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FACTORS AFFECTING THE TEXTURAL QUALITY OF COOKED SPAGHETTI AND THE RELATIONSHIP BETWEEN ITS INSTRUMENTAL AND SENSORY EVALUATION

by

SUSAN GLENISE MARSHALL

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FACTORS AFFECTING THE TEXTURAL QUALITY OF COOKED SPAGHETTI AND THE RELATIONSHIP BETWEEN ITS INSTRUMENTAL AND SENSORY EVALUATION

MAJOR PROFESSOR: Dr. G. N. Irvine

The effects of durum variety and processing and cooking conditions on the textural quality of cooked spaghetti were measured using the Grain Research Laboratory (GRL) spaghetti tenderness testing apparatus. Standardization of these factors then permitted assessment of the relationship between this instrument and firmness of samples as perceived by a sensory panel. Multiple linear regression analysis indicated a significant ($p < 0.01$) correlation of 0.97 between instrument and panel and permitted formulation of an equation for prediction of sensory response from instrumental results.

The effect on texture, of addition of egg albumin up to 15% by weight was assessed and optimization of the instrumental parameters tenderness, compressibility and recovery was found to occur with addition of 2%. Increasing the level of protein reduced the rate of cooking as well as influencing textural quality. Studies with the amylograph and microscopic examination under polarized light, of starch extracted from cooked and uncooked spaghetti, indicated a direct relationship between rate of starch gelatinization and textural quality. This was especially true with respect to recovery. Gelatinization was found to proceed from

the outside of the strand inwards and the rate varied inversely with the protein level. Temperature of the cooking water affected the degree of gelatinization and hence the textural quality of the sample. The most desirable combination of textural paramaters occurred when the sample was cooked to al dente, and it was not until all the starch had been gelatinized that this stage was reached, thereby suggesting that it is the nature of the starch gel which is responsible for the texture of cooked spaghetti. The characteristics of this structure also appear to be affected by other factors such as the protein component, the nature of the starch present and possibly the pentosan fraction.

REVIEW OF LITERATURE

Pasta is one of the oldest forms in which processed wheat products have been sold (Irvine, 1964). Originally available as food for infants and invalids, sold only through the apothecary (Le Clerc, 1933), it has come a long way to the present where numerous brands are freely available on the supermarket shelves and the annual per capita consumption in Canada alone is 4.2 kg (IWC, 1972). With today's concern over nutrition, it is available with or without added enrichment in the form of B vitamins and iron. Apart from its ascorbic acid and calcium content, spaghetti is a fairly acceptable substitute, nutritionally, for rice or potatoes, two of the more commonly used carbohydrate sources in the North American main meal (Table 1).

Contribution of Chemical Components to Quality

Durum wheat has traditionally been the raw material chosen for pasta production since it results in a product of high quality. However, the contribution of the biochemical components of durum to quality has not been well elucidated, nor is there much information available concerning varietal reasons for quality differences.

Starch. In considering first the starch fraction in pasta, a review of the literature indicates that very little research has been reported on this subject. Studies by Sheu *et al.* (1967), dealing with the interchange of various biochemical components of hard red spring (HRS) farina and durum semolina, indicated that starch had only a small effect on the cooking quality of pasta. HRS starch resulted in increased firmness of the cooked product when substituted for durum starch, however, this

Table 1. Comparison of the nutritional composition[1] of spaghetti, rice, and potatoes[2]

Nutrients		Spaghetti enriched cooked to al dente	Rice enriched steamed	Potatoes boiled
Protein	g	5.0	2.1	1.9
Carbohydrate	g	30.1	23.3	14.5
Calcium	mg	11.0	19.0	6.0
Iron	mg	1.1	0.8	0.5
Thiamin	mg	0.18	0.11	0.09
Riboflavin	mg	0.10	0.10	0.03
Niacin	mg	1.4	1.2	1.2
Ascorbic acid	mg	0.0	0.0	16.0

[1] Watt and Merrill, 1963.

[2] Composition per 100 g edible portion.

increase was small when compared with the effect of substitution of the gluten fraction.

In 1970, Frey reported results indicating that starch had an important part in both the consistency and water absorption of pasta products. He also indicated that the protein component could be replaced with pregelatinized wheat or potato starch and still result in spaghetti of acceptable quality.

More recently, Lintas and d'Appolonia (1973) reported the results of studies dealing with the effect of spaghetti processing on semolina carbohydrates. Results indicated that starch was damaged during the mixing and extruding phases of processing but even more so during drying. No indication was given, however, as to the relationship between starch, starch damage and cooking quality.

Because the information linking starch with pasta quality is so limited, it may be worthwhile to consider the studies done to investigate the relation between starch and bread making.

A number of reports (Sandstedt, 1961; Jongh et al., 1968) have been made concerning the feasibility of producing a bread with good crumb characteristics from dough in which the gluten has been replaced by such hydrocolloids as sodium alginate, carrageenan and gelatinized potato and waxy maize starches. Jongh (1961) was even able to prepare an acceptable loaf from dough made from starch to which 0.1% of the emulsifier glycerol monostearate (GMS) was added.

From these reports it appears that starch plays a definite and important role in dough structure and baking quality of bread. Sandstedt (1961) notes the following as functions performed by starch in baking: dilution of gluten to desirable consistency; production of sugar through amylase activity and contribution of a surface suitable for a strong union with the gluten adhesive. Due to gelatinization, starch also becomes flexible allowing further stretching of the gas-cell film and is responsible for setting of the dough during the baking so that it does not collapse on cooling.

From these studies investigating the role of starch in bread baking, it is possible to hypothesize its role in pasta quality. As starch appears to affect the structure of the bread, it is probably in this area that it makes its contribution to pasta quality. It has been shown that starch gelatinization constitutes one of the most characteristic processes occurring during bread baking (Jongh et al., 1968). Gelatinization also takes place during cooking of pasta (Voisey and Larmond, 1973a; Marshall and Wasik, 1974). In fact it appears that the Braibanti technique, used to determine the al dente stage of cooking, is based on this phenomenon. This technique consists of squeezing a strand of cooked spaghetti between two plexiglass plates. If the sample is only partially cooked, a white core will be apparent in the flattened strand. At the point of disappearance of this core, the sample is said to be cooked to the al dente stage. Samples cooked beyond this stage require less pressure to flatten them and become increasingly softer in texture. It is interesting to note that although the protein fraction is generally reported as controlling cooking quality, it appears to be the starch component which is used as the basis for determining optimum cooking time. For this reason, preliminary studies into the degree of gelatinization occurring during processing and cooking, were conducted in the present study.

In considering the contribution of starch to pasta quality in the light of its contribution to bread making quality it must be remembered that starches have been shown to vary in characteristics not only from species to species but also among varieties within a species (Alsberg and Rask, 1924). For this reason, differences between bread wheat and durum wheat starches could be expected.

Protein. In contrast to starch, the relationship between protein quality and quantity, and pasta quality has received more extensive consideration.

In 1939, Binnington et al. reported that the breaking strength of dry pasta appeared to increase with increasing protein content. However since no simple correlation could be calculated, it was felt by these authors that other factors such as protein quality, were also involved.

The effect of the biochemical constituents of durum and HRS wheats on pasta quality was investigated by Sheu et al. (1967). In this study, semolina and farina were fractionated into starch, gluten, water solubles and sludge components. A series of reconstituted starting materials was then constructed using various combinations and substitutions of the 4 component fractions. While interchanging of the starch and sludge fractions had only a small effect on cooking quality, interchanging the other 2 components produced major changes in the cooking quality. Interchanging the gluten fractions produced the most drastic changes in cooked weight and firmness. Substitution of HRS gluten for durum gluten reduced the cooked weight of the macaroni, however, this substitution also produced a firmer product. Gluten, in conjunction with the water-soluble fraction, also appeared to affect the amount of residue in the cooking water. Durum gluten and water solubles increased the amount of cooking water residue when substituted for the corresponding HRS components. As a result of these studies, the authors recommended that future explorations be directed towards a more detailed study of the effects of gluten and water-solubles on pasta quality.

Matveef (1959) reported that 'bite' in cooked pasta appeared to be a function of the percentage of gluten in the sample. In studies (1966) involving macaroni samples ranging in gluten content from 9 to 18%, he noted parallel increases in force required to break the samples, from 60 to 130 g. Holliger (1963) also reported that increasing the amount of gluten in spaghetti decreased the amount of cooking water residue and increased the force required to produce a given extension in the cooked product.

As a follow up to these and other studies, Matsuo and Irvine (1970) reported results of experiments done to determine the effect of different types of gluten on spaghetti quality. Weak gluten products appeared to be softer when cooked, suggesting that the type of gluten does affect the tenderness of the cooked product. Interchanging the gluten fraction of Stewart 63 semolina, which is weak, with that from Pelissier semolina, which is strong, had a marked effect on firmness of the spaghetti produced. Stewart 63, which generally produces a fairly soft product, when substituted with Pelissier gluten produced a firm product and vice versa. In addition to the type of gluten present, the amount of gluten and its effect on firmness was also considered. Tests indicated that the type had a much more pronounced effect on quality than the amount.

