SPAGHETTI OPTIMIZATION USING RESPONSE SURFACE METHODOLOGY: EFFECTS OF DRYING TEMPERATURE, DURUM PROTEIN LEVEL AND FARINA BLENDING

by

Linda June Malcolmson

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ABSTRACT

Response surface methodology was used in the optimization of the textural and color characteristics of spaghetti. The relationship between durum protein level and spaghetti drying temperature and their effects on cooked spaghetti quality were investigated. Firmness and compression were primarily affected by protein level, whereas elasticity was mainly affected by drying temperature. Cooking loss of optimally cooked spaghetti was primarily influenced by protein level while cooking loss of overcooked spaghetti appeared to be equally influenced by both variables. As durum protein level decreased, higher drying temperatures were necessary to produce spaghetti of comparable quality to commercial spaghetti.

The relationship between spaghetti drying temperature and blending level of hard red spring farina with durum semolina and their effects on cooking quality and color characteristics were also examined. Superimposing the individual contour plots for all responses permitted the identification of the region where all quality parameters met or exceeded commercial spaghetti quality. The most limiting factors were firmness and stickiness of optimally cooked spaghetti and compression and elasticity of overcooked spaghetti. To satisfy these constraints, blending levels with at least 60% durum semolina were required with drying temperatures greater than 70° C. As the level of durum semolina decreased in the blend, higher drying temperatures were necessary to produce acceptable spaghetti.

Instron methods for measuring spaghetti firmness, compression, elasticity, and stickiness were developed and the effects of operating conditions on measurements were examined. Compression force strongly influenced compression and elasticity measurements of spaghetti. Plunger size had a modest effect, although variability was reduced with smaller plunger sizes. Compression depth and crosshead speed influenced firmness measurements of spaghetti. Stickiness measurements were only modestly affected by compression force and plunger size. Validation of instrumental tests was attained by comparing instrumental and sensory measurements of spaghetti texture. Furthermore, predictability of sensory measurements of firmness, chewiness and stickiness were achieved from instrumental measurements of spaghetti texture obtained using the Instron and the Grain Research Laboratory tenderness apparatus and compression tester.

Cooking water composition was shown to influence stickiness and cooking loss of spaghetti. Spaghetti made from common wheat was affected more by changes in cooking water hardness than durum spaghetti. An artificially hardened water was developed and adopted for all cooking studies.

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CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

1.1 INTRODUCTION

Durum wheat (Triticum turgidum L.) is considered the best raw material for pasta production. It has a similar gluten and protein content to bread wheat but the gluten formed does not have the elastic strength of bread wheat (Banasik, 1981). Durum wheat has a high yellow pigment content, making it superior for pasta production. The kernel has a hard, translucent endosperm that upon milling yields a granular product called semolina. Pasta made from durum wheat is a bright yellow color, and when cooked, is generally more resilient and less sticky than pasta made from the farina of common wheats (Kim et al., 1989).

Cooked spaghetti should be firm, resilient and non-sticky (Dexter et al., 1983a). In a study by Larmond and Voisey (1973), consumers preferred spaghetti which had been rated by a trained sensory panel as having low scores for gumminess, adhesiveness and starchiness and high scores for firmness, chewiness and individuality.

Recent advances in pasta processing have focused on the use of high temperature drying. Reported benefits include: reduced drying times, improved microbiological quality (especially for egg pasta), and enhanced cooking quality. This latter point has caused researchers to question previous concepts concerning the quality of the raw material that is necessary to achieve spaghetti with optimum cooking characteristics. Thus, it may be possible to produce pasta with superior cooking quality using lower protein durum wheat and by blending with other classes of wheat if high temperature drying is applied. This is of particular interest when the availability of durum wheat is low and the price is high.

The need for simple and reliable methods for assessing the cooking quality of pasta is widely recognized, but at present, no universally accepted methods exist. The Instron Universal Testing Machine has proven to be a effective method of texture measurement (Buckley et al., 1984) and has gained prominence as a method of measuring the textural properties of food. It would seem reasonable therefore, to utilize the Instron in the development of procedures for judging pasta cooking quality.

The first overall objective of this research was to develop standardized cooking procedures and Instron methods for measuring the textural properties of cooked spaghetti. The second overall objective was to optimize spaghetti cooking quality characteristics, through the use of response surface methodology, by varying raw material levels and spaghetti drying temperatures. In order to achieve the latter objective, two separate studies were undertaken; one study examined the relationship between durum protein levels and drying temperatures and the second study investigated the relationship between blending levels of durum semolina and hard red spring farina and drying temperatures.

This research was undertaken by completing five separate experiments presented in Chapters 2-6 of this thesis. This information is preceded by a general review of literature (Chapter 1) and is succeeded by a general summary, general conclusions and discussion of future research needs (Chapter 7). The specific objectives of each experiment have been compiled here, and are restated in each chapter.

The first experiment investigated the effects of cooking water composition on the cooking quality of spaghetti. The specific objectives of this experiment were:

1. To determine the effects of cooking water composition on the stickiness and cooking loss of spaghetti.
2. To determine if spaghetti made from common wheat behaves the same as spaghetti made from durum wheat to changes in cooking water composition.
3. To establish a cooking water formulation for artificially hardened water that gives similar results to tap water, that can then be used in routine assessments of spaghetti cooking quality.

The second experiment was undertaken to examine the effects of Instron operating conditions on the detection of textural differences in spaghetti. The specific objectives of this experiment were:

1. To develop test methods to measure firmness, compressibility, elasticity, and stickiness of cooked spaghetti using the Instron Universal Testing Machine.

2. To determine the effects of compression depth and crosshead speed on firmness measurements of spaghetti.
3. To determine the effects of compression force and plunger size on measurements of compression, elasticity, and stickiness of spaghetti.
4. To identify operating conditions for evaluating firmness, compression, elasticity, and stickiness of cooked spaghetti with high repeatability and reproducibility and reasonable discrimination between spaghetti samples.

The third experiment was designed to compare sensory and instrumental measurements of cooked spaghetti texture. The specific objectives of this study were:

1. To establish a texture profile panel to evaluate cooked spaghetti quality.
2. To determine the textural properties of commercial spaghetti samples using sensory, Instron, and Grain Research Laboratory texture testing procedures.
3. To examine the relationship between instrumental measurements and sensory ratings of spaghetti texture using multivariate techniques to determine if instrumental evaluations can be used to predict sensory quality.

The last two experiments were optimization studies. The specific objectives of the first optimization experiment were:

1. To examine the effects of spaghetti drying temperature and durum semolina protein levels on cooked spaghetti quality.

2. To explore the relationship between spaghetti drying temperature and durum semolina protein level on cooking quality of optimally cooked and overcooked spaghetti using response surface methodology.

3. To generate contour plots from fitted models in order to determine which combinations of drying temperatures and protein levels yield spaghetti with optimum cooking quality.

The specific objectives of the second optimization study were:

1. To examine the relationship between spaghetti drying temperature and blending of hard red spring farina with durum semolina on the cooking quality of optimally cooked and overcooked spaghetti using response surface methodology.

2. To generate contour plots from fitted models in order to determine which combinations of drying temperatures and blending levels yield spaghetti with optimum cooking quality.

1.2 REVIEW OF LITERATURE

Much research has been undertaken to clarify the basis of the cooking quality of durum wheat. Difficulties exist however, in relating the chemical composition and structure of durum wheat components to the functional properties in pasta. Thus, the phenomenon of pasta quality is not clearly understood. Nevertheless, a certain amount of knowledge concerning the biochemical basis of pasta cooking quality has been acquired and will be the subject of this review. The effects of blending hard red spring farina with durum semolina will also be discussed as will the effects of drying temperature on the cooking quality of pasta. Following this, sensory and physical test methods used in the assessment of cooked spaghetti quality will be reviewed with particular attention paid to the use of the Instron Universal Testing Machine for instrumental texture evaluations. Statistical methods to establish the relationship between sensory and physical texture parameters will also be presented with an emphasis on multivariate techniques. Finally, the use of response surface methodology in optimization research will be addressed.

1.2.1 Biochemical Basis of Pasta Cooking Quality

The basis of a good cooking quality durum wheat likely involves the formation of an insoluble protein network which entraps swollen and gelatinized starch granules (Feillet, 1984). This prevents spaghetti surface disruption and consequent leaching of carbohydrates and proteins into the cooking water.

Protein composition of durum wheat varies widely in quantity and quality, depending on the variety and on environmental conditions (Feillet, 1984). The protein content of durum wheat ranges from 9 to 18%. Matveef (1966) has shown that a wheat protein content above 13% yields a satisfactory final product whereas a protein content lower than 11% gave a poor product. Wheat protein content appears to account for 30-40% of the variability in cooking quality (Damidaux and Feillet, 1978; Dexter et al., 1980). Pasta cooking quality has been shown to improve with increasing protein content (Matsuo et al., 1972; Dexter and Matsuo, 1977; Grzybowski and Donnelly, 1979; Autran et al., 1986). One explanation for this is the fact that at higher protein levels, the more numerous are the polypeptide chains, increasing the chances of proteins to interact with one another to form a strong network (Feillet, 1984).

Protein quality, as measured by gluten properties, has also been identified as an important factor in the cooking quality of spaghetti (Matveef, 1966; Sheu et al., 1967; Matsuo and Irvine, 1970; Matsuo et al., 1972; Dexter and Matsuo, 1977; Grzybowski and Donnelly, 1979). Feillet et al. (1977) demonstrated that strong gluten varieties with high elastic recovery, exhibited good cooking quality while weak gluten varieties with low elastic recovery had poorer quality.

Interestingly, Matsuo et al. (1982a) were not able to confirm that protein content significantly affected gluten quality.

Durum proteins include albumins (soluble in water), globulins (soluble in neutral salt solutions), gliadins (soluble in 70% ethanol and in acids), and glutenins (soluble in acids, bases, hydrogen, and hydrophobic bond breaking solvents). Albumins and globulins are cytoplasmic proteins with enzymatic activities and foaming and emulsifying properties. Gliadins are characterized by their medium molecular weight (25,000 - 100,000) and high extensibility. Glutenins are characterized by their high molecular weight (100,000 to > 3,000,000) and high elasticity. Both gliadins and glutenins are associated with lipids, and other components, including minerals and carbohydrates. In the presence of water, they form a unique, viscoelastic protein complex referred to as gluten (Feillet, 1988). The gluten of durum wheat appears to differ from the gluten of bread wheat. A more porous appearance has been observed for the relaxed gluten of durum wheat compared to the gluten of bread wheat (Dronzek et al., 1980).

No clear differences can be seen between common and durum wheats in the proportions of soluble proteins, gliadins, or glutenins (Feillet, 1988). Wasik (1978) observed that 8-11% of total protein was comprised of albumins, 4-7% of globulins, 40-50% of gliadins, 10-20% of acetic-acid-soluble glutenins and 17-35% of insoluble residue. Dexter and Matsuo (1977) showed that the proportion of soluble proteins decreased significantly with increasing protein content and that the increase in total protein was completely accounted for by an increase in the amount of gluten proteins.

Recent research on durum wheat has been directed towards the study of gluten components. At present, it is still not clearly known which gluten components are favourable to pasta cooking quality but the evidence suggests that several components are involved. Firstly, a highly significant correlation has been demonstrated between γ-gliadin components fractionated by electrophoresis and durum wheat visco-elasticity (Damidaux et al., 1978; Kosmolak et al., 1980; du Cros et al., 1982). Durum wheat varieties which possess the 45-γ gliadin component have strong gluten and high cooking quality, whereas those that possess the 42-γ gliadin have a weaker gluten and poor cooking quality. Current evidence suggests that the γ-gliadin proteins are genetic markers for other proteins responsible for differences in quality (Damidaux et al., 1980; du Cros et al., 1982; Autran, 1981; Payne et al., 1984; Pogna et al., 1988).

A high glutenin-gliadin ratio or a high percentage of insoluble proteins has also been linked to superior pasta cooking quality. A comparison of the protein fractions from solvent extraction and gel filtration led Walsh and Gilles (1971) to conclude that high spaghetti firmness was associated with high glutenin but low gliadin contents. Wasik and Bushuk (1975) were able to classify durum cultivars on the basis of glutenin to gliadin ratio obtained from gel filtration chromatography in essentially the same order established by rheological and cooking tests. Dexter and Matsuo (1977) also found that a high glutenin to gliadin ratio was related to superior cooking quality.

Insoluble residue proteins were found by Dexter and Matsuo (1978, 1980) to exhibit an effect on pasta cooking quality. Furthermore, differences in lactic-acid-soluble gluten proteins (Dexter and Matsuo, 1980) and in isopropanol-soluble proteins (D'Egidio et al., 1976) have also been suggested to be durum wheat quality factors. Recently, Sgrulletta and De Stefanis (1989) reported a good correlation between acetic acid insoluble residue protein and pasta cooking quality.

The relationship of specific glutenin subunits in durum wheat to pasta quality parameters has received less attention. Wasik and Bushuk (1975) reported that the amount of certain glutenin polypeptides appeared to be related to spaghetti-making quality. These polypeptides of medium molecular weight were considered by Autran et al. (1982) to be gliadin types. They found no relationship between high molecular weight (HMW) glutenin polypeptides and viscoelastic properties of durum wheat although, there seemed to be an association between cooking quality and some unusual HMW glutenin patterns. du Cros (1987) found low molecular weight (LMW) glutenins were highly correlated with gluten strength whereas the HMW glutenin polypeptides were found in general to be poor indicators of viscoelastic properties. Pogna et al. (1988)

also suggested that LMW glutenin subunits could be responsible for differences in gluten viscoelasticity. Feillet et al. (1989) reported that LMW glutenin proteins make up a major fraction of durum wheat gluten and their content in durum wheat of γ-45 type is higher (28%) than in γ-42 type (15%). According to these authors, LMW glutenins strongly aggregate through heat treatment and contribute to pasta firmness and elasticity. Autran and Feillet (1987) and Autran and Galterio (1989) found a weak but significant relationship between HMW glutenin blocks and cooking quality.

The suggestion by Fabriani et al. (1970 and 1975) that a high ratio of reactive to total SH groups may be a prerequisite for superior pasta cooking quality was not confirmed by Dexter and Matsuo (1977). Nevertheless, Scarascia-Venezian (1973) reported that accessible sulfydryl and urea dispersible proteins appear to be good markers of pasta making quality. Recently, Alary and Kobrehel (1987) and Kobrehel and Alary (1989) were successful in extracting durum wheat sulphur rich glutenin fractions (DSG). These fractions were composed of two LMW glutenin proteins and were shown to have a strong association with surface state of cooked pasta and firmness. Feillet et al. (1989) also found sulfur rich glutenin proteins were associated with the surface condition of cooked pasta and proposed that DSG proteins contribute to aggregation of LMW glutenins and possibly HMW glutenins through hydrophobic and disulfide bonds. They further postulate that these bonds would be sufficiently strong to prevent starch leaching during cooking and thereby maintain a satisfactory surface condition.

Starch is the major component of pasta, present at a level of approximately 73%. It is comprised of two fractions, amylose, present at approximately 25%, and amylopectin, present at 75% of the total amount of starch (Feillet, 1984). Current knowledge concerning the role of starch on pasta quality is extremely limited. Medcalf and Gilles (1965) observed that starches from durum wheat have larger water binding properties, greater rates of iodine absorption, and slightly lower initial pasting temperature than those from other classes of wheat. Sheu et al. (1967) reported little change in cooking quality of pasta when starch isolated from durum and hard red spring wheat were interchanged, although it should be noted that surface characteristics were not measured. Starch gelatinization takes place gradually during spaghetti cooking in a inward direction (Marshall and Wasik, 1974) and is more rapid at lower protein than at higher protein levels (Grzybowski and Donnelly, 1977). According to Eliasson (1983), the slower gelatinization observed at higher protein is likely due to greater competition between the gluten and starch for the available water. Damaged starch, such as what might occur during milling can lower cooking quality (Seyam et al., 1976). If starch is gelatinized before the formation of the insoluble protein network, high cooking loss will be observed (Dalbon et al., 1981; D'Egidio et al., 1982). Dexter et al. (1985b) and Matsuo et al. (1986) suggest that high levels of amylose on the surface of the pasta are responsible for stickiness. D'Egidio et al. (1983) however, reported that the cooking process results in the accumulation of amylose in the cooking water and an increase in amylopectin on the surface of the pasta. Pasta of low quality has more amylopectin on the surface than pasta of high quality. This suggests that amylopectin has broken down more extensively in the pasta of low quality.

The lipid content of semolina and pasta ranges from 1.5 to 2.0% depending on the variety and milling condition (Feillet, 1984). Free lipids account for 50% of the total lipid fraction in semolina and only for 5% in pasta since 90% of the free lipids are bound during processing, especially in the drying step due to water loss (Barnes et al., 1983). Only a few studies have been undertaken to assess the effects of lipids on the cooking quality of pasta. Dahle and Muenchow (1968) reported the removal of lipids or proteins increased the amount of amylose in the cooking water. Removal of lipids led primarily to an increase in stickiness. Lin et al. (1974) concluded that neither nonpolar nor polar lipids affected the cooking quality of spaghetti to any extent although it should be noted that surface characteristics were not measured. Matsuo et al. (1986) found that the removal of nonpolar lipids increased stickiness of spaghetti. A possible explanation for this finding is that in the presence of lipids, there was less exudation of amylose during gelatinization due to lipid-amylose complexing. Studies done on the interactions of lipids, proteins, and starches during breadmaking suggested that lipids interact with proteins and starch to form starch-glycolipid-protein complex through hydrogen bonds between glycolipids and gelatinized starch or gliadins, and hydrophobic bonds between glycolipids and glutenins (Chung et al., 1978; Cherry, 1982).

Thus, progress has been made in recent years in the identification of components present in durum wheat that are associated with pasta cooking quality. The importance of protein quality, protein quantity and protein composition has been established by a number of workers. More work on starch and lipids is required as is a better understanding of the interactions between protein, starch, and lipids.

1.2.2 Optimization of Pasta Cooking Quality

With new advances in the technology of pasta processing, especially with the application of higher drying temperatures, the quality of raw material may no longer be as critical as it once was (Cubadda, 1989; Feillet, 1984; Matsuo, 1988) suggesting a need for research to examine the relationship between raw material characteristics and drying temperatures and their effect on the cooking quality of pasta.

1.2.2.1 Drying Temperature

The drying process is considered to be the most critical phase in spaghetti processing. Moisture must be removed at a uniform rate to prevent moisture gradients within the strands that can cause checking or cracking (Dick and Matsuo, 1988). Initially, pasta undergoes a pre-drying phase where the moisture of the pasta is lowered from approximately 30% to about 20%. The usual time required for this phase is about one hour. After this, the pasta undergoes further drying to a final moisture content of about 12%. The time required at this stage of drying depends on the spaghetti diameter and on the drying temperature utilized.

"Traditional", "conventional" or "low temperature" (LT) drying refers to the use of temperatures no higher than 60° C (Dalbon and Oehler, 1983). "High temperature" (HT) drying refers to temperatures between 60° and 90° C (Manser, 1980). "Very high" (VHT) (Pagani et al., 1986) and "tres haute" (THT) (Mondelli, 1989) temperature drying refer to temperatures greater than 90° C. HT drying of pasta is very common (Dick and Matsuo, 1988) and commercial THT drying lines have recently been introduced (Mondelli, 1989). Reported benefits of HT/THT drying include: reduced drying times, improved microbiological quality and enhanced cooking quality. According to Manser (1980) pasta dried under high temperatures are firmer and less sticky, especially if the samples are blended with common wheat. Nevertheless, the effects of HT drying on the improvement of cooking quality of pasta remains controversial since few studies have been published which report experimental data and of those studies in which data are reported the pasta has been processed in a laboratory (Cubadda, 1989). Despite this, the use of laboratory processed pasta is often the only feasible alternative available for studying the effect of drying conditions on end product quality. Discrepancies also exist among the studies in the method of application of HT during the drying cycle with some workers applying HT at the beginning of the drying cycle while others apply HT after first subjecting the pasta to pre-drying at LT.

Dexter et al. (1981b) found spaghetti dried initially at LT followed by HT drying at 70° C had improved cooking quality compared with spaghetti dried at LT (39° C) throughout the entire drying cycle and with spaghetti dried initially at HT (70° C) followed by LT drying. However, spaghetti dried initially at HT had enhanced color intensity whereas spaghetti dried at HT after pre-drying at LT, had equal color quality to LT dried spaghetti. Inactivation of lipoxidase by HT was at least partially responsible for the improved color.

In a second study by Dexter et al. (1981a), spaghetti dried initially at either 65° or 80° C followed by LT drying showed no marked improvement in cooking quality compared to spaghetti dried at LT (39° C) throughout the entire drying cycle. Spaghetti dried at 80° C did however, have superior color characteristics to spaghetti dried at 39° C. The lack of improvement in cooking quality for the HT dried spaghetti in this experiment suggests that the application of HT should occur after predrying at conventional LT. It has been speculated that the poorer cooking quality of the spaghetti dried initially at HT may be due to premature denaturation of gluten, and possibly some starch gelatinization (Manser, 1980).

Wyland and D'Appolonia (1982) evaluated three HT drying cycles with conventional LT drying (40° C for 18 hr). The HT cycled involved pre-drying at 40° C for 2 hr followed by drying at 60°, 70° or 80° C for 8.5, 6.5, or 4.5 hr respectively. Spaghetti dried under HT conditions was significantly firmer than spaghetti dried at LT. No difference in spaghetti firmness was observed among the three HT treatments. Significantly lower cooking losses were found for spaghetti dried at 80° C compared to the other drying temperatures and the highest cooking losses were obtained for the spaghetti dried at 40° C. No assessment was done on color or surface characteristics.

Dexter et al. (1984) investigated the effect of 5 different HT drying cycles on the cooking quality of spaghetti compared to LT drying at 39° C. Three of the cycles involved an initial pre-drying for 1 hr at low temperatures followed by 8 hr at HT (either 70°, 80° or 85° C) then rapid cooling to 40° C and holding at this temperature for the remainder of the cycle. The fourth cycle, designated as 40°/85° C, was comprised of an initial pre-drying at LT (40° C) for 1 hr, followed by 2 hr at 85° C, then 6 hr at 40° C. The fifth cycle, designated as 85°/40° C, applied HT (85° C) for 2 hr, followed by 18 hr at 40° C. All five cycles had improved cooking scores (the ratio of recovery to the product of compressibility and tenderness) compared to conventional LT (40° C for 28 hr) dried spaghetti. However, only the 70° C and the 40°/85° C dried spaghetti had lower cooking loss values and only the 80° and 85° C spaghetti were less sticky than the LT spaghetti. Short term exposure of spaghetti to HT drying resulted in improved color and much reduced loss of lysine compared to drying cycles with longer exposure to HT.

Taha and Sagi (1988) compared LT drying of macaroni at 40° C with HT drying (70° C for the first 3 hr, followed by 80° C for 1 hr then 40° C for 18 hr). No differences in macaroni strength were observed but significantly higher cooking losses were found for HT macaroni. Macaroni color was improved with HT drying. D'Egidio et al. (1990) reported higher sensory scores and lower total organic material (TOM) with pasta dried at 80° C compared to 40° C.

Resmini and Pagani (1983) reported the best cooking quality was achieved with a drying cycle that applied HT (90° C) after predrying the spaghetti at LT to a low moisture content. The application of HT at a high moisture content and at a medium moisture content resulted in poor cooking quality. The authors suggest that initial drying to a low moisture content appears to be critical in order to prevent starch swelling during the application of HT.

Abecassis et al. (1989) devised an experimental dryer in order to more closely examine the effects of moisture removal during drying and the application of HT drying on the cooking quality of spaghetti. Spaghetti dried at 55° C for 20 hr was compared with spaghetti dried at 55° C to a moisture content of 24, 18, and 13% before applying HT of 90° C for 2 hr and then continuing to dry at 55° C for the remainder of the drying cycle. All cooking quality parameters were improved by HT drying. The most noticeable improvement was in surface characteristics and this improvement was particularly noticeable when the pasta had a low water content at the time of the HT treatment. Cooking loss values were lowest for LT dried spaghetti and for spaghetti dried at HT drying once a low moisture content (13%) was reached. In subsequent experiments the authors confirmed the beneficial effects of applying a thermal treatment phase (90° C for 2 hr) after drying initially to a low moisture content. Not only were improvements made in textural quality but also in cooking losses. However, the application of HT after a low moisture content was achieved, did cause changes in color (development of a slight redness, and an increase in brown and yellow indexes). The authors did not feel that these changes would be detrimental to the acceptance of the spaghetti.

Thus, on the basis of this literature, there appears to be evidence to support the claim that HT application improves the cooking quality of pasta especially if HT is applied after pre-drying under LT conditions to a low moisture level. What requires clarification however, is a better understanding of which intrinsic characteristics of the raw material are still important in ensuring the production of high quality pasta when HT drying is used.

1.2.2.2 Durum Protein Level

Only a few studies have looked at the effects of protein level and drying temperature on the cooking quality of spaghetti. Dexter et al. (1981b) found the cooking quality characteristics for both low and high protein durum semolinas were enhanced slightly with the application of HT conditions. Cooking losses were however, greatly reduced for the low protein semolina processed under HT conditions compared to high protein semolina. This was less obvious in a second study by Dexter et al. (1983b). Surface characteristics were found to improve in the second study for one of the varieties tested when low and high protein durum was processed at HT. No difference was observed for the other variety. Recovery only improved at HT for the higher protein samples and firmness actually decreased for the low protein samples processed at HT. Clearly, more work needs to be done to assess the relationship of spaghetti drying temperature and semolina protein level on the cooking quality of spaghetti. It would be of great interest to determine which combinations of drying temperatures and protein levels yield optimum spaghetti.

1.2.2.3 Blending of Durum Wheat With Common Wheat

Few studies have been done to compare the quality of spaghetti made from durum semolina with spaghetti made from farina or from blends of semolina and farina. Sheu et al. (1967) reported that pasta made from hard red spring (HRS) farina had lower cooking losses and cooked weight and was firmer than spaghetti made from durum semolina. This was confirmed by Mousa et al. (1983) using spaghetti made with durum semolina and with HRS and hard red winter (HRW) farina. Both HRS and HRW spaghetti were firmer and had lower cooked weight and cooking loss values than spaghetti made from durum. As expected, durum spaghetti had higher color scores than the other spaghetti.

In studies done on farina blending, Wyland and D'Appolonia (1982) found a similar trend. As the level of HRS increased in the spaghetti, firmness increased, whereas cooking loss, cooked weight, and spaghetti color decreased. In contrast, Dexter et al. (1981c) found cooking scores decreased with increasing farina levels especially when the spaghetti was overcooked indicating that spaghetti containing farina was not as tolerant to overcooking as durum spaghetti.

Studies done by Kim et al. (1986 and 1989) on semolina and farina spaghetti were in agreement with the study by Dexter et al. (1981b). Spaghetti made with semolina had a firmer texture than spaghetti made with farina. As for cooking losses, Kim et al. (1986) found durum spaghetti had higher cooking losses than farina spaghetti when cooked in distilled water whereas the opposite was found when the spaghetti was cooked in prepared hard water (Kim et al., 1989). Kim et al. (1989) also reported that durum spaghetti was less sticky than farina spaghetti but the workers reported difficulties in the assessment of spaghetti stickiness.

Thus, the effects of farina blending on the cooking quality of pasta, especially stickiness, has not been widely studied and merits further investigation.

The effect of drying temperature on the quality of farina spaghetti has been examined by several workers. Kim et al. (1989) found both semolina and farina spaghetti dried under HT (70° C) conditions were firmer, less sticky and had lower cooking losses than samples dried under LT (45° C) conditions. Results by Dexter et al.(1983b) were in agreement with those of Kim et al. (1989) except firmness of farina spaghetti was not found to increase with HT drying compared to durum spaghetti. Blends of durum and farina were not examined. Wyland and D'Appolonia (1983) studied the effect of farina blending with drying temperatures of 40°, 60°, 70°, and 80° C. As drying temperature increased, firmness also increased and cooking loss values decreased. Spaghetti stickiness was not measured. The authors did not indicate what combinations of farina blends and drying temperatures gave optimum cooking quality thereby limiting the conclusions that can be drawn from this study.

Thus, the use of HT drying conditions appears promising in terms of improving the cooking quality of spaghetti prepared from blends of durum semolina and HRS farina. More work needs to be done however, to examine the relationship of spaghetti drying temperature and farina blending on the cooking quality of spaghetti with the goal of determining which combinations of drying temperatures and farina blends yield spaghetti with optimum cooking quality.

1.2.3 Assessment of Pasta Cooking Quality

Considerable effort has been made to develop simple and reliable methods for evaluating cooked pasta quality using instrumental and sensory techniques, but to date no universally accepted methods are available. In addition, there is a lack of standardized cooking procedures, especially with the type of cooking water used, which has compounded the problem.

1.2.3.1 Cooking Water

Cooking quality of pasta, especially surface stickiness, amount of rinsed material collected from the strands, and cooking loss, have been shown to be influenced by the type of cooking water used. Several workers have shown that as water hardness increased, cooked spaghetti became stickier (Menger, 1980; D'Egidio et al., 1981; Dexter et al., 1983b; Seibel et al., 1985), had higher total organic materials (TOM) in the rinse and cooking waters (D'Egidio et al., 1981; Seibel et al., 1985), and had higher cooking losses (Dexter et al., 1983b).

Attempts to quantify the effects of mineral composition on cooking quality of pasta have not been successful. Oh et al. (1985a) found the level of Ca in the cooking water had to be greater than 80 ppm before a difference in surface firmness of noodles could be observed. No effect was observed for cooking loss and Mg did not appear to have any effect on these parameters. Surface stickiness was not measured however, and the pH of the water (9.2) was very high which likely influenced the results. Menger (1980) found the addition of 10,000 ppm $CaCl_2$ to distilled water caused a deterioration in sensory quality of cooked spaghetti and rinsing water residues. A 5,000 ppm $CaCl_2$ addition resulted in only a slight deterioration in spaghetti quality but the spaghetti was firmer. The addition of 1,000 ppm $MgSO_4$ also caused a deterioration in quality but it was less pronounced than with Ca. The spaghetti was also softer after cooking in the presence of Mg. Although this study demonstrated a clear effect of mineral composition on spaghetti quality, the levels of Ca and Mg used were extremely high.

D'Egidio et al. (1981) found the addition of 5,000 ppm NaCl to distilled water had no effect on spaghetti quality whereas Menger (1980) found the addition of 7,000 ppm caused a deterioration in surface swelling, and enhanced stickiness and rinsing water residues. Seibel et al. (1985) found the addition of 6,000 and 600 ppm NaCl caused only a minor deterioration in quality when added to distilled water compared to an adverse effect when added to tap water. This suggests an interactive effect of other ions present in the tap water and/or pH effect. The levels of NaCl addition in these studies are realistic in light of recommendations made by pasta manufacturers and in terms of naturally occurring levels of Na in water.

Cooking water pH has also been shown to influence cooked spaghetti quality. Alary et al. (1979) and Abecassis et al. (1980) were able to decrease surface disintegration and stickiness and lower cooking losses by adjusting the pH of mineral water to 6.0. To further elucidate the importance of cooking water pH on spaghetti quality, Abecassis et al. (1980) also adjusted the pH of distilled water and found spaghetti cooking quality was at its peak at pH 6. On either side of this pH, quality was found to decline. These findings were confirmed by Seibel et al. (1985) who found weakly acidic cooking water gave good sensory quality and decreased TOM levels. Oh et al. (1985a) reported noodle firmness decreased rapidly and cooking losses increased when a pH greater than 8 was used for cooking. Surface firmness and cooking loss were not affected between pH 6-8.

Shifts in the pH of mineral water during cooking have been suggested by several workers to be responsible for the diminished quality of spaghetti rather than the presence of the ions themselves. Menger (1980) found NaCl causes a shift in pH upward, whereas $CaCl_2$ caused a shift downward. Alary et al. (1979) observed the pH of mineral water shifted upward during cooking, whereas distilled water remained constant.

Despite the lack of agreement as to which factor, water hardness or pH, influences cooked spaghetti quality, it would seem reasonable to conclude that both factors are involved and they likely influence each other. Therefore, both the mineral composition and the pH of the cooking water should be standardized if comparisons are to be made from one testing session to another. The use of distilled water may not permit adequate discrimination between spaghetti samples. Indeed, D'Egidio et al. (1981) have stated that hard water permits better discrimination among spaghetti samples. This may also be true of water that is slightly alkaline since spaghetti cooking quality has been shown to be at its peak at a pH of 6. Ideally, spaghetti should be examined under the conditions that it is most likely to encounter in the marketplace.

The use of "artificially" hardened water is a practical alternative since local water supplies differ from region to region and may fluctuate from season to season. Dexter et al. (1985a) provided a formulation for preparing artificially hardened water which they have incorporated into their durum wheat screening program. ISO (1985) has also published a procedure for preparing artificially hardened water. Thus, limited information exists on prepared hard water despite the need for a standardized prepared water for cooking spaghetti.

1.2.3.2 Physical/Instrumental Evaluations

An extensive effort has been made to establish instrumental methods for measuring the textural properties of cooked spaghetti since sensory techniques involve substantial time and money expenditures, and can often exhibit poor reproducibility. As well, use of sensory panels to evaluate a large number of samples or to evaluate samples when sample size is limited is not feasible. Instrumental measurements must be calibrated however, against sound sensory measurements in order to validate the instrumental procedure.

A number of instrumental methods have been reported for measuring the textural properties of pasta utilizing tensile forces (Hollinger, 1963; Glabe et al., 1957; Shimizu et al., 1958; Voisey and Larmond, 1973). These techniques present operational difficulties with spaghetti since it is difficult to grip the ends without damaging the strand. Although Voisey and Larmond (1973) established a correlation between tensile readings and sensory measurements of firmness and chewiness, they found instrumental shear readings obtained from a multiblade shear compression cell were more closely related to sensory results. This can be attributed to the shearing and compression forces that takes place during mastication rather than the application of tensile forces.

Several workers have reported methods for measuring firmness of pasta using compression forces. Binnington et al. (1939), Harris and Knowles (1939) and Harris and Sibbitt (1958) used a plunger to compress a sample of cooked macaroni until it collapsed or deformed a preset amount. They reported high variability with their readings. Szczesniak and Hall (1975) described a "full cup" technique to assess the hardness, cohesiveness and gumminess of cooked macaroni using the General Foods Texturometer and Lee et al. (1987) also used a "full cup" technique with the Rheometer to measure the firmness of cooked noodles. Neither of these instruments are in wide use.

Voisey and Larmond (1973) used a multiblade shear compression cell mounted to the Ottawa Texture Measuring System (OTMS) to measure the firmness of spaghetti. They found the multiblade cell the most reliable of all the test cells evaluated in their study. This finding confirms the importance of measuring more than one strand of spaghetti since variations within and among strands exist. By testing numerous samples and averaging the results, these variations are minimized.

Matsuo and Irvine (1969) simulated the bite test on cooked spaghetti by applying a continuously increasing force to a cutting edge resting on a strand of spaghetti. A tenderness index was derived from the slope of the linear portion of the penetration-time curve and this was an indication of the length of time it took the loaded cutting edge to cut through the specimen. Results were correlated with sensory measurements of firmness (Matsuo and Irvine, 1974). Walsh (1971) described a similar bite test using the Instron Universal Testing Machine. Firmness was expressed as the amount of work in g.cm required to shear a strand of spaghetti. Results were found to correlate with sensory measurements of firmness. Oh et al. (1983) adapted this technique for noodles by shearing three strands with a plexiglass tooth that was bevelled on both sides of the contact surface. Good correlations were established with sensory measurements of firmness and chewiness. Recently, AACC (1989) adopted an Instron method for assessing the firmness of pasta utilizing the blade designed by Oh et al. (1983). Five strands of spaghetti are sheared and firmness is expressed as the energy (work) in g.cm to shear one strand of spaghetti.

Several workers have developed methods for measuring the compressibility and elasticity of pasta. Dalbon et al. (1985) used the Instron to measure compressibility and recovery (a measure of elasticity) of eight strands of spaghetti using a plunger 3.5 cm in diameter. The strands were compressed to a fixed load at which point the load was immediately removed. Compression was defined as the relationship of the diameter of the compressed spaghetti to the original diameter multiplied by 100. Recovery was defined as the relationship of spaghetti diameter after recovery to the diameter of the compressed spaghetti. No attempt was made by the authors to correlate Instron measurements with sensory measures of elasticity and compressibility. Oh et al. (1983) described a similar Instron method for measuring the compressibility and recovery of noodles except that three strands were compressed with a blunt blade, similar in design to that used by Matsuo and Irvine (1971). Instron measures were found to correlate with sensory measures of firmness and chewiness. Huang and Morrison (1988) measured the compressibility and recovery of Chinese noodles using this method.

Abecassis et al. (1989) described a method for determining the index of viscoelasticity from compressibility and relative recovery values obtained from the Chopin INRA Viscoelastograph. Essentially, compressibility and recovery scores are derived from this instrument similar to the method described by Dalbon et al.(1985) using the Instron.

Matsuo and Irvine 1971 measured compression and recovery of spaghetti using their tenderness testing apparatus. The cutting blade was replaced with a blunt blade and a single strand was compressed under a fixed load, held for 15 sec before the load was removed. Once the load was removed there was an instantaneous partial elastic recovery. Bourne (1982) describes this method for measuring the time aspects of deformation as an assessment of the change in height over a period of time at a constant level of deformation. Another technique that can be used for measuring the time aspects of deformation involves the measurement of the change in force over a period of time at a constant level of deformation. That is, the specimen is compressed to a pre-determined compression depth or load and held at that compression while changes in force are measured (Bourne, 1982). The decay of stress under a constant strain is known as stress relaxation. This test can be easily performed using the Instron (Bourne et al., 1966) and has been successfully used to measure the relaxation of bread doughs (Heaps et al., 1967; Frazier et al., 1973; Rasper and deMan, 1980). Relaxation time is defined as the time required for the stress at constant strain to decrease to 1/e of its original value, where e is the base of natural logarithms. Since 1/e = 0.3678, the relaxation time is the time required for the force to decay to 36.8% of its original value. Often the time to relax to 1/e is excessive, in which case some other value is taken as an arbitrary relaxation time (Bourne, 1982).

Several attempts have been made to measure spaghetti stickiness using instrumental techniques. Voisey et al. (1978b) reported the use of a multi strand test fixture mounted on the Instron to assess the stickiness of cooked spaghetti. Ten strands were mounted on a serrated baseplate and were compressed to a fixed compression force with a plunger with a flat surface. After allowing the spaghetti to relax the plates were pulled apart and the maximum tensile force was used as the index of stickiness. This required a load cell with two outputs to record both the compressive forces required to push the plates together and the tensile forces to pull the plates apart. Stickiness readings were found to be related to non-oral sensory assessments of stickiness.

Numerous studies have attempted to measure stickiness of a variety of food using the Instron by compressing the sample to a fixed force or depth and deriving a stickiness measurement from the area under the force-distance curve. Dalbon et al. (1985) compressed eight strands of spaghetti using a plunger with a diameter of 3.5 cm. No information was given as to the compression force used. Results appeared to be in agreement with sensory measures of stickiness. Similar techniques have been employed by workers measuring the stickiness of rice (Mossman et al., 1983; Fellers et al., 1983; Biswas and Juliano, 1988). Fellers et al. (1983)

reported a good correlation between Instron stickiness measures and sensory scores for rice stickiness. In contrast, Boyd and Sherman (1975b) were unable to correlate Instron and sensory measurements of stickiness for a variety of foods. This lack of correlation applied irrespective of whether the Instron plate had been wetted with saliva or not. Atkins (1989) was also unable to correlate Instron measurements of stickiness with a bakers assessment of dough stickiness although a correlation was found between compression energy and sensory stickiness. The correlation between Instron stickiness and sensory stickiness improved however, when a lower compression force was used suggesting that the force used may be critical to obtaining a valid measurement of stickiness.

Dexter et al. (1983a) reported a method for measuring stickiness using the Grain Research Laboratory Compression Tester. A number of strands were compressed with a flat plunger and upon lifting the plunger, the force of adhesion of the spaghetti to the plunger was measured. This differs from the previous studies which defined stickiness as the energy or work (area) to separate the sample from the plunger. Kim et al. (1989) adapted this technique for use with the Instron but encountered some difficulties with the measurement which they attributed to surface water released from the spaghetti during compression. According to the authors, a low stickiness score could mean either a water-logged (overcooked) spaghetti with water released during compression or a firm spaghetti that was not sticky. It is possible that the use of a lower compression force may have overcome this problem.

Several researchers have found the amount of residue in the cooking water and the amount of rinsed material collected from the surface of pasta are good indicators of pasta quality. The amount of residue in the cooking water denotes the degree of breakdown of the pasta during cooking and is referred to as cooking loss or cooking-water residue (Dick and Matsuo, 1988). The residue can be determined by evaporating the cooking water by either heating or freeze-drying or by measuring the absorption of the iodine-amylose complex (Matsuo et al., 1990). The amount of total organic matter (TOM) that can be isolated from the surface of spaghetti strands by exhaustive rinsing has been reported by D'Egidio et al. (1982) to be a reliable means of estimating the cooking quality of spaghetti.

The Instron has been widely used as a method of measuring the textural properties of various foods due to its convenience, accuracy and flexibility (Finney, 1969). Coupled with data acquisition software, the Instron has proven to be an effective method of texture measurement (Buckley et al., 1984). The Instron is a multiple measuring instrument which can be used to assess a number of different textural parameters. A wide variety of test cells and operating conditions can be employed which enhances its versatility. This has caused the proliferation of unstandardized conditions of texture measurement (Breene, 1975). As well, many researchers do not publish enough detail of their method for it to be reproduced by others.

A number of studies have been undertaken to assess the effects of operating conditions on Instron measurements including crosshead speed (Baker et al., 1986; Betker, 1990; Boyd and Sherman, 1975a and 1975b; Hibberd and Parker, 1985; Shama and Sherman, 1973; Voisey et al., 1978a and 1978b), plunger area (Baker et al., 1986; Betker, 1990; Walker et al., 1987) and compression depth (Baker et al., 1986 and 1988; Betker, 1990; Boyd and Sherman, 1975a; Redlinger et al., 1985; Shama and Sherman, 1973). The effects of sample characteristics and dimensions have also been examined (Bagley et al., 1985; Brinton and Bourne, 1972; Redlinger et al., 1985). In all studies, varying the operating conditions significantly influenced the results obtained. This suggests the need to identify operating conditions which are most effective in detecting differences among samples and which have high reproducibility and repeatability. According to Baker et al. (1986), a complete evaluation of the operating factors of the Instron (crosshead speed, compression depth or force, plunger size, sample characteristics) is necessary in order to develop reliable methods for measuring the textural properties of a food.

1.2.3.3. Sensory Evaluations

Despite the effort that has been made to establish instrumental methods for measuring the textural properties of cooked spaghetti, several workers believe that the most reliable tests for assessing pasta are sensory evaluations (Cubadda, 1988; Matsuo, 1988). This is likely because the perception of texture involves a complex response to a number of physical and physicochemical properties of food (Peleg, 1987). This makes it extremely difficult to replicate the responses instrumentally and suggests that it is unrealistic to assume that one instrumental method can measure all of the textural properties of a food. Indeed, Bourne (1982) has stated that there is no instrument available that has the sophistication, elegance, sensitivity, and range of mechanical motions as the mouth or that can promptly change speed and mode of mastication in response to the sensations received during the previous chew.

Sensory evaluation procedures are often criticized as being "subjective" techniques. However, if done under controlled testing conditions, utilizing trained panelists and appropriate sensory methods, the procedures are "objective" (Larmond, 1987). Bourne (1982) also acknowledges that a properly trained descriptive panel is "objective" since the two criteria of objectivity are met namely: freedom from personal bias and, repeatability.

Szczesniak (1963) classified the textural characteristics of food into mechanical, geometrical and those related to fat and moisture content of a food. Mechanical characteristics are those parameters related to the reaction of food to stress. They include five primary (hardness, cohesiveness, viscosity, springiness, adhesiveness) and three secondary parameters (fracturability, chewiness, gumminess) which are composites of primary parameters. Geometrical characteristics are related to the geometrical arrangement of the food matrix and are divided into two classes: those related to particle size and shape and those related to particle shape and orientation. This classification of texture was intended for both instrumental and sensory measurements and is the basis of sensory and instrumental texture profile analysis (TPA). The sensory profile analysis relies on the use of trained judges who describe the textural characteristics of a food qualitatively and quantitatively in the order of appearance from first bite through complete mastication. Guidelines for the training and use of a texture profile panel can be found in Brandt et al., 1963; Civille and Szczesniak (1973) and Civille and Liska (1975). Szczesniak et al. (1963) published operational definitions and standard rating scales for all of the mechanical parameters in order to standardize terminology and methods of assessment. The rating scales also provide an illustration of the intensity range for each attribute. Munoz (1986) has since published modifications to several of these rating scales and has added several new parameters.

A number of researchers have used trained panelists to assess the textural properties of pasta (Tables 1.1 - 1.5). Firmness, chewiness and stickiness have been evaluated in a number of studies, suggesting that these parameters are important attributes of pasta quality. The parameters of

Table 1.1 Summary of Studies Rating Pasta Firmness

Definition	Scaling Method	Reference
Force required to penetrate sample with molars.	1=soft, 8=ext.firm	1.
Force required to compress between molars during first bite.	unstructured soft to firm	2.
Resistance to cutting between teeth & to crush between tongue & palate.	1=v.tender, 9=v.firm	3.
None given.	1=mushy, 10=tough	4.
None given.	magnitude estimation	5.
Force required to crush between the molars.	1=v.soft, 5=firm	6.
Resistance to chewing.	1=v.low, 10=optimal	7.
None given.	1=mushy, 7=rubbery	8.
None given.	1=soft, 10=firm	9,12.
Force required to bite through a strand between molars.	1=soft, 10=firm	10.
None given.	1=soft, mushy 100=firm, elastic	11.
Resistance when chewed or flattened between fingers or sheared between teeth.	0=absent, 100=excellent	12.

1. (spaghetti) Larmond and Voisey, 1973.
2. (spaghetti) Voisey et al., 1978a.
3. (spaghetti) ISO, 1985.
4. (spaghetti) Walsh, 1971.
5. (spaghetti) Marshall, 1974.
6. (spaghetti) Dalbon et al., 1985.
7. (spaghetti) D'Egidio et al., 1982.
8. (macaroni) Hanna et al., 1978.
9. (spaghetti) Wu et al., 1987.
10. (noodles) Oh et al., 1983.
11. (noodles) Chompreeda et al., 1987.
12. (noodles) Moss et al., 1986.
13. (spaghetti) Cubadda, 1988.

Table 1.2 Summary of Studies Rating Pasta Chewiness

Definition	Scaling Method	Reference
Length of time required to masticate to a state ready for swallowing.	1=ext.tender, 8=ext. chewy	1.
Time required to prepare 3 strands for swallowing while chewing at a constant rate.	unstructured slow to fast	2.
Length of time required to masticate 10 g at rate of 1 chew per sec.	actual time (sec)	10.
Count number of chews required to reduce sample to state ready for swallowing.	number of chews	11.

1. (spaghetti) Larmond & Voisey, 1973.
2. (spaghetti) Voisey et al., 1978a.
10. (noodles) Oh et al., 1983.
11. (noodles) Chompreeda et al., 1987.

Table 1.3 Summary of Studies Rating Pasta Gumminess and Elasticity

Definition	Scaling Method	Reference
A. Gumminess		
Denseness that persists throughout mastication.	1=none, 8=ext. gummy	1.
B. Elasticity		
None given. Assessed by mouth.	1=none, 10=elastic	12.
Resilience when strands stretched with fingers.	unstructured	2.

1. (spaghetti) Larmond & Voisey, 1973.
2. (spaghetti) Voisey et al., 1978a.
12. (noodles) Moss et al., 1986.

