	Fold two strands in four and place in the mouth. Measure the amount of energy to masticate the sample until the sample is swallowed.	15 cm line scale 0 = slightly chewy 15 = very chewy	Malcolmson (1991)
Chewiness	Length of time, or amount of chewing, required to masticate the sample at a constant rate of force application, to reduce it to a consistency suitable for swallowing.	15 cm line scale 1.6 = slightly chewy 13.4 = very chewy	Kovacs et al. (1997)
Rate of Breakdown	Time required to prepare three strands of spaghetti for swallowing while chewing at a constant rate.	15 cm line scale 1.3 = slow 13.7 = fast	Voisey et al. (1978b)

Table 2.4: Summary of Sensory Rating Scales Used for the Evaluation of Cohesiveness.

Term Used	Definition/Technique	Scales Used	Reference
Cohesiveness	Degree to which 1 strand of product holds together in a mass after 5 chews.	15 cm line scale 0 = loose mass 15 = tight mass	D. Hahn (personal communication)
Cohesiveness of Chewed Mass	Fold two strands in four and chew thoroughly (i.e. until the mass is ready for swallowing) between the molars on one side of the mouth, spreading the sample during chewing to determine the degree to which the mass holds together.	15 cm line scale 0 = low degree of cohesiveness 15 = high degree of cohesiveness	Malcolmson (1991)
Cohesiveness of Mass[1]	Chew 2-3 noodles between the molars 5-10 chews. Amount that the chewed mass holds together.	15 cm line scale 0 = loose 15 = thick/gummy	Noodle Lexicon Development Study Lexicon
Gumminess	Denseness that persists during mastication.	8-pt scale 1 = no gumminess 8 = extremely gummy	Larmond and Voisey, (1973)

[1] Evaluations were performed using noodles. Definitions were provided during a short course on noodle texture at Oregon State University, August 30, 1995 to September 1, 1995.

Table 2.5: Summary of Sensory Rating Scales Used for the Evaluation of Toothpack/Tooth Adhesiveness.

Term Used	Definition/Technique	Scales Used	Reference
Tooth Adhesiveness	After swallowing the product, the amount of force required to remove the product and/or product residue which sticks to the teeth.	15 cm line scale 0 = none 15 = extreme	D. Hahn (personal communication)
Adhesiveness	Force required to remove material that adheres to the mouth during normal eating.	8-pt scale 1 = no stickiness 8 = extremely sticky	Larmond and Voisey (1973)
Tooth Pack	Fold 2 strands in 4 and place in the mouth. Measure the degree of tooth packing during mastication and after swallowing the sample.	15 cm line scale 0 = low degree of tooth pack 15 = high degree of tooth pack	Malcolmson (1991)
Stickiness	Amount of product adhering on/in the teeth after mastication.	15 cm line scale 1.6 = slightly sticky 13.6 = very sticky	Kovacs et al. (1997)
Adhesiveness	Force required to remove the chewed sample from the teeth.	15 cm line scale 1.3 = very little 13.7 = very much	Voisey et al. (1978b)
Toothpull[1]	Force required to pull the molars apart and out of the noodle mass.	15 cm line scale 0 = no force 15 = high force	Noodle Lexicon Development Study

[1] Evaluations were performed using noodles. Definitions were provided during a short course on noodle texture at Oregon State University, August 30, 1995 to September, 1, 1995.

Table 2.6: Summary of Sensory Rating Scales Used for the Evaluation of Visual Stickiness/Surface Conditions.

Term Used	Definition/Technique	Scales Used	Reference
Surface Condition	Condition of superficial disintegration of cooked pasta assessed using reference photographs.	9-pt scale 1 = very stuck together 9 = completely separate	ISO (1985)
Surface Stickiness	Dip index finger in water and dry with a napkin. Touch surface of spaghetti strands with finger, compress slightly and release. Degree the strands adhere to finger.	15 cm line scale 0 = low degree of stickiness 15 = high degree of stickiness	Malcolmson (1991)
Stickiness	Degree to which the product sticks to itself when lifting 3 strands of product with the thumb and index fingers.	15 cm line scale 0 = not sticky 15 = extremely sticky	D. Hahn (personal communication)
Stickiness	Ease with which the sample can be removed from a beaker (after storage overnight in a refrigerator).	5-pt scale 1 = easy 5 = not easy	Voisey et al. (1978a)
Stickiness	Amount of force required to stir and spread a spaghetti sample with the index finger.	5-pt scale 1 = easy 5 = not easy	Voisey et al. (1978a)
Stickiness	Force needed to separate strands adhering together.	5-pt scale 1 = easy 5 = not easy	Voisey et al. (1978a)
Stickiness	Spaghetti is spread over the area of a galvanized steel sheet and gradually tilted until the mass began to slide. The angle from the horizontal is measured.	Measure the angel from the horizontal.	Voisey et al. (1978a)

Table 2.7: Summary of Sensory Rating Scales Used for the Evaluation of Other Textural Parameters.

Term Used	Definition/Technique	Scales Used	Reference
Surface Smoothness	Absence of gritty/grainy particles felt on the surface of the product by the tongue.	15 cm line scale 0 = gritty/grainy 15 = smooth	D. Hahn (personal communication)
Surface Conditions-Macro Roughness[1]	Amount of large bumps, lumps, ridges on the surface of the noodle.	15 cm line scale 0 = smooth 15 = lumpy	Noodle Lexicon Development Study
Moistness	Perceived amount of moisture released from one strand of product after 5 chews.	15 cm line scale 0 = dry 15 = extremely moist	D. Hahn (personal communication)
Mouthcoating	After swallowing the product, the amount of starch/pasty coating felt by the tongue when moved over the surface of the mouth.	15 cm line scale 0 = not starchy 15 = extremely starchy	D. Hahn (personal communication)
Starchiness	The taste of uncooked starch which remains in the mouth after the sample is swallowed.	5-pt scale 1 = no starchiness 5 = extremely starchy	Larmond and Voisey (1973)

[1] Evaluations were performed using noodles. Definitions were provided during a short course on noodle texture at Oregon State University, August 30, 1995 to September 1, 1995.

CHAPTER 3

CHARACTERIZATION OF THE RHEOLOGICAL AND STARCH PROPERTIES OF SEMOLINAS WITH VARYING GLUTEN STRENGTH

3.1 INTRODUCTION

There is widespread agreement that gluten strength is an important factor that influences pasta cooking quality (Gryzbowski and Donnelly, 1979; Dexter et al., 1980; Dick and Quick, 1983). Durum cultivars with short, inextensible gluten, are thought to produce pasta with the best cooking quality (Matsuo, 1978).

Many tests have been used to evaluate the gluten strength of semolina including chemical tests such as the Berliner test and the sodium dodecyl sulfate sedimentation (SDS) test (Dexter et al., 1980). The Berliner test however, is no longer widely used (Cole, 1991). Cultivars with increased gluten strength have higher SDS sedimentation volumes than cultivars with weaker gluten strength (Dexter et al., 1980). Instrumental, or physical tests, have also been used to assess the rheological properties of semolina doughs including such methods as the farinograph, mixograph, alveograph, extensograph and viscoelastograph. Rheological properties have been primarily assessed by evaluating the mixing properties of semolina doughs using the farinograph and/or the mixograph. The development of the 2 g micromixograph has allowed for the assessment of rheological properties in early generations to be performed with as little as 3-5 g of seed (Gras and O'Brien, 1992). The alveograph has been used, primarily in

Europe, to assess the rheological properties of doughs by measuring the resistance of a dough disc to biaxial extension by inflating it into a bubble. Semolina doughs with strong gluten properties are characterized by the farinograph and mixograph as having long mixing times, low mixing tolerance index values (less breakdown) (Bloksma and Bushuk, 1988) and wider curve bandwidths (Dexter and Matsuo, 1980). Increased resistance (higher *P* values) and decreased extensibility (lower *L* values) along with increased deformation energy (*W*) values are seen in doughs with strong gluten properties using the alveograph . Doughs made from cultivars with strong gluten properties will also exhibit higher recovery values using the viscoelastograph and increased resistance to extension using the extensograph.

Other tests that have been used to assess gluten strength include a modified extensograph test using wet gluten using the Kieffer rig for the TA.XT2 texture analyzer (Anonymous, 1995) and the Gluten Index (GI) method (Perten, 1990). With the GI method, washed gluten is centrifuged on a special screen and the proportion of gluten that remains on the screen after centrifugation is expressed as a percentage of the total amount of wet gluten as the GI value. GI values can range from 0 to 100. Cultivars with high GI values exhibit stronger gluten strength properties than cultivars with low GI values.

Pasta cooking quality has been found to be related to farinograph characteristics (Matsuo and Irvine, 1970), SDS sedimentation volume (Dexter et al., 1981a), mixograph characteristics (Dick and Quick, 1983), alveograph parameters (D'Egidio et al., 1990) and gluten strength (Grzybowski and Donnelly, 1979; Dexter et al., 1980).

Although, the role of gluten in pasta cooking quality has received much attention, knowledge of the role of starch in determining pasta cooking quality is limited even though it constitutes 60-70% of semolina (Berry et al., 1971). Amylose constitutes approximately 25% of starch (Medcalf and Gilles, 1965; Morrison et al., 1984). It has been found that addition of amylomaize starch (51.9% amylose) to semolina imparts a slight improvement in cooked pasta firmness (Dexter and Matsuo, 1979b). High amounts of amylose of the surface have been thought to contribute to stickiness in cooked pasta (Dexter et al., 1985a). Total starch content of the semolina has been found to have a negative relationship to pasta cooking quality (D'Egidio et al., 1983). Starch paste viscosity measurements, using the Rapid Visco Analyzer (RVA), have been found to be related to the eating quality of udon noodles (Konik et al., 1994). However no studies have been published which have evaluated the pasting properties of durum wheat using the RVA.

Starch damage can have an effect on rheological properties and pasta cooking quality. Damage to starch can occur during milling (Feillet, 1984) and pasta processing (Lintas and D'Appolonia, 1973). Strong correlations between starch damage, as a result of milling, and cooking loss have been found (Matsuo and Dexter, 1980). Damaged starch affects rheological measurements since less water available for absorption (Farrand, 1964). If the amount of damaged starch is not taken into consideration, the resulting doughs may appear stronger than they actually are (Dexter et al., 1994) since damaged starch absorbs more water (2.0g water/g) than undamaged starch (0.44g water/g) (Greer and Stewart 1964).

Little work has been done to assess the rheological properties and starch characteristics of durum wheat cultivars with extra strong gluten properties. New methods for assessing gluten strength and starch pasting properties have been developed but have not been used to evaluate durum wheat. Therefore it was the objective of this phase of the study:

1. To investigate the rheological properties of semolina from durum wheat samples varying in gluten strength.
2. To characterize the starch properties of semolina from durum wheat samples varying in gluten strength.

3.2 EXPERIMENTAL DESIGN

3.2.1 Materials

Seven samples with a range in gluten strength, but within a narrow range of protein content, were selected for study. Three of these samples were breeding lines (DT 662, AC Pathfinder (DT 671) and AC Navigator (DT 673)), one was a sample with extra strong gluten grown in the southwestern United States commonly referred to as a desert durum (Durex) and the remaining three samples were registered Canada Western Amber Durum (CWAD) cultivars (Kyle, AC Melita and Plenty). Wheats were grown during the 1996 growing season in Swift Current, SK. Kyle, Plenty, AC Melita and AC Navigator were part of the 1996 Market Development Study and supplied by the Canadian Wheat Board, while the remaining samples were supplied by J.M. Clarke, Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada, Swift Current, SK. The pedigree and country of origin for each of the samples is presented in Table 3.1. Samples were graded by the Industry Services Division of the Canadian Grain Commission (Winnipeg, MB) for selected primary grade determinants.

3.2.2 Wheat Milling

Wheats were milled into semolina at the Grain Research Laboratory (Winnipeg, MB) using an Allis-Chalmers laboratory mill (Dexter et al., 1990) used in

Table 3.1: Pedigree and Origin of Samples Examined.

Sample	Country of Origin	Pedigree
Durex	USA	Not available
AC Pathfinder	Canada	DT367/Westbred 881[1]
AC Navigator	Canada	Kyle/Westbred 881[1]
AC Melita	Canada	Medora/Lloyd[1]
DT 662	Canada	DT 367/Medora//DT 367/DT 379
Kyle	Canada	Wakooma/DT 320//Wakooma/DT 322
Plenty	Canada	Wascana/Vic[1]/3/Hercules/2/RL3498/Lakota

[1] American sample.

conjunction with a laboratory purifier (Black, 1966).

3.2.3 Protein Content Determination

Wheat and semolina protein contents (N x 5.7) were determined by the Kjeldahl procedure as modified by Williams (1973) and performed in duplicate. Wheat protein content for Plenty could not be determined due to insufficient sample size.

3.2.4 Falling Number

Falling numbers were determined according to AACC method 56-81B (AACC, 1994) from wheat ground in a Falling Number Laboratory Mill 3100 (Perten Instruments Inc., Reno, NV, USA).

3.2.5 Storage of Semolina Samples

All samples were stored in air tight containers at 4°C during the study but were allowed to equilibrate to room temperature at least one day prior to conducting the tests.

3.2.6 Moisture Determination

Moisture contents were determined using a Brabender moisture oven (C.W. Brabender Instruments, Inc., South Hackensack, NJ, USA) according to AACC

method 44-15A (AACC, 1994). Moisture contents were determined regularly before any test was performed in order to ensure accurate moisture levels.

3.2.7 Assessment of Gluten Strength

3.2.7.1 Gluten Index

The gluten index test was performed using semolina according to AACC Method 38-12 (AACC, 1995; wholemeal method) using the Glutomatic (model 2200) and Gluten Index centrifuge (model 2015, Perten Instruments, North America Inc., Reno, NV, USA). Wet gluten was dried using the Glutork 2020 (Perten Instruments North American Inc., Reno, NV, USA). Wet and dry gluten contents were expressed on a 14.0% moisture basis. Tests were performed in duplicate.

3.2.7.2 Gluten Extensibility

Gluten was obtained by washing a 10 g semolina sample according to the gluten index method (AACC 38-12, 1995; wholemeal method). Gluten extensibility was determined according to the method of Kieffer et al (1998) with the following modifications: after washing was completed, the gluten was placed in a 50 mL plastic centrifuge tube, covered with distilled water and centrifuged using a Beckman centrifuge (model GS-15R, Beckman Instruments, Palo Alto, CA, USA) at 5,000 rpm for 6 minutes to remove air bubbles in the gluten. After pouring off the water, the gluten was gently removed to avoid

stretching or tearing the sample and then placed in the Teflon dough form and press for the Kieffer rig (Stable Micro Systems, Godalming, Surrey, UK). The press was placed in a humidity cabinet and allowed to relax for 40 minutes at 30°C. A single gluten strip was removed from the dough form, clamped into the sample plate holder and placed in the Kieffer rig. Gluten extensibility was measured using the TA.XT2 texture analyzer (25 kg model; Stable Micro Systems, Godalming, Surrey, UK) with the following test parameters; measure force in tension, manual trigger force, test speed was 5.0 mm/sec, distance set to 200 mm. These parameters were chosen based on previous experimentation. Parameters measured were; force required to break the strand (peak breaking force), peak time, extensibility and area under the force-distance curve. Tests were performed in duplicate with 2 subsamples per duplicate.

3.2.7.3 Sodium Dodecyl Sulfate Sedimentation Test

SDS sedimentation volumes were obtained using the method of Axford et al. (1979) on udy ground wholemeal (0.5 mm particle size) using 3% SDS. Tests were performed in duplicate. SDS sedimentation volumes could not be determined for Plenty due to insufficient sample size.

3.2.7.4 Two Gram Micromixograph

Semolina (2.000 ± 0.001 g) on a 14.0% moisture basis was placed in a water

jacketed bowl (National Manufacturing Division, TMCO, Lincoln, NE, USA). Room temperature distilled water was weighed using a syringe and added to the semolina to give an absorption of 55.0%. Determination of the absorption used was based on previous experimentation using a set of 10 samples, with a range in gluten strength, at 5 absorptions (49, 52, 55, 58, 62%) in duplicate. A water bath (model RTE-100, Neslab Instruments, Newington, NH, USA) was set to 25.0±0.1°C to provide constant temperature to the micromixograph bowl. Curves were analyzed using envelope and mid-line analyses using the computer software program Mixsmart® (version 3.40, National Manufacturing Division, TMCO, Lincoln, NE, USA). Tests were performed in quadruplicate.

3.2.7.5 Alveograph

AACC Method 54-30A (AACC, 1994) was used using the constant pressure model MA 82 alveograph equipped with an integrating computer (Relaxo-Calculator RCV4, Tripette & Reynaud/Chopin, Villeneuve-La-Garenne Cedex, France). Curve parameters of *P*, *L*, *P/L*, *W*, *H*, *G* and *S* were determined. Tests were performed in duplicate with five subsamples per duplicate.

3.2.8 Starch Evaluation and Characterization

3.2.8.1 Starch Content

Determination of the starch content of the samples was performed on udy

ground semolina (0.5 mm particle size) according to AACC Method 76-13 (1995) using the Megazyme Total Starch assay kit (AA/AMG, Megazyme, Wicklow, Ireland). Tests were performed in duplicate.

3.2.8.2 Amylose Determination

Starch was extracted from udy ground semolina (0.5 mm particle size) according to the method of Morrison et al. (1984) with the following modifications: after addition of protease, the samples were incubated at 35°C and after centrifugation on day three, the samples were layered over 15 mL of 70% cesium chloride and then centrifuged at 15000 x g for 30 minutes (this step was repeated if necessary). The determination of the amount of amylose was performed colorimetrically according to the method of Chrastil (1987) using a standard curve prepared from wheat amylose. Tests were performed in duplicate.

3.2.8.3 Starch Damage

The amount of starch damage in semolina and udy ground semolina (0.5 mm particle size) was performed according to AACC Method 76-31 (1995) using the Megazyme Starch Damage assay kit (SDA, Megazyme, Wicklow, Ireland). Tests were performed in duplicate.

3.2.8.4 Rapid Visco Analyzer

The Rapid Visco Analyzer (RVA, Newport Scientific, Warriewood, Australia) was used to determine semolina pasting properties. Udy ground semolina (3.5 g, 0.5 mm particle size) was added to 25 mL of room temperature distilled water in the metal sample cylinder. The paddle was then placed in the sample cylinder and moved up and down five times to pre-mix the sample. The cylinder and paddle were then placed in the RVA and the test was started. Heating started at 50°C and increased to 95°C. The temperature was held at 95°C for 8 minutes then decreased to 50°C, followed by a hold at 50°C for 1 min, resulting in a total test time of 13 min. The following parameters were evaluated: peak viscosity, peak time, breakdown viscosity, breakdown viscosity time, breakdown, setback viscosity and total setback viscosity (Dengate, 1984). Figure 2.5 shows a typical pasting curve labelled with the parameters measured. Tests were performed in duplicate.

3.2.9 Statistical Analysis

Analysis of Variance (ANOVA) was performed on all data except ash content (wheat and semolina) and falling number using the PROC GLM procedure (SAS, 1992). Multiple comparisons of the means were performed using Tukey's test ($p \leq 0.05$).

Micromixograph data, for both mid-line and envelope analyses, was also analyzed using Pearson's correlation to reduce the number of parameters required to explain the data. The means (average of quadruplicate measurements) of the reduced parameters were then analyzed for their similarity using PROC CLUSTER (SAS, 1992). Cluster analysis was also performed on the RVA data.

3.3 RESULTS

To assist the reader, the same ordering of samples, in descending order of their GI values, has been used in all figures and tables. Results for all tests are presented in Appendices 1-11.

3.3.1 Grading Results

Samples ranged in grade from a number 1CWAD to a number 4CWAD, demonstrating a wide range of grades (Table 3.2). The percentage of hard vitreous kernels (HVK) ranged from 82-93% (Table 3.2). All samples meet the minimum requirements for 1CWAD for HVK (≥80.0%), however other primary grading determinants, such as percent sprouted kernels, resulted in their down grading. AC Pathfinder was found to have a higher degree of sprouted kernels (9.0%) than the other samples, however, its FN value (235 sec) was still within the acceptable range (Table 3.2). Durex and AC Navigator were down graded from 1CWAD to 2CWAD since they had greater than 0.5% but less than or equal to 2.0% sprouted kernels. DT 662, which had greater than 2.0% but less than or equal to 8.0% sprouted kernels was down graded to 3CWAD. AC Pathfinder was down graded to 4CWAD since it had greater than 8.0% sprouted kernels.

Table 3.2: Summary of Selected Grading Criteria.

Sample	Grade	HVK[1] (%)	Wheat FN[2] (sec)	Sprouting (%)
Durex	2CWAD	84	515	0.8
AC Pathfinder	4CWAD	83	235	9.0
AC Navigator	2CWAD	93	370	2.0
AC Melita	1CWAD	82	380	nd[3]
DT 662	3CWAD	85	350	2.5
Kyle	1CWAD	91	470	nd
Plenty	1CWAD	82	440	nd

1 HVK = hard vitreous kernels.
2 FN = falling number.
3 nd = not determined.

3.3.2 Results of Analytical Tests

The protein content of the wheat and semolina samples are listed in Table 3.3. Wheat protein contents ranged from 12.7% to 13.5% and semolina protein contents ranged from 11.5% to 12.4%. A significant sample effect was found for both the wheat and semolina protein content (Table 3.4). Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) revealed that DT 662 had a significantly higher wheat protein content than AC Pathfinder, AC Melita and AC Navigator (Table 3.3). Kyle was also found to have a significantly higher wheat protein content than AC Navigator. No wheat of Plenty was available for analysis. However, the same sample of Plenty was included in the 1996 Market Development Study, and results show the wheat protein content to be 12.8%. This indicates that Plenty would be considered to have a lower wheat protein content than DT 662.

For semolina protein content, multiple comparisons of the means using Tukey's test ($p \leq 0.05$) indicated that DT 662 had a significantly higher semolina protein content than AC Melita, Plenty, and AC Navigator. Durex had a significantly higher semolina protein content than Plenty and AC Navigator (Table 3.3). AC Pathfinder and Kyle had a significantly higher semolina protein content than AC Navigator.

Table 3.3: Protein Content of Wheat and Semolina[1].

Sample	Wheat Protein (%)	Semolina Protein (%)
Durex	13.2^{abc}	12.2^{ab}
AC Pathfinder	13.1^{bc}	12.0^{abc}
AC Navigator	12.8^{c}	11.5^{d}
AC Melita	13.0^{bc}	11.9^{bcd}
DT 662	13.6^{a}	12.4^{a}
Kyle	13.2^{ab}	12.0^{abc}
Plenty[2]	---	11.7^{cd}

[1] Results are the average of duplicate measurements for wheat and semolina protein contents and are reported on a 14.0% moisture basis.

[2] Due to insufficient sample size, wheat protein content could not be determined for Plenty.

[a,b,c,d] Means with the same letter in the same column are not significantly different ($p \leq 0.05$).

Table 3.4: Summary of Selected Analysis of Variance Results for Wheat and Semolina Protein Contents.

Parameter	Source	df	Mean Square	F value	Pr>F
Wheat Protein	Sample	5	0.131	11.82	0.0046
	Error	6	0.011		
Semolina Protein	Sample	6	0.198	11.91	0.0023
	Error	7	0.017		

3.3.3 Results of Gluten Strength Tests

A significant sample effect for GI and wet and dry gluten contents was found (Table 3.5). Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) showed that Durex had a significantly higher GI value than AC Melita, DT 662, Kyle and Plenty (Table 3.6). Also, AC Pathfinder, AC Navigator and AC Melita had higher GI values than DT 662, Kyle and Plenty. Higher GI values indicate stronger gluten properties, while lower values indicate weaker gluten properties. These results indicated that there appeared to be two distinct groupings of samples based on GI results; samples with higher GI values, and therefore stronger gluten properties (Durex, AC Pathfinder, AC Navigator and AC Melita) and those with lower GI values and therefore weaker gluten properties (DT 662, Kyle and Plenty).

Wet gluten content values ranged from 29.9 to 33.7% on a 14.0% moisture basis. Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) for wet gluten content revealed that DT 662 and Durex had significantly higher wet gluten contents than AC Pathfinder, Kyle, Plenty, AC Melita and AC Navigator (Table 3.6). AC Pathfinder and Kyle had higher wet gluten contents than AC Navigator. Dry gluten content values ranged from 11.4 to 14.0 % on a 14.0% moisture basis. Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) for dry gluten content revealed that Durex had a significantly higher ($p \leq 0.05$)

Table 3.5: Summary of Selected Analysis of Variance Results for Gluten Index, Wet and Dry Gluten Contents and Sodium Dodecyl Sulfate (SDS) Sedimentation Data.

Parameter	Source	df	Mean Square	F value	Pr>F
Gluten Index	Sample	6	2869.304	254.61	0.0001
	Error	7	11.269		
Wet Gluten	Sample	6	0.039	32.13	0.0001
	Error	7	0.001		
Dry Gluten	Sample	6	0.019	4.79	0.0296
	Error	7	0.004		
SDS	Sample	5	383.883	200.29	0.0001
	Error	6	1.917		

Table 3.6: Summary of Gluten Index, Wet and Dry Gluten Contents and Sodium Dodecyl Sulfate (SDS) Sedimentation Results[1].

Sample	Gluten Index (%)	Wet Gluten[2] (%)	Dry Gluten[2] (%)	SDS (mL)
Durex	84[a]	33.5[a]	14.0[a]	69[b]
AC Pathfinder	78[ab]	32.1[b]	13.2[ab]	83[a]
AC Navigator	73[ab]	29.9[c]	11.5[ab]	54[b]
AC Melita	68[b]	30.8[bc]	11.8[ab]	64[b]
DT 662	9[c]	33.7[a]	12.0[ab]	49[cd]
Kyle	6[c]	31.4[b]	11.4[b]	46[d]
Plenty	2[c]	31.2[bc]	11.7[ab]	----[3]

1 Values are the mean of duplicate measurements.

2 Values for wet and dry gluten have been reported on a 14.0% moisture basis.

3 Due to insufficient sample size, SDS sedimentation volumes could not be determined for Plenty.

a,b,c,d Means with the same letter in the same column are not significantly different ($p \leq 0.05$).

dry gluten content than Kyle (Table 3.6). Both wet and dry gluten content values give an indication of the quantity of gluten in the samples, but not necessarily the quality of the gluten.

Results from the ANOVA for the SDS sedimentation test revealed a significant sample effect (Table 3.5). Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) showed that AC Pathfinder had a significantly higher sedimentation volume than all other samples (Table 3.6). Durex, AC Melita and AC Navigator had higher sedimentation volumes than DT 662 and Kyle. Higher sedimentation volumes indicate samples with stronger gluten properties. No wheat of Plenty was available for analysis. However, results from the 1996 Market Development Study, which used the same sample, found that Plenty had a sedimentation volume of 37 mL indicating that this sample has weaker gluten properties.

Results from the ANOVA for gluten extensibility are provided in Table 3.7. A significant sample effect was found for the parameters of peak breaking force and area. A significant sample effect was observed for both extensibility and time ($p = 0.0518$). Multiple comparisons of means using Tukey's test ($p \leq 0.05$) for the parameter of peak breaking force revealed that, AC Navigator had a higher peak breaking force value than Plenty, DT 662 and Kyle (Table 3.8). Durex had a higher peak breaking force value than DT 662 and Kyle. Higher

Table 3.7: Summary of Selected Analysis of Variance Results for Gluten Extensibility Data.

Parameter	Source	df	Mean Square	F value	Pr>F
Peak Breaking Force	Sample	6	0.0018	8.07	0.0072
	Error	7	0.0002		
Time	Sample	6	58.50	3.81	0.0518
	Error	7	15.36		
Extensibility	Sample	6	1463.08	3.81	0.0518
	Error	7	384.28		
Area	Sample	6	34111847.30	5.28	0.0231
	Error	7	646700.27		

Table 3.8: Summary of Gluten Extensibility Results[1].

Sample	Peak Breaking Force (g)	Time (sec)	Extensibility (mm)	Area (g·mm)
Durex	102^{ab}	22.7^{a}	-113.6^{a}	6144^{a}
AC Pathfinder	92^{abc}	20.9^{a}	-104.5^{a}	5643^{ab}
AC Navigator	103^{a}	21.0^{a}	-105.2^{a}	5236^{ab}
AC Melita	75^{abc}	21.9^{a}	-109.5^{a}	5007^{ab}
DT 662	40^{c}	30.9^{a}	-154.7^{a}	2923^{b}
Kyle	36^{c}	30.4^{a}	-152.3^{a}	2868^{b}
Plenty	43^{bc}	33.3^{a}	-166.5^{a}	3960^{ab}

[1] Results are the mean of duplicate measurements with two subsamples per duplicate.

[a,b,c] Means with the same letter in the same column, are not significantly different ($p \leq 0.05$).

peak breaking force values indicate samples with stronger gluten properties since more force is required to break the gluten strand. For area, Durex was found to have a significantly greater area under the force-distance curve than DT 662 and Kyle. Higher area values mean that more work is required to break the gluten strand indicating greater strength. Although results from Tukey's test did not reveal any significant sample differences for extensibility and time ($\alpha = 0.05$) it can be seen that there appear to be two groupings of samples for both parameters. Durex, AC Pathfinder, AC Navigator and AC Melita were found to have lower extensibility values therefore suggesting greater gluten strength as well as decreased time values whereas DT 662 and Kyle and Plenty had greater extensibility and increased time values suggesting they had lower gluten strength. High variability was observed for both extensibility and time measurements and this may explain why a significant sample effect was not observed.

Data from the micromixograph was analyzed using envelope and mid-line analyses. Differences between the two types of analyses are related to how peak time (MPT), the times before (left of peak, MLT) and after (right of peak, MRT) peak and measurements taken at these points, such as curve height and bandwidth are determined. Envelope analysis determines MLT by finding an inflection point in the ascending portion of the curve, whereas, for mid-line

analysis, this point can be determined by the user at any set time (Walker and Walker, 1992). For MRT, envelope analysis determines this as the point were the right slope intersects the tail slope, whereas, in mid-line analysis, the time right of peak can be determined by the user at any set time (Walker and Walker, 1992). Mid-line analysis also offers the user the advantage of determining the area under the curve at selected points. These points include: area under the curve at the time left (MLE) and right (MRE) of peak, peak (MPE) and at the end of analysis (MEE). A typical curve, with some of the parameters measured, for both envelope and mid-line analysis is shown in Figures 3.1 and 3.2.