The effect of protein composition on cooking quality of pasta has also been studied. Recently, Walsh and Gilles (1971) reported tests on eight durum and common wheat varieties of varying pasta making quality. The proteins of these wheats were separated into 5 fractions: albumins, globulins, gliadins, glutenins and base-solubles; statistical analyses were applied to examine their relationship to various cooking quality parameters. Albumins and glutenin were shown to be negatively correlated with spaghetti color and cooking loss. Globulins showed the reverse, as well as a negative correlation with firmness. The gliadin fraction showed no significant ($p < 0.05$) correlation with quality. The base-soluble fraction showed positive correlations with cooking loss and color. Further study using Sephadex G-200 gel filtration indicated that gliadin could be positively related to spaghetti color but negatively to cooked pasta firmness.

Investigations to determine the effect of protein content on spaghetti cooking quality have also been reported (Matsuo et al., 1972). In these studies, high protein samples were firmer, less compressible and more elastic than the low protein samples, indicating a definite relationship between protein content and cooking quality. For an acceptable product, the authors suggest that the protein content should be at least 11%. If it is not, the protein content may be increased by addition of protein from other sources. The alternate source, however, must be chosen carefully since not all proteins will improve the cooking quality. Addition of fish protein concentrate, for example, actually decreased the cooking quality of the finished product. In studying a number of possible additional protein sources, Matsuo et al. (1972) found that only egg albumin and wheat gluten improved the cooking quality. Rapeseed flour, soya flour and durum albumin and gliadin showed little if any ability to improve the cooking quality.

In studying the effects of additions of protein from sources other than wheat, Dürr (1971) found that not only egg white but also native whey proteins produced improvements in spaghetti cooking quality. This author reported that the suitability of milk proteins as sources of enrichment depended on the isolation methods used to obtain them. Products produced with milk proteins which had been irreversibly coagulated by heat or rennet were poor in textural quality while those produced from milk concentrates added in liquid form and hence coagulating during pasta cooking were of good quality.

The most recently reported work dealing with the protein fraction and spaghetti cooking quality is that concerning the components of gluten: glutenin and gliadin.

Preliminary studies by Matsuo and Bradley (1973) showed glutenin content to be related to quality factors such as dough development time, tolerance index, gluten resistance to extension, tenderness index and % recovery in the cooked spaghetti. A low ratio of gliadin to glutenin was also suggested as being important in determining cooking quality.

The relationship between glutenin and pasta quality was examined in much greater detail by Wasik (1973). Conclusions reached in this study were that varieties having a high glutenin content and low gliadin/glutenin ratios had the best rheological and cooking properties. These conclusions were based on a study of 15 durum wheat varieties. Gel filtration studies indicated differences in protein composition among varieties of different spaghetti making qualities. On the basis of glutenin to gliadin ratios, the varieties could be ranked in almost the same order as that derived by considering the rheological and cooking test results. No significant intervarietal differences were observed in scanning electron microscope and amino acid analysis studies of the samples. However, sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE) studies on the glutenins indicated distinct varietal differences in molecular weight distribution and relative concentrations of the first 6 subunits. These differences were felt to be directly related to pasta quality, suggesting that not only the amount, but also the composition of the glutenin is an important factor in determining the quality of the finished product.

Despite all these studies, however, there is still no clear-cut biochemical explanation for the variation in pasta making quality of durum wheats.

Quality Measurements

Many attempts to elucidate the roles of the various components of wheat have, as mentioned, involved the substitution of one fraction for another. Samples produced are then tested for quality and the effect of the component is determined by inference. Although this approach is fairly sound, it is of little value unless the comparisons can be made in concrete terms and are repeatable. For this purpose, instrumental measurements are desirable.

The term 'quality' is fairly nebulous and involves the consideration of a number of aspects. These include color, translucency, mechanical strength, surface, cooking characteristics and even flavor. Many of these factors, such as color, translucency and surface conditions may be measured instrumentally and official methods of analysis are well established. The characterization of cooking quality, however, is more difficult since its measurements and definitions tend to be more subjective.

Instrumental assessment of quality. In the past, cooking quality has been defined in terms of the increase in volume of the cooked product, the ability of the product to resist disintegration during cooking and the texture of the product as determined by some mechanical means (Binnington et al., 1939; Holliger,1963b). Texture measurements, however, have often been applied to the raw pasta and as such do not really reflect the quality of the cooked product (Matsuo and Irvine, 1969). A number of instruments have now been developed which will evaluate cooked pasta and thus facilitate textural quality comparisons on a common basis.

In 1939, Binnington et al. described an apparatus for testing the tenderness of cooked macaroni. It consisted of a plunger to which a steadily increasing load could be applied until a predetermined reduction in sample thickness was obtained. The increasing load was obtained by adding mercury at a constant rate and the weight of the mercury was taken as an index of tenderness of the sample. This apparatus was accepted as the official method in Cereal Laboratory Methods and its use was reported for a number of years. Because it does not sufficiently characterize the properties of cooked pasta, Holliger (1963b) introduced an instrument which assessed the mechanical properties of both cooked and uncooked pasta. This machine consisted of a mobile beam through which a continuously increasing force could be applied to the sample. Dry samples were assessed for bending strength and cooked samples were tested for tensile strength. No attempt was made by the author to interpret his results in terms of sensory texture perception. This instrument was subsequently refined and offered for commercial use by Buhler as Model TLU-101 Laboratory Tester for macaroni products (Holliger, 1966). From the description given of the method, it appears to be a fairly cumbersome one in that samples must first be mounted in clamps, then cooked and tested. Once again, no information is given as to the relationship between sensory and instrumental results.

In 1969, the development of a testing instrument designed to simulate the 'bite test' was reported by Matsuo and Irvine. This apparatus consisted of a cutting edge shaped like a tooth which was applied, with a continuously increasing force, to a single strand of spaghetti. The rate of cutting is recorded and results interpreted in terms of a tenderness index. The greater the magnitude of this tenderness index, the softer the sample. The test is rapid, thereby minimizing changes in the cooked product, reproducibility is good and the instrument is fairly sensitive. No attempt to relate the results of this instrument to sensory firmness perception were reported by these authors in their first paper. This apparatus was subsequently adapted to measure compressibility and recovery. In the paper dealing with its modification, mention is made of a very limited sensory test, the results of which correlated fairly well with the instrumental results (Matsuo and Irvine, 1971). Measurements made on samples to determine these 2 additional parameters were based on curves resulting from placing a fixed load on the blade for 15 sec then removing it for 15 sec. For this test the blade used is flat rather than tooth-shaped. Compressibility is then determined as the relation between blade penetration and pasta diameter while recovery is calculated as the ratio of the distance the blade is forced back, to the penetration.

This machine is simple to operate, requires no added equipment such as Holliger's sample holders (1966), allows samples to be cooked by the same methods used by a consumer and is relatively inexpensive to construct. Since it is the main vehicle used for assessing the cooking quality of spaghetti samples tested by the Grain Research Laboratory (GRL) of the Canadian Grain Commission, it would be useful to establish the degree of correlation which exists between it and human perception of firmness. Extensive studies were done as part of this thesis to test this relationship and, in addition, to formulate an equation which could be used to predict 'firmness' on the basis of all 3 textural parameters assessed.

In addition to the GRL spaghetti tenderness testing apparatus, there are two additional instruments for pasta texture testing which bear mentioning. In 1971, Walsh reported the development of a method to measure the firmness of cooked spaghetti using an Instron Universal Tester. The tooth designed for this test was similar to that used by Matsuo and Irvine (1969) for firmness assessment and once again, testing was done on a single strand of spaghetti (Walsh and Gilles, 1971). In conjunction with the instrumental testing of the samples, a taste panel assessment was done. A correlation of 0.812, significant at the 1% level of confidence, was reported between the average taste panel scores and the instrumental results. This result may not be as meaningful as it appears, however, since only 6 of the 9 panelists showed significant correlations with the instrument. Furthermore, panelist assessments were made using a 'desirability' scale. Since individual preferences differ greatly, a method such as this is likely to introduce a large degree of variability. The author (Walsh, 1971) notes that the panel members showed a great deal of variation in their concepts of firmness which probably also affected the results.

Voisey and Larmond (1973a) also reported results of tests conducted with an Instron adapted to test multiple strands at one time. Since the human consumes more than one strand at the time of eating, this adaptation probably gives a more accurate assessment of texture than do those tests consisting of a single 'bite' on a single strand. Good correlation was found between the results from the multiple blade shear cell and panel data.

The second instrument modified to measure the texture of cooked pasta is the Ottawa Texture measuring system (OTMS) developed by Voisey (1971). A multiple blade shear cell similar to the one described for the Instron (Voisey and Larmond, 1973a) has been developed to fit the OTMS and is commercially available. It too shows a good correlation between instrumental and sensory data. The results for both these machines were reported only for shearing attachments and gave no results for parameters such as compressibility and recovery. Since texture is perceived as a complex of rheological properties, measurement of as many of these as possible is important for adequate assessment.

Another drawback with the Instron and OTMS is the cost which is approximately 10 times that of the GRL spaghetti tenderness testing apparatus.

From the previous discussion it may be seen that a number of instruments are available for testing the cooking quality of spaghetti. Although much time has been spent in developing these instruments which assess various textural attributes of cooked pasta, much less effort has been expended to examine their correlation with sensory evaluation. Since the human is the final judge of pasta texture and the one who will be most influenced by cooking quality, this relationship between human and instrument bears closer examination.