Table 1.4 Summary of Studies Rating Pasta Stickiness by Mouth

Definition	Scaling Method	Reference
Force required to remove material that adheres to mouth during eating.	1=not sticky 8=ext. sticky	1.
Force required to remove chewed sample from teeth.	unstructured v. little to v. much	2, 14.
Sticking to teeth when being chewed.	1=none 5=extreme	6.
Freedom from surface stickiness.	1=extreme 10=none.	12.
Retention of individual strands during chewing.	yes/no	2.

1. (spaghetti) Larmond and Voisey, 1973.
2. (spaghetti) Voisey et al., 1978a.
6. (spaghetti) Dalbon et al., 1985.
12. (noodles) Moss et al., 1986.
14. (spaghetti) Voisey et al., 1978b.

Table 1.5 Summary of Studies Rating Pasta Stickiness by Visual/Tactile Methods

Definition	Scaling Method	Reference
Tendency to remain in mass.	1=low, 10=high	7.
Tendency to stick together.	1=very, 10=not	15, 16.
Bulkiness: degree of adhesion of strands.	0=totally, 100=absent	13.
Surface condition (compared to photographs).	1=v.stuck 9=completely separate	3.
Surface disintegration.	1=very, 10=none 0=totally, 100=absent	16. 13.
Surface deterioration & stickiness.	1=v.poor, 9=excellent	17.
Degree of surface swelling.	1=v.swollen, 10=not	15.
Stickiness of 8 strands pressed together by hand.	1=none, 5=extreme	6.
Ease which sample is removed from beaker. Ease which sample is stirred & spread with finger. Force required to separate strands adhering together. Ease which samples slide when tipped.	1=easy, 5=not easy	14.

3. (spaghetti) ISO, 1985.
6. (spaghetti) Dalbon et al., 1985.
7. (spaghetti) D'Egidio et al., 1982.
13. (spaghetti) Cubadda, 1988.
14. (spaghetti) Voisey et al., 1978b.
15. (spaghetti) Abecassis et al., 1980.
16. (spaghetti) Alary et al., 1979.
17. (spaghetti) Autran et al., 1986.

gumminess and elasticity have received much less attention. Attempts to quantify stickiness have involved both oral (Table 1.4) and non-oral (Table 1.5) procedures including visual and tactile assessments. A series of reference photographs have been developed for use in the visual assessment of surface condition (ISO, 1985).

Few studies have been undertaken that involve a comprehensive assessment of cooked pasta texture. Larmond and Voisey (1973) used a trained panel to assess the firmness, chewiness, gumminess, adhesiveness and individuality of spaghetti strands. Panelists were able to distinguish differences among the spaghetti samples for all parameters. When these results were compared with consumer acceptability tests, it was found that consumers preferred spaghetti that was firm, chewy, and maintained individuality and was not gummy or adhesive. Further analysis suggested that firmness and gumminess were sufficient to predict consumer acceptability. In another study by these same researchers, trained panelists were able to distinguish differences among spaghetti samples in firmness, springiness, adhesiveness, and rate of breakdown (Voisey et al., 1978a).

Menger (1985) developed an extensive scoring system for assessing the quality of raw and cooked pasta. Trained panelists assessed twenty factors, six related to the uncooked product, seventeen to the cooked product. The scoring system was weighted such that, uncooked quality accounted for 30% towards the final score and cooked quality accounted for 70%.

Factors such as: retention of shape, surface characteristics, bite/firmness, odor and taste were judged in the assessment of cooked pasta quality.

Cubadda (1988) also described a scoring method for assessing cooked pasta quality. Experts (at least three persons) evaluated stickiness, firmness and bulkiness using scales ranging from 0 to 100. An overall quality score is then calculated by totalling the scores for the three parameters, multiplied by 33.3, and dividing by 100. An overall score greater than 80 indicates excellent quality.

Thus, the textural properties of cooked pasta have been widely studied by sensory evaluation techniques. Many of these studies however, can be viewed as only partial texture profile techniques since a complete assessment of all textural characteristics was not carried out. By establishing a trained texture profile analysis panel, a detailed and comprehensive sensory description of the textural characteristics of spaghetti can be obtained which can then be used to validate instrumental measures of cooked spaghetti texture.

1.2.4 Relating Sensory and Physical Data

To verify that physical/instrumental values have meaning in terms of sensory ratings of texture, a relationship between the sensory and instrumental measurements must be established. The two most common methods for establishing a relationship between sensory and physical data are correlation analysis and multiple regression techniques. Often however, the sensory data are subjected to a data reduction technique, such as principle component analysis prior to establishing the relationship with physical data.

1.2.4.1 Principle Component Analysis of Sensory Data

Due to the textural complexity of most food products, qualitative description of the textural properties of a food, generally involves the measurement of numerous sensory attributes. Many of these attributes may be redundant making the task of relating sensory and instrumental data cumbersome. For this reason, the use of multivariate techniques are often used to examine sensory data. Multivariate methods are effective in simplifying semantic and compositional data to manageable proportions (Ennis et al., 1982) without losing important information (Martens, 1983).

One multivariate technique that has been particularly useful in the assessment of sensory data is principle component analysis (PCA). The function of PCA is to identify the interrelationships or similarities among a set of variables and reduce the original number of variables to a smaller number of components (Cardello and Maller. 1987). PCA constructs linear combinations of the original data with maximal variance (Resurreccion, 1988). The first component extracted will account for the greatest portion of the variance, the second component for the second largest portion, etc. Principle component analysis has been successfully used to reduce the number of variables in the sensory assessment of cabbage (Martens, 1985); soy sauce (Aishima, 1983); and whisky (Piggot and Jardine, 1979).

1.2.4.2 Correlation Analysis

Instrumental measurements must be calibrated against reliable sensory judgements in order to validate the instrumental method. Szczesniak (1968) discussed factors which led to poor correlations between sensory and instrumental measures including: improper execution of sensory tests, inadequate knowledge of what the instrumental test actually measured, sampling errors, heterogeneity of food products, and interpretation of the meaning of correlation coefficients. As well, factors such as the selection of sensory terms and sensory scales, and the similarity of the physical aspects of the two sets of measurements have been shown to affect correlations (Szczesniak, 1987).

The most common approach to relating sensory and instrumental measurements is the use of correlation analysis even though several disadvantages have been shown to exist with this approach. In this technique, each sensory measure is regressed against each instrumental measure such that, the likelihood of finding high correlations by chance increases with the number of correlations attempted (Cardello and Maller, 1987). In addition, statistically significant correlation coefficients can be achieved between sensory and instrumental measures if the sample size is large enough (Bourne, 1982). Therefore, if correlation coefficients are to be used, it is important to distinguish between statistical significance and predictive reliability. Kramer (1951) provided a useful guide for determining the predictive reliability of correlation coefficients.

1.2.4.3 Multiple Regression Analysis

Multiple regression techniques have become more widely used to relate sensory descriptive data to instrumental measures (Szczesniak, 1987; Cardello and Maller, 1987). In this statistical technique, a series of independent or predictor variables (instrumental measures) are employed to predict some dependent variable (sensory measure). The predictor variable that contributes the most to the prediction of a dependent variable is selected first. Additional variables are added to the regression equation in order of their contribution to the prediction of the dependent variable, providing they contribute at a specified level of significance (Schutz, 1983). Multiple regression has been successfully used to predict sensory measures based on instrumental measures for a number of products including: peanuts (Buckholtz et al., 1980); cucumbers (Ennis and O'Sullivan, 1979); coffee (Voilley et al., 1981); mutton (Rajalakshumi et al., 1987) and ham (Varnadore et al.,1980).

1.2.5. Response Surface Methodology

The objective in optimization research can be described as the collective process of finding the set of conditions required to achieve the best result from a given situation (Beveridge and Schechter, 1970). Three major methods are presently being used in food optimization research: multiple regression, gradient search and response surface methodology

(Lagrange and Norback, 1987). Of these methods, response surface methodology (RSM) appears to be the most popular.

RSM has been described as a set of statistical techniques used in the empirical study of the relationships between one or more measured quality responses and a number of independent variables or factors (Cornell, 1984). The methodology derives its name from the regression surface (or response surface) that is defined when the independent variables in a regression equation are allowed to vary and the response variable is plotted as a function of the independent variables (Cardello and Maller, 1987). Thus, experimental data are used to produce regression equations or models, which define the relationship between independent variables and response variables. The models are first tested for adequacy of the fitted surface and then used to predict effects of variable combinations which were not actually tested. Due to the complexity of the derived models, response surface or contour plots are generated to help visualize the effects of the independent variables on the response variables. By examining the response surface, it is possible to determine how the independent variables, singly, or in combination influence the response variable (Giovanni, 1983). As well, combinations of independent variables that will lead to optimum responses can be identified. An optimum response can be either a maximum or a minimum depending on the nature of the response (Gacula and Singh, 1984).

RSM is an attractive tool in food research, since it affords the detection of optimum responses of several variables coincidentally, without the necessity of testing all possible combinations (Vaisey-Genser et al., 1987). Through the use of specialized experimental designs, the number of treatment combinations required for testing is minimized and the efficiency of experimentation is increased. For this reason, RSM has gained rapid popularity in product optimization studies. Min and Thomas (1980) successfully used RSM in the formulation of whipped topping, Henselman et al. (1974) in the development of high protein bread, Vaisey-Genser et al. (1987) to optimize cake formulations containing canola oil, Oh et al. (1985b) to describe the optimum processing conditions for noodle production and Shelke (1987) to optimize formulations for noodles. To date, no studies have been undertaken to optimize drying temperature for processing of spaghetti or to optimize the replacement of durum semolina with either hard red spring farina or low protein durum wheat.

CHAPTER 2

EFFECTS OF COOKING WATER COMPOSITION ON STICKINESS AND COOKING LOSS OF TWO BRANDS OF COMMERCIAL SPAGHETTI

2.1 INTRODUCTION

Surface stickiness, amount of rinsed material collected from the strands and cooking loss are influenced by a number of factors including: the cooking water characteristics, the pasta:cooking water ratio, and the uniformity of cooking temperature (Menger, 1979). Thus, to ensure that observed differences among pasta samples are not due to variation in cooking procedures, standardized methods must be followed. The later two factors are relatively easy to standardize whereas standardization of the cooking water has proven to be more difficult.

Several workers have shown that as water hardness increases, cooked spaghetti become stickier (Menger, 1980; D'Egidio et al., 1981; Dexter et al., 1983b; Seibel et al., 1985) has higher total organic materials (TOM) in the rinse and cooking waters (D'Egidio et al., 1981; Seibel et al., 1985) and has higher cooking losses (Dexter et al., 1983b). The presence of high levels of calcium and magnesium in the cooking water have been shown to adversely affect spaghetti cooking quality (Menger, 1980; Oh et al., 1985a). Sodium has also been shown to have a minor effect on surface characteristics of spaghetti (Menger, 1980; Seibel et al., 1985), although D'Egidio et al. (1981) reported no effect.

Other workers have demonstrated the importance of cooking water pH on cooking quality of pasta. Alary et al. (1979) and Abecassis et al. (1980) decreased surface disintegration and stickiness and lowered cooking losses of spaghetti by adjusting the pH of mineral water to 6.0. Abecassis et al. (1980) also adjusted the pH of distilled water and found spaghetti cooking quality was at its peak at pH 6. On either side of this pH, quality was found to decline. These findings were confirmed by Seibel et al. (1985) who found weakly acidic cooking water gave good sensory quality and decreased TOM levels. Oh et al. (1985a) reported surface firmness of noodles decreased rapidly and cooking losses increased when a pH greater than 8 was used for cooking. Surface firmness and cooking loss were not affected between pH 6-8. In reviewing the work of Chung et al. (1978) and Cherry (1982), Feillet (1984), concluded that at an acidic pH, protein molecules are positively charged and starch molecules are negatively charged. Under these conditions, electrostatic interactions between proteins and gelatinized starch readily occur enhancing starch-protein interactions. In a basic medium, both protein and starch are negatively charged and therefore few interactions develop. Thus, at pH 6, the cooking water favours starch protein interactions preventing the leaching of starch into the cooking medium.

Ideally, the cooking water used in the assessment of spaghetti cooking quality characteristics should be typical of what is used in the marketplace and should permit discrimination among samples. Thus, the use of distilled water and/or water at pH 6 is not recommended since it will likely not allow adequate discrimination among spaghetti samples in terms of surface characteristics. The use of "artificially" hardened water is a practical solution since local water supplies differ from region to region and may fluctuate from season to season. Only two formulations have been published for the preparation of artificially hardened water (Dexter et al., 1985a; ISO, 1985). Thus, limited information exists on prepared hard water despite the need for a standardized prepared water for cooking spaghetti. Therefore, this study was undertaken to meet the following objectives:

1. To determine the effects of cooking water composition on stickiness and cooking loss of spaghetti.
2. To determine if spaghetti made from common wheat behaves the same as spaghetti made from durum wheat to changes in cooking water composition.
3. To establish a cooking water formulation for artificially hardened water that gives similar results to tap water, that can then be used in routine assessments of spaghetti cooking quality.

2.2 MATERIALS AND METHODS

2.2.1 Selection of Cooking Waters and Procedures For Preparing Formulated Waters

Seven types of water were selected for study as follows: tap, deionized, well, Grain Research Laboratory (GRL) prepared water, diluted GRL prepared water, and two reformulated prepared waters (reform 1, reform 2). The well water was obtained from a community a few kilometres north of Winnipeg (Middlechurch, MB). The deionized water was obtained by distillation, deionized by reverse osmosis, and passed through a series of columns (Millipore Corp., Belford, MA) including a pre-filtration, charcoal, and ion-exchange column, and a final filtration. The tap, well and deionized waters were analyzed for mineral content using standard methods of determining water quality (American Public Health Association, 1981) by W.M. Ward Technical Services Laboratory (Winnipeg, MB).

The GRL prepared water was developed by Dexter et al. (1985a) to ensure repeatability of results since tap water can fluctuate from season to season. This water is used routinely in their cooking quality screening program. It was observed however, that in the preparation of the GRL water, a substantial amount of 6 M H_2SO_4 had to be added to dissolve the precipitate that developed which then required the addition of 1 M NaOH to adjust the pH to 7.5. This raised the question as to whether or not the desired hardness of the water had been obtained. For this reason, two reformulated prepared waters were investigated in this study, which substituted dihydrous $CaCl_2$ for anhydrous $CaCl_2$. This change permitted the use of 1 M H_2SO_4 for pH adjustment only. In addition, the level of $NaHCO_3$ was reduced in one of the reformulations since the level of Na in the GRL water seemed to be unnecessarily high. The mineral composition for tap, well, and the four prepared waters is presented in Table 2.1. Table 2.2 provides information on the chemicals used to prepare the formulated waters and their amounts.

Sufficient quantities of all waters were obtained prior to experimentation to ensure that any differences observed was not due to any variations in the water quality from day to day in the case of the deionized, tap and well waters and in any variations in the preparation of the prepared waters.

2.2.2 Spaghetti Cooking and Testing Procedures

Two commercial spaghetti samples (brand H made from durum semolina, and brand I made from unbleached wheat flour) were cooked in each of the seven waters. These samples were selected since they represented the range of spaghetti quality available in the marketplace and they permitted a comparison of the effects of cooking water composition on spaghetti made from durum and non-durum wheat.

Table 2.1 Mineral Composition of Cooking Waters

Water	Mineral Composition (ppm)				
	Ca	Mg	Na	K	SO_4
Tap	24.20	7.46	2.47	-	3.40
GRL Diluted	14.48	1.55	41.20	5.82	7.16
GRL	28.96	3.11	82.41	11.64	14.32
Reform 1	32.58	3.59	93.14	13.49	16.55
Reform 2	32.58	3.59	72.60	13.49	16.55
Well	93.00	68.00	153.00	-	170.00

Table 2.2 Chemical Composition of Prepared Cooking Waters

Chemical g/L	Water			
	GRL Diluted	GRL	Reform 1	Reform 2
$CaCl_2$	0.040	0.080	-	-
$CaCl_2.2H_2O$	-	-	0.095	0.095
$MgCl_2.6H_2O$	0.013	0.026	0.030	0.030
K_2SO_4	0.013	0.026	0.030	0.030
$NaHCO_3$	0.067	0.133	0.150	0.075
Na_2CO_3	0.053	0.106	0.120	0.120

Seven grams of spaghetti in 5 cm strands were added to 175 mL of rapidly boiling water. Samples were cooked in 250 mL glass beaker on ceramic hot plates. Spaghetti samples were cooked until optimum defined as the time in minutes required for the centre core in the strands to disappear. After cooking, the spaghetti was drained and assessed for stickiness using the GRL compression tester adapted for spaghetti as described by Dexter et al. (1983a) except that a compression force of 24,000 N/m^2 was used. Strands were not rinsed after draining and were placed parallel to each other on the sample holder and covered. Samples were assessed for stickiness 7 min after cooking. This is the procedure currently used at GRL (Daniel, 1989) in order to maximize stickiness values (Dexter et al., 1983a) since stickiness tends to be an after cooking phenomena. Other textural properties such as firmness, compressibility and recovery were not measured since Dexter et al. (1983b) found these parameters were not influenced by cooking water.

Cooking loss of the recovered water was determined by freeze-drying, weighing the freeze-dried material, adjusting for mineral residue present in the cooking water and calculating the proportion of solids lost to the cooking water as percentage of spaghetti cooked.

Eight cooking replications were completed for each brand by cooking water treatment. On a given test day, four cooking replications of each brand in one type of water was assessed. Therefore, 14 days were required to complete this experiment.

2.2.3 Statistical Analysis of Data

Analysis of variance was used to determine the significant effects of brand and cooking water on stickiness and cooking loss (SAS, 1988).

2.3 RESULTS AND DISCUSSION

2.3.1 Cooking Water Composition

The pH and calculated hardness for each of the seven waters are provided in Table 2.3. The waters were included in the study based on their similarity in pH and on their differences in hardness. With the exception of the deionized water, all waters had pH values around 7.7. Waters ranged in hardness from 1.65 to 512 ppm $CaCO_3$. Bigelow and Stevenson (1923) classified waters according to their level of $CaCO_3$. Thus, according to their classification, the deionized and diluted GRL waters would be classified as soft, the tap, GRL and reformulated waters would be classified as slightly hard and the well water would be classified as very hard.

2.3.2 Effect of Water Composition on Stickiness

Significant brand and cooking water main effects and a significant brand by cooking water interaction were observed for stickiness (Table 2.4). Mean stickiness values and their standard deviations across all cooking replications are provided in Appendix 1.

As expected, Brand I made from common wheat was stickier than brand H made from durum wheat regardless of the cooking water used (Figure 2.1). For both spaghetti samples, the highest stickiness values were found for tap, well, reform 1 and reform 2 waters and the lowest stickiness values were found for the deionized and GRL diluted waters.

Table 2.3 Calculated Hardness and pH of Cooking Waters

Water	Calculated Hardness (ppm $CaCO_3$)*	pH
Deionized**	1.65	6.1
Tap	91.20	7.7
GRL Diluted	42.56	7.7
GRL	85.12	7.7
Reform 1	96.12	7.8
Reform 2	96.12	7.6
Well	512.00	7.6

* Hardness, mg equivalent $CaCO_3$/L = 2.497 (Ca mg/L) + 4.118 (Mg mg/L), American Public Health Assoc. et al., 1985.

** Values from Dexter et al., 1983b.

Table 2.4 Analysis of Variance for Stickiness and Cooking Loss Measurements

Parameter	Source	df	Mean Square	F value
Stickiness	Water(W)	6	486739.58	27.50a
	Day(Water)	7	17701.79	0.88
	Brand(B)	1	7354375.00	363.92a
	W*B	6	154085.42	7.63b
	B*Day(Water)	7	20208.93	
	Error	84	8895.24	
Cooking Loss	Water(W)	6	19.34	33.75a
	Day(Water)	7	0.57	0.32
	Brand(B)	1	16.71	9.22c
	W*B	6	22.58	12.47b
	B*Day(Water)	7	1.81	
	Error	84	0.46	

a significant at $p<0.001$
b significant at $p<0.01$
c significant at $p<0.05$

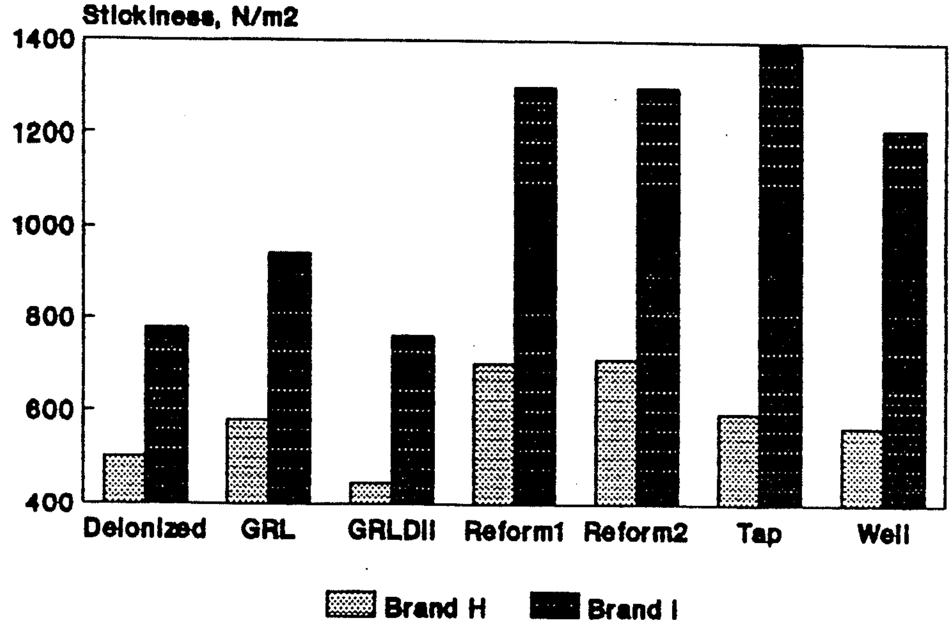


Figure 2.1 Effect of Water Composition on Stickiness of Two Brands of Spaghetti

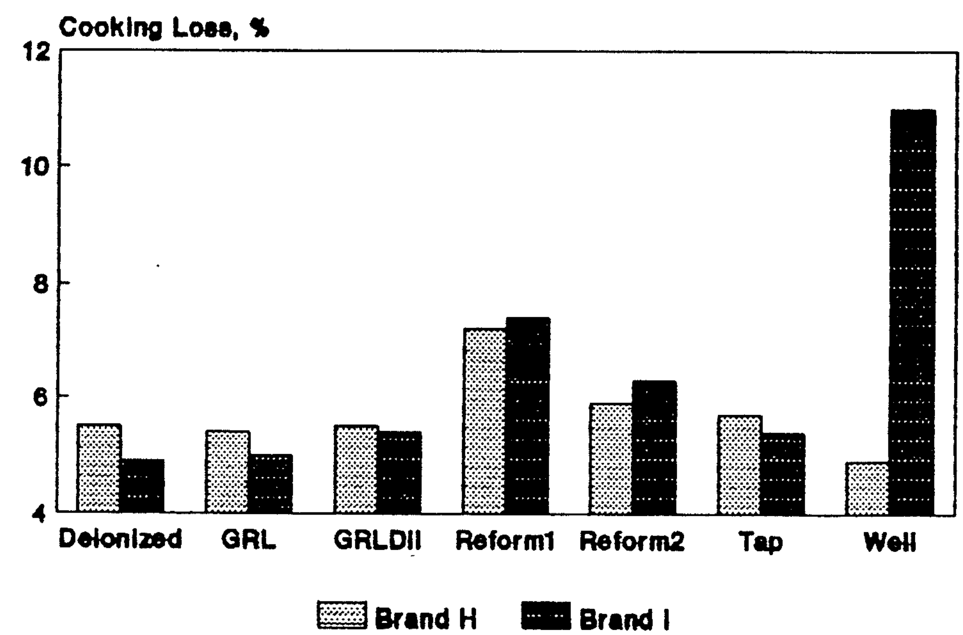


Figure 2.2 Effect of Water Composition on Cooking Loss of Two Brands of Spaghetti

GRL water gave spaghetti of intermediate stickiness. These results support those of Menger (1980), Seibel et al. (1985), D'Edigio et al. (1981), and Dexter et al. (1983b) who reported stickier spaghetti with harder water. However, unlike the study by Dexter et al. (1983b), the well water used in this study did not yield stickier spaghetti than spaghetti cooked in tap water despite the large difference in water hardness. This suggests that water hardness alone does not account for the effects on spaghetti quality. The well water used in Dexter et al.'s study was slightly more alkaline (pH of 8.0) compared to the well water used in this study (pH of 7.6). This may account for the discrepancy in the findings between the two studies, since the level of alkalinity has also been shown to have a deleterious effect on spaghetti stickiness (Alary et al., 1979).

2.3.3 Effect of Water Composition on Cooking Loss

As with stickiness, significant brand and cooking water main effects and a significant brand by cooking water interaction were observed for cooking loss (Table 2.4). Mean cooking loss values and their standard deviations across all cooking replications are provided in Appendix 1.

Similar cooking losses were observed between the two brands for all cooking waters except well water (Figure 2.2). Brand H made from durum wheat did not appear to be affected by the hardness of the well water. As with stickiness, these results are not in agreement with those of Dexter et al. (1983b) who observed higher cooking losses with durum spaghetti cooked in well water than in tap water. This may also be partly explained by the differences in pH of the well waters used in the two studies since Alary et al. (1979) was able to reduce the cooking loss of durum spaghetti cooked in mineral water by lowering the pH. In addition, the level of Ca in the well water used in this study was higher than that found in the well water used in Dexter et al.'s (1983b) study (93 versus 80 ppm). This may be significant since Menger (1980) found Ca caused a downward shift in pH during cooking.

In contrast, Brand I made from common wheat had a much higher cooking loss when cooked in well water compared to any other cooking water. This result alone likely accounted for the significant brand main effect.

Interestingly, Kim et al. (1989) observed that spaghetti made from durum wheat had higher cooking losses than spaghetti made from hard red spring wheat when cooked in distilled water whereas the opposite was found when cooked in hard water. This same effect was observed in this study. Brand H made from durum wheat had a higher cooking loss than brand I made from common wheat when cooked in deionized water whereas the opposite was observed when the spaghetti was cooked in the hardest waters (reform 1, reform 2 and well).

For both brands, cooking in reform 1 water gave higher cooking losses than for the tap and reform 2 waters despite the similarity in hardness (Table 2.3). The only difference between reform 1 and reform 2 waters was the higher level of $NaHCO_3$ in reform 1 water.

2.4 CONCLUSIONS

Cooking loss and stickiness of spaghetti were influenced by the type of water used for cooking. The magnitude of this effect appeared to be influenced by the raw material (durum versus common wheat) used in the spaghetti. This finding supports the observation by Seibel et al. (1985) that pasta with inferior cooking quality reacts more to differences in cooking water quality (pH, ion content) than does pasta with higher cooking quality.

Higher stickiness scores were found with the harder waters, although well water did not produce the stickiest spaghetti. Spaghetti made from unbleached flour was stickier than durum wheat spaghetti regardless of the cooking water used. For both brands of spaghetti, reform 1, reform 2 and well water gave similar stickiness results to tap water.

Similar cooking losses between the two types of spaghetti were found for all cooking waters except well water. Spaghetti made with common wheat had much higher cooking losses when cooked in well water. In contrast, spaghetti made from durum wheat was not affected by the hardness of the well water. For both brands of spaghetti, cooking in reform 2 water gave similar cooking losses to tap water whereas cooking in reform 1 water resulted in much higher cooking losses than tap water.

These results confirm the need to use a standardized cooking water if results are to be compared from one test session to another or from one laboratory to another. Reform 2 water was selected as the standardized prepared water for use in all remaining studies since similar findings for stickiness and cooking loss were obtained for reform 2 water and tap water. Reform 2 water is slightly hard and has a slightly alkaline pH which should permit discrimination among pasta samples in light of suggestions made by D'Egidio et al. (1981).

Clearly, more work is needed to determine whether pH or mineral composition plays the greater role in influencing spaghetti cooking quality. More importantly, there is a need to investigate the extent that they influence each other and how this affects cooked spaghetti quality. Until we have a better understanding of how water quality influences the textural properties of spaghetti, the use of a standardized cooking water is necessary to ensure that data obtained from cooking assessments are reliable.

CHAPTER 3

SELECTION OF INSTRON OPERATING CONDITIONS FOR MEASURING COOKED SPAGHETTI TEXTURE

3.1 INTRODUCTION

The texture of cooked spaghetti is an important consideration in determining the overall quality of spaghetti. According to Dexter et al. (1983a) cooked spaghetti must be firm, resilient and non-sticky for maximum consumer acceptance.

The need for simple and reliable methods for evaluating the cooking quality of pasta has been stressed by a number of workers (Cubadda, 1989; D'Egidio et al., 1982; Dexter et al., 1985b; Menger, 1985). Considerable effort has been made to establish instrumental methods for measuring the textural properties of cooked spaghetti since sensory techniques involve substantial time and money expenditures, and can often exhibit poor reproducibility especially if the principles of measuring the human responses to food are not appreciated.

Several workers have reported methods for measuring firmness of pasta. Voisey and Larmond (1973) found a multiblade shear compression cell mounted to the Ottawa Texture Measuring System (OTMS) was the most reliable of all test cells evaluated. This confirms the importance of measuring multiple strands of spaghetti due to variations within and among strands. Matsuo and Irvine (1969) simulated the bite test on cooked spaghetti by applying a continuously increasing force to a cutting edge resting on a strand of spaghetti. A tenderness index was derived from the slope of the linear portion of the penetration-time curve and this was an indication of the length of time it took the loaded cutting edge to cut through the specimen. Results were found to correlate with sensory measurements of firmness (Matsuo and Irvine, 1974). Walsh (1971) described a similar bite test using the Instron Universal Testing Machine. Firmness was expressed as the amount of work in g.cm required to shear a strand of spaghetti. Results were found to correlate with sensory measurements of firmness. Oh et al. (1983) adapted this technique for noodles by shearing three strands with a plexiglass tooth that was bevelled on both sides of the contact surface. Good correlations were established with sensory measurements of firmness and chewiness. Recently, AACC (1989) adopted an Instron method for assessing the firmness of pasta utilizing the blade designed by Oh et al. (1983). Five strands of spaghetti are sheared and firmness is expressed as the energy (work) in g.cm to shear one strand of spaghetti.

Several workers have developed methods for measuring the compressibility and elasticity of pasta. Dalbon et al. (1985) compressed spaghetti using the Instron to a fixed load, at which point, the load was immediately removed. Compression was defined as the relationship of the diameter of the compressed spaghetti to the original diameter multiplied by 100. Recovery (a measure of elasticity) was defined as the relationship of spaghetti diameter after recovery to the diameter of the compressed spaghetti. Oh et al. (1983) described a similar

Instron method for measuring the compressibility and recovery of noodles which were found to correlate with sensory measures of firmness and chewiness. Matsuo and Irvine (1971) compressed a single strand under a fixed load using their tenderness testing apparatus equipped with a blunt blade. The load was held for 15 sec before being removed at which time there was an instantaneous partial elastic recovery. Thus, in this method, elasticity was measured by the change in height over a period of time at a constant level of deformation (Bourne, 1982). Elasticity can also be measured by the change in forces over a constant level of deformation using the Instron. The decay of stress under a constant strain is known as stress relaxation. Relaxation time is defined as the time required for the stress at constant strain to decrease to 1/e of its original value, where e is the base of natural logarithms. Since 1/e = 0.3678, the relaxation time is the time required for the force to decay to 36.8% of its original value. Often the time to relax to 1/e is excessive, in which case some other value is taken as an arbitrary relaxation time (Bourne, 1982). Heaps et al. (1968), Frazier et al. (1973), and Rasper and deMan (1980) successfully measured the relaxation of bread doughs using this method.

Several attempts have been made to measure spaghetti stickiness using instrumental techniques. Voisey et al. (1978b) mounted spaghetti strands on a serrated baseplate and compressed them to a fixed force with a flat plunger using the Instron. After allowing the spaghetti to relax the plates were pulled apart and the maximum tensile force was used as the index of stickiness. This required a load cell with two outputs to record both the compressive forces required to push the plates together and the tensile forces to pull the plates apart. Stickiness readings appeared to be related to non-oral sensory assessments of stickiness.

The stickiness of spaghetti (Dalbon et al., 1985) and the stickiness of rice (Mossman et al., 1983; Fellers et al., 1983; Biswas and Juliano, 1988) have been estimated by measuring the area under the force-distance curve of the Instron. Fellers et al. (1983) reported a good correlation between Instron and sensory measures of rice stickiness. In contrast, Boyd and Sherman (1975b) were unable to correlate Instron and sensory measurements of stickiness for a variety of foods. This lack of correlation applied irrespective of whether the Instron plate had been wetted with saliva or not. Atkins (1989) was also unable to correlate Instron measurements of stickiness with a bakers assessment of dough stickiness although a correlation was found between compression energy and sensory stickiness.

Dexter et al. (1983a) compressed a number of strands with a flat plunger using the Grain Research Laboratory Compression Tester. The force of adhesion of the spaghetti to the plunger was measured rather than the energy or work (area) to separate the sample from the plunger. Kim et al. (1989) adapted this technique for use with the Instron but encountered some difficulties which they attributed to surface water released from the spaghetti during compression.

With the prominence of the Instron in food texture assessments, it would seem prudent to establish procedures for measuring the textural properties of cooked spaghetti using this instrument. A number of studies have been undertaken to assess the effects of operating conditions on Instron measurements including crosshead speed (Baker et al., 1986; Betker, 1990; Boyd and Sherman, 1975a and 1975b; Hibberd and Parker, 1985; Shama and Sherman, 1973; Voisey et al., 1978a and 1978b), plunger area (Baker et al., 1986; Betker, 1990; Walker et al., 1987) and compression depth (Baker et al., 1986 and 1988; Betker, 1990; Boyd and Sherman, 1975a; Redlinger et al., 1985; Shama and Sherman, 1973). The effects of sample characteristics and dimensions have also been examined (Bagley et al., 1985; Brinton and Bourne, 1972; Redlinger et al., 1985). In all studies, varying the operating conditions significantly influenced the results obtained. This suggests the need to identify operating conditions which are most effective in detecting differences among samples and which have high reproducibility and repeatability. According to Baker et al. (1986), a complete evaluation of the operating factors of the Instron is necessary in order to develop reliable methods for measuring the textural properties of a food. Thus, the objectives of this study were:

1. To develop test methods to measure the firmness, compression, elasticity and stickiness of cooked spaghetti using the Instron Universal Testing Machine.
2. To determine the effects of compression depth and crosshead speed on firmness measurements of spaghetti.
3. To determine the effects of compression force and plunger size on measurements of compression, elasticity, and stickiness of spaghetti.
4. To identify operating conditions for evaluating firmness, compression, elasticity, and stickiness of cooked spaghetti with high repeatability and reproducibility and reasonable discrimination between spaghetti samples.

3.2 MATERIALS AND METHODS

Two brands of commercial spaghetti differing in composition (brand H made from durum semolina, and brand I made of unbleached wheat flour) were selected for study since they represent the range of spaghetti quality available in the marketplace. It was felt that they would be substantially different from each other and would therefore facilitate the objective of selecting Instron operating conditions that permit detection of textural differences among spaghetti.

3.2.1 Development of Instron Test Procedures

The Instron Universal Testing Machine (Model 4201, Instron Corp., Canton, MA) equipped with a 10 N compression load cell was used to assess the textural characteristics of spaghetti. Test procedures for four textural parameters; firmness, compression, relaxation, and stickiness were developed following suggestions made in the literature and by preliminary testing.

Figure 3.1 presents typical force-distance and force-time curves for spaghetti evaluated by the Instron test procedures developed in this study. Information is also provided as to how data were derived from the curves. The shape and dimensions of the various test fixtures are given in Figure 3.2.

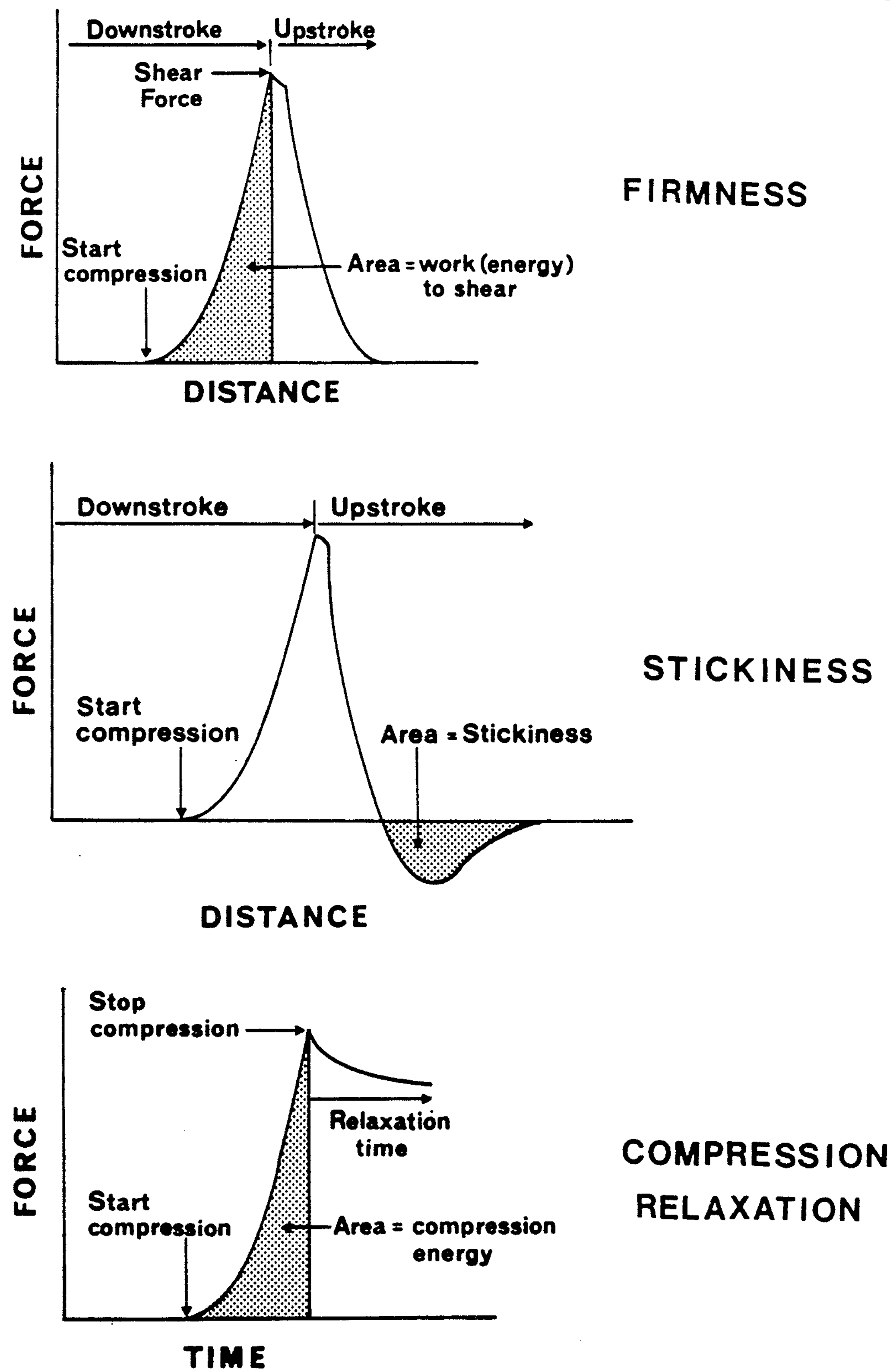
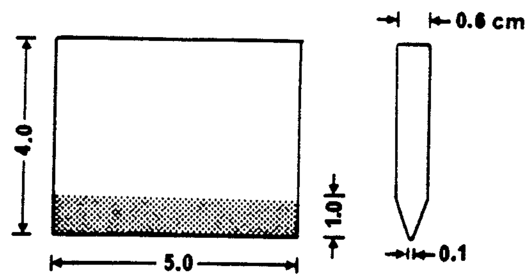
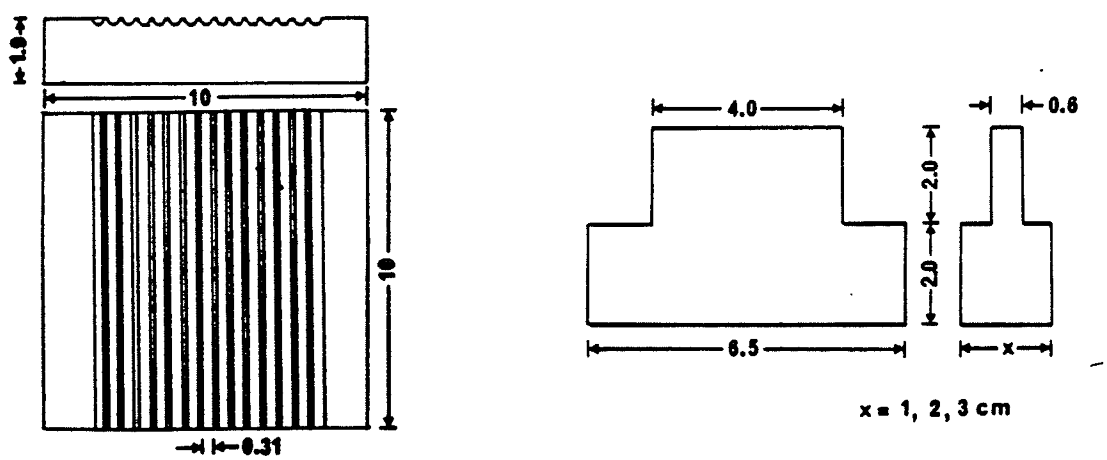


Figure 3.1 Force-Distance and Force-Time Curves For Instron Measurements of Firmness, Stickiness, Compression and Relaxation

FIRMNESS TEST BLADE



STICKINESS, COMPRESSION & RELAXATION BASEPLATE & PLUNGER



Grooved base plate

Figure 3.2 **Plungers and Baseplate Dimensions For Instron Assessments of Firmness, Stickiness, Compression and Relaxation**

3.2.1.1 Assessment of Firmness

The test procedure adopted for firmness conforms to the AACC method 16-50 (1989) which at the time of this work was only a proposed method. Five strands of spaghetti were placed on a flat baseplate parallel to each other, leaving no space between the strands. The strands were sheared crosswise to a fixed compression depth using a plexiglass tooth meeting the specifications of the AACC standard (Figure 3.2). Firmness was expressed as both the shear force in g and the energy (work to shear) in g.mm required to shear five strands of spaghetti (Figure 3.1). This differs from the AACC standard which expresses firmness as the energy in g.cm required to shear one strand of spaghetti.

3.2.1.2 Assessment of Compression and Relaxation

The Instron methods reported by Dalbon et al. (1985) and Oh et al. (1983) for measuring compressibility and elasticity of pasta were found, during preliminary testing, to yield unsatisfactory measures (i.e. did not permit discrimination between spaghetti samples) and were therefore, discarded as unsuitable techniques. The test procedure that was adopted was inspired by the work of Heaps et al. (1968), Frazier et al. (1973) and Rasper and deMan (1980) on stress relaxation studies of bread doughs. Compression and relaxation assessments of spaghetti were carried out by placing nine strands in a grooved baseplate and compressing to a fixed compression force with a flat plexiglass plunger (Figure 3.2) using a crosshead speed of 5 mm/min. The crosshead was programmed to stop movement when the fixed compression load was reached. The spaghetti was then allowed to relax at constant deformation. Compression relaxation curves were recorded using a chartspeed of 200 mm/min. Compression was expressed as the energy in g.mm to compress the nine strands to the fixed force and relaxation was defined as the time in seconds, required for a 50 g reduction in the fixed load (Figure 3.1).

3.2.1.3 Assessment of Stickiness

The method for stickiness was developed following the procedures of the Texture Profile Analysis (TPA) as described for the General Foods Texturometer (Friedman et al. 1963; Szczesniak et al., 1963) and later adapted to the Instron by Bourne (1968, 1974). One of the seven parameters comprising the TPA is adhesiveness defined as the work (energy) necessary to pull the compressing plunger away from the sample. This is derived from the area of the curve under the force-distance curve (Friedman et al., 1963). Mossman et al. (1983), Fellers et al. (1983) and Biswas and Juliano (1988) have applied this principle to the measurement of rice stickiness and Dalbon et al. (1985) have applied it to the measurement of pasta stickiness. Unfortunately, not enough details were reported by Dalbon et al. to reproduce their method.

The method developed in this study was as follows: Nine strands were placed in a grooved baseplate and compressed to a fixed force with a flat plexiglass plunger (Figure 3.2) using a crosshead speed of 5 mm/min. Stickiness curves were recorded using a chartspeed of 500 mm/min and stickiness was expressed as the area under the force-distance curve (Figure 3.1).

3.2.2 Operating Conditions and Levels Selected For Study

As a further refinement to the Instron tests established during preliminary testing, the effects of compression depth and crosshead speed on firmness, and plunger size and compression force on compression, relaxation and stickiness were examined utilizing the operating levels listed in Table 3.1. The effect of crosshead speed on compression, relaxation, and stickiness was not examined in this study since it was found during preliminary testing that a slow crosshead speed was necessary in order to enhance data recording of these parameters.

Five cooking replications were completed for each compression depth/crosshead speed/brand combination for firmness and each plunger size/compression force/brand combination for compression and relaxation. Six cooking replications were completed for each plunger size/compression force/brand combination for stickiness. In order to minimize a possible day effect, one cooking replication of each combination for a given test procedure was completed in one test session. Test procedures and test combinations were performed in a random order to eliminate a possible order effect.

Table 3.1 Instron Operating Conditions Selected For Study

Instron Test Procedure	Condition	Levels
Firmness	Compression Depth	0.50 mm of baseplate 0.05 mm of baseplate
	Crosshead Speed	10 mm/min 50 mm/min 100 mm/min
Compression Relaxation Stickiness	Compression Force	400 g 800 g
	Plunger Size	1 cm 2 cm 3 cm

3.2.3 Preparation of Spaghetti For Testing

Spaghetti in 5 cm strands was cooked to optimum (defined as the time required for the centre core in the strands to disappear) in rapidly boiling prepared water (as described in Chapter 2). A ratio of 1:25 spaghetti to water was used. Samples were cooked in 250 mL glass beakers on a ceramic hot plate. Spaghetti was drained and rinsed in cold tap water to prevent further cooking for the assessments of firmness, compression and relaxation. Samples for stickiness were not rinsed and were placed on the baseplate and covered. Samples were assessed for stickiness 7 min after cooking. This was done in order to maximize stickiness values (Dexter et al., 1983a) since stickiness tends to be an after cooking phenomena. These handling procedures were consistent with those used at the Grain Research Laboratory in their cooking quality evaluation program (Daniel, 1989) and with procedures reported in the literature.

3.2.4 Statistical Analysis of Data

For firmness, compression, and relaxation, mean values across duplicate readings were calculated for each determination, cooking replication and test combination. For stickiness, because two determinations within a cooking replication were not possible, means across duplicate readings were calculated for each cooking replication and test combination. Values were plotted by cooking replications to assess the reproducibility and the repeatability of the operating condition. Coefficients of variation (CV) were also calculated as measures of the variability at each operating condition.

3.3 RESULTS AND DISCUSSION

The operating conditions of compression force and plunger size were varied to determine their effects on compression energy, relaxation time and stickiness of cooked spaghetti. As well, crosshead speed and compression depth were varied to determine their effects on firmness measurements of spaghetti.

3.3.1 Effect of Operating Conditions on Instron Measurements of Compression Energy

Figures 3.3 and 3.4 show the effects of plunger size and compression force on compressibility of two brands of spaghetti. Plunger size had a small impact on compression energy values compared to compression force. As plunger size increased, compression energy decreased slightly, likely because less energy (work) was needed to reach the compression force since a larger surface area was being tested with the larger plunger. Compression force had a large effect on compression energy values for both brands of spaghetti. As compression force increased, there was a corresponding increase in compression energy.