Using envelope analysis, significant sample effects were found for all parameters analyzed (Table 3.9). Due to the large number of parameters generated, the data from envelope analysis was subjected to correlation analysis (PROC CORR, SAS, 1992) to reduce the number of parameters required to explain the data. Results from the correlation analysis performed on the envelope analysis data can be found in Appendix 6. If several parameters were highly correlated with each other, then only one parameter was chosen to represent the correlated parameters. The parameters remaining after the data was collapsed included; MLT, MPT, MRT, MLH, MPH, BWL, BWP, MLS, MRS and MES. Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) can be found in Table 3.10. Durex took significantly longer to reach MLT than DT

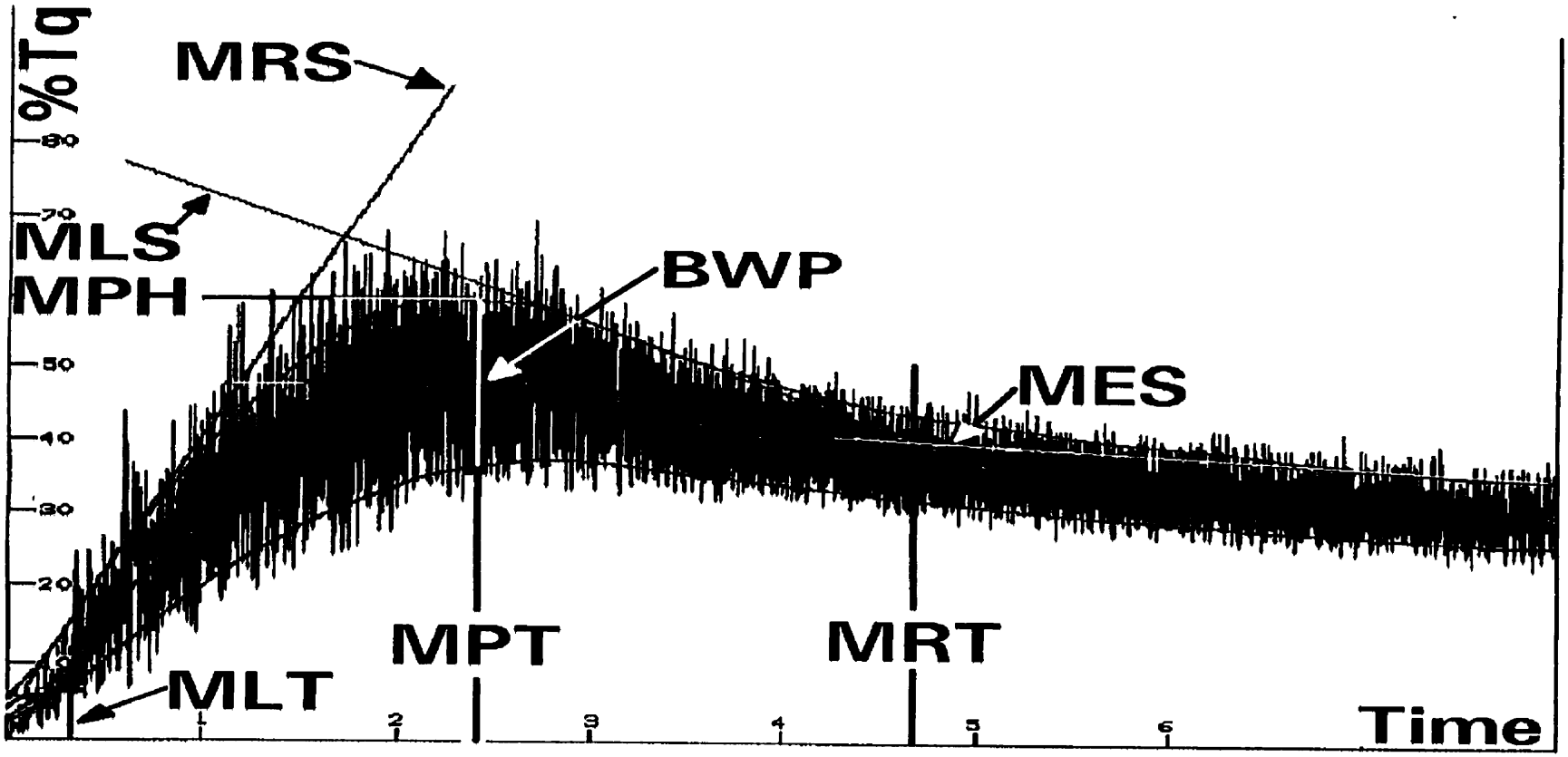

Figure 3.1: A Typical Micromixograph Curve Analyzed Using Envelope Analysis. The following abbreviations have been used; MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MPH is the height of the curve at peak; BWP is the width of the curve at peak; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes).

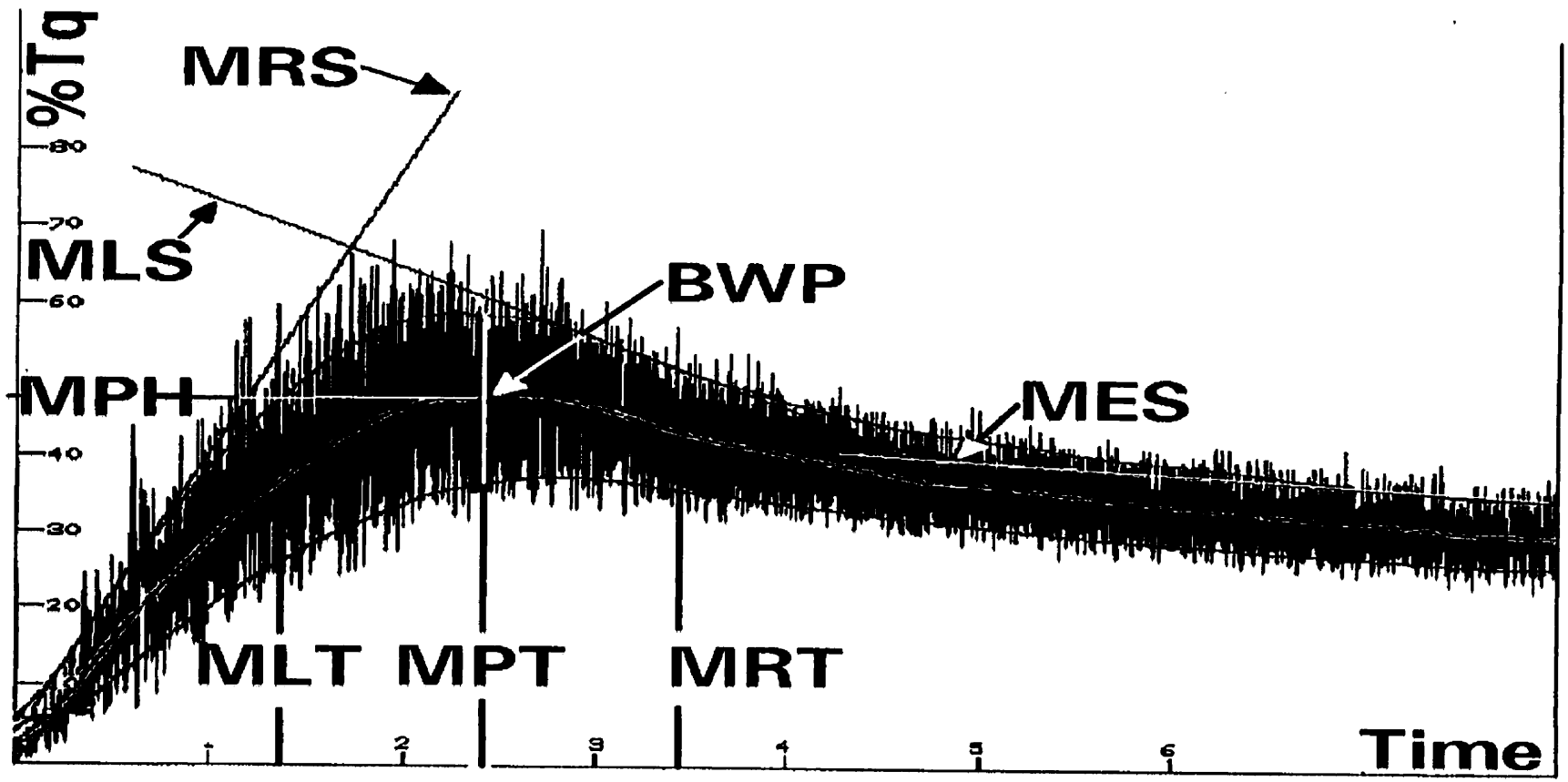

Figure 3.2: A Typical Micromixograph Curve Analyzed Using Mid-Line Analysis. The following abbreviations have been used; MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MPH is the height of the curve at peak; BWP is the width of the curve at peak; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes).

Table 3.9: Summary of Selected Analysis of Variance Results for Micromixograph Data Using Envelope Analysis.

Parameter[1]	Source	df	Mean Square	F value	Pr>F
MLT	Sample	6	0.625	14.39	0.0001
	Error	21	0.043		
MPT	Sample	6	0.926	115.92	0.0001
	Error	21	0.008		
MRT	Sample	6	2.949	46.95	0.0001
	Error	21	0.063		
MLH	Sample	6	149.545	13.40	0.0001
	Error	21	11.162		
MPH	Sample	6	158.442	53.50	0.0001
	Error	21	2.962		
MRH	Sample	6	221.281	59.99	0.0001
	Error	21	3.688		
MEH	Sample	6	249.456	80.49	0.0001
	Error	21	3.099		
BWL	Sample	6	35.476	15.34	0.0001
	Error	21	2.313		
BWP	Sample	6	75.748	148.80	0.0001
	Error	21	0.509		
BWR	Sample	6	63.980	115.73	0.0001
	Error	21	0.553		
BWE	Sample	6	60.766	131.25	0.0001
	Error	21	0.463		
MLS	Sample	6	4.221	4.87	0.0029
	Error	21	0.866		
MRS	Sample	6	2.861	21.11	0.0001
	Error	21	0.136		
MES	Sample	6	0.726	10.03	0.0001
	Error	21	0.072		

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; MRH is the time to the point right of peak; MEH is the time at the end of analysis; BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; BWR is the width of the curve at the point MRT; BWE is the width of the curve at MET; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes).

662, Kyle, Plenty and AC Navigator. AC Melita and AC Pathfinder took longer to reach MLT than Kyle, Plenty and AC Navigator. AC Navigator required significantly longer to reach MPT than AC Pathfinder, DT 662, Kyle and Plenty. AC Melita, Durex and AC Pathfinder took longer to reach MPT than DT 662, Kyle and Plenty. DT 662 took longer to reach MPT than Plenty. AC Navigator and AC Melita took significantly longer to reach MRT than AC Pathfinder, Durex, DT 662, Kyle and Plenty. Durex and AC Pathfinder took longer to reach MRT than DT 662, Kyle and Plenty. Durex had a significantly higher MLH value than all other samples except AC Melita. AC Pathfinder and AC Melita had higher MLH values than AC Navigator. Durex and AC Pathfinder had significantly higher MPH values than AC Melita, DT 662, Kyle and Plenty. AC Navigator and AC Melita had higher MPH values than DT 662, Kyle and Plenty. DT 662 had a higher MPH value than Plenty. Durex had a significantly wider BWL than all other samples except AC Melita. AC Melita had a wider BWL value than Kyle, Plenty and AC Navigator. AC Pathfinder had a wider BWL value than Plenty and AC Navigator. Durex had a significantly wider BWP than all other samples except AC Pathfinder. AC Pathfinder had a wider BWP than AC Melita, DT 662, Kyle and Plenty. AC Navigator and AC Melita had a wider BWP values than DT 662, Kyle and Plenty. AC Melita had a significantly lower MLS (rate of curve increase) than Kyle and DT 662. AC Navigator had a lower MLS value than DT 662. AC Pathfinder had a significantly higher MRS (rate of curve

Table 3.10: Summary of Reduced Micromixograph Parameters Analyzed Using Envelope Analysis[1].

Sample	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	BWL (%Tq)	BWP (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)
Durex	1.65^{a}	3.46^{ab}	6.09^{b}	31.2^{a}	51.7^{a}	14.8^{a}	23.1^{a}	18.02^{abc}	-2.74^{ab}	-0.83^{ab}
AC Pathfinder	1.00^{ab}	3.39^{b}	6.10^{b}	22.4^{bc}	51.6^{a}	10.2^{bc}	22.3^{ab}	18.98^{abc}	-2.58^{a}	-0.78^{ab}
AC Navigator	0.57^{c}	3.61^{a}	7.18^{a}	13.7^{d}	48.1^{ab}	6.6^{d}	21.0^{bc}	17.15^{bc}	-3.51^{b}	-1.73^{c}
AC Melita	1.40^{ab}	3.53^{ab}	7.06^{a}	26.4^{ab}	47.5^{b}	12.1^{ab}	20.5^{c}	16.93^{c}	-3.18^{ab}	-1.32^{bc}
DT 662	0.96^{bc}	2.74^{c}	5.44^{c}	21.3^{bcd}	40.6^{c}	9.7^{bcd}	14.4^{d}	19.69^{a}	-3.13^{ab}	-0.53^{a}
Kyle	0.83^{c}	2.63^{cd}	5.22^{c}	19.2^{bcd}	39.1^{cd}	8.5^{cd}	14.1^{d}	19.12^{ab}	-4.52^{c}	-0.72^{ab}
Plenty	0.63^{c}	2.48^{d}	5.01^{c}	15.2^{cd}	36.1^{d}	6.6^{d}	12.9^{d}	18.30^{abc}	-4.76^{c}	-0.69^{a}

1 Values are the mean of four replications. The following abbreviations have been used; MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes).

a,b,c,d Means with the same letter in the same column are not significantly different ($p \leq 0.05$).

decrease) than AC Navigator, Kyle and Plenty. Durex, DT 662, AC Navigator and AC Melita had higher MRS values than Kyle and Plenty. DT 662 and Plenty had significantly higher MES values than AC Melita and AC Navigator. Kyle, AC Pathfinder and Durex had higher MES value than AC Navigator.

The procedure PROC CLUSTER (SAS, 1992) was used to determine if there were any similar groupings of samples based on the reduced parameters that would assist in further summarizing the results. The basis of cluster analysis is to group, or cluster, data based on their similarity. The first cluster joined represents samples that are the most similar of all the samples. Further clustering proceeds to join the next most similar sample, either to another sample, or to the cluster previously joined. Clustering proceeds until all clusters are joined, however this may not be the most ideal place to stop clustering. Examination of the RMS Normalized Distance value provides some indication as to when clustering should stop. Large increases (usually >0.3) in the RMS Normalized Distance value indicates that further clustering will result in new clusters being formed that are less similar then the clusters first joined. Stopping clustering before all clusters are joined simply indicates that not all samples are similar in respect to the parameters analyzed.

Results from the cluster analysis for envelope analysis are presented in the form

of a dendogram (or tree diagram) in Figure 3.3. It can be seen that Kyle and Plenty are the first samples to be joined, followed by AC Melita and Durex, then DT 662 with the cluster of Kyle and Plenty. Next, AC Pathfinder joins the cluster of AC Melita and Durex. A large jump in the RMS Normalized Distance (0.39) indicates that furthering clustering would result in clusters that have less similarity.

As observed using envelope analysis, a significant sample effect for all parameters analyzed was found using mid-line analysis (Table 3.11). The large number of parameters generated using mid-line analysis were also subjected to correlation analysis (PROC CORR, SAS, 1992) to reduce the number of parameters needed to explain the data. Results from the correlation analysis performed using mid-line analysis can be found in Appendix 7. The parameters remaining after the data was collapsed included; MPT, MPH, BWP, MLS, MRS, MES, and MPE. Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) for the reduce parameters can be found in Table 3.12. AC Navigator, AC Pathfinder, AC Melita and Durex took significantly longer to reach MDT and MPH than DT 662, Kyle and Plenty. DT 662 took longer to reach MDT and MPH than Plenty. Durex had a significantly wider BWP than all other samples. AC Navigator had a wider BWP than AC Melita, DT 662, Kyle and Plenty. AC Pathfinder, AC Melita and DT 662 had significantly lower MLS values than (rate

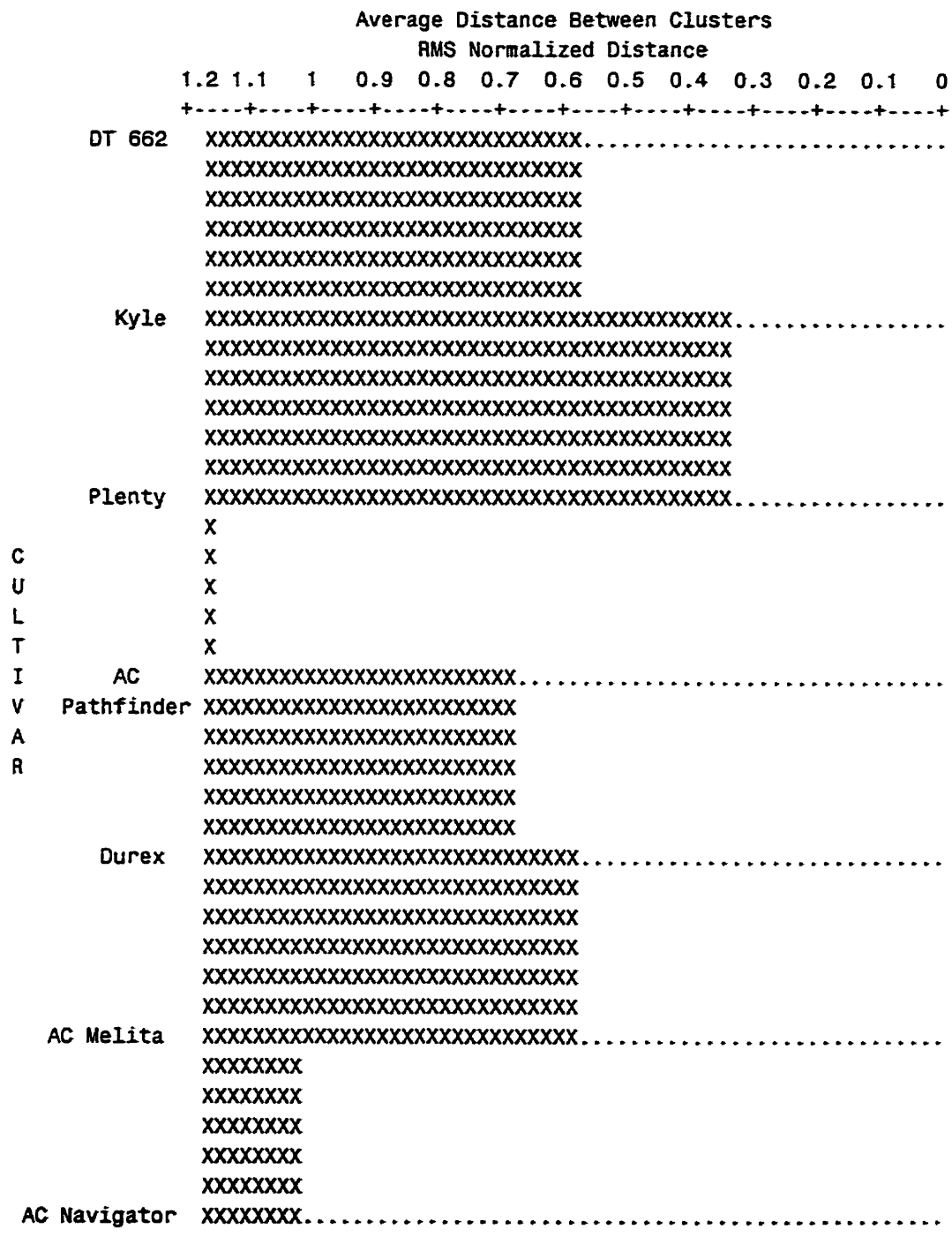

Figure 3.3: Dendogram for the Results from Cluster Analysis Using Envelope Analysis for the Micromixograph.

Table 3.11: Summary of Selected Analysis of Variance Results for Micromixograph Data Using Mid-line Analysis.

Parameter[1]	Source	df	Mean Square	F value	Pr>F
MLT	Sample	6	0.844	67.53	0.0001
	Error	21	0.012		
MPT	Sample	6	0.844	67.53	0.0001
	Error	21	0.012		
MRT	Sample	6	0.844	67.53	0.0001
	Error	21	0.012		
MLH	Sample	6	74.057	35.54	0.0001
	Error	21	2.084		
MPH	Sample	6	70.467	33.39	0.0001
	Error	21	2.110		
MRH	Sample	6	93.349	44.66	0.0001
	Error	21	2.090		
MEH	Sample	6	149.546	72.80	0.0001
	Error	21	2.054		
BWL	Sample	6	65.594	112.56	0.0001
	Error	21	0.583		
BWP	Sample	6	82.686	176.69	0.0001
	Error	21	0.468		
BWR	Sample	6	94.345	295.93	0.0001
	Error	21	0.319		
BWE	Sample	6	60.766	131.25	0.0001
	Error	21	0.463		
MLS	Sample	6	3.074	7.69	0.0002
	Error	21	0.400		
MRS	Sample	6	3.914	33.03	0.0001
	Error	21	0.119		
MES	Sample	6	0.423	11.58	0.0001
	Error	21	0.037		
MLE	Sample	6	932.756	45.90	0.0001
	Error	21	20.323		
MPE	Sample	6	1197.113	47.18	0.0001
	Error	21	25.372		
MRE	Sample	6	1871.137	48.69	0.0001
	Error	21	38.427		
MEE	Sample	6	3804.582	42.15	0.0001
	Error	21	90.265		

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

Table 3.12: Summary of Reduced Micromixograph Parameters Analyzed Using Mid-line Analysis.

Sample	MPT (min)	MPH (%Tq)	BWP (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	MPE (%Tq·min)
Durex	3.56^{a}	40.5^{a}	22.9^{a}	5.04^{a}	-1.86^{b}	-0.59^{a}	86.7^{a}
AC Pathfinder	3.67^{a}	40.6^{a}	21.6^{bc}	2.80^{b}	-0.66^{a}	-0.66^{ab}	96.6^{a}
AC Navigator	3.73^{a}	37.7^{a}	20.8^{b}	3.74^{a}	-1.98^{b}	-1.35^{c}	89.7^{a}
AC Melita	3.66^{a}	37.4^{a}	20.3^{c}	3.12^{b}	-1.42^{ab}	-1.06^{bc}	86.9^{a}
DT 662	3.02^{b}	33.6^{b}	13.4^{c}	3.27^{b}	-2.18^{b}	-0.43^{a}	66.8^{b}
Kyle	2.83^{bc}	32.2^{bc}	13.4^{c}	4.20^{a}	-3.34^{c}	-0.65^{ab}	60.0^{bc}
Plenty	2.63^{c}	29.7^{c}	12.3^{c}	4.89^{a}	-3.41^{c}	-0.57^{a}	51.3^{c}

† Values are the mean of four replications. The following abbreviations have been used; MPT is the time to peak; MPH is the height of the curve at MPT; BWP is the width of the curve at MPT; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MPE is the area under the curve to MPT.

a,b,c,d Means in the same column with the same letter are not significantly different ($p \leq 0.05$).

of curve increase) than all other samples. AC Pathfinder had a significantly higher MRS (rate of curve decrease) than all other samples except AC Melita. AC Melita, Durex and AC Navigator had higher MRS values than Kyle and Plenty. DT 662, Plenty and Durex had significantly higher MES (rate of decrease) values than AC Melita and AC Navigator. AC Pathfinder and Kyle had significantly higher MES values than AC Navigator. AC Pathfinder, AC Navigator, AC Melita and Durex had significantly higher MPE values than all other samples. DT 662 had a higher MPE value than Plenty.

The dendogram from the cluster analysis for mid-line analysis shows the first cluster formed was Kyle with Plenty and AC Navigator with AC Melita (Figure 3.4). Clustering should stop at this point since a large jump (0.28) in the RMS Normalized Distance value occurs before DT 662 joins the cluster of Kyle and Plenty. Overall, results from the cluster analysis for both envelope and mid-line analysis show samples with stronger gluten properties (Durex, AC Pathfinder, AC Navigator and AC Melita) grouped together, while samples with weaker gluten properties (DT 662, Kyle and Plenty) grouped together. Based on the results from the cluster analysis, samples with stronger gluten strength properties can be described as having longer times to peak (MPT), higher peak heights (MPH), wider curve bandwidths at peak (BWP) or at other times (i.e. BWL and BWR) and increased areas under the curve (MPE) regardless of

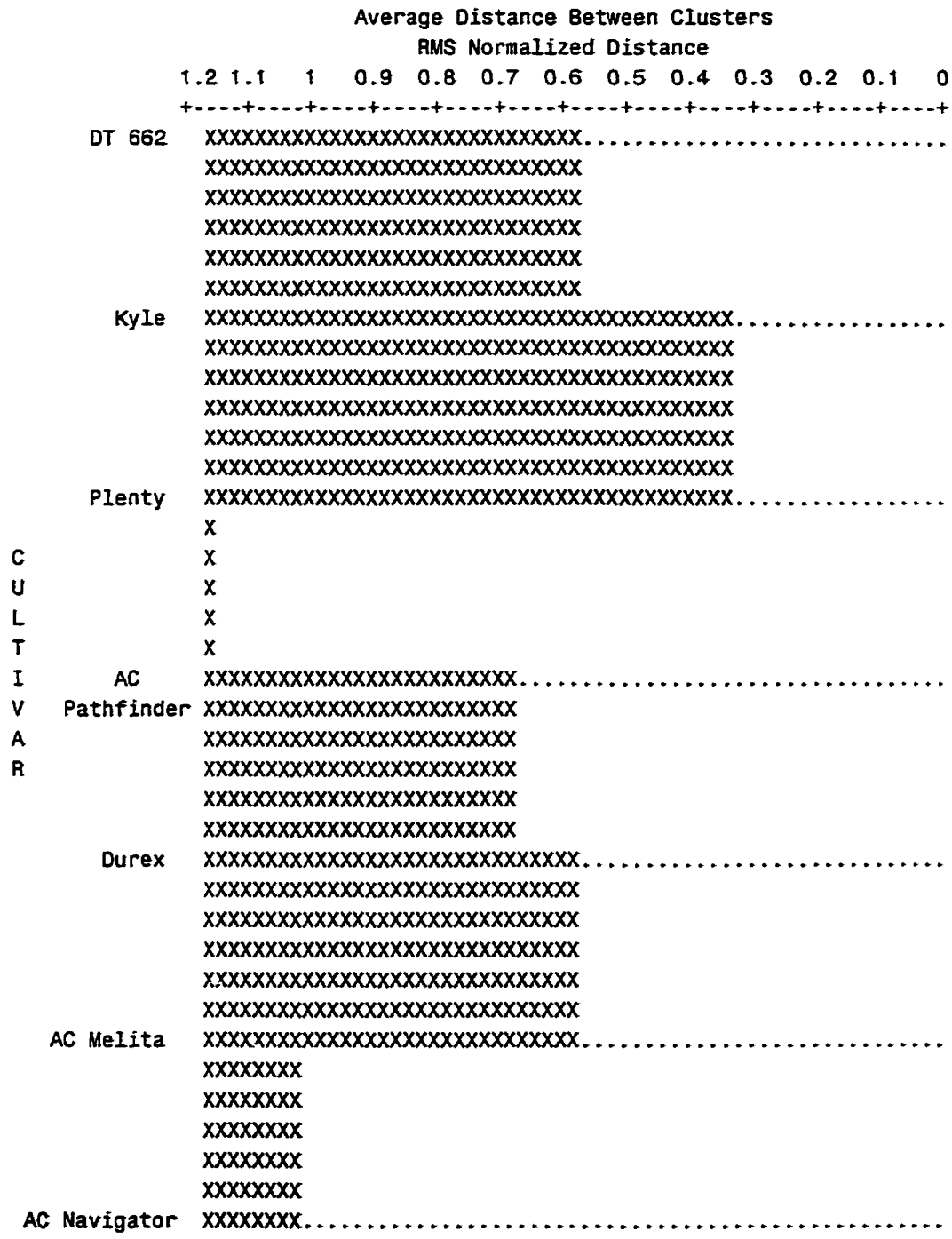

Figure 3.4: Dendogram for the Results from Cluster Analysis Using Mid-Line Analysis for the Micromixograph.

whether envelope or mid-line analysis was used. Results from the alveograph data analyzed using ANOVA are summarized in Table 3.13. Significant sample effects were found for all alveograph parameters. Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) revealed that AC Navigator and AC Melita had significantly higher *P* values than all other samples. Durex and AC Pathfinder had higher *P* values than Plenty, Kyle and DT 662. Plenty and Kyle had higher *P* values than DT 662. Identical results were found for *H* since a mathematical relationship between the two parameters exists ($P = 1.1H$). For *L*, or extensibility, DT 662 was found to have significantly greater *L* value than AC Navigator. The parameter *G*, has a mathematical relationship to *L* ($G = 2.226\sqrt{L}$), therefore identical trends were observed for *G* and *L* values. AC Navigator had a significantly higher *P/L* ratio than Durex, AC Pathfinder, Plenty, Kyle and DT 662. AC Melita had a higher *P/L* ratio than Plenty, Kyle and DT 662. Durex and AC Pathfinder had higher *P/L* ratios than Kyle and DT 662. For *W*, or the work required to inflate the dough bubble, Durex, AC Melita, AC Pathfinder and AC Navigator had higher values than Kyle, DT 662 and Plenty. The parameter of *S* is mathematically related to *W* since $S = W/6.54$, therefore identical results were found for both *W* and *S*. As expected samples with stronger gluten strength properties (AC Navigator, AC Melita, AC Pathfinder and Durex) had higher maximum pressure values (*P*) and were less extensible (lower *L* values) than samples with weaker gluten strength properties. Also, more work

Table 3.13: Summary of Selected Analysis of Variance Results for Alveograph Data.

Parameter[1]	Source	df	Mean Square	F value	Pr>F
P	Sample	6	1222.525	606.21	0.0001
	Error	7	2.02		
L	Sample	6	576.236	5.01	0.0264
	Error	7	114.969		
P/L	Sample	6	0.352	23.44	0.0003
	Error	7	0.015		
W	Sample	6	12888.164	41.89	0.0001
	Error	7	307.651		
H	Sample	6	1007.020	589.52	0.0001
	Error	7	1.708		
G	Sample	6	7.543	4.99	0.0267
	Error	7	1.512		
S	Sample	6	301.424	41.90	0.0001
	Error	7	7.194		

[1] The following abbreviations have been used; *P* is the maximum over pressure ($P=1.1H$); *L* is a measure of extensibility; *P/L* is the curve configuration ratio; *W* is the work required to inflate the dough bubble; *H* is the height of the curve; *G* is the swelling index ($G=2.226\sqrt{L}$); *S* is the area under the curve ($S=W/6.54$).

Table 3.14: Summary of Alveograph Results[1].

Sample	*P* (mm)	*L* (mm)	*P/L*	*W* (x10^3 ergs)	*H* (mm)	*G* (cm^3)	*S* (cm^2)
Durex	85^{b}	88^{ab}	1.0^{bc}	266^{a}	77^{b}	21^{ab}	41^{a}
AC Pathfinder	82^{b}	87^{ab}	1.0^{bc}	256^{a}	75^{b}	21^{ab}	39^{a}
AC Navigator	99^{a}	65^{b}	1.5^{a}	240^{a}	90^{a}	18^{b}	37^{a}
AC Melita	96^{a}	86^{ab}	1.1^{ab}	262^{a}	88^{a}	21^{ab}	40^{a}
DT 662	41^{d}	121^{a}	0.3^{d}	110^{b}	38^{d}	24^{a}	17^{b}
Kyle	48^{c}	96^{ab}	0.5^{d}	112^{b}	43^{c}	21^{ab}	17^{b}
Plenty	49^{c}	85^{ab}	0.6^{cd}	98^{b}	44^{c}	20^{ab}	15^{b}

[1] Values the mean of measurements performed in duplicate with five subsamples per duplicate. The following abbreviations have been used; *P* is the maximum over pressure ($P=1.1H$); *L* is a measure of extensibility; *P/L* is the curve configuration ratio; *W* is the work required to inflate the dough bubble; *H* is the height of the curve; *G* is the swelling index ($G=2.226\sqrt{L}$); *S* is the area under the curve ($S=W/6.54$).