Sensory evaluation of quality. Texture is a composite property related to various physical properties of a foodstuff such as elasticity, firmness and cohesiveness. Sensory perception of texture is a fairly complex matter involving sense organs in the tongue, gums and hard and soft palate. The influence of textural properties on human acceptance of foods has been shown to be fairly substantial, especially in products which are bland in flavor (Szczesniak, 1969). Since pasta is a fairly bland food, perhaps this explains the great concern of consumer and researcher alike, with the texture of the cooked product. Because texture is so complex, its assessment by means of sensory panels is important. In fact, Matz (1962) reports that sensory tests are probably the only way to obtain meaningful information on food texture.

A large number of test methods exist for sensory evaluation of texture. For simplicity, they may be classed as either (i) difference tests or (ii) preference tests. The latter are generally used to establish consumer acceptance or preference for a certain foodstuff while the former are used as analytical tools to establish differences among products or levels of a substance within a product. Within these categories of tests there are a myriad of test types available for use depending on the type of product being tested and information desired.

The method chosen for use in this research is that of ratio estimation. Psychophysical testing has shown that people handle sensory information in varied ways and in a logarithmic rather than linear fashion. The method of ratio estimation has been found to compensate for these differences since it allows panelists to judge samples on a sensory continuum which is permitted to vary in the same way as the physical one (Moskowitz *et al.*, 1972). Furthermore, this technique is fairly simple to use, has been shown to give reproducible results and requires little training of the panel other than to familiarize them with the concept of rating samples in proportion to a standard. Simple power functions of the equation form $S = kI^n$ have been found to be adequate to describe the relationship of experimental results produced using this technique. For this power function, S = subjective response, I = instrumental response, k is a constant and n provides a measure of the rate of increase in sensory magnitude with concommitant increases in physical intensity. The exponent n is independent of the units of sensory and instrumental measurement and is unaffected when all the subjective results are multiplied by a constant factor.

Although sensory evaluation of cooking quality is important, few reports of investigation into this aspect of quality appear to have been published. As previously mentioned, Walsh (1971) compared instrumental results from the Instron with taste panel data. Statistical analysis of the two sets of data indicated good agreement, however, taste panel methods used are somewhat suspect.

The most extensive sensory testing of pasta quality to date appears to be that conducted by the Food Research Institute in Ottawa (Larmond and Voisey, 1973; Voisey and Larmond, 1973a). Using a panel of experienced judges, 8 samples of commercially and laboratory produced spaghettis were tested for firmness, gumminess, adhesiveness chewiness, flavor, starchiness and 'individuality'. These parameters were also examined for relationships with consumer panel opinions. Significant differences ($p < 0.05$) were detected among varieties for all parameters. The parameters of firmness and gumminess seemed adequate to describe the pasta samples, as gumminess was highly interrelated with starchiness, adhesiveness and individuality. Consideration of flavor and chewiness were also discontinued since they were not shown to correlate with any of the characteristics rated by the consumer panel. This consumer panel consisted of 375 Italian housewives who were given spaghetti samples which they were asked to rate for flavor, appearance before and after cooking, ease of preparation and handling. These ratings were made on a 7 point scale and data were manipulated to give a value for overall quality. These consumers were also requested to give their reaction to 8 other quality attributes including color before and after cooking, appearance and handling characteristics and firmness by mouth. Although an Italian brand name pasta rated best for overall quality, a sample made from the Canadian durum variety Hercules was second. The amount of confidence which can be placed in the ability of these consumers to discriminate among samples is questionable, however, since the mean values of the ratings for all samples covered a very small range of 4.42 to 4.84. Correlation between panel and consumer results was 0.95 for firmness (significant $p < 0.05$) and 0.90 when laboratory panel results for gumminess were tested against consumer ratings for "taste". Significant correlation was also found between panel firmness and consumer assessment of 'overall quality'. The conclusion of these authors (Larmond and Voisey, 1973) was that firmness and gumminess could be used to predict consumer acceptability.

Similar experiments were conducted to determine the correlation between the panel and instrumental results. As previously mentioned, fairly good agreement was found between sensory assessment of firmness and the Instron and OTMS. Differences can probably be accounted for by the fact that the cooking methods used for sensory testing and instrumental evaluations were somewhat different (Voisey and Larmond, 1973). Slightly different temperatures were used, thus cooking times varied. In addition, samples prepared for human consumption were cooked in water containing 1% salt. Since Binnington et al. (1939) reported that the presence of salt in the cooking water results in increased tenderness, some of the variation may be due to this.

Thus it appears that a trained panelist may be used to help predict consumer acceptance of pasta, and that prediction of panelists' results may be possible by instrumental means. Part of the research involved in this thesis then was to establish the correlation between the GRL spaghetti tenderness testing apparatus and sensory panel data, and if possible, to construct some type of prediction formula for the purposes of anticipating human response to cooked pasta quality.

Once a suitable method has been established for comparison of samples, then the cooking quality of the pasta may be studied.

Contribution of External Influences to Quality

Quality may be affected by internal and external influences. The internal ones are those such as the biochemical constituents whose effects on quality have previously been discussed. The external influences include such things as conditions under which the sample was processed, and conditions under which it was cooked. In other words, those things which serve to modify the intrinsic make up of the starting or cooked product will be considered as external influences and will now be reviewed at greater length.

Processing conditions. Pasta is generally produced by mixing water with durum semolina to produce a dough, and extruding or sheeting and cutting this to yield the desired form. In some cases, egg or milk solids may be added. Following extrusion, the product is dried to 13% moisture or less under controlled conditions of temperature and humidity. This general procedure is followed for both laboratory and commercial production of pasta. A good review of industrial processing is found in an article by Hoskins (1959).

Although the process of pasta production is fairly straightforward, there are a number of things which can have an effect on the quality of the finished product. These include the wheat variety from which the semolina is milled, as well as the processing conditions. Certain varieties of durum wheat have been shown to yield pastas of superior cooking quality. Variation in processing conditions has also been shown to affect quality characteristics, regardless of the variety used (Anderson and Cunningham, 1943). The correct absorption, vacuum applied during mixing, mixing time and temperature as well as temperature, pressure and duration of the resting period following mixing and prior to extrusion, must all be controlled to optimize results during pasta production. Although tests have been reported on various aspects of these conditions as they affect laboratory production of pasta, most of the results have related to their effect on color and handling properties, rather than effects on cooking quality. Initial laboratory investigations were conducted on small disks of pasta dough or on macaroni (Martin et al., 1946), but today spaghetti is the preferred form for evaluation purposes. High absorption has been shown to have adverse effects on firmness and cooked weight (Walsh et al., 1971).

The application of vacuum during mixing has been implicated in cooking quality and color of pasta. High vacuum tends to adversely affect color but improves firmness, cooked weight and reduces cooking loss (Walsh et al., 1971).

Duration and temperature of dough mixing are also important factors affecting the quality of the finished product. In studies dealing with the effect of processing conditions on paste properties, Cunningham and Anderson (1943) reported that short mixing times (40 sec) produced pasta disks which were more yellow and more transparent than those processed for long mixing times (100 sec). This they felt was presumably due to the increase in the number of small air bubbles incorporated into the dough. In subsequent tests (Anderson and Cunningham, 1943) these authors reported that increasing the mixing time also resulted in a definite decrease in pigment content and attributed this to destruction of the pigment by oxidation during mixing. These authors also reported that increases in mixing time made the dough more sensitive to changes in other processing factors. The effect of increasing the temperature during mixing appears to have the same effect as increasing the time. Cunningham and Anderson (1943) report, however, that this relationship is not linear over all mixing temperatures, especially in cases below $26^{o}C$.

Following mixing, the dough is generally allowed to rest for a certain length of time prior to extrusion. The length of this rest period, temperature during resting and application of pressure have been the subject of a number of pieces of research. This period provides for maximum efficiency during extrusion. It permits the dough to reach the same temperature as the press which in turn produces the desired degree of plasticity responsible for the smooth surface on the finished product and controls the tendency of the samples to stretch and break during the initial steps of the drying process (Geddes, 1936). The length of resting time desirable was studied by Cunningham and Anderson (1943) who reported that increases in time beyond 15 min did not produce significant improvements. The standard resting period for laboratory pasta production was subsequently chosen as 9 min (Martin et al., 1946). No reports on the effect of length of rest period on cooking quality have been found. Control of press temperature is necessary to the extent that the temperature of the dough will affect its consistency which in turn could affect the extrusion process. In the micro laboratory processing of pasta the dough is rested at a fairly high temperature (50°C) in order to reduce its viscosity and thus lower the required extrusion pressure, thereby improving the surface of the pasta (Martin et al., 1946).

In surveying the literature, the processing condition exerting the greatest effect of all, however, appears to be pressure applied during the rest period. Martin et al. (1946) reported two effects of pressure. First it increases the translucency of the dough and secondly it decreases dough viscosity thereby lowering the required extrusion pressure and hence improving pasta surface finish. Smith et al. (1946) reported that small numbers of relatively large bubbles in pasta dough contribute to high translucency whereas large numbers of small bubbles contribute to high opacity. In studies with pasta disks, they were able to show that application of pressure to pasta dough would cause the bubbles to coalesce and translucency would be improved. The relationship between pressure and the number of bubbles was reported to be curvilinear and the effect of pressure was shown to increase with the length of time it was applied. This same pressure effect was reported by Irvine and

Anderson (1951) in conjunction with macaroni dough.