For both compression forces studied, the greatest discrimination between brands occurred with a plunger size of 1 cm. However, at a compression force of 400 g, the repeatability within a cooking replication was not as good as it was at a compression force of 800 g. Reproducibility among cooking replications appeared to be similar for both compression forces. These results were confirmed by the coefficients of

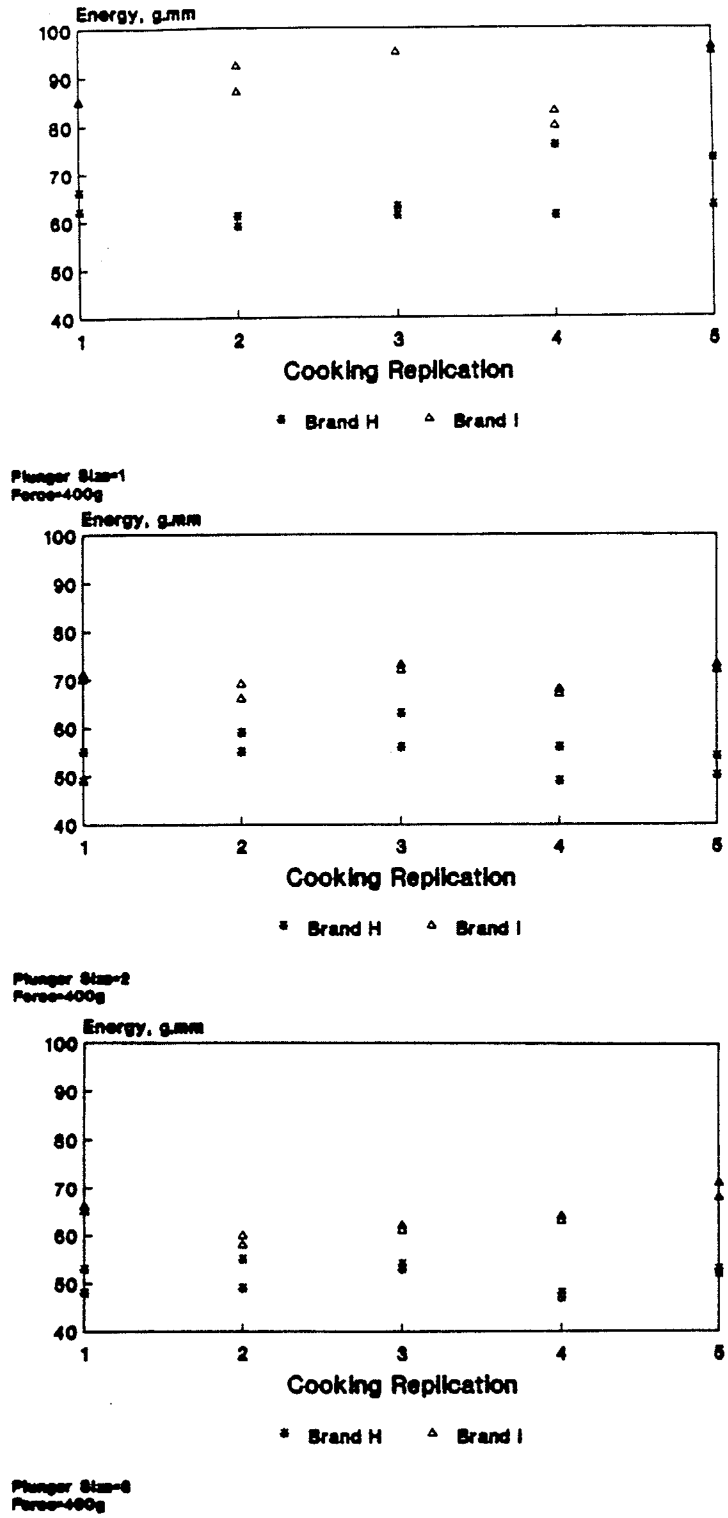


Figure 3.3 Effect of Plunger Size on Compression Energy of Spaghetti Using Compression Force of 400 g

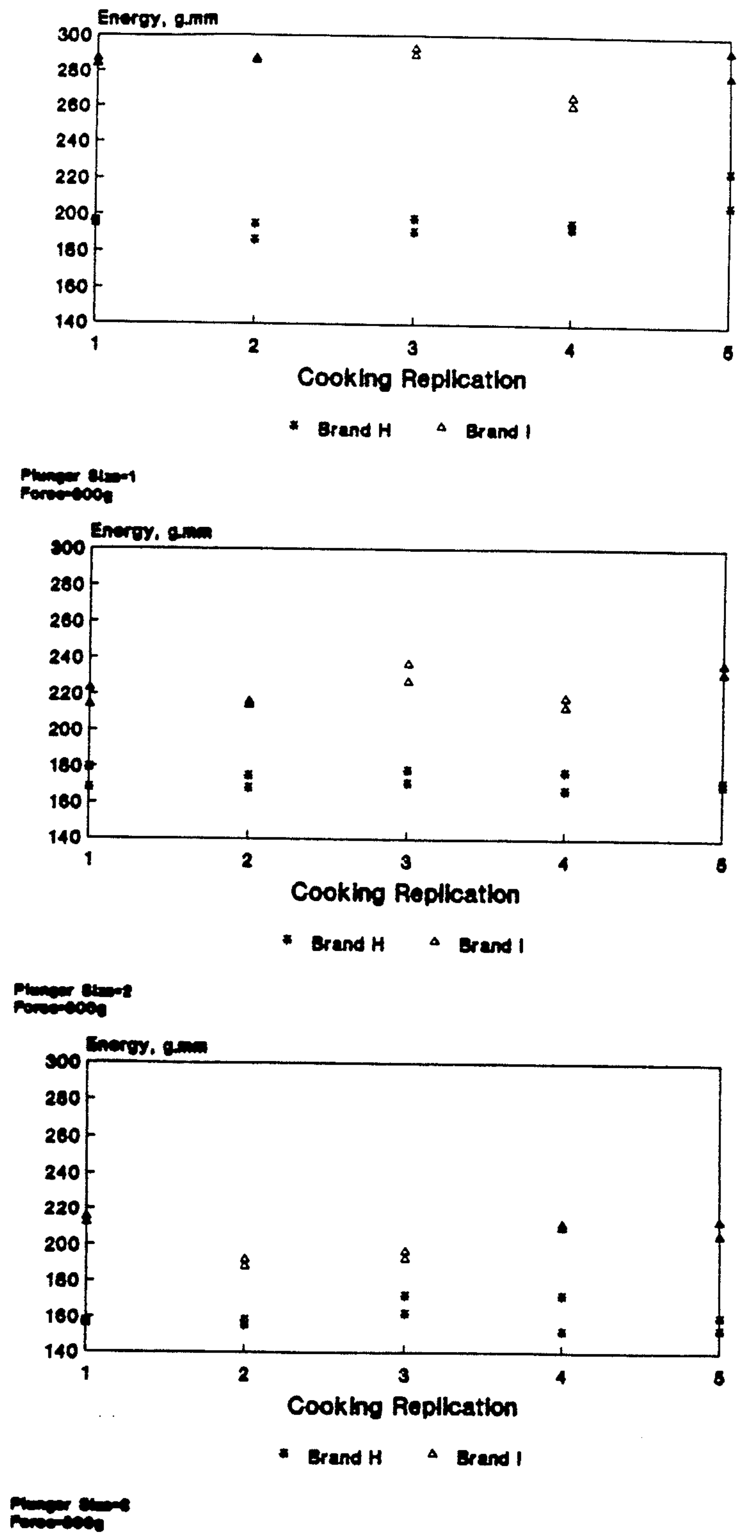


Figure 3.4 Effect of Plunger Size on Compression Energy of Spaghetti Using Compression Force of 800 g

variation (CV) which were calculated for each compression force/plunger size/brand combination (Table 3.2). CV describe the amount of variation relative to the mean (Baker et al., 1988). For both brands, a compression force of 400 g gave the highest CV indicating greater variability. Lowest CV were observed for both brands using a compression force of 800 g and plunger sizes of 1 and 2 cm.

3.3.2 Effect of Operating Conditions on Instron Measurements of Relaxation Time

The effects of compression force and plunger size on relaxation time are shown in Figures 3.5 and 3.6. Unlike compression energy, relaxation time decreased as compression force increased. Relaxation time was defined as the time required for a 50 g reduction of the fixed load. This equates to a 93.75% relaxation of the fixed load at the beginning of the relaxation period when a compression force of 800 g was used compared to a 87.5% relaxation of the fixed load when a compression force of 400 g was used. Therefore, it is not surprising that values for relaxation time increased with the lower compression force since a greater relaxation period was being measured.

Plunger size did not appear to have a profound effect on relaxation time. As plunger size increased there was a modest increase in relaxation time. This was likely due to the larger surface area of the spaghetti being measured. Betker (1990) also reported a modest effect of plunger size on cohesiveness and springiness of sponge cake compared to a sizable effect of

Table 3.2 **Coefficient of Variation (CV) For Compression, Relaxation and Stickiness Tests**

Parameter	Instron Condition Compression Force (g)	Plunger Size (cm)	CV (%) Brand H	I
Compression Energy	400	1	9.4	6.8
		2	10.0	4.4
		3	7.8	7.4
	800	1	6.1	4.3
		2	4.5	4.4
		3	6.3	6.0
Relaxation Time	400	1	28.1	26.4
		2	39.8	41.7
		3	29.7	53.1
	800	1	23.1	8.0
		2	44.5	17.4
		3	25.9	18.5
Stickiness	400	1	33.3	14.2
		2	25.0	12.5
		3	26.6	10.0
	800	1	25.0	18.1
		2	16.6	14.3
		3	25.0	14.3

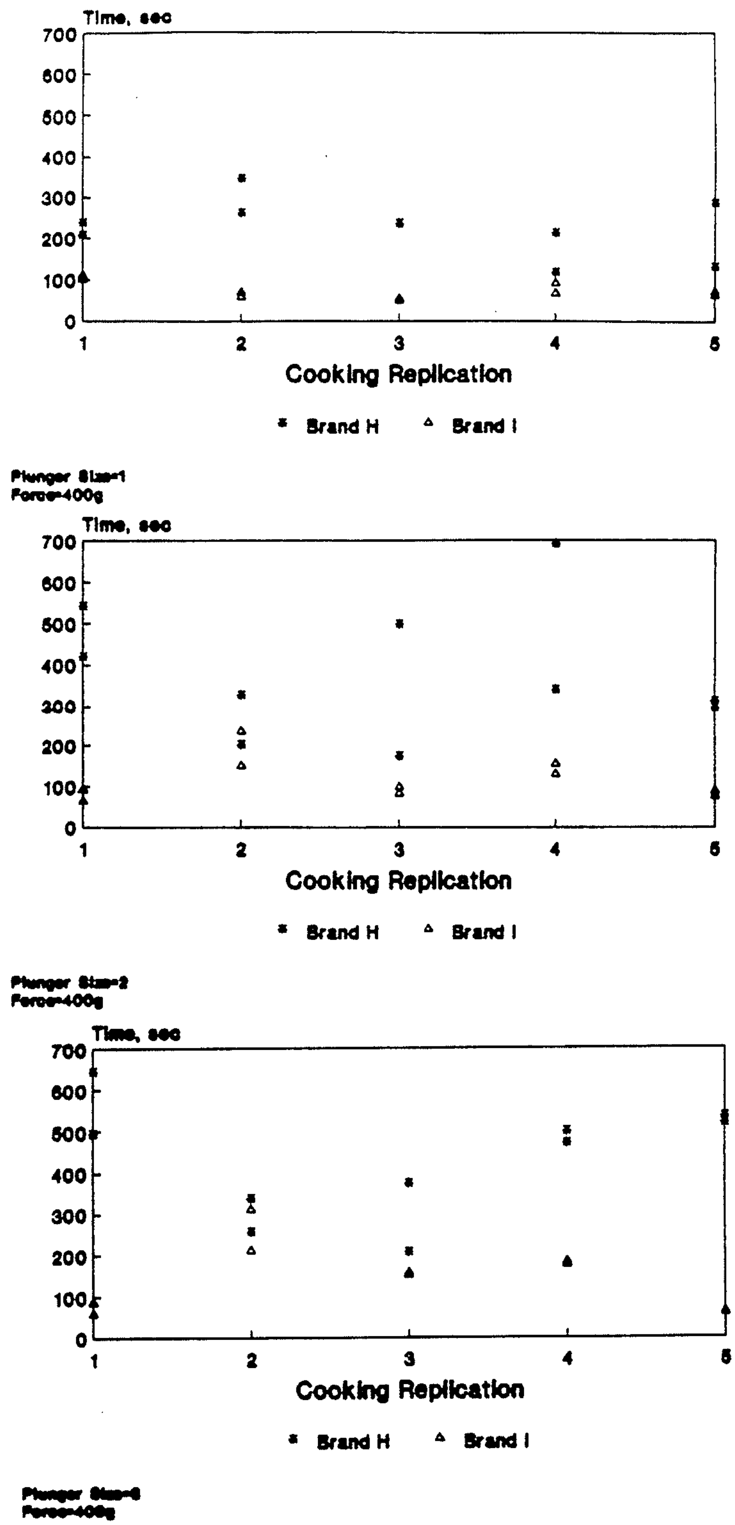


Figure 3.5 **Effect of Plunger Size on Relaxation Time of Spaghetti Using Compression Force of 400 g**

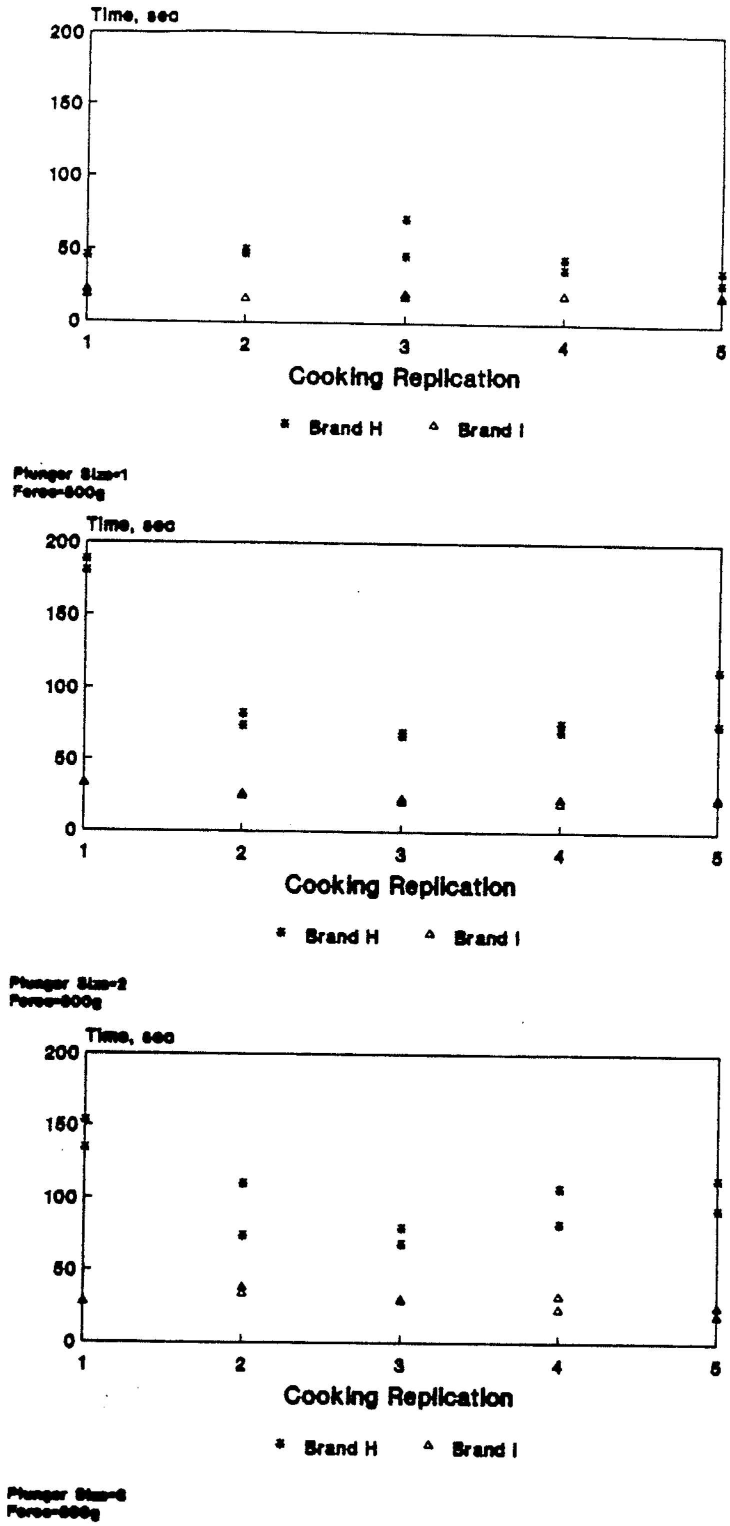


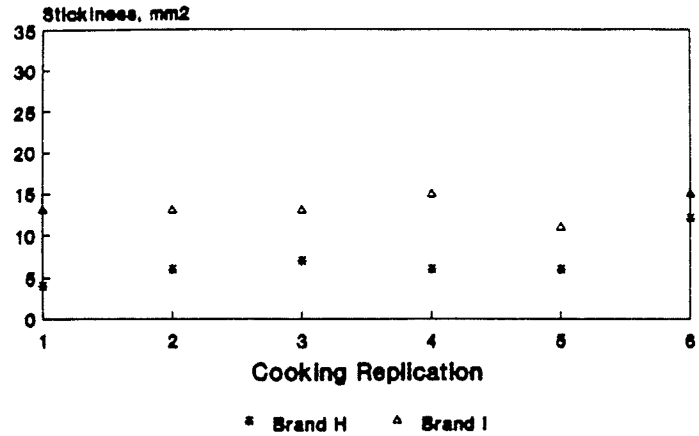
Figure 3.6 Effect of Plunger Size on Relaxation Time of Spaghetti Using Compression Force of 800 g

plunger size on hardness and gumminess. Walker et al. (1987) suggested that plunger area is associated with compression forces while plunger diameter is associated with tensile and shearing forces. These later two forces become important when high compression forces are used. Since low compression forces were selected for use in this study, plunger size was not expected to have a substantial impact on the results obtained.

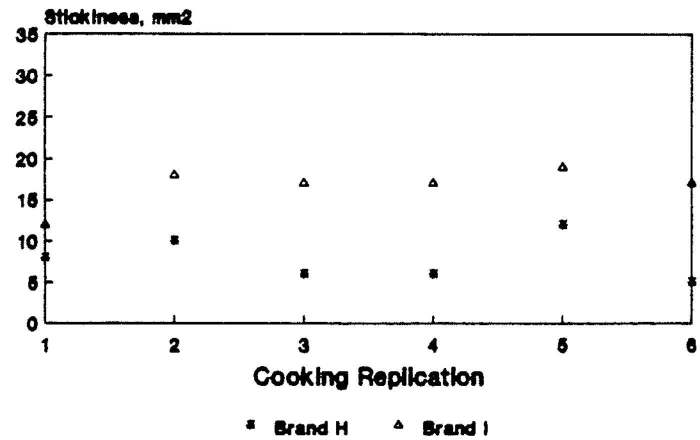
Reasonable discrimination between brands was observed at all compression force and plunger size combinations. However, at a compression force of 400 g, poor reproducibility among cooking replications and repeatability within a cooking replication was observed especially when a plunger size of 2 and 3 cm was used. At a compression force of 800 g, poor reproducibility among cooking replications was observed for brand H when a plunger size of 2 and 3 cm was used. Examination of the CV confirmed these findings (Table 3.2). Highest CV were found for brand H with the 2 cm wide plunger at both compression forces whereas for brand I, highest CV were observed at a compression force of 400 g and plunger sizes of 2 and 3 cm. Lowest CV's were observed for both brands with a compression force of 800 g and a plunger size of 1 cm.

3.3.3 Effect of Operating Conditions on Instron Measurements of Stickiness

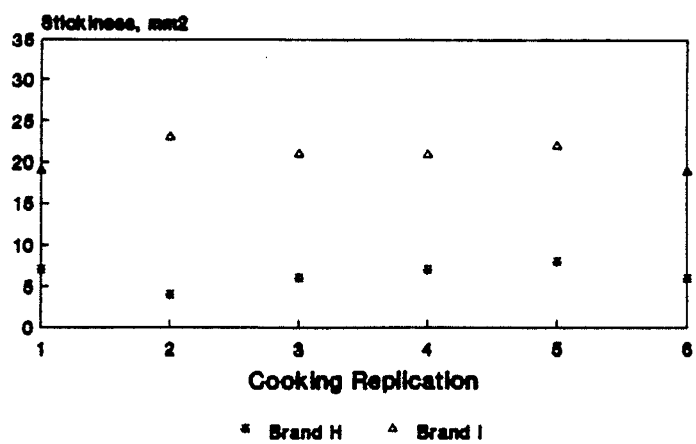
Figures 3.7 and 3.8 show the effects of compression force and plunger size on stickiness measurements for both brands of spaghetti. Both plunger size and compression force influenced stickiness measurements to a small extent. As plunger size



Plunger Size=1
Force=400g



Plunger Size=2
Force=400g



Plunger Size=6
Force=400g

Figure 3.7 Effect of Plunger Size on Stickiness of Spaghetti Using Compression Force of 400 g

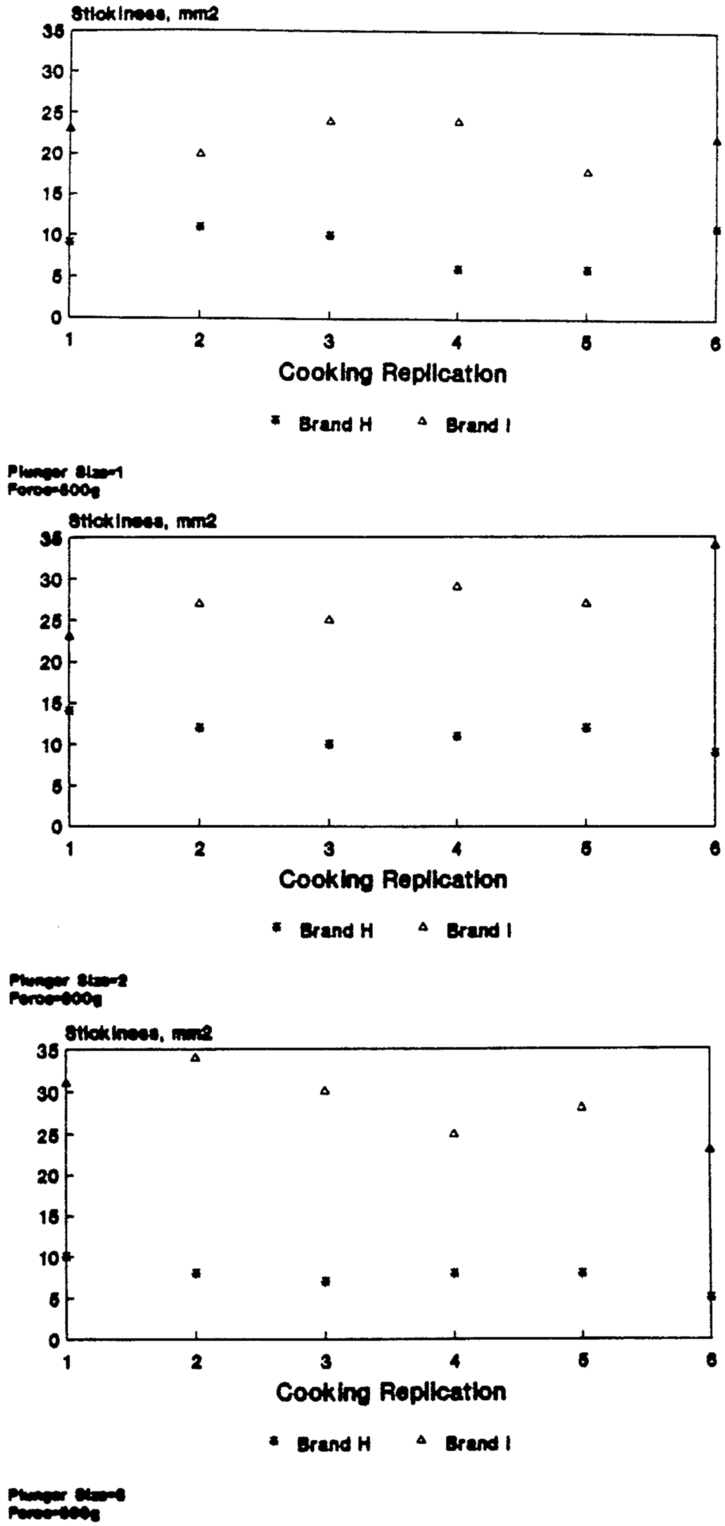


Figure 3.8 **Effect of Plunger Size on Stickiness of Spaghetti Using Compression Force of 800 g**

increased there was a modest increase in stickiness for both brands of spaghetti. This same trend was observed for compression force. Voisey et al. (1978b) reported that stickiness measurements of spaghetti were independent of the compression force up to 50 kg. It is quite possible that sensitivity in data recording may account for the slight difference observed between the two compression forces used in this study.

All test combinations showed good discrimination between brands. A modest improvement in discrimination was observed for a compression force of 800 g. Reproducibility among cooking replications appeared to be similar for all test combinations. Indeed, similar CV among the test combinations were found for the two brands (Table 3.2). Thus, for this test there did not appear to be one set of operating conditions that had greater discriminating power or low variability than another.

3.3.4 Effect of Operating Conditions on Instron Measurements of Firmness

Spaghetti firmness was measured using compression depths of 0.50 and 0.05 mm of the baseplate. With both compression depths, firmness was measured as the work (energy) required to shear the strands of spaghetti. The force required to shear the strands was also measured when a compression force of 0.50 mm was used.

Figures 3.9 and 3.10 show the effect of compression depth and crosshead speed on work to shear values for both brands of spaghetti. Work to shear values were greater for a compression depth to within 0.05 mm of the baseplate compared to a compression depth to within 0.50 mm of the baseplate. This is expected since the shear blade is cutting through a greater percentage of the strand when a compression depth of 0.05 mm is used. Similar findings have been reported for the effect of compression depth on firmness measurements (Baker et al., 1986 and 1988; Betker, 1990; Boyd and Sherman, 1975a; Redlinger et al., 1985).

Regardless of the compression depth, work to shear values tended to increase with increasing crosshead speeds. This was particularly evident when speeds increased from 10 to 50 mm/min. A number of workers have also reported a profound effect of crosshead speed on Instron measurements (Baker et al., 1986; Betker, 1990; Boyd and Sherman, 1975a and 1975b; Hibberd and Parker, 1985; Shama and Sherman, 1973; Voisey et al., 1978a and 1978b). Voisey et al. (1978a) found deformation rate affected the relationship with sensory results suggesting that the speed selected is critical. Their data did not however, suggest an optimal crosshead speed that should be used but, the authors concluded that the use of high deformation rates to simulate mastication does not appear to be justified. Use of low rates allows simpler recording techniques to be used. High rates were not selected for use in

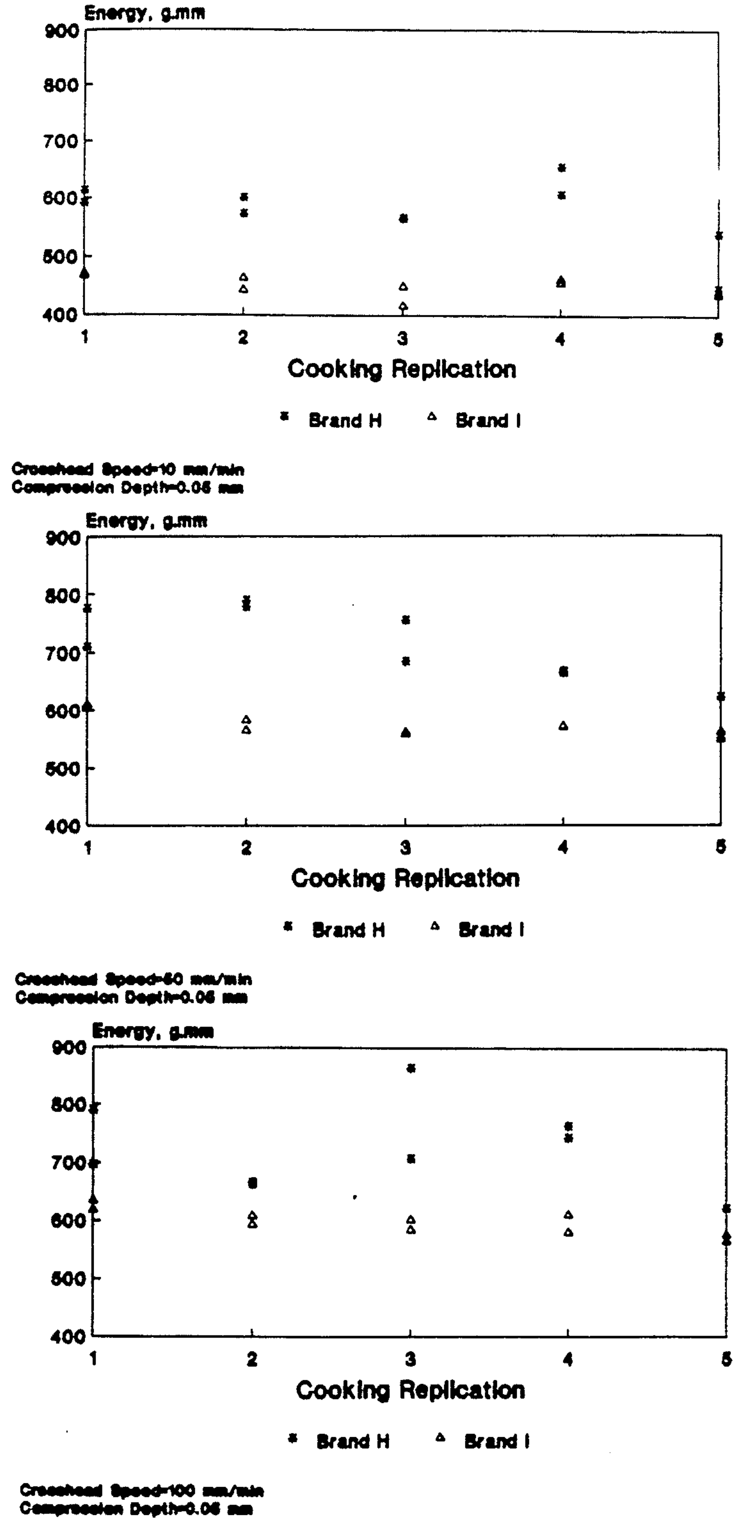


Figure 3.9 **Effect of Crosshead Speed on Work to Shear Values of Spaghetti Using Compression Depth of 0.05 mm**

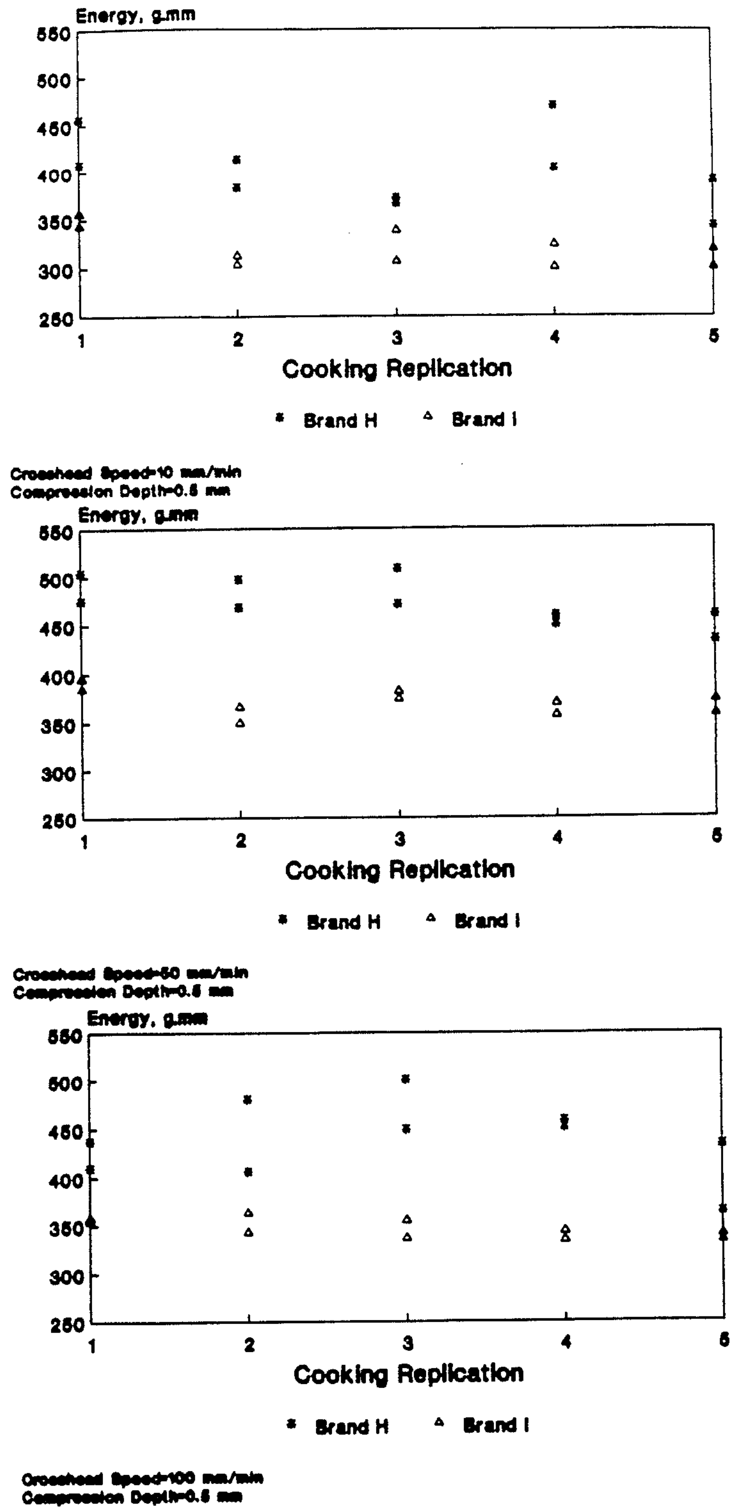


Figure 3.10 Effect of Crosshead Speed on Work to Shear Values of Spaghetti Using Compression Depth of 0.50 mm

this study since utilization of low deformation rates improves the precision with which the test cycle conditions are controlled and the data are recorded (Voisey and Kloek, 1975). The use of a high speed recorder may overcome these difficulties but was not available for this research.

High variability within cooking replications and among cooking replications was observed at a compression depth of 0.05 mm for brand H at all three crosshead speeds (Figure 3.9). This was confirmed by high CV (Table 3.3). Thus, for this brand, a compression depth of 0.05 mm was not optimal.

Discrimination among brands appeared to be good at all crosshead speeds when a compression force of 0.50 mm was used (Figure 3.10). Poor reproducibility among replications and repeatability within replications for work to shear values were observed for brand H at crosshead speeds of 10 and 100 mm/min. Reproducibility among replications was not as good for brand I at a crosshead speed of 10 mm/min compared to the other two crosshead speeds examined. This was confirmed by a low CV for brand H at a crosshead speed of 50 mm/min and low CV for brand I at crosshead speeds of 50 and 100 mm/min (Table 3.3). Interestingly, AACC (1989) recommends a crosshead speed of 10 mm/min at a compression depth of 0.50 mm. This crosshead speed showed the greatest variability among cooking replications and within replications for both brands of spaghetti evaluated in this study. It is not known if AACC reviewed other crosshead speeds in the development of their method.

Table 3.3 Coefficient of Variation (CV) For Firmness Tests

Parameter	Instron Condition Compression Depth (mm)	Crosshead Speed (mm/min)	CV (%) Brand H	I
Shear Force	0.50	10	9.8	3.1
		50	9.2	3.4
		100	9.4	2.6
Work to Shear	0.50	10	9.6	6.0
		50	5.2	3.8
		100	9.0	3.7
Work to Shear	0.05	10	9.6	3.7
		50	10.8	3.5
		100	10.6	4.0

Shear force, measured at compression depth of 0.50 mm also increased with increasing crosshead speeds (Figure 3.11). The best discrimination between brands in shear force was found at crosshead speeds of 50 and 100 mm/min. Similar repeatability and reproducibility were observed at all three crossheads. This was confirmed by the similar CV obtained for the three crosshead speeds (Table 3.3).

3.3.5 Selection of Instron Operating Conditions For Instron Tests

The final objective of this study was to select a set of operating conditions for each of the four Instron test procedures. The selection of operating conditions was based on the discrimination between the two brands of spaghetti and on low variability within cooking replications and among replications.

For firmness, a compression depth of 0.50 mm and a crosshead speed of 50 mm/min are recommended since this combination of operating conditions showed enhanced discrimination between brands of spaghetti and high reproducibility among replications and repeatability within replications.

For compression and relaxation, a compression force of 800 g and a plunger size of 1 cm are recommended since at these operating levels there was good discrimination between brands of spaghetti and high reproducibility and repeatability.

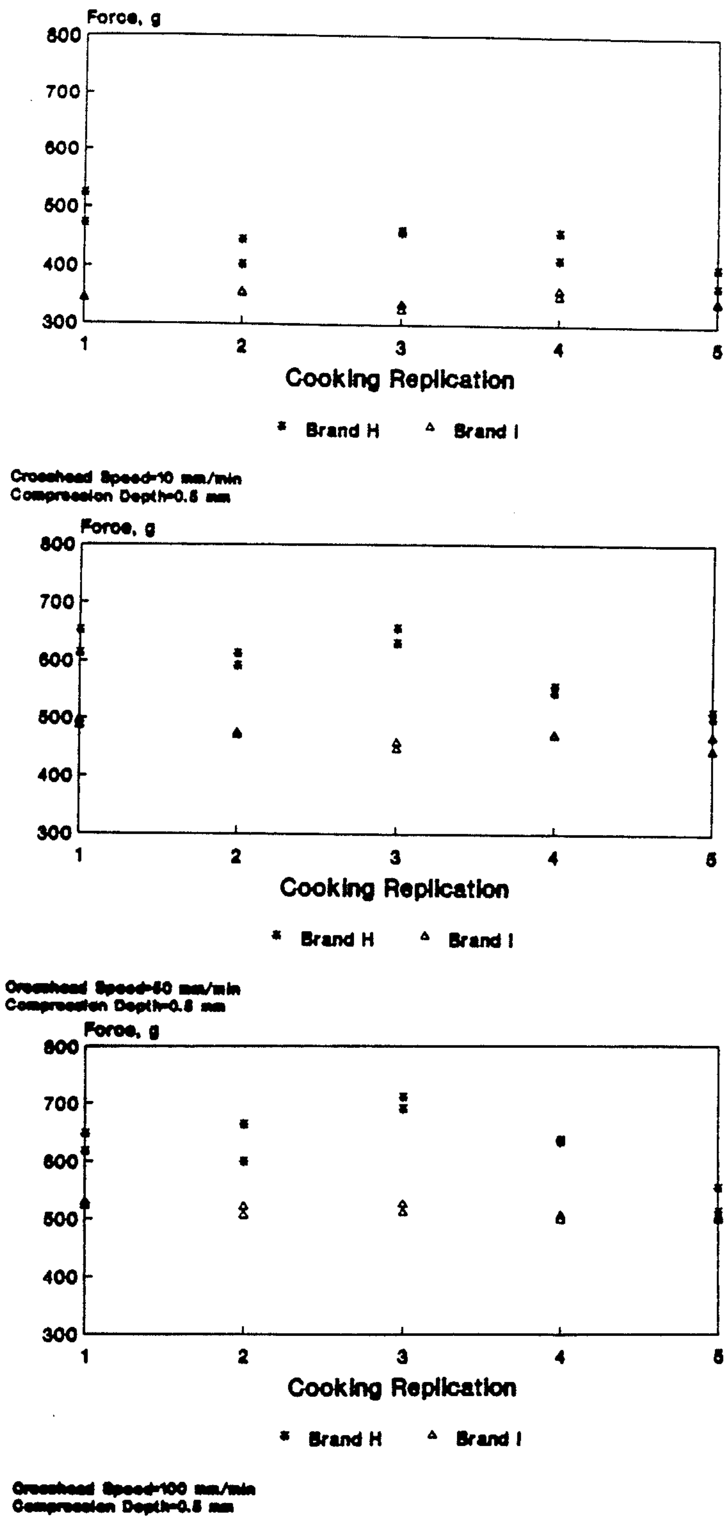


Figure 3.11 Effect of Crosshead Speed on Shear Force Values of Spaghetti Using Compression Depth of 0.50 mm

Although the data for stickiness suggested a number of combinations of compression force and plunger size that could be used, a compression force of 800 g and a plunger size of 2 cm are recommended since at these operating levels there was good discrimination between the two brands of spaghetti and slightly better reproducibility among cooking replications.

3.4 CONCLUSIONS

Compression force strongly influenced compression and relaxation measurements of spaghetti. Plunger size had a modest effect on these parameters but variability was reduced with the smaller plunger sizes. Compression depth and crosshead speed strongly influenced firmness measurements of spaghetti. Stickiness measurements of spaghetti were only modestly affected by compression force and plunger size.

For firmness, a compression depth of 0.50 mm of the baseplate and a crosshead speed of 50 mm/min enhanced discrimination between the two brands of spaghetti and gave reliable results as measured by low variability among cooking replications and within replications. For compression and relaxation, a compression force of 800 g and a plunger size of 1 cm showed good discrimination between spaghetti samples and reduced variability among cooking replications and within replications. Although the stickiness data revealed a number of possible plunger sizes and compression force combinations that might be used, a compression force of 800 g and a plunger size of 2 cm showed good discrimination between spaghetti samples and had a modest advantage in reproducibility among cooking replications. Using these selected combinations of Instron operating conditions it was possible to discriminate between the two brands of spaghetti on the basis of firmness, compressibility, elasticity, and stickiness. In addition, these operating conditions gave results that were repeatable within cooking replications and reproducible among cooking replications.

The importance of selecting Instron testing conditions after fully examining the operating factors has been stressed by Baker et al. (1986) and Shama and Sherman (1973). This study describes a procedure that can be used to select operating conditions on the basis of repeatability, reproducibility and discriminatory power. By plotting the results, the optimal operating conditions can quickly be identified. The final step that remains however, is to investigate the relationship between instrumental measures and sensory measures of spaghetti texture. This is necessary, to verify if the instrumental measurements have meaning in terms of sensory measurements (Malcolmson et al., 1989). Thus, validation of the Instron methods developed in this study is necessary by calibration against sound sensory judgements.

CHAPTER 4

COMPARISON OF SENSORY AND INSTRUMENTAL MEASUREMENTS OF SPAGHETTI TEXTURE

4.1 INTRODUCTION

In order to validate physical or instrumental procedures for assessing the textural properties of food, it is necessary to calibrate instrumental results against sound sensory judgements of texture. Reliable sensory measures of texture can be achieved using a trained panel that evaluates the product under controlled testing conditions using appropriate sensory methods. Through training, panelists learn to disregard their personal preferences and become consistent in their judgements. Thus, according to Bourne (1982) the two criteria of objectivity are met.

Szczesniak (1963) classified the textural characteristics of food into mechanical, geometrical and those related to fat and moisture content of a food. This classification of texture was intended for both instrumental and sensory measurements and is the basis of sensory and instrumental texture profile analysis (TPA). The sensory profile analysis relies on the use of trained judges who describe the textural characteristics of a food qualitatively and quantitatively in the order of appearance from first bite through complete mastication. Guidelines for the training and use of a texture profile panel can be found in Brandt et al., (1963); Civille and Szczesniak (1973) and Civille and Liska (1975). Operational definitions and standard rating scales for the mechanical parameters have been published by Szczesniak et al. (1963) and Munoz (1986) which are useful in standardizing terminology and methods of assessment among panelists.

A number of researchers have used trained panelists to assess firmness, chewiness and stickiness of pasta. The parameters of gumminess and elasticity have received much less attention. Attempts to quantify stickiness have involved both oral and non-oral procedures including visual and tactile assessments.

Few studies have been undertaken that involve a comprehensive assessment of cooked pasta texture. Larmond and Voisey (1973) used a trained panel to assess the firmness, chewiness, gumminess, adhesiveness and individuality of spaghetti strands. Panelists were able to distinguish differences among the spaghetti samples for all parameters. When these results were compared with consumer acceptability tests, it was found that consumers preferred spaghetti that was firm, chewy, and maintained individuality and was not gummy or adhesive. Further analysis suggested that firmness and gumminess were sufficient to predict consumer acceptability.

Menger (1985) developed an extensive scoring system for assessing the quality of raw and cooked pasta. Trained panelists assessed twenty factors, six related to the uncooked product, and seventeen related to the cooked product. The scoring system was weighted such that, uncooked quality accounted for 30% towards the final score and cooked quality accounted for 70%. Factors such as: retention of shape, surface characteristics, bite/firmness, odor and taste were judged in the assessment of cooked pasta quality.

Cubadda (1988) also described a scoring method for assessing cooked pasta quality. Experts (at least three persons) evaluated stickiness, firmness and bulkiness using scales ranging from 0 to 100. An overall quality score was then calculated by totalling the scores for the three parameters, multiplying by 33.3, and dividing by 100. An overall score greater than 80 indicated excellent quality.

Thus, it is possible to obtain reliable sensory data if a properly trained texture profile analysis panel is used. These results can then be used to validate instrumental measures of cooked spaghetti texture. Through the use of multivariate statistical techniques such as principle component analysis and multiple regression analysis, it is possible to estimate sensory judgements of texture from instrumental measures. Therefore, the objectives of this study were:

1. To establish a texture profile analysis panel to evaluate cooked spaghetti quality.
2. To determine the textural properties of commercial spaghetti samples using sensory, Instron, and Grain Research Laboratory (GRL) texture testing procedures.
3. To examine the relationship between instrumental measurements and sensory ratings of spaghetti texture using multivariate techniques to determine if instrumental evaluations can be used to predict sensory quality.

4.2 MATERIALS AND METHODS

4.2.1 Selection of Commercial Spaghetti Samples

Nine commercial brands of spaghetti were selected for assessment by sensory, GRL and Instron instrumental tests. Sample background and characteristics are given in Table 4.1. Five Canadian, three American and one Italian brand were included in the study. All were made from durum wheat except for brand I which was made from unbleached wheat flour and brand F which was a blend of durum and hard red spring wheat. Samples also varied in strand diameter with brand A having the smallest diameter and brand G having the largest strand diameter. Although it would have been ideal to have brands with equal strand diameter it was not possible.

4.2.2 Spaghetti Cooking and Handling Procedures

All samples were cooked to optimum (defined as the time when the centre core in the strands disappears) and to 10 minutes past the optimum cooking time (overcooked) for a total of 18 treatments. Spaghetti was cooked in rapidly boiling prepared water (as described in Chapter 2) using a ratio of 1:25 spaghetti to water. Samples were cooked in glass beakers on ceramic hot plates. Seven grams of spaghetti in five cm strands were cooked for instrumental evaluations of texture and cooking loss determinations. Seventy grams of spaghetti in twelve cm strands were cooked for sensory evaluations. This was approximately eight g of spaghetti per panelist.

Table 4.1 Spaghetti Sample Background and Characteristics

Sample Identity Letter	Origin	Content	Optimum Cooking Time (min)	Diameter* Before Cooking (mm)
A	American	durum semolina	10	1.62 (0.02)
B	American	durum semolina	12	1.68 (0.03)
C	American	durum semolina	12	1.75 (0.02)
D	Italian	durum semolina	14	1.90 (0.02)
E	Canadian	durum semolina	13	1.81 (0.03)
F	Canadian	semolina, flour	13	1.69 (0.05)
G	Canadian	durum semolina	15	1.91 (0.04)
H	Canadian	durum semolina	11	1.71 (0.06)
I	Canadian	unbleached flour	14	1.78 (0.02)

* mean (sd) of 60 determinations

Spaghetti for all textural parameters except stickiness were rinsed in cold tap water to prevent further cooking, and immediately assessed for their textural properties. Samples for stickiness assessment were not rinsed in order to maximize stickiness values (Dexter et al., 1983a). Stickiness was assessed 7 minutes after cooking. These handling practices were consistent with current practices used at GRL in their cooking quality evaluation program (Daniel, 1989) and represent the average time it took panelist to complete their assessment of the other textural attributes before beginning their assessment of stickiness.