[a,b,c,d] Means in the same column, with the same letter are not significantly different ($p \leq 0.05$).

was required to inflate the dough bubble (higher *W*) in samples with stronger gluten properties. A *P/L* ratio between 1.5-2.5 is demanded by some pasta manufacturers (Marchylo et al., 1998).

3.3.3 Results of Starch Characterization

A significant sample effect was found for starch damage values as assessed on the semolina but not for the udy ground semolina (Table 3.15). Semolina was udy ground in order to aid in its dispersion when using the RVA (Dexter et al., 1990). Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) revealed that semolina from AC Melita and Plenty had significantly higher levels of starch damage than DT 662 (Table 3.16) however, this is of no practical signficance. No significant sample effect was found for total starch content nor amylose content (Table 3.17). The reason a significant sample effect was not seen for total starch or amylose contents may relate to the high variability observed between duplicate measurements. Means and the standard deviations for total starch and amylose contents are presented in Appendix 10.

Significant samples effects for found for all parameters analyzed using the RVA except breakdown viscosity time (Table 3.19). Multiple comparisons of the means using Tukey's test ($p \leq 0.05$) indicate that Kyle was found to have a significantly higher peak viscosity than AC Melita, AC Navigator, DT 662 and

Table 3.15: Summary of Selected Analysis of Variance Results for Starch Damage Data.

Parameter	Source	df	Mean Square	F value	Pr > F
Semolina Starch Damage	Sample	6	0.220	6.09	0.0158
	Error	7	0.036		
Udy Ground Semolina Starch Damage	Sample	6	5.966	1.41	0.3302
	Error	7	4.945		

Table 3.16: Summary of Starch Damage Results[1].

Sample	Semolina Starch Damage (%)	Udy Ground Semolina Starch Damage (%)
Durex	4.1[ab]	7.3[a]
AC Pathfinder	3.8[ab]	7.4[a]
AC Navigator	4.3[ab]	7.2[a]
AC Melita	4.5[a]	8.1[a]
DT 662	3.6[b]	6.2[a]
Kyle	4.1[ab]	8.1[a]
Plenty	4.5[a]	6.6[a]

[1] Results are the mean of tests performed in duplicate.

[a] Means in the same column, with the same letter are not significantly different ($p \leq 0.05$).

Table 3.17: Summary of Selected Analysis of Variance Results for Total Starch and Amylose Content Data.

Parameter	Source	df	Mean Square	F value	Pr > F
Total Starch	Sample	6	37.128	0.64	0.6988
	Error	7	58.057		
Amylose Content	Sample	6	2.198	1.00	0.4938
	Error	7	2.207		

Table 3.18: Summary of Total Starch and Amylose Content Results[1].

Sample	Total Starch (%)	Amylose (%)
Durex	78.5[a]	25.1[a]
AC Pathfinder	66.8[a]	22.2[a]
AC Navigator	74.8[a]	24.2[a]
AC Melita	73.4[a]	22.6[a]
DT 662	79.1[a]	23.9[a]
Kyle	70.9[a]	23.2[a]
Plenty	72.4[a]	22.4[a]

[1] Results are the mean tests performed in duplicate on UDY ground semolina (0.5 mm particle size).

[a] Means with the same letter in the same column are not significantly different ($p \leq 0.05$).

AC Pathfinder. Durex, Plenty and AC Melita had higher peak viscosity values than AC Navigator, DT 662 and AC Pathfinder. AC Navigator and DT 662 had higher peak viscosity values than AC Pathfinder. Kyle was found to take a significantly longer time to reach peak (peak time) than Durex, AC Navigator, DT 662 and AC Pathfinder. Plenty and AC Melita took longer to reach peak than AC Navigator, DT 662 and AC Pathfinder. Durex took longer to reach peak than DT 662 and AC Pathfinder. AC Navigator and DT 662 took longer to reach peak than AC Pathfinder. For breakdown viscosity, Kyle had a significantly higher breakdown viscosity value than all other samples. Plenty, AC Melita and Durex had higher breakdown viscosity values than AC Navigator, DT 662 and AC Pathfinder. AC Navigator and DT 662 had higher breakdown viscosity values than AC Pathfinder. Durex had a significantly higher degree of breakdown than all other samples except Plenty. Plenty and AC Melita had higher degrees of breakdown than Kyle, DT 662, AC Navigator and AC Pathfinder. Kyle, DT 662 and AC Navigator had higher degrees of breakdown than AC Pathfinder. Kyle had a significantly higher setback viscosity than all other samples. Plenty, AC Melita and Durex had higher setback viscosity values than AC Navigator, DT 662 and AC Pathfinder. AC Navigator and DT 662 had higher setback viscosity values than AC Pathfinder. Kyle had a higher degree of total setback than all other samples. AC Melita, Durex and Plenty had higher degrees of total setback than AC Navigator, DT 662 and AC Pathfinder. AC Navigator and DT 662 had

Table 3.19: Summary of Selected Analysis of Variance Results for Rapid Visco Analyzer (RVA) Data[1].

Parameter	Source	df	Mean Square	F value	Pr > F
Peak Viscosity	Sample	6	5632.143	1433.64	0.0001
	Error	7	3.929		
Peak Time	Sample	6	0.254	69.23	0.0001
	Error	7	0.004		
Breakdown Viscosity	Sample	6	3329.833	1607.51	0.0001
	Error	7	2.071		
Breakdown Viscosity Time	Sample	6	0.751	1.72	0.2471
	Error	7	0.437		
Breakdown	Sample	6	401.476	281.03	0.0001
	Error	7	1.429		
Setback Viscosity	Sample	6	7020.238	1665.82	0.0001
	Error	7	4.214		
Total Setback	Sample	6	811.310	811.31	0.0001
	Error	7	1.00		

[1] The following terms have been used; peak viscosity is the maximum viscosity of the curve at 95°C, peak time is the time required to reach maximum viscosity at 95°C, breakdown viscosity is the viscosity after holding at 95°C, breakdown viscosity time is the time when breakdown viscosity occurs, breakdown is the difference in viscosity between peak viscosity and breakdown viscosity, setback viscosity is the viscosity at the end of cooling, total setback is the difference in viscosity between setback viscosity and breakdown viscosity.

Table 3.20: Summary of Rapid Visco Analyzer (RVA) Results[1].

Sample	Peak Viscosity (RVU)	Peak Time (min)	Breakdown Viscosity (RVU)	Breakdown Viscosity Time (min)	Breakdown (RVU)	Setback Viscosity (RVU)	Total Setback (RVU)
Durex	172^{ab}	6.0^{bc}	108^{b}	11.7^{a}	64^{a}	163^{b}	55^{b}
AC Pathfinder	40^{d}	5.3^{e}	18^{d}	11.3^{a}	23^{d}	28^{d}	5^{d}
AC Navigator	103^{c}	5.8^{cd}	61^{c}	11.2^{a}	42^{c}	98^{c}	37^{c}
AC Melita	167^{b}	6.1^{ab}	111^{b}	11.6^{a}	57^{b}	166^{b}	56^{b}
DT 662	100^{c}	5.7^{d}	58^{c}	10.6^{a}	43^{c}	92^{c}	35^{c}
Kyle	178^{a}	6.3^{a}	132^{a}	11.4^{a}	46^{c}	196^{a}	64^{a}
Plenty	174^{ab}	6.2^{ab}	113^{b}	12.6^{a}	61^{ab}	168^{b}	55^{b}

[1] Results are the mean of two replications performed on UDY ground semolina (0.5 mm particle size). The following terms have been used; peak viscosity is the maximum viscosity of the curve at 95°C, peak time is the time required to reach maximum viscosity at 95°C, breakdown viscosity is the viscosity after holding at 95°C, breakdown viscosity time is the time when breakdown viscosity occurs, breakdown is the difference in viscosity between peak viscosity and breakdown viscosity, setback viscosity is the viscosity at the end of cooling, total setback is the difference in viscosity between setback viscosity and breakdown viscosity.

[a,b,c,d,e] Means with the same letter in the same column are not significantly different ($p \leq 0.05$).

a higher degree of total setback than AC Pathfinder. Results from the cluster analysis are presented in Figure 3.5. The dendogram shows the first cluster consisted of AC Melita with Durex. The next cluster formed was AC Navigator with DT 662, followed by Plenty joining the cluster of AC Melita and Durex. Kyle joined the cluster of Plenty, AC Melita and Durex. No further clustering is advised.

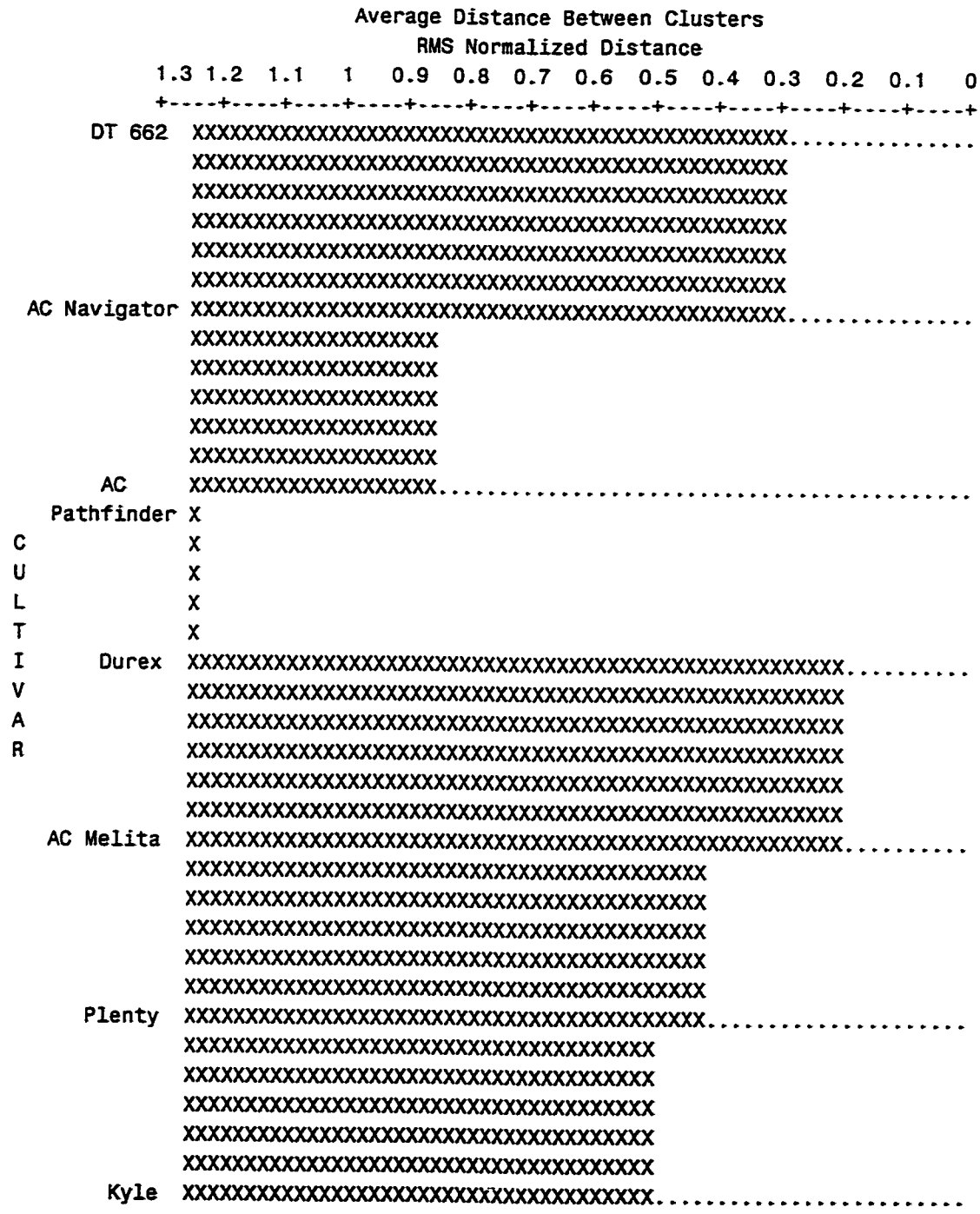

Figure 3.5: Dendogram for the Results from Cluster Analysis Using the Rapid Visco Analyzer (RVA).

3.4 DISCUSSION

Gluten strength was assessed using several methods. Durex, AC Pathfinder, AC Navigator and AC Melita, were found to have higher GI values (closer to 100) and higher SDS sedimentation volumes than DT 662, Kyle and Plenty. Both the GI test (Cubadda et al., 1992) and the SDS sedimentation test (Dexter et al., 1980) have been found to be reliable predictors of gluten strength in durum wheat. Similarly, higher peak breaking force values, measured using a modified extensibility test, were found for samples that had stronger gluten properties, indicating the gluten was less extensible. Matsuo (1978) used a gluten-stretching apparatus to measure extensibility properties and found that samples with stronger gluten properties had higher breaking strength values than samples with weaker, more extensible gluten.

For both envelope and mid-line analyses determined using the micromixograph, samples with stronger gluten properties were generally found to have longer times to peak (MPT), higher curve heights at peak (MPH), and wider bandwidths at peak (BWP), than samples with weaker gluten properties. Using mid-line analysis, samples with stronger gluten properties also had larger areas under the curve (energy values) at the time left (MLE) and right of peak (MRE) and also at peak (MPE). These results are similar to those of Khatkar et al. (1996) who found longer mixing times, higher curve heights at peak and larger areas under

the curve in extra strong bread wheat varieties using mid-line analysis for the micromixograph. The results from the present study were also confirmed using cluster analysis which showed that samples Durex, AC Pathfinder, AC Navigator and AC Melita, determined to have stronger gluten strength properties, tended to cluster together. This was found for the data from both envelope and mid-line analyses.

Alveograph parameters usually associated with strong doughs, namely high *P/L* ratios and high deformation energy values (*W*), were found in samples with stronger gluten strength properties. European pasta manufacturers have requested *P/L* rations between 1.5-2.5 and *W* values between 200-250 for their high quality pasta products (Marchylo et al., 1998). Starch damage has been found to have an effect on the shape of the curve, resulting in curves with decreased length/extensibility (*L*), increased height (*P*) and increased area under the curve (*W*) (Dexter et al., 1985b). These changes to the shape of the curve can be misinterpreted as an increase in dough strength due to very tenacious and inelastic gluten, rather than an increase in water requirements due to increased damaged starch levels (Preston et al., 1987). Plenty and AC Melita were found to have significantly higher semolina starch damage levels than the other samples. However, comparison of the alveograph results for Plenty did not indicate that this sample behaved any differently than other samples having

weaker gluten strength properties (DT 662 and Kyle) as a result of its higher levels of starch damage. Also, comparison of the alveograph results for Plenty with those from the GRL data for the same sample of Plenty (used in the 1996 Market Development Study) were similar (GRL data: P=50 mm, L=80 mm P/L=0.5, W=98x10^{3}ergs).

Differences were seen among samples in starch pasting properties determined using the RVA but not in total starch and amylose contents. Amylose contents determined in the samples used in this research had a narrow range and were in agreement with levels reported by other researchers (Williams et al., 1970; Lii and Lineback, 1977; Dexter and Matsuo, 1979b; Boyacioğlu and D'Appolonia, 1994). Amylose content has been found to be positively related to cooked pasta firmness (Dexter and Matsuo, 1979b). Amylose is the fraction of starch responsible for gel formation, therefore it seems reasonable that high levels of amylose may have beneficial effects on the texture of cooked pasta. However, Dexter and Matsuo (1979b) found that once a certain level of amylose is present, other starch properties, such as starch water absorption, may supersede amylose content in imparting superior cooking quality. Also, the improvement in firmness as a result of increased amylose content was not nearly as great as that which resulted from the manipulation of gluten proteins (Dexter and Matsuo, 1978).

Total starch content of the samples had a wide range but were in agreement with levels determined by other researchers (Berry et al., 1971; Klassen and Hill, 1971). The only exception was the low total starch content observed in AC Pathfinder. However this value was not found to be significantly different from the total starch contents of the other samples.

The RVA was used with udy ground semolina having a particle size of 0.5 mm in order to aid in its dispersion. It is recognized that grinding the semolina will result in increased starch damage and this was observed by the increase in damaged starch values between the udy ground semolina and semolina that was not udy ground. Using the RVA, differences were seen in all of the parameters analyzed except for breakdown time. Marshall (1967) found amylograph peak viscosity to be inversely related to cooked pasta recovery values as measured by the GRL tenderness testing apparatus. Differences in the pasting properties in durum wheat samples have been observed by other researchers using the amylograph, however, the relationship to pasta cooking quality was not investigated (Shuey and Gilles (1964); Lintas and D'Appolonia (1973). Nonetheless, comparison between results from other researchers and the results from this research cannot be made due to differences in the heating and cooling cycles and different flour to water concentrations used. Also, researchers have typically compared only one or two durum samples, or they

have compared durum wheat to wheats of other classes. Relationships between various RVA parameters and noodle eating quality as assessed using a trained panel has been investigated (Panozzo and McCormick, 1993; Konik et al., 1994). However, relationships between RVA parameters, or even starch pasting properties of durum wheat using the amylograph, and pasta cooking quality have not been thoroughly investigated. Results from the cluster analysis performed on the RVA data did not show similar clustering tendencies as found with the results from the cluster analysis performed on tests used to assess gluten strength.

It must be mentioned that the high sprouting value and low falling number value of AC Pathfinder had a significant influence on its pasting properties. Samples with high α-amylase activity will generally have lower peak viscosities and faster peak times due to the release of increased amylose (Dengate, 1984). This was observed in AC Pathfinder.

Clearly, more work needs to be undertaken in the area of durum carbohydrates. The possible effect of starch granule size distribution on the pasting properties of durum wheat should be investigated as this may have an influence on cooked pasta texture. Also, the relationship between RVA parameters and cooked pasta texture should be examined more closely. The tests used to assess the

rheological properties of samples with varying gluten strength properties were able to discriminate between the samples. Several of the tests used to assess the rheological properties of semolina doughs or gluten require very little sample and also offer new techniques to evaluate gluten strength. The micromixograph, requiring only a 2 g sample size, should prove to be a benefit in assessing gluten strength in the early stages of a breeding program.

CHAPTER 4

EFFECTS OF DURUM WHEAT GLUTEN STRENGTH ON SPAGHETTI COOKING QUALITY

4.1 INTRODUCTION

The texture of cooked pasta is the primary criterion for determining the overall quality of pasta (D'Egidio and Nardi, 1996). Cooked pasta should have a smooth surface that is free of stickiness (Guan and Seib, 1994). It should be firm, elastic, resilient and resist surface disintegration during cooking (Dexter et al., 1983a; du Cros, 1987; Kovacs et al., 1995b). Gluten strength is believed to be an important factor influencing pasta cooking quality (Lui et al., 1994). As long as protein is present in amounts so as not to be a limiting factor, gluten strength plays a more important role in determining pasta cooking quality than protein quantity (Dick and Quick, 1983).

Numerous researchers have found relationships between gluten strength and cooked pasta firmness (Matsuo and Irvine, 1970; Grzybowski and Donnelly, 1979) and pasta cooking quality (Dexter and Matsuo, 1980). Dexter et al. (1981a) found that pasta made from gluten of intermediate strength was better able to retain its structural integrity during cooking than pasta made from a weaker gluten. It was thought that pasta made from an intermediate strength gluten would possess more elasticity and therefore be less susceptible to

rupture under the stress of swelling and denaturation during cooking as compared to pasta made from a very strong gluten. This belief however is not widely held by pasta manufacturers. Pasta manufacturers believe that durum wheats possessing extra strong gluten properties, such as those from the southwestern United States, also referred to as desert durums, produce cooked pasta with less stickiness and increased resistance to overcooking (B. Marchylo, personal communication). Currently, some pasta manufacturers are buying greater quantities of Australian and American durum cultivars since these cultivars are believed to have the strength which satisfies their pasta processing requirements (B. Marchylo, personal communication). In order to respond to the changing demands of pasta manufacturers and remain competitive on the international market, Canadian durum wheat breeders have been developing new Canadian Western Amber Durum (CWAD) cultivars with extra strong gluten properties.

Another factor that affects the texture of cooked pasta is the use of high temperature (HT) drying. The use of HT and very high temperature (VHT) drying cycles have been one of the most important innovations in pasta manufacturing in recent years (Cubadda, 1989). Not only do HT and VHT drying allow the pasta to be dried in less time and with less energy input, but HT and VHT drying can result in dried pasta with increased yellow color due to inactivation of

enzymes (Mondelli, 1989), and increased cooking quality, by decreasing stickiness and increasing firmness (Manser, 1989). HT and VHT drying also allow for the production of good quality pasta from low quality raw materials (Donnelly, 1991). Changes in the properties of the proteins occurring at temperatures 90°C or higher may partly explain the improved cooking quality (Atkan, 1990).

The characterization and measurement of cooked pasta texture has been accomplished through the use of instrumental procedures and sensory panels. Although there are distinct advantages to both instrumental and sensory methods, both must be carefully standardized in order to provide meaningful and reproducible results. Whereas instrumental methods measure a limited number of characteristics, which may or may not relate to sensory measurements, sensory panels have the ability to measure the overall textural characteristics (Matsuo, 1988; D'Egidio and Nardi, 1996). Correlations between sensory evaluations and instrumental measurements have been established by several researchers (Voisey and Larmond, 1973; Matsuo and Irvine, 1974; Dalbon et al., 1985; Malcolmson, 1991).

Thus, methods to evaluate the texture of cooked pasta have already been established. However, only a few research studies have investigated the pasta

cooking quality of durum wheats with extra strong gluten properties (Ames et al., 1998; Ames et al., 1999). It is already known that gluten strength plays a role in pasta cooking quality (Matsuo and Irvine, 1970; Dexter and Matsuo, 1977b), however, what is not known is if pasta made from cultivars with extra strong gluten properties offers any additional advantage. Instrumental and sensory methods of analysis have not been used to assess the textural properties of pasta made from durum wheat cultivars with extra strong gluten properties, nor has the effect of drying temperature on varying gluten strength been assessed. Therefore, the objectives of this study were:

1. To examine the effects of gluten strength on the textural properties of cooked spaghetti.
2. To investigate the effect of drying temperature on the cooking quality of pasta made from durum wheat samples with varying gluten strength.
3. To examine the relationship between instrumental and sensory measurements of cooked pasta texture.

4.2 EXPERIMENTAL DESIGN

4.2.1 Spaghetti Processing and Drying Cycles

Semolina from the seven samples was processed into spaghetti using a DEMACO S-25 laboratory scale continuous extrusion press (De Francisci Machine Corporation, Brooklyn, NY) according to the method of Matsuo et al. (1978). Semolina (2 kg) was mixed with distilled water to achieve an extruded pasta with a moisture content of 31.7% (see Appendix 12 for calculations). Spaghetti was dried using a laboratory scale AFREM dryer (AFREM, Lyon, France) using two different drying cycles, 70°C and 90°C. Drying cycles are illustrated in Figures 4.1 and 4.2. After completion of the drying cycles, the spaghetti was removed from the dryer and placed in plastic bags. The spaghetti samples were held at room temperature for 5 days before testing according to recommended procedures of the Grain Research Laboratory (Winnipeg, MB).

4.2.2 Spaghetti Cooking Procedures for Instrumental Evaluation

Seven grams of spaghetti was broken into 5 cm long pieces and cooked in rapidly boiling tap water using a ratio of 1:25 (spaghetti to water). Spaghetti was cooked to optimum (defined as the time required for the centre core of the strand to disappear) and to 5 minutes past the optimum cooking time (overcooked). Overcooking was chosen as optimum cooking time plus 5 minutes based on previous experimentation which showed that optimum plus 10

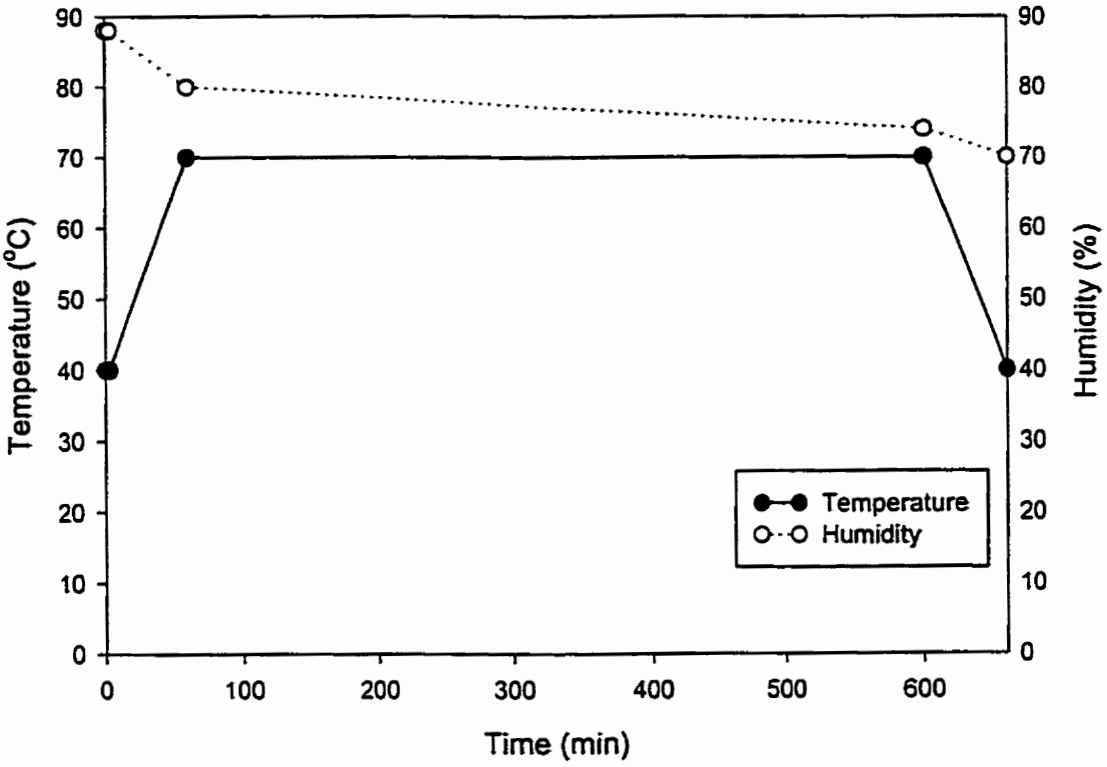

Figure 4.1: 70°C Drying Cycle.

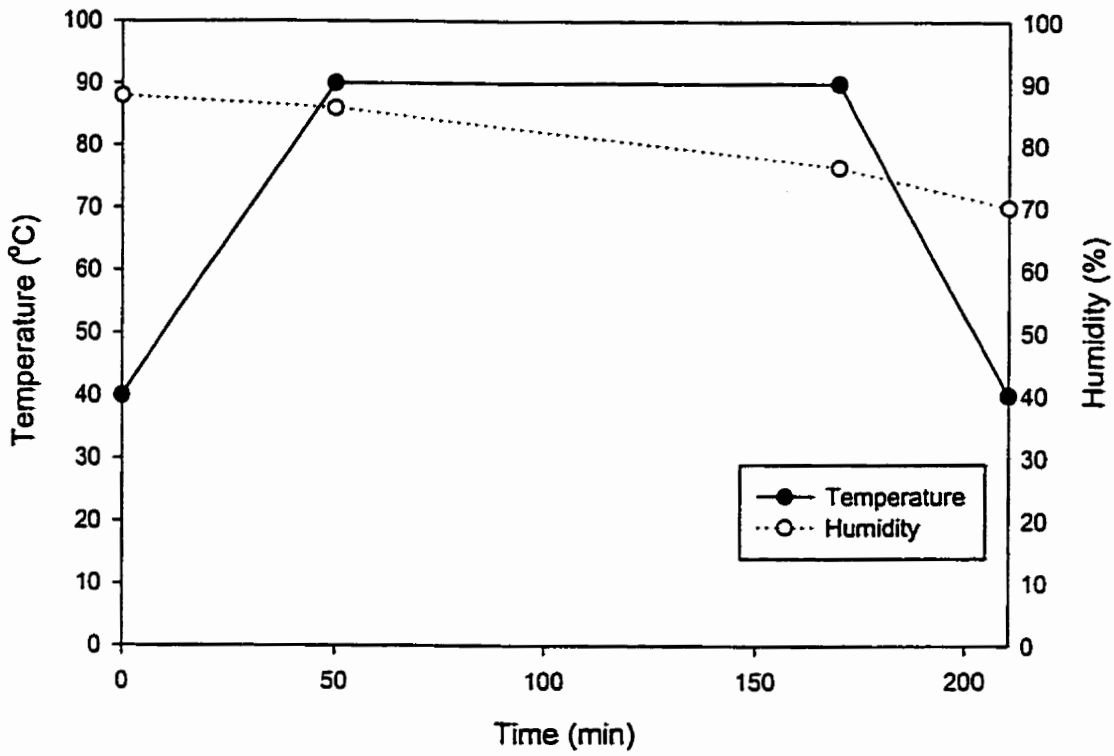

Figure 4.2: 90°C Drying Cycle.

minutes resulted in spaghetti that was so overcooked that textural differences were not observed. Optimum cooking time was determined by removing 2 strands from the cooking water and pressing them between two glass petri plates. In order to get an approximation of the optimum cooking time for each sample a preliminary cooking was performed using five grams of spaghetti in 5 cm long pieces. Testing for doneness began at 8 minutes and was performed every 30 seconds thereafter. Spaghetti was cooked in 250 mL glass beakers on ceramic hot plates. Spaghetti for all instrumental tests except stickiness, was drained in a sieve, rinsed with cold tap water for 1 minute, and allowed to drain for 2 minutes. The sample was then placed on a plate and covered with plastic wrap to prevent drying. Samples evaluated for stickiness were not rinsed in order to maximize stickiness values (Dexter et al. 1983a). Samples were held uncovered for seven minutes before testing. Two replications were completed for a total of 168 cookings (7 samples x 2 drying temperatures x 2 cooking times x 3 instrumental tests x 2 replications).

4.2.3 Spaghetti Cooking for Viscoelastograph Evaluation

Spaghetti was broken into one 2.5 cm piece from the centre of a strand. The tip of the piece was colored black with a permanent marker and placed in a stainless steel tea ball. The next sample was then prepared and colored red, so that there were two spaghetti pieces in each tea ball, one black and one red.

Since there were an uneven number of samples a dummy sample was included in the last tea ball. Four tea balls, each containing two samples, were hooked onto a glass stirring rod and immersed into a glass 2 L beaker containing 2 L of rapidly boiling deionized water on an electric element. A preliminary cooking was performed with all seven samples to determine the approximate time for doneness. All samples, for each drying temperature, were cooked at the same time for 14 minutes. After cooking, the glass rod holding the tea balls, was removed from the boiling water and plunged into a beaker containing 1 L of room temperature deionized water for 25 sec. The tea balls were then removed from the water and the spaghetti was removed from the tea balls. Using a razor, the end of the sample that was colored with permanent marker was removed and 2 pieces, each 1 cm in length, were cut from each sample. These pieces were placed in covered glass petri plates containing a piece of mesh on top of moistened filter paper to prevent drying while waiting to be tested. A total of 18 cookings were performed (2 drying temperatures x 3 weights x 3 replications).