As well as their effects singly, certain combinations of the various processing conditions have been shown to affect the quality of pasta. Combinations involving pressure plus one other processing variable produce the most significant effects, however, their contributions have been reported only with respect to color and translucency. Their influence on other quality characteristics, while not statistically significant, was thought important enough by Anderson and Cunningham (1943) for the authors to suggest that the exact effect on quality of a given processing factor could not be stated unless the levels at which all the other processing factors were standardized were also specified.

Since processing conditions appear to affect color, translucency and the handling properties of the dough, it is conceivable that they could also affect the cooking quality of the finished product. Part of the purpose of this study, therefore, was to examine the effect on cooking quality of variations in resting temperature and pressure during spaghetti production.

Cooking conditions. A second external influence on observed cooking quality results is the actual conditions under which the pasta is cooked. This would include the temperature of the cooking water, the length of cooking time and the treatment following cooking.

There is a certain amount of controversy as to the correct method for cooking the samples prior to quality testing. Some researchers (Feillet, 1970) feel that all samples should be cooked for a fixed length of time, whereas others prefer to cook each sample to al dente since this is generally the point to which it is cooked for human consumption.

Spaghetti is traditionally cooked with the water at a full rolling boil. No information was discovered in the literature as to the effects of cooking at lower temperatures, on quality.

Finally, samples may or may not be placed in cold water, or blanched, following cooking. The effects of cooking time, water temperature and blanching, on cooking quality, were also studied in this research.

Thus, consideration of the literature published to date, indicates that research is proceeding as to the probable biochemical explanations for cooking quality and into the role of the various components and their contribution to quality. The starch component has apparently received little consideration, however, there is some suggestion that it may be implicated in the firmness of the cooked product. Gluten, the wheat protein, and its various subfractions, glutenin and gliadin have received much more extensive consideration. Cooking quality appears to be related to the quality as well as quantity of gluten, the ratio of gliadin to glutenin in the sample and to the proportion of the various subunits making up glutenin. To date, however, no definite component has been proven to be the one on which quality depends.

To examine the roles of these various fractions, substitutions have been made and samples compared on common bases using the results of mechanical testing. A number of instruments have been developed for testing purposes and these were discussed at length. Little has been done, however, to relate the results from these machines to human evaluation of texture. Since human evaluation is the ultimate test of quality, this constitutes a serious ommission.

Processing conditions as well as cooking conditions have been implicated in pasta quality. These, however, like the instruments can be standardized for evaluation purposes. This standardization of methods then provides a tool for examining quality.

As has been mentioned for both starch and protein, varietal differences exist and these exert a definite influence on quality. The use of instrumental assessment, therefore, can be very important in variety testing. Quality differences may be exaggerated or minimized by controlled breeding programs, and the varieties produced examined by standardized techniques. Results of this quality testing may then be used to guide plant breeders towards the development of varieties suitable for the export market as well as for domestic purposes. Most of the durum wheat grown in Canada is exported, and since purchasing countries are interested in buying varieties which will produce pasta of excellent cooking quality according to their standards, the ability to measure the potential cooking quality of a wheat is extremely important. When the requirements of the consumer are known, together with the biochemical bases of these requirements, the product can be tailored to meet these, not only by controlling processing conditions, but also by breeding programs aimed at alteration of specific biochemical characteristics.

METHODS

Spaghetti samples produced by both laboratory and commercial means were tested for cooking quality. The effects of such external influences as blanching, temperature of cooking water and length of cooking time as well as temperature and pressure variation during processing, were examined in relation to the textural quality of the cooked product.

Standardization of these variables then permitted assessment of the relationship between sensory panel and instrumental evaluation of cooking quality and formulation of an equation with which to predict sensory response on the basis of instrumental results.

The final area of study was that involving evaluation of the internal influences on cooking quality. This included consideration of the effect on texture of added egg albumin, and examination of the gelatinization process of starch during spaghetti production and cooking and its possible relationships to textural quality.

Spaghetti Production

Micro scale laboratory samples. Samples produced under laboratory conditions were made following a modification of the micro method reported by Martin *et al*. (1946). 50 g of semolina were mixed in a water jacketed farinograph bowl (40°C), adapted for high vacuum, with sufficient distilled water to bring it to 33% absorption. After 0.5 min mixing, a vacuum of approximately 700 mm Hg was applied and mixing continued for another 3 min. The dough was then transferred to a water jacketed press cylinder (Martin *et al*., 1946) and allowed to rest for 9 min at 50°C and 2000 psi pressure. Following this it was extruded through a 4 hole teflon coated spaghetti die and dried, with a controlled decrease in relative humidity, for 28 hr at 39°C.

Temperature-pressure variations. To gain some insight into the effect of processing conditions on cooking quality, a number of spaghetti samples were made under varying processing conditions. The micro scale method was used with the following combinations of temperature and pressure replacing that (50°C, 2000 psi pressure) commonly used during the 9 min resting period.

Temp (°C)	Pressure (psi)			
25	0	1000	2000	5000
40	0	1000	2000	5000
60	0	1000	2000	5000
80	0	1000	2000	5000

Semolinas from two varieties of durum wheat, Hercules and Stewart 63, were included in this experiment and each treatment combination was applied in duplicate for a total of 32 samples for each variety. Analysis of variance was applied to the instrumental results to determine statistically significant differences in texture due to the processing treatments applied. A study was also made of the surface characteristics of uncooked samples, using a scanning electron microscope. All 32 samples produced from Stewart 63 were examined as well as some of the Hercules samples.

Sensory panel samples. To provide a range in texture, samples produced for sensory panel work contained added portions of commercially produced spray dried egg albumin[1]. Egg albumin at 0, 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0% levels was added on a weight per weight basis to 2 CWAD, Canada Western Amber Durum (CWAD), average sample '72-73 crop semolina, and pasta was then produced using the micro scale method. Approximately 200 g of each treatment were produced for this experiment. 50 g samples of spaghetti containing 0.5, 1.0, 1.5 and 2.0% egg albumin were also produced to determine the minimum level of protein addition required to significantly improve textural quality. These samples were not used for sensory evaluation.

Commercial samples. Samples used to study cooking time and temperature effects were produced on commercial scale by Primo Macaroni Co. from semolina milled from 3 durum varieties; Wakooma, Wascana and Quilafen (Matsuo, 1973). These samples were produced on a Pavan press under 30 in. Hg vacuum and with the ammeter on the extrusion worm maintained at 18 amps to ensure proper absorption. For Wakooma and Quilafen, the absorption used was increased from that used for Wascana. Since this processing operation was run on a continuous basis, large enough samples of semolina (400 g) were provided that the initial spaghetti extruded following a change from one variety to another, could be discarded. It was felt that by collecting only the spaghetti from the middle part of the run for each variety, mixing of varieties would be reduced to a minimum. Subsequent protein testing of spathettis and corresponding semolinas showed that this was not so and that a fair amount of contamination had taken place despite these precautions.

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[1] Cham Foods Ltd., Winnipeg, Manitoba

Other samples, used to examine the range in texture to be expected from commercially available products, were purchased at various retail outlets in Winnipeg. Commercial brands used were Agnesi, Barilla, Buitoni, Catelli, Constant, Creamette, Lancia and Primo. The surface characteristics of these pastas were also examined by scanning electron microscopy to determine whether cooking quality could be related to a surface characteristic.

Cooking Method

Regular method. 5 g samples of approximately 5 cm in length were cooked in 150 ml boiling tap water ($98.5^{o}C \pm 0.5^{o}$) to 'al dente' as established by the Braibanti technique (Voisey and Larmond, 1973a). Following this, the samples were drained and blanched 3 times with cold tap water. Samples cooked for the purposes of instrumental assessment were placed between layers of plastic film[2] to prevent drying prior to and during testing; those cooked for panel assessment were stored in 3 oz paper cups[3] covered with aluminum foil to prevent drying.

Blanching. A fair amount of change in texture was observed in test samples during the period of instrumental assessment. Since previous tests (Matsuo and Irvine, 1969) with the GRL spaghetti tenderness testing apparatus had shown satisfactory reproducibility, these discrepencies were attributed to textural changes occurring in the samples during

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[2] Saran Wrap, Dow Chemicals Ltd., Montreal, Que.

[3] Dixie Water Cup, No. 44, Dixie Cup Co. Canada Ltd., Brampton, Ont.

testing. These changes were thought to be due to residual cooking taking place during the time that the warm samples sat between layers of plastic film prior to and during testing. To cool the samples and reduce these changes, samples were blanched 3 times with cold water immediately following cooking. The effect of blanching was tested on 6 commercial brand name pastas. Samples were cooked by the regular method then blanched or not blanched and tested for variation in texture.