4.2.3 Assessment of Texture Using GRL Instrumental Methods

Tenderness, compression, and recovery were evaluated using the GRL spaghetti testing apparatus as described by Matsuo and Irvine (1969, 1971). Tenderness values were derived from the slope of the linear portion of the penetration-time curve. Compression was defined as the ratio of the diameter of the compressed spaghetti strand to the original diameter of the strand x 100. Recovery was defined as the ratio of strand diameter after recovery to the diameter of the compressed spaghetti x 100. Cooking quality parameter (CQP) was determined as follows: (recovery/compression x tenderness) x 1000. Stickiness was determined using the GRL compression tester adapted for spaghetti as described by Dexter et al. (1983a) except that a compression force of 24,000 N/m^2 was used. Stickiness values were defined as the force of adhesion of the spaghetti to the plunger.

Measurements of tenderness, compression and recovery were performed on single strands of spaghetti. For each parameter, four strands were assessed in a cooking replication and three cooking replications were completed for a total of 12 determinations. For stickiness, only one determination per cooking replication could be performed. Six cooking replications were completed for a total of six determinations.

4.2.4 Cooking Loss Assessment Of Spaghetti

Actual cooking loss of the recovered water was determined by freeze-drying, weighing the freeze-dried material, adjusting for mineral residues left in the cooking water and calculating the proportion of solids as percentage of spaghetti cooked. Predicted cooking loss values were determined from iodine absorbance values measured at 650 nm following the method developed by Matsuo et al. (1990). Six cooking replications were completed for actual and predicted cooking loss assessments for a total of six determinations.

4.2.5. Instron Assessment of Spaghetti Texture

Spaghetti was assessed for firmness, compression, relaxation, and stickiness using the Instron Universal Testing Machine (Model 4201, Instron Corp., Canton, MA) equipped with a 10 N compression load cell. The test procedures used were developed in a previous study and are described in Chapter 3. Firmness was expressed as both the shear force and the work (energy) to shear five strands of spaghetti. Compression was expressed as the energy to compress nine strands and relaxation was defined as the time in seconds required for a

50 g reduction in the fixed load. Stickiness was expressed as the area under the force-distance curve.

Three cooking replications were completed for firmness, compression and relaxation. Within each cooking replication, duplicate measurements on two subsamples were completed for a total of twelve determinations. Four cooking replications were completed for stickiness. Within each cooking replication, duplicate measurements on one subsample were completed for a total of eight determinations.

4.2.6 Instron Assessment of Strand to Strand Stickiness

Stickiness of the commercial spaghetti samples was also assessed using a modified Instron method. This method was developed in an attempt to measure strand to strand adhesion or stickiness. It uses a much lower compression force than the other Instron stickiness test method and spaghetti strands are compressed by a plunger which has spaghetti strands mounted to it. This way the strands are contacting other strands rather than the surface of the plunger. The procedure used is as follows: Five strands were placed in a grooved baseplate and compressed to a maximum force of 50 g with a 2 cm wide grooved plexiglass plunger (Figure 4.1) to which 3 strands of spaghetti were mounted. A crosshead speed of 2 mm/min was used and data was recorded using a chartspeed of 500 mm/min set at 10% range. Stickiness was expressed as the area under the force-distance curve.

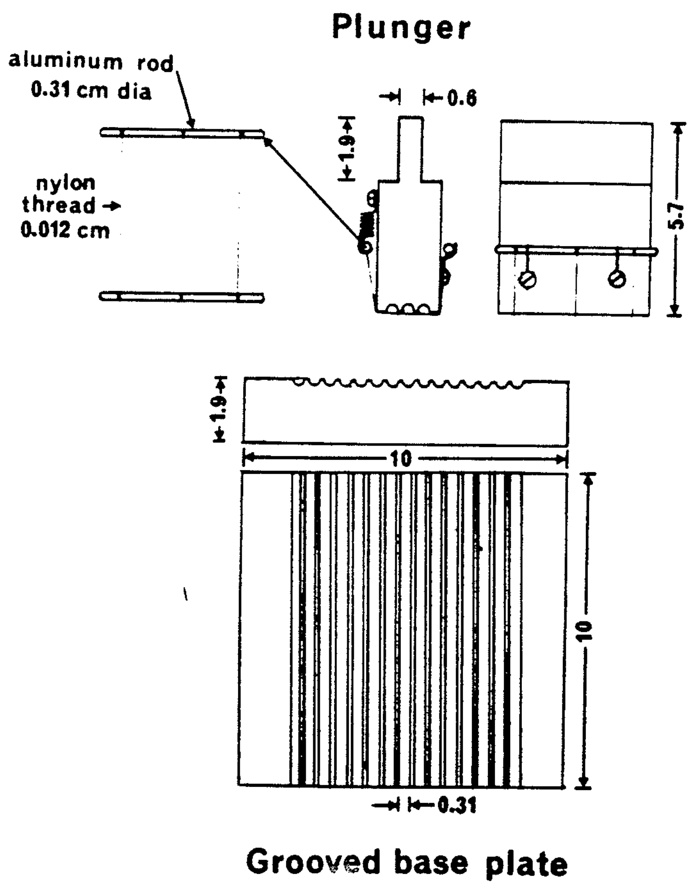


Figure 4.1 Plunger and Baseplate Dimensions For Instron Assessment of Strand Stickiness

4.2.7 Selection and Training of a Texture Profile Panel

Eleven judges were selected to participate in the study based on their interest and their experience and performance in previous sensory studies. Panelists (all females ranging in age from 20 to 45) were students and staff members in the Department of Foods and Nutrition, University of Manitoba, Winnipeg.

Ten, one hour training sessions were held over a two week period. The first few training sessions were held to acquaint the judges with the product by introducing them to number of spaghetti samples varying in textural quality similar to the range they would be evaluating in the study. The panelists learned how to handle the product during their evaluations and became familiar with the textural parameters to be assessed. Reference samples were provided for each textural parameter to illustrate endpoint and in some cases midpoint intensities. Rainey (1986) has stressed the importance of using reference standards in the training of panelists. Judges began each training session by evaluating a number of spaghetti samples for their textural properties. After the panelists had completed their independent evaluations, a group discussion followed. Panelists were encouraged to make suggestions and to identify any difficulties they were having with the parameters in terms of its definition, evaluation technique, and the reference samples provided. Through these discussions, modifications were made to the definitions, evaluation techniques and reference samples. Definitions of the textural parameters developed during training were based on those proposed by Szczesniak et al. (1963) and Munoz (1986).

Once panelists had standardized their evaluation techniques and were satisfied with the reference samples provided, the scaling technique that was to be used in the study was introduced. Unstructured line scales, 15 cm in length were chosen, since most of the panelists were familiar with these scales and had extensive experience with them. Many of the panelists had also expressed a preference for this scaling technique over other methods. One of the scaling exercises used to acquaint panelists with the use of these scales is provided in Appendix 2. Values were assigned to panelists' ratings on the scales by measuring the distance on the line in centimetres.

The remaining training sessions were held in order to anchor the reference samples on the scales and to provide the panelists with an opportunity to evaluate several spaghetti samples for their textural properties using the ballot developed during training.

Training ended when the panelists were consistent in their scoring of spaghetti samples and were confident in their ability to perform the task. In the end, only nine judges qualified to participate in the study. The final ballot that was agreed upon by all judges is provided in Figure 4.2. Information concerning the reference samples is provided in Appendix 3.

SENSORY EVALUATION OF SPAGHETTI

Evaluate the coded samples for each texture parameter in the following order _______ _______ _______ _______.

STAGE 1: PARTIAL COMPRESSION

ADHESIVENESS TO LIPS:

Remove lipstick from lips if present. Moisten lips slightly. Place a single strand between lips, compress for 2 seconds and release. Measure the amount of force required to separate lips and the degree of adhesion to the lip.

tomato — almond — cereal

not sticky ———————————— very sticky

ELASTICITY:

Twirl two strands around your index finger to form a ball. Remove ball from finger and place between molars. Slightly compress sample between molars and release. Repeat several times. Measure the degree of elasticity of the sample.

apricot — mushroom

low degree of elasticity ———————————— high degree of elasticity

STAGE 2: FIRST BITE

FIRMNESS:

Break a single strand in two pieces. Place one piece lengthwise between the molars. Measure the force required to bite through the sample.

Havarti — cheddar

soft ———————————— firm

STAGE 3: MASTICATORY

COHESIVENESS OF CHEWED MASS:

Fold 2 strands in four and chew thoroughly (i.e. until mass is ready for swallowing) between the molars on one side of the mouth, spreading the sample in the mouth during chewing to determine the degree to which the chewed mass holds together.

carrot — brownie

low degree of cohesiveness ———————————— high degree of cohesiveness

CHEWINESS:

Fold 2 strands in four and place in mouth. Measure the amount of energy required to masticate the sample until the sample is swallowed.

Havarti — cheddar

slightly chewy ———————————— very chewy

TOOTH PACK:

Fold 2 strands in four and place in mouth. Measure the degree of tooth packing during mastication and after swallowing sample.

carrot — cheddar — cracker

low degree of tooth pack ———————————— high degree of tooth pack

SURFACE STICKINESS:

Dip your index finger in water and dry with napkin. Touch the surface of the spaghetti strands with your finger, compress slightly and release. Determine the degree the strands adhere to your finger. Repeat on several areas of the spaghetti sample.

low degree of stickiness ———————————— high degree of stickiness

Figure 4.2 Sensory Ballot Used to Assess Textural Properties of Spaghetti

4.2.8 Sensory Evaluation of Spaghetti Texture

Spaghetti samples for all texture evaluations except stickiness were rinsed in cold tap water and placed in three digit coded 200 mL styrofoam cups with lids. Samples for surface stickiness evaluation were not rinsed and were served in coded glass petri plates with lids. Panelists were provided with distilled water, unsalted crackers and toothpicks for rinsing and clearing teeth between treatments. A plastic fork was also provided to assist panelists with their evaluations. A set of reference samples was provided at the first panel session of the day in order to re-orientate the panelists with the texture scales. Evaluations were made at individual work stations under fluorescent lights. Room temperature (20° C) and humidity (40%) were consistent over the three day period. Judges evaluated their set of samples for all textural parameters in the session. This procedure was considered more efficient and has been validated by Mela (1989) in a study which compared results from single and concurrent evaluations.

Four samples of spaghetti were evaluated at each panel session. Two replications were completed. Thus, a total of 9 sessions (9 brands x 2 cooking times x 2 replications) were required to complete the sensory evaluation of the spaghetti. Three sessions were held each day (2 hours apart) over a three day period. All panelists received the same four spaghetti samples at any one session but the order of presentation was randomized.

4.2.9 Experimental Designs and Statistical Analysis of Data

The experimental design selected for both the Instron and sensory experiments was a two way treatment structure (brand and cooking time) in a randomized complete block design with replications serving as the blocks. Brands and cooking times were considered to be fixed effects and replications to be a random effect.

A split plot design was selected for the GRL and cooking loss data since both cooking times for the nine brands of spaghetti could not be evaluated on the same day. Therefore on a given test day, one cooking time was assessed for all nine brands of spaghetti. Thus, at the main plot level there were six plots (two cooking times replicated three times over a six day period). Within each main plot there were nine subplots (nine brands). For stickiness and cooking loss data there were twelve plots at the main plot level (two cooking times replicated six times over a twelve day period).

Analysis of variance was performed on each of the three data sets (sensory, GRL, Instron) to determine the significant effects of brand and cooking time on texture measurements. For the sensory data, panel means within a cooking replication were analyzed since the possible effects of differences among panelists were not of interest. Similarly, for the Instron and GRL data, means of all determinations within a cooking replication were analyzed since the possible effects of differences in subsampling were not of interest.

Principle component analysis was used to identify underlying characteristics providing common elements among the sensory attributes.

Correlations were calculated between mean sensory and mean Instron and GRL instrumental values to determine the relationship between sensory and instrumental measures.

Multiple regression analysis using both r^2 and stepwise methods were applied to predict perceived textural quality of spaghetti. Based on this analysis, equations to predict selected sensory attributes from Instron and GRL measurements were obtained. All statistical analysis was performed using the Statistical Analysis System (SAS, 1988) utilizing GLM, PRINCOMP, CORR, and REG, procedures.

4.3. RESULTS AND DISCUSSION

4.3.1 Instrumental Evaluation of Texture

Significant brand and cooking time main effects were found for all GRL parameters and a significant brand by cooking time interaction was also found for all parameters except stickiness (Table 4.2). Significant brand by cooking time interactions indicate that brands were not equally influenced by overcooking.

A significant brand effect was found for all Instron parameters and a significant cooking time effect was found for all Instron parameters except strand stickiness (Table 4.3). Significant brand by cooking time interactions were also found for shear force, compression and relaxation time. A significant replication effect was found for Instron strand stickiness indicating variability between cooking replications. It should be noted, that only two replications were completed for this test method compared to four replications that were completed for the other Instron stickiness determination. It is likely that if more cooking replications had been completed for the revised stickiness test the replication effect would be minimized.

Means and their standard deviations for all GRL and Instron parameters are provided in Appendices 4 and 5 respectively.

Low scores for GRL tenderness indicated a firmer product whereas high values for Instron shear force and work to shear

Table 4.2 Analysis of Variance for GRL Data

Parameter	Source	df	Mean Square	F value
Tenderness	Cooking Time (CT)	1	1249.446	217.22a
	Day (CT)	4	5.752	
	Brand (B)	8	178.765	45.40a
	B*CT	8	13.487	3.43b
	Error	32	3.937	
Compression	Cooking Time (CT)	1	7361.671	147.89a
	Day (CT)	4	49.775	
	Brand (B)	8	386.342	16.28a
	B*CT	8	80.767	3.40b
	Error	32	23.727	
Recovery	Cooking Time (CT)	1	29983.870	242.93a
	Day (CT)	4	123.423	
	Brand (B)	8	1382.629	13.24a
	B*CT	8	539.715	5.17a
	Error	32	104.443	
CQP	Cooking Time (CT)	1	9207.757	222.70a
	Day (CT)	4	41.346	
	Brand (B)	8	494.142	20.96a
	B*CT	8	90.996	3.86b
	Error	32	23.580	
Stickiness	Cooking Time (CT)	1	56489.815	4.49c
	Day (CT)	4	12569.815	
	Brand (B)	8	845711.343	45.40a
	B*CT	8	22621.065	1.76
	Error	32	12884.815	

a significant at $p<0.001$
b significant at $p<0.01$
c significant at $p<0.05$

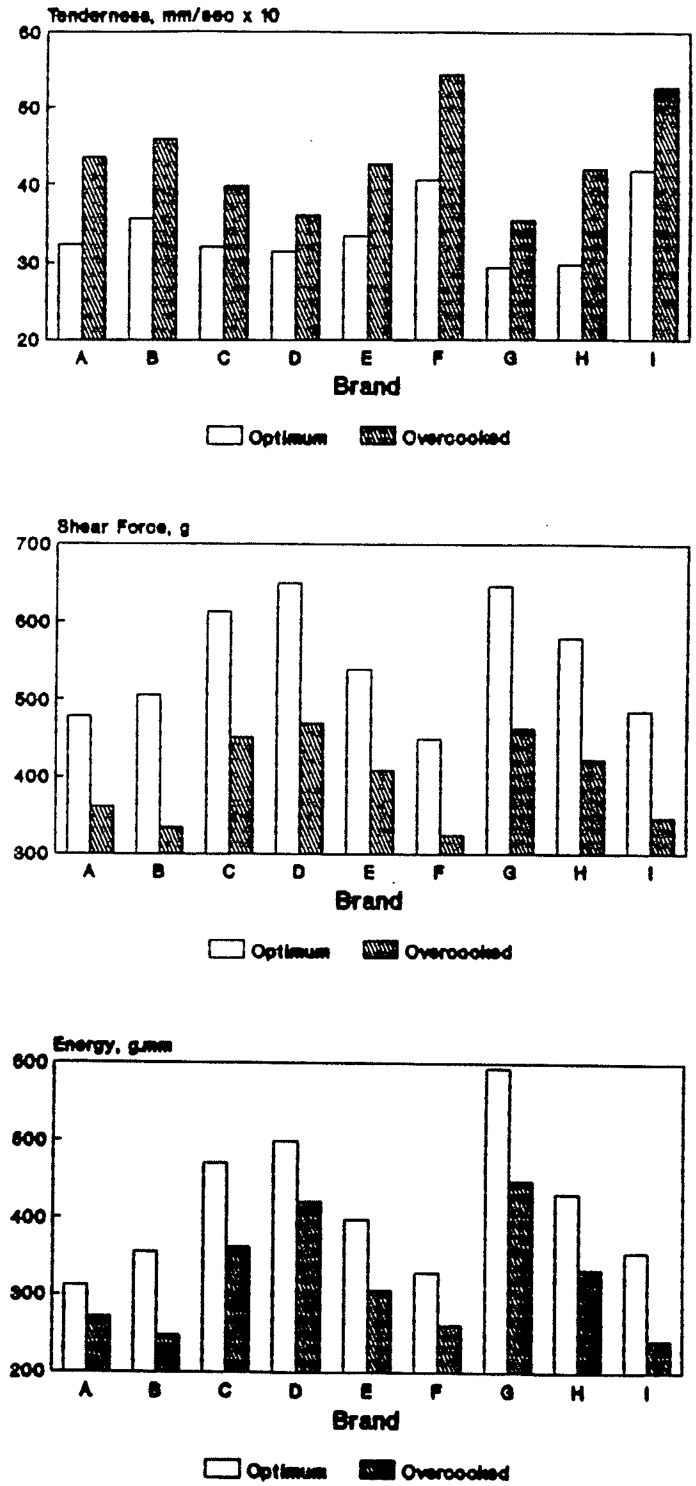
Table 4.3 Analysis of Variance of Instron Data

Parameter	Source	df	Mean Square	F value
Shear Force	Replication	2	625.365	1.51
	Brand (B)	8	25931.255	62.60a
	Cooking Time (CT)	1	309514.593	747.19a
	B*CT	8	946.094	2.28c
	Error	34	414.239	
Work to Shear	Replication	2	289.701	0.39
	Brand (B)	8	41454.480	55.10a
	Cooking Time (CT)	1	120943.770	160.77a
	B*CT	8	1372.088	1.82
	Error	34	752.298	
Compression Energy	Replication	2	29.948	0.94
	Brand (B)	8	3266.353	102.11a
	Cooking Time (CT)	1	82616.356	2582.57a
	B*CT	8	350.377	10.95a
	Error	34	31.990	
Relaxation Time	Replication	2	9.237	1.40
	Brand (B)	8	219.895	3.38a
	Cooking Time (CT)	1	3031.878	460.27a
	B*CT	8	42.407	6.44a
	Error	34	6.587	
Stickiness	Replication	2	23.741	1.96
	Brand (B)	8	213.306	17.62a
	Cooking Time (CT)	1	76.056	6.28b
	B*CT	8	12.931	1.07
	Error	34	12.103	
Strand Stickiness	Replication	1	1671.720	9.16b
	Brand (B)	8	642.500	3.52b
	Cooking Time (CT)	1	22.310	0.12
	B*CT	8	270.060	1.48
	Error	17	182.444	

a significant at p<0.001
b significant at p<0.01
c significant at p<0.05

indicated a firmer product. Differences were found in firmness even though spaghetti samples were cooked to the same endpoint (Figure 4.3). As expected, firmness decreased with over-cooking. Regardless of the cooking time, Brands F and I were found to be the softest when assessed using the GRL tenderness apparatus whereas brands A, F, and I were the softest when assessed using the Instron. Brand B also had low Instron values for firmness when overcooked. Brands I and F were expected to be softer than the other spaghetti samples since brand I was made from unbleached wheat flour and brand F was a blend of durum and hard red spring wheat. All other brands were made from durum wheat. Dexter et al. (1983b) and Kim et al. (1986 and 1989) also found spaghetti made from non-durum wheat was less firm than spaghetti made from durum wheat. Brands A and B might be expected to have lower scores for firmness when overcooked since they had the smallest diameter of all brands evaluated (Table 4.1). According to the GRL apparatus, Brands G and H were the firmest when cooked to optimum and brands D and G were the firmest when overcooked. Brands C, D, and G were the firmest when assessed with the Instron regardless of cooking time. Since brands D and G had the largest diameter of all brands evaluated (Table 4.1) they might be expected to have higher scores for firmness with overcooking.

Low values for both GRL and Instron compression and high values for elasticity indicated superior cooking quality. Not



GRL

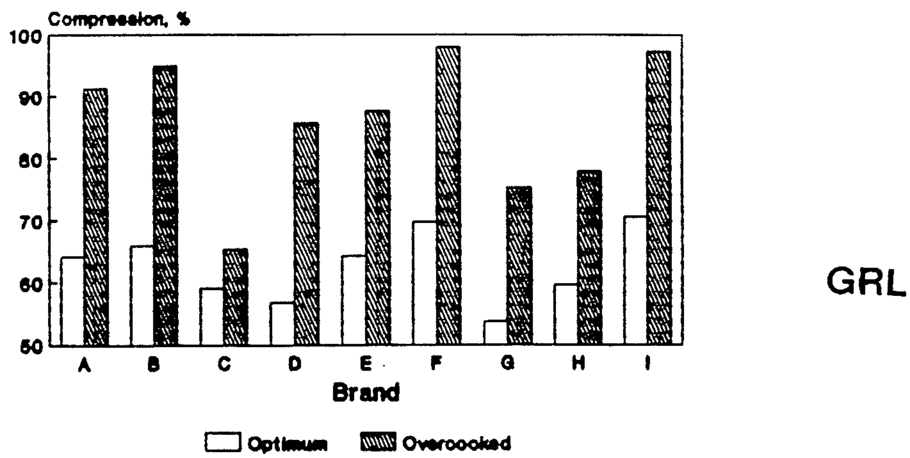
INSTRON SHEAR FORCE

INSTRON WORK TO SHEAR

Figure 4.3 Commercial Spaghetti Firmness as Quantified by GRL Tenderness Index, Instron Shear Force, and Instron Work to Shear Values surprising, compression values increased (Figure 4.4) and recovery/relaxation rates decreased with overcooking (Figure 4.5). For the GRL apparatus, brands D and G had low compressibility when cooked to optimum and brands C, G, and H had low compressibility when overcooked (Figure 4.4). For the Instron, brands A, C and H had low compressibility when cooked to optimum and when overcooked. For both instruments, high compressibility was observed for brands B, E, F, and I when cooked to optimum and brands B, F, and I when overcooked.

An extremely low recovery rate (measured with the GRL apparatus) was found for brand I and low recoveries for brands E and F were found at optimum cooking time (Figure 4.5). Recovery values were similar for the remaining brands with brand G having the highest recovery. Brands C, G, and H showed high recovery when overcooked. Dexter et al. (1983b) also reported high compression rates and low recovery rates for spaghetti made from red spring wheat compared to spaghetti made from durum. Brand I had the lowest relaxation time (measured by the Instron) followed by brand E when cooked to optimum. Brands E, F, and I had low relaxation times when samples were overcooked. High relaxation times were observed for brands A, D, G, and H regardless of cooking time. Brand C also exhibited high elasticity when overcooked.

High values for GRL and both Instron stickiness determinations indicated diminished quality. Generally, stickiness increased modestly with overcooking for the GRL and the first Instron method (Figure 4.6). Cooking time was not significant



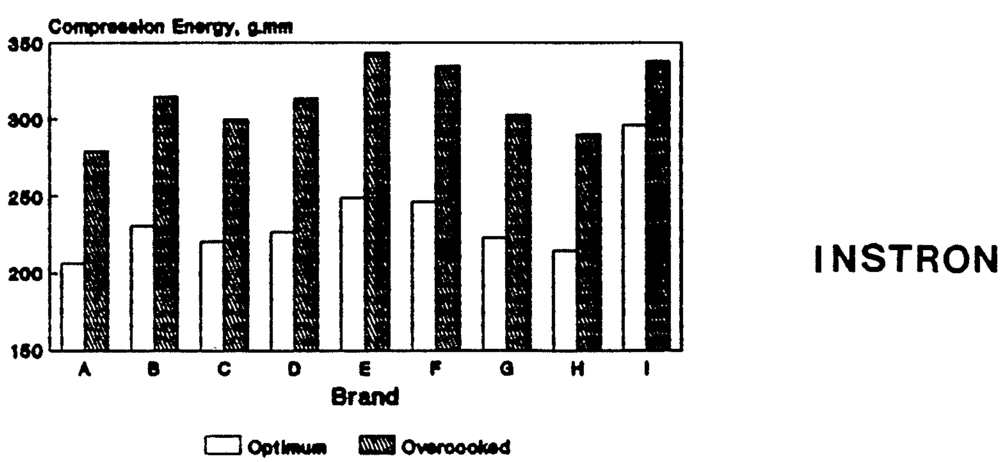
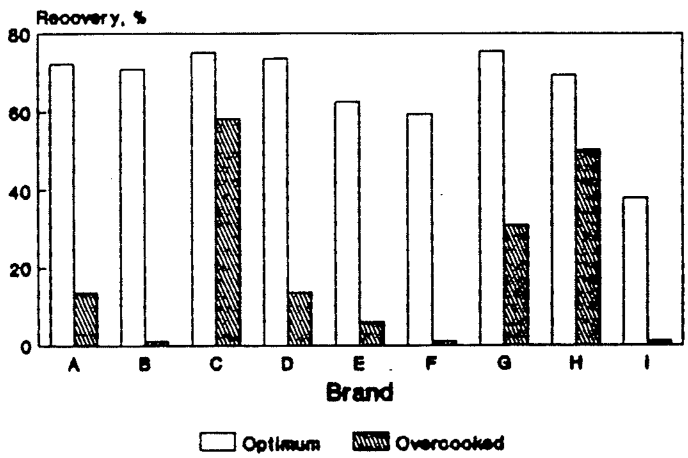


Figure 4.4 **Commercial Spaghetti Compressibility as Determined by the GRL Tenderness Apparatus and the Instron**



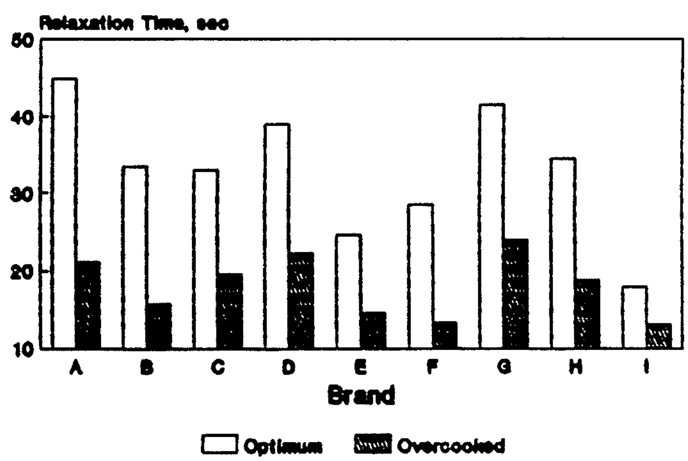


Figure 4.5 Commercial Spaghetti Elasticity as Quantified by GRL Recovery Rate and Instron Relaxation Time

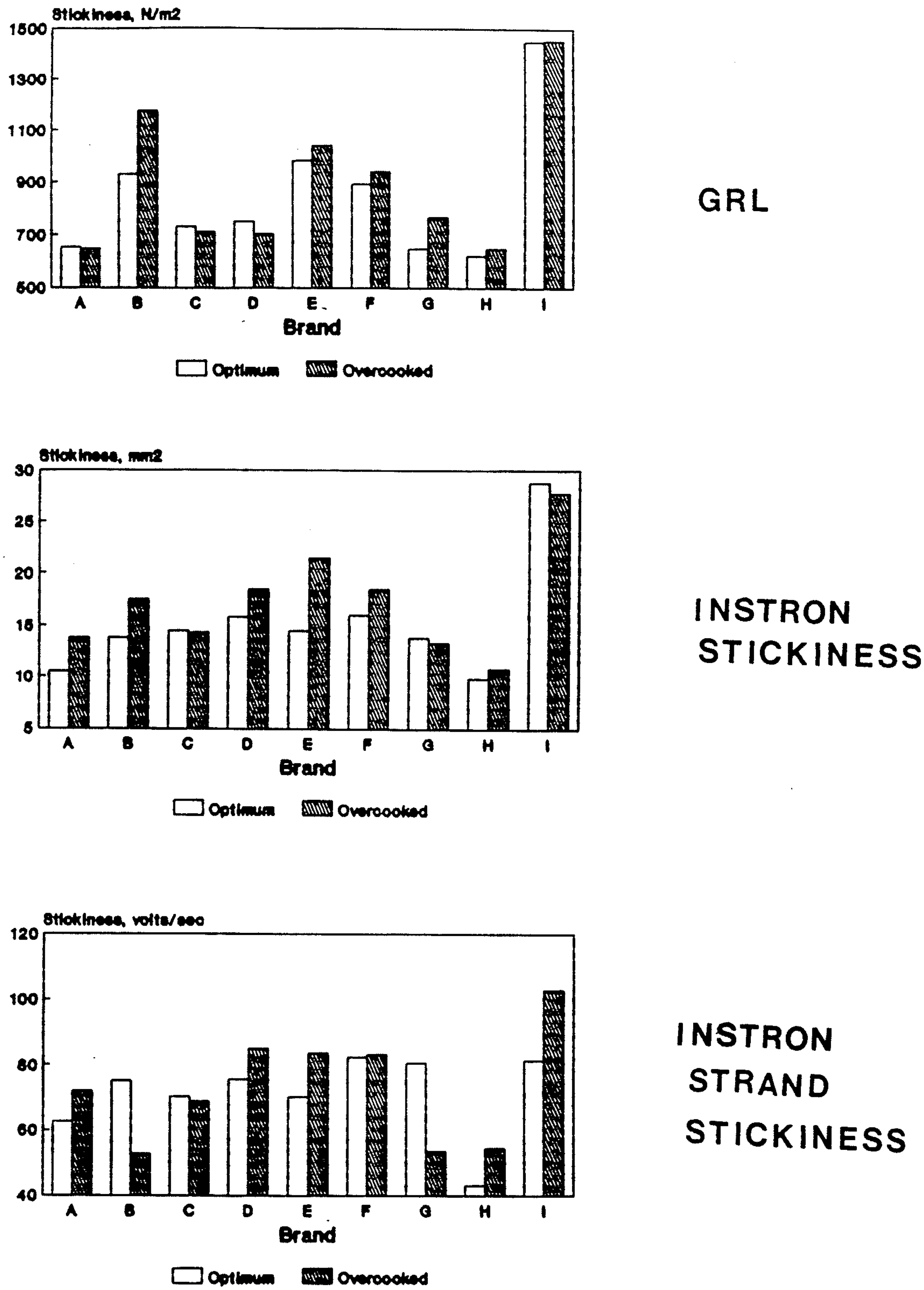


Figure 4.6 Commercial Spaghetti Stickiness as Determined by the GRL Compression Tester and the Instron

for Instron strand stickiness (Table 4.3). Regardless of the cooking time, brands A, G, and H were the least sticky spaghetti samples whereas brands B, E, F, and I were the most sticky when assessed using the GRL compression tester. Brand I was extremely sticky compared to all other samples tested. Instron results confirmed that brand I was the stickiest and brand H was the least sticky at both cooking times. Brand A also exhibited low stickiness at optimum cooking time. Assessment of Instron strand stickiness revealed that brands A and H had low strand to strand stickiness compared to brands F, G, and I. Dexter et al. (1983b) and Kim et al. (1989) also reported that durum spaghetti was less sticky than spaghetti made from common wheat.

CQP scores were derived from the ratio of the product of GRL tenderness and compressibility to recovery multiplied by 1000. A high CQP score indicated superior cooking quality. Results for CQP, confirm previous findings. At optimum cooking times brands F and I had the poorest quality whereas brand G had the highest quality followed by brands C, D, and H (Figure 4.7). Brands B, F, and I had the poorest quality and brands C, G and H had the highest quality when samples were overcooked. Dexter et al. (1981c) also reported lower CQP scores for spaghetti made from common wheat compared to spaghetti made from durum wheat.

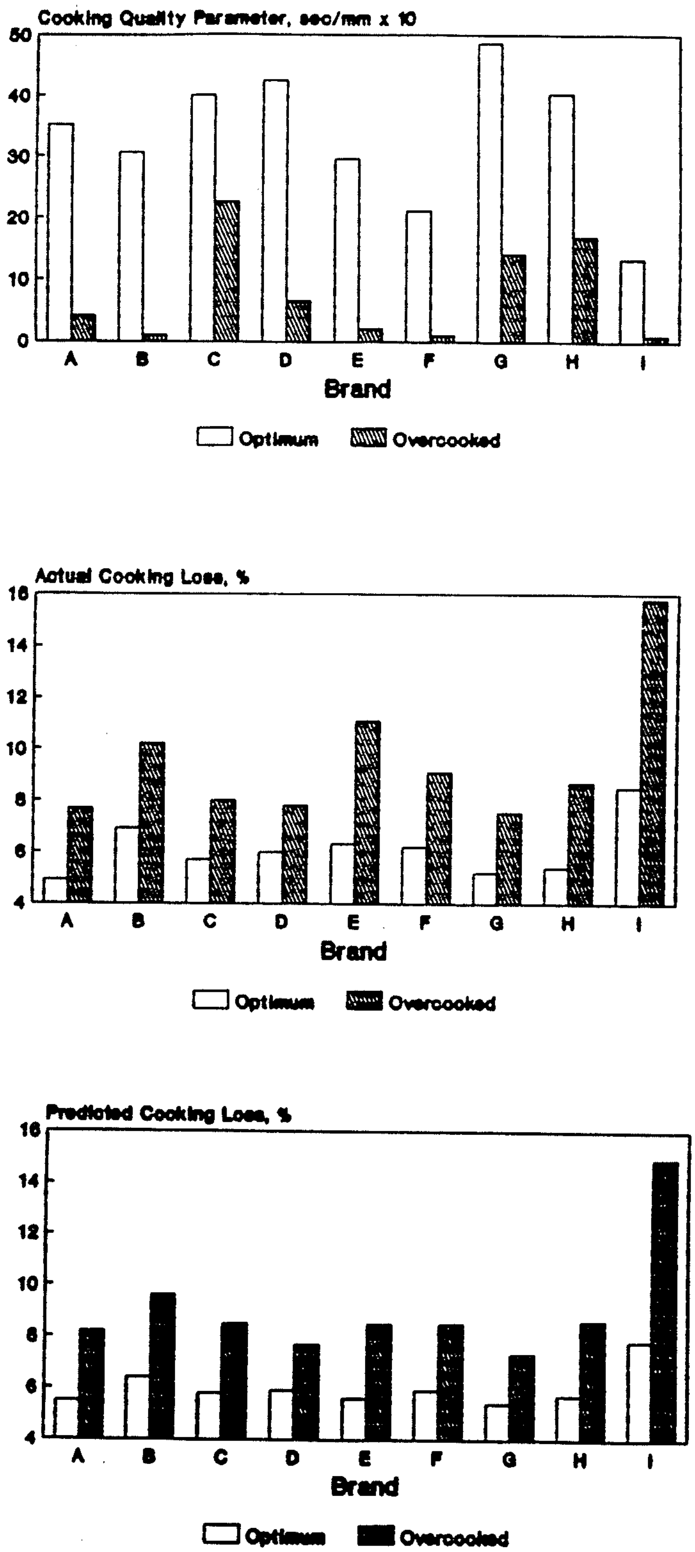


Figure 4.7 CQP Score and Cooking Loss of Commercial Spaghetti

4.3.2 Cooking Loss Evaluation

Significant brand and cooking time main effects, and significant brand by cooking time interactions were found for both measurements of cooking loss (Table 4.4). Means and their standard deviations for all parameter are provided in Appendix 6.

Cooking loss values between 5 and 7% are considered typical (Daniel, 1989). Cooking losses increased with an increase in cooking time. (Figure 4.7). Much higher cooking losses were found for brand I than all other spaghetti samples. Brand B was also found to have high cooking losses except for predicted cooking loss at optimum cooking time. Lower cooking losses for durum spaghetti have also been reported by Kim et al. (1989) when samples were cooked in prepared hard water.

4.3.3 Sensory Evaluation of Texture

Significant differences among brands were found for all sensory parameters except adhesiveness to lips and between cooking times for all parameters except adhesiveness to lips and cohesiveness (Table 4.5). No significant brand by cooking time interactions were found for any of the sensory parameters. Mean sensory scores and their standard deviations for all parameters are provided in Appendix 7.

Results for perceived firmness and chewiness were quite similar despite the fact that firmness is assessed on the first bite whereas chewiness is assessed during mastication.

Table 4.4 Analysis of Variance for Cooking Loss Data

Parameter	Source	df	Mean Square	F value
Actual Cooking Loss	Cooking Time (CT)	1	316.556	547.67a
	Day (CT)	4	0.578	
	Brand (B)	8	40.447	30.63a
	B*CT	8	8.197	6.21a
	Error	32	1.321	
Predicted Cooking Loss	Cooking Time (CT)	1	255.148	492.56a
	Day (CT)	4	0.518	
	Brand (B)	8	27.051	43.72a
	B*CT	8	7.297	11.79a
	Error	32	0.619	

a significant at $p<0.001$

Table 4.5 Analysis of Variance for Sensory Data

Parameter	Source	df	Mean Square	F value
Adhesive to Lips	Replication	1	0.044	0.02
	Brand (B)	8	0.456	0.20
	C.Time (CT)	1	3.384	1.47
	B*CT	8	1.177	0.51
	Error	17	2.302	
Elasticity	Replication	1	0.186	0.33
	Brand (B)	8	2.947	5.16b
	C.Time (CT)	1	36.779	64.43a
	B*CT	8	1.047	1.83
	Error	17	0.571	
Firmness	Replication	1	1.051	0.46
	Brand (B)	8	8.501	3.72b
	C.Time (CT)	1	118.810	52.01a
	B*CT	8	1.146	0.50
	Error	17	2.284	
Cohesiveness	Replication	1	2.848	5.51c
	Brand (B)	8	3.105	6.01a
	C. Time (CT)	1	1.745	3.38
	B*CT	8	1.149	2.22
	Error	17	0.517	
Chewiness	Replication	1	0.001	0.00
	Brand (B)	8	7.435	10.67a
	C. Time (CT)	1	110.425	158.50a
	B*CT	8	0.695	1.00
	Error	17	0.697	
Tooth Pack	Replication	1	0.490	0.65
	Brand (B)	8	2.733	3.65b
	C. Time (CT)	1	30.710	40.96a
	B*CT	8	0.909	1.21
	Error	17	0.750	
Surface Stickiness	Replication	1	2.627	2.29
	Brand (B)	8	3.694	3.21c
	C.Time (CT)	1	11.903	10.36b
	B*CT	8	1.014	0.88
	Error	17	1.149	

a significant at $p<0.001$
b significant at $p<0.01$
c significant at $p<0.05$

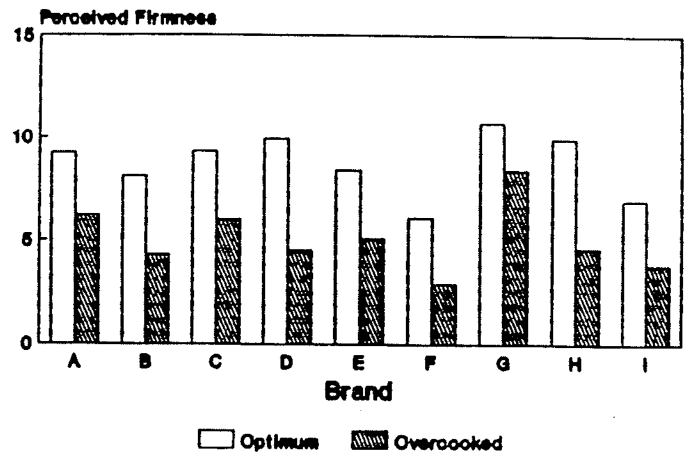
Both parameters decreased with overcooking (Figure 4.8). Like instrumental measures, differences were found among brands at optimum cooking time despite being cooked to the same end-point. Brands F and I were found to be the least firm and the least chewy and brands D, G, and H were found to be the most firm and the most chewy regardless of the cooking time.

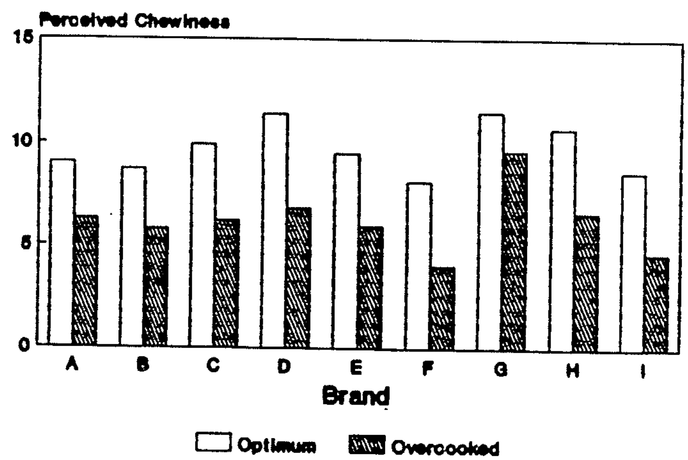
Perceived elasticity decreased with overcooking except for brand D (Figure 4.8). For optimally cooked samples, brands F and I were less elastic than all other spaghetti samples. Brands B, E, F, and I were less elastic than other brands when samples were overcooked.

Panelists could perceive differences in cohesiveness between brands but could not find differences between the two cooking times (Table 4.5). Brand A was the least cohesive and brands D, G, I were the most cohesive (Figure 4.9).

Perceived tooth pack decreased with overcooking for all brands except C (Figure 4.9). Brands D and I had high tooth pack and brand C had low tooth pack when cooked to optimum. Brand D had high tooth pack and brand A had low tooth pack when samples were overcooked.

Perceived stickiness generally decreased slightly with overcooking (Figure 4.9) whereas the opposite was found for the instrumental determinations of stickiness. Stickiness determined using the GRL compression tester and using the Instron generally increased with overcooking. Strand stickiness as determined by the Instron showed no difference





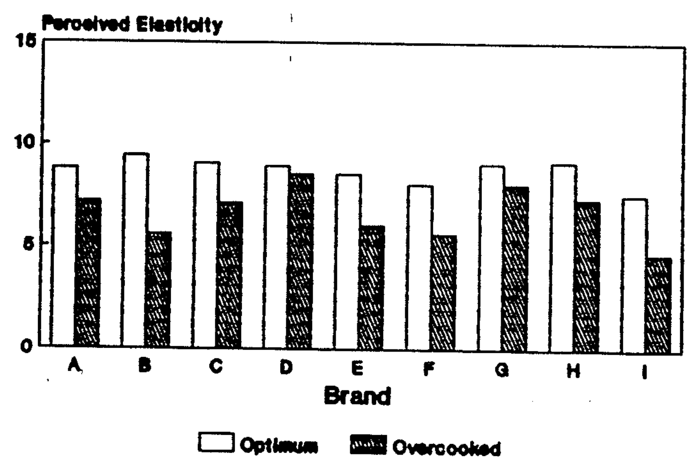


Figure 4.8 Perceived Firmness, Chewiness, and Elasticity, of Commercial Spaghetti

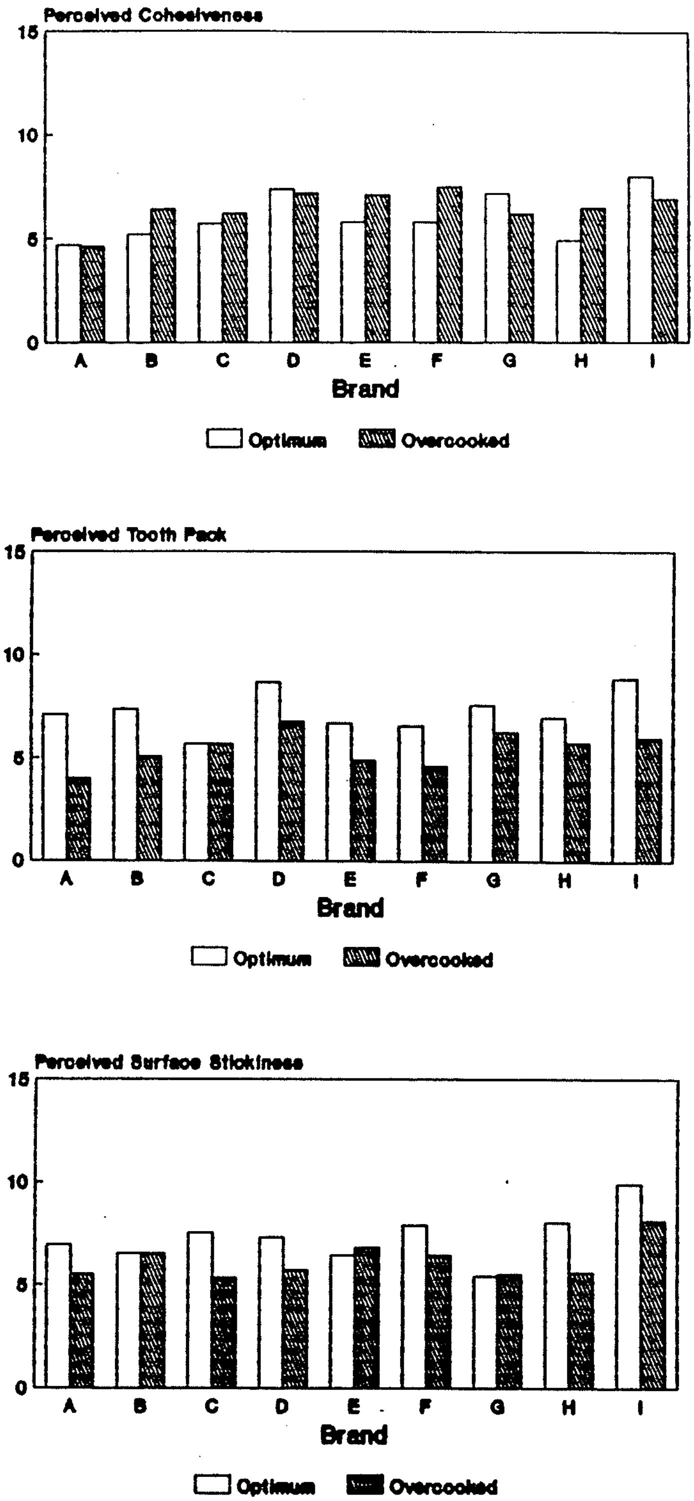


Figure 4.9 Perceived Cohesiveness, Tooth Pack and Stickiness of Commercial Spaghetti

between cooking times. A possible explanation for this discrepancy has been offered by Voisey et al. (1978b). According to these researchers, adhesive forces depend on the area of contact between the spaghetti and the upper plate of the Instron. When force is applied to the spaghetti strands, the strands flatten to distribute the applied force. Thus, the area of contact is governed by the deformability of the spaghetti. It can be reasoned then, that overcooked spaghetti would have higher deformability, therefore greater area of contact and consequently higher stickiness values. In theory, this same principle would hold true for tactile assessments of stickiness. Our results however, do not indicate that this was a factor.

Agreement between sensory and instrumental results was achieved for differences among brands in stickiness. Brands A, B and G were perceived by the panelists to be the least sticky and brands F, H, and I were the most sticky when samples were cooked to optimum. With overcooking, brands A, C, D, H, and G were the least sticky and brands E, F, and I were the most sticky.

4.3.4 Principle Component Analysis of Sensory Data

Principle component analysis (PCA) was carried out to identify underlying characteristics which provided common elements among the sensory attributes. The goal was to reduce the number of sensory attributes to a smaller number of components without losing important information.