4.2.4 Spaghetti Cooking Procedures for Sensory Evaluation

4.2.4.1 Spaghetti Cooking Procedures for Oral Evaluations

Spaghetti, broken into 5 cm long pieces, was cooked to optimum in rapidly boiling tap water in 1.5 L glass Pyrex saucepans on electric stove elements

using a ratio of 1:10 (spaghetti to tap water). Six g of each spaghetti sample and 8 g of the reference spaghetti, was cooked for each panelist. After cooking to optimum, the spaghetti was drained into a sieve and then immersed in cold tap water for one minute. The spaghetti was then allowed to drain for 2 min before dividing into coded glass custard cups (500 mL for the reference spaghetti and 250 mL for the samples) for evaluation by the panel.

4.2.4.2 Spaghetti Cooking Procedures for Strand to Strand Evaluation

Twenty g of spaghetti, broken into 12 cm long pieces, was cooked to optimum using a ratio of 1:25 (spaghetti to tap water) in 1.5 L glass Pyrex saucepans on electric stove elements. After the required cooking time, the spaghetti was drained into a sieve and allowed to drain for 2 min. The spaghetti was then placed in a 250 mL glass beaker and lightly packed down using 20 strokes with a fork. The beaker was allowed to sit for 5 min and then inverted over a 23 cm high beaker stand placed on a black colored baking sheet. A square white box (each side was 33.2 x 25.5 cm) was then centred over the coded spaghetti sample and a photograph of the sample was immediately taken in a darkened room. The camera set-up was as follows; a Pentax camera with a 50 mm lens (fstop 16, shutter speed 1/60) was mounted on a copy stand, a Vivitar 283 flash (manual mode, 45° angle) was mounted on a tripod, Kodak Elite II 200 ASA film for color slides was used.

4.2.5 Assessment of Instrumental Texture

The Lloyd Texture Testing Instrument (model L1000R, Lloyd Instruments Limited, Hampshire, UK) equipped with a 20 N load cell was used to assess the textural properties of the cooked spaghetti. Data was collected using the software RCONTROL (version 2.21, Lloyd Instruments Limited, New Hampshire, UK).

4.2.5.1 Assessment of Firmness

Five strands of cooked spaghetti were centred on a flat plexiglass baseplate (9.9 x 9.9 x 1.7 cm) parallel to each other, leaving no spaces between the strands. A bevelled plexiglass tooth (Oh et al., 1983), raised 5.0 mm above the baseplate, was used to shear the strands crosswise to a fixed compression depth of 4.5 mm (0.5 mm from the baseplate). The crosshead speed was 50 mm/min. Three subsamples were evaluated for each cooking and the mean of these readings was used in the statistical analyses. Firmness was expressed as the work in N·mm required to shear five strands of spaghetti. Shear force was expressed as the force in N to shear five strands of spaghetti. Figure 4.3a shows a typical firmness curve obtained.

4.2.5.2 Assessment of Compression/Relaxation Time

Nine strands of cooked spaghetti were placed parallel to each other on a grooved plexiglass baseplate (9.9 x 9.9 x 1.7 cm). The grooves ran the length of the baseplate and were 0.31 cm wide and spaced 0.1 cm apart. Using a crosshead speed of 5 mm/min, the strands were compressed using a flat plexiglass plunger (6.6 x 1.2 cm contact area) to a fixed load of 8.0 N. Once the required compression load was reached, the strands were allowed to relax at constant deformation until 85% of the maximum load was reached (6.8 N). Three subsamples of each cooking were evaluated and the mean of these readings was used in the statistical analyses. Compression was expressed as the energy in N·mm to compress the nine strands to the fixed force and relaxation time was expressed as the time in seconds required to reduce the load from 8.0 N to 6.8 N (15% reduction). Figure 4.3b shows a typical compression/relaxation curve obtained.

4.2.5.3 Assessment of Stickiness

Nine strands of cooked spaghetti were placed parallel to each other in the grooved plexiglass baseplate described previously (Section 4.2.5.2) and compressed to a fixed force of 8.0 N with a flat plexiglass plunger (9.5 x 6.5 cm contact area) using a crosshead speed of 5.0 mm/min. Once the fixed load was reached the plunger was returned to 1.0 mm above the starting point. Three subsamples of each cooking were evaluated and the mean of these readings was used in the statistical analyses.

Stickiness was defined as the negative area under the force-distance curve expressed in N·mm. Adhesiveness was defined as the maximum force of the stickiness curve expressed in N, and energy was defined as the area under the force distance to the maximum force expressed in N·mm. Figure 4.3c shows a typical stickiness curve obtained.

4.2.6 Assessment of Texture Using the Viscoelastograph

Two strands were placed parallel to each other, with no space between them, on a square piece of waxed paper placed on the baseplate. One drop of mineral oil was placed on the sample to prevent sticking to the upper plunger. Since it has been found to be important to select the correct weight for testing (Kovacs et al., 1994), three different weights were evaluated; 1000 g, 1500 g and 2000 g. The relative recovery (R_r%) values were recorded. Rr% is calculated using the following equation; Rr% = ((e2-e1)/(E-e1)), where E is the initial height of the sample, e1 is the height of the sample after the load is applied, e2 is the height of the sample after the load is removed.

4.2.7 Sensory Evaluation

4.2.7.1 Selection of Panelists

Ethical approval for the use of research subjects was approved by the Faculty of Human Ecology Ethics Committee (Appendix 14). Panelists were recruited by a letter

of invitation (Appendix 15) via electronic mail (e-mail) and notices posted in the Faculty of Human Ecology, Cereal Research Centre of Agriculture and Agri-Food Canada and the Grain Research Laboratory of the Canadian Grain Commission. Eleven panelists (9 females and 2 males) were selected to take part in the study based on availability and the desire to learn more about sensory evaluation.

4.2.7.2 Training of Panelists

The purpose of the first training session was to introduce the panelists to each other and the panel leader and to acquaint them with the use of unstructured line scales through the use of a scaling exercise (Appendix 16). A total of eleven, 30 minute, training sessions were held over a 4 week period with 3 sessions per week. During the training sessions panelists were introduced to the textural properties to be evaluated and shown the proper techniques for handling the samples and performing the evaluations. Panelists made their evaluations using 15 cm unstructured line scales. A reference sample (a commercial brand of spaghetti) was provided to the panelists to calibrate them on the line scales. The reference sample was placed on each line scale as follows; for springiness at 7.9 cm, firmness at 10.3 cm, breakdown at 10.6 cm and adhesiveness to teeth at 7.0 cm. For evaluation of the textural property of chewiness, panelists were asked to establish their own reference value by counting the number of chews for the reference sample. Each panelist's reference value (number of chews for the reference sample) was then subtracted from each of their sample evaluations

in order to standardize the panelists' chew counts. Differences in the surfaces of the teeth and in the size deemed suitable for swallowing between panelists led to the development of counting the number of chews for the evaluation of chewiness. The final ballot used for oral evaluations is presented in Figure 4.4.

For strand to strand adherence evaluations, panelists were given a set of three reference photographs, R1, R2 and R3 (L. Malcolmson, unpublished data), which were marked on the line scale at 0, 7.5 and 15 cm respectively. The ballot used for strand to strand adherence is presented in Figure 4.5. Definitions of the textural parameters used were based on those used by other researchers in the evaluation of spaghetti and noodle texture (See Tables 2.1-2.7).

The samples evaluated during the training sessions were chosen, and or manipulated (by adjusting the cooking time), in order to demonstrate the specific textural properties evaluated during a particular training session. This was done so the panelists would become familiar with the end points of each textural scale, the possible range of samples that they may encounter during the

Sensory Evaluation of Cooked Spaghetti

Instructions:
You are presented with a reference sample (R) and four coded samples. Read the definition and technique for each attribute. Evaluate the reference sample (R) first and note its position on the line scale. Evaluate the coded samples in the order given in relation to the reference sample. Place a mark on the line scale at the point that best describes that sample. Proceed to the next sample. You may go back to the reference sample as needed. Always use the same side of your mouth for your evaluations. Rinse your mouth with water before starting your evaluations and between each sample. You may expectorate the sample if you wish.

Order: ____ ____ ____ ____

Springiness: The degree to which the sample returns to its original shape/size after slight compression between the molars.

Technique: Place two strands side by side between the molars and gently apply a small amount of force to the surface of the spaghetti and release. Do this four times in succession. Evaluate the degree to which the sample springs back (i.e returns to its original size/shape).

- A sample with a **low degree** of springiness **does not spring back** after slight compression.
- A sample with a **high degree** of springiness **springs back** to its original shape after slight compression.

R
low degree — high degree

Order: ____ ____ ____ ____

Firmness: The amount of force required to bite completely through one strand of spaghetti when placed between the molars.

Technique: Place one strand between the molars and slowly bite completely down using a constant amount of force. Evaluate the amount of force required to completely bite through the strand.

- A **soft** sample requires a **small amount of force** to completely bite through the strand.
- A **firm** sample requires a **moderate amount of force** to completely bite through the strand.

R
soft — firm

Chewiness: The number of chews, at a constant rate of one chew per second, to reduce the sample to a suitable size for swallowing.

Technique: Fold one strand in half, place in the mouth and chew using a constant rate of one chew per second using the molars on one side of the mouth. Count the number of chews required to reduce the sample to a suitable size for swallowing.

Sample	Number of Chews
R	

Order: ____ ____ ____ ____

Breakdown: The type of breakdown perceived after the sample is masticated.

Technique: Fold one strand in half, place in the mouth and chew the sample the determined number of times using a rate of one chew per second. Use the molars on one side of the mouth. Gently use your tongue to spread the sample out in your mouth. Evaluate the sample for the type of breakdown, from large pieces to very small pieces.

If: 5-10 chews: use 1 less chew
11-15 chews: use 2 less chews
16-20 chews: use 3 less chews

R
very small pieces — large pieces

Order: ____ ____ ____ ____

Adhesiveness to Teeth: The amount of sample that adheres to the teeth after swallowing.

Technique: Fold one strand in half, place in the mouth and chew using a rate of one chew per second and then swallow. Evaluate the amount of sample adhering to the teeth after swallowing.

- A **low degree** of adhesiveness to teeth is characterized by **very little sample** left in the teeth.
- A **high degree** of adhesiveness to teeth is characterized by a **large amount of sample** left in the teeth.

R
low degree — high degree

Comments:

Figure 4.4: Sensory Ballot Used for the Assessment of the Textural Properties of Cooked Pasta (Orally).

Strand to Strand Adherence

Instructions:

Look at the pictures of the three reference samples and note their position on the line scale. Evaluate the samples shown and place a mark on the line scale that best describes that sample. Write the sample number above the mark. Proceed to the next sample.

Strand to Strand Adherence: The degree to which the spaghetti strands adhere to each other.

Technique: Visually evaluate the spaghetti for strand to strand adherence. Specifically note the tightness of the mass.

- A **low degree** is characterized by strands that have a **low amount** of adherence to each other and **do not form a tight mass.**
- A **high degree** is characterized by strands that have a **high amount** of adherence to each other and **form a tight mass.**

R1 R2 R3

___ |——————————|——————————|

low degree high degree

R1 R2 R3

___ |——————————|——————————|

low degree high degree

R1 R2 R3

___ |——————————|——————————|

low degree high degree

Comments:

Figure 4.5: Ballot Used for the Evaluation of Strand to Strand Adherence (Visually).

test sessions and to build confidence in their evaluations. After the panelists completed their individual evaluations, a discussion regarding the tasks performed followed after each evaluation session. Panelists were encouraged to make suggestions, comment on the placement of the reference sample on the line scales and address any other difficulties they encountered during the training sessions. Their comments were used to plan the remaining training sessions.

Panelists who missed a training sessions were required to make-up the missed session with the group leader at a mutually convenient time before continuing with the next training session. One panelist was not able to complete all of the training sessions and was excused from the panel. The remaining ten panelists completed all training and test sessions. Training ended when panelists were consistent in their evaluations and confident with their ability to perform the tasks.

4.2.7.3 Test Sessions

At each test session, panelists received the reference sample (coded "R") and four samples coded with three digit random numbers. Samples dried using the same drying temperature were always evaluated together at a given test session. Panelists were provided with filtered water for rinsing, a plastic fork

and a styrofoam cup for expectoration. Eight panelists performed their test sessions in the computerized sensory facility in the George Weston Limited Sensory and Food Research Centre located in the Department of Foods and Nutrition in the Faculty of Human Ecology, University of Manitoba. The CSA software program (version 4.3, Compusense Inc, Guelph, ON) provided on-screen instructions, ballot and data recording. Due to limited space in the computerized facility (only 8 booths available), the remaining two panelists performed their evaluations in a separate room equipped with individual sensory booths using paper ballots. The same panelists were always in the same rooms in order to minimize a possible room effect. Ballots from the two panelists using paper ballots were decoded and the values were entered into the CSA program after completion of their evaluations. Panelists evaluated the samples for all textural attributes, except strand to strand adherence, on the same day. Sample presentation for each panelist was randomized. All evaluations were done under red light in order to mask any possible differences in appearance between the samples.

Eight test sessions were required to complete all evaluations (7 samples x 2 drying temperatures x 2 replications). Samples were blocked by drying temperature, such that the 70°C drying temperature was evaluated first in the first replication and then evaluated last in the second replication (i.e. the order

was reversed). In order to balance out the presentation of samples a dummy sample (Ralph, a USA commercial store brand made with 100% durum semolina) was added.

Evaluation of strand to strand adherence was done at each session by presenting two sets of seven slides. Each set of slides consisted of all seven samples at one drying temperature. Each slide was shown for 15 seconds before proceeding to the next slide. Presentation of the slides within each set was randomized for each group of 2-3 panelists that were selected to perform their evaluations after completing their oral evaluations for that day. Panelists were required to come to two test sessions in order to complete the two replications of strand to strand adherence evaluations.

4.2.8 Statistical Analyses

4.2.8.1 Instrumental Texture Evaluations

ANOVA was performed using the PROC GLM procedure (SAS, 1992) to analyze the data collected from all instrumental tests using the Lloyd. Each test was analyzed separately. The model included the main effects of sample, cooking time and drying temperature and their interactions. A least squared means test was used to determine the significant difference between treatment means ($p \leq 0.05$).

4.2.8.2 Viscoelastograph Evaluations

ANOVA was used to analyze the data collected from all tests using the viscoelastograph using PROC GLM (SAS, 1992). Each weight used was analyzed separately. The model included the main effects of sample and drying temperature and their interaction. A least square means test was used to determine the significant difference between treatment means ($p \leq 0.05$).

4.2.8.3 Sensory Evaluations

Analysis of the sensory data was carried out using the PROC MIXED procedure (SAS, 1992). The main effects of panelist and replication and their interactions with sample and drying temperature were treated as random effects, whereas the main effects of sample and drying temperature and their interaction were treated as fixed effects.

Analysis of the full model of random effects was done followed by a stepwise elimination of terms. The full model was compared to the reduced model using the Likelihood Ratio Test (LRT) to determine if the reduced model resulted in any significant loss of information over the full model. The reduced model was then compared to the null model to see if there was any significant improvement over the null model. After the reduced model was fitted, the fixed effects were

tested for significance ($p \leq 0.05$).

4.8.2.4 Correlations between Instrumental and Sensory Measurements

Correlations between mean sensory evaluations and mean Lloyd and mean Viscoelastograph evaluations were performed using the PROC CORR (SAS, 1992).

4.3 RESULTS

4.3.1 Evaluations of Instrumental Texture

4.3.1.1 Firmness Evaluation

A significant interaction of sample x drying temperature was found for shear force ($p = 0.009$) and firmness ($p = 0.0521$) (Table 4.1). A significant sample x drying temperature interaction indicates the samples, when summed over all cooking times, varied in both their shear force and firmness values when the spaghetti was dried at either of the two drying temperatures. For firmness, comparisons within a sample revealed that Durex, AC Navigator, Kyle and Plenty all had significantly higher firmness values when dried at 90°C than when dried at 70°C over both cooking times ($p \leq 0.05$) (Figure 4.6). Comparisons between samples at 70°C revealed that AC Melita, Durex, Kyle, AC Navigator and AC Pathfinder all had significantly higher firmness values than Plenty over both cooking times ($p \leq 0.05$) (Figure 4.7). When dried at 90°C, AC Navigator had a significantly higher firmness value than Kyle, AC Melita, AC Pathfinder, Plenty and DT 662 over all cooking times ($p \leq 0.05$). Durex had a significantly higher firmness value than Plenty and DT 662 when dried at 90°C over all cooking times ($p \leq 0.05$).

For shear force values, comparisons within a sample revealed that Durex, AC Navigator, AC Melita, Kyle and Plenty all had higher shear force values when

Table 4.1: Summary of Selected Analysis of Variance Results of Lloyd Data for Firmness and Shear force.

Parameter	Source	df	Mean Square	F value	Pr>F
Firmness	Sample	6	0.165	7.75	0.0001
	Drying Temp (DT)	1	0.679	31.75	0.0001
	Cooking Time (CT)	1	1.377	64.37	0.0001
	Sample x CT	6	0.007	0.32	0.9232
	Sample x DT	6	0.052	2.42	0.0521
	CT x DT	1	0.045	2.10	0.1585
	Sample x CT x DT	6	0.025	1.15	0.3616
	Error	28	0.021		
Shear Force	Sample	6	0.221	10.44	0.0001
	Drying Temp (DT)	1	1.992	94.27	0.0001
	Cooking Time (CT)	1	4.403	208.34	0.0001
	Sample x CT	6	0.018	0.84	0.5512
	Sample x DT	6	0.076	3.59	0.0092
	CT x DT	1	0.010	0.49	0.4911
	Sample x CT x DT	6	0.039	1.85	0.1250
	Error	28	0.021		

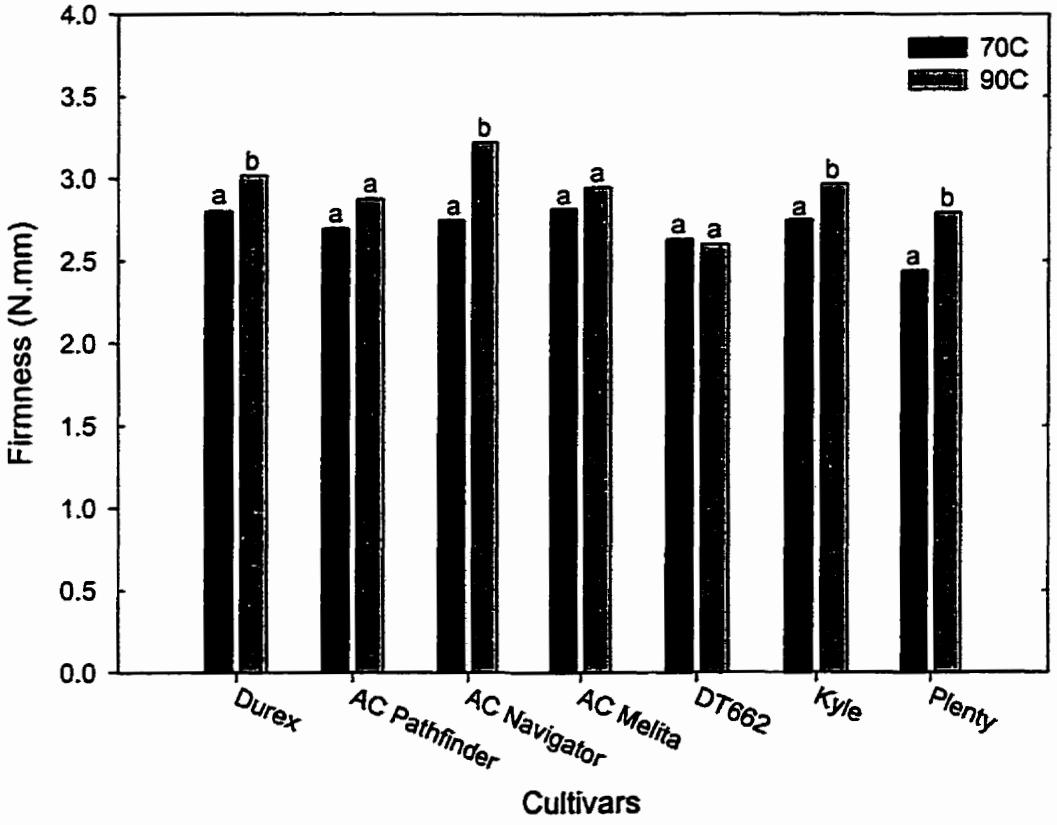

Figure 4.6: Mean Lloyd Firmness Values of Sample x Drying Temperature - Comparison within Sample. Bars with the same letter within the same sample are not significantly different ($p \leq 0.05$).

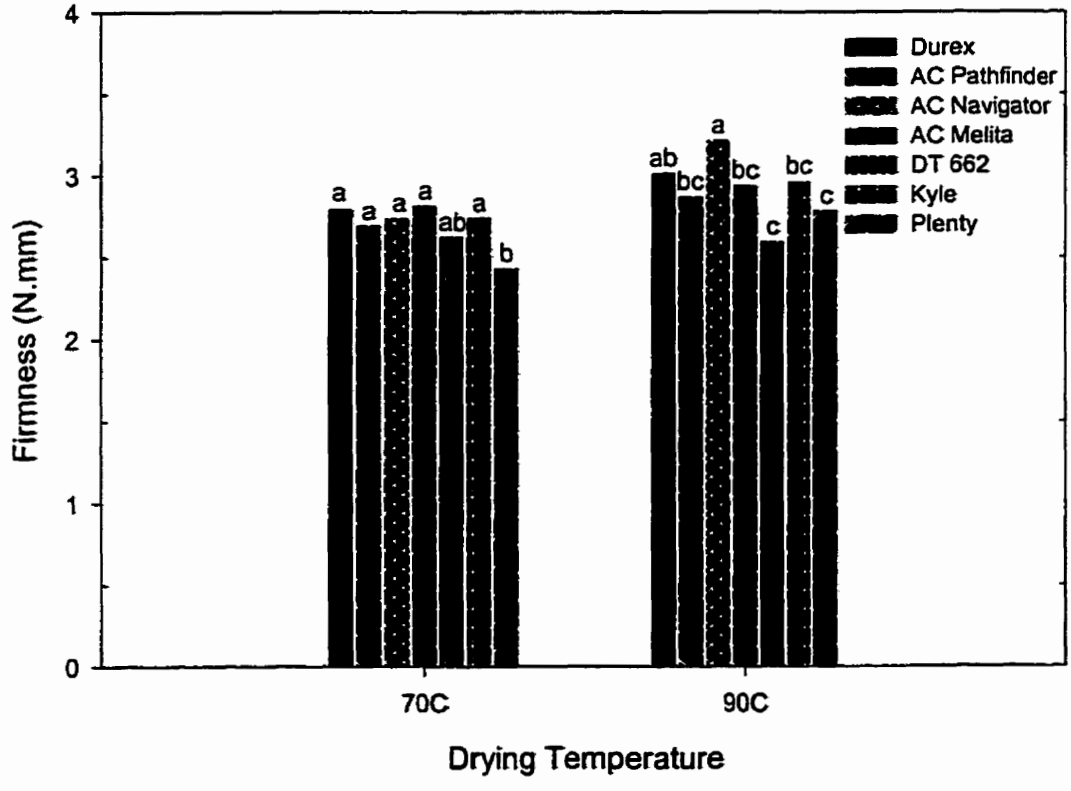

Figure 4.7: Mean Lloyd Firmness Values of Sample x Drying Temperature - Comparison within Drying Temperature. Bars with the same letter within the same drying temperature are not significantly different. ($p \leq 0.05$).

dried at 90°C than when dried at 70°C over both cooking times ($p \leq 0.05$) (Figure 4.8). Comparisons between samples dried at 70°C revealed that Durex, AC Pathfinder, AC Navigator, AC Melita and Kyle had significantly higher shear force values than Plenty over both cooking times ($p \leq 0.05$) (Figure 4.9). AC Navigator had a significantly higher shear force value than Kyle, AC Melita, AC Pathfinder, Plenty and DT 662 when dried at 90°C over both cooking times. Durex, Kyle, AC Melita and AC Pathfinder had higher shear force values than DT 662 when dried at 90°C over both cooking times ($p \leq 0.05$).

A significant cooking time effect was found for firmness and shear force (Table 4.1). Overcooking resulted in significantly lower firmness and shear force values than cooking to optimum over all samples and drying temperatures ($p \leq 0.05$).

4.3.1.2 Compression/Relaxation Time Evaluation

No significant sample effects were observed for either compression or relaxation time over all cooking times and drying temperatures (Table 4.2). A significant cooking time effect was found for both compression and relaxation time. Overcooking resulted in significantly higher compression values and significantly shorter relaxation times than cooking to optimum over all samples and drying temperatures ($p \leq 0.05$). A significant drying temperature effect was

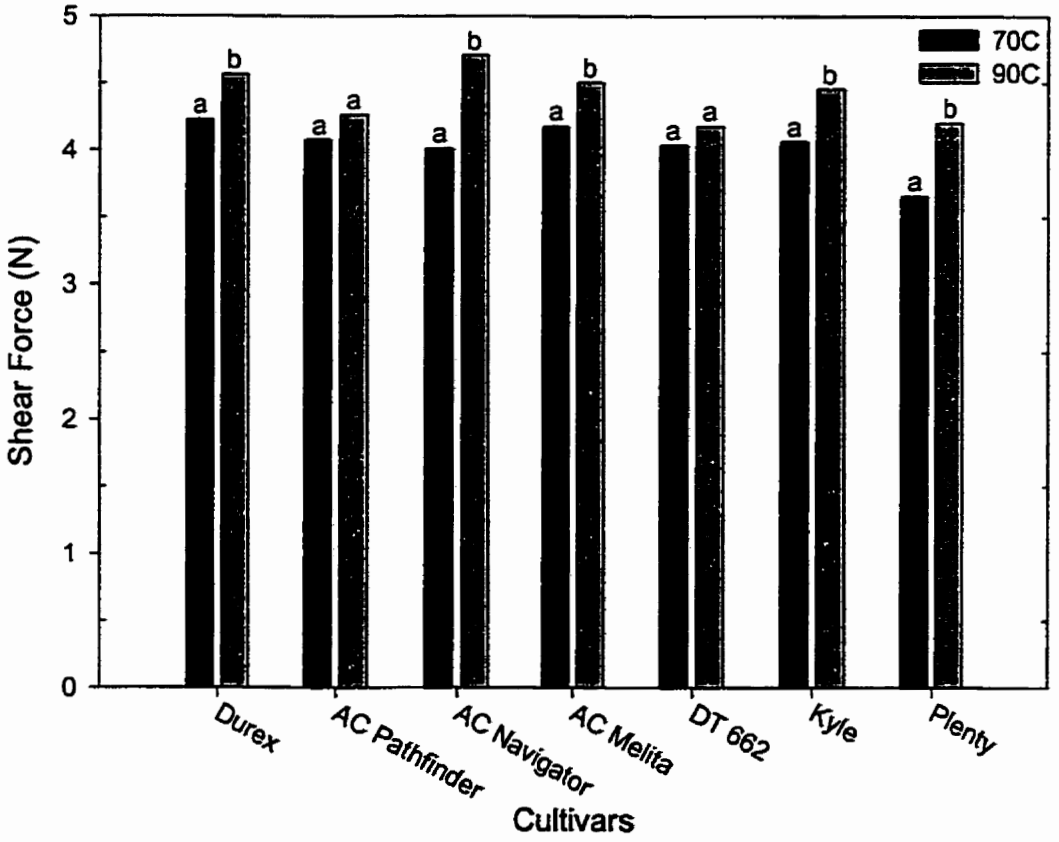

Figure 4.8: Mean Lloyd Shear Force Values of Sample x Drying Temperature - Comparison within Sample. Bars with the same letter within the same sample are not significantly different ($p \leq 0.05$).

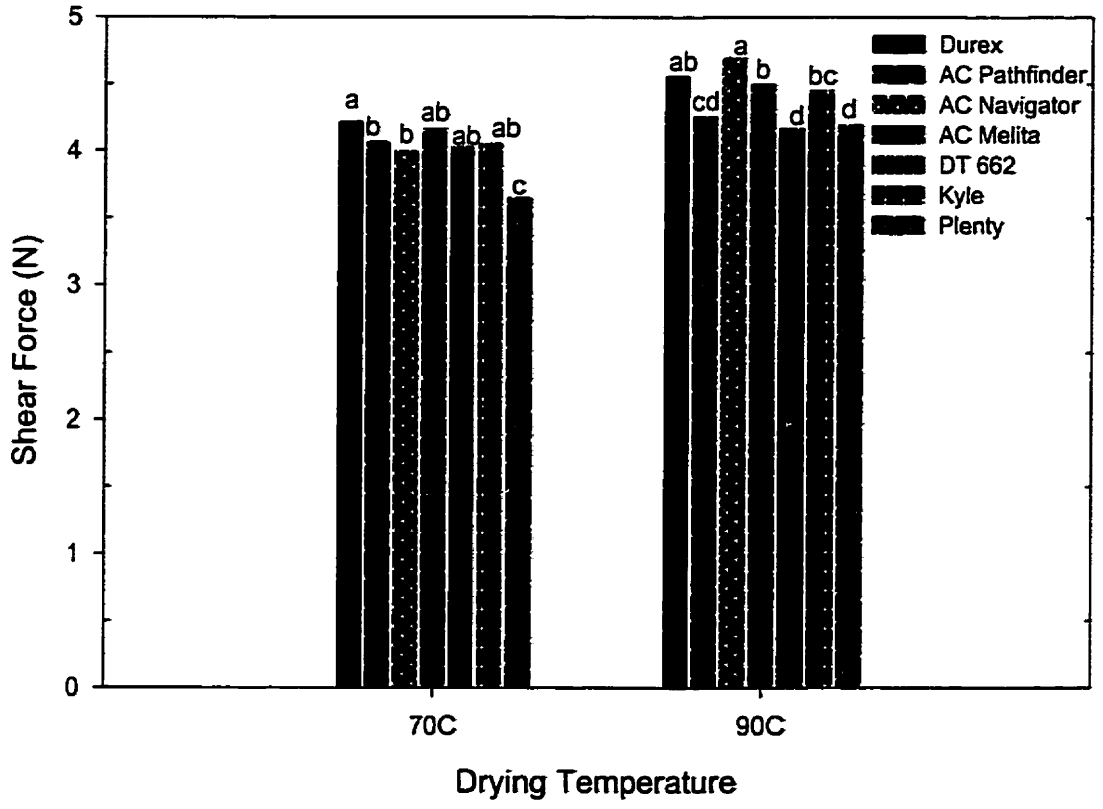

Figure 4.9: Mean Lloyd Shear Force Values of Sample x Drying Temperature - Comparison within Drying Temperature. Bars with the same letter within the same drying temperature are not significantly different ($p \leq 0.05$).

Table 4.2: Summary of Selected Analysis of Variance Results of Lloyd Data for Compression and Relaxation Time.

Parameter	Source	df	Mean Square	F value	Pr>F
Compression	Sample	6	0.032	0.94	0.4815
	Drying Temp (DT)	1	0.444	12.95	0.0012
	Cooking Time (CT)	1	5.493	160.12	0.0001
	Sample x CT	6	0.012	0.34	0.9072
	Sample x DT	6	0.034	0.99	0.4530
	CT x DT	1	0.091	2.65	0.1145
	Sample x CT x DT	6	0.023	0.66	0.6810
	Error	28	0.034		
Relaxation Time	Sample	6	12.896	1.76	0.1440
	Drying Temp (DT)	1	7.515	1.03	0.3199
	Cooking Time (CT)	1	194.438	26.53	0.0001
	Sample x CT	6	3.020	0.41	0.8647
	Sample x DT	6	2.612	0.36	0.9000
	CT x DT	1	6.110	0.83	0.3692
	Sample x CT x DT	6	2.502	0.34	0.9089
	Error	28	7.328		

found for compression. Spaghetti dried at 70°C had significantly lower compression values than spaghetti dried at 90°C over all samples and cooking times ($p \leq 0.05$).