Temperature and duration of cooking time effects. To determine the effect of water temperature and duration of cooking time on cooking quality, Quilafen, Wakooma and Wascana spaghetti samples were cooked in 60^{o} and $90^{o}C$ water baths as well as in boiling water. The method followed was the same as the regular method except that the beakers were placed in a water bath and the temperature of the cooking water was allowed to equilibrate before the samples were added for cooking. For the $60^{o}C$ bath the cooking water temperature was found to be $58.5^{o}C \pm 0.5^{o}$. For the $90^{o}C$ bath the cooking water temperature was $82^{o}C \pm 1^{o}$. Samples were cooked for periods ranging from 2 to 30 min in 2 min intervals and cooking tests were repeated 3 times for each of the 3 commercial spaghettis produced from pure durum varieties. The average instrumental results for each variety were then plotted against temperature and against time. Additional samples cooked for 30 min at $58.5^{o}C$ were immersed in boiling water for 5 sec prior to instrumental testing. A further extension of this part of the experiment was done using only samples produced from Wakooma. In this case, samples were placed in boiling water for 30, 60, 90 and 120 sec after they had been cooked at $58.5^{o}C$ for 30 min. These samples were also tested for textural quality using the GRL spaghetti tester.

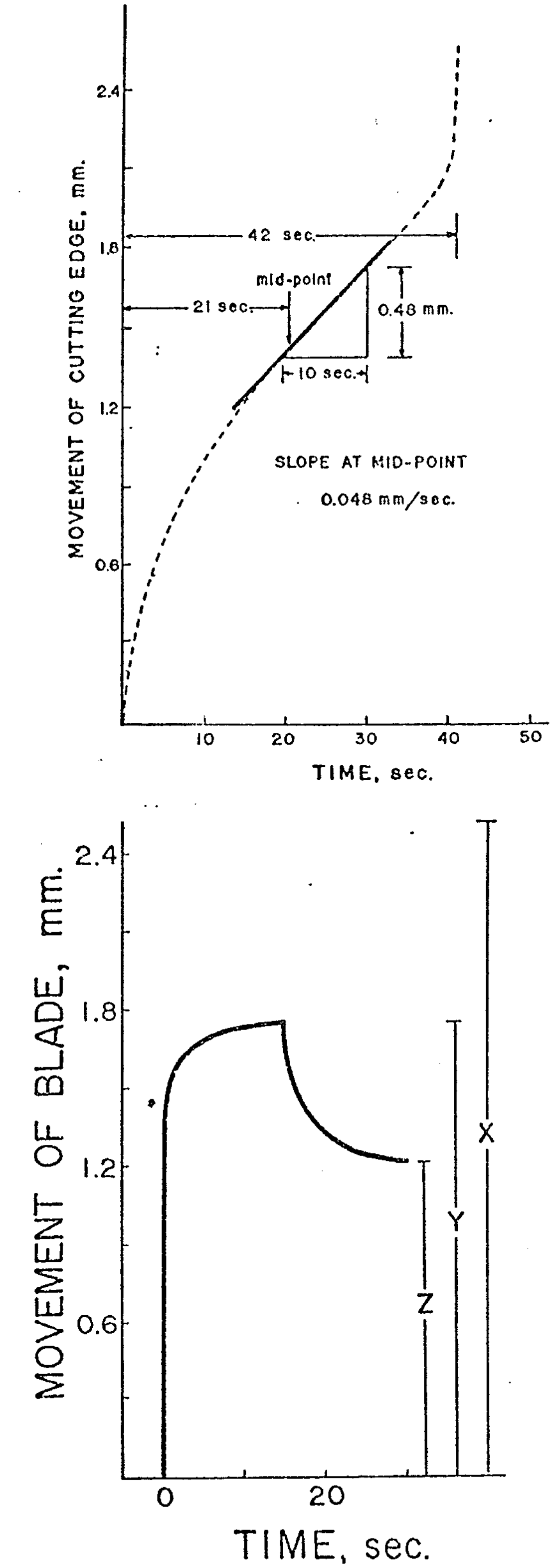
Evaluation of Texture

Instrumental. All instrumental assessment of cooking quality was done using the GRL spaghetti tenderness testing apparatus (Matsuo and Irvine, 1969; 1971). The mechanics of this instrument are described in the literature review. Three parameters are measured by this instrument; tenderness, compressibility and recovery, and they are calculated as shown in Figure 1. For all tests, the 3 textural parameters were calculated, then the appropriate statistical analysis was applied to assess results.

To determine the range of textures generally encountered in commercially available spaghettis, 6 brand name samples were tested in a series of 4 replicates. Results were averaged and analysis of variance was applied to determine significant differences among brands and to obtain an indication of the reliability of both the instrument and the method.

Samples used for the study of correlation between instrumental and sensory evaluation, were cooked following the standard method except that sample weights of 200 g for the standard sample and 25 g for the test samples were used. The ratio of pasta to water, approximately 1:30 was retained. A number of strands were held for instrumental testing following cooking, and the remainder of the sample was placed into sample containers for the panelists. Instrumental assessment was made during the same time period as the panel was being conducted.

Sensory. The concept of ratio estimation was taught to the panelists in a short training session by using cards of various sizes. Following this, 8 pairs of samples, each consisting of an identified reference



Tenderness =
slope at mid-point

X = diameter of cooked spaghetti

Y = blade penetration into sample

Z = related to elastic components

Compressibility (%)

$$= \frac{Y}{X} \times 100$$

Recovery (%)

$$= \frac{Y-Z}{Y} \times 100$$

Figure 1. Classical GRL spaghetti tenderness testing apparatus curves and formulae for calculation of textural parameters (Matsuo and Irvine, 1969; 1971).

sample and a coded test sample, were presented to the 5 panelists who were asked to assess sample firmness. Panelists were requested to make their judgement on a sample pair then discard the samples before proceeding to the next judgement. This was done to prevent comparison of the coded samples with anything other than the reference sample. Panelists were provided with water for rinsing if desired and a paper cup for expectoration of the samples. The samples used were those containing 0.0 to 15.0% egg albumin added to produce a range in sample textures. The reference sample used was a spaghetti commercially produced by Catelli and available on the retail market. Judges were requested to rate the proportion of difference between the coded sample and the reference sample. A sample of the questionnaire used is presented in Figure 2. The pairs were presented in randomized order and the panel assessment was repeated 3 times. The panel results were then transformed to logarithms (Moskowitz, 1970) and a multiple linear regression analysis applied. On the basis of this analysis, a model equation was devised to relate panel results to instrumental results.

To test the use of the model formula as a prediction equation, a second experiment was done. In this case 5 commercially available spaghetti samples were used for panel assessment. Panelists were presented with 10 (duplicates of 5 samples) pairs of samples with instructions to rate these using the method previously described. The test pairs were presented in random order. Instrumental assessment was made concurrently and these results were substituted into the formula. The predicted panel scores derived were then compared to the actual scores assigned by the panelists.

Since there were some discrepancies among some of the instrumental

RATIO ESTIMATION OF FIRMNESS

NAME ______________________________ DATE ____________________

Please rate the firmness of the coded samples in relation to the standard (S) sample. If the coded sample seems 14 times as firm as the standard, give it a value of 14. If it seems one-eleventh as firm, give it a value of 1/11 or 0.09. There is no limit to the numbers, decimals or fractions that you may use, but make each assignment proportional to the firmness as you perceive it.

CODE NUMBER	RATIO ESTIMATION VALUE

Figure 2. Questionnaire used for sensory evaluation of pasta firmness.

results, a second set of samples was cooked and tested. Instrumental results for these samples were also substituted into the formula and the predicted scores were compared to those from the panel as well as to those predicted from the first set of samples.

Volume Increase

To determine the degree of volume increase with increase in cooking time, samples of the 3 commercially produced pastas were tested as follows. Samples 4 cm long were weighed, then cooked at $98^{o}C \pm 0.5^{o}$ in an excess of tap water. One piece was removed every 2 min and its volume determined by water displacement in the following apparatus. A 10 ml burette, graduated in 0.5 ml units was filled with tap water and mounted upright in a burette holder. A small piece of iron rod approximately 1 cm in length and slightly smaller in diameter than the internal diameter of the burette, was placed in the bottom of it. The level of the water was then adjusted to the 3 ml line. Following each determination, the metal piece was drawn up the burette with a magnet, thereby facilitating rapid removal of the spaghetti strand. Three sets of determinations were done for each variety and average volume increases were then plotted against time.

Starch Gelatinization During Processing and Cooking

Samples of semolina, raw pasta and cooked pasta were tested using an amylograph[4], to determine the extent of gelatinization of starch during processing and cooking. The 3 varieties produced commercially,

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[4] Brabender Amylograph-Viscograph, Brabender Corp., Rochelle Park, N.J.

Wascana, Wakooma and Quilafen, were used for these tests.

a) Semolina: 65 g semolina (14% moisture basis) and 350 ml tap water were mixed in a bowl using a rotary beater. This slurry was then poured into the amylograph bowl and beater and bowl were rinsed with an additional 100 ml of water. The standard AACC procedure (1962) was then followed for operation of the amylograph with temperature being increased, from 30^{o} to 95^{o}C, at the rate of 1.5^{o}C per minute.

b) Raw pasta: Uncooked pasta was ground in a Buhler laboratory grinder[5] and treated in the same manner as the semolina.

c) Cooked pasta: Spaghetti samples were cooked following the standard method, then 100 g of the cooked spaghetti and 350 ml tap water were blended in a Waring blender[6] for 15 sec at low speed then 60 sec at high speed. This mixture was then poured into the amylograph bowl, the blender was rinsed with an additional 100 ml water then the same procedure was followed as for the semolina.