Two principle components were extracted from the data (Table 4.6). This solution accounted for 81.7% of the variance among samples. Factor loadings which are the correlations between the components and the variables were examined to interpret the components. Component 1, which accounted for 56.2% of the variance was interpreted as a "firmness" component due to high loadings for chewiness (0.97), firmness (0.95), elasticity (0.91) and tooth pack (0.76). Component 2 accounted for 25.5% of the variance. This component was interpreted as a "type of breakdown" component as it had high loadings for cohesiveness (0.77), and stickiness (0.74), and a modest loading for tooth pack (0.55). These results suggest that fewer textural attributes could be used in routine assessment of spaghetti cooking quality since no additional information was obtained using all attributes. One parameter could be chosen to represent a component based on the parameter's size of loading for the component and on the ease and convenience to measure the attribute by the panel. Thus, for Component 1 either firmness or chewiness could be chosen to represent this component since both attributes had high loadings and were not difficult to assess by the panelists. For Component 2, stickiness is the best choice to represent this component. Although, cohesiveness had a slightly higher loading, panelists were unable to distinguish differences in cooking time with this parameter, suggesting that they may have had difficulty assessing this parameter. Panelists showed no difficulty evaluating stickiness.

Table 4.6 Factor Loadings for PCA Components

Sensory Attribute	Component 1	Component 2
Elasticity	0.91	-0.24
Firmness	0.95	-0.15
Cohesiveness	-0.26	0.77
Chewiness	0.97	-0.01
Tooth Pack	0.76	0.55
Stickiness	0.19	0.74
% of variance	56.18	25.48
Cumulative % of Variance	56.18	81.66

4.3.5 Relationship Between Sensory And Physical Parameters

Correlations between the sensory ratings and Instron, GRL, and cooking loss measurements are provided in Tables 4.7 - 4.9. Statistical significance is not indicated in the tables since it is possible to achieve a significant relationship between two variables with a low correlation coefficient if a sample size large enough is used. Therefore, it is preferable to interpret results on the basis of predictive reliability rather than statistical significance. A useful guide for determining the suitability of a correlation for prediction purposes was published by Kramer (1951). When the correlation coefficient between the sensory scores and the instrumental measurements falls in the range of ± 0.9 to ± 1.0, the instrumental test can be used with confidence as a predictor of the sensory score. When the correlation coefficient lies between ± 0.8 and ± 0.9, the test can be used as a predictor but, with less confidence. Bourne (1982) extended this concept further and suggested that when correlations fall between ± 0.7 and ± 0.8, the test is of marginal use as a predictor and less than ± 0.7, the test is not a good predictor. Thus, perceived elasticity, firmness, and chewiness can be predicted from both cooking loss tests and all Instron and GRL measurements except stickiness determinations. No instrumental test proved to be a good predictor of perceived cohesiveness, tooth pack, or stickiness. High correlations have also been found between instrumental and sensory measurements of firmness (Matsuo and Irvine, 1974; Walsh, 1971; Oh et al., 1983), instrumental

Table 4.7 Correlation Coefficients Between Sensory and Instron Measurements

Sensory Parameter	Instron Measurements Shear Force	Work to Shear	Compress-ion	Relax-ation	Sticki-ness	Strand Sticki-ness
Elasticity	0.84	0.74	-0.81	0.84	-0.60	-0.33
Firmness	0.89	0.77	-0.88	0.87	-0.48	-0.34
Cohesiveness	-0.04	0.13	0.51	-0.40	0.67	0.50
Chewiness	0.93	0.85	-0.82	0.84	-0.43	-0.33
Tooth Pack	0.69	0.57	-0.51	0.56	0.10	0.06
Sensory Stickiness	0.11	-0.14	-0.17	-0.00	0.56	0.23

Table 4.8 Correlation Coefficients Between Sensory and GRL Measurements

Sensory Parameter	GRL Measurements Tender ness	Compress-ion	Recovery	CQP	Sticki-ness
Elasticity	-0.92	-0.85	0.85	0.84	-0.61
Firmness	-0.90	-0.89	0.83	0.91	-0.43
Cohesiveness	0.33	0.21	-0.36	-0.28	0.47
Chewiness	-0.92	-0.90	0.82	-0.39	-0.76
Tooth Pack	-0.57	-0.68	0.60	0.60	0.09
Sensory Stickiness	0.09	-0.11	0.07	0.04	0.61

Table 4.9 Correlation Coefficients Between Sensory and Cooking Loss Measurements

Sensory Parameter	Cooking Loss Measurements Actual	Predicted*
Elasticity	-0.89	-0.87
Firmness	-0.76	-0.74
Cohesiveness	0.40	0.31
Chewiness	-0.76	-0.76
Tooth Pack	-0.39	-0.39
Sensory Stickiness	0.14	0.08

*from iodine absorbance measurement

firmness and chewiness (Voisey et al., 1978a), and instrumental compression and recovery rates and sensory chewiness (Oh et al., 1983). The failure to establish a high correlation between instrumental and sensory stickiness is not entirely inconsistent with results of other researchers. With the exception of Feller et al. (1983) who reported a good correlation between sensory and instrumental measures of stickiness (r=0.98) on studies with rice, other researchers have not been as successful. Voisey et al. (1978b) had modest success in correlating manual and instrumental assessments of spaghetti stickiness. Boyd and Sherman (1975b) were unable to establish a correlation between Instron and either oral or non-oral sensory assessments of stickiness for a number of different foods. Atkins (1989) was also unable to correlate Instron and tactile assessments of bread dough stickiness but did find a correlation between compression energy and sensory stickiness.

4.3.6 Prediction of Sensory Firmness, Chewiness and Stickiness

Multiple regression analysis was conducted in order to quantify the relationship between the sensory and physical dimensions. Equations to predict the sensory ratings of firmness, chewiness and stickiness were derived using maximum R^2 and stepwise procedures. Firmness and chewiness were selected to represent the first principle component and stickiness was selected to represent the second principle component. Components had high loadings for these parameters and the technique for assessing these parameters was relatively simple compared to other sensory parameters identified in each of the two components.

Good predictability of sensory firmness was possible using a two variable model based on measurements of Instron shear force (X1) and compression energy (X3) (Table 4.10). The equation derived from the Instron combinations was:

Firmness = 7.233 + (0.012)X1 - (0.023)X3

The multiple coefficient of determination (R^2) for this equation was 0.88. The R^2 is a measure of the amount of variance in the dependent variable accounted for by all the variables contributing to the equation (Schutz, 1983). Thus, this model accounted for 88% of the variation in the sensory firmness score. Only a small improvement in R^2 was evident when three variables were included in the equation (Table 4.10).

Sensory chewiness can be predicted from the one variable model based on the Instron measurements of shear force (X1) using the equation:

Chewiness = -1.903 + (0.021)X1

The R^2 for this equation was 0.86 (Table 4.11). Only a modest improvement in R^2 was achieved using a two and three variable model.

Good predicability of sensory firmness and chewiness were achieved using a one variable model based on GRL measurements.

Table 4.10 Multiple Regression Analysis Using R^2 and Stepwise Procedures for Predicting Perceived Firmness of Commercial Spaghetti Samples from Instron Measurements

Instron Description	Parameter Estimate* 1 variable	2 variable	3 variable
Y intercept	-3.059	7.233	8.516
X1 Shear Force	0.021	0.012	0.013
X2 Work to Shear			
X3 Compression Energy		-0.023	-0.021
X4 Relaxation Time			
X5 Stickiness			
X6 Strand Stickiness			-0.026
R^2	0.79	0.88	0.91

* In the stepwise regression procedure no other variable met the 0.15 significance level for entry into the model

Table 4.11 Multiple Regression Analysis Using R^2 and Stepwise Procedures for Predicting Perceived Chewiness of Commercial Spaghetti Samples from Instron Measurements

Instron Description	Parameter Estimate* 1 variable	2 variable	3 variable
Y intercept	-1.903	0.588	4.668
X1 Shear Force	0.021	0.020	0.017
X2 Work to Shear			
X3 Compression Energy			-0.010
X4 Relaxation Time			
X5 Stickiness			
X6 Strand Stickiness		-0.030	-0.027
R^2	0.86	0.90	0.92

* In the stepwise regression procedure no other variable met the 0.15 significance level for entry into the model

Perceived firmness can be predicted from the CQP score (X4) using the equation:

Firmness = 4.196 + (0.132)X4

This equation had a R^2 of 0.83 (Table 4.12). Only a minor improvement in R^2 was achieved using a two variable model. The derived equation for perceived firmness is similar to the equation developed by Marshall (1974) to predict sensory firmness of spaghetti in that linear combinations of GRL tenderness, compression and recovery are used. Perceived chewiness can be predicted from the GRL measurement of tenderness (X1) using the equation:

Chewiness = 18.873 - (0.281)X1

This equation had a R^2 of 0.84 (Table 4.13). As with firmness, only a modest improvement in R^2 was found with two and three variable models.

Predictability of sensory stickiness was not as successful as firmness and chewiness. Perceived stickiness can be predicted from Instron measurements of compression energy (X3), stickiness (X5), and strand stickiness (X6) using the equation:

Stickiness = 9.676 - (0.017)X3 + (0.296)X5 - (0.044)X6

This equation had a R^2 of 0.72 (Table 4.14). Thus, only 72% of the variability in the rating for sensory stickiness can be explained by a linear combination of these Instron measures.

Table 4.12 Multiple Regression Analysis Using R^2 and Stepwise Procedures for Predicting Perceived Firmness of Commercial Spaghetti Samples from GRL Measurements

GRL Description	Parameter Estimate* 1 variable	2 variable
Y intercept	4.197	11.121
X1 Tenderness		-0.148
X2 Compression		
X3 Recovery		
X4 CQP	0.132	0.075
X5 Stickiness		
R^2	0.83	0.88

* In the stepwise regression procedure no other variable met the 0.15 significance level for entry into the model

Table 4.13 Multiple Regression Analysis Using R^2 and Stepwise Procedures for Predicting Perceived Chewiness of Commercial Spaghetti Samples from GRL Measurements

GRL Description	Parameter Estimate* 1 variable	2 variable	3 variable
Y intercept	18.873	13.841	13.699
X1 Tenderness	-0.281	-0.179	-0.219
X2 Compression			
X3 Recovery			
X4 CQP		0.053	0.053
X5 Stickiness			0.002
R^2	0.84	0.88	0.91

* In the stepwise regression procedure no other variable met the 0.15 significance level for entry into the model

Table 4.14 **Multiple Regression Analysis Using R^2 and Stepwise Procedures for Predicting Perceived Stickiness of Commercial Spaghetti Samples from Instron Measurements**

Instron Description	Parameter Estimate* 1 variable	2 variable	3 variable
Y intercept	4.604	7.490	9.676
X1 Shear Force			
X2 Work to Shear			
X3 Compression Energy		-0.014	-0.017
X4 Relaxation Time			
X5 Stickiness	0.130	0.199	0.296
X6 Strand Stickiness			-0.044
R^2	0.31	0.59	0.72

* In the stepwise regression procedure no other variable met the 0.15 significance level for entry into the model

Table 4.15 **Multiple Regression Analysis Using R^2 and Stepwise Procedures for Predicting Perceived Stickiness of Commercial Spaghetti Samples from GRL Measurements**

GRL Description	Parameter Estimate* 1 variable	2 variable
Y intercept	4.249	2.435
X1 Tenderness		
X2 Compression		
X3 Recovery		0.020
X4 CQP		
X5 Stickiness	0.003	0.004
R^2	0.37	0.55

* In the stepwise regression procedure no other variable met the 0.15 significance level for entry into the model

Prediction of perceived stickiness using GRL measurements was achieved using measurement of recovery (X3) and stickiness (X5) using the equation:

$$\text{Stickiness} = 2.435 + (0.020)X3 + (0.004)X5$$

This equation however, only had a R^2 of 0.55 (Table 4.15).

4.4 CONCLUSIONS

A texture profile panel identified seven textural parameters important in the assessment of cooked spaghetti quality. With the exception of adhesiveness to lips, panelists were able to perceive differences between brands of commercial spaghetti. Differences between optimally cooked and overcooked spaghetti were also perceived by the judges in firmness, chewiness, elasticity, stickiness and tooth pack.

Instrumental measurements of firmness, compressibility, elasticity and stickiness were made using the Instron and the GRL tenderness apparatus and compression tester. Cooking loss was also determined using two methods. Significant differences among brands were found for all physical tests and between cooking times for all physical tests except Instron strand stickiness.

The predictive reliability of correlation coefficients between sensory and physical measurements was explored. Several physical tests were found to have predictive reliability for estimating sensory ratings for firmness, chewiness, and elasticity. None of the physical tests on their own was a reliable predictor of sensory ratings of cohesiveness, stickiness, or tooth pack.

Principle component analysis was used to reduce the number of sensory attributes into a smaller set of components that accounted for the greatest amount of variance. Two components were extracted which accounted for 81.7% of the variance among the samples. Firmness and chewiness were chosen to represent the first component and stickiness was chosen to represent the second component. Equations to predict these three attributes from instrumental measurements were derived using multiple regression analysis. Good predictability was found for sensory firmness using either Instron shear force and compression energy or GRL CQP score. Good predictability was also found for perceived chewiness using either Instron shear force or GRL tenderness index. Predictability of sensory stickiness was derived from Instron measures of compression energy, stickiness, and strand stickiness and from GRL measures of recovery and stickiness. These equations had lower coefficient of determinations however, than those obtained for equations for perceived firmness and chewiness. Nevertheless, a relationship was established between sensory stickiness and instrumental measures of texture.

This study has validated instrumental measures of estimating perceived sensory quality of cooked spaghetti. Clearly, much work remains to refine instrumental procedures of estimating perceived stickiness. Simpler and more accurate methods are required.

CHAPTER 5

TEXTURAL OPTIMIZATION OF SPAGHETTI USING RESPONSE SURFACE METHODOLOGY: EFFECTS OF PROTEIN LEVEL AND DRYING TEMPERATURE

5.1 INTRODUCTION

The basis of a good cooking quality durum wheat is one in which the protein forms an insoluble network entrapping swollen and gelatinized starch granules (Feillet, 1984). This prevents spaghetti surface disruption and consequent leaching of carbohydrates and proteins into the cooking water. Both protein quantity and quality are considered to be important factors influencing pasta cooking quality.

Matveef (1966) has shown that a durum wheat protein content above 13% yields a satisfactory final product whereas a protein content lower than 11% gave a poor product. Spaghetti cooking quality has been shown to improve as protein content increases (Matsuo et al., 1972; Dexter and Matsuo, 1977; Grzybowski and Donnelly, 1979; Autran et al., 1986). Protein quality, as measured by gluten properties has also been shown to influence the cooking quality of spaghetti (Matveef, 1966; Sheu et al., 1967; Matsuo and Irvine, 1970; Matsuo et al., 1972; Dexter and Matsuo, 1977; Grzybowski and Donnelly, 1979). Feillet et al. (1977) demonstrated that strong gluten varieties with high elastic recovery, exhibit good cooking quality while weak gluten varieties with low elastic recovery have poorer quality.

Recent innovations in pasta drying technology have resulted in the use of high temperature (HT) and very high temperature (VHT) drying lines. HT drying refers to temperatures between 60° and 90° C (Manser, 1980) whereas VHT drying refers to temperatures greater than 90° C. Low temperature (LT) or conventional drying refers to the use of temperatures no higher than 60° C (Dalbon and Oehler, 1983). Reported benefits of HT/VHT drying include: reduced drying times, improved microbiological quality and enhanced cooking quality. According to Manser (1980) pasta dried under high temperatures are firmer and less sticky. HT can be applied at the start of the drying cycle or following initial pre-drying using LT conditions. The first method has not proven effective in enhancing pasta cooking quality (Dexter et al., 1981a; Taha and Sagi, 1988). Manser (1980) has speculated that the poorer cooking quality of spaghetti dried initially at HT may be due to premature denaturation of gluten and possibly some starch gelatinization. The second method appears to yield pasta with improved cooking quality (Manser, 1980; Dexter et al., 1981b and 1984; Wyland and D'Appolonia, 1982). Resmini and Pagani (1983) and Abecassis et al. (1989) have reported that the best cooking quality is achieved with a drying cycle that applies HT after first achieving a low moisture content using LT drying conditions. The ability to produce pasta with good cooking quality by the use of HT drying has caused a number of workers to question the need for using high quality raw materials in the production of pasta. That is, it may be possible to produce pasta with good cooking quality utilizing lower protein durum wheat. Studies by Dexter et al. (1981b and

1983b) provide some evidence to support this suggestion. Cooking losses of low protein semolina were greatly reduced with HT drying compared to high protein semolina (Dexter et al. 1981b) although this was less obvious in a later study by the same authors (Dexter et al., 1983b). Examination of stickiness data revealed only one of the two varieties of durum tested at both a high and low protein content had improved surface characteristics when processed at HT. The other variety showed no improvement at either protein level when processed at HT. Recovery only improved at HT for the higher protein samples and firmness actually decreased for the low protein samples processed at HT. Clearly, more work needs to be done to assess the relationship of spaghetti drying temperature and semolina protein level on the cooking quality of spaghetti. It would be of great interest to determine which combinations of drying temperatures and protein levels yield optimum spaghetti. Thus, the objectives of this study were:

1. To examine the effects of spaghetti drying temperature and durum semolina protein levels on cooked spaghetti quality characteristics.
2. To explore the relationship between spaghetti drying temperature and durum semolina protein level on cooking quality of optimally cooked and overcooked spaghetti using response surface methodology.

3. To generate contour plots from the fitted models in order to determine which combinations of drying temperatures and protein levels yield spaghetti with optimum cooking quality.

5.2 MATERIALS AND METHODS

5.2.1 Selection and Analysis of Plant Material

Harvest survey samples of durum wheat from the 1988 crop, qualifying for No. 1 CWAD (Canadian Western Amber Durum) grade, were screened initially for protein content using near-infrared reflectance (NIR) spectroscopy (Automated Digital Analyzer, Neotec, Silver Springs, MD). Based on these findings, samples were segregated into seven protein levels ranging from 12 to 18%. The composite samples were then analyzed for protein content by the standard Kjeldahl method as modified by Williams (1973) for confirmation. To ensure composite samples had similar varietal composition, 100 kernels of each samples were examined by acidic polyacrylamide gel electrophoresis following the method of Tkachuk and Mellish (1980).

Ash content of wheat samples were determined using 4 g samples. Samples were placed in silica dishes and incinerated overnight at 600° C. After cooling, the dishes and ash were weighed, the ash brushed out, the dishes reweighed, and the weight of ash determined by difference.

Alpha-amylase levels in the wheat were examined to determine the presence of sprout damage. High amylolytic activity in spaghetti has been shown to increase the amount of residue in the cooking water, increase the level of reducing sugars in both semolina and spaghetti and has a tendency to give a slightly softer cooked spaghetti (Matsuo et al., 1982b). Levels were determined using the method of Kruger and Tipples (1981).

Gluten strength was estimated in duplicate by the sodium dodecyl sulfate (SDS) sedimentation test as described by Axford et al. (1979), except that a 3% solution of SDS was used.

Determinations of protein, ash, alpha-amylase and SDS sedimentation values were performed in duplicate on the seven wheat samples.

5.2.2 Milling and Assessment of Semolina Quality

Wheat samples were cleaned, scoured and tempered overnight to 16.5% moisture. The millroom was controlled for temperature (22° C) and humidity (RH 60%). Samples were milled using a modified Allis-Chalmers procedure as described by Matsuo and Dexter (1980). Semolina yields of 65% were obtained.

Semolina protein and ash content were determined in duplicate as previously described. Wet gluten content of semolina samples was determined in duplicate using the Glutomatic system according to ICC Standard Method No. 137 (1982).

5.2.3 Spaghetti Processing and Drying

Spaghetti was processed by the micro spaghetti-making procedure of Matsuo et al. (1972). Samples were dried using five temperature conditions (40°, 60°, 70°, 80°, 90° C) modelled after commercial drying cycles. A modified Blue M FR-381C environment chamber (Blue M Electric Co., Blue Island, IL) as described by Dexter et al. (1981b) was used for drying the spaghetti.

5.2.4 Experimental Design

The experimental design selected was a two way treatment structure (protein level and drying temperature) in a randomized complete block design with replications serving as the blocks. Two processing replications were completed.

5.2.5 Assessment of Cooked Spaghetti Quality

Spaghetti samples were cooked to optimum (defined as the time when the centre core disappears) and to optimum plus 10 minutes (a measurement of tolerance to overcooking) in prepared water as described in Chapter 2.

Predicted cooking loss values were determined from iodine absorbance values measured at 650 nm following the method developed by Matsuo et al. (1990). Absorbance values were determined in duplicate for a total of four determinations.

Firmness, compressibility, elasticity, and strand stickiness were measured using the Instron following the procedures described in Chapters 3 and 4 except SI units of measurement were used. Thus, a compression force of 8 N was used for compression and relaxation studies and a compression force of 0.5 N was used for studies on strand stickiness. Due to sample size limitations, both measurements of Instron stickiness could not be performed. It was decided to pursue the method of strand stickiness even though it showed less predictive ability than the other stickiness test. It was felt that this method may have merit as a technique for assessing strand stickiness and rather than abandon it at this juncture we wished to work with the method further. Duplicate measurements of two subsamples per replication were completed for firmness, compression and relaxation for a total of eight determinations. Duplicate measurements per replication were completed for strand stickiness for a total of four determinations.

Thirty-five treatment combinations (7 protein levels x 5 drying temperatures) were processed and evaluated in each replication for a total of 70 samples. Because this was excessive in terms of the number of samples to cook, only 15 treatment combinations were submitted to overcooking using the following selection procedure:

	P1	P2	P3	P4	P5	P6	P7
90°				*			
80°		*	*	*	*	*	
70°	*			*			*
60°		*	*	*	*	*	
40°				*			

* sample selected for overcooking

Thus, 70 samples were cooked to optimum and 30 were over-cooked.

5.2.6 Statistical Analysis of Data

Analysis of variance was performed on the optimally cooked data to determine the significant effects of protein level and drying temperature on physical measurements (SAS, 1988). Means of all determinations within a cooking replication were analyzed since the effects of possible differences in sub-sampling was not of interest. Protein level and drying temperature were considered to be fixed effects and replications to be a random effect. Duncan's multiple range test was used to determine significant differences among protein levels and among drying temperatures.

Optimally cooked and overcooked data were analyzed using the RSEG procedure of Statistical Analysis System (SAS, 1988) to fit second order polynomial equations to all response variables. Lack of fit tests were performed on the fitted models. Coefficients for the linear, quadratic, and interaction terms of each polynomial were calculated and tested for difference from zero. Response surface two-dimensional and three-dimensional contour plots were generated from the fitted models using the GCONTOUR and G3D procedures (SAS, 1988).

5.3 RESULTS AND DISCUSSION

5.3.1 Wheat and Semolina Characteristics

Wheat and semolina characteristics are provided in Table 5.1. Wheat protein levels ranged from 11.8 - 18.3% with semolina protein levels ranging from 10.7 - 17.3%. According to Irvine (1971), semolina with protein levels of 11.5 to 13.0% process with little difficulty and can be expected to give satisfactory results. Lower protein semolinas can produce pasta with poor mechanical strength in the dried product and lower cooking stability and cooked firmness (Grzybowski and Donnelly, 1979). Too high a protein levels may result in products that stretch excessively upon extrusion (Irvine, 1971).

Ash levels for wheat ranged from 1.52 to 1.8% and for semolina from 0.62 to 0.78% (Table 5.1). Ash levels in commercial durum semolina (of about 65% extraction rate) generally range from 0.55 to 0.75% (14% moisture basis) (Irvine, 1971). Thus, the ash levels of the semolina samples used in this study, conform with reported ash levels in commercial durum semolina.

Alpha-amylase levels ranged from 1.9 to 11.9 mg malt/min/gm x 10^{-3} indicating low amylolytic activity. The levels exhibited normal variation and were not considered a factor in the differences in cooking quality observed between the samples.

TABLE 5.1 Wheat and Semolina Quality Characteristics of Composite Samples

Quality Parameter	% Wheat Protein Level Designation						
	12	13	14	15	16	17	18
Wheat							
Protein (%)*	11.80	13.20	14.30	15.10	16.50	17.00	18.30
Ash (%)	1.58	1.56	1.55	1.52	1.63	1.67	1.80
SDS Sedimentation (mL)	33.50	37.00	40.50	42.50	43.00	42.50	44.50
α-Amylase (mg malt/min/gm x 10-3)	1.90	2.60	4.30	4.80	3.60	5.70	11.90
Semolina							
Protein (%)**	10.70	12.10	13.00	13.70	14.90	16.20	17.30
Ash (%)	0.64	0.66	0.65	0.62	0.64	0.72	0.78
Wet Gluten (%)**	31.20	33.30	36.60	39.50	41.40	45.70	48.50

*13.5% moisture basis, N x 5.7
**14.0% moisture basis

Not surprising, SDS sedimentation values (a measure of wheat gluten strength) and wet gluten content increased with increasing protein levels. Thus, as protein level increased, gluten strength increased and higher levels of gluten were found. Gluten properties have been identified as an essential factor of cooking quality (Matveef, 1966; Sheu et al., 1967; Matsuo and Irvine, 1970). Dexter and Matsuo (1977) reported that gluten characteristics improved with increasing protein content. Matsuo et al. (1982a) were unable to confirm that protein content significantly affected gluten quality. Similarly, Autran et al. (1986) found gluten characteristics were independent of protein content. Results of this study clearly show a relationship between protein content and gluten characteristics as measured by SDS sedimentation and wet gluten content.

Varietal composition of the seven composite samples is provided in Table 5.2. In particular, we were concerned about the level of Wascana in the samples since this variety has been shown to contain gliadin band 42 associated with weak gluten. A range of 11-19% Wascana was found which was not considered a large enough difference to influence the results. All other durum varieties identified in the samples contained gliadin band 45 associated with strong gluten. Thus, it was felt that the observed differences in varietal composition were not a factor in the results obtained.

TABLE 5.2 Varietal Comparison[1] of Wheat Samples

Variety	% Wheat Protein Level Designation						
	12	13	14	15	16	17	18
	Proportion of Variety, %						
Wascana	11	17	19	16	11	18	15
Wakooma A or Kyle[2]	37	39	34	13	36	48	43
Wakooma B	16	15	6	32	10	10	40
Medora	26	19	24	31	35	18	1
Macoun	-	2	-	2	-	-	-
Pelissier	1	2	8	3	6	1	-
Arcola	-	4	3	-	-	-	-
Coulter	9	2	6	3	1	5	-
Non-Durum	-	-	-	-	1	-	-

[1]Based on electrophoretic analysis of 100 kernels.
[2]indistinguishable by electrophoresis.

5.3.2 Drying Cycles

Drying temperature and spaghetti moisture profiles for each of the five drying cycles are provided in Figures 5.1-5.5. Compared to the conventional low temperature (40° C) drying cycle (Figure 5.1), all of the high temperature cycles (Figures 5.2-5.5) resulted in more rapid loss of moisture from the spaghetti during the earlier stages of drying. The moisture content of the spaghetti at the end of each cycle was about 12%, but upon equilibration at room conditions moisture decreased to about 9%.

In the 40° C drying cycle (Figure 5.1), spaghetti was dried over a 16 hour period with a controlled decrease in relative humidity. Temperature was maintained at 40° C for the entire 16 hour period, before equilibration to room conditions.

The 60° and 70° C cycles (Figures 5.2 and 5.3), featured an initial 10 hour exposure to the high temperature followed by a decrease in temperature to 40° C where it was held for 6 hours before equilibration to room conditions. The 80° and 90° C cycles (Figures 5.4 and 5.5), featured a short initial exposure to the high temperature followed by a decrease in temperature to 70° C where it was held for several hours. This was followed by a decrease in temperature to 40° C and stabilization.

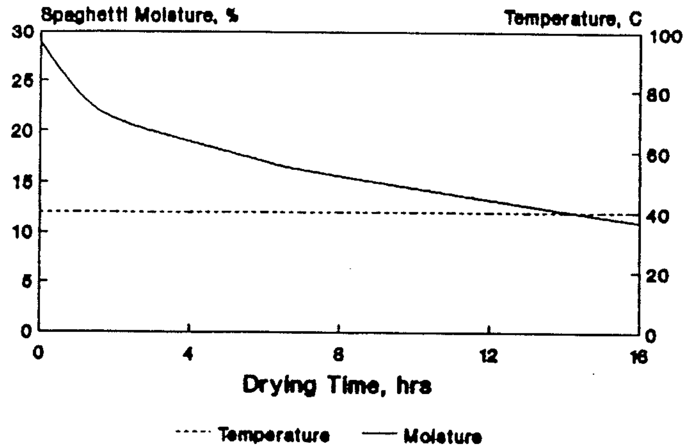


Figure 5.1 Dryer Temperature and Rate of Moisture Loss in Spaghetti For 40° C Drying Cycle

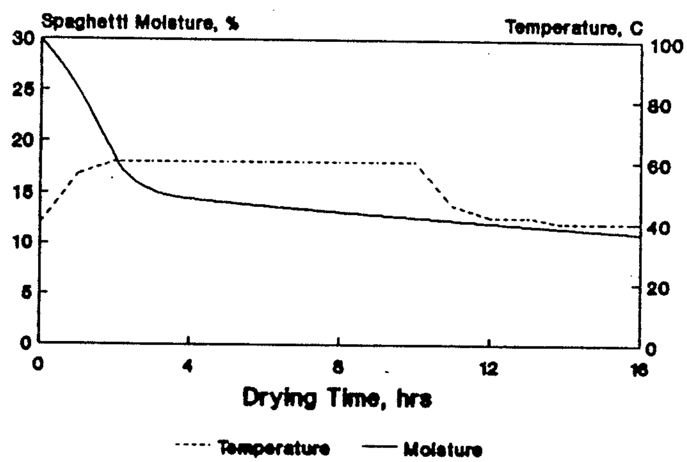


Figure 5.2 Dryer Temperature and Rate of Moisture Loss in Spaghetti For 60° C Drying Cycle

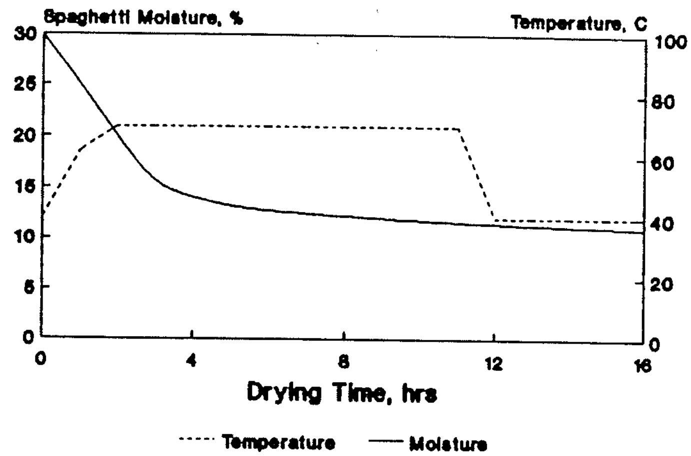


Figure 5.3 Dryer Temperature and Rate of Moisture Loss in Spaghetti For 70° C Drying Cycle

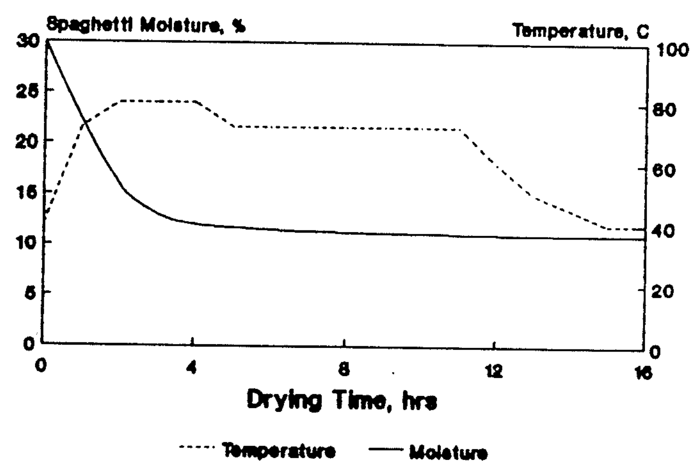


Figure 5.4 Dryer Temperature and Rate of Moisture Loss in Spaghetti For 80° C Drying Cycle

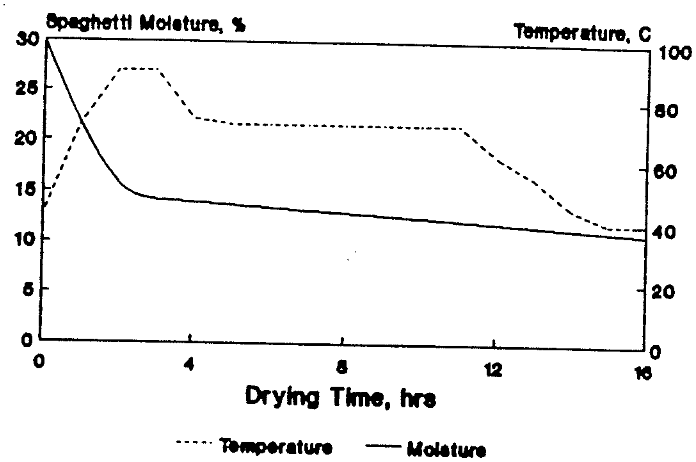


Figure 5.5 Dryer Temperature and Rate of Moisture Loss in Spaghetti For 90° C Drying Cycle

5.3.3 Quality of Optimally Cooked Spaghetti

Firmness, compression energy, relaxation time, cooking loss and strand stickiness were significantly affected by both protein content and drying temperature (Table 5.3). although surface stickiness was only significantly affected by drying temperature at $p<0.06$. Interestingly, no significant drying temperature by protein level interactions were observed for any of the quality parameters measured.

Spaghetti dried at 70° C was firmer than spaghetti dried at 40° and 80° (Figure 5.6A). Spaghetti firmness also increased with increasing protein level. All protein levels were significantly different from each other with the exception of the samples prepared from semolina containing 13.7 and 14.9% protein and samples prepared from semolina containing 13.0 and 13.7% protein.

All samples except spaghetti dried to 90° C had significantly lower compression energy (indicating higher quality) than spaghetti dried to 40° C (Figure 5.6B). Spaghetti dried to 70° C also had significantly lower compression energy values than spaghetti dried to 90° C. Compression energy also decreased with increasing protein. All protein levels had significantly lower compression energy values than spaghetti made from 10.7% semolina protein. As well, spaghetti made from the four highest protein levels had lower compression energy values than samples made from semolina containing 12.1 and 13.0% protein. Lastly, spaghetti

Table 5.3 Summary of Analysis of Variance

Variable	Source	df	Mean Square	F value
Firmness (Shear Force)	Replication	1	1.519	3.92
	D.Temp.(DT)	4	1.034	2.67c
	Protein Level (PL)	6	13.886	35.82a
	DT*PL	24	0.327	0.84
	Error	34	0.388	
Compression Energy	Replication	1	0.003	0.20
	D.Temp.(DT)	4	0.088	5.77a
	Protein Level (PL)	6	0.449	29.33a
	DT*PL	24	0.019	1.22
	Error	34	0.015	
Relaxation Time	Replication	1	65.089	5.90c
	D.Temp. (DT)	4	849.467	77.03a
	Protein Level (PL)	6	33.607	3.05c
	DT*PL	24	16.207	1.47
	Error	34	11.027	
Predicted Cooking Loss	Replication	1	0.223	4.34c
	D.Temp. (DT)	4	0.519	10.08a
	Protein Level (PL)	6	1.822	35.40a
	DT*PL	24	0.057	1.10
	Error	34	0.051	
Surface Stickiness	Replication	1	35.714	0.00
	D.Temp. (DT)	4	50408.571	2.57d
	Protein Level (PL)	6	56136.191	2.87c
	DT*PL	24	15101.071	0.77
	Error	34	19576.891	

a significant at p<0.001
b significant at p<0.01
c significant at p<0.05
d significant at p<0.06

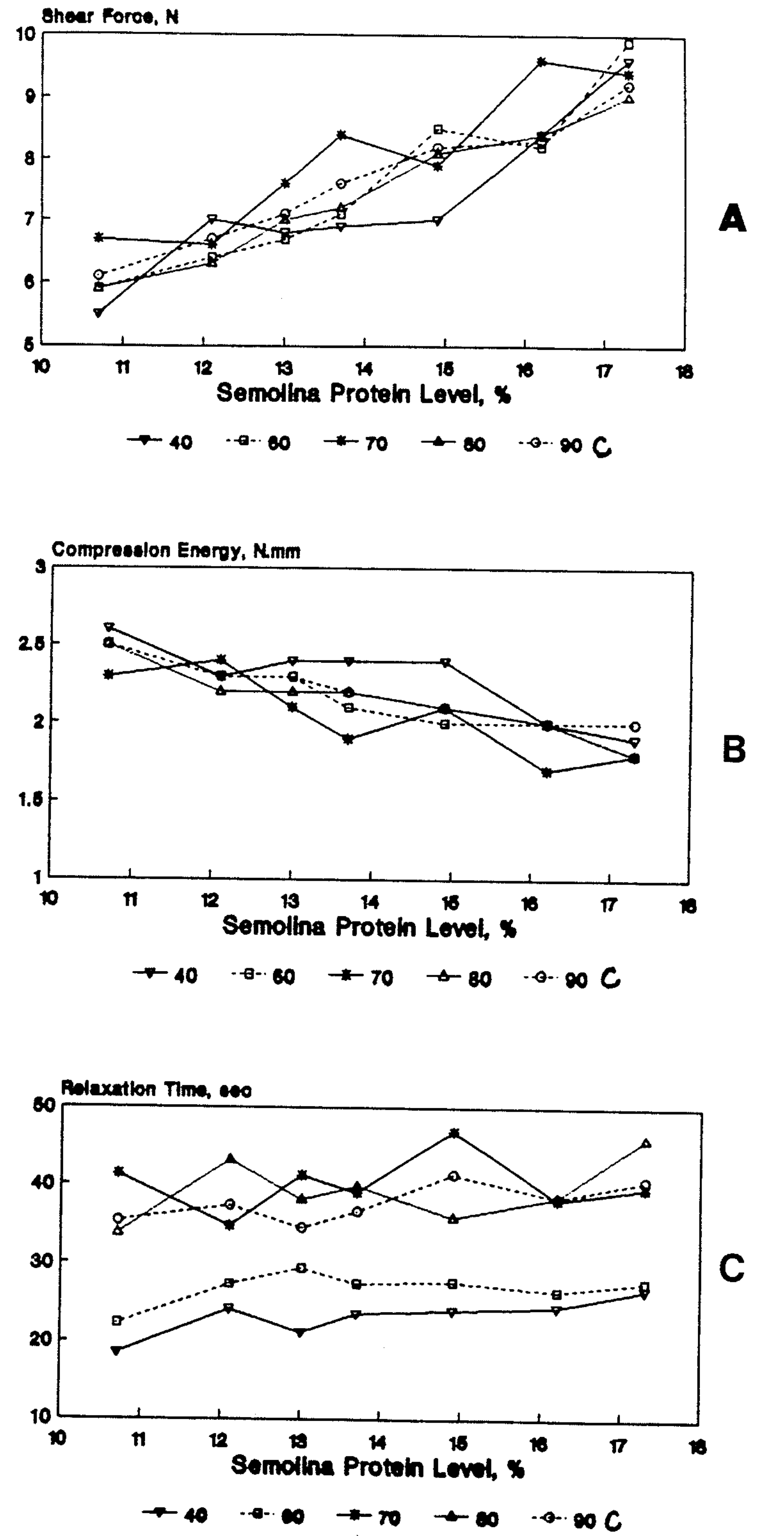


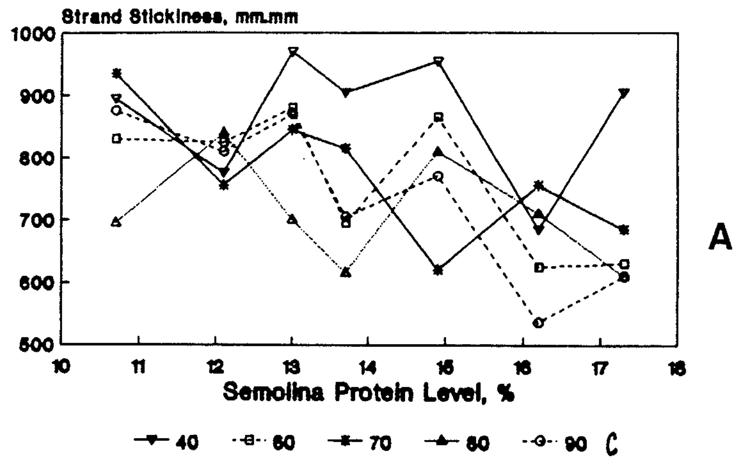
Figure 5.6 **Effects of Drying Temperature and Protein Level on Spaghetti Firmness, Compression Energy, and Relaxation Time**

made from the two highest protein levels also had significantly lower compression values than samples made from 13.7 and 14.9% protein.

Significantly higher relaxation times were found with the spaghetti dried at higher temperatures (Figure 5.6C). Spaghetti dried at 70°, 80°, and 90° C had higher relaxation times (in-dicating greater elasticity) than spaghetti dried at 40° and 60° C. The spaghetti dried at 60° C also had greater elasticity than the spaghetti cooked to 40° C. Spaghetti made from semolina containing 14.9 and 17.3% protein was more elastic than spaghetti made from semolina containing 10.7% protein.

Strand stickiness tended to decrease with increasing drying temperature (Figure 5.7A). Spaghetti dried at 40° C was stickier than spaghetti dried to 80° and 90° C. Strand stickiness also tended to decrease with increasing protein level. Spaghetti made from semolina containing 16.2 and 17.3% protein had lower strand stickiness than spaghetti made from 10.7 and 13.0% protein. Spaghetti made with 16.2% protein was also less sticky than spaghetti made from 12.1 and 14.9% protein.

Lower cooking losses were found for spaghetti dried at 70° and 80° C compared to the other drying temperatures (Figure 5.7B). However spaghetti dried at 90° C had the highest cooking losses of all drying cycles for all protein levels except 14 and 16%. Cooking losses also decreased with increasing protein levels. All protein levels were



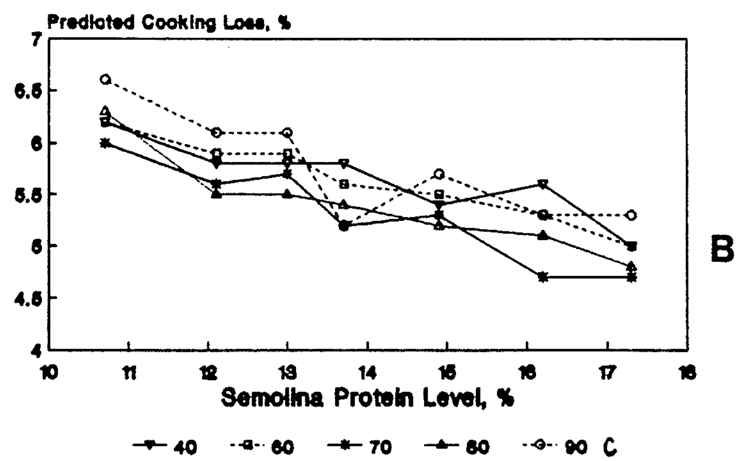


Figure 5.7 **Effects of Drying Temperature and Protein Level on Spaghetti Strand Stickiness and Cooking Loss**

significantly different from each other with the exception of the samples made from 13.7 and 14.9% protein and samples made from 12.1 and 13.0% protein.

Thus, this study confirmed that spaghetti cooking quality as measured by Instron firmness, compression energy, relaxation time, strand stickiness, and predicted cooking loss was found to improve with higher protein levels. Matveef (1966) showed that a wheat protein content above 13% yielded a satisfactory product while protein content lower than 11% gave a very poor product. The lowest wheat protein level used in this study was 12%. Spaghetti firmness, elasticity and surface characteristics have been shown to improve with increasing protein content (Matsuo et al., 1972; Dexter and Matsuo, 1977; Grzybowski and Donnelly, 1979; Autran et al.,1986). With higher protein levels the greater is the chance for proteins to interact to form an insoluble network due to the presence of higher number of polypeptide chains (Feillet, 1984).

In this study, a drying temperature of 70° C significantly improved spaghetti cooking quality compared to 40 and 60° C. However, drying temperatures greater than 70° C did not appear to improve spaghetti cooking quality. Similar findings have been reported by other researchers. Wyland and D'Appolonia (1982) found spaghetti dried at 60°, 70°, and 80° C were firmer than spaghetti dried at 40° C, but no differences in spaghetti firmness were observed among the three high drying temperatures. Dexter et al. (1984) only found significantly lower cooking losses for spaghetti dried at 70° C compared to spaghetti dried at 39° C. No further reduction in cooking loss was observed with spaghetti dried at 80° and 85° C. Abecassis et al. (1984) found color and cooking quality were superior with spaghetti dried at 70° and 90° C compared to 37° C but improvements in quality between 70° and 90° C were slight. Seibel et al. (1985) also reported marginal differences in cooking quality between spaghetti dried at 50° and 75° C. Studies by Manser (1983) led him to conclude that a tempera-ture of 68° C was optimum. The only parameter that may be influenced by drying temperatures greater than 70° C is stick-iness. In this study, stickiness decreased with higher drying temperatures confirming findings by Dexter et al. (1984).

5.3.4 Response Surface Analysis

In order to gain a better understanding of the relationship between protein level and drying temperature and their effects on cooked spaghetti quality, response surface methodology (RSM) was a applied to the data collected on optimally cooked and overcooked spaghetti.

The analysis of variance for the two response variables (drying temperature and protein level) for the quality parameters of firmness, compression energy, relaxation time, strand stickiness and cooking loss for optimally cooked and overcooked spaghetti are presented in Tables 5.4 and 5.5 respectively. Several criteria can be used to evaluate the adequacy of the fitted model. A test for lack of fit can be

Table 5.4 ANOVA For Evaluation of Models For Quality Parameters For Optimally Cooked Spaghetti

Variable	Source	df	Sum of Squares	F value
Firmness (Shear Force)	Model	5	84.749	42.977a
	Residual	64	25.241	
	Lack of Fit	29	10.536	0.865
	Pure Error	35	14.705	
R^2			0.77	
Coefficient of Variation (%)			8.3	
Model Significance			0.0001	
Compression Energy	Model	5	2.973	36.390a
	Residual	64	1.046	
	Lack of Fit	29	0.523	1.205
	Pure Error	35	0.523	
R^2			0.74	
Coefficient of Variation (%)			5.9	
Model Significance			0.0001	
Relaxation Time	Model	5	2774.937	21.481a
	Residual	64	1653.553	
	Lack of Fit	29	1213.538	3.329a
	Pure Error	35	440.016	
R^2			0.63	
Coefficient of Variation (%)			15.2	
Model Significance			0.0001	
Strand Stickiness	Model	5	455031.0	5.240a
	Residual	64	1111496.0	
	Lack of Fit	29	445846.0	0.808
	Pure Error	35	665650.0	
R^2			0.29	
Coefficient of Variation (%)			17.1	
Model Significance			0.0004	
Predicted Cooking Loss	Model	5	11.454	30.034a
	Residual	64	4.882	
	Lack of Fit	29	2.909	1.780
	Pure Error	35	1.973	
R^2			0.70	
Coefficient of Variation (%)			4.9	
Model Significance			0.0001	

a significant at $p<0.001$

Table 5.5 ANOVA For Evaluation of Models For Quality Parameters For Overcooked Spaghetti

Variable	Source	df	Sum of Squares	F value
Firmness (Shear Force)	Model	5	8.430	18.363a
	Residual	24	2.204	
	Lack of Fit	9	0.280	0.243
	Pure Error	15	1.924	
R^2			0.79	
Coefficient of Variation (%)			5.4	
Model Significance			0.0001	
Compression Energy	Model	5	0.600	16.489a
	Residual	24	0.175	
	Lack of Fit	9	0.021	0.230
	Pure Error	15	0.153	
R^2			0.78	
Coefficient of Variation (%)			2.9	
Model Significance			0.0001	
Relaxation Time	Model	5	575.616	15.770a
	Residual	24	175.209	
	Lack of Fit	9	100.115	2.222
	Pure Error	15	75.094	
R^2			0.77	
Coefficient of Variation (%)			10.7	
Model Significance			0.0001	
Strand Stickiness	Model	5	427099.0	1.848
	Residual	24	1109331.0	
	Lack of Fit	9	434381.0	1.073
	Pure Error	15	674950.0	
R^2			0.28	
Coefficient of Variation (%)			22.5	
Model Significance			0.1414	
Predicted Cooking Loss	Model	5	11.944	23.287a
	Residual	24	2.462	
	Lack of Fit	9	1.306	1.883
	Pure Error	15	1.156	
R^2			0.83	
Coefficient of Variation (%)			4.5	
Model Significance			0.0001	

a significant at $p<0.001$

used whereby a low F value indicates that the second-order model is an adequate approximation to the data (Morgan et al., 1989). Joglekar and May (1987) suggest that R^2 values, CV values and model signi-ficance be used to judge the adequacy of the model. R-square value is the proportion of variation in the response attributed to the model rather than to random error (Khuri and Cornell, 1987), CV value describes the amount of variation in a population relative to the mean, and model significance indicates the level of confidence that the selected model cannot be due to experimental error. Thus, according to these authors, for good fit of a model, R^2 values should be at least 80%, CV values should not exceed 10% and model significance should be at least $p<0.05$. The use of a R^2 value of 80% appeared to be excessively high for a preliminary study of this nature (Balshaw, 1990), so a value of 60% was used instead of the 80% suggested by Joglekar and May (1987).