4.3.1.3 Stickiness Evaluation

A significant interaction of cooking time x drying temperature was found for both stickiness and adhesiveness (Table 4.3). A significant interaction of cooking time x drying temperature indicates that stickiness and adhesiveness values differed between each cooking time and drying temperature over all samples. For stickiness, comparisons within a drying temperature revealed that overcooking resulted in significantly higher stickiness values than cooking to optimum when using a drying temperature of 90°C over all samples (Figure 4.10). Comparisons within a cooking time revealed that drying at 90°C resulted in significantly lower stickiness values only for optimally cooked spaghetti over all samples (Figure 4.11). For adhesiveness, comparisons within a drying temperature revealed that overcooking resulted in significantly higher adhesiveness values than cooking to optimum when using a drying temperature of 90°C over all samples (Figure 4.12). Comparisons within a cooking time revealed that significantly lower adhesiveness values were found when spaghetti was dried at 90°C and cooked to optimum over all samples (Figure 4.13). Overcooking resulted in the opposite trend, whereas spaghetti dried at

Table 4.3: Summary of Selected Analysis of Variance Results of Lloyd Data for Stickiness, Energy and Adhesiveness.

Parameter	Source	df	Mean Square	F value	Pr>F
Stickiness	Sample	6	0.001	0.92	0.4966
	Drying Temp (DT)	1	0.006	10.54	0.0030
	Cooking Time (CT)	1	0.040	68.37	0.0001
	Sample x DT	6	0.000	0.39	0.8764
	Sample x CT	6	0.000	0.29	0.9386
	CT x DT	1	0.020	34.16	0.0001
	Sample x CT x DT	6	0.000	0.24	0.9583
	Error	28	0.016		
Energy	Sample	6	0.008	0.29	0.9366
	Drying Temp (DT)	1	0.668	22.93	0.0001
	Cooking Time (CT)	1	0.153	5.26	0.0295
	Sample x DT	6	0.004	0.14	0.9887
	Sample x CT	6	0.003	0.10	0.9956
	CT x DT	1	0.172	0.59	0.4484
	Sample x CT x DT	6	0.001	0.05	0.9994
	Error	28	0.029		
Adhesiveness	Sample	6	0.028	0.98	0.4551
	Drying Temp (DT)	1	0.289	10.07	0.0036
	Cooking Time (CT)	1	0.696	24.28	0.0001
	Sample x DT	6	0.019	0.65	0.6893
	Sample x CT	6	0.009	0.30	0.9319
	CT x DT	1	1.716	59.82	0.0001
	Sample x CT x DT	6	0.008	0.28	0.9395
	Error	28	0.029		

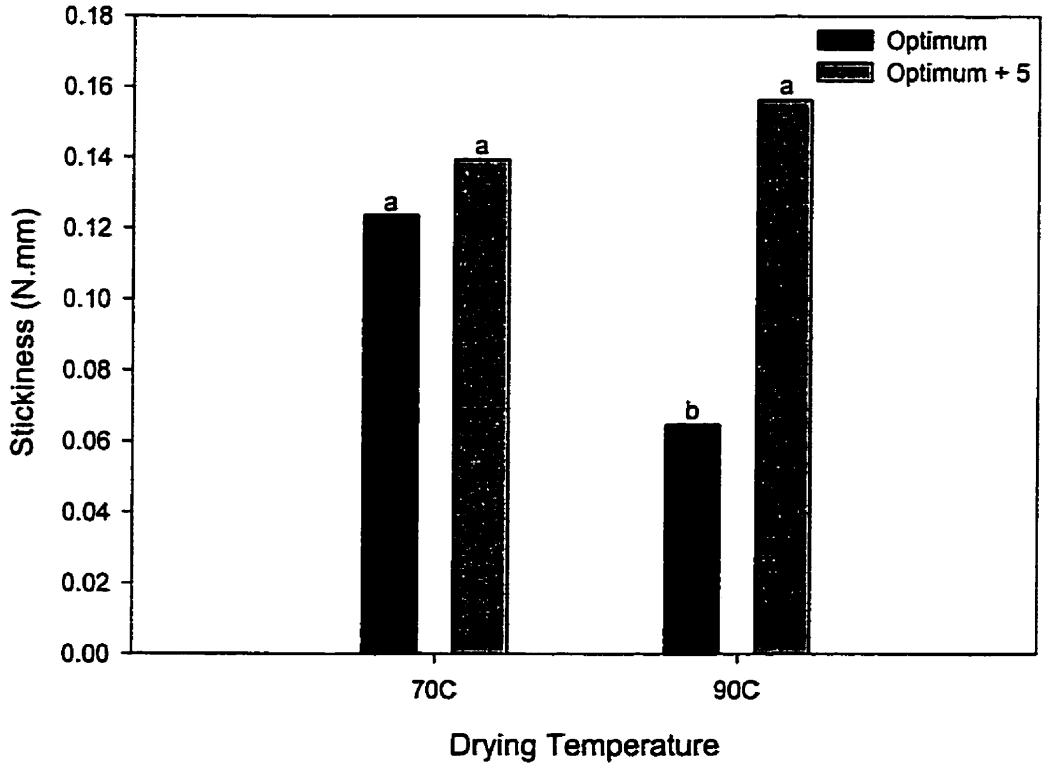

Figure 4.10: **Mean Lloyd Stickiness Values of Cooking Time x Drying Temperature - Comparisons within Drying Temperature. Bars with the same letter within the same drying temperature are not significantly different ($p \leq 0.05$).**

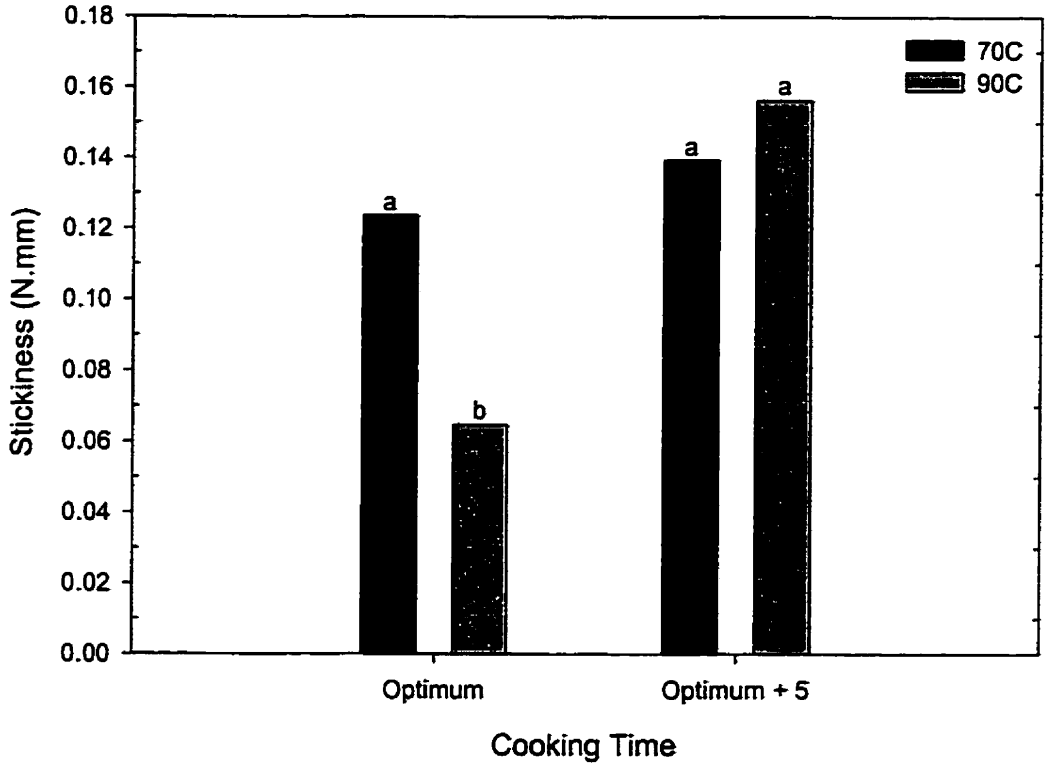

Figure 4.11: **Mean Lloyd Stickiness Values of Cooking Time x Drying Temperature - Comparisons within Cooking Time. Bars with the same letter within the same cooking time are not significantly different ($p \leq 0.05$).**

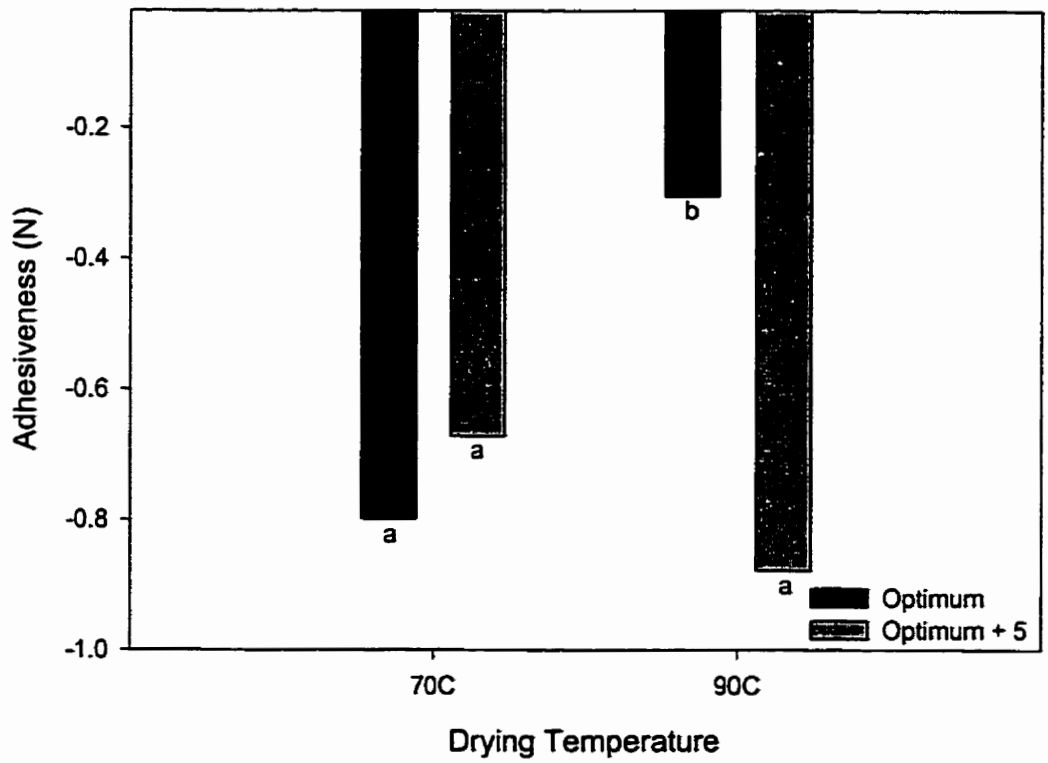

Figure 4.12: **Mean Lloyd Adhesiveness Values of Cooking Time x Drying Temperature - Comparisons within Drying Temperature. Bars with the same letter within the same drying temperature are not significantly different ($p \leq 0.05$).**

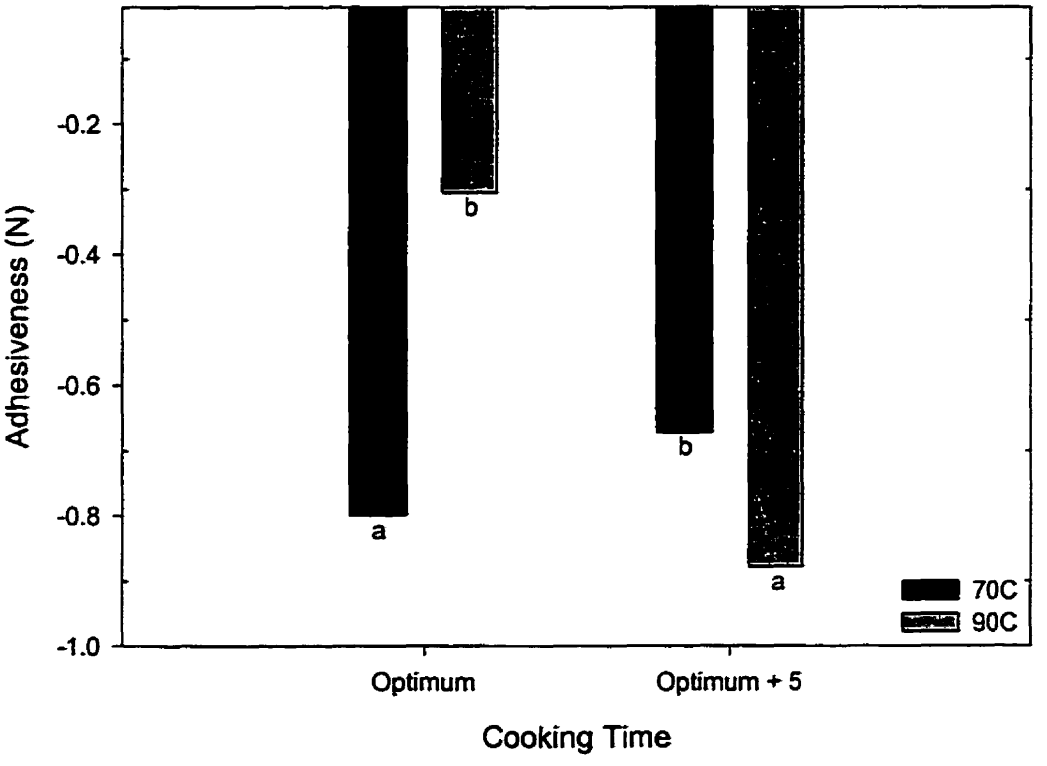

Figure 4.13: **Mean Lloyd Adhesiveness Values of Cooking Time x Drying Temperature - Comparisons within Cooking Time. Bars with the same letter within the same cooking time are not significantly different ($p \leq 0.05$).**

70°C had significantly lower adhesiveness values than spaghetti dried at 90°C over all samples.

Significant drying temperature and cooking time effects were found for energy (Table 4.3). Spaghetti dried at 90°C had significantly higher energy values than spaghetti dried at 70°C over samples and cooking times ($p \leq 0.05$). Overcooking resulted in significantly higher energy values than cooking to optimum over all samples and drying temperatures ($p \leq 0.05$).

4.3.2 Viscoelastograph Evaluation

A significant sample effect was found for the 1000 g weight ($p \leq 0.05$) (Table 4.4). Plenty and Kyle had significantly higher R_r% values than AC Navigator, AC Melita, AC Pathfinder and Durex over all drying temperatures ($p \leq 0.05$) (Figure 4.14). DT 662 had a significantly higher R_r% value than AC Pathfinder and Durex over all drying temperatures ($p \leq 0.05$).

A significant interaction between sample x drying temperature was found for R_r% values assessed using the 1500 g weight (Table 4.5). A significant interaction of sample x drying temperature indicates that some samples behaved differently to the two drying temperatures when evaluated using the 1500 g weight. Comparison within a sample revealed that Kyle and Durex had

Table 4.4: Summary of Selected Analysis of Variance Results for Viscoelastograph Evaluations at 1000g.

Parameter	Source	df	Mean Square	F value	Pr>F
Relative Recovery	Sample	6	341.833	4.01	0.0051
	Drying Temp (DT)	1	19.687	0.23	0.6347
	Sample x DT	6	69.346	0.81	0.5691
	Error	28	85.336		

Table 4.5: Summary of Selected Analysis of Variance Results for Viscoelastograph Evaluations at 1500g.

Parameter	Source	df	Mean Square	F value	Pr>F
Relative Recovery	Sample	6	5500.083	50.10	0.0001
	Drying Temp (DT)	1	0.727	0.07	0.7989
	Sample x DT	6	45.822	4.17	0.0040
	Error	28	10.980		

Table 4.6: Summary of Selected Analysis of Variance Results for Viscoelastograph Evaluations at 2000g.

Parameter	Source	df	Mean Square	F value	Pr>F
Relative Recovery	Sample	6	73.459	21.75	0.0001
	Drying Temp (DT)	1	7.840	2.32	0.1389
	Sample x DT	6	4.161	1.23	0.3202
	Error	28	3.378		

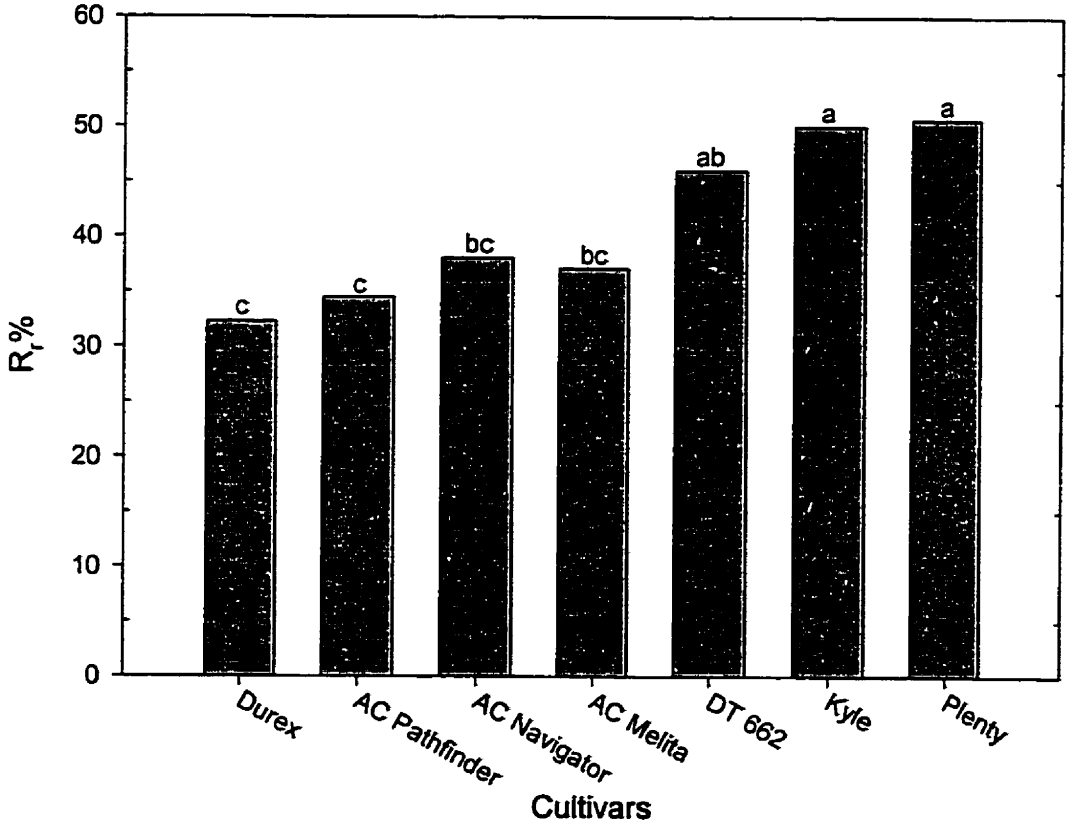

Figure 4.14: **Mean Relative Recovery (R_r%) Values for Viscoelastograph Evaluation using 1000 g. Bars with the same letter are not significantly different ($p \leq 0.05$).**

significantly lower R_r% values when dried at 90°C than when dried at 70°C ($p \leq 0.05$) (Figure 4.15). Plenty however, exhibited the opposite trend, whereas a significantly higher R_r% value was found when the spaghetti was dried at 90°C than when dried at 70°C ($p \leq 0.05$). Comparisons within a drying temperature revealed that for spaghetti dried at 70°C, DT 662 and Kyle had significantly higher R_r% values than Plenty, Durex, AC Pathfinder, AC Melita and AC Navigator ($p \leq 0.05$) (Figure 4.16). Plenty and Durex had significantly higher R_r% values than AC Pathfinder, AC Melita and AC Navigator ($p \leq 0.05$). When using a drying temperature of 90°C, DT 662 had a significantly higher R_r% value than all other samples ($p \leq 0.05$). Plenty had a significantly higher R_r% value than Kyle, AC Pathfinder, Durex, AC Melita and AC Navigator ($p \leq 0.05$). Kyle had a significantly higher R_r% value than AC Pathfinder, Durex, AC Melita and AC Navigator ($p \leq 0.05$).

A significant sample effect was found for R_r% values when assessed using the 2000 g weight ($p \leq 0.05$) (Table 4.6). DT 662 had a significantly higher R_r% value than all other samples over both drying temperatures ($p \leq 0.05$) (Figure 4.17). Kyle had a significantly higher R_r% value than Plenty, AC Pathfinder, Durex, AC Melita and AC Navigator over both drying temperatures ($p \leq 0.05$). Plenty had a significantly higher R_r% value than AC Melita and AC Navigator over both drying temperatures.

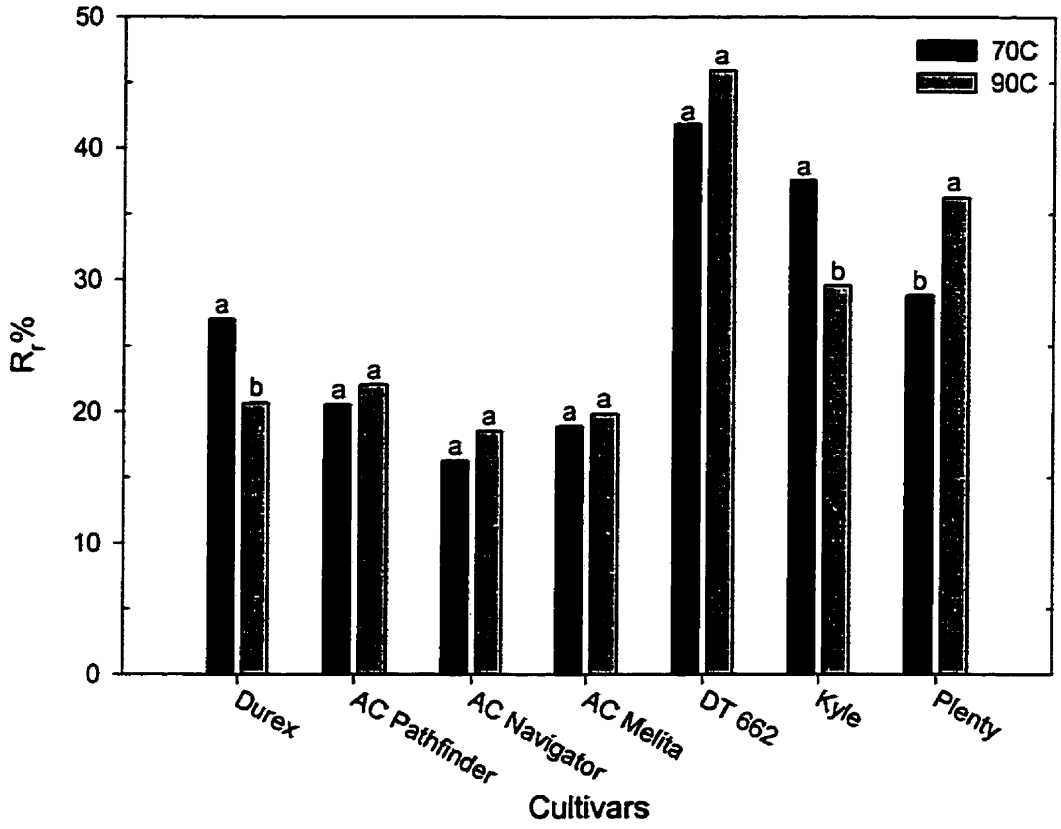

Figure 4.15: **Mean Relative Recovery (R_r %) Values of Sample x Drying Temperature for Viscoelastograph Evaluation using 1500 g - Comparisons within Sample. Bars with the same letter are not significantly different ($p \leq 0.05$).**

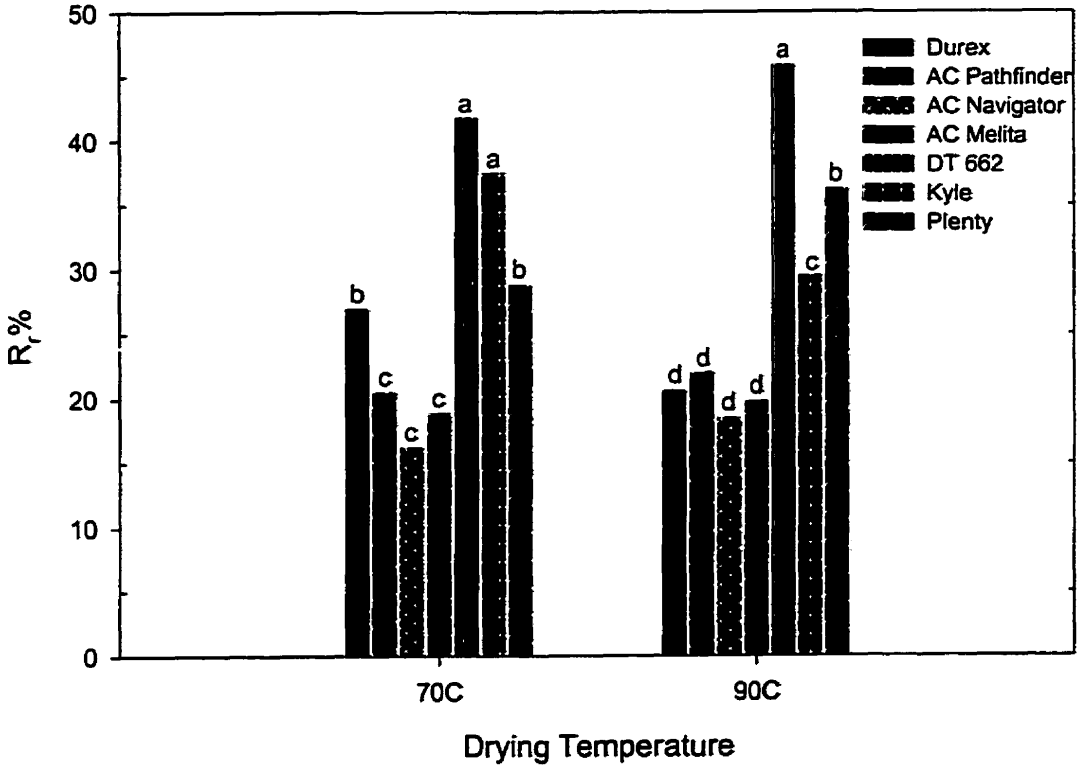

Figure 4.16: **Mean Relative Recovery (R_r%) Values for Viscoelastograph Evaluations Using 1500 g - Comparisons within Drying Temperature. Bars with the same letter are not significantly different ($p \leq 0.05$).**

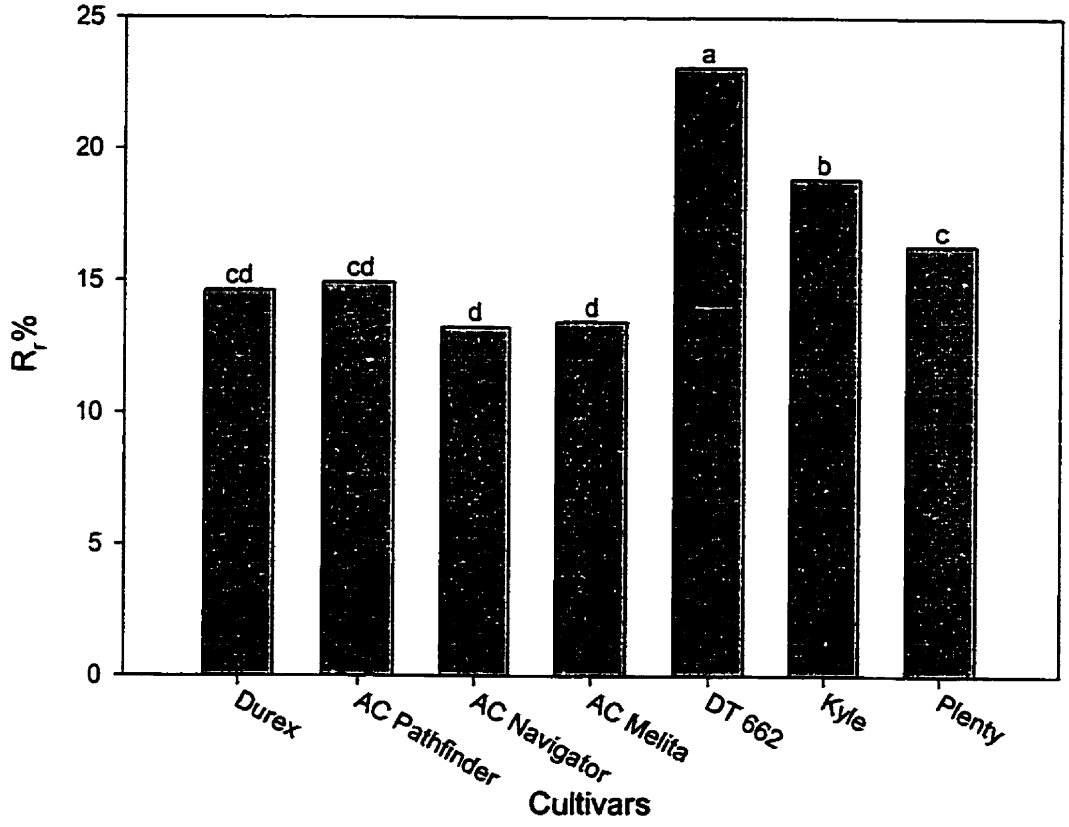

Figure 4.17: **Mean Relative Recovery (R_r%) Values for Viscoelastograph Evaluation using 2000 g. Bars with the same letter are not significantly different ($p \leq 0.05$).**

4.3.3 Sensory Evaluation

Table 4.7 summarizes the reduced models fitted for the random effects for the sensory data. The reduced models were found not to result in any significant loss of information over the full models, but were a significant improvement over the null models. The reduced model for the analysis of springiness included panelist as an additional random term. None of the fixed effects were found to be significant for the textural property of springiness (Table 4.8). This indicates that the samples did not differ in their springiness values and there were no differences in springiness scores between the two drying temperatures.

For firmness, the reduced model included panelist as an additional random term (Table 4.7). For analysis of the fixed effects, a significant sample effect was found (Table 4.8). Multiple comparisons of the least square means indicated that Ralph (dummy sample) was significantly less firm than DT 662, Durex, AC Pathfinder, Kyle and AC Melita over all panelists, drying temperatures, and replications (Figure 4.18).

The reduced model for chewiness contained the additional random term of panelist x replication x drying temperature (Table 4.7). Interpretation of the interaction of panelist x replication x drying temperature indicates that the panelists differed in their assessments of the temperature effect in the two

Table 4.7: Fitting of Models for Random Effects for Sensory Textural Properties.