To further examine the degree of gelatinization of starch during processing and various stages of cooking, a number of samples were examined by polarized light microscopy. Commercially produced spaghetti samples of 3 varieties; Quilafen, Wakooma and Wascana, as well as a number of samples processed in the laboratory using the micro method, were examined. The laboratory samples consisted of spaghetti made from Leeds and Tunisian varieties both at 8% and 17% protein, as well as samples made from 2 CWAD semolina with 2.5% or 15.0% added egg albumin.

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[5] Buhler laboratory grinder. Buhler Bros. Ltd., Uzwil, Switzerland.

[6] Waring blender. Waring Products Corp., Winsted, Conn.

In addition, samples of Quilafen, Wakooma and Wascana semolina were examined.

Semolina and uncooked spaghetti samples were soaked in tap water at room temperature for 4 hr. Experimental 5 g samples were cooked in 150 ml of tap water by the regular method. A portion of the sample was removed after 5 min cooking and examined. The rest of the sample was cooked to al dente as established using the Braibanti test (Voisey and Larmond, 1973). All samples were blanched following cooking.

For microscopic examination, samples were squeezed between 2 plexiglass plates and wet mounts were made of a full width section of the squashed strand. With samples cooked for 5 min, squeezing them revealed 2 or 3 zones. In this case, each zone was dissected out and examined separately. Examinations were made under polarized and bright light at 63X and 250X magnification with a Zeiss photomicroscope.

RESULTS AND DISCUSSION

Effects of External Influences on Cooking Quality

Blanching. Study of the effect of blanching was undertaken because of a problem which arose during instrumental testing of commercial brands in the initial stages of this project. Following cooking, samples were held between layers of plastic film to reduce moisture loss during testing. When the results were calculated, wide discrepencies were found between readings on the first and last strands tested. This was especially true for compressibility and recovery testing where consideration of results for only the first strand tested suggested desirable levels for these parameters within the sample. However, inspection of results for only the last strand tested indicated that the sample was overcooked. Since this phenomenon was fairly consistent and the changes in observed texture were always in the same direction, they were thought to be due to extended cooking occurring after the sample was removed from the heat. To counteract this, samples were blanched immediately after cooking. Comparison of the results for blanched and unblanched samples are shown in Table 2. A study of the deviations, indicates that blanching effectively controlled the tendency of the samples to continue cooking. In most cases, it also resulted in a slight improvement of the results for all 3 textural characteristics. This is most likely due to the reduction of the range of variation and since these changes are in the same direction for all samples, should not exert any confounding effects in statistical analysis.

As the result of this study, all other samples prepared for the purposes of this thesis, were blanched immediately after cooking and

Table 2. Comparison of texture of blanched and unblanched spaghetti samples.[1]

Sample[2]		Tenderness mm/sec x 10^{-3}	σ	Compressibility %	σ	Recovery %	σ
Agnesi	unblanched	33.1	2.95	67.1	2.72	52.5	2.96
	blanched	29.0	2.94	66.9	2.66	59.0	2.54
Barilla	unblanched	36.8	4.87	85.3	10.63	18.0	22.25
	blanched	35.1	0.48	77.0	1.52	28.8	2.86
Catelli	unblanched	39.2	1.32	68.4	3.44	26.9	7.21
	blanched	34.6	1.11	66.4	1.58	36.6	1.61
Constant	unblanched	40.8	2.02	87.7	11.83	7.4	18.76
	blanched	34.8	0.50	63.9	2.92	27.7	3.05
Creamette	unblanched	38.8	2.90	85.1	8.32	11.0	16.33
	blanched	33.2	0.64	78.4	6.20	27.3	9.30
Primo	unblanched	34.1	2.49	90.9	6.60	2.4	10.33
	blanched	36.6	0.47	71.0	1.07	28.8	1.36

[1] Values are averages of at least 4 readings.

[2] Listed in alphabetical order.

prior to testing.

Temperature and duration of cooking time effects. The results for tests done to examine the effect of cooking water temperature and length of cooking time are shown in Tables 3 to 5. As can be seen, the lower the water temperature used, the longer it takes for the sample to cook, as indicated by the disappearance of the central core. It should be noted that for the 58.5^{o}C samples, although this core disappeared after 30 min cooking, the entire strand was slightly opaque when squashed between plastic plates. This was the case for all 3 varieties. In addition, samples taking longer to cook were softer, more compressible and showed no recovery at any point. For each of the textural parameters measured, the effects of time and temperature for each variety as well as the relationship of the varieties to each other, are shown in Figures 3 to 20. Considering the relationship of varieties at any one temperature (Figures 3 to 11), results for tenderness and compressibility showed little difference among varieties. For recovery, tests conducted at 58.5^{o} and 82^{o}C showed little difference among varieties, however, samples cooked in boiling water showed Quilafen and Wakooma as having similar recoveries and Wascana to be inferior. Time effects were also apparent from these figures. Both tenderness and compressibility tended to increase with increasing cooking time regardless of variety or temperature. Plotting recovery against time for samples cooked in boiling water showed an initial increase, followed by a plateau then a decrease to zero. Plots for samples cooked at 58.5^{o} and 82^{o}C were virtually straight and indicated no recovery in these tests. From these graphs, it is not possible to state that one variety is superior to another, however, there was a tendency for Wascana to rate the poorest overall. Since these

Table 3. Average instrumental results for spaghetti made from Quilafen and cooked at 58.5°, 82°C and boiling water for 2 to 30 min.

	Temperature (°C)								
	58.5°C			82°C			Boiling water (98.5°C)		
Cooking time (min)	Avg[1] Tenderness mm/sec x 10^{-3}	Avg Compressibility %	Avg Recovery %	Avg Tenderness mm/sec x 10^{-3}	Avg Compressibility %	Avg Recovery %	Avg Tenderness mm/sec x 10^{-3}	Avg Compressibility %	Avg Recovery %
2	7.5	54.7	0.0	10.2	34.7	0.1	12.3	54.4	14.6
4	7.7	59.8	0.0	15.7	44.7	0.9	16.6	51.6	32.0
6	9.9	57.6	0.0	12.2	48.8	0.6	23.0	49.9	42.2
8	11.6	59.0	0.0	16.0	46.2	1.6	25.2	69.6	35.1
10	14.8	60.9	0.0	28.4	50.6	0.8	29.4	72.0	35.2
12	15.4	63.9	0.0	39.1	64.6	0.8	34.7*	77.6*	36.0*
14	15.4	67.4	0.2	48.2	78.0	0.0	36.2	76.8	30.3
16	20.0	70.8	0.4	51.8	79.7	0.1	41.2	80.7	22.8
18	27.3	69.0	0.0	53.2*	84.7*	0.0*	43.9	88.3	8.9
20	31.8	69.4	0.5	59.9	90.6	0.0	48.3	94.0	1.2
22	40.6	74.5	0.0	63.4	95.0	0.0	50.3	99.9	0.0
24	44.7	77.6	0.3	68.5	98.3	0.0	58.8	99.2	0.0
26	50.8	80.2	0.0	75.3	95.7	0.0	55.0	99.4	0.0
28	64.6	89.3	0.0	73.9	95.1	0.0	67.0	99.6	0.0
30	86.4*	94.2*	0.0*	81.3	98.7	0.0	73.0	100.0	0.0

[1] Average of 3 replicates.

* Sample al dente using Braibanti test.

Table 4. Average instrumental results for spaghetti made from Wakooma and cooked at 58.5°, 82°C and boiling water for 2 to 30 min.

	Temperature (°C)								
	58.5°C			82°C			Boiling water (98.5°C)		
Cooking time (min)	Avg[1] Tenderness mm/sec x 10^{-3}	Avg Compressibility %	Avg Recovery %	Avg Tenderness mm/sec x 10^{-3}	Avg Compressibility %	Avg Recovery %	Avg Tenderness mm/sec x 10^{-3}	Avg Compressibility %	Avg Recovery %
2	5.3	55.3	0.0	8.6	43.7	0.0	14.3	55.7	9.1
4	8.2	56.8	0.0	11.0	45.9	0.1	18.4	56.8	28.8
6	11.6	59.2	0.0	13.8	56.2	0.6	19.2	51.1	41.5
8	14.1	61.6	0.2	15.0	49.0	1.2	26.0	72.6	33.6
10	11.4	61.2	0.0	22.6	51.3	1.0	28.7	74.3	33.5
12	13.8	65.4	0.4	34.6	62.5	0.3	32.4*	76.0*	33.0*
14	14.1	65.0	0.2	41.7	70.6	0.1	35.3	76.9	29.6
16	19.3	68.3	0.0	45.5	81.4	0.0	36.3	80.9	20.3
18	23.4	71.6	0.0	54.4*	86.8*	0.0*	42.3	84.1	12.0
20	29.8	71.6	0.0	53.3	94.6	0.0	48.1	98.6	1.5
22	36.9	73.8	0.0	56.9	91.7	0.0	52.5	98.8	0.0
24	40.8	76.1	0.0	63.0	95.7	0.0	57.7	99.2	0.0
26	47.8	81.9	0.0	65.1	97.5	0.0	66.8	99.8	0.0
28	59.3	86.7	0.0	63.8	95.6	0.0	68.5	98.6	0.0
30	74.6*	91.7*	0.0*	65.6	94.0	0.0	71.4	99.6	0.0

[1] Average of 3 replicates.