The models developed for the quality parameters of firm-ness, compression, and cooking loss for optimally cooked and overcooked spaghetti and for relaxation time for overcooked spaghetti were considered highly adequate since they possessed no significant lack of fit and had satisfactory levels of R^2, CV and model significance (Tables 5.4 and Table 5.5).

The predictive model for relaxation time for optimally cooked spaghetti was less predictive since the CV value was slightly higher than 10% and showed a significant lack of fit (Table 5.4). A better estimate of the second-order model can be obtained using the experimental error mean square rather than the residual mean square to calculate estimated variance of individual coefficients (Gacula and Singh, 1984). This however was beyond the capability of the statistical program utilized in this study. Nevertheless, satisfactory levels of model significance and R^2 value were obtained for this parameter suggesting that the predictive model merits examination.

Models developed for strand stickiness were judged to be inadequate due to very low R^2 values, and high CV values suggesting high variability rather than model inadequacy since lack of fit tests were not significant. Test procedures, or variability among the spaghetti strands themselves, could account for the observed variability. The selected model for overcooked spaghetti was also not significant for this parameter (Table 5.5).

The regression coefficients for the fitted models for all quality parameters except strand stickiness are presented in Table 5.6. Values for strand stickiness are not provided since models were judged inadequate. The regression coefficients represent the unit change in the dependent variable (Yi) per unit change in the independent variable (Xi), while all other regressors remain constant (Wonnacott and Wonnacott, 1982). The sign preceding the coefficient indicates the direction in which to change the variables to improve the response. The size of the coefficients denotes the relative importance of

Table 5.6 Values of the Regression Coefficients of the Second Order Polynomials*

Coefficient	Optimally Cooked Spaghetti Firmness	Compression	Relaxation	Predicted Cooking Loss
b_o	1.9136	4.3726	-35.0065	11.2845
Linear				
b_1	0.0891	-0.0388	1.0589	-0.0417
b_2	-0.1974	-0.0265	2.4744	-0.4144
Quadratic				
b_{11}	-0.0004	0.0002	-0.0054	0.0004
b_{22}	0.0286	-0.0036	-0.0576	0.0096
Interaction				
b_{21}	-0.0017	0.0006	-0.0009	-0.0009

Coefficient	Overcooked Spaghetti Firmness	Compression	Relaxation	Predicted Cooking Loss
b_o	13.1617	2.9431	-1.1480	41.8547
Linear				
b_1	-0.0848	-0.0329	0.9617	-0.3771
b_2	-1.0041	0.2448	-3.9990	-2.4828
Quadratic				
b_{11}	0.0003	0.0001	-0.0012	0.0004
b_{22}	0.0345	-0.0127	0.2883	0.0237
Interaction				
b_{21}	0.0040	0.0008	-0.0384	0.0204

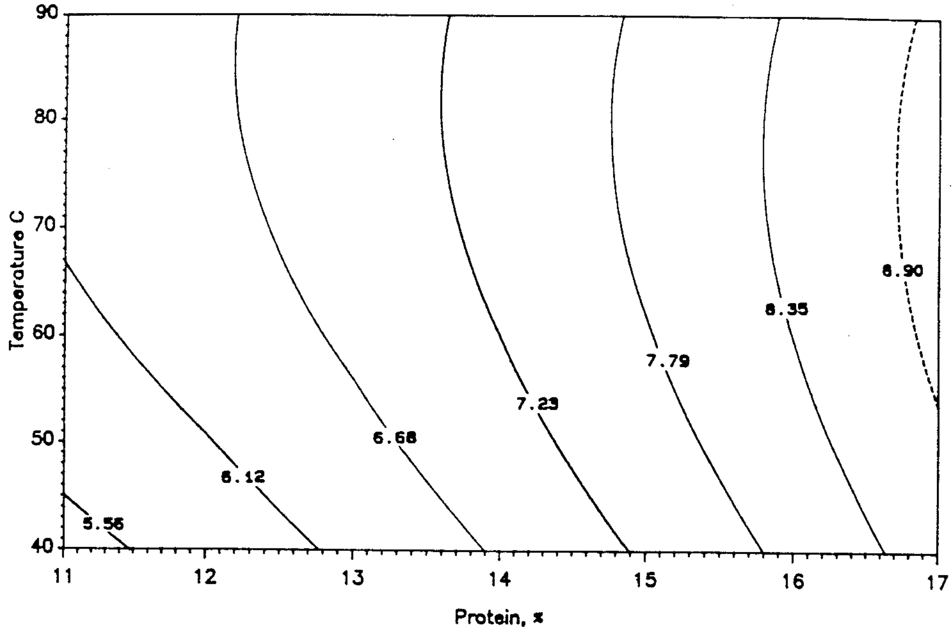
* $Y_i = b_o + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$

the independent variable to the prediction of the dependent variable.

In order to visualize the combined effects of the two independent variables on the dependent responses of quality, two-dimensional and three-dimensional contour plots were generated for each of the fitted models.

The contour plots for firmness of optimally cooked spaghetti are presented in Figure 5.8. Firmness was affected mainly by protein level and to a small degree by drying temperature. Spaghetti firmness increased with increasing semolina protein level and to a modest extent by higher drying temperatures. The area of maximum response was defined by the highest protein level and drying temperatures greater than 55° C. Similar findings were observed for spaghetti that was overcooked (Figure 5.9). The region of optimized response was localized in the corner defined by high levels of protein and high drying temperatures.

Figures 5.10 and 5.11 are contour plots of compression energy as a function of protein level and drying temperature for optimally cooked and overcooked spaghetti respectively. Similar to firmness, lower compression energy values (indicating superior cooking quality) were achieved in the direction of higher protein levels and higher drying temperatures. For optimally cooked spaghetti the area of minimal response was achieved at the highest protein level and drying temperatures greater than 55° C. The region of



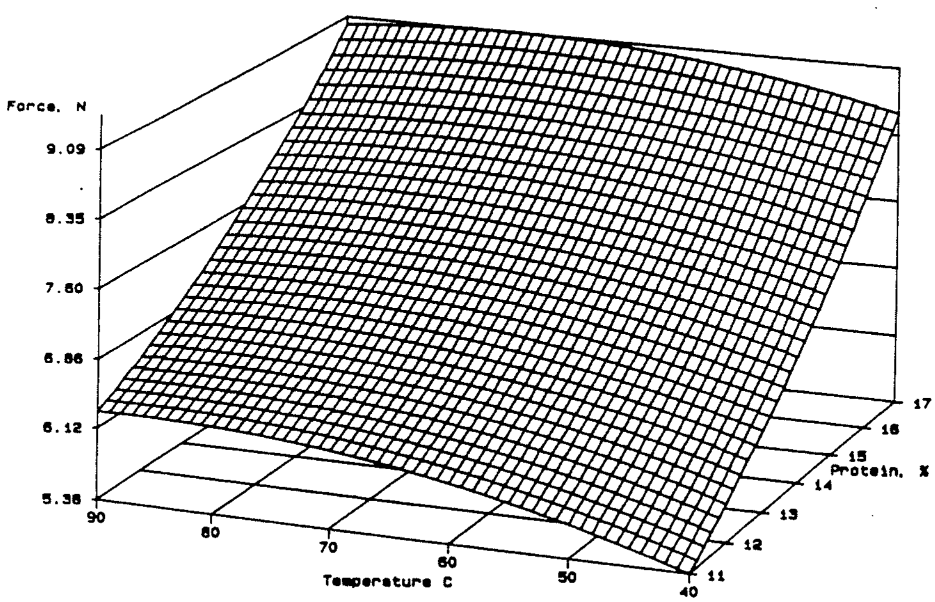


Figure 5.8 **Two and Three-Dimensional Response Surface Plots of Firmness of Optimally Cooked Spaghetti as a Function of Protein Level and Drying Temperature**

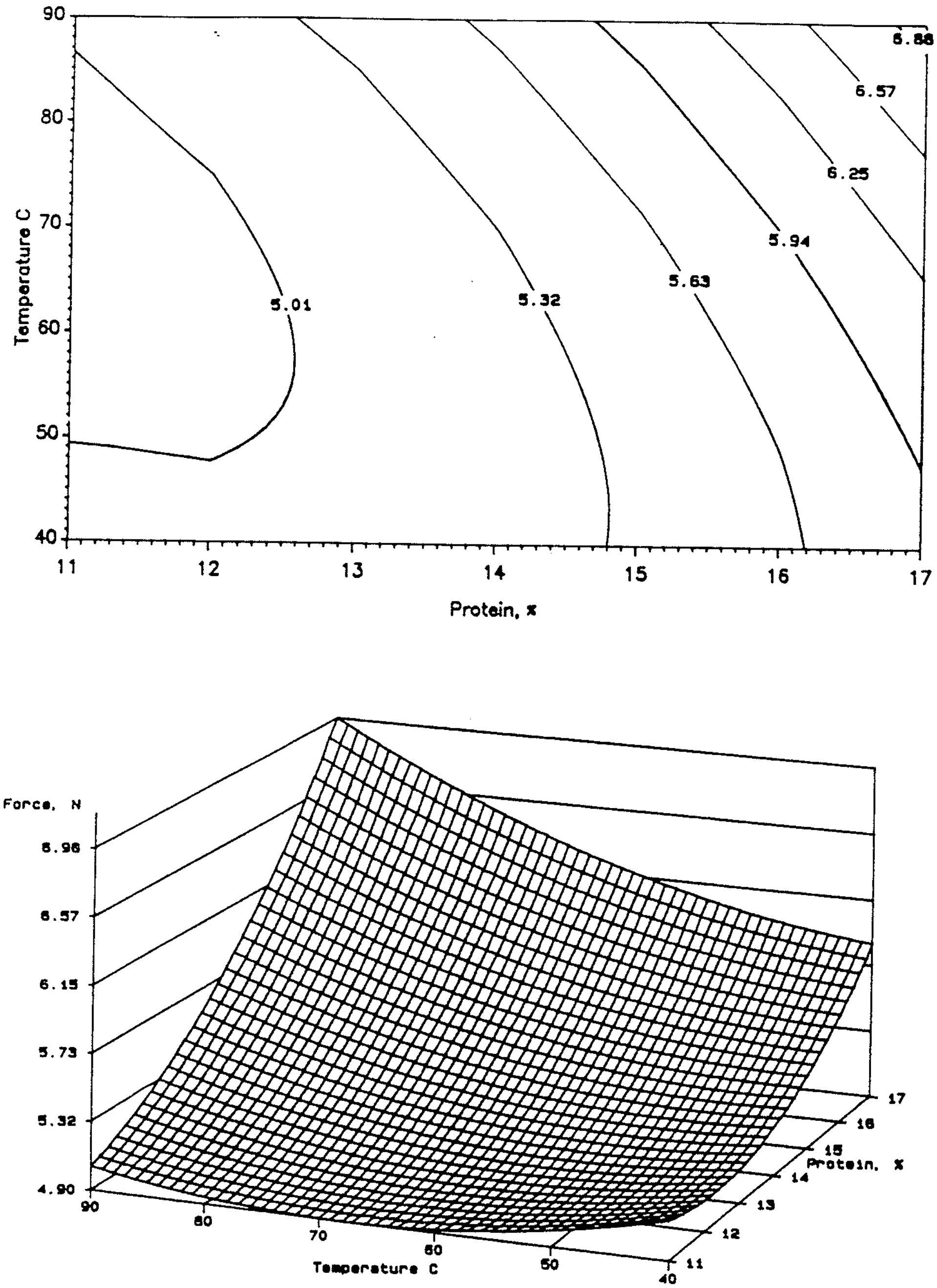


Figure 5.9 **Two and Three-Dimensional Response Surface Plots of Firmness of Overcooked Spaghetti as a Function of Protein Level and Drying Temperature**

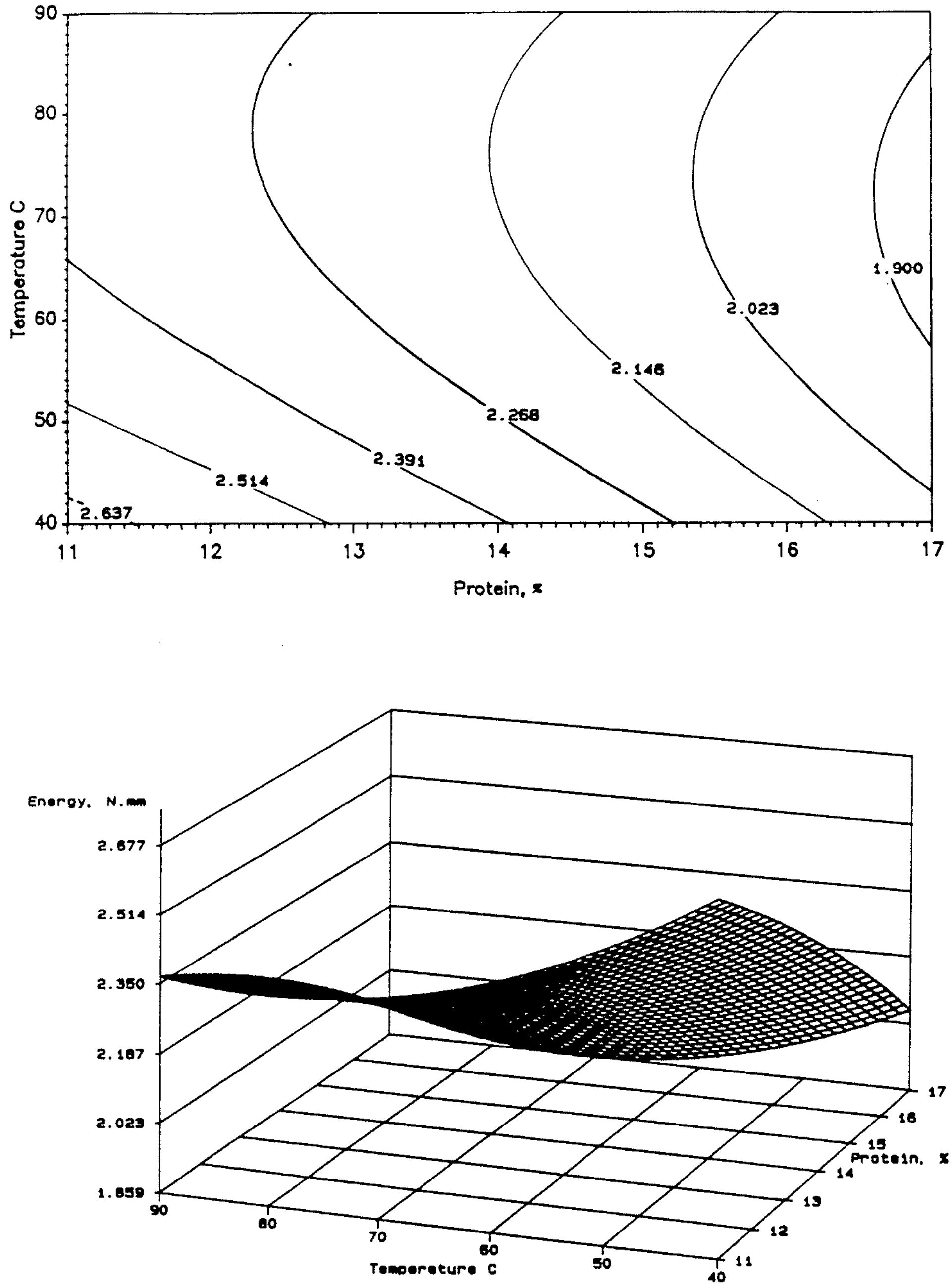
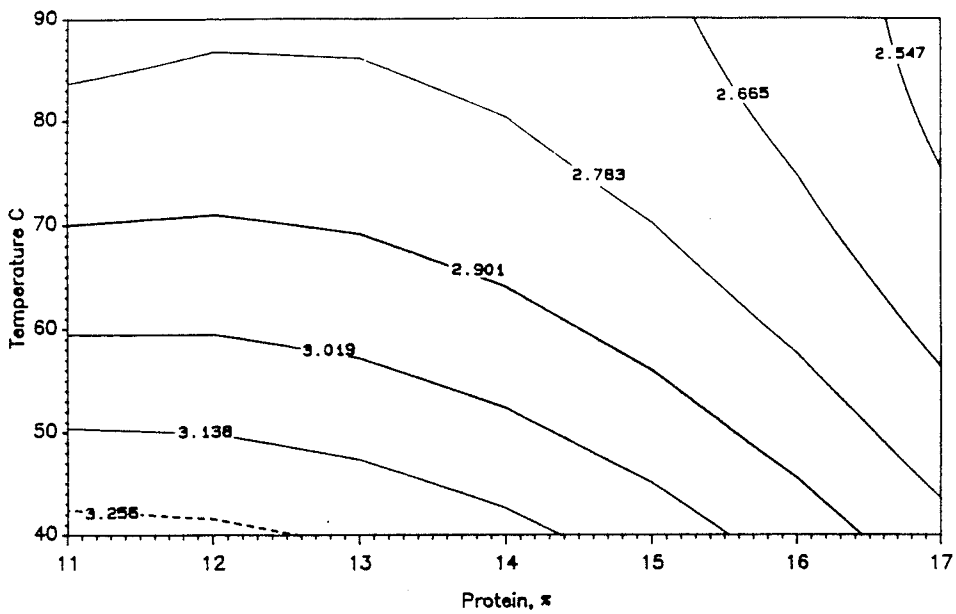


Figure 5.10 Two and Three-Dimensional Response Surface Plots of Compression Energy of Optimally Cooked Spaghetti as a Function of Protein Level and Drying Temperature



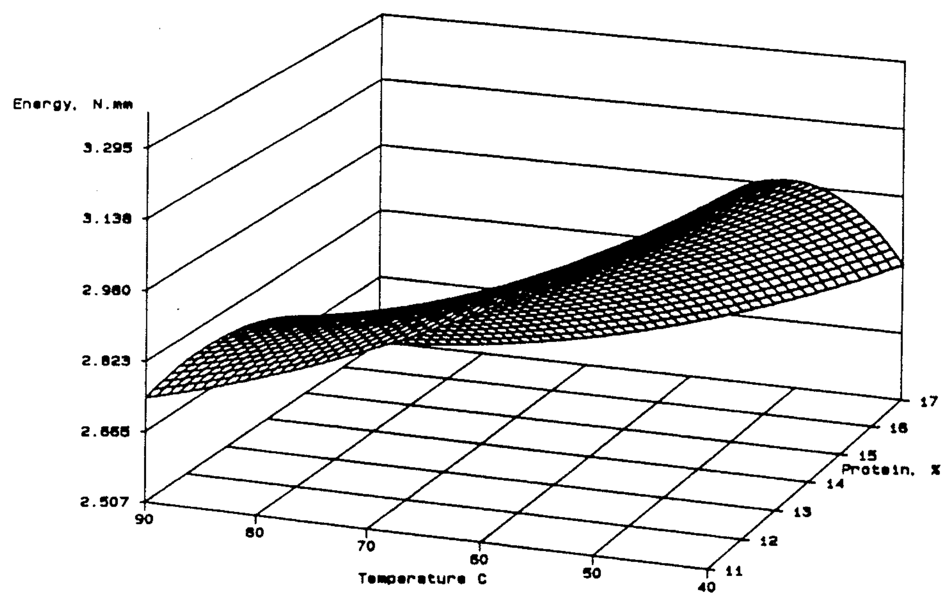


Figure 5.11 **Two and Three-Dimensional Response Surface Plots of Compression Energy of Overcooked Spaghetti as a Function of Protein Level and Drying Temperature**

optimized response for overcooked spaghetti was defined by the highest drying temperature and protein level.

Response surface plots for relaxation time of optimally cooked and overcooked spaghetti are presented in Figures 5.12 and 5.13. For both cooking times, a greater change in the surface contour is observed along the drying temperature axis than the protein level axis. Relaxation time increased with higher drying temperature. The area of maximum response for both cooking times is defined by the highest drying temperatures and to a lesser extent by the higher protein levels.

Contour plots for cooking loss values for optimally cooked spaghetti showed that cooking loss was less sensitive to changes in drying temperature than to changes in protein level (Figure 5.14). The area of optimum response for cooking loss was defined by the highest protein level and drying temperatures between 58° and 85° C. Response surface plots for overcooked spaghetti (Figure 5.15) show that cooking loss decreases in the direction of high drying temperature and to a lesser extent with protein level, although protein level exerts a greater effect on cooking loss values at low drying temperatures. The region of optimum response for cooking loss of overcooked spaghetti was localized in two areas. The first area was defined by the highest drying temperature and a wide range of protein levels. The second area of optimized response was unexpected as it was defined by the lowest drying temperature and a high protein level.

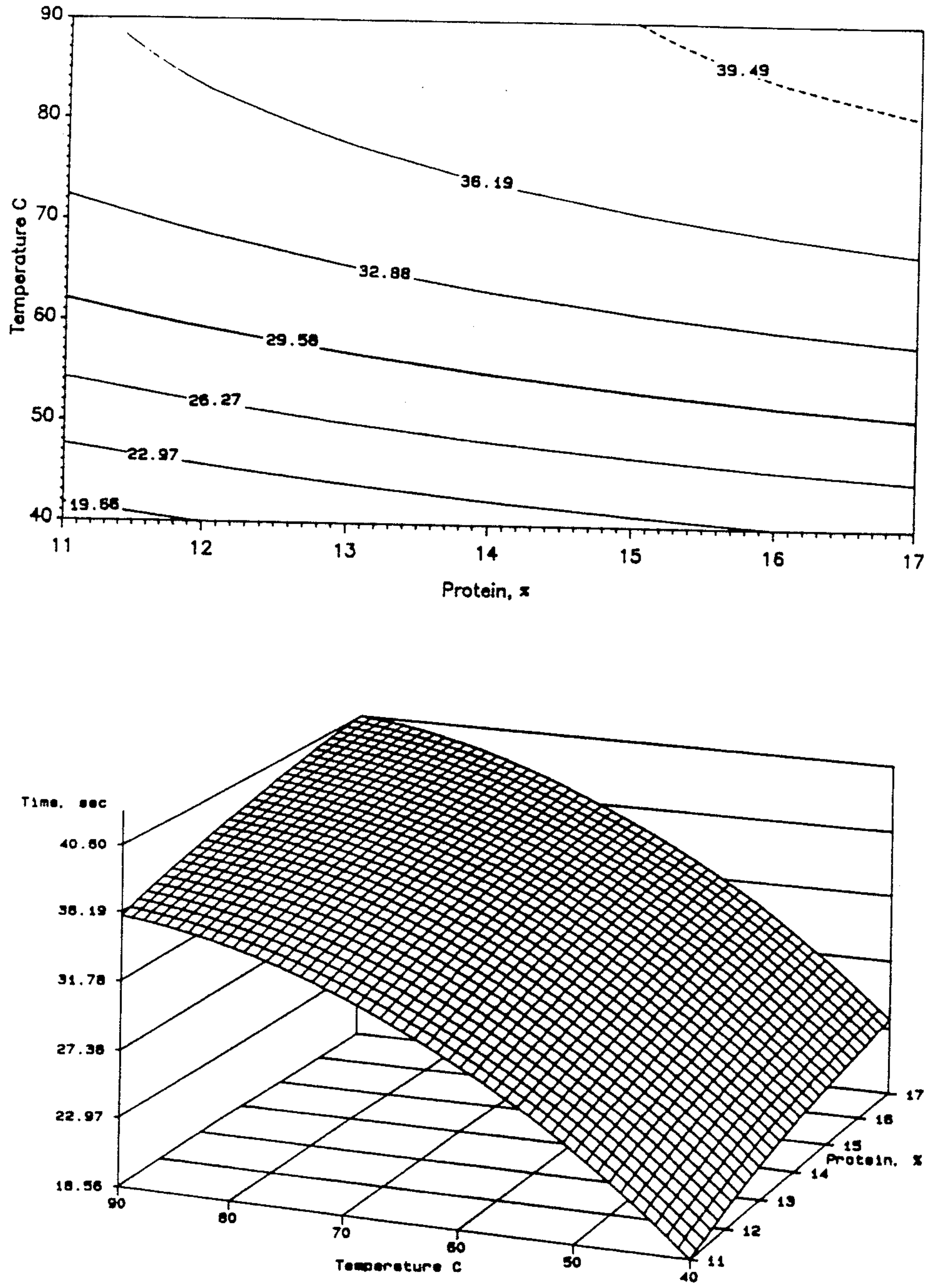


Figure 5.12 Two and Three-Dimensional Response Surface Plots of Relaxation Time of Optimally Cooked Spaghetti as a Function of Protein Level and Drying Temperature

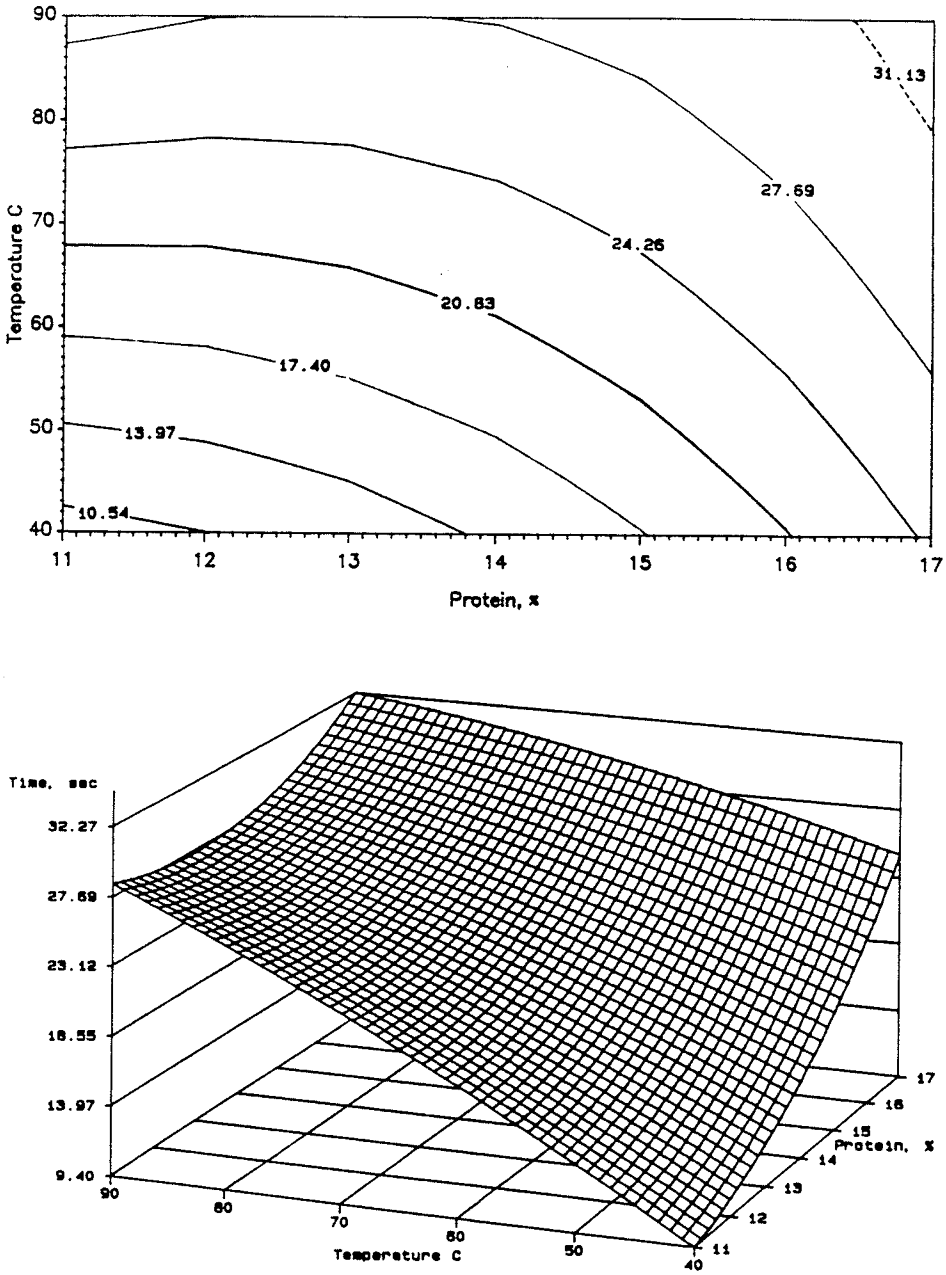
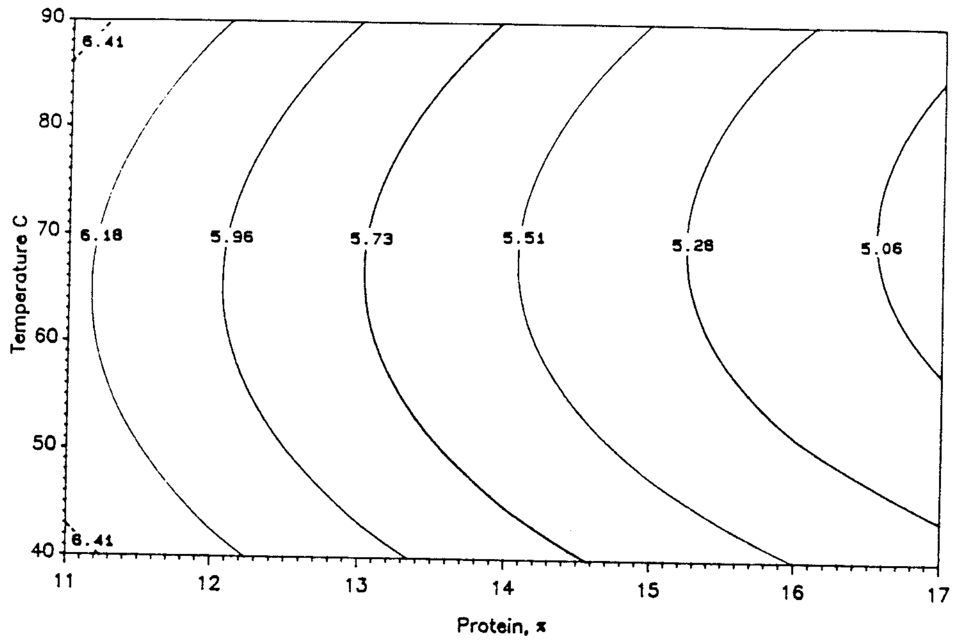


Figure 5.13 **Two and Three-Dimensional Response Surface Plots of Relaxation Time of Overcooked Spaghetti as a Function of Protein Level and Drying Temperature**



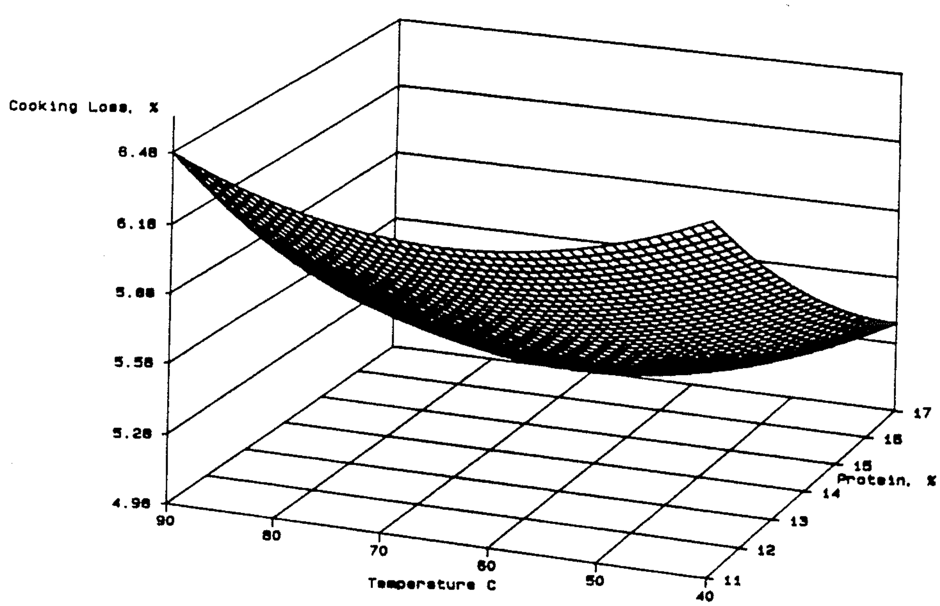
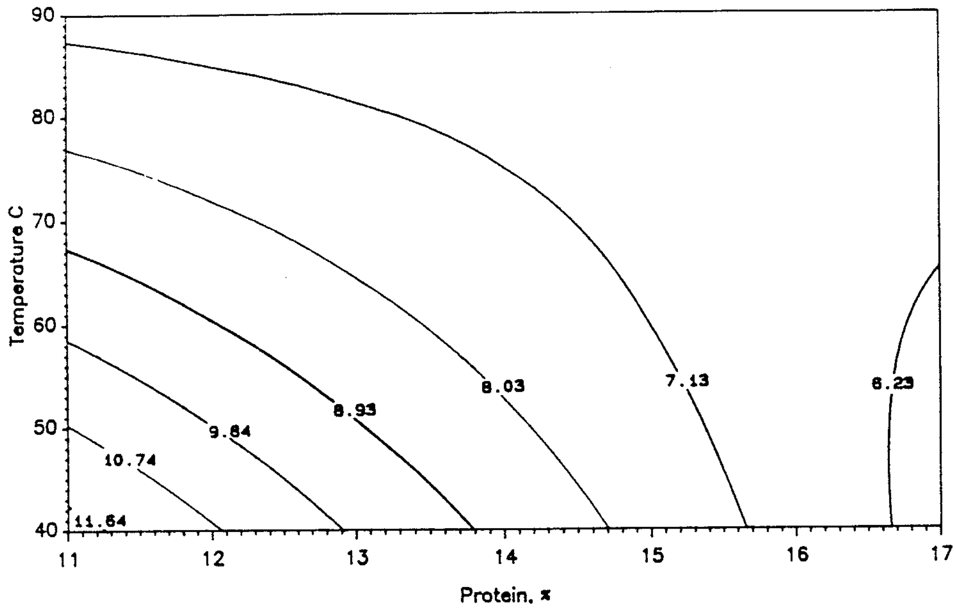


Figure 5.14 **Two and Three-Dimensional Response Surface Plots of Cooking Loss of Optimally Cooked Spaghetti as a Function of Protein Level and Drying Temperature**



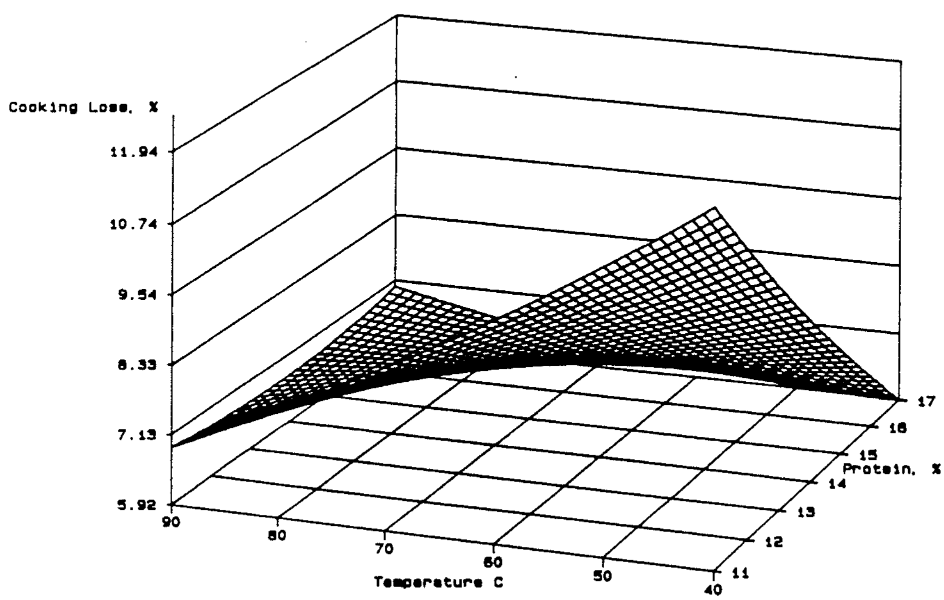


Figure 5.15 **Two and Three-Dimensional Response Surface Plots of Cooking Loss of Overcooked Spaghetti as a Function of Protein Level and Drying Temperature**

Thus, the predicted optimum responses for spaghetti firmness, compressibility, elasticity and cooking loss were generally produced with a combination of high protein levels and high drying temperatures, although in most cases, spaghetti quality was primarily affected by protein level and to a smaller extent by drying temperature. Values for commercial durum spaghetti samples are presented in Table 5.7. Experimental spaghetti samples generally met or exceeded these values for durum spaghetti. The only exception to this was for relaxation time for both optimally cooked and overcooked spaghetti and cooking loss for overcooked spaghetti. Individual two-dimensional contour plots for these responses were superimposed in order to locate drying temperatures and protein levels which met commercial durum spaghetti standards for these responses. The resulting multiple contour plot is provided in Figure 5.16. The shaded area represents the region where the quality of these quality characteristics are equal to or exceed commercial durum spaghetti limits for these parameters. Drying temperatures must exceed 60° C in order to achieve spaghetti with satisfactory quality as measured by the parameters tested in this study. At a protein level of 11%, a drying temperature greater than 60° C is required. At protein levels between 12 and 13%, a drying temperature of at least 55° is required whereas, at protein levels greater than 14%, a drying temperature greater than 50° C is recommended. Thus, as the level of durum protein increased, drying temperature was not as critical to the final quality of the cooked spaghetti.

Table 5.7 Cooking Quality Measurements of Commercial Durum Spaghetti

Quality Parameter	Commercial Range	
	Optimally Cooked	Overcooked
Firmness (N)	4.7-5.7	3.3-4.6
Compression Energy (N.mm)	2.0-2.4	2.7-3.4
Relaxation Time (sec)	25-45	15-24
Cooking Loss (%)	5.5-6.4	7.3-9.6

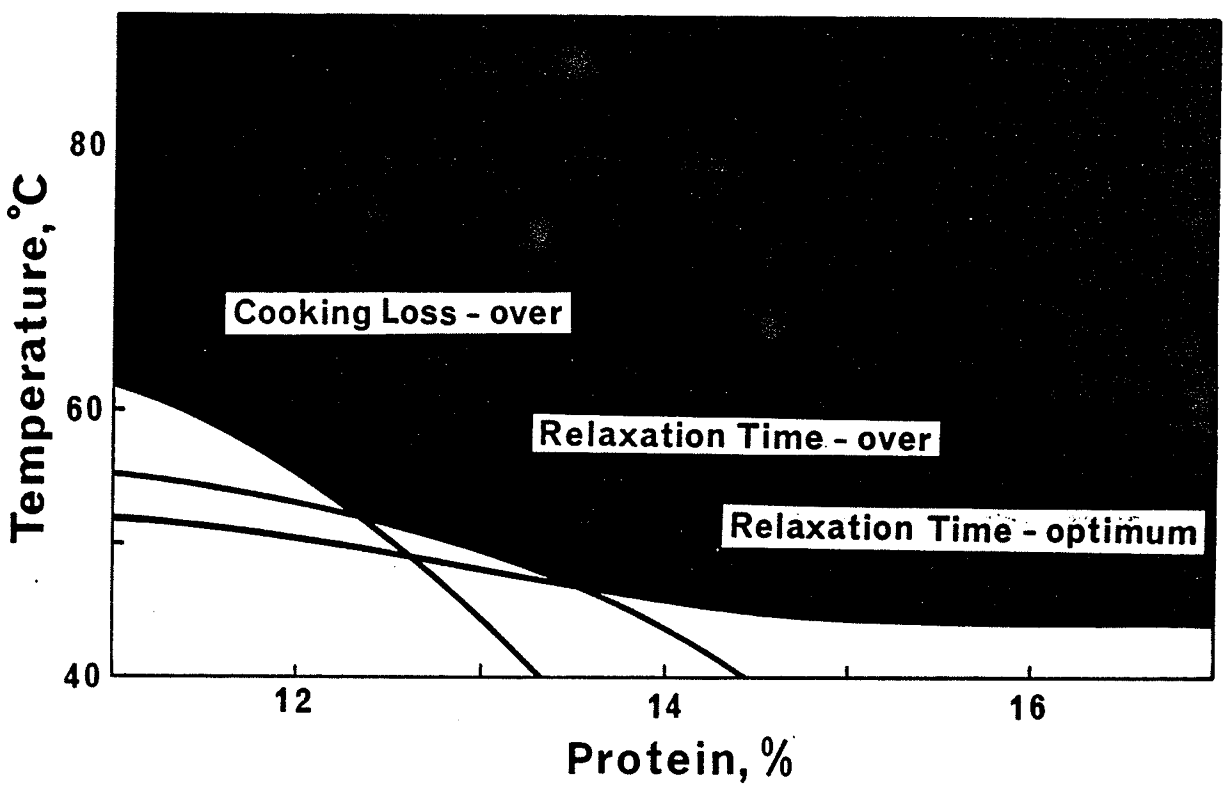


Figure 5.16 Multiple Contour Plot Showing the Region (Shaded) Meeting the Cooking Quality Characteristics of Commercial Durum Spaghetti Samples

5.4 CONCLUSIONS

Cooking quality of spaghetti was significantly affected by both semolina protein level and spaghetti drying temperature. Quality increased as protein level increased. Spaghetti quality did not appear to be greatly improved when temperatures greater than 70° C were utilized, although the data revealed a possible reduction in strand stickiness with higher drying temperatures.

Response surface methodology was successfully used to clarify relationships between protein level and drying temperature and their effects on cooked spaghetti quality. Contour plots were generated from fitted regression equations for firmness, compression, elasticity and cooking loss. Plots for firmness and compressibility revealed that these responses were primarily affected by protein level whereas plots for relaxation time showed that this response was primarily affected by drying temperature. Cooking loss values for optimally cooked spaghetti was mainly influenced by protein level whereas, overcooked spaghetti appeared to be equally influenced by both variables.

Predicted responses for experimental spaghetti met or exceeded commercial durum spaghetti samples except for relaxation time and cooking loss. In order to meet the commercial standards for durum spaghetti for these parameters, drying temperatures greater than 60° C are required for low protein levels. As protein level increased, lower drying temperatures are indicated such that, at protein levels greater than 14%, a drying temperature of 50° C was satisfactory. However, the results of this study also indicate that if a higher quality spaghetti is desired, the use of high protein durum combined with high drying temperatures should be utilized.

Thus, the results of this study suggest, that high quality raw material is still required to produce an optimum quality spaghetti, even when high drying temperatures are to be utilized. Adequate cooking quality was achieved using drying temperatures greater than 60° C across all protein levels. Spaghetti with cooking quality that exceeds the minimum quality of the commercial durum samples can be achieved using high protein levels and drying temperatures greater than 60° C. This study was carried out under laboratory drying conditions making it difficult to predict what results may be achieved under commercial drying operations. Therefore, future research should be undertaken in order to document the role of high temperature drying and semolina protein levels under commercial plant conditions. Drying temperatures greater than 90° C should also be examined, since very high temperature (VHT) drying lines have recently been introduced to pasta manufacturers.

CHAPTER 6

OPTIMIZATION OF SPAGHETTI QUALITY USING RESPONSE SURFACE METHODOLOGY: EFFECTS OF DRYING TEMPERATURE AND BLENDING HARD RED SPRING FARINA WITH DURUM SEMOLINA

6.1 INTRODUCTION

Durum wheat is considered the best raw material for pasta production. In some European countries, notably Italy and France, pasta must be made from durum semolina. In other countries, the USA and Canada included, the use of non-durum wheats is permitted and fluctuates depending on the availability and price of durum semolina (Dexter et al., 1981c). Therefore, it is of interest to determine the effect of farina blending on the cooking quality of spaghetti.

Sheu et al. (1967) reported that pasta made from hard red spring (HRS) farina had lower cooking losses and cooked weight and was firmer than spaghetti made from durum semolina. This was confirmed by Mousa et al. (1983) using spaghetti made with durum semolina and with HRS and hard red winter (HRW) farina. Both HRS and HRW spaghetti were firmer and had lower cooked weight and cooking loss values than spaghetti made from durum. As expected, durum spaghetti had higher color scores than the other spaghetti.

In studies done on farina blending, Wyland and D'Appolonia (1982) found a similar trend. As the level of HRS increased in the spaghetti, firmness increased, whereas cooking loss, cooked weight, and spaghetti color decreased. In contrast, Dexter et al. (1981c) found cooking scores decreased with increasing farina levels especially when the spaghetti was overcooked indicating that spaghetti containing farina was not as tolerant to overcooking as durum spaghetti. Dexter et al. (1983b) suggests the reason for this discrepancy can be explained on the basis of poorer cooking quality of American durum compared to Canadian durum in these earlier studies.

Studies done by Kim et al. (1986 and 1989) on semolina and farina spaghetti were in agreement with the study by Dexter et al. (1981c). Spaghetti made with semolina had a firmer texture than spaghetti made with farina. As for cooking losses, Kim et al. (1986) found durum spaghetti had higher cooking losses than farina spaghetti when cooked in distilled water whereas the opposite was found when the spaghetti was cooked in prepared hard water (Kim et al., 1989). Kim et al. (1989) also reported that spaghetti made from durum was less sticky than spaghetti made from farina. Thus, the effects of farina blending on the cooking quality of pasta has not been widely studied and merits further investigation.

High temperature (HT) drying has been shown to improve spaghetti cooking quality if applied after initial drying at low temperature to low moisture levels (Dexter et al., 1981b and 1984; Wyland and D'Appolonia, 1982; Resmini and Pagani, 1983; Abecassis et al., 1989). Several workers have suggested that the quality of the raw material may no longer be as critical with the advent of HT drying (Feillet, 1984; Matsuo, 1988, Cubadda, 1989). Thus it may be possible to produce spaghetti with good cooking quality using blends of durum semolina and hard red spring (HRS) farina using HT drying. Kim et al. (1989) found both semolina and farina spaghetti dried under HT (70° C) conditions were firmer, less sticky and had lower cooking losses than samples dried under LT (45° C) conditions. Results of Dexter et al. (1983b) were in agreement with those of Kim et al. (1989) except firmness of farina spaghetti was not found to improve with HT drying compared to durum spaghetti. Wyland and D'Appolonia (1983) examined the effect of farina blending with drying temperatures of 40°, 60°, 70°, and 80° C. As drying temperature increased, firmness also increased and cooking loss values decreased. Spaghetti stickiness was not measured. The authors did not indicate what combinations of farina blends and drying temperatures gave optimum cooking quality thereby limiting the conclusions that can be drawn from this study.