Sensory Attribute	Model	-2REML[1]	p-value
Springiness	Full[2]	1370.039	
	Reduced (panelist)	1372.229	0.9947
	Null[3]	1403.119	≤0.0001
Firmness	Full[2]	1385.867	
	Reduced (panelist)	1386.789	≥0.9999
	Null[3]	1425.352	≤0.0001
Chewiness	Full[2]	1077.393	
	Reduced (panelist x rep x drying temp)	1087.989	0.3898
	Null[3]	1107.613	≤0.0001
Breakdown	Full[2]	1382.418	
	Reduced (panelist x drying temp)	1385.234	≥0.9999
	Null[3]	1408.692	≤0.0001
Adhesiveness To Teeth	Full[2]	1432.660	
	Reduced (panelist x drying temp)	1438.136	0.8572
	Null[3]	1455.835	≤0.0001
Strand to Strand Adherence	Full[2]	1121.364	
	Reduced (panelist, panelist x drying temp x rep, sample x drying temp x rep)	1132.615	0.1878
	Null[3]	1266.808	≤0.0001

1 REML = Restricted Maximum Likelihood.

2 The full model contains the following terms; panelist, rep, panelist x rep, panelists x sample, panelist x drying temp, panelists x sample x drying temp, rep x sample, rep x drying temp, rep x sample x drying temp, panelist x rep x sample, panelist x rep x drying temp) and residual error.

3 The NULL model includes only the error term.

Table 4.8: Summary of Fixed Effect Results for Sensory Evaluations.

Sensory Attribute	Effect	F value	P value
Springiness	Sample	1.80	0.0864
	Drying Temperature (DT)	0.00	0.9446
	Sample x DT	1.54	0.1545
	Error		
Firmness	Sample	3.90	0.0004
	Drying Temperature (DT)	3.34	0.0686
	Sample x DT	1.56	0.1459
	Error		
Chewiness	Sample	2.15	0.0389
	Drying Temperature (DT)	1.51	0.2272
	Sample x DT	0.91	0.4976
	Error		
Breakdown	Sample	4.32	0.0001
	Drying Temperature (DT)	0.36	0.5554
	Sample x DT	0.50	0.8317
	Error		
Adhesiveness to Teeth	Sample	0.98	0.4424
	Drying Temperature (DT)	0.02	0.8876
	Sample DT	1.17	0.3227
	Error		
Strand to Strand Adherence	Sample	8.30	0.0010
	Drying Temperature (DT)	13.93	0.0029
	Sample x DT	1.21	0.3644
	Error		

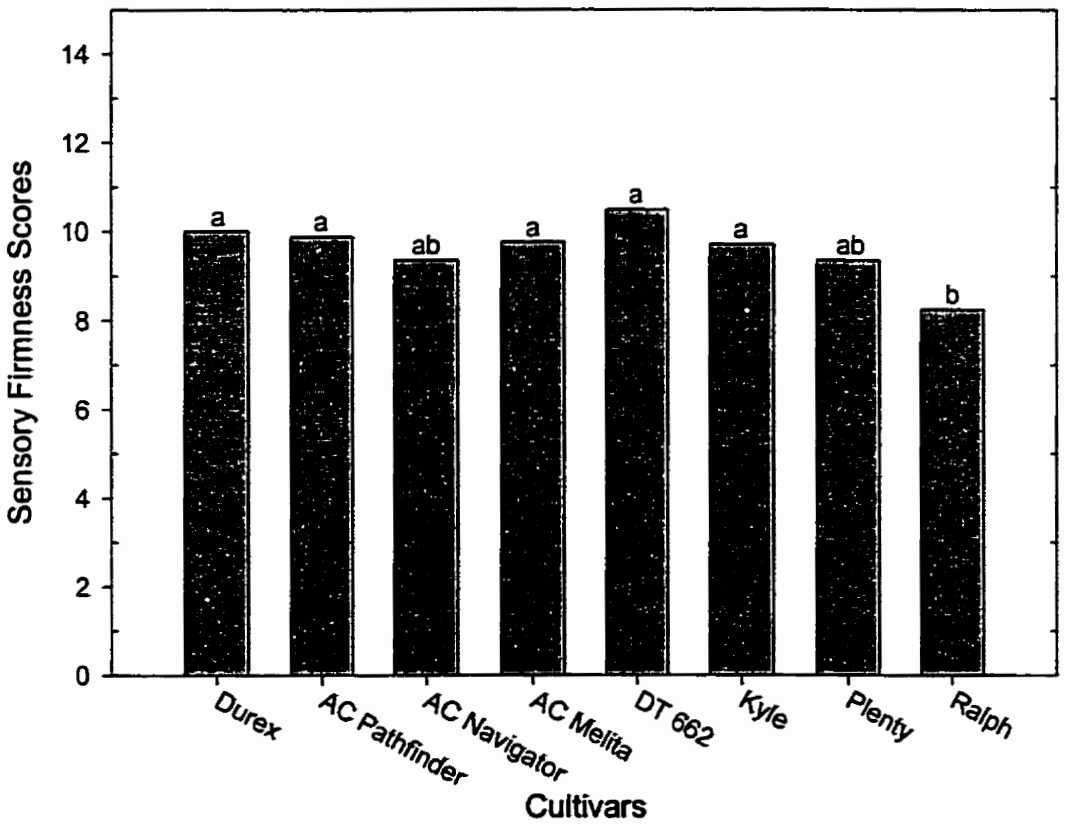

Figure 4.18: **Mean Sensory Scores for Firmness. Bars with the same letter are not significantly different ($p \leq 0.05$).**

replications. Examination of the fixed effects revealed a significant sample effect (Table 4.8). Multiple comparisons of the least square means revealed that AC Melita was rated significantly less chewy than DT 662 and AC Pathfinder over all panelists, drying temperatures and replications (Figure 4.19).

For the analysis of breakdown, the reduced model contained the additional random term of panelist x drying temperature (Table 4.7). Interpretation of a panelists x drying temperature interaction indicates that the panelists differed in their assessments of the drying temperature effect. Analysis of the fixed effects revealed a significant sample effect (Table 4.8). Multiple comparisons of the least square means revealed that DT 662 had a significantly higher degree of breakdown (breaks down into larger pieces) than AC Navigator, AC Pathfinder and Ralph over all panelists, drying temperatures and replications (Figure 4.20). AC Melita, Kyle, Plenty and Durex were rated as having a significantly higher degree of breakdown than AC Pathfinder over all panelists, drying temperatures and replications.

The reduced model for adhesiveness to teeth contained panelist x drying temperature as an additional random term (Table 4.7). Interpretation of this interaction indicates that the panelists differ somewhat in their assessment of the drying temperature effect. None of the fixed effects were found to be

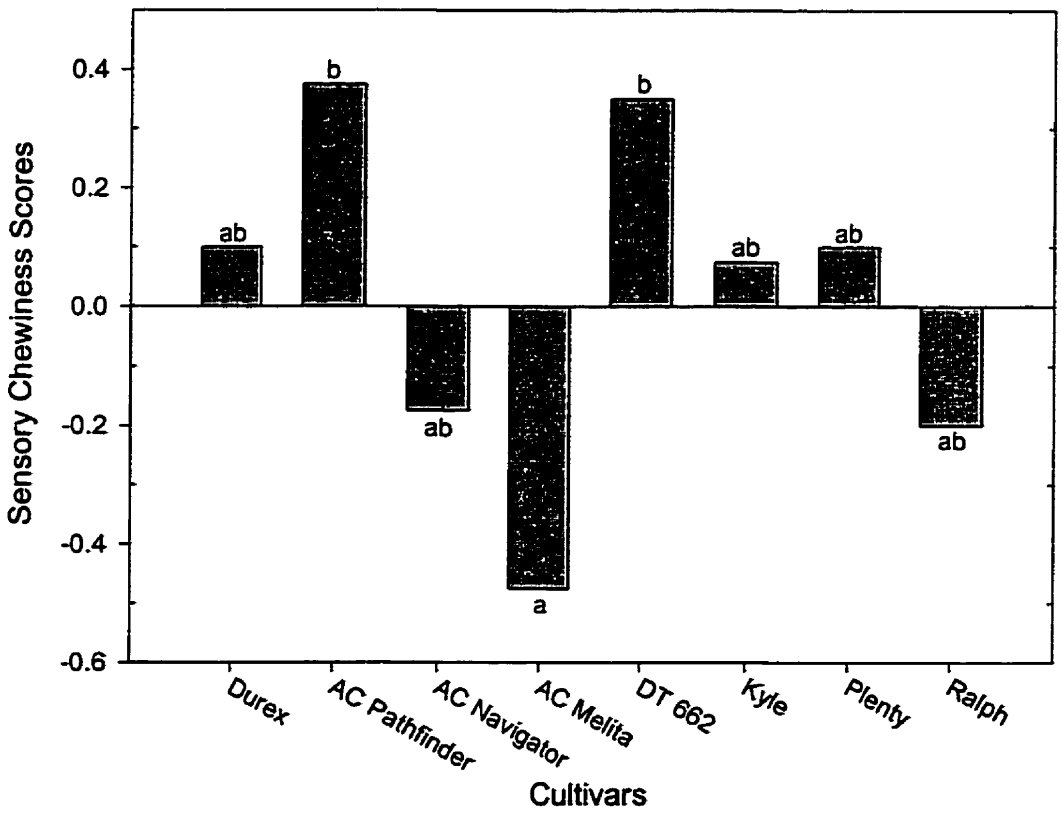

Figure 4.19: **Means Sensory Scores for Chewiness. Bars with the same letter are not significantly different ($p \leq 0.05$).**

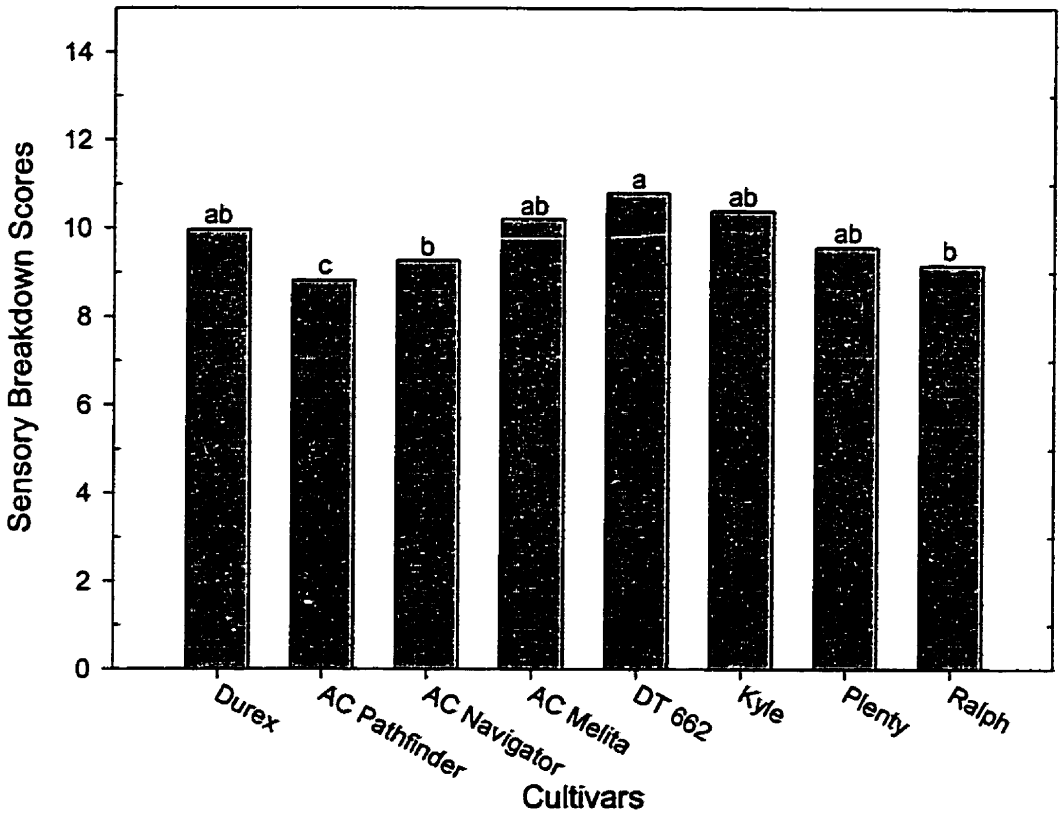

Figure 4.20: **Mean Sensory Scores for Breakdown. Bars with the same letter are not significantly different ($p \leq 0.05$).**

significant (Table 4.8). For the analysis of strand to strand adherence, the reduced model contained panelist, panelist x drying temperature x replication and sample x drying temperature x replication as additional random terms (Table 4.7). Interpretation of a significant panelist effect indicates that the panelists differ in their evaluations of the samples. A significant panelist x drying temperature interaction indicates that the panelists differ in their assessments of the drying temperature effect. Finally, the interaction between sample x drying temperature x replication indicates that the samples differ in their reaction to the different drying temperatures between replications. Analysis of the fixed effects revealed that there were significant sample and drying temperature effects (Table 4.8). Multiple comparisons of the least square means for the effect of sample revealed that AC Pathfinder and AC Navigator were rated as having higher strand to strand adherence values than Durex, AC Melita and Plenty over all panelists, drying temperatures and replications (Figure 4.21). Multiple comparisons of the least square means for the effect of drying temperature revealed that samples dried using a drying temperature of 70°C were rated as having higher strand to strand adherence values than when a drying temperature of 90°C was used over all samples, panelists and replications.

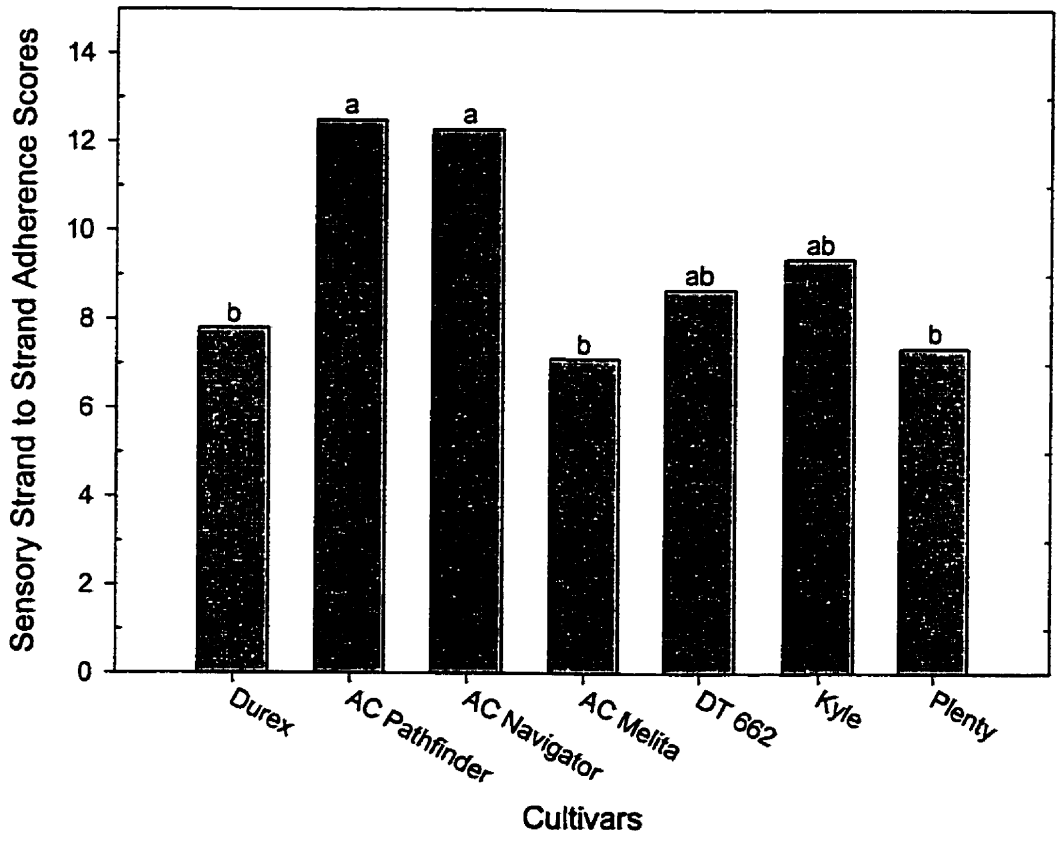

Figure 4.21: **Mean Sensory Scores for Strand to Strand Adherence Scores. Bars with the same letter are not significantly different ($p \leq 0.05$).**

4.3.4 Relationships Between Instrumental and Sensory Evaluations

Correlations between the sensory evaluations and Lloyd and viscoelastograph measurements are presented in Tables 4.9 - 4.10. Measurement of energy using the Lloyd was found to be a good predictor of sensory chewiness ($r = 0.8195$, $p = 0.0241$). Sensory springiness could be predicted by using instrumental stickiness ($r = -0.7517$, $p = 0.0514$) or instrumental adhesiveness ($r = 0.6585$, $p = 0.1078$). No other instrumental tests, performed using the Lloyd proved to be good predictors of sensory springiness, firmness, chewiness, breakdown or adhesiveness to teeth.

Correlation coefficients between sensory measurements and R_r% using the Viscoelastograph are presented in Table 4.10. Only relationships between sensory measurements of springiness, firmness, chewiness and breakdown with R_r% were examined since these sensory measurements were considered to be similar to the evaluations made using the viscoelastograph. Breakdown could be predicted using R_r% when using the 1500 and 2000 g weights ($r = 0.6937$, $p = 0.0839$ and $r = 0.7031$, $p = 0.0780$, respectively). No other sensory measurements could be predicted using R_r% at any other weight tested.

Table 4.9: Correlation Coefficients Between Sensory and Instrumental Measurements of Cooked Spaghetti[1].

Sensory Parameter	Lloyd Measurements						
	Firmness	Shear Force	Compression	Relaxation Time	Stickiness	Energy	Adhesiveness
Springiness	0.0922 (0.8441)	0.2565 (0.5787)	-0.0915 (0.8452)	-0.3540 (0.4359)	-0.7517 (0.0514)	0.6585 (0.1078)	0.7597 (0.0476)
Firmness	-0.2253 (0.6271)	0.0382 (0.9353)	-0.1243 (0.7906)	0.0273 (0.9537)	-0.1627 (0.7275)	0.3307 (0.4688)	0.1557 (0.7388)
Chewiness	-0.5965 (0.1575)	-0.5496 (0.2012)	0.1767 (0.7047)	0.2537 (0.5830)	-0.0650 (0.8898)	0.8195 (0.0241)	0.4430 (0.3195)
Breakdown	-0.1540 (0.7417)	0.0131 (0.9778)	0.2920 (0.5251)	0.4773 (0.2787)	-0.1337 (0.7751)	-0.2649 (0.5659)	-0.0899 (0.8481)
Adhesiveness to Teeth	0.3457 (0.4475)	0.4220 (0.3456)	-0.3013 (0.7130)	-0.3042 (0.5072)	0.0670 (0.8864)	-0.5629 (0.1883)	-0.5120 (0.2401)
Strand to Strand Adherence	0.2614 (0.5712)	0.1488 (0.7501)	-0.6378 (0.1233)	-0.4867 (0.2680)	0.4312 (0.3341)	0.1910 (0.6816)	-0.0610 (0.8966)

[1] Values shown are the correlation coefficient (r) and p-value in parentheses (n = 7).

Table 4.10: Correlation Coefficients between Sensory and Viscoelastograph Measurements of Spaghetti.

Sensory Parameter	Relative Recovery		
	1000 g	1500 g	2000 g
Springiness	-0.5057 (0.2470)	0.0592 (0.8996)	0.1244 (0.7905)
Firmness	-0.1634 (0.7264)	0.5160 (0.2359)	0.6458 (0.1171)
Chewiness	0.1769 (0.7043)	0.5669 (0.1844)	0.6025 (0.1522)
Breakdown	0.5032 (0.2496)	0.6937 (0.0839)	0.7031 (0.0780)

[1] Values shown are the correlation coefficient (r) and p-value in parentheses (n = 7).

4.4 DISCUSSION

Instrumental texture analysis of cooked pasta texture as assessed using the Lloyd showed that pasta made from samples with weaker gluten properties did not necessarily result in pasta with poorer cooking quality than pasta made from samples with stronger gluten properties. Pasta with good cooking quality should have high firmness and shear force values, low compression values, short relaxation times, and low stickiness, energy and adhesiveness values. Results from the evaluation of firmness and shear force values showed that Kyle, with a gluten index value of 6, was not significantly different from AC Navigator, Durex and AC Melita, which all had high firmness values, nor was it significantly different from Durex, AC Navigator and AC Melita, which had high shear force values, over all cooking times and drying temperatures. No significant differences in compression values, relaxation times, stickiness, energy or adhesiveness values were seen between any of the samples when summed over all cooking times and drying temperatures. Grant et al. (1993) also found no significant differences in instrumental stickiness values in samples with different gluten strength. However they only evaluated two samples.

Pasta with good cooking quality should also be better able to tolerate overcooking by retaining its firmness and not increasing in stickiness. Overcooking resulted in decreased values for firmness, shear force,

compression, relaxation time, and increased values for stickiness, energy and adhesiveness when summed over all samples and drying temperatures. Gluten has been found to help prevent the disintegration of pasta during cooking in boiling water (Feillet, 1984). Dexter et al (1981a) found that pasta made from durum wheat with strong gluten properties, as assessed by SDS volume, is more tolerant to overcooking. However, there were no significant interactions between sample and cooking time for any of the parameters evaluated. This indicates that samples with varying gluten strength properties did not react differently to overcooking.

The use of HT drying cycles has been shown to result in improvements in cooking quality, especially for pasta made from poorer quality raw materials (Braibanti, 1980; Abecassis et al., 1989). Improvements imparted by the use of HT and VHT drying include improved firmness (Manser, 1980), decreases in stickiness (Dexter et al., 1981a; Dexter et al., 1983b; De Stefanis and Sgrulletta, 1990) and improved surface conditions (Abecassis et al., 1989). Increasing the drying temperature from 70°C to 90°C resulted in significantly increased values for firmness, shear force, and compression and significantly decreased stickiness, energy and adhesiveness values when summed over all samples and cooking times. A significant interaction between sample and drying temperature was observed for shear force. This indicates that some of the

samples reacted differently to the different drying temperatures when summed over all cooking times. Five of the samples, Durex, AC Navigator, AC Melita, Kyle and Plenty, all had increases in their shear force values when the drying temperature was increased, indicating an increase in firmness with an increase in drying temperature over all cooking times. The interaction between sample and drying temperature for firmness was only slightly greater than the α-level ($Pr>F = 0.0521$). Durex, AC Navigator, Kyle and Plenty all had increases in their firmness values when the drying temperature was increased from 70°C to 90°C over all cooking times. A significant interaction between drying temperature and cooking time was observed for stickiness and adhesiveness values when summed over all samples. Samples dried at 90°C and overcooked (optimum + 5 minutes) resulted in significantly increased stickiness and adhesiveness values, whereas this trend was not observed at 70°C. This occurrence seems to contradict what would be expected. Mondelli (1989) suggests that HT drying results in improvements in cooking resistance. This would be due to the strengthening of the gluten network due to the increased heat of the HT drying cycle (Manser, 1980; De Stefanis and Sgrulletta, 1990). Therefore it would be expected that the pasta dried at 90°C and overcooked would have lower stickiness and adhesiveness values than pasta dried at 70°C and overcooked since HT drying cycles are believed to result in improvements to pasta cooking quality such as decreases in stickiness values and the ability

to better tolerate overcooking. One reason for this could be that the two drying cycles used did not fully simulate commercial drying cycles where differences between 70 and 90°C drying cycles are known to occur.

Results from the viscoelastograph evaluation of spaghetti texture showed that samples with weaker gluten properties had higher R_r% values than samples with stronger gluten properties when summed over both drying temperatures for all weights evaluated. Higher R_r% values were found in pasta discs made from samples with stronger gluten properties, indicating a higher degree of elasticity (Kovacs et al., 1995b). However this was not observed. Pasta made from samples with stronger gluten properties (Durex, AC Pathfinder, AC Navigator, AC Melita) tended to have lower R_r% values than pasta made from samples with weaker gluten properties (DT 662, Kyle, Plenty) for all weights examined over all drying temperatures. This was also observed by Ames et al (1999).

A significant interaction between sample and drying temperature was observed for only the 1500 g weight indicating that some of the samples behaved differently to the different drying temperatures. Using a drying temperature of 90°C resulted in decreased R_r% values for Kyle, having weaker gluten properties, and Durex, having stronger gluten properties. However Plenty, a sample with weaker gluten properties exhibited the opposite trend; an increase

in R_r% values with increased drying temperature.

Sensory evaluation of the textural properties of cooked pasta dried at 70°C and 90°C showed that there were differences between samples for firmness, chewiness, breakdown and strand to strand adherence. As previously mentioned, pasta with good cooking quality should have high springiness, firmness, chewiness and breakdown scores and low adhesiveness to teeth and strand to strand adherence scores. Samples with lower gluten strength properties were not found to be significantly different in sensory springiness and firmness scores than pasta made from samples with stronger gluten properties over all panelists, drying temperatures and replications. For breakdown, DT 662, Kyle and Plenty, all having weaker gluten properties, were found to have high breakdown scores, indicating that they breakdown into large pieces, and were not significantly different from Durex, having stronger gluten properties. Visual evaluation of strand to strand adherence showed that AC Melita, which has strong gluten properties, had the lowest strand to strand adherence score over all panelists, drying temperatures and replications, however it was not significantly different from Plenty, DT 662 or Kyle, all having weaker gluten properties. AC Pathfinder and AC Navigator, both having stronger gluten properties, were found to have significantly higher strand to strand adherence values than Durex, AC Melita and Plenty.

Correlations between instrumental and sensory measurements of cooked pasta were investigated. However, few significant correlations were found. When correlations between sensory and instrumental measurements are between ± 0.9 to ± 1.0 they can be used with confidence to say that the instrumental test is a valid as a predictor of the sensory score (Kramer, 1951). Correlation coefficients between ± 0.8 to ± 0.9 can be used as predictors, but with less confidence. Correlation coefficients between ± 0.7 to ± 0.8, are marginally predictive and those less than ± 0.7 suggest that the instrumental test is a poor predictor of the sensory score (Bourne, 1982). The inability to establish correlations between instrumental and sensory measurements in the present study may be the result of the narrow range of cooking quality in the samples for some of the parameters evaluated. Differences in the testing protocol between instrumental and sensory analyses may also have contributed to the inability to establish correlations. Sensory panelists were required to evaluate all five textural parameters (orally) during a test session. Whereas, for instrumental evaluations, spaghetti samples were tested seven minutes after cooking was completed. This difference in spaghetti sample waiting time may have played a role since it is known that textural changes occur after cooking (Voisey et al., 1978b).

Other researchers have also been unable to establish correlations between

instrumental and sensory measurements of cooked pasta texture. Voisey et al. (1978a) were unable to correlate instrumental stickiness (tensile force) measurements with sensory ratings ($r=-0.17$). They suggested the poor relationship could be a result of (1) the insufficient range of adhesiveness in the samples, (2) instrumental and sensory readings may not have been related to the same physical characteristics and (3) saliva was not used in the instrumental test so that the adhesive properties were not comparable to those in the mouth. However Boyd and Sherman (1975a) have suggested that the lack of correlation between instrumental stickiness and sensory measurements occurred even when saliva was used for instrumental measurements. Selection of instrumental test conditions that closely simulate conditions during mastication are of utmost importance if instrumental data is to be used to predict sensory measurements (Boyd and Sherman, 1975b). Walsh (1971) was able to find a high positive correlation between firmness (work to shear) and panel scores for firmness ($r=0.812$). Voisey et al. (1978b) were able to find relationships between the results of the mean instrumental cutting force and mean sensory scores for firmness ($r=0.54$, $p=0.05$) and rate of breakdown ($r=-0.72$, $p=0.01$).

It must be mentioned that AC Pathfinder had a low falling number (FN 235 sec) and high sprouting value (9.0%) (See Chapter 3, Table 3.2). Effects of high sprout damage on pasta cooking quality have been inconclusive. Maier (1980)

found that even 1% sprout damage can adversely affect firmness in cooked spaghetti. Matsuo et al. (1982b) found that high α-amylase activity was related to a higher tenderness index (i.e. loss of firmness) possibly as a result of the breakdown of the starch gel structure by α-amylases resulting in a softer cooked product. Grant et al. (1993) also found that sprouted samples, with a falling number value between 150-200 sec, had decreased firmness values as compared to unsprouted samples. However, Dexter et al. (1990) found that α-amylase activity did not have a significant effect on spaghetti cooking score (firmness and resilience), regardless of drying temperature. Even the pasta made from samples having a falling number of 105 sec and 175 sec ranked near the middle in overall cooking quality. Dexter et al. (1990) found that pasta made from highly sprouted sample (FN 105 sec) had the lowest stickiness value. Dick et al. (1974) and Donnelly (1980) also found very little effect of sprout damage on pasta cooking quality. It has also been suggested that HT drying can result in reduced stickiness values in pasta made from sprouted samples. However Grant et al. (1993) did not observe this effect.

In this study, the results clearly showed that pasta made from samples with increased gluten strength did not necessarily result in increased pasta cooking quality. Pasta made from samples with weaker gluten properties did not necessarily have poor cooking quality than pasta made from samples with

stronger gluten properties. Results from both instrumental and sensory evaluations support these conclusions.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 CONCLUSIONS

The objective of the first part of this thesis was to characterize the rheological and starch properties of semolina from seven durum wheat cultivars varying in gluten strength. Cultivars with stronger gluten strength properties (Durex, AC Pathfinder, AC Navigator, AC Melita) had higher GI values, higher SDS sedimentation volumes, higher gluten extensibility peak force values, longer mixograph times to peak (MPT), higher curves heights at peak (MPH) and wider curve bandwiths at peak (BWP) and higher alveograph P/L ratios and deformation energy (W) values than cultivars with weaker gluten strength properties (DT 662, Kyle, Plenty).

Differences between the cultivars were observed in starch pasting properties but not total starch and amylose contents. Differences between cultivars in starch pasting properties did not relate to cultivar differences based on gluten strength properties.

The objectives of the second part of this thesis were to investigate the effects of gluten strength on spaghetti cooking quality and to determine the effect of drying temperature on the cooking quality of spaghetti made from cultivars

varying in gluten strength. The relationship between instrumental and sensory measurements of cooked spaghetti was also examined.

Spaghetti cooking quality, measured using the Lloyd, did not show significant textural differences among cultivars in terms of firmness, shear force, compression, relaxation time, stickiness, adhesiveness or energy. Overcooking resulted in poorer cooking quality, specifically decreased firmness, shear force, compression and relaxation times and increased stickiness, adhesiveness and energy values for all cultivars but no differences in tolerance to overcooking were found among cultivars. Higher viscoelastograph R_t% values were found for cultivars with weaker gluten strength properties regardless of the weights used. This was also observed by Ames et al. (1999).

No significant differences among cultivars were observed for springiness and adhesiveness to teeth scores when evaluated using a trained sensory panel. Significant differences were observed among cultivars for firmness, chewiness and breakdown scores, but no consistent trend was observed between cultivars with weak and strong gluten properties. Low strand to strand adherence values were observed for cultivars with weak gluten strength properties but cultivars with stronger gluten strength properties were found to have both low and high strand to strand adherence values.