* Sample al dente using Braibanti test.

Table 5. Average instrumental results for spaghetti made from Wascana and cooked at 58.5°, 82°C and boiling water for 2 to 30 min.

Cooking time (min)	Temperature (°C) 58.5°C Avg[1] Tenderness mm/sec x 10^{-3}	58.5°C Avg Compressibility %	58.5°C Avg Recovery %	82°C Avg Tenderness mm/sec x 10^{-3}	82°C Avg Compressibility %	82°C Avg Recovery %	Boiling water (98.5°C) Avg Tenderness mm/sec x 10^{-3}	Boiling water (98.5°C) Avg Compressibility %	Boiling water (98.5°C) Avg Recovery %
2	5.6	54.4	0.0	10.4	42.3	0.0	18.4	56.6	4.2
4	6.2	53.3	0.0	14.3	46.9	0.3	18.9	52.5	23.6
6	9.0	57.7	0.0	14.9	47.7	0.5	22.9	49.0	36.9
8	11.5	60.2	0.0	21.0	46.4	1.0	25.1	72.9	22.6
10	13.4	61.6	0.0	25.3	51.6	0.5	32.9	76.9	27.7
12	14.0	64.8	0.0	36.1	63.1	0.3	36.3*	79.8*	22.6*
14	14.2	63.6	0.0	45.2	77.7	0.3	37.9	81.5	16.6
16	18.8	67.3	0.0	50.0	84.5	0.0	41.4	86.8	11.0
18	25.0	70.2	0.0	53.1*	86.1*	0.0*	46.1	96.9	0.0
20	31.4	72.8	0.0	58.7	94.0	0.0	52.6	98.5	0.0
22	35.9	73.1	0.0	64.6	95.7	0.0	62.2	99.2	0.0
24	43.2	76.2	0.0	68.0	99.4	0.0	69.3	99.7	0.0
26	48.9	78.2	0.0	67.4	96.9	0.0	74.1	98.2	0.0
28	53.7	82.6	0.0	74.9	97.0	0.0	70.3	99.1	0.0
30	67.4*	87.2*	0.0*	79.1	98.8	0.0	85.7	100.0	0.0

[1] Average of 3 replicates.

* Sample al dente using Braibanti test.

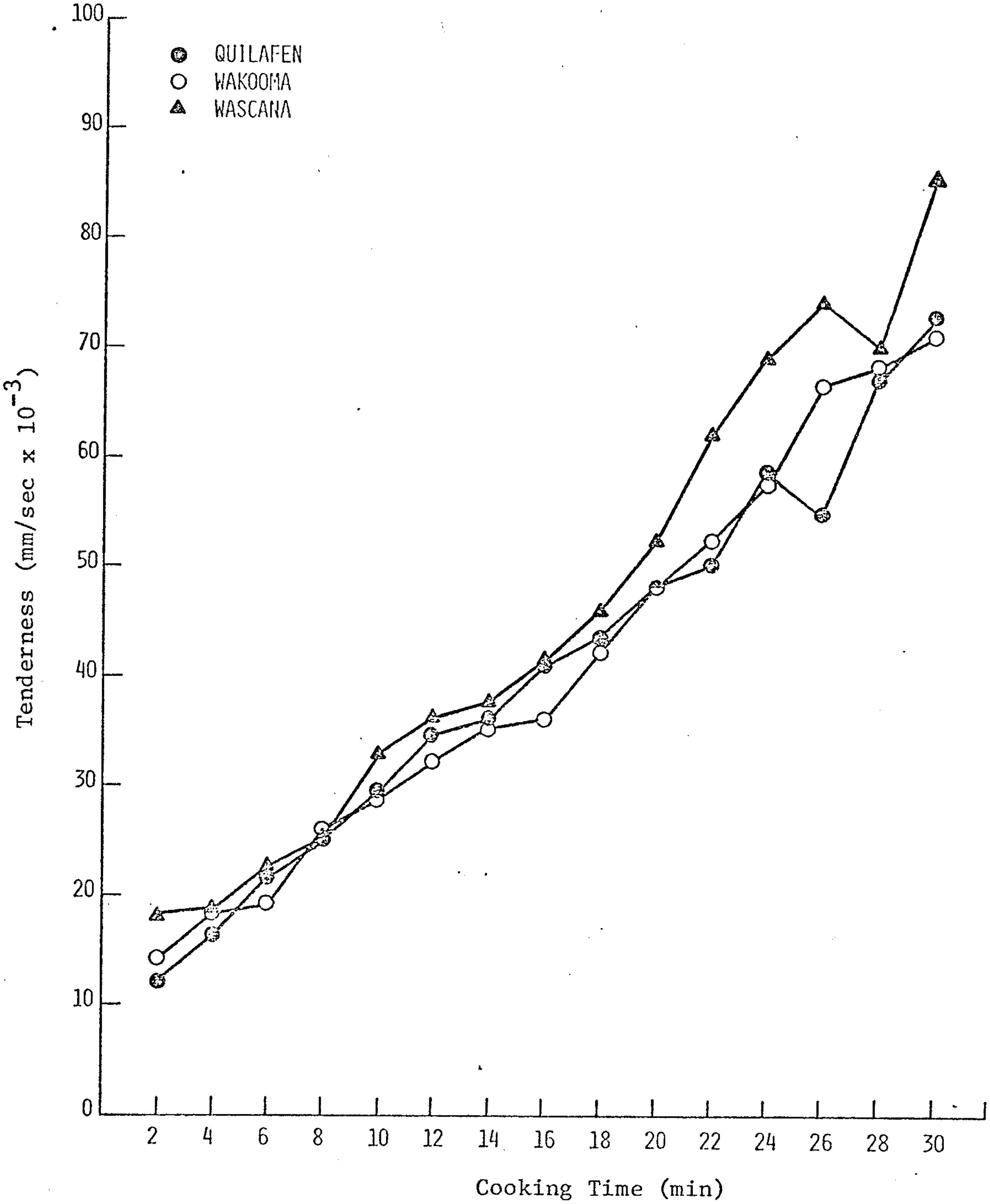


Figure 3. Effect of length of cooking time and durum variety on instrumentally assessed tenderness of spaghetti cooked at 98.5°C.

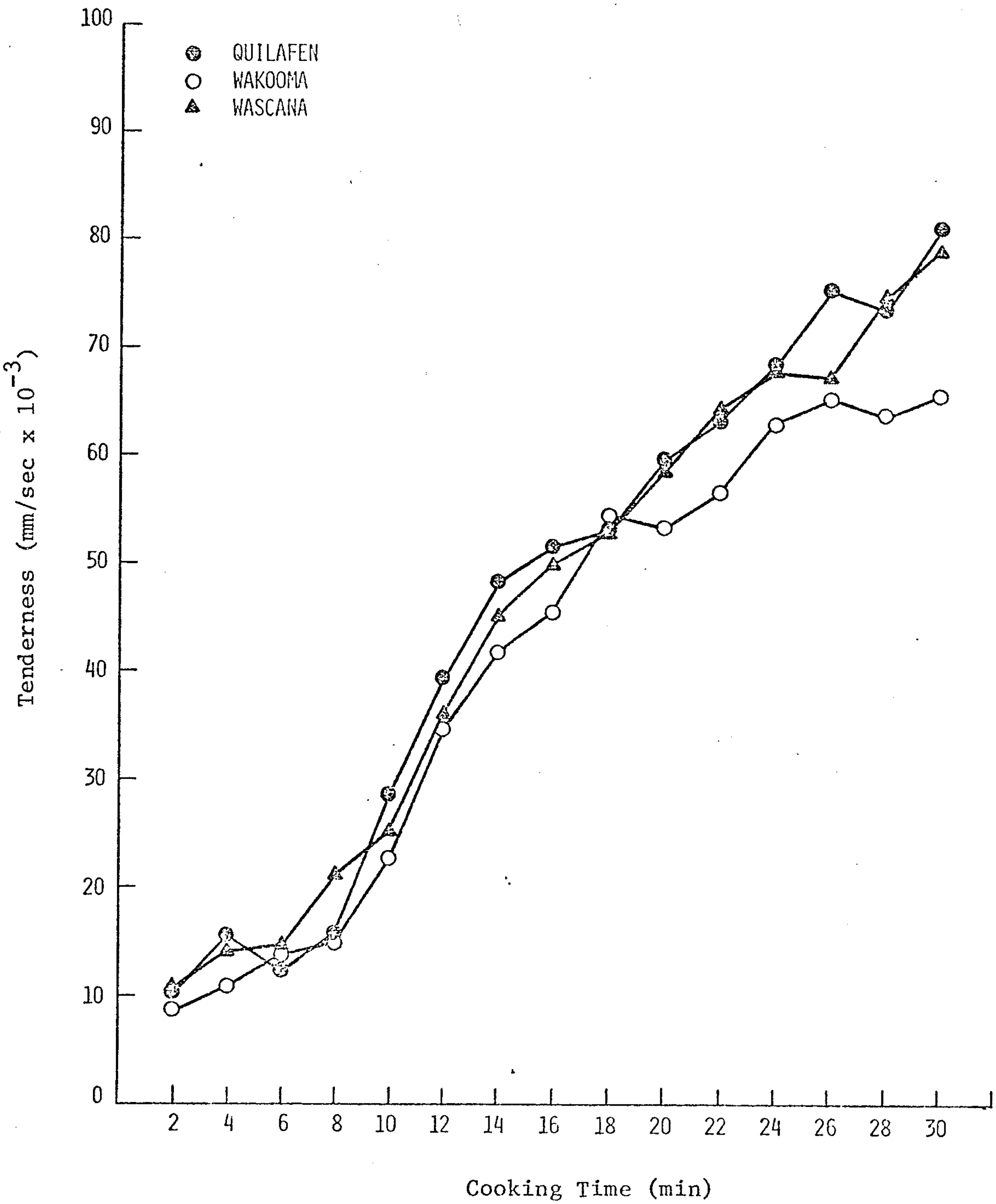


Figure 4. Effect of length of cooking time and durum variety on instrumentally assessed tenderness of spaghetti cooked at 82°C.