Thus, the use of HT drying conditions appears promising in terms of improving the cooking quality of spaghetti prepared from blends of semolina and farina. More work needs to be done however, to examine the relationship of spaghetti drying temperature and farina blending on the cooking quality of spaghetti with the goal of determining which combinations of drying temperatures and farina blends yield an optimal spaghetti. Since such a study could be excessive in terms of the possible treatment combinations that could be examined, the use of response surface methodology (RSM) would appear beneficial. RSM is a statistical technique used to determine optimal conditions in a minimal number of experimental trials.

It has been used successfully in a number of product optimization studies. Min and Thomas (1980) used RSM in the formulation of whipped topping, Henselman et al. (1974) in the development of high protein bread, Vaisey-Genser et al. (1987) to optimize cake formulation containing canola oil, Oh et al. (1985b) to describe the optimum processing conditions for noodle production and Shelke (1987) to optimize noodle formulations. To date, no studies have been undertaken to optimize drying temperatures for processing of spaghetti or to optimize the replacement of durum semolina with HRS farina. Thus, the objectives of this study were:

1. To examine the relationship between spaghetti drying temperature and blending of hard red spring (HRS) farina with durum semolina on the cooking quality of optimally cooked and overcooked spaghetti using response surface methodology.
2. To generate contour plots from the fitted models in order to determine which combinations of drying temperatures and blending levels yield spaghetti with optimum cooking quality.

6.2 MATERIALS AND METHODS

6.2.1 Preparation and Analysis of Blends

A ten kg sample of durum semolina and HRS wheat middlings (farina) were obtained from Ogilive Mills Ltd, Winnipeg. Three blends (75/25, 50/50, 25/75 semolina/farina) were prepared on a dry matter basis. The 3 blends, plus a sample of 100% semolina and 100% farina for a total of five treatment blends were then analyzed for protein content by the standard Kjeldahl method as modified by Williams (1973) and for ash content as described in Chapter 5. Determinations of protein, and ash were performed in duplicate.

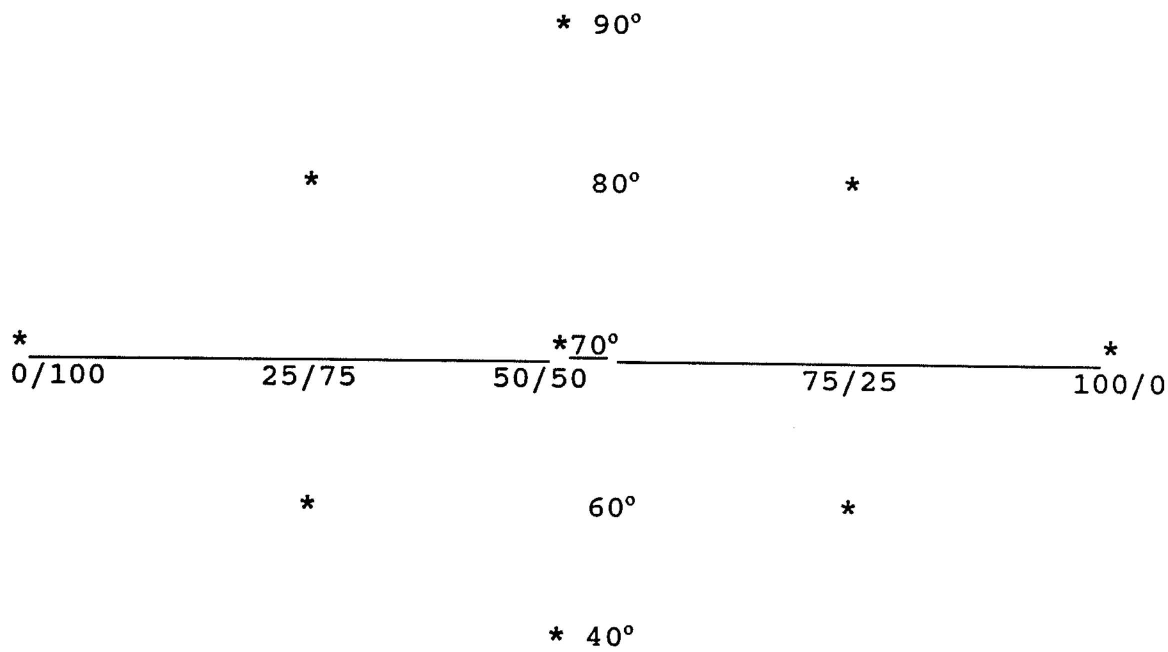
Wet gluten content of the five blends was determined in duplicate using the Glutomatic system according to ICC standard method No. 137 (1982).

6.2.2 Spaghetti Processing and Drying

Spaghetti was processed in a Demaco S-25 laboratory-scale continuous extrusion press (De Francisci Machine Corporation, Brooklyn, NY) as described by Matsuo et al. (1978). Samples were dried using five temperature conditions (40°, 60°, 70°, 80°, 90° C). A modified Blue M FR-381C environment chamber (Blue M Electric Co., Blue Island, IL) as described by Dexter et al. (1981a) was used for drying the spaghetti. Drying temperature and spaghetti moisture profiles for the five drying cycles are provided in Chapter 5.

6.2.3 Experimental Design

RSM was selected to determine appropriate blending levels and drying temperatures for durum and HRS spaghetti blends. The following experimental design was selected:



* sample selected for evaluation

The complete design consisted of 16 experimental points, which included four replications of the centre point and two replications of the interior points. Thus, 9 treatment combinations were required to test the range of combinations that would have required 25 treatment combinations in a traditional factorial arrangement, plus replications. The 17 treatments of spaghetti were processed in a randomized order over and a three week period. Spaghetti was tested in a randomized order over a four day period.

6.2.4 Assessment of Cooked Spaghetti Quality

Spaghetti samples were cooked to optimum (defined as the time when the centre core disappears) and to optimum plus 10 minutes (overcooked) in prepared water as described in Chapter 2. Cooking loss of the recovered water was determined by freeze-drying, weighing the freeze dried material, adjusting for mineral residue present in the cooking water and calculating the proportion of solids lost to the cooking water as percentage of spaghetti cooked.

Instron firmness, compression, relaxation and strand stickiness were determined as described in Chapter 5.

6.2.5 Color Assessment of Spaghetti

Spaghetti color was assessed on whole strands of uncooked spaghetti mounted on white cardboard, by reflectance using a Beckman DU-7 Spectrophotometer (Beckman Instruments Inc., Fullerton, CA). Dominant wavelength, brightness, and purity were determined by the ten selected ordinates method (Hardy, 1936).

6.2.6 Statistical Analysis of Data

Data were analyzed using the RSREG procedure of Statistical Analysis System (SAS, 1988) to fit second order polynomial equations to all response variables. Lack of fit tests were performed on the fitted models. Coefficients for the linear, quadratic and interaction terms of each polynomial were calculated and tested for difference from zero. Response surface two-dimensional and three-dimensional contour plots were generated from the fitted models using GCONTOUR and G3D procedures (SAS, 1988). Individual, two-dimensional contour plots were superimposed to determine the region where levels of durum semolina and drying temperatures produced spaghetti which was comparable to commercial durum spaghetti in terms of cooking quality and color parameters.

6.3 RESULTS AND DISCUSSION

6.3.1 Semolina and Farina Characteristics

Protein, ash and gluten content of the five prepared blends of durum semolina and hard red spring farina are provided in Table 6.1. Protein levels were similar for the five blends with a range of 12.0-12.4%. As expected, ash content increased as the level of durum semolina increased in the blend. Wet gluten content increased slightly with increasing levels of durum semolina in the blend.

6.3.2 Response Surface Analysis

The analyses of variance for cooked spaghetti quality parameters for optimally cooked and overcooked spaghetti are presented in Tables 6.2 and 6.3 respectively. Lack of fit tests, R^2 value, CV value and model significance were used to judge adequacy of model fit as described in Chapter 5. The predictive models developed for firmness, compression, and relaxation time were considered adequate since they possessed no significant lack of fit and had satisfactory levels of R^2, CV, and model significance. The developed model for strand stickiness of optimally cooked spaghetti was less predictive since the R^2 value was less than 0.60 (0.44), the CV value was slightly higher than 10% (13%), and the model significance was greater than $p < 0.05$ ($p = 0.25$). Similarly, the developed model for cooking loss of overcooked spaghetti was also less predictive due to a R^2 value of 0.44, a CV value of 11.5% and model significance of $p = 0.25$. Models developed for strand stickiness of overcooked spaghetti and cooking loss

Table 6.1 Protein, Ash and Wet Gluten Content* of Prepared Blends of Durum Semolina and Hard Red Spring Farina

Quality	Blend (% Durum Semolina)				
	0	25	50	75	100
Protein (%)	12.0	12.2	12.1	12.4	12.4
Ash (%)	0.37	0.44	0.53	0.59	0.65
Wet Gluten (%)	31.5	32.0	32.4	32.9	32.8

*14.0% moisture basis

Table 6.2 ANOVA For Evaluation of Models For Quality Parameters of Optimally Cooked Spaghetti

Variable	Source	df	Sum of Squares	F value
Firmness (Shear Force)	Model	5	0.745	2.062
	Residual	10	0.723	
	Lack of Fit	9	0.721	36.215
	Pure Error	1	0.002	
R^2			0.51	
Coefficient of Variation (%)			5.2	
Model Significance			0.1545	
Compression Energy	Model	5	0.299	6.192
	Residual	10	0.097	
	Lack of Fit	9	0.096	9.308
	Pure Error	1	0.001	
R^2			0.76	
Coefficient of Variation (%)			3.9	
Model Significance			0.0072	
Relaxation Time	Model	5	423.376	15.270
	Residual	10	55.452	
	Lack of Fit	9	53.694	3.394
	Pure Error	1	1.758	
R^2			0.88	
Coefficient of Variation (%)			8.9	
Model Significance			0.0002	
Strand Stickiness	Model	5	141898.0	1.567
	Residual	10	181145.0	
	Lack of Fit	9	156945.0	0.721
	Pure Error	1	24200.0	
R^2			0.44	
Coefficient of Variation (%)			13.1	
Model Significance			0.2549	
Cooking Loss	Model	5	2.915	0.586
	Residual	10	9.942	
	Lack of Fit	3	4.782	2.162
	Pure Error	7	5.160	
R^2			0.23	
Coefficient of Variation (%)			20.19	
Model Significance			0.7109	

Table 6.3 ANOVA For Evaluation of Models For Quality Parameters of Overcooked Spaghetti

Variable	Source	df	Sum of Squares	F value
Firmness (Shear Force)	Model	5	0.886	7.866
	Residual	10	0.225	
	Lack of Fit	9	0.172	0.356
	Pure Error	1	0.054	
R^2			0.79	
Coefficient of Variation (%)			3.9	
Model Significance			0.0030	
Compression Energy	Model	5	13.369	3.706
	Residual	10	7.215	
	Lack of Fit	9	7.189	26.875
	Pure Error	1	0.030	
R^2			0.65	
Coefficient of Variation (%)			23.2	
Model Significance			0.0370	
Relaxation Time	Model	5	50.997	4.669
	Residual	10	21.846	
	Lack of Fit	9	21.776	34.412
	Pure Error	1	0.070	
R^2			0.70	
Coefficient of Variation (%)			9.9	
Model Significance			0.0185	
Strand Stickiness	Model	5	182236.0	0.533
	Residual	10	683564.0	
	Lack of Fit	9	676364.0	10.428
	Pure Error	1	7200.0	
R^2			0.21	
Coefficient of Variation (%)			19.0	
Model Significance			0.7472	
Cooking Loss	Model	5	5.434	1.588
	Residual	10	6.843	
	Lack of Fit	3	2.691	1.512
	Pure Error	7	4.415	
R^2			0.44	
Coefficient of Variation (%)			11.51	
Model Significance			0.2493	

of optimally cooked spaghetti were judged to be inadequate due to very low levels of R^2, high levels of CV and lack of model significance.

The analyses of variance for spaghetti color parameters are presented in Table 6.4. The predictive models developed for brightness and purity were considered adequate since they possessed no significant lack of fit and had satisfactory levels of R^2, CV, and model significance. The model developed for dominant wavelength also had adequate levels of R^2, CV, and model significance but, a marginally significant lack of fit was found indicating the possibility that additional parameters are needed in the model.

The regression coefficients for the fitted models for all quality parameters except those parameters judged to be inadequate (strand stickiness of overcooked spaghetti and cooking loss of optimally cooked spaghetti) are presented in Table 6.5. The regression coefficients for the fitted models for all color parameters are presented in Table 6.6.

In order to visualize the combined effects of the two independent variables of durum semolina level and drying temperature on the dependent responses of cooked quality and color, two-dimensional and three-dimensional contour plots were generated for each of the fitted models. The contour plots show predicted responses for cooking quality and color characteristics due to varying levels of the two independent variables.

Table 6.4 ANOVA For Evaluation of Models For Spaghetti Color

Variable	Source	df	Sum of Squares	F value
Brightness	Model	5	37.820	21.655
	Residual	10	3.492	
	Lack of Fit	3	2.277	4.371c
	Pure Error	7	1.216	
R^2			0.92	
Coefficient of Variation (%)			1.2	
Model Significance			0.0001	
Purity	Model	5	198.673	57.525
	Residual	10	6.907	
	Lack of Fit	3	1.704	0.764
	Pure Error	7	5.203	
R^2			0.97	
Coefficient of Variation (%)			2.0	
Model Significance			0.0001	
Dominant Wavelength	Model	5	1.338	11.502
	Residual	10	0.233	
	Lack of Fit	3	0.197	12.661b
	Pure Error	7	0.036	
R^2			0.85	
Coefficient of Variation (%)			0.03	
Model Significance			0.0007	

b significant at $p<0.01$
c significant at $p<0.05$

Table 6.5 Regression Coefficients of the Second Order Polynomials* For Quality Parameters

Optimally Cooked Spaghetti

Coeff-icient	Firmness	Compress-ion	Relax-ation	Strand Stickiness
b_o	5.3353	3.1548	5.0367	-145.6931
Linear				
b_1	0.0054	-0.0072	0.1846	37.6395
b_2	-0.0328	-0.0056	0.0339	5.6165
Quadratic				
b_{11}	-0.0002	0.00004	0.0002	-0.2642
b_{22}	-0.0001	0.0001	0.00004	0.0013
Interaction				
b_{21}	0.0006	-0.0001	0.0017	-0.1200

Overcooked Spaghetti

Coeff-icient	Firmness	Compress-ion	Relax-ation	Cooking Loss
b_o	0.7662	5.5007	4.4784	19.0735
Linear				
b_1	0.0580	-0.0385	0.2865	-0.3402
b_2	0.0272	-0.0662	-0.0884	0.0006
Quadratic				
b_{11}	-0.0003	0.0003	-0.0019	0.0023
b_{22}	-0.0001	0.0010	0.0014	-0.0001
Interaction				
b_{21}	-0.0002	-0.0001	0.0000	0.0002

* $Y_i = b_o + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$

Table 6.6 Regression Coefficients of the Second Order Polynomials* For Color Parameters

Coeff-icient	Brightness	Purity	Dominant Wavelength
b_o	56.4513	20.9947	577.5820
Linear			
b_1	-0.0361	0.1957	-0.0321
b_2	-0.0529	0.3321	-0.0154
Quadratic			
b_{11}	-0.0001	-0.0005	0.0003
b_{22}	0.00002	-0.0009	0.0001
Interaction			
b_{21}	-0.00001	-0.0015	0.0001

* $Y_i = b_o + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$

The contour plots for firmness of optimally cooked spaghetti are presented in Figure 6.1. The region of optimum firmness is localized in the upper corner with high levels of durum semolina and high drying temperatures. The area of minimum response was defined by high levels of durum and low drying temperatures. Contour plots for firmness of overcooked spaghetti are presented in Figure 6.2. A larger region of optimization is indicated than was evident for optimally cooked spaghetti. It is defined by semolina levels greater than 50% and drying temperatures greater than 50° C. Similar to optimally cooked spaghetti, the region of minimum response is located in the direction of low durum levels and low drying temperatures. Results for compression are presented in Figures 6.3 and 6.4. Lower compression values (indicating superior cooking quality) were achieved for optimally and overcooked spaghetti in the direction of high levels of durum semolina and high drying temperature. A second region of optimum response was indicated for overcooked spaghetti in the region of low durum semolina levels and low drying temperatures. A region of maximum response for optimally cooked spaghetti was found with low durum levels and low drying temperatures. For overcooked spaghetti, two regions maximum response were found. One defined by low durum levels and high drying temperatures and the second defined by high durum levels and low drying temperatures.

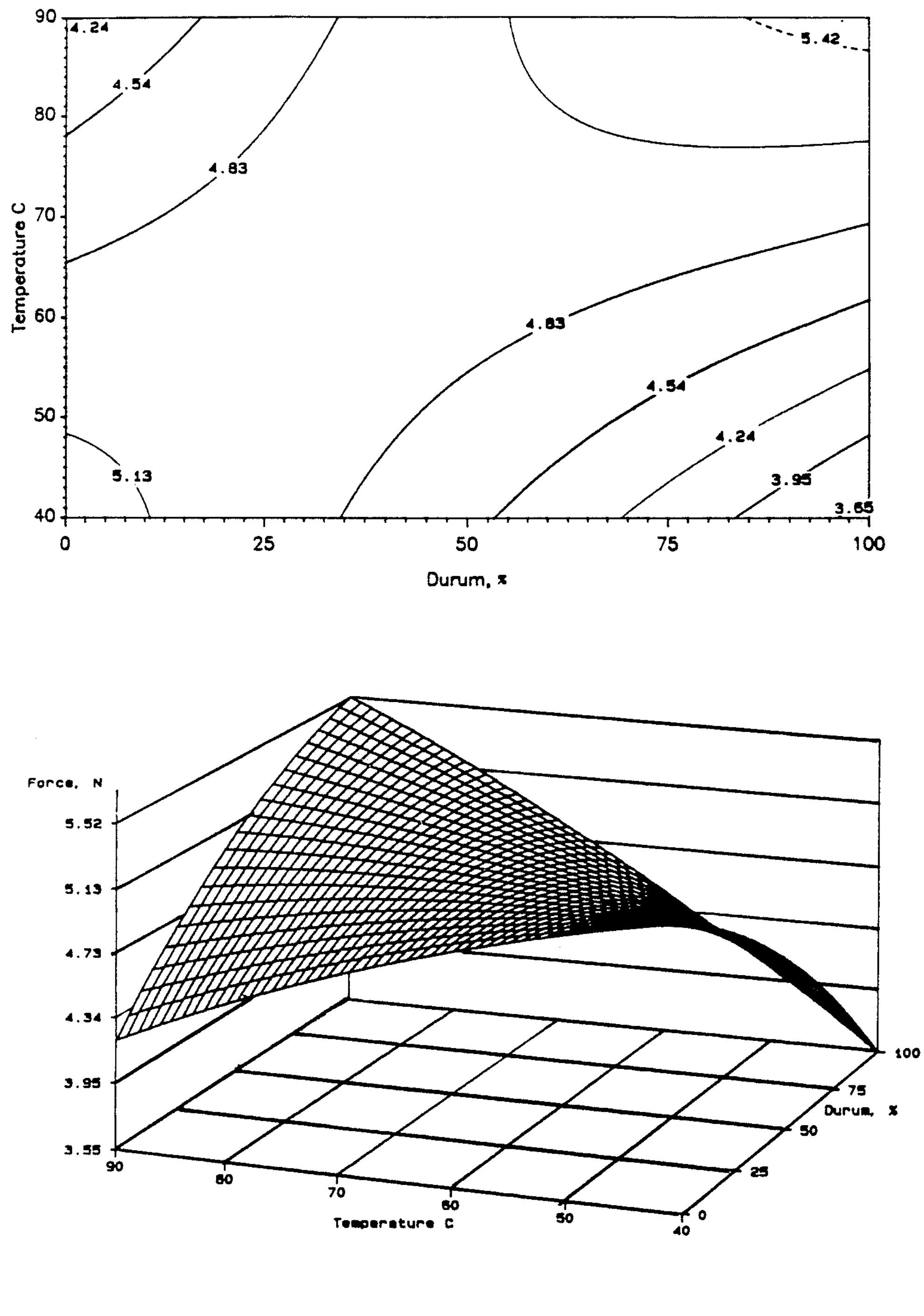


Figure 6.1 **Two and Three-Dimensional Response Surface Plots of Firmness of Optimally Cooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**

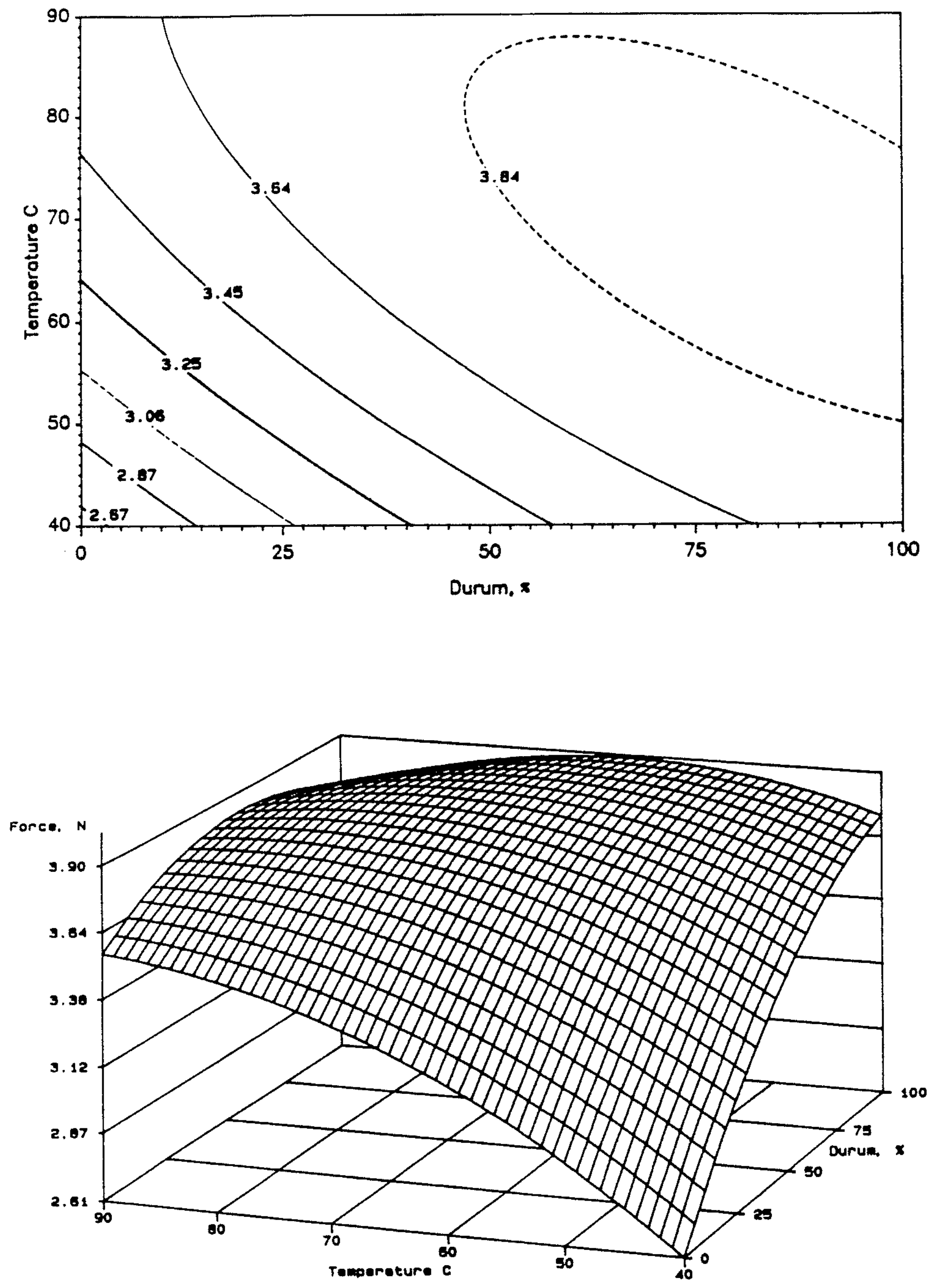
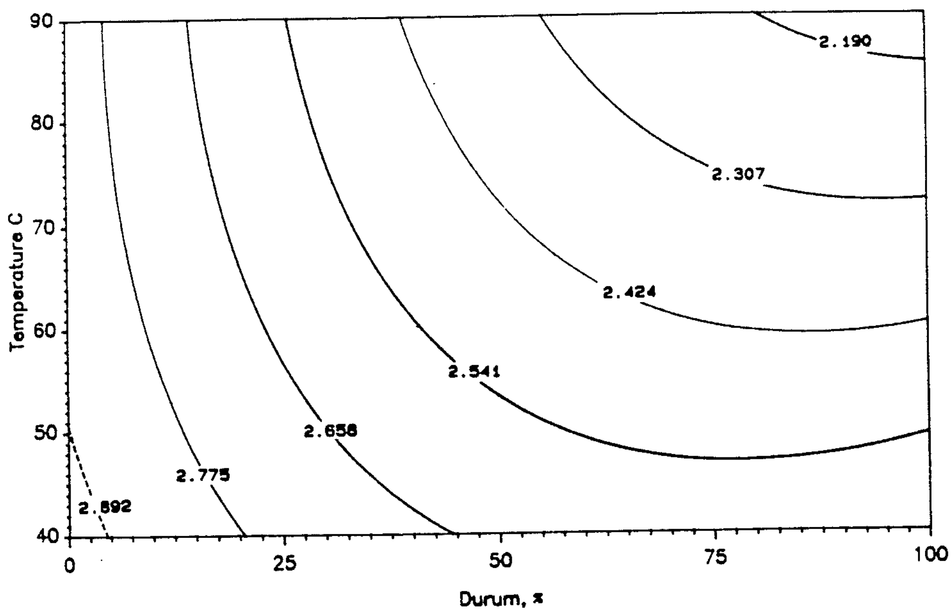


Figure 6.2 **Two and Three-Dimensional Response Surface Plots of Firmness of Overcooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**



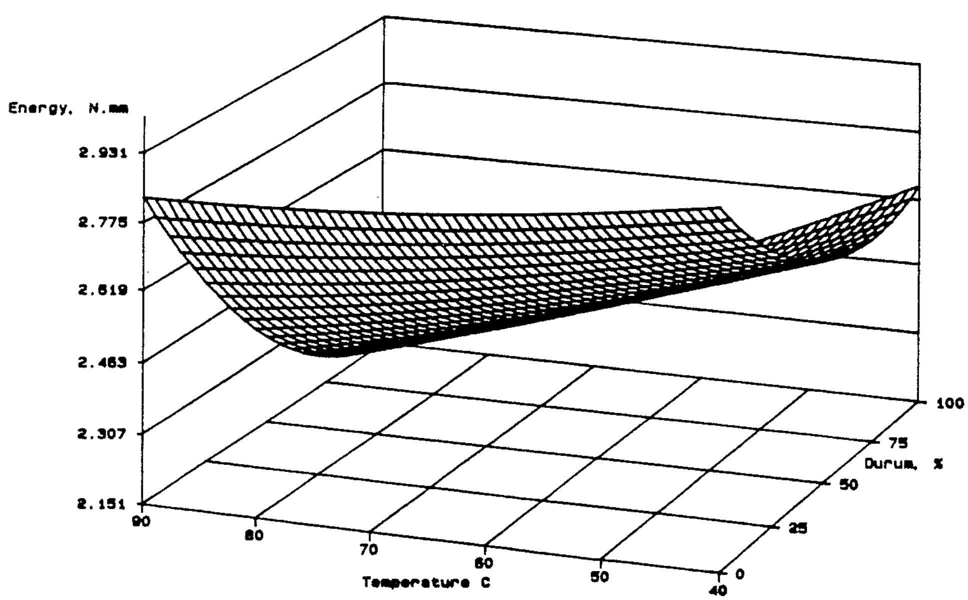
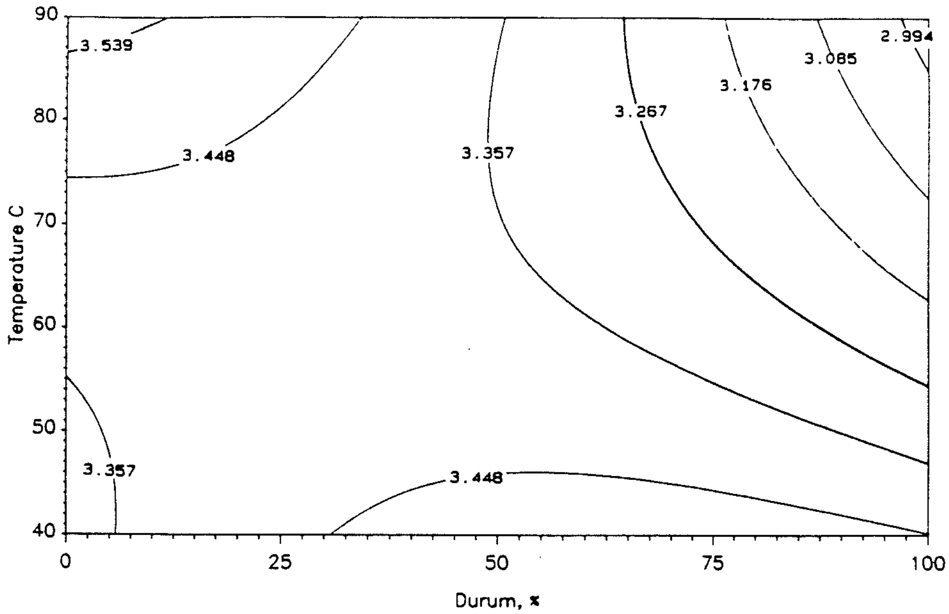


Figure 6.3 **Two and Three-Dimensional Response Surface Plots of Compression Energy of Optimally Cooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**



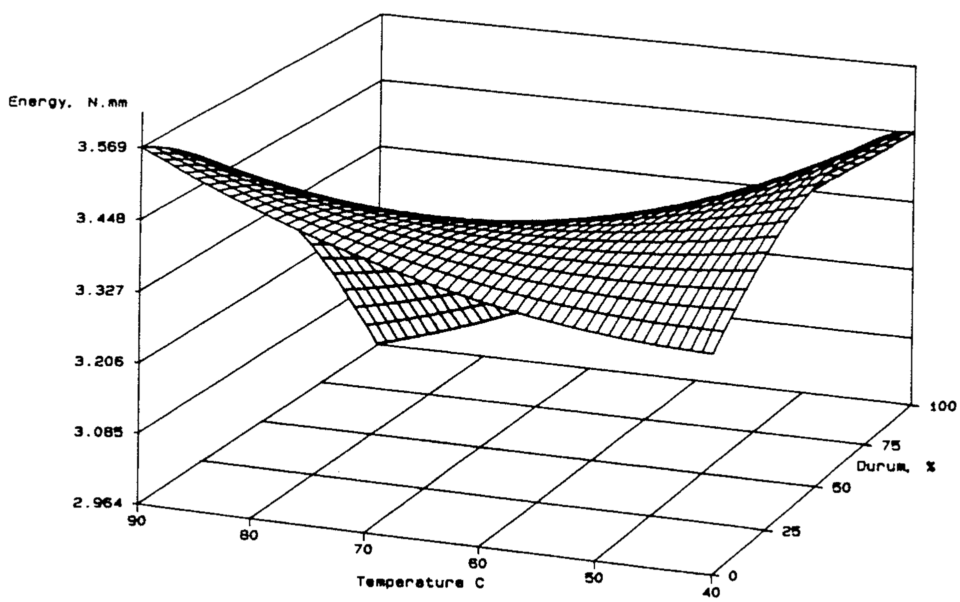


Figure 6.4 **Two and Three-Dimensional Response Surface Plots of Compression Energy of Overcooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**

Contour plots for relaxation time of optimally cooked spaghetti showed that relaxation time was more sensitive to changes in drying temperature than durum level (Figure 6.5). The area of optimized response was located in the upper corner with high drying temperatures and high durum levels. The region of minimal response was found in the direction of low drying temperatures and low durum levels. The region of optimization for relaxation of overcooked spaghetti was localized at the highest durum level (100%) and drying temperatures greater than 60° C (Figure 6.6). Minimum responses were achieved at 40° C and durum levels less than 50%.

The contour plots for strand stickiness of optimally cooked spaghetti and cooking loss of overcooked spaghetti were generated even though the developed models may be less predictive. The region of optimized response for strand stickiness was defined by high durum levels and high drying temperature (Figure 6.7). Surprisingly, a second region of optimization appeared to be located at 40° C and low durum levels. The region of maximum response was found at low durum levels and drying temperatures between 60° and 80° C. Two areas of optimized response for cooking loss of overcooked spaghetti were identified. The first region was defined by durum semolina levels greater than 75% and drying temperatures between 70° and 85° C (Figure 6.8). The second region was defined by durum levels less than 10% and drying temperatures between 55° and 65° C. The region of maximum response was found at the 40° C drying temperature at the high durum levels.

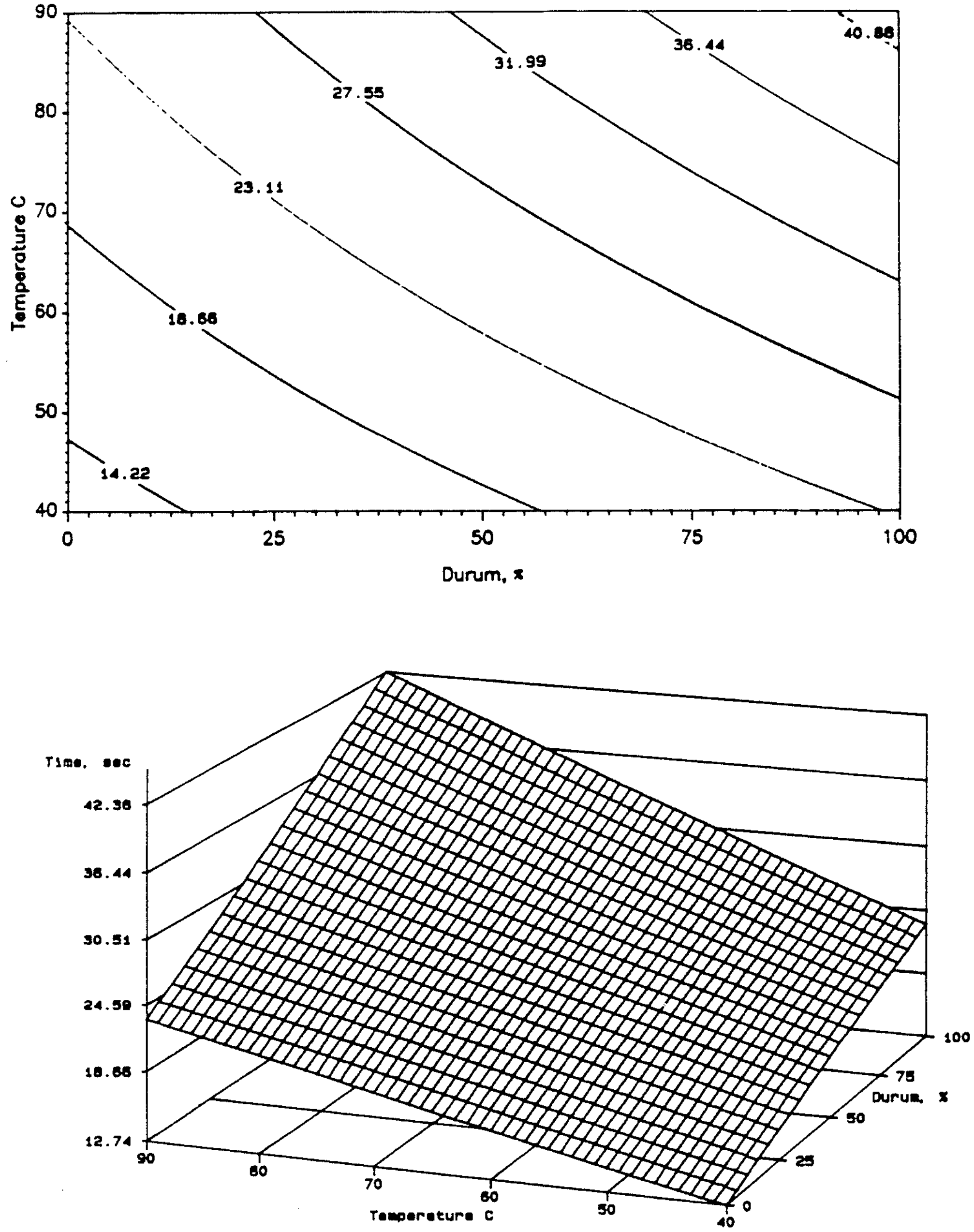


Figure 6.5 Two and Three-Dimensional Response Surface Plots of Relaxation Time of Optimally Cooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature

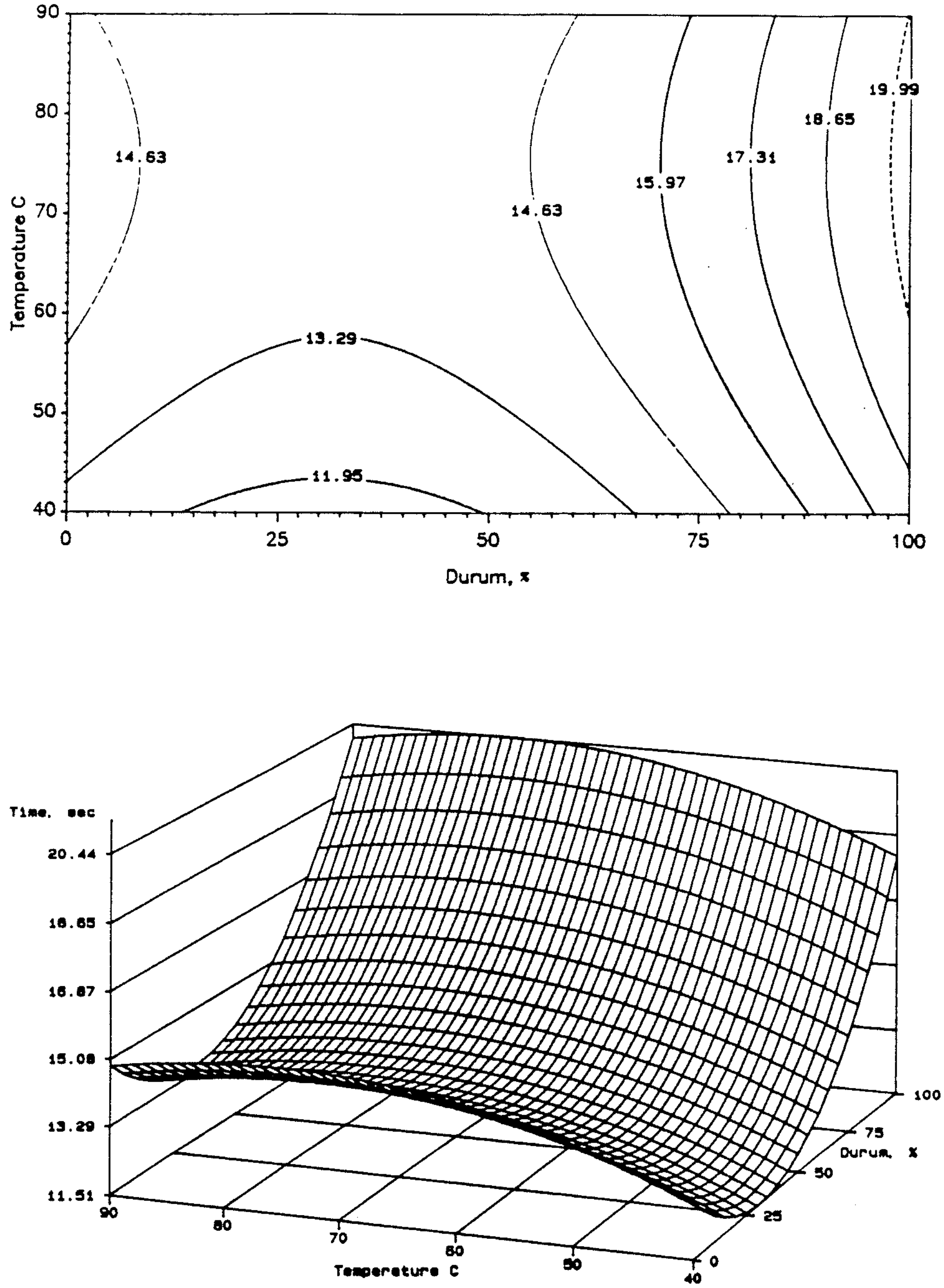


Figure 6.6 **Two and Three-Dimensional Response Surface Plots of Relaxation Time of Overcooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**

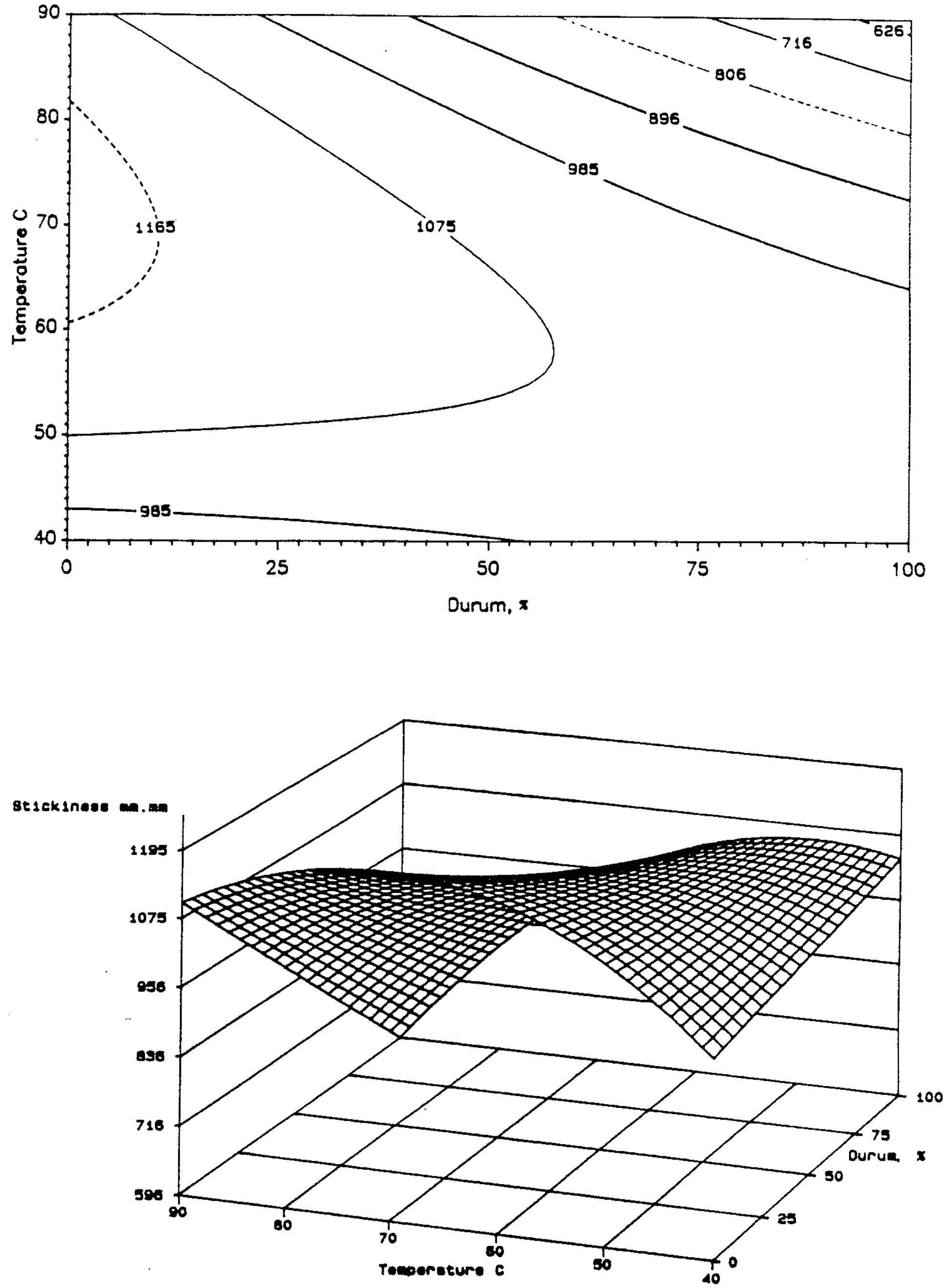
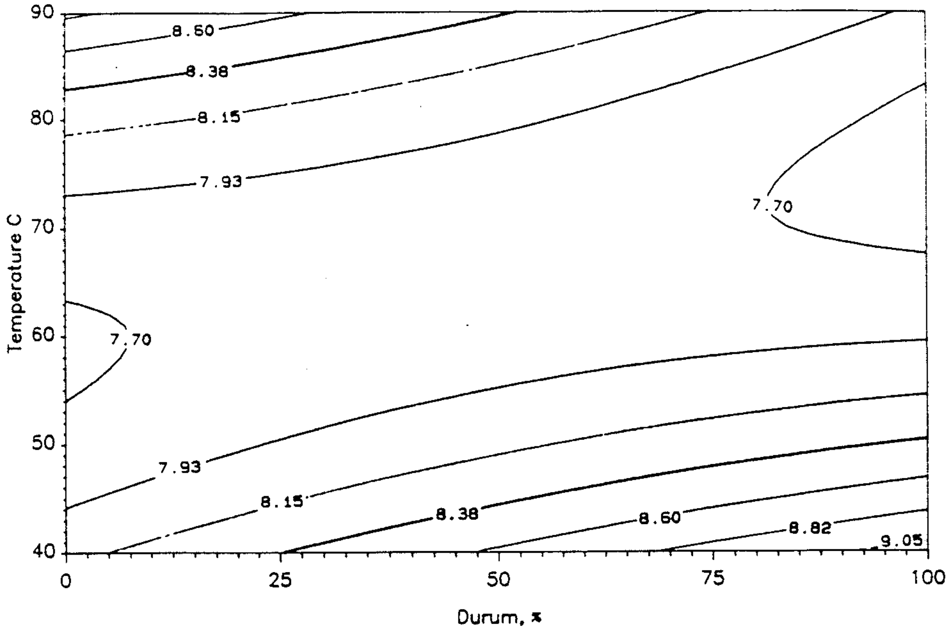


Figure 6.7 **Two and Three-Dimensional Response Surface Plots of Strand Stickiness of Optimally Cooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**



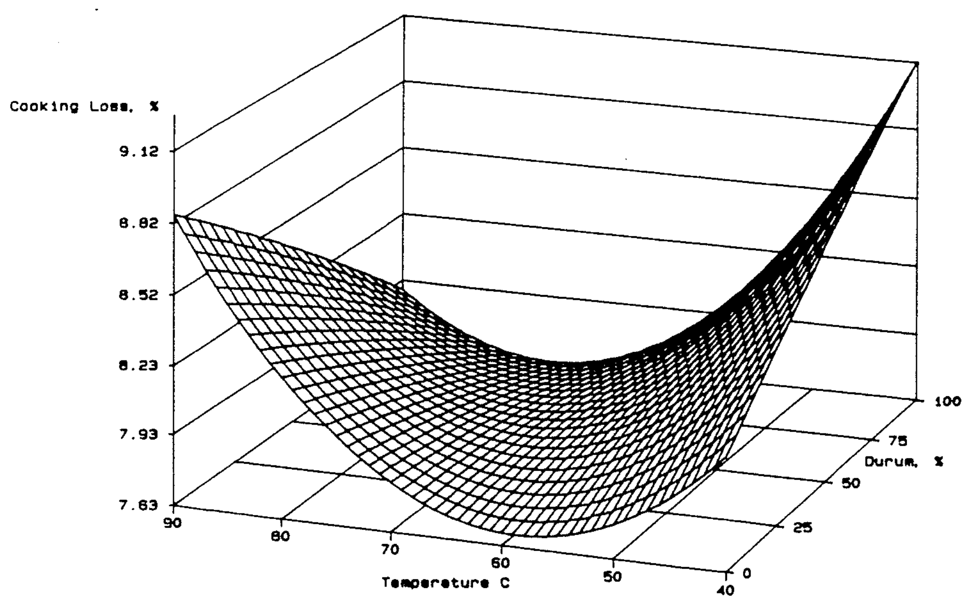


Figure 6.8 **Two and Three-Dimensional Response Surface Plots of Cooking Loss of Overcooked Spaghetti as a Function of Durum Semolina Level and Drying Temperature**

Contour plots for color parameters are presented in Figures 6.9 to 6.11. Purity is an indication of hue or color intensity and is therefore related to pigment content. A high value for purity is desirable. Brightness is a measure of the amount of light reflected from the surface of the spaghetti relative to that reflected from a white surface. Brightness values tend to decrease with increasing values of purity. Dominant wavelength is an indicator of "off-color". Values between 576-577 nm indicate a desirable amber yellow color, values lower than 576 indicate a less desirable yellow color that is slightly greenish, and values greater than 577 indicate a brownish tinge.