Pasta dried at 90°C had higher firmness, shear force, compression and relaxation times and decreased stickiness, adhesiveness and energy values compared to cultivars dried at 70°C when summed over all cultivars and cooking times. Significant increases in shear force and firmness values were observed among cultivars when dried at 90°C, however no consistent trend was observed between cultivars with weak and strong gluten strength properties. No difference in R_r% values were seen between pasta dried at 70 or 90°C for both the 1000 and 2000g weights. Using a weight of 1500g, differences in R_r% were observed between the two drying temperatures. However, the trend was not related to gluten strength and was also not consistent, in that some cultivars had increased R_r% values, while others had decreased R_r% values. No significant differences were observed in sensory springiness, firmness, chewiness, breakdown and adhesiveness to teeth for either of the two drying temperatures. Strand to strand adherence scores were lower for pasta dried at 90°C but was not related to gluten strength properties.

There were few, if any, significant relationships between instrumental and sensory measurements of cooked pasta texture. This was most likely a result of the narrow range in cooking quality present in the spaghetti samples. Overall, gluten strength properties had more of an effect on rheological properties of the semolina than it did on spaghetti cooking quality. Spaghetti made from cultivars

with weaker gluten strength was comparable to spaghetti made from cultivars with stronger gluten strength properties.

5.2 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

One of the limitations of this research was that some of the cultivars used were graded lower than a No. 1 CWAD. As well, AC Pathfinder had a low falling number (235 sec) and also had a high degree of sprouted kernels (9.0%). This would account for its poor pasting characteristics and may account for the high degree of strand to strand adherence observed. It was hoped that the cultivars selected for this study would have the same protein content. However, even though the protein content of the semolinas only ranged from 11.4 to 12.5% this range was found to be significantly different. Ideally, samples used in future studies should be of the same grade, soundness and protein content.

Spaghetti processed and dried for this research was done using a laboratory scale extruder and drier. Therefore it may not be comparable to spaghetti made by commercial manufacturers where continuous processing occurs. It would therefore be beneficial for future research to occur on a larger scale, using equipment which is used in commercial processing. In addition, the drying temperature cycles (70 and 90°C) used in this research may not have been different enough to allow differences in cooking quality to be seen between the

cultivars dried at the two temperatures. Laboratory drying cycles that more closely mimic commercial drying cycles should be developed and evaluated.

Currently pasta manufacturers are using blends of durum cultivars differing in their strength properties in order to achieve the desired end product quality. The use of cultivars with stronger gluten strength properties may be desirable in the blends in order to "carry" the cultivars with weaker gluten strength properties. Further research is needed in this area to evaluate the ability of cultivars with stronger gluten strength properties to carry weaker cultivars and the levels of each required to produce pasta with acceptable cooking quality.

New varieties of durum wheats with increased gluten strength are currently being developed because of the demand by some pasta manufacturers for greater gluten strength. More research is needed to understand what properties durum wheat with extra strong gluten properties offers in terms of pasta cooking quality. Further investigation into starch properties such as starch granule size distribution is also recommended in order to provide additional information about the role of starch in pasta cooking quality.

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APPENDIX 1

Protein Content of Wheat and Semolina

Sample	Rep	Wheat Protein (%)	Semolina Protein (%)
Durex	1	13.064	12.222
	2	13.127	12.257
AC Pathfinder	1	13.084	11.999
	2	12.883	11.994
AC Navigator	1	12.862	11.463
	2	12.616	11.447
AC Melita	1	12.936	11.918
	2	12.949	11.827
DT 662	1	13.463	12.626
	2	13.529	12.176
Kyle	1	13.255	12.025
	2	13.102	11.934
Plenty	1	----[1]	11.777
	2	----[1]	11.934

[1]No wheat sample of Plenty was available for testing.

APPENDIX 2

Results from Gluten Index (GI), Wet and Dry Gluten Contents and Sodium Dodecyl Sedimentation (SDS) Tests

Sample	Rep	GI (%)	Wet Gluten (g)	Dry Gluten (g)	SDS (mL)
Durex	1	85.0	3.30	1.38	68
	2	82.1	3.40	1.41	69
AC Pathfinder	1	75.4	3.21	1.22	81
	2	81.1	3.21	1.10	84
AC Navigator	1	74.9	2.98	1.10	54
	2	70.9	2.99	1.20	54
AC Melita	1	69.8	3.05	1.21	64
	2	66.4	3.11	1.14	64
DT 662	1	12.1	3.34	1.19	50
	2	5.0	3.40	1.21	48
Kyle	1	9.0	3.14	1.16	44
	2	2.9	3.14	1.11	47
Plenty	1	1.3	3.12	1.15	---[1]
	2	2.6	3.12	1.18	---[1]

[1]No wheat sample of Plenty was available for testing.

APPENDIX 3

Summary of Means and Standard Deviations for Gluten Extensibility Data[1]

Sample	Rep	Peak Breaking Force (g)	Time (sec)	Extensibility (mm)	Area (g·mm)
Durex	1	110(30)	21.86(1.04)	-109.3(5.2)	7054(1597)
	2	100(10)	23.56(2.68)	-117.8(13.4)	5234(643)
AC Pathfinder	1	100(20)	18.22(0.30)	-91.1(1.5)	4978(1261)
	2	90(0)	23.59(4.10)	-118.0(20.5)	6308(535)
AC Navigator	1	80(10)	25.48(1.79)	-127.4(8.9)	5111(253)
	2	130(10)	16.58(0.67)	-82.9(3.3)	5361(1368)
AC Melita	1	70(10)	20.36(4.00)	-101.8(20.0)	4118(4)
	2	80(0)	23.44(1.04)	-117.2(5.2)	5896(653)
DT 662	1	40(0)	35.03(1.34)	-175.2(6.7)	3305(377)
	2	40(0)	26.83(2.84)	-134.2(14.2)	2542(666)
Kyle	1	40(10)	30.91(3.89)	-154.6(19.5)	2733(164)
	2	40(0)	29.99(5.91)	-149.9(29.6)	3003(396)
Plenty	1	40(0)	30.72(0.70)	-153.6(3.5)	3806(375)
	2	40(0)	35.87(3.21)	-179.4(16.1)	4115(900)

[1]Values are the mean and (sd) of two subsamples per duplicate.

APPENDIX 4

Results from Micromixograph Data Analyzed Using Envelope Analysis

Results for Micromixograph Data Analyzed Using Envelope Analysis for DT 662[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	1.00	2.80	5.56	20.6	38.5	32.7	30.4	18.94	-2.69	-0.54	9.3	13.9	9.2	8.4
2	1.00	2.76	5.46	21.5	40.2	33.4	30.8	19.23	-3.40	-0.50	9.7	14.1	9.3	8.4
3	0.88	2.67	5.16	21.3	42.2	36.3	33.4	20.59	-3.20	-0.66	9.8	15.1	10.0	9.4
4	0.94	2.73	5.58	21.7	41.4	34.9	32.5	19.99	-3.23	-0.41	9.8	14.5	9.5	8.8
avg	0.95	2.74	5.44	21.3	40.6	34.3	31.8	19.69	-3.13	-0.53	9.6	14.4	9.5	8.7
(sd)	(0.06)	(0.05)	(0.19)	(0.5)	(1.6)	(1.6)	(1.4)	(0.75)	(0.31)	(0.10)	(0.2)	(0.5)	(0.3)	(0.5)

Results for Micromixograph Data Analyzed Using Envelope Analysis for AC Pathfinder[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	1.06	3.42	6.10	22.0	49.2	44.2	42.0	17.97	-2.57	-0.49	9.8	21.4	14.1	13.0
2	0.71	3.28	6.30	17.2	51.2	46.1	43.4	19.09	-2.24	-1.02	7.7	22.4	14.7	13.2
3	1.32	3.38	5.97	28.7	52.9	47.7	45.1	19.26	-2.84	-0.61	13.5	22.8	15.0	13.7
4	0.92	3.46	6.01	21.7	53.2	48.4	45.1	19.59	-2.67	-0.99	9.7	22.7	15.4	13.8
avg	1.00	3.38	6.09	22.4	51.6	46.6	43.9	18.98	-2.58	-0.78	10.2	22.3	14.8	13.4
(sd)	(0.25)	(0.08)	(0.15)	(4.7)	(1.8)	(1.9)	(1.5)	(0.70)	(0.25)	(0.27)	(2.4)	(0.6)	(0.5)	(0.4)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; MRH is the time to the point right of peak; MEH is the time at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; BWR is the width of the curve at the point MRT; BWE is the width of the curve at MET;

APPENDIX 4 cont'd

Summary of Results for Micromixograph Data Analyzed Using Envelope Analysis for AC Navigator[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	0.34	3.66	7.27	9.5	45.7	34.7	33.4	16.49	-3.56	-1.60	4.8	19.8	12.1	11.4
2	0.59	3.66	7.33	13.6	47.9	38.2	37.1	16.75	-3.17	-1.58	6.5	21.3	13.7	13.1
3	0.51	3.58	6.92	13.3	48.9	39.3	37.0	17.21	-3.52	-1.73	6.2	21.1	13.9	12.6
4	0.82	3.55	7.19	18.3	49.7	38.4	36.6	18.15	-3.80	-2.00	8.7	21.7	13.5	12.5
avg (sd)	0.56 (0.20)	3.61 (0.06)	7.18 (0.18)	13.7 (3.6)	48.0 (1.7)	37.6 (2.0)	36.0 (1.8)	17.15 (0.73)	-3.51 (0.26)	-1.73 (0.19)	6.5 (1.6)	21.0 (0.8)	13.3 (0.8)	12.4 (0.7)

Results for Micromixograph Data Analyzed Using Envelope Analysis for Durex[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	1.96	3.48	5.70	33.9	49.3	44.5	41.3	16.84	-2.71	-1.13	16.0	22.0	17.6	15.3
2	1.86	3.39	6.49	35.5	52.6	45.3	43.8	18.16	-2.74	-0.58	16.7	23.6	17.4	16.6
3	1.53	3.45	5.80	30.3	52.7	47.2	44.1	18.37	-3.04	-1.08	14.5	23.7	18.8	16.3
4	1.26	3.52	6.37	25.1	52.2	46.8	45.0	18.70	-2.48	-0.51	12.1	23.1	18.4	17.0
avg (sd)	1.65 (0.32)	3.46 (0.05)	6.09 (0.40)	31.2 (4.6)	51.7 (1.6)	45.9 (1.3)	43.5 (1.6)	18.02 (0.81)	-2.74 (0.23)	-0.82 (0.32)	14.8 (2.0)	23.1 (0.8)	18.0 (0.7)	16.3 (0.7)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; MRH is the time to the point right of peak; MEH is the time at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; BWR is the width of the curve at the point MRT; BWE is the width of the curve at MET;

APPENDIX 4 cont'd

Results for Micromixograph Data Analyzed Using Envelope Analysis for Kyle[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	0.80	2.49	5.24	18.8	38.1	28.6	25.1	19.45	-4.77	-0.57	8.2	14.0	7.3	6.0
2	0.78	2.62	5.16	18.5	38.5	29.3	27.0	19.22	-4.63	-0.39	8.2	13.9	7.5	6.9
3	0.96	2.89	5.41	19.6	38.6	32.3	29.2	17.22	-3.46	-0.63	8.6	13.1	8.8	7.3
4	0.76	2.51	5.08	20.0	41.2	31.2	25.5	20.60	-5.23	-1.29	8.9	15.4	8.2	6.0
avg (sd)	0.82 (0.09)	2.63 (0.18)	5.22 (0.14)	19.2 (0.7)	39.1 (1.4)	30.3 (1.7)	26.7 (1.8)	19.12 (1.40)	-4.52 (0.75)	-0.72 (0.39)	8.5 (0.3)	14.1 (0.9)	7.9 (0.7)	6.5 (0.6)

Results for Micromixograph Data Analyzed Using Envelope Analysis for AC Melita[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	1.27	3.55	7.25	23.4	46.4	35.2	33.9	16.31	-3.55	-1.55	10.8	20.2	11.3	10.6
2	1.07	3.50	7.22	21.7	46.7	36.6	35.4	17.96	-3.18	-1.36	10.3	20.3	11.7	11.1
3	1.69	3.47	6.87	29.7	46.2	38.6	37.0	15.81	-2.81	-1.02	13.6	20.0	13.3	12.3
4	1.57	3.58	6.88	30.7	50.5	42.2	40.2	17.65	-3.18	-1.36	13.8	21.6	13.9	13.1
avg (sd)	1.40 (0.28)	3.52 (0.05)	7.05 (0.21)	26.4 (4.5)	47.4 (2.0)	38.1 (3.0)	36.6 (2.7)	16.93 (1.03)	-3.18 (0.30)	-1.32 (0.22)	12.1 (1.8)	20.5 (0.7)	12.5 (1.2)	11.8 (1.1)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; MRH is the time to the point right of peak; MEH is the time at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; BWR is the width of the curve at the point MRT; BWE is the width of the curve at MET;

APPENDIX 4 cont'd

Results for Micromixograph Data Analyzed Using Envelope Analysis for Plenty[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
1	0.63	2.41	4.91	14.6	34.3	25.3	22.1	17.83	-4.68	-0.53	6.4	12.5	6.4	5.3
2	0.67	2.48	4.76	15.4	35.0	26.5	22.6	17.76	-4.65	-0.91	6.6	12.6	7.0	5.7
3	0.68	2.57	4.82	16.2	37.2	28.6	24.5	17.99	-4.87	-0.93	7.0	13.1	7.5	5.8
4	0.54	2.46	5.53	14.7	37.9	26.3	23.4	19.60	-4.84	-0.37	6.5	13.3	6.3	5.1
avg (sd)	0.63 (0.06)	2.48 (0.07)	5.00 (0.35)	15.2 (0.7)	36.1 (1.72)	26.7 (1.4)	23.1 (1.0)	18.3 (0.9)	-4.76 (0.11)	-0.68 (0.28)	6.6 (0.3)	12.9 (0.4)	6.8 (0.5)	5.5 (0.3)

Mean Values for All Samples Analyzed Using Envelope Analysis[1]

Sample	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)
DT 662	0.95	2.74	5.44	21.3	40.6	34.3	31.8	19.69	-3.13	-0.53	9.6	14.4	9.5	8.7
AC Pathfinder	1.00	3.38	6.09	22.4	51.6	46.6	43.9	18.98	-2.58	-0.78	10.2	22.3	14.8	13.4
AC Navigator	0.56	3.61	7.18	13.7	48.0	37.6	36.0	17.15	-3.51	-1.73	6.5	21.0	13.3	12.4
Durex	1.65	3.46	6.09	31.2	51.7	45.9	43.5	18.02	-2.74	-0.82	14.8	23.1	18.0	16.3
Kyle	0.82	2.63	5.22	19.2	39.1	30.3	26.7	19.12	-4.52	-0.72	8.5	14.1	7.9	6.5
AC Melita	1.40	3.52	7.05	26.4	47.4	38.1	36.6	16.93	-3.18	-1.32	12.1	20.5	12.5	11.8
Plenty	0.63	2.48	5.00	15.2	36.1	26.7	23.1	18.3	-4.76	-0.68	6.6	12.9	6.8	5.5

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; MRH is the time to the point right of peak; MEH is the time at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; BWR is the width of the curve at the point MRT; BWE is the width of the curve at MET.

APPENDIX 5

Results from Micromixograph Data Analyzed Using Mid-Line Analysis

Results for Micromixograph Data Analyzed Using Mid-Line Analysis for DT 662[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	2.61	3.11	4.11	31.1	31.7	30.4	26.2	2.56	-1.68
2	2.47	2.97	3.97	32.3	33.3	31.7	26.5	3.70	-2.49
3	2.43	2.93	3.93	34.0	35.0	33.5	28.6	3.86	-2.23
4	2.58	3.08	4.08	33.7	34.5	32.8	28.0	2.96	-2.33
avg	2.52	3.02	4.02	32.8	33.6	32.1	27.3	3.27	-2.18
(sd)	(0.09)	(0.09)	(0.09)	(1.3)	(1.5)	(1.3)	(1.1)	(0.61)	(0.35)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-0.36	14.5	12.8	10.4	8.4	49.8	65.5	96.8	204.8
2	-0.37	14.8	13.4	10.7	8.4	47.5	64.0	96.7	211.2
3	-0.59	15.8	14.2	11.3	9.4	49.8	67.2	101.6	225.9
4	-0.39	15.1	13.3	10.9	8.8	53.5	70.6	104.4	221.0
avg	-0.43	15.0	13.4	10.8	8.7	50.1	66.8	99.9	215.7
(sd)	(0.11)	(0.6)	(0.6)	(0.4)	(0.5)	(2.5)	(2.8)	(3.8)	(9.5)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Results for Micromixograph Data Analyzed Using Mid-Line Analysis for AC Pathfinder[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	3.04	3.54	4.54	37.5	38.5	38.0	35.5	4.07	-0.80
2	3.16	3.66	4.66	39.9	40.4	39.9	36.8	2.22	-0.47
3	3.11	3.61	4.61	40.9	41.6	41.0	38.3	3.09	-0.65
4	3.37	3.87	4.87	41.6	42.0	41.4	38.1	1.82	-0.72
avg	3.17	3.67	4.67	40.0	40.6	40.1	37.2	2.80	-0.66
(sd)	(0.14)	(0.14)	(0.14)	(1.8)	(1.6)	(1.5)	(1.3)	(1.0)	(0.14)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-0.57	21.6	21.1	18.1	13.0	67.1	86.2	124.5	252.1
2	0.71	22.5	21.4	18.0	13.2	76.2	96.3	136.5	265.2
3	-0.49	23.3	22.2	18.6	13.7	75.3	96.1	137.4	272.2
4	-0.86	22.9	21.5	18.0	13.8	87.0	107.9	149.7	274.9
avg	-0.66	22.6	21.5	18.2	13.4	76.4	96.6	137.0	266.1
(sd)	(0.16)	(0.7)	(0.5)	(0.3)	(0.4)	(8.2)	(8.9)	(10.3)	(10.2)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Results for Micromixograph Data Analyzed Using Mid-Line Analysis for AC Navigator[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	3.28	3.78	4.78	35.1	35.9	34.2	27.5	3.25	-2.46
2	3.33	3.83	4.83	36.8	37.5	36.2	30.2	3.09	-1.72
3	3.15	3.65	4.65	37.3	38.4	37.2	30.4	4.15	-1.87
4	3.14	3.64	4.64	37.9	39.1	37.8	30.1	4.46	-1.87
avg	3.22	3.72	4.72	36.8	37.7	36.3	29.5	3.74	-1.98
(sd)	(0.09)	(0.09)	(0.09)	(1.2)	(1.4)	(1.6)	(1.4)	(0.67)	(0.33)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-1.29	19.9	19.6	17.8	11.4	69.6	87.4	122.7	221.4
2	-1.33	21.5	21.1	18.8	13.1	73.4	92.1	129.0	234.0
3	-1.27	21.4	20.9	19.2	12.6	70.6	89.6	127.5	240.0
4	-1.50	21.6	21.5	19.5	12.5	70.4	89.7	128.3	242.0
avg	-1.35	21.1	20.8	18.8	12.4	71.0	89.7	126.9	234.3
(sd)	(0.10)	(0.80)	(0.8)	(0.7)	(0.7)	(1.6)	(1.9)	(2.8)	(9.3)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Results for Micromixograph Data Analyzed Using Mid-Line Analysis for Durex[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	3.07	3.57	4.57	37.3	38.5	37.2	33.8	4.97	-1.55
2	3.01	3.51	4.51	39.6	41.0	39.6	35.3	5.24	-1.92
3	3.07	3.57	4.57	40.0	41.2	39.8	35.8	4.96	-2.01
4	3.09	3.59	4.59	39.8	41.1	39.8	36.4	5.00	-1.94
avg	3.06	3.56	4.56	39.2	40.4	39.1	35.3	5.04	-1.85
(sd)	(0.03)	(0.03)	(0.03)	(1.3)	(1.3)	(1.3)	(1.1)	(0.13)	(0.21)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-0.63	21.8	21.9	19.6	15.3	62.5	81.5	119.6	240.5
2	-0.59	23.5	23.3	21.1	16.6	66.1	86.4	126.8	256.1
3	-0.76	23.6	23.4	21.2	16.3	69.1	89.5	130.1	258.5
4	-0.36	23.3	23.1	21.2	17.0	69.1	89.4	130.1	258.7
avg	-0.58	23.05	22.9	20.8	16.3	66.7	86.7	126.6	253.4
(sd)	(0.16)	(0.84)	(0.7)	(0.8)	(0.7)	(3.1)	(3.7)	(4.9)	(8.7)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Results for Micromixograph Data Analyzed Using Mid-Line Analysis for Kyle[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	2.18	2.68	3.68	30.2	31.3	29.1	21.8	4.40	-3.46
2	2.36	2.86	3.86	30.7	31.7	29.2	23.4	3.56	-3.51
3	2.59	3.09	4.09	31.3	32.2	30.2	25.5	3.70	-2.50
4	2.17	2.67	3.67	32.3	33.7	31.1	22.2	5.13	-3.89
avg	2.32	2.82	3.82	31.1	32.2	29.9	23.2	4.20	-3.34
(sd)	(0.20)	(0.20)	(0.20)	(0.9)	(1.0)	(0.9)	(1.7)	(0.72)	(0.59)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-0.57	14.7	13.4	9.8	6.0	39.6	55.1	85.6	190.6
2	-0.42	14.5	12.8	9.6	6.9	45.0	60.7	91.3	195.0
3	-0.51	14.0	12.6	10.2	7.3	48.8	64.7	96.1	202.9
4	-1.10	16.4	14.8	10.7	6.0	42.7	59.3	92.1	203.5
avg	-0.65	14.9	13.4	10.1	6.5	44.0	59.9	91.3	198.0
(sd)	(0.31)	(1.0)	(1.0)	(0.5)	(0.6)	(3.9)	(4.0)	(4.3)	(6.3)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Results for Micromixograph Data Analyzed Using Mid-Line Analysis for AC Melita[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	3.18	3.68	4.68	35.8	36.5	35.3	28.5	2.98	-1.76
2	3.11	3.61	4.61	35.8	36.7	35.6	29.9	3.50	-1.42
3	3.08	3.58	4.58	35.4	36.4	35.7	30.7	3.63	-0.95
4	3.25	3.75	4.75	39.4	40.0	39.2	33.5	2.36	-1.54
avg	3.15	3.65	4.65	36.6	37.4	36.4	30.6	3.12	-1.42
(sd)	(0.07)	(0.07)	(0.07)	(1.9)	(1.7)	(1.8)	(2.1)	(0.58)	(0.34)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-1.27	20.5	20.0	16.9	10.6	66.9	85.0	121.0	226.5
2	-0.94	20.6	20.1	17.2	11.1	66.5	84.7	121.0	231.5
3	-0.83	20.2	19.9	17.5	12.3	63.3	81.4	117.5	230.8
4	-1.20	21.9	21.3	18.5	13.1	76.6	96.5	136.3	254.0
avg	-1.06	20.8	20.3	17.5	11.8	68.3	86.9	123.9	235.7
(sd)	(0.21)	(0.7)	(0.6)	(0.7)	(1.1)	(5.7)	(6.6)	(8.4)	(12.4)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Results for Micromixograph Data Analyzed Using Midline Analysis for Plenty[1]

Rep	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
1	2.04	2.54	3.54	26.7	28.0	25.7	19.1	5.06	-3.02
2	2.15	2.65	3.65	27.7	28.8	26.2	19.6	4.42	-3.50
3	2.21	2.71	3.71	29.4	30.7	28.1	21.4	5.05	-3.56
4	2.11	2.61	3.61	29.9	31.3	28.7	20.5	5.03	-3.56
avg	2.13	2.63	3.63	28.4	29.7	27.2	20.1	4.89	-3.41
(sd)	(0.07)	(0.07)	(0.07)	(1.5)	(1.5)	(1.4)	(1.0)	(0.31)	(0.26)

Rep	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
1	-0.56	13.1	12.1	8.7	5.3	32.6	46.4	73.5	168.3
2	-0.80	13.2	11.9	8.8	5.7	36.0	50.3	78.1	172.5
3	-0.62	13.8	12.6	9.3	5.8	39.1	54.2	83.9	185.6
4	-0.31	14.1	12.7	9.4	5.1	38.7	54.1	84.4	186.1
avg	-0.57	13.5	12.3	9.0	5.5	36.6	51.2	80.0	178.1
(sd)	(0.20)	(0.5)	(0.4)	(0.3)	(0.3)	(3.0)	(3.7)	(5.2)	(9.1)

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 5 (Cont'd)

Mean Values for All Samples Analyzed Using Mid-Line Analysis[1]

Sample	MLT (min)	MPT (min)	MRT (min)	MLH (%Tq)	MPH (%Tq)	MRH (%Tq)	MEH (%Tq)	MLS (%Tq/min)	MRS (%Tq/min)
DT 662	2.52	3.02	4.02	32.8	33.6	32.1	27.3	3.27	-2.18
AC Pathfinder	3.17	3.67	4.67	40.0	40.6	40.1	37.2	2.8	-0.66
AC Navigator	3.22	3.72	4.72	36.8	37.7	36.3	29.5	3.74	-1.98
Durex	3.06	3.56	4.56	39.2	40.4	39.1	35.3	5.04	-1.85
Kyle	2.32	2.82	3.82	31.1	32.2	29.9	23.2	4.20	-3.34
AC Melita	3.15	3.65	4.65	36.6	37.4	36.4	30.6	3.12	-1.42
Plenty	2.13	2.63	3.63	28.4	29.7	27.2	20.1	4.89	-3.41

Sample	MES (%Tq/min)	BWL (%Tq)	BWP (%Tq)	BWR (%Tq)	BWE (%Tq)	MLE (%Tq·min)	MPE (%Tq·min)	MRE (%Tq·min)	MEE (%Tq·min)
DT 662	-0.43	15.0	13.4	10.8	8.7	50.1	66.8	99.9	215.7
AC Pathfinder	-0.66	22.6	21.5	18.2	13.4	76.4	96.6	137.0	266.1
AC Navigator	-1.35	21.1	20.8	18.8	12.4	71.0	89.7	126.9	234.3
Durex	-0.58	23.05	22.9	20.8	16.3	66.7	86.7	126.6	253.4
Kyle	-0.65	14.9	13.4	10.1	6.5	44.0	59.9	91.3	198.0
AC Melita	-1.06	20.8	20.3	17.5	11.8	68.3	86.9	123.9	235.7
Plenty	-0.57	13.5	12.3	9.0	5.5	36.6	51.2	80.0	178.1

[1] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 6

Correlation Matrix[1] for Micromixograph Data Analyzed Using Envelope Analysis[2]

	MLT	MPT	MRT	MLH	MPH	MRH	MEH	BWL	BWP	BWR	BWE	MLS	MRS	MES
MLT	1,00000 0,0	0,44701 0,3146	0,24355 0,5987	0,99084 0,0001	0,57003 0,1815	0,62824 0,1308	0,62736 0,1315	-0,17702 0,7042	0,55481 0,1961	0,66998 0,0996	0,65854 0,1077	0,62456 0,1338	0,11222 0,8107	0,99178 0,0001
MPT	0,44701 0,3146	1,00000 0,0	0,92574 0,0028	0,39414 0,3816	0,92751 0,0026	0,80670 0,0283	0,84651 0,0163	-0,66176 0,1054	0,95109 0,0010	0,85962 0,0131	0,89010 0,0072	0,73468 0,0600	-0,72183 0,0670	0,45665 0,3030
MRT	0,24355 0,5987	0,92574 0,0028	1,00000 0,0	0,16197 0,7286	0,72236 0,0667	0,53985 0,2110	0,60270 0,1520	-0,78916 0,0349	0,76566 0,0448	0,61365 0,1427	0,66783 0,1011	0,53243 0,2186	-0,89233 0,0069	0,22199 0,6324
MLH	0,99084 0,0001	0,39414 0,3816	0,16197 0,7286	1,00000 0,0	0,56038 0,1907	0,64868 0,1150	0,63875 0,1225	-0,05290 0,9103	0,52920 0,2219	0,65835 0,1079	0,64237 0,1198	0,64649 0,1166	0,21426 0,6446	0,99562 0,0001
MPH	0,57003 0,1815	0,92751 0,0026	0,72236 0,0667	0,56038 0,1907	1,00000 0,0	0,96613 0,0004	0,97782 0,0001	-0,39476 0,3808	0,99042 0,0001	0,96333 0,0005	0,97104 0,0003	0,86243 0,0125	-0,43176 0,3334	0,61297 0,1433
MRH	0,62824 0,1308	0,80670 0,0283	0,53985 0,2110	0,64868 0,1150	0,96613 0,0004	1,00000 0,0	0,99623 0,0001	-0,16601 0,7220	0,92859 0,0025	0,95232 0,0009	0,95120 0,0010	0,92084 0,0032	-0,19045 0,6825	0,68991 0,0863
MEH	0,62736 0,1315	0,84651 0,0163	0,60270 0,1520	0,63875 0,1225	0,97782 0,0001	0,99623 0,0001	1,00000 0,0	-0,22411 0,6290	0,94464 0,0013	0,95849 0,0007	0,96451 0,0004	0,93441 0,0020	-0,25453 0,5818	0,68363 0,0904
BWL	-0,17702 0,7042	-0,66176 0,1054	-0,78916 0,0349	-0,05290 0,9103	-0,39476 0,3808	-0,16601 0,7220	-0,22411 0,6290	1,00000 0,0	-0,50797 0,2445	-0,35870 0,4295	-0,38441 0,3945	-0,06464 0,8905	0,86050 0,0129	-0,09866 0,8333
BWP	0,55481 0,1961	0,95109 0,0010	0,76566 0,0448	0,52920 0,2219	0,99042 0,0001	0,92859 0,0025	0,94464 0,0013	-0,50797 0,2445	1,00000 0,0	0,95768 0,0007	0,96399 0,0005	0,80087 0,0304	-0,51195 0,2402	0,58506 0,1676
BWR	0,66998 0,0996	0,85962 0,0131	0,61365 0,1427	0,65835 0,1079	0,96333 0,0005	0,95232 0,0009	0,95849 0,0007	-0,35870 0,4295	0,95768 0,0007	1,00000 0,0	0,99544 0,0001	0,84178 0,0175	-0,32712 0,4739	0,71532 0,0707
BWE	0,65854 0,1077	0,89010 0,0072	0,66783 0,1011	0,64237 0,1198	0,97104 0,0003	0,95120 0,0010	0,96451 0,0004	-0,38441 0,3945	0,96399 0,0005	0,99544 0,0001	1,00000 0,0	0,86956 0,0110	-0,37339 0,4094	0,70141 0,0791
MLS	0,62456 0,1338	0,73468 0,0600	0,53243 0,2186	0,64649 0,1166	0,86243 0,0125	0,92084 0,0032	0,93441 0,0020	-0,06464 0,8905	0,80087 0,0304	0,84178 0,0175	0,86956 0,0110	1,00000 0,0	-0,12530 0,7889	0,68266 0,0910
MRS	0,11222 0,8107	-0,72183 0,0670	-0,89233 0,0069	0,21426 0,6446	-0,43176 0,3334	-0,19045 0,6825	-0,25453 0,5818	0,86050 0,0129	-0,51195 0,2402	-0,32712 0,4739	-0,37339 0,4094	-0,12530 0,7889	1,00000 0,0	0,15095 0,7467
MES	0,99178 0,0001	0,45665 0,3030	0,22199 0,6324	0,99562 0,0001	0,61297 0,1433	0,68991 0,0863	0,68363 0,0904	-0,09866 0,8333	0,58506 0,1676	0,71532 0,0707	0,70141 0,0791	0,68266 0,0910	0,15095 0,7467	1,00000 0,0