Brightness values decreased with durum levels and to a lesser extent by increasing drying temperatures (Figure 6.9). The area of minimal response was defined by high drying temperature and high durum levels whereas the area of maximum response was defined by low drying temperatures and low durum levels.

Contour plots for purity, showed that purity was affected more by durum levels than drying temperature (Figure 6.10). The area of maximum response was defined by the highest durum levels over the full range of drying temperatures predicted. Minimum responses were found with low durum levels and low drying temperatures, although durum levels appear to be the more dominant of the two variables.

Contour plots for dominant wavelength were generated even though a marginally significant lack of fit was found

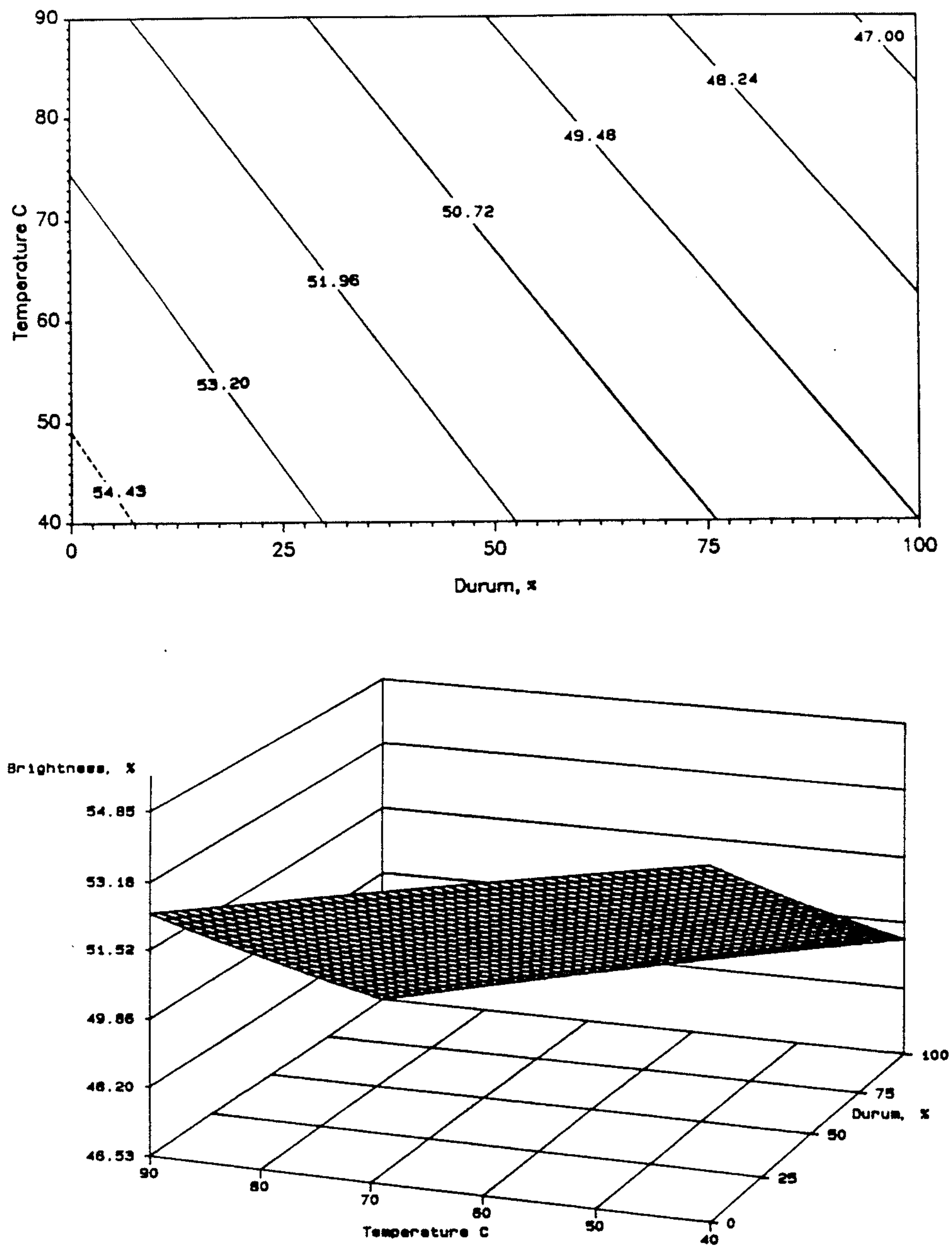
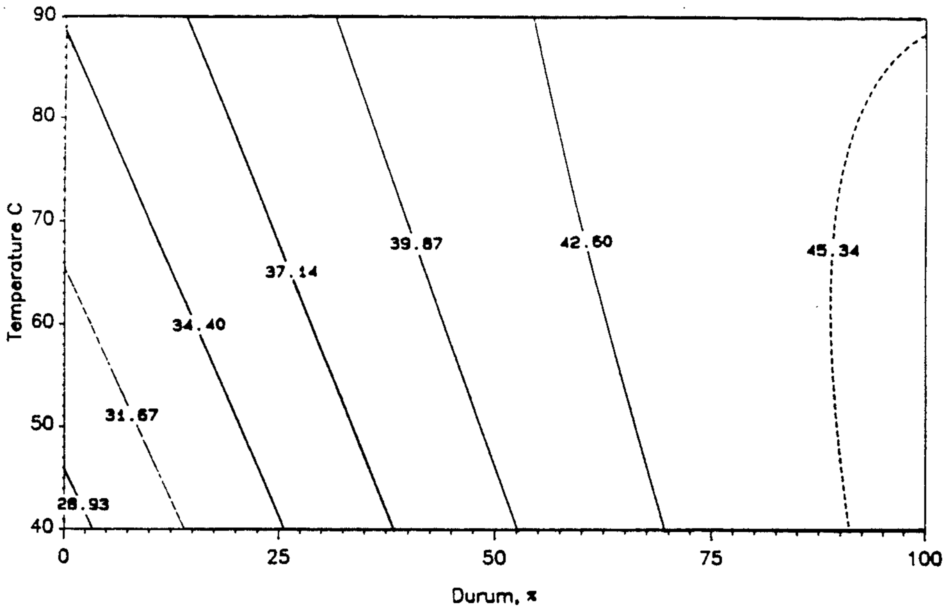


Figure 6.9 Two and Three-Dimensional Response Surface Plots of Brightness, a Measure of Spaghetti Color as a Function of Durum Semolina Level and Drying Temperature



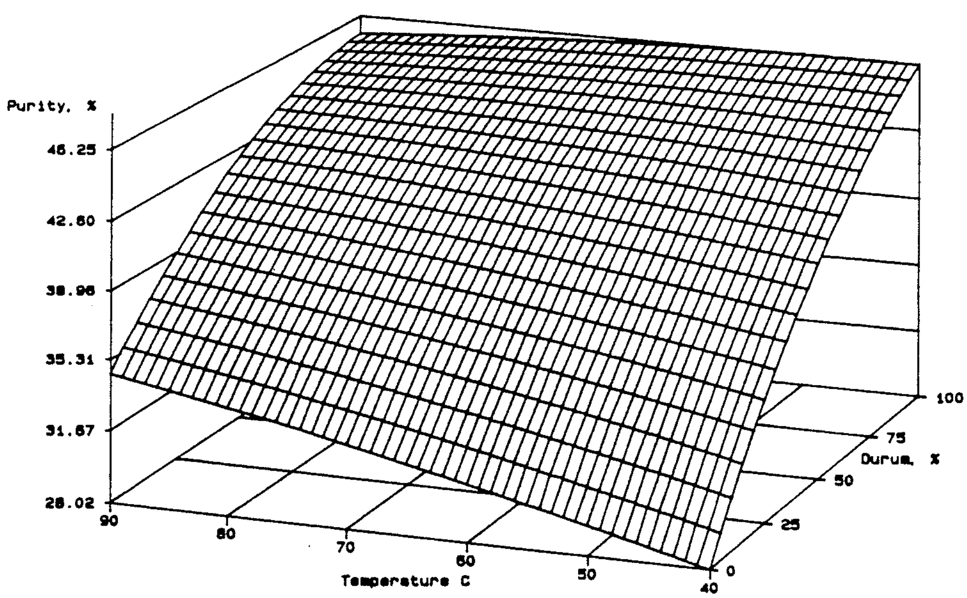


Figure 6.10 **Two and Three-Dimensional Response Surface Plots of Purity, a Measure of Spaghetti Color as a Function of Durum Semolina Level and Drying Temperature**

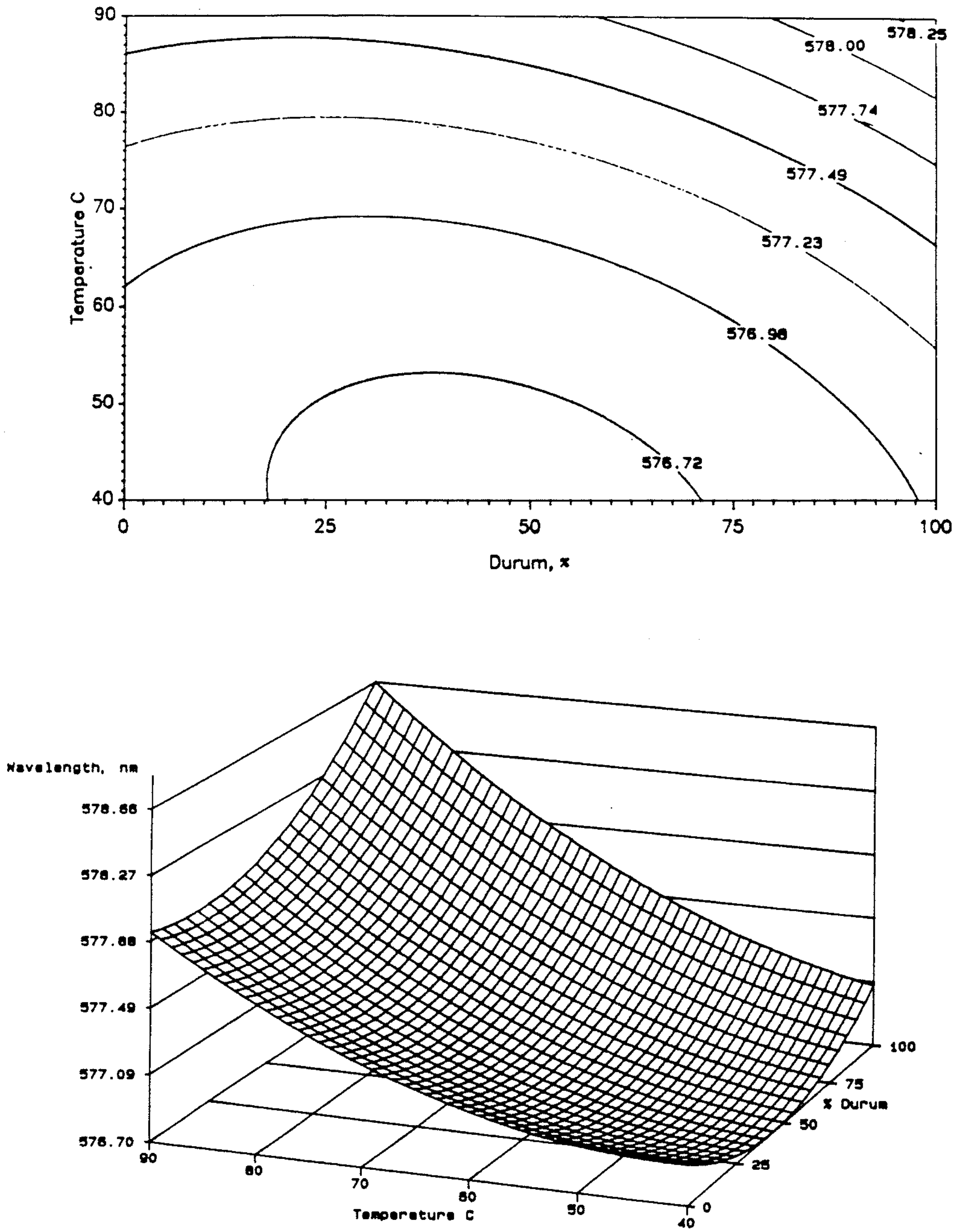


Figure 6.11 Two and Three-Dimensional Response Surface Plots of Dominant Wavelength, a Measure of Spaghetti Color as a Function of Durum Semolina Level and Drying Temperature

suggesting the possibility of missing components to the model. It was felt that the model developed offered a reasonable and significant starting point in the effort to model color responses in spaghetti. Dominant wavelength showed a greater change in the surface contour along the drying temperature axis than the durum semolina level axis (Figure 6.11). With higher drying temperatures and to a lesser extent higher durum levels, dominant wavelength values begin to move out of the ideal range above 577 nm. Optimum responses were defined by drying temperatures less than 80° C across the full range of durum levels.

In summary, the predicted optimum responses for firmness, compression, elasticity and stickiness of optimally cooked spaghetti were produced with a combination of high durum levels and high drying temperatures. These results are not unexpected, since durum semolina spaghetti has been reported to be firmer, more elastic and less sticky than spaghetti made with hard red spring wheat farina (Dexter et al., 1981c and 1983b; Manser, 1980; Kim et al., 1986 and 1989). As well, spaghetti dried under HT conditions has also been found to have better cooking quality than spaghetti dried under LT conditions (Manser, 1980; Wyland and D'Appolonia, 1982; Dexter et al., 1981b and 1984; Abecassis et al., 1984).

Predicted optimum responses for firmness, compression energy and relaxation time of overcooked spaghetti were found over a wide range of drying temperatures. Optimum relaxation time of overcooked spaghetti was achieved at 100% durum levels, optimum compression energy was found between 25 and 50% durum levels, and optimum firmness was achieved at durum levels greater than 50%. Optimum cooking loss of overcooked spaghetti was found with durum levels greater than 70% and drying temperatures between 60° and 80° C and with durum levels less than 20% and drying temperatures between 65° and 80° C. Reported effects of farina blending and HT drying on cooking loss is not consistant. Studies by Sheu et al. (1967), Mousa et al. (1983), Wyland and D'Appolonia (1982), Dexter et al. (1983b), and Kim et al. (1986) found durum spaghetti to have higher cooking losses compared to spaghetti made from HRS farina. However, a recent study by Kim et al. (1989) reported lower cooking losses for durum spaghetti when spaghetti was cooked in prepared water. This was also observed in a previous study presented in Chapter 2. Some evidence also exists, that cooking losses decrease with HT drying (Wyland and D'Appolonia, 1982; Dexter et al., 1981b and 1984).

Predicted optimum responses for purity were achieved at high durum levels (a reflection of increasing yellow pigment content) over the full range of drying temperatures. Brightness tended to diminish with combinations of high durum levels and high drying temperatures. Optimum responses for dominant wavelength were found at drying temperatures less than 80° C over the full range of durum levels. Color scores have been found to decrease with HRS farina spaghetti (Dexter et al., 1981c; Wyland and D'Appolonia, 1982; Mousa et al., 1983; Kim et al. 1986 and 1989). HT drying has been shown to decrease brightness and increase purity and dominant wavelength (Dexter et al., 1984). Kim et al. (1989) also found pigment retention was greater in both farina and semolina spaghetti dried under HT conditions compared to LT conditions. The tendency of HT spaghetti to develop an slight undesirable browness has been attributed to Maillard reactions (Laignelet, 1977; Manser, 1978; Pavan 1979), although some of the effect could be due to increased oxidase activities during drying (Kobrehel et al., 1974; Feillet et al., 1974). The Maillard reaction in spaghetti has been linked to relative humidity as well as drying temperature (Laignelet, 1977) suggesting that controlling the relative humidity during drying may limit the reaction. As well, Pavan (1979) has stated that drying temperatures below 80° C do not pose any problem for browning to occur. Results of this study, are in agreement with observations made by Pavan.

Cooking quality values and color values for commercial durum spaghetti samples are presented in Table 6.7. Experimental spaghetti generally met or exceeded these values for commercial durum spaghetti. Two-dimensional contour plots for all responses were superimposed in order to locate spaghetti formulation and drying conditions which met commercial durum spaghetti standards for all responses. Only the most limiting parameters are reproduced in Figure 6.12. Limiting parameters were strand stickiness and firmness of optimally cooked spaghetti and compression energy and relaxation time of overcooked spaghetti. Thus the shaded area

Table 6.7 Cooking Quality and Color Measurements of Commercial Durum Spaghetti

Cooking Quality Parameter	Commercial Range Optimally Cooked	Overcooked
Firmness (N)	4.7-5.7	3.3-4.6
Compression Energy (N.mm)	2.0-2.4	2.7-3.4
Relaxation Time (sec)	25-45	15-24
Strand Stickiness (mm^2)	483-805	585-850
Cooking Loss (%)	5.5-6.4	7.3-9.6

Color Parameter	Commercial Range
Purity	36.9-43.7
Brightness	45.7-51.4
Dominant Wavelength	577.2-578.3

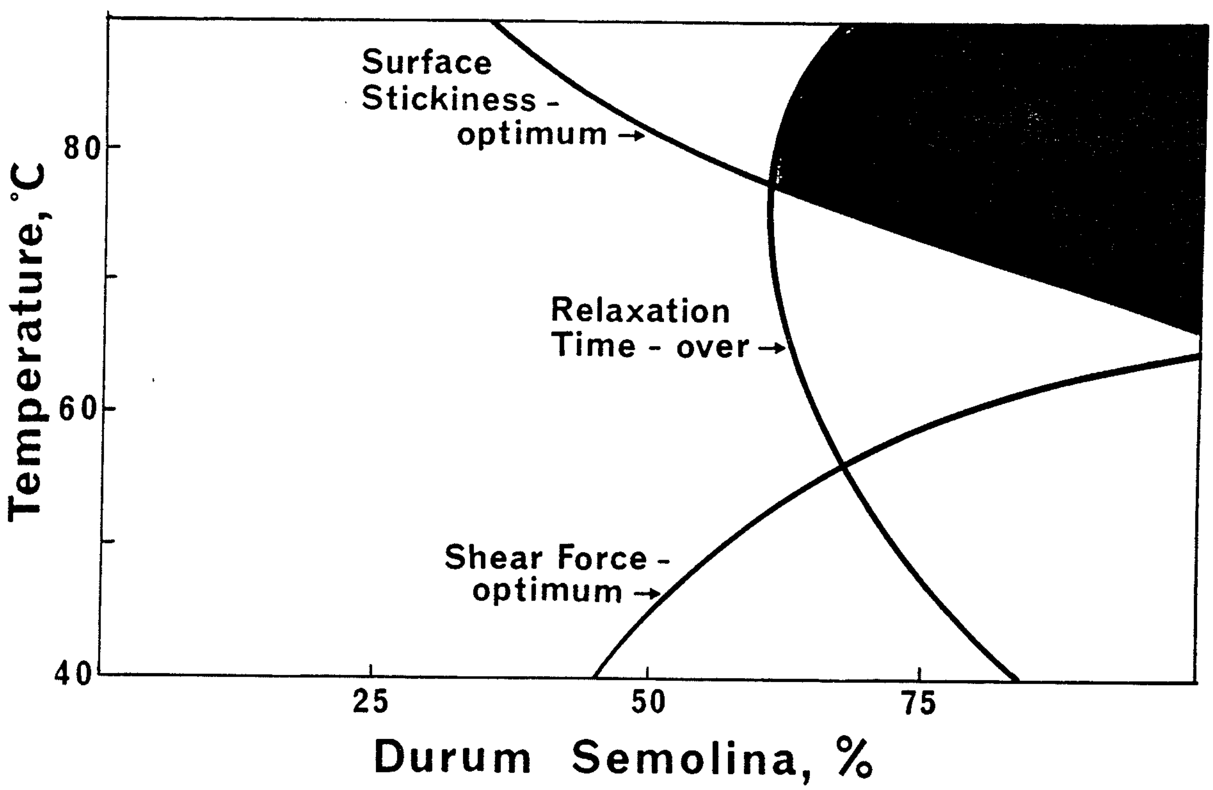


Figure 6.12 **Multiple Contour Plot Showing the Region (Shaded) Meeting the Cooking Quality and Color Characteristics of Commercial Durum Spaghetti Samples**

in the upper right quadrant of the plot represents the region where all cooking quality characteristics of optimally cooked and overcooked spaghetti and all color characteristics are equal to or exceed commercial durum spaghetti limits for these parameters. Levels of durum semolina must exceed 60% and drying temperatures must be greater than 70° C in order to achieve spaghetti with satisfactory quality as measured by the parameters tested in this study.

6.4 CONCLUSIONS

In this study, response surface methodology was successfully used to identify the effects of drying temperature and blending of hard red spring farina with durum semolina on the cooking quality and color characteristics of spaghetti. Good fit models were developed for firmness, compression, relaxation, purity and brightness. Models developed for strand stickiness of optimally cooked spaghetti, cooking loss of overcooked spaghetti and dominant wavelength did not meet all criteria of good fit. Contour plots were generated for these models however, since they offered an initial solution, which appeared reasonable, to model quality responses of these parameters in spaghetti. Models for strand stickiness of overcooked spaghetti and cooking loss of optimally cooked spaghetti were not used since these models had low predictive ability.

Contour plots, generated from fitted regression equations for firmness, compression, relaxation, and strand stickiness of optimally cooked spaghetti indicated that high durum levels in combination with high drying temperature was the region of optimized response. Drying temperatures were not as critical to responses of firmness, relaxation and compression of overcooked spaghetti but, high levels of durum semolina were important in optimizing these responses. Optimized responses for cooking loss of overcooked spaghetti was achieved with drying temperatures between 60° and 80° C, and with either low or high durum levels. The color parameter of brightness was found to diminish whereas purity was found to intensify with high durum levels and high drying temperatures. The area of optimized response for dominant wavelength was defined by drying temperatures less than 80° C.

Superimposing the individual contour plots for all response variables exhibiting reasonable model fit, permitted the identification of the region where all characteristics met or exceeded commercial durum spaghetti samples. The most limiting factors were strand stickiness and firmness of optimally cooked spaghetti and compression energy and relaxation time of overcooked spaghetti. Thus, to satisfy these constraints, durum levels greater than 60% are required with drying temperatures greater than 70° C. Within this optimized region, a number of combinations of durum semolina levels and drying temperatures can be identified that will yield acceptable spaghetti. For instance, at the minimum durum semolina level (60%) drying temperatures between 80° and 90° C are predicted to impart acceptable cooking quality characteristics to the spaghetti whereas, at 100% durum semolina level, drying temperatures between 70° and 90° C are predicted. Thus, as the level of durum semolina increases in the blend, lower drying temperatures can be used. However, similar to the conclusions drawn in the previous study, if a higher quality spaghetti is desired high levels of durum semolina coupled with high drying temperatures are indicated.

The models developed in this study for predicting response variables not only provide an understanding of the interaction between spaghetti formulation and drying temperature but should serve as a guide to selecting final product processing and ingredient conditions. The models for all response variables proposed in this study, will however require additional study to verify and further extend their applicability. This is particularly true for the models proposed for strand stickiness of optimally cooked spaghetti, cooking loss of overcooked spaghetti and dominant wavelength. In addition, other response variables should also be examined now that the initial screening experiment has narrowed the region of durum levels and drying temperatures that should be studied in more detail.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 SUMMARY

The first study of this thesis (Chapter 2) arose out of the need to standardize the cooking water used to prepare spaghetti for assessment of cooking quality characteristics. Seven cooking waters differing in their mineral composition were examined for their effects on stickiness and cooking loss of spaghetti. Cooking water composition was found to affect these parameters significantly suggesting the importance of standardizing the cooking water used in spaghetti cooking studies. Spaghetti made from common wheat was affected more by changes in cooking water composition than was spaghetti made from durum wheat. An artificially hardened water which gave similar results to tap water was selected for all future cooking studies.

The second study (Chapter 3) was undertaken to establish Instron test methods for measuring the textural properties of cooked spaghetti. The effects of Instron operating conditions on textural measurements were examined. Compression force strongly influenced compression and elasticity (relaxation) measurements of spaghetti. Plunger size had only a modest effect on these parameters but variability was reduced with the smaller plunger sizes. Compression depth and crosshead speed strongly influenced firmness measurements of spaghetti. Stickiness measurements were only modestly affected by compression force and plunger size. Since operating factors were shown to influence test results, the operating conditions that gave high repeatability and reproducibility and reasonable discrimination between spaghetti samples for each of the Instron test procedures were identified and adopted for future cooking studies.

As a follow up to this study, a third experiment (Chapter 4) was carried out to compare sensory and instrumental measures of spaghetti texture. A trained texture profile analysis panel identified seven textural parameters present in cooked spaghetti. Principal component analysis reduced the number of sensory attributes into a smaller set of two principal components which accounted for 81.7% of the variance. Either firmness or chewiness appeared to be suitable to represent the first component. Stickiness was chosen to represent the second component. Equations to predict these three sensory attributes from instrumental texture measures were derived using multiple regression analysis. Good predictability was found for perceived firmness using Instron measures of firmness and compression or Grain Research Laboratory (GRL) measures of tenderness, compression, and recovery. Perceived chewiness can be accurately predicted from Instron measures of firmness or GRL measures of tenderness. Perceived stickiness can be reasonably predicted from Instron measures of compression, stickiness and strand stickiness or GRL measures of recovery and stickiness. By establishing a relationship between sensory and instrumental measures of texture, this study validated the use of instrumental measures to estimating the perceived sensory quality of cooked spaghetti.

Chapter 5 presented the first experiment in the optimization of cooked spaghetti quality. Response surface methodology was used to evaluate the relationships between durum protein level and spaghetti drying temperature and their effects on cooked spaghetti quality. Contour plots were generated from fitted regression equations for firmness, compression, relaxation, and cooking loss. Firmness and compression were primarily affected by protein level whereas relaxation was mainly affected by drying temperature. Cooking loss for optimally cooked spaghetti was mainly influenced by protein level whereas cooking loss of overcooked spaghetti appeared to be equally influenced by both variables. Superimposing the two-dimensional contour plots permitted identification of regions where protein level and drying temperature might be expected to yield spaghetti of comparable cooking quality to commercial durum spaghetti samples. Most experimental spaghetti met or exceeded the satisfactory quality range of commercial durum spaghetti. Limiting factors were relaxation time for optimally cooked and overcooked spaghetti and cooking loss of overcooked spaghetti. To meet these constraints, at a protein level of 11%, a drying temperature greater than 60° C can be expected to give acceptable spaghetti. At protein levels between 12 and 13%, a drying temperature of at least 55° C can be expected to give acceptable spaghetti. For protein levels greater than 14%, drying temperatures greater than 50° C can be expected to yield spaghetti of acceptable quality.

The final optimization study (Chapter 6) investigated the relationship between blending level of hard red spring farina with durum semolina and spaghetti drying temperature and their effects on cooking quality and color characteristics of spaghetti. Contour plots generated from fitted regression equations for firmness, compression, relaxation and strand stickiness of optimally cooked spaghetti revealed that high durum levels in combination with high drying temperatures was the region of optimized response. Drying temperature was not as critical to responses of firmness, relaxation, and compression of overcooked spaghetti but high levels of durum semolina were important in optimizing these responses. The optimum response for cooking loss of overcooked spaghetti was achieved with drying temperatures between 60° and 80° C. The color parameter of brightness was found to diminish with high levels of durum semolina and high drying temperatures whereas purity was found to intensify this region. The area of optimum response for dominant wavelength was defined by drying temperatures less than 80° C.

Superimposing the individual contour plots for all response variables permitted the identification of regions where all quality characteristics met or exceeded satisfactory quality range of commercial durum spaghetti. The most limiting factors were strand stickiness and firmness of optimally cooked spaghetti and compression energy and relaxation time of overcooked spaghetti. To satisfy these constraints, durum levels no lower than 60% are required with drying temperatures greater than 70° C. Within this optimized region, a number of combinations of durum semolina levels and drying temperature were identified that can be expected to yield acceptable spaghetti. For example, at a durum level of 60%, drying temperatures between 80° and 90° C can be expected to give acceptable spaghetti. At a durum level of 75%, drying temperatures between 75° and 90° can be expected to give acceptable spaghetti and at a durum level of 100%, drying temperatures between 70° and 90° C can be expected to yield spaghetti of acceptable quality.

7.2 GENERAL CONCLUSIONS

The first overall objective of this research was to develop standardized cooking procedures and Instron methods for measuring the textural properties of cooked spaghetti. The second overall objective was to optimize spaghetti cooking quality characteristics through the use of response surface methodology by varying raw material levels and spaghetti drying temperatures.

The importance of using a standardized cooking water for preparing spaghetti for the assessment of cooking quality was confirmed by this research. An artificially hardened cooking water was adopted for spaghetti cooking studies that gave similar results to tap water for spaghetti stickiness and cooking loss.

Instron test methods for assessing the firmness, compression, elasticity, and stickiness of cooked spaghetti were developed and operating factors that influenced results were identified. Operating conditions that showed high repeatability and reproducibility and reasonable discrimination between spaghetti samples were selected for each of the developed Instron tests. Validation of the instrumental tests for assessing spaghetti texture was performed by relating instrumental measurements with sensory ratings of texture. Although some progress was made in developing a method for measuring the surface stickiness of spaghetti using the Instron, further work is necessary to develop a method that is more reliable.

Response surface methodology was shown to be an effective and useful method in identifying optimal raw material levels and spaghetti drying temperatures to produce spaghetti of comparable quality to commercial durum spaghetti samples. Two and three-dimensional contour plots illustrated and clarified relationships and interactions between the independent variables and their effects on response variables. Spaghetti cooking quality was found to be influenced by protein level of durum semolina and drying temperature and by blending level of hard red spring farina and durum semolina and drying temperature. For low durum semolina protein levels (11-13%) drying temperatures of at least 55°-60° C are indicated whereas at higher protein levels (14-17%) drying temperatures of at least 50° C are indicated in order to yield acceptable cooked spaghetti. The second optimization study predicted that blending levels of durum semolina exceeding 60% combined with drying temperatures between 70° and 90° C will yield spaghetti of acceptable commercial quality. Drying temperature was found to depend on the blending level, with a small temperature range (80°-90° C) indicated at the lower durum level (60%) compared to a large temperature range (70°-90° C) indicated at a high durum level (100%).

7.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Cooking water composition was found to influence spaghetti stickiness and cooking loss. Research is needed to more clearly establish the role of specific mineral constituents and the role of cooking water pH in influencing these cooking quality characteristics. The extent to which the two factors influence each other should also be examined. Furthermore, the effect of water hardness and pH used in pasta processing should also be investigated.

With increasing use of the Instron in textural assessments of food products, a need exists for the development of test methods and the selection of operating conditions that offer high repeatability, reproducibility and discrimination among samples. Research should continue in this area with the goal of providing a systematic approach for establishing testing procedures for a number of food products. Continued work in the validation of instrumental procedures by relating instrumental and sensory measurements of texture is necessary. Much work remains in refining an instrumental procedure for estimating perceived stickiness.

Response surface methodology was successfully used to clarify relationships between raw material levels and drying temperature and their effects on cooking quality characteristics. Developed models require additional study to verify and further extend their applicability. In particular, the relationships between raw material levels and drying temperature and their effects on spaghetti cooking quality needs to be examined using spaghetti processed commercially. Drying temperatures greater than 90° C should also be examined. A follow up study to the initial optimization study completed on the effects of blending levels and drying temperature should be undertaken now that the screening experiment has identified the projected region of optimization. Additional response variables should be considered in succeeding studies.

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APPENDIX 1

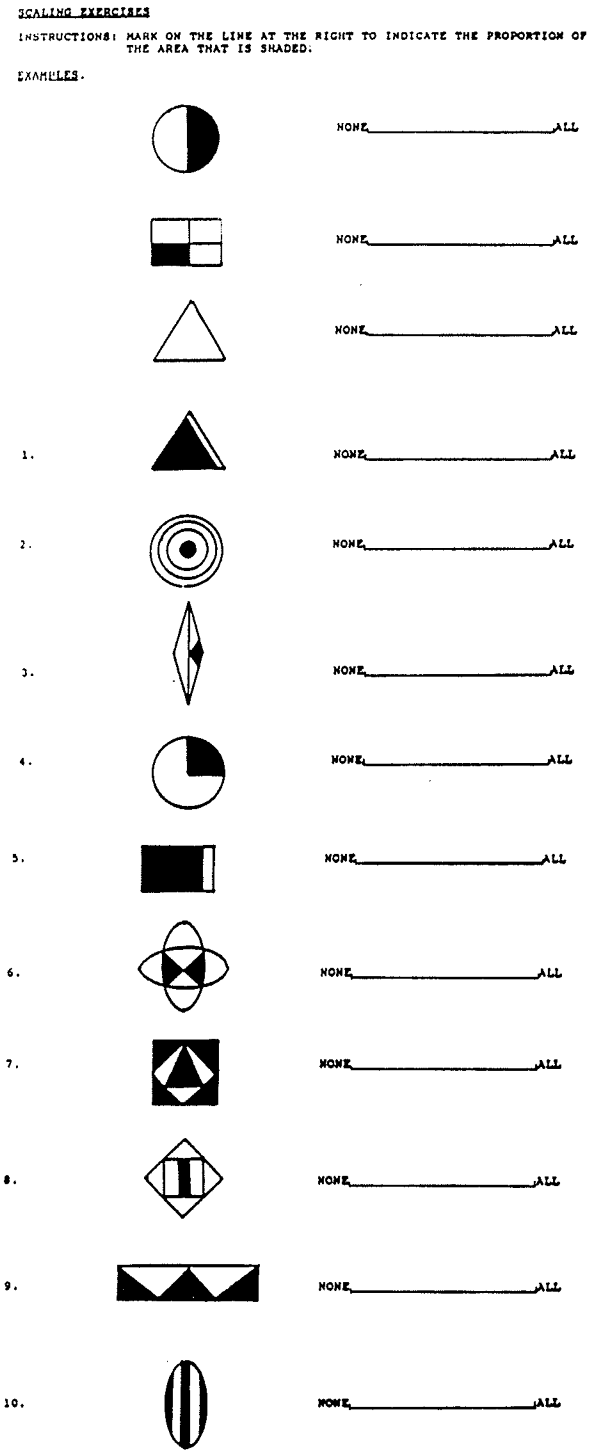
Stickiness and Cooking Loss Values* for Two Brands of Spaghetti Cooked in Seven Types of Cooking Water

Brand	Water	Stickiness N/m^2	Cooking Loss %
H	Deionized	503.8 (119.1)	5.5 (0.22)
	GRL	578.8 (95.5)	5.4 (0.21)
	GRL Diluted	445.0 (50.5)	5.5 (0.20)
	Reform 1	702.5 (98.1)	7.2 (1.16)
	Reform 2	711.3 (102.0)	5.9 (0.23)
	Tap	595.0 (87.0)	5.6 (0.32)
	Well	567.5 (75.0)	4.9 (0.22)
I	Deionized	777.5 (66.8)	4.9 (0.20)
	GRL	941.3 (115.3)	5.0 (0.19)
	GRL Diluted	761.3 (98.7)	5.4 (0.39)
	Reform 1	1302.3 (90.1)	7.4 (1.46)
	Reform 2	1301.3 (98.3)	6.3 (0.92)
	Tap	1392.5 (120.4)	5.4 (0.48)
	Well	1215.0 (88.0)	11.0 (1.66)

* mean (sd) of 8 cooking replications

APPENDIX 2

Scaling Exercise Used in Training of Panelists



From: Meilgaard, M., Civille, G.V. and Carr, B.T. (1987).

APPENDIX 3

Reference Samples Used For Sensory Assessment of Spaghetti Texture

Parameter	Endpoint	Reference	Brand Name & Sample Size
Adhesiveness to Lips	not sticky	cherry tomato	1 cm slice, discard ends
	moderately sticky	almond	Harvest Time, 0.5 cm slice, blanched
	very sticky	corn flake	President's Choice, 1 piece
Elasticity	low degree	dried apricot	Golden Harvest, 1 x 2 cm piece
	high degree	canned whole mushroom	Taste Tells, 1 piece stem removed, drained well
Firmness & Chewiness	soft sl. chewy	Havarti cheese	Lucerne, 2.5 cm cube
	firm very chewy	cheddar cheese	Lucerne, 2.5 cm cube
Cohesiveness	low degree	carrot	1 x 1.5 x 1 cm piece
	high	brownie	Double Fudge, Duncan Hines, 1 cm cube
Tooth Pack	low degree	carrot	1 x 1.5 x 1 cm piece
	moderate	cheddar cheese	Lucerne, 2.5 cm cube
	high	cracker	Bite Size Saltines, 1 piece

APPENDIX 4

GRL Texture Values* For Commercial Spaghetti

Sample Identity Letter	Cooking Time	Tenderness mm/sec $x10^3$	Compression %	Recovery %	CQP sec/mm $x10^{-3}$	Stickiness N/m^2
A	optimum	32.3	64.2	72.3	35.3	651.7
		(2.7)	(4.1)	(5.1)	(4.7)	(125.6)
	over	43.5	91.3	13.5	4.2	648.3
		(2.4)	(11.7)	(24.7)	(7.8)	(80.6)
B	optimum	35.6	65.9	70.9	30.7	930.0
		(2.8)	(4.6)	(5.4)	(5.5)	(140.9)
	over	45.8	95.0	0.0	0.0	1176.7
		(3.5)	(4.0)	(0.0)	(0.0)	(96.1)
C	optimum	32.0	59.1	75.3	40.0	730.0
		(1.9)	(3.8)	(5.6)	(4.1)	(114.4)
	over	39.8	65.4	58.3	22.7	713.3
		(1.6)	(4.1)	(11.7)	(5.3)	(65.3)
D	optimum	31.4	56.8	73.6	42.4	751.7
		(4.0)	(4.9)	(4.4)	(8.2)	(122.5)
	over	36.0	85.7	13.6	6.6	701.7
		(1.5)	(16.1)	(24.7)	(12.1)	(127.5)
E	optimum	33.3	64.0	62.4	29.7	985.0
		(2.4)	(4.4)	(8.9)	(6.1)	(73.7)
	over	42.7	87.7	6.0	2.0	1043.3
		(2.5)	(11.0)	(14.1)	(4.8)	(175.4)
F	optimum	40.6	69.8	59.4	21.2	893.3
		(2.7)	(4.9)	(7.5)	(3.5)	(106.7)
	over	54.5	98.0	0.0	0.0	941.7
		(3.2)	(1.3)	(0.0)	(0.0)	(123.4)
G	optimum	29.3	53.6	75.6	48.7	673.3
		(1.5)	(5.2)	(5.8)	(6.6)	(37.2)
	over	35.3	75.4	30.9	14.2	768.3
		(2.1)	(17.9)	(24.4)	(13.6)	(76.5)
H	optimum	29.7	59.7	69.4	40.3	620.0
		(3.6)	(6.0)	(5.8)	(9.0)	(127.1)
	over	42.0	78.0	50.1	16.9	646.6
		(4.6)	(16.8)	(34.1)	(11.6)	(95.2)
I	optimum	41.8	70.5	37.7	13.3	1448.3
		(2.4)	(6.1)	(14.1)	(6.2)	(79.6)
	over	52.8	97.3	0.0	0.0	1455.0
		(3.3)	(3.8)	(0.0)	(0.0)	(172.5)

* mean (sd)

APPENDIX 5

Instron Values* For Commercial Spaghetti

Sample Identity Letter	Cooking Time	Shear Force g	Work to Shear g.mm	Compress-ion g.mm	Relax-ation sec	Sticki-ness mm²	Strand Sticki-ness v/sec
A	optimum	478.4	312.0	206.3	44.9	10.5	62.6
		(28.4)	(29.9)	(7.4)	(4.0)	(2.3)	(8.3)
	over	361.8	271.6	279.6	21.1	13.8	71.9
		(13.4)	(20.3)	(4.3)	(1.4)	(6.0)	(17.2)
B	optimum	505.7	355.6	230.7	33.4	13.8	75.1
		(17.9)	(20.7)	(4.9)	(2.4)	(4.0)	(20.9)
	over	334.4	247.8	314.5	15.8	17.5	52.6
		(21.1)	(23.9)	(7.1)	(0.8)	(2.5)	(12.0)
C	optimum	612.0	470.8	220.4	33.0	14.5	70.3
		(11.2)	(9.9)	(3.0)	(2.1)	(5.5)	(6.9)
	over	450.9	361.8	299.5	19.6	14.3	68.8
		(13.8)	(24.4)	(4.1)	(1.6)	(2.2)	(12.0)
D	optimum	649.7	499.0	226.4	39.0	15.8	75.6
		(17.5)	(22.6)	(4.7)	(2.9)	(3.9)	(16.5)
	over	469.0	421.4	313.7	22.3	18.5	85.1
		(6.6)	(26.6)	(7.3)	(2.6)	(4.6)	(15.1)
E	optimum	538.7	397.5	248.8	24.6	14.5	71.0
		(46.6)	(40.5)	(9.1)	(5.0)	(1.7)	(22.0)
	over	408.8	306.3	343.9	14.6	21.5	83.7
		(24.2)	(23.7)	(3.5)	(0.9)	(1.4)	(15.4)
F	optimum	448.4	328.7	246.1	28.6	16.0	82.5
		(14.0)	(15.4)	(3.7)	(4.3)	(3.8)	(12.9)
	over	324.3	260.7	334.5	13.3	18.5	83.5
		(13.6)	(19.1)	(11.2)	(1.1)	(3.8)	(16.7)
G	optimum	646.1	594.4	222.6	41.5	13.8	80.8
		(27.3)	(30.3)	(5.9)	(5.4)	(4.0)	(10.0)
	over	462.1	448.5	302.4	24.0	13.3	53.6
		(34.1)	(35.2)	(5.7)	(2.8)	(3.9)	(6.6)
H	optimum	579.0	432.1	214.4	34.5	9.8	43.0
		(30.2)	(33.8)	(8.7)	(4.0)	(3.1)	(20.0)
	over	422.1	333.4	289.8	18.8	10.8	54.5
		(22.5)	(39.5)	(5.8)	(2.4)	(2.8)	(15.9)
I	optimum	485.1	355.0	295.6	17.9	28.8	81.5
		(14.3)	(35.8)	(4.3)	(1.2)	(6.7)	(18.2)
	over	346.9	241.7	337.3	13.1	27.8	102.9
		(8.7)	(11.2)	(4.2)	(1.1)	(5.0)	(42.3)

* mean (sd)

APPENDIX 6

Cooking Loss Values* For Commercial Spaghetti

Sample Identity Letter	Cooking Time	Actual Cooking Loss %	Predicted Cooking Loss %
A	optimum	4.9 (0.3)	5.5 (0.2)
	over	7.7 (0.3)	8.1 (0.2)
B	optimum	6.9 (0.7)	6.4 (0.3)
	over	10.2 (0.2)	9.6 (0.2)
C	optimum	5.7 (0.3)	5.8 (0.1)
	over	7.9 (0.9)	8.5 (0.2)
D	optimum	5.9 (0.8)	5.9 (0.2)
	over	7.8 (0.5)	7.7 (0.3)
E	optimum	6.3 (0.2)	5.6 (0.2)
	over	11.1 (1.3)	8.5 (0.3)
F	optimum	6.3 (0.8)	5.9 (0.2)
	over	9.1 (1.0)	8.5 (0.6)
G	optimum	5.2 (0.3)	5.4 (0.1)
	over	7.5 (1.0)	7.3 (0.5)
H	optimum	5.4 (0.1)	5.7 (0.1)
	over	8.7 (1.4)	8.6 (0.6)
I	optimum	8.5 (1.3)	7.8 (1.3)
	over	15.8 (3.3)	14.9 (2.8)

* mean (sd)

APPENDIX 7

Sensory Texture Scores For Commercial Spaghetti

Sample Identity Letter	Cooking Time	Adhesiveness	Elasticity	Firmness	Cohesiveness	Chewiness	Tooth Pack	Stickiness
A	optimum	6.0 (3.6)	8.8 (3.4)	9.2 (2.6)	4.7 (2.6)	9.0 (3.0)	7.1 (2.4)	6.9 (3.6)
	over	4.1 (2.7)	7.2 (2.5)	6.2 (3.4)	4.6 (2.6)	6.3 (2.8)	4.0 (2.3)	5.5 (2.5)
B	optimum	5.7 (2.8)	9.4 (3.0)	8.1 (3.2)	5.2 (2.8)	8.7 (2.3)	7.4 (2.8)	6.5 (2.6)
	over	4.0 (2.7)	5.6 (3.0)	4.3 (1.9)	6.4 (2.5)	5.8 (2.5)	5.1 (2.2)	6.5 (3.0)
C	optimum	4.7 (2.7)	9.0 (3.3)	9.3 (3.2)	5.7 (2.4)	9.7 (2.3)	5.7 (2.6)	7.5 (2.9)
	over	5.6 (2.7)	7.1 (2.1)	6.0 (3.4)	6.2 (2.6)	6.2 (2.1)	5.7 (2.8)	5.3 (3.4)
D	optimum	6.0 (2.7)	8.9 (2.7)	9.9 (2.6)	7.4 (2.5)	11.4 (2.0)	8.7 (2.5)	7.3 (2.9)
	over	5.0 (2.2)	8.5 (2.3)	4.5 (1.8)	7.2 (2.5)	6.8 (3.1)	6.8 (2.7)	5.7 (2.6)
E	optimum	4.4 (2.5)	8.5 (2.6)	8.4 (2.6)	5.8 (2.8)	9.5 (1.6)	6.7 (3.6)	6.4 (2.8)
	over	4.8 (2.8)	6.0 (2.9)	5.1 (2.6)	7.1 (2.3)	5.9 (2.2)	4.9 (2.8)	6.8 (3.6)
F	optimum	5.3 (2.6)	8.0 (2.5)	6.1 (3.0)	5.8 (2.9)	8.1 (2.7)	6.6 (2.0)	7.9 (3.9)
	over	4.1 (2.4)	5.6 (2.7)	2.9 (1.3)	7.5 (2.3)	4.0 (1.3)	4.6 (2.4)	6.4 (3.4)
G	optimum	5.2 (2.7)	9.0 (3.4)	10.7 (2.2)	7.2 (3.1)	11.5 (2.3)	7.6 (2.9)	5.4 (3.1)
	over	3.9 (2.2)	8.0 (2.3)	8.4 (3.2)	6.2 (3.1)	9.6 (2.2)	6.3 (2.1)	5.5 (3.4)
H	optimum	5.3 (2.3)	9.1 (3.2)	9.9 (2.7)	4.9 (3.0)	10.7 (1.1)	7.0 (2.8)	8.0 (3.3)
	over	4.9 (3.3)	7.3 (2.9)	4.6 (2.4)	6.5 (2.4)	6.6 (2.7)	5.8 (2.0)	5.6 (3.7)
I	optimum	4.2 (2.7)	7.5 (3.1)	6.9 (2.8)	8.0 (2.4)	8.6 (2.3)	8.9 (3.1)	9.9 (2.6)
	over	5.0 (2.8)	4.6 (2.9)	3.8 (2.8)	6.9 (2.9)	4.6 (2.2)	6.0 (2.8)	8.1 (4.8)

* mean (sd)