[1] Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 7

[2] MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at the point MLT; MPH is the height of the curve at peak; MRH is the time to the point right of peak; MEH is the time at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); BWL is the width of the curve at the point MLT; BWP is the width of the curve at peak; BWR is the width of the curve at the point MRT; BWE is the width of the curve at MET;

APPENDIX 7

Correlation Matrix[1] for Micromixograph Data Analyzed Using Mid-Line Analysis[2]

	MLT	MPT	MRT	MLH	MPH	MRH	MEH	BWL	BWP	BWR	BWE	MLE	MPE	MRE	MEE	MLS	MRS	MES
MLT	1.00000 0.0	1.00000 0.0001	1.00000 0.0001	0.93682 0.0019	0.93176 0.0023	0.93961 0.0017	0.86873 0.0112	-0.45056 0.3103	0.94733 0.0012	0.94691 0.0012	0.89088 0.0071	0.98590 0.0001	0.98373 0.0001	0.97871 0.0001	0.90762 0.0047	0.87100 0.0107	-0.61569 0.1410	0.94928 0.0011
MPT	1.00000 0.0001	1.00000 0.0	1.00000 0.0001	0.93682 0.0019	0.93176 0.0023	0.93961 0.0017	0.86873 0.0112	-0.45056 0.3103	0.94733 0.0012	0.94691 0.0012	0.89088 0.0071	0.98590 0.0001	0.98373 0.0001	0.97871 0.0001	0.90762 0.0047	0.87100 0.0107	-0.61569 0.1410	0.94928 0.0011
MRT	1.00000 0.0001	1.00000 0.0001	1.00000 0.0	0.93682 0.0019	0.93176 0.0023	0.93961 0.0017	0.86873 0.0112	-0.45056 0.3103	0.94733 0.0012	0.94691 0.0012	0.89088 0.0071	0.98590 0.0001	0.98373 0.0001	0.97871 0.0001	0.90762 0.0047	0.87100 0.0107	-0.61569 0.1410	0.94928 0.0011
MLH	0.93682 0.0019	0.93682 0.0019	0.93682 0.0019	1.00000 0.0	0.99876 0.0001	0.99953 0.0001	0.98259 0.0001	-0.37736 0.4040	0.95576 0.0008	0.94267 0.0015	0.95814 0.0007	0.96404 0.0005	0.97281 0.0002	0.98334 0.0001	0.99315 0.0001	0.90376 0.0052	-0.32469 0.4774	0.97332 0.0002
MPH	0.93176 0.0023	0.93176 0.0023	0.93176 0.0023	0.99876 0.0001	1.00000 0.0	0.99772 0.0001	0.97951 0.0001	-0.33110 0.4682	0.96433 0.0005	0.95294 0.0009	0.96870 0.0003	0.95582 0.0008	0.96565 0.0004	0.97763 0.0001	0.98810 0.0001	0.88491 0.0081	-0.32091 0.4828	0.97955 0.0001
MRH	0.93961 0.0017	0.93961 0.0017	0.93961 0.0017	0.99953 0.0001	0.99772 0.0001	1.00000 0.0	0.98371 0.0001	-0.38884 0.3886	0.95557 0.0008	0.94202 0.0015	0.95710 0.0007	0.96612 0.0004	0.97455 0.0002	0.98466 0.0001	0.99349 0.0001	0.91362 0.0040	-0.32478 0.4772	0.97311 0.0002
MEH	0.86873 0.0112	0.86873 0.0112	0.86873 0.0112	0.98259 0.0001	0.97951 0.0001	0.98371 0.0001	1.00000 0.0	-0.39307 0.3830	0.90177 0.0055	0.88184 0.0086	0.93600 0.0019	0.91669 0.0037	0.92883 0.0025	0.94465 0.0013	0.99425 0.0001	0.92167 0.0032	-0.15475 0.7404	0.92869 0.0025
BWL	-0.45056 0.3103	0.45056 0.3103	-0.45056 0.3103	-0.37736 0.4040	-0.33110 0.4682	-0.38884 0.3886	-0.39307 0.3830	1.00000 0.0	-0.19979 0.6676	-0.16175 0.7290	-0.14235 0.7608	-0.50687 0.2457	-0.48913 0.2653	-0.46370 0.2946	-0.43796 0.3257	-0.67052 0.0992	-0.24922 0.5899	-0.24499 0.5965
BWP	0.94733 0.0012	0.94733 0.0012	0.94733 0.0012	0.95576 0.0008	0.96433 0.0005	0.95557 0.0008	0.90177 0.0055	-0.19979 0.6676	1.00000 0.0	0.99460 0.0001	0.95873 0.0004	0.94064 0.0016	0.94778 0.0012	0.95529 0.0008	0.91717 0.0036	0.80514 0.0289	-0.47848 0.2774	0.99734 0.0001
BWR	0.94691 0.0012	0.94691 0.0012	0.94691 0.0012	0.94267 0.0015	0.95294 0.0009	0.94202 0.0015	0.88184 0.0086	-0.16175 0.7290	0.99460 0.0001	1.00000 0.0	0.96717 0.0004	0.92794 0.0026	0.93484 0.0020	0.94255 0.0015	0.89916 0.0059	0.77554 0.0405	-0.50047 0.2527	0.98766 0.0001
BWE	0.89088 0.0071	0.89088 0.0071	0.89088 0.0071	0.95814 0.0007	0.96870 0.0003	0.95710 0.0007	0.93600 0.0019	-0.14235 0.7608	0.95873 0.0006	0.96717 0.0004	1.00000 0.0	0.88836 0.0075	0.90169 0.0055	0.91962 0.0034	0.93419 0.0021	0.79256 0.0335	-0.28783 0.5314	0.96190 0.0005
MLE	0.98590 0.0001	0.98590 0.0001	0.98590 0.0001	0.96404 0.0005	0.95582 0.0008	0.96612 0.0004	0.91669 0.0037	-0.50687 0.2457	0.94064 0.0016	0.92794 0.0026	0.88836 0.0075	1.00000 0.0	0.99936 0.0001	0.99623 0.0001	0.94865 0.0011	0.91995 0.0033	-0.52676 0.2244	0.95322 0.0009
MPE	0.98373 0.0001	0.98373 0.0001	0.98373 0.0001	0.97281 0.0002	0.96565 0.0004	0.97455 0.0002	0.92883 0.0025	-0.48913 0.2653	0.94778 0.0012	0.93484 0.0020	0.90169 0.0055	0.99936 0.0001	1.00000 0.0	0.99868 0.0001	0.95894 0.0006	0.92060 0.0033	-0.50363 0.2492	0.96085 0.0006
MRE	0.97871 0.0001	0.97871 0.0001	0.97871 0.0001	0.98334 0.0001	0.97763 0.0001	0.98466 0.0001	0.94465 0.0013	-0.46370 0.2946	0.95529 0.0008	0.94255 0.0015	0.91962 0.0034	0.99623 0.0001	0.99868 0.0001	1.00000 0.0	0.97049 0.0003	0.92046 0.0033	-0.46813 0.2894	0.96906 0.0003
MEE	0.90762 0.0047	0.90762 0.0047	0.90762 0.0047	0.99315 0.0001	0.98810 0.0001	0.99349 0.0001	0.99425 0.0001	-0.43796 0.3257	0.91717 0.0036	0.89916 0.0059	0.93419 0.0021	0.94965 0.0011	0.95894 0.0006	0.97049 0.0003	1.00000 0.0	0.92995 0.0024	-0.24523 0.5961	0.94246 0.0015
MLS	0.87100 0.0107	0.87100 0.0107	0.87100 0.0107	0.90376 0.0052	0.88491 0.0081	0.91362 0.0040	0.92167 0.0032	-0.67052 0.0992	0.80514 0.0289	0.77554 0.0405	0.79256 0.0335	0.91995 0.0033	0.92060 0.0033	0.92046 0.0033	0.92995 0.0024	1.00000 0.0	-0.26005 0.5733	0.83679 0.0189
MRS	-0.61569 0.1410	-0.61569 0.1410	-0.61569 0.1410	-0.32469 0.4774	-0.32091 0.4828	-0.32478 0.4772	-0.15475 0.7404	0.24922 0.5899	-0.47848 0.2774	-0.50047 0.2527	-0.28783 0.5314	-0.52676 0.2244	-0.50363 0.2492	-0.46813 0.2894	-0.24523 0.5961	-0.26005 0.5733	1.00000 0.0	-0.44159 0.3212
MES	0.94928 0.0011	0.94928 0.0011	0.94928 0.0011	0.97332 0.0002	0.97955 0.0001	0.97311 0.0002	0.92869 0.0025	-0.24499 0.5965	0.99734 0.0001	0.98766 0.0001	0.96190 0.0005	0.95322 0.0009	0.96085 0.0006	0.96906 0.0003	0.94246 0.0015	0.83679 0.0189	-0.44159 0.3212	1.00000 0.0

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 7.

MLT is the time to the point left of the peak; MPT is the time to peak; MRT is the time to the point right of peak; MLH is the height of the curve at MLT; MPH is the height of the curve at MPT; MRH is the height at the curve at MRT; MEH is the height of the curve at the end of analysis; BWL is the width of the curve at MLT; BWP is the width of the curve at MPT; BWR is the width of the curve at MRT; BWE is the width of the curve at the end of analysis; MLS is the slope of the ascending portion of the curve; MRS is the slope of the descending portion of the curve; MES is the slope of the curve at the end of analysis (8 minutes); MLE is the area under the curve to MLT; MPE is the area under the curve to MPT; MRE is the area under the curve to MRT; MEE is the area under the curve at the end of analysis.

APPENDIX 8

Summary of Means and Standard Deviations for Alveograph Data[1]

Sample	Rep	*P* (mm)	*L* (mm)	*P/L*	*W* (x10^{3}ergs)	*H* (mm)	*G* (cm^3)	*S* (cm^2)
Durex	1	84.50 (4.62)	73.55 (16.60)	1.207 (0.264)	234.62 (35.61)	76.82 (4.20)	18.79 (2.13)	35.97 (5.44)
	2	85.34 (3.40)	103.05 (7.69)	0.834 (0.085)	298.1 (15.31)	77.58 (3.09)	22.58 (0.86)	45.58 (2.34)
AC Pathfinder	1	81.96 (10.15)	87.53 (22.66)	0.999 (0.276)	253.52 (63.45)	74.51 (9.22)	21.85 (3.75)	38.76 (9.70)
	2	82.78 (1.69)	87.33 (18.75)	0.998 (0.244)	258.52 (38.77)	75.26 (1.54)	20.68 (2.28)	39.53 (5.93)
AC Navigator	1	98.40 (2.28)	60.60 (5.10)	1.660 (0.119)	233.56 (25.10)	91.27 (4.94)	17.32 (0.72)	35.66 (3.88)
	2	97.02 (5.30)	68.73 (4.90)	1.422 (0.159)	247.22 (8.47)	88.20 (4.82)	18.44 (0.64)	37.80 (1.30)
AC Melita	1	97.68 (7.11)	85.27 (13.17)	1.180 (0.242)	261.46 (20.27)	88.80 (6.46)	20.50 (1.56)	39.97 (3.10)
	2	95.22 (1.24)	86.17 (6.91)	1.112 (0.091)	262.82 (12.59)	86.56 (1.13)	20.65 (0.83)	40.19 (1.92)
DT 662	1	41.66 (1.06)	108.84 (8.31)	0.385 (0.039)	106.34 (1.87)	37.87 (0.97)	23.21 (0.89)	16.26 (0.29)
	2	41.20 (0.64)	133.96 (5.79)	0.308 (0.012)	113.86 (4.064)	37.46 (0.56)	25.77 (0.56)	17.41 (0.62)
Kyle	1	48.76 (0.44)	92.88 (5.70)	0.527 (0.037)	113.52 (3.80)	44.33 (0.40)	21.44 (0.66)	17.36 (0.58)
	2	46.62 (1.06)	97.04 (9.52)	0.464 (0.039)	110.78 (5.64)	42.38 (0.96)	22.14 (0.83)	16.94 (0.86)
Plenty	1	47.48 (0.56)	82.35 (12.57)	0.588 (0.080)	95.61 (6.23)	43.16 (0.51)	20.15 (1.48)	14.62 (0.95)
	2	49.78 (0.46)	84.85 (7.86)	0.591 (0.049)	101.35 (6.50)	45.25 (0.41)	20.48 (0.92)	15.50 (0.99)

[1] Values are the mean and (sd) of 5 subsamples per duplicate. The following abbreviations have been used; *P* is the maximum over pressure ($P=1.1H$); *L* is a measure of extensibility; *P/L* is the curve configuration ratio; *W* is the work required to inflate the dough bubble; *H* is the height of the curve; *G* is the swelling index ($G=2.226\sqrt{L}$); *S* is the area under the curve ($S=W/6.54$)..

APPENDIX 9

Summary of Results of Tests for Starch Damage[1]

Sample	Rep	Semolina Starch Damage (%)	Udy Ground Semolina Starch Damage (%)
Durex	1	3.89	7.41
	2	4.25	7.16
AC Pathfinder	1	3.92	7.45
	2	3.67	7.37
AC Navigator	1	4.24	7.58
	2	4.26	6.80
AC Melita	1	4.68	7.91
	2	4.27	8.18
DT 662	1	3.47	5.62
	2	3.68	6.72
Kyle	1	3.95	7.74
	2	4.17	8.39
Plenty	1	4.57	5.18
	2	4.34	7.92

[1]Values are the mean of two subsamples per trial.

APPENDIX 10

Summary of Results of Tests for Total Starch and Amylose Contents[1]

Sample	Rep	Total Starch (%)	Amylose Content (%)
Durex	1	80.1	24.66
	2	76.9	25.43
AC Pathfinder	1	75.7	21.03
	2	57.8	23.41
AC Navigator	1	76.9	24.19
	2	69.9	24.18
AC Melita	1	78.1	21.55
	2	68.6	23.64
DT 662	1	79.4	25.17
	2	78.8	22.64
Kyle	1	64.3	23.49
	2	77.5	22.80
Plenty	1	77.9	24.27
	2	66.8	20.61

[1]Values are the mean of two subsamples per trial.

APPENDIX 11

Summary of Results for Rapid Visco Analyzer Data

Sample	Rep	Peak Viscosity (RVU)	Peak Time (min)	Breakdown Viscosity (RVU)	Breakdown Viscosity Time (min)	Breakdown (RVU)	Setback Viscosity (RVU)	Total Setback (RVU)
Durex	1	172	5.98	107	12.32	65	163	56
	2	171	5.97	108	11.15	63	162	54
AC Pathfinder	1	39	5.23	17	11.43	22	28	5
	2	41	5.32	18	11.18	23	27	5
AC Navigator	1	102	5.77	60	11.77	42	96	36
	2	104	5.78	62	10.72	42	100	38
AC Melita	1	168	6.17	111	11.43	57	166	55
	2	166	6.12	110	11.85	56	166	56
DT 662	1	98	5.65	56	10.65	42	90	34
	2	102	5.77	59	10.50	43	94	35
Kyle	1	177	6.23	130	12.30	47	162	54
	2	178	6.38	133	10.52	45	194	64
Plenty	1	176	6.23	114	12.83	62	170	56
	2	171	6.17	112	12.37	59	166	54

APPENDIX 12

Calculation of Amount of Semolina and Water Required to Process Pasta on the Basis of 31.7% Moisture Content.

1. Determine moisture content of semolina using an accepted method.

2. Determine corrected absorption to used based on using an absorption of 26.0% on a 14.0% moisture basis.

$$\frac{26 + 14}{100 - 14} = \frac{\text{corrected absorption} + \text{moisture content of semo}}{100 - \text{moisture content of semo}}$$

3. Determine the amount of water required based on the corrected absorption.

$$\text{water (mL)} = \text{semo (g)} \left\{ \frac{100 - 14.0}{100 - \text{moisture content}} \right\} \text{x corr absorption}$$

APPENDIX 13

Ethical Approval for the Use of a Sensory Panel

THE UNIVERSITY OF MANITOBA

INTER-DEPARTMENTAL CORRESPONDENCE

Date: 29 March, 1997 Ref:9710

To: Dr. Linda Malcolmson, Foods and Nutrition

From: Dr. G.P. Sevenhuysen, Chair Ethics Review Committee

Subject: Ethics Review: Sensory Evaluation of Cooked Spaghetti

The Ethics Review Committee has reviewed tha research procedures you submitted on 13 March, 1997, entitled: "Sensory Evaluation of Cooked Spaghetti". The procedures meet ethical guidelines for research with human subjects.

The Ethics Review Committee approves the proposed research procedures for implementation.

APPENDIX 14

Letter of Invitation to Panelists

George Weston Limited Sensory & Food Research Centre
Department of Foods and Nutrition
University of Manitoba

January 6, 1998

Dear Fellow Colleague,

We are conducting a panel on cooked spaghetti and invite you to participate. This letter explains what your commitment will be and the tasks involved. If you have any questions please call Elaine Sopiwnyk at 474-6974 or Donna Ryland at 474-8071.

If your schedule permits, you will be trained on how to evaluate the textural properties of cooked spaghetti. This will require 9 to 12 training sessions of 30 minutes each. Once training is completed you will be asked to attend 12 test sessions of 20-30 minutes each.

You will receive a gift certificate for $40 after you have completed the study.

The training will take place Monday, Wednesday and Friday from 1:30 to 2:00 p.m., starting Wednesday, January 14 in room 403 Human Ecology Building.

If you are interested in taking part in this study please reply to this message indicating your willingness to participate. A consent form and questionnaire will then be delivered to you to be filled out and returned to Elaine Sopiwnyk by January 9, 1998.

We hope that you will be able to participate and look forward to hearing from you.

Sincerely,

Elaine Sopiwnyk	Linda Malcolmson	Donna Ryland
Graduate Student	Associate Professor	Research Coordinator

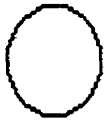
APPENDIX 15

Line Scaling Exercise

Name:_____

Instructions:

Estimate the proportion of the circle that is shaded and place a vertical mark across the line scale to indicate that amount.



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APPENDIX 16

Summary of Means and Standard Deviations for Instrumental Textural Tests Performed Using the Lloyd for Spaghetti Dried at 70°C and Cooked to Optimum[1]

Sample	Rep	Firmness (N·mm)	Shear Force (N)	Compression (N·mm)	Relaxation Time (sec)	Stickiness (N·mm)	Energy (N·mm)	Adhesiveness (N)
Durex	1	3.08(0.02)	4.75(0.10)	2.96(0.06)	7.85(1.06)	0.09(0.01)	1.49(0.01)	-0.44(0.06)
	2	2.92(0.04)	4.45(0.12)	2.60(0.03)	9.63(1.57)	0.13(0.01)	1.34(0.04)	-0.91(0.11)
AC Pathfinder	1	2.94(0.07)	4.56(0.07)	2.46(0.03)	11.11(2.74)	0.14(0.03)	1.39(0.18)	-0.69(0.14)
	2	2.85(0.09)	4.38(0.12)	2.64(0.07)	10.11(0.77)	0.13(0.01)	1.38(0.03)	-0.89(0.04)
DT 673	1	2.78(0.20)	4.16(0.13)	2.79(0.04)	8.28(1.15)	0.11(0.01)	1.48(0.05)	-0.55(0.11)
	2	2.89(0.15)	4.36(0.12)	2.45(0.05)	12.18(5.92)	0.15(0.03)	1.38(0.04)	-1.07(0.14)
AC Melita	1	2.86(0.04)	4.45(0.03)	2.60(0.11)	10.07(1.02)	0.13(0.01)	1.34(0.04)	-0.89(0.01)
	2	2.98(0.07)	4.48(0.11)	2.65(0.09)	9.60(2.06)	0.14(0.01)	1.33(0.05)	-1.08(0.11)
DT 662	1	2.82(0.06)	4.46(0.08)	2.62(0.03)	15.80(3.22)	0.09(0.01)	1.50(0.05)	-0.52(0.12)
	2	2.64(0.07)	4.17(0.07)	2.78(0.03)	11.41(0.28)	0.14(0.02)	1.36(0.02)	-1.03(0.16)
Kyle	1	2.92(0.09)	4.39(0.12)	2.72(0.06)	11.97(2.24)	0.18(0.02)	1.38(0.03)	-0.60(0.08)
	2	2.87(0.03)	4.32(0.11)	2.66(0.08)	13.55(2.53)	0.13(0.02)	1.39(0.01)	-0.92(0.11)
Plenty	1	2.44(0.04)	3.73(0.14)	2.98(0.03)	19.61(2.12)	0.13(0.02)	1.40(0.02)	-0.83(0.11)
	2	2.56(0.05)	3.94(0.06)	2.92(0.04)	9.88(1.23)	0.11(0.01)	1.42(0.01)	-0.76(0.09)

[1]Values are the mean and (sd) of three subsamples per cooking duplicate.

APPENDIX 17

Summary of Means and Standard Deviations for Instrumental Textural Tests Performed Using the Lloyd for Spaghetti Dried at 90°C and Cooked to Optimum[1]

Sample	Rep	Firmness (N·mm)	Shear Force (N)	Compression (N·mm)	Relaxation Time (sec)	Stickiness (N·mm)	Energy (N·mm)	Adhesiveness (N)
Durex	1	3.13(0.07)	4.80(0.11)	2.73(0.07)	11.58(2.74)	0.06(0.01)	1.73(0.09)	-0.28(0.02)
	2	3.14(0.11)	4.76(0.04)	2.71(0.04)	10.05(0.82)	0.04(0.01)	1.67(0.04)	-0.18(0.05)
AC Pathfinder	1	2.87(0.10)	4.25(0.10)	2.79(0.03)	11.01(1.34)	0.06(0.02)	1.76(0.05)	-0.26(0.10)
	2	3.03(0.07)	4.55(0.14)	2.89(0.03)	9.03(0.72)	0.10(0.04)	1.65(0.06)	-0.49(0.33)
DT 673	1	3.40(0.09)	4.92(0.09)	2.75(0.03)	10.49(1.14)	0.06(0.02)	1.65(0.07)	-0.28(0.07)
	2	3.44(0.15)	5.19(0.21)	2.86(0.09)	9.20(1.58)	0.05(0.01)	1.57(0.08)	-0.25(0.04)
AC Melita	1	3.12(0.06)	4.80(0.06)	2.74(0.04)	11.86(2.46)	0.054(0.01)	1.51(0.12)	-0.30(0.06)
	2	3.32(0.05)	4.99(0.07)	2.91(0.06)	12.77(2.31)	0.07(0.00)	1.63(0.02)	-0.32(0.05)
DT 662	1	2.70(0.16)	4.21(0.08)	2.94(0.04)	13.32(3.83)	0.07(0.01)	1.74(0.02)	-0.36(0.05)
	2	2.94(0.07)	4.57(0.08)	2.77(0.12)	12.88(2.40)	0.06(0.01)	1.63(0.08)	-0.24(0.05)
Kyle	1	3.05(0.22)	4.62(0.31)	2.83(0.03)	8.38(1.00)	0.06(0.01)	1.72(0.02)	-0.29(0.06)
	2	3.36(0.02)	4.99(0.12)	2.77(0.04)	13.68(1.83)	0.10(0.03)	1.48(0.06)	-0.45(0.11)
Plenty	1	2.91(0.01)	4.31(0.08)	2.76(0.01)	15.92(0.84)	0.05(0.02)	1.66(0.11)	-0.24(0.14)
	2	3.00(0.07)	4.57(0.13)	2.76(0.05)	11.91(6.41)	0.06(0.00)	1.69(0.05)	-0.31(0.03)

[1]Values are the mean and (sd) of three subsamples per cooking duplicate.

APPENDIX 18

Summary of Means and Standard Deviations for Instrumental Textural Tests Performed Using the Lloyd for Spaghetti Dried at 70°C and Overcooked (optimum + 5 minutes)[1]

Sample	Rep	Firmness (N·mm)	Shear Force (N)	Compression (N·mm)	Relaxation Time (sec)	Stickiness (N·mm)	Energy (N·mm)	Adhesiveness (N)
Durex	1	2.68(0.01)	3.87(0.08)	2.54(0.09)	3.89(0.23)	0.17(0.03)	1.19(0.25)	-0.6690.25)
	2	2.52(0.09)	3.84(0.11)	3.43(0.08)	8.95(0.93)	0.10(0.02)	1.61(0.03)	-0.48(0.10)
AC Pathfinder	1	2.53(0.03)	3.61(0.01)	3.071(0.02)	3.407(0.19)	0.18(0.03)	1.05(0.08)	-0.91(0.20)
	2	2.47(0.08)	3.76(0.05)	3.39(0.24)	8.71(1.62)	0.13(0.01)	1.55(0.07)	-0.67(0.07)
DT 673	1	2.81(0.04)	3.78(0.12)	3.077(0.05)	3.93(0.47)	0.18(0.02)	1.03(0.04)	-0.87(0.03)
	2	2.51(0.06)	3.73(0.08)	3.44(0.05)	8.01(0.30)	0.11(0.05)	1.61(0.07)	-0.44(0.15)
AC Melita	1	2.92(0.03)	3.93(0.08)	3.15(0.02)	4.39(0.44)	0.19(0.04)	1.03(0.01)	-0.92(0.04)
	2	2.49(0.11)	3.83(0.06)	3.37(0.08)	10.74(2.91)	0.12(0.01)	1.47(0.03)	-0.69(0.02)
DT 662	1	2.53(0.04)	3.64(0.03)	3.19(0.02)	5.98(0.87)	0.12(0.01)	1.15(0.02)	-0.55(0.06)
	2	2.53(0.19)	3.88(0.03)	3.50(0.06)	11.38(2.71)	0.13(0.05)	1.54(0.06)	-0.69(0.27)
Kyle	1	2.69(0.08)	3.72(0.08)	3.00(0.02)	5.24(0.56)	0.14(0.13)	1.25(0.10)	-0.44(0.20)
	2	2.51(0.04)	3.82(0.08)	3.34(0.07)	12.92(2.20)	0.12(0.03)	1.53(0.13)	-0.63(0.16)
Plenty	1	2.52(0.04)	3.46(0.03)	3.28(0.03)	4.47(0.45)	0.17(0.02)	1.03(0.03)	-0.92(0.11)
	2	2.23(0.09)	3.50(0.10)	3.69(0.02)	7.65(0.50)	0.11(0.01)	1.54(0.02)	-0.52(0.05)

[1]Values are the mean and (sd) of three subsamples per cooking duplicate.

APPENDIX 19

Summary of Means and Standard Deviations for Instrumental Textural Tests Performed Using the Lloyd for Spaghetti Dried at 90°C and Overcooked (optimum + 5 minutes)[1]

Sample	Rep	Firmness (N·mm)	Shear Force (N)	Compression (N·mm)	Relaxation Time (sec)	Stickiness (N·mm)	Energy (N·mm)	Adhesiveness (N)
Durex	1	2.81(0.09)	4.32(0.08)	3.59(0.05)	7.59(0.25)	0.13(0.03)	1.59(0.05)	-0.70(0.14)
	2	2.99(0.04)	4.38(0.13)	3.42(0.01)	8.50(0.90)	0.15(0.03)	1.49(0.03)	-0.81(0.15)
AC Pathfinder	1	2.59(0.03)	3.99(0.03)	3.44(0.04)	7.17(1.42)	0.16(0.02)	1.54(0.03)	-0.89(0.09)
	2	3.00(0.05)	4.28(0.05)	3.36(0.05)	9.12(0.77)	0.15(0.02)	1.53(0.06)	-0.89(0.16)
DT 673	1	2.85(0.04)	4.25(0.16)	3.54(0.07)	6.35(0.17)	0.17(0.02)	1.44(0.06)	-0.98(0.14)
	2	3.19(0.12)	4.47(0.07)	3.41(0.04)	6.87(1.07)	0.17(0.03)	1.43(0.02)	-1.08(0.15)
AC Melita	1	2.57(0.08)	4.04(0.09)	3.68(0.10)	9.18(0.49)	0.17(0.01)	1.50(0.09)	-0.86(0.16)
	2	2.76(0.06)	4.20(0.17)	3.53(0.05)	8.11(1.34)	0.13(0.01)	1.52(0.03)	-0.77(0.12)
DT 662	1	2.25(0.02)	3.84(0.04)	3.61(0.02)	8.40(1.85)	0.14(0.01)	1.53(0.02)	-0.79(0.05)
	2	2.51(0.11)	4.09(0.16)	3.67(0.03)	8.71(0.16)	0.14(0.01)	1.53(0.03)	-0.81(0.05)
Kyle	1	2.67(0.14)	4.06(0.11)	3.43(0.02)	9.92(0.72)	0.16(0.01)	1.55(0.02)	-0.87(0.02)
	2	2.78(0.04)	4.16(0.05)	3.49(0.08)	7.98(1.16)	0.16(0.03)	1.47(0.04)	-0.93(0.13)
Plenty	1	2.60(0.09)	3.94(0.08)	3.44(0.12)	11.40(2.36)	0.19(0.04)	1.54(0.05)	-0.98(0.16)
	2	2.65(0.12)	4.00(0.13)	3.47(0.06)	9.86(0.20)	0.16(0.02)	1.49(0.02)	-0.94(0.19)

[1]Values are the mean and (sd) of three subsamples per cooking duplicate.

APPENDIX 20

Results for Viscoelastograph Data Using 1000, 1500 and 2000 g Weights for Spaghetti Dried at 70°C.

Sample	Rep	%Relative Recovery (R,%)		
		1000 g	1500 g	2000 g
Durex	1	25.407	29.852	10.75
	2	41.637	29.988	14.244
	3	33.153	21.205	15.763
AC Pathfinder	1	35.167	21.258	11.489
	2	32.808	18.267	15.541
	3	34.998	22.099	13.589
AC Navigator	1	29.713	15.592	13.116
	2	51.375	17.032	14.428
	3	24.703	16.271	11.132
AC Melita	1	38.265	16.777	12.147
	2	35.894	19.712	14.471
	3	35.063	20.27	14.453
DT 662	1	56.066	40.956	26.87
	2	50.375	43.508	23.572
	3	49.99	41.067	23.819
Kyle	1	51.97	35.918	17.087
	2	30.023	37.441	19.222
	3	52.179	39.338	19.94
Plenty	1	51.546	20.913	15.517
	2	39.14	31.053	14.371
	3	50.062	34.563	15.139

APPENDIX 21

Results for Viscoelastograph Data Using 1000, 1500 and 2000 g Weights for Spaghetti Dried at 90°C.

Sample	Rep	%Relative Recovery (R,%)		
		1000 g	1500 g	2000 g
Durex	1	31.479	21.281	17.237
	2	31.116	20.414	14.132
	3	32.494	20.317	15.688
AC Pathfinder	1	41.221	19.811	17.165
	2	29.335	23.484	14.69
	3	33.454	22.896	17.133
AC Navigator	1	25.806	18.191	16.221
	2	57.604	17.978	13.131
	3	29.201	19.496	11.472
AC Melita	1	38.265	21.353	12.459
	2	32.461	18.413	14.342
	3	35.063	19.682	12.861
DT 662	1	54.489	50.608	24.483
	2	31.265	42.697	22.854
	3	36.797	44.444	19.876
Kyle	1	56.02	23.529	19.172
	2	49.107	34.149	16.464
	3	60.933	31.077	19.626
Plenty	1	56.377	39.835	18.2
	2	54.58	33.333	17.671
	3	52.196	35.616	17.043