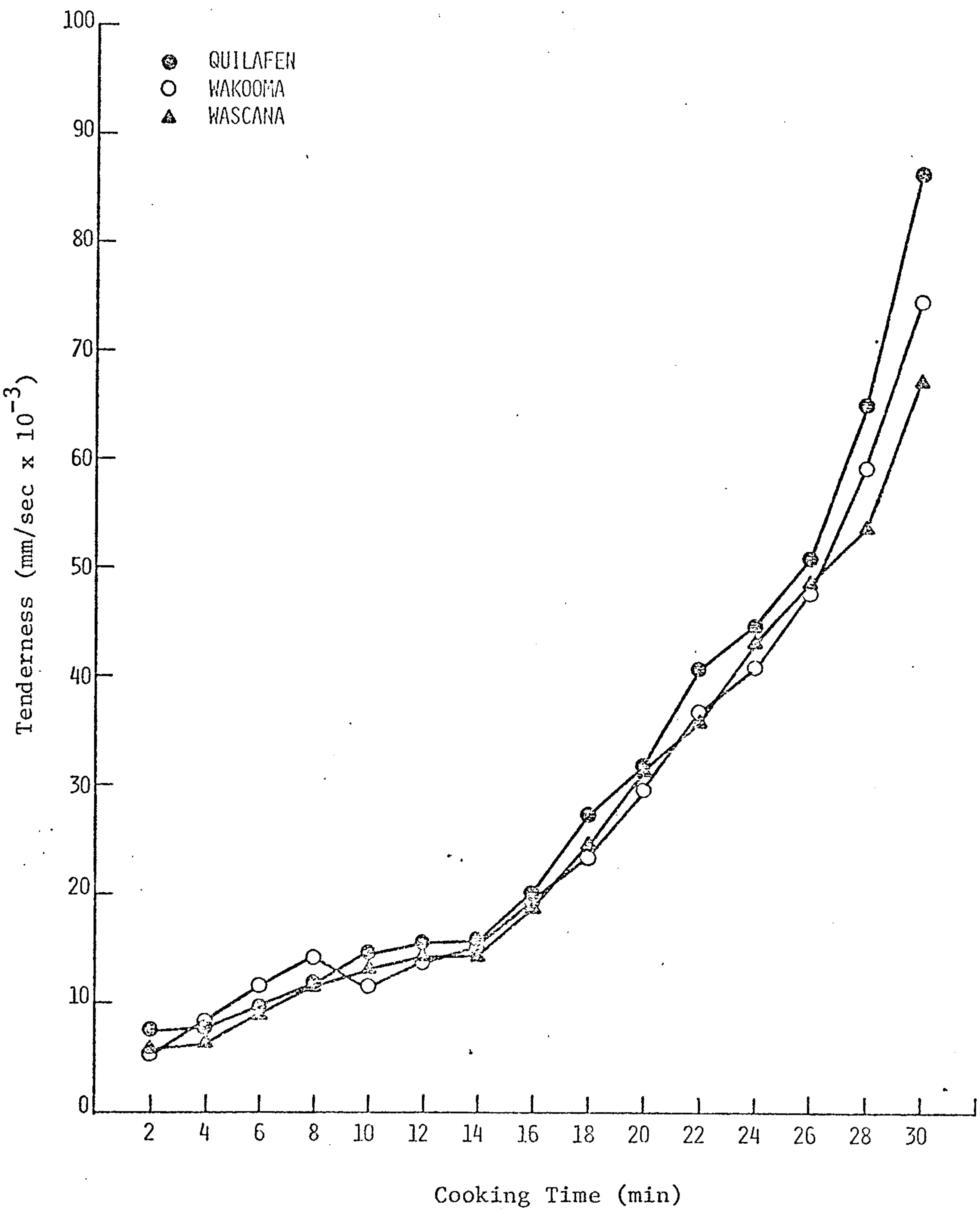


Figure 5. Effect of length of cooking time and durum variety on instrumentally assessed tenderness of spaghetti cooked at 58.5°C.

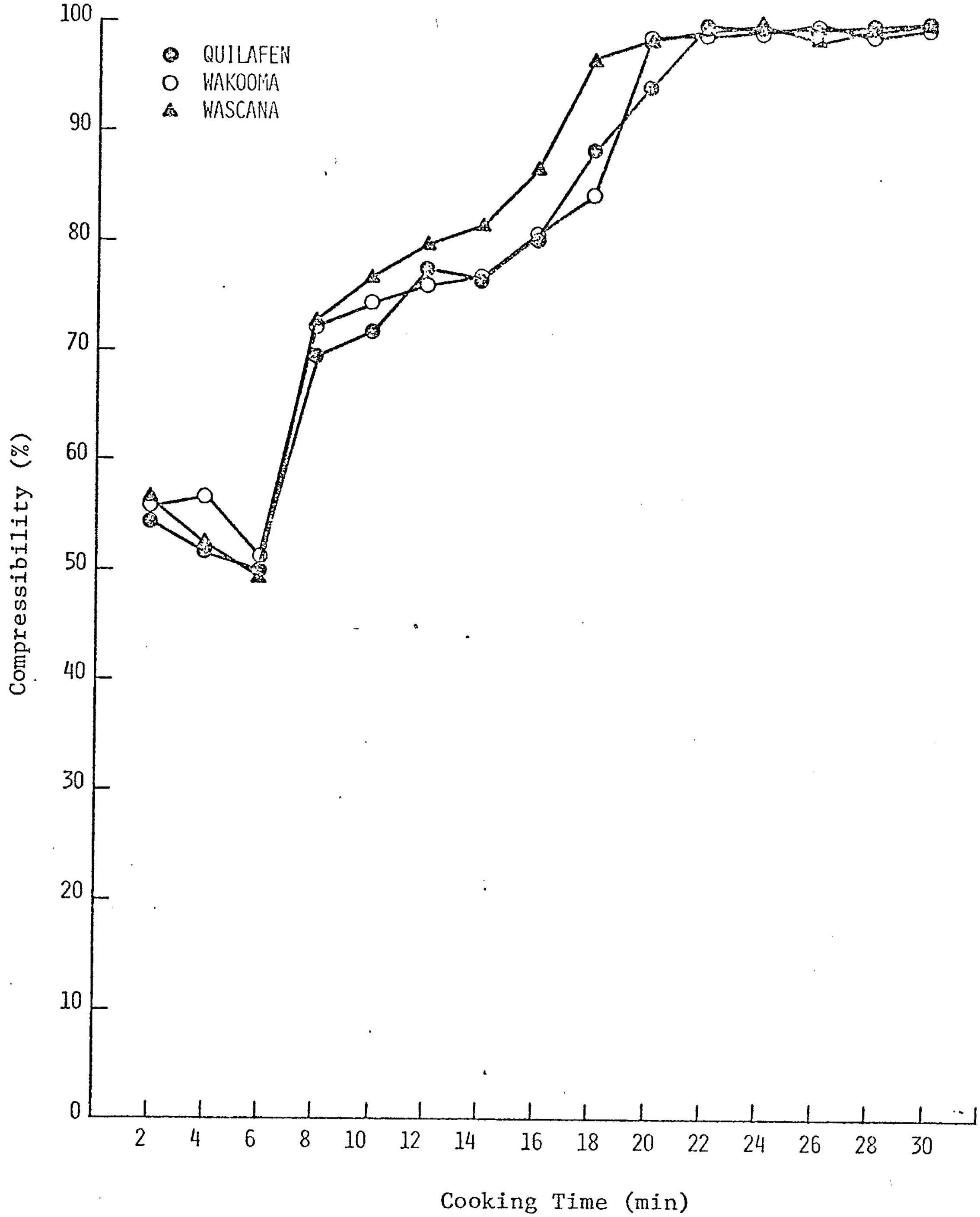


Figure 6. Effect of length of cooking time and durum variety on instrumentally assessed compressibility of spaghetti cooked at 98.5°C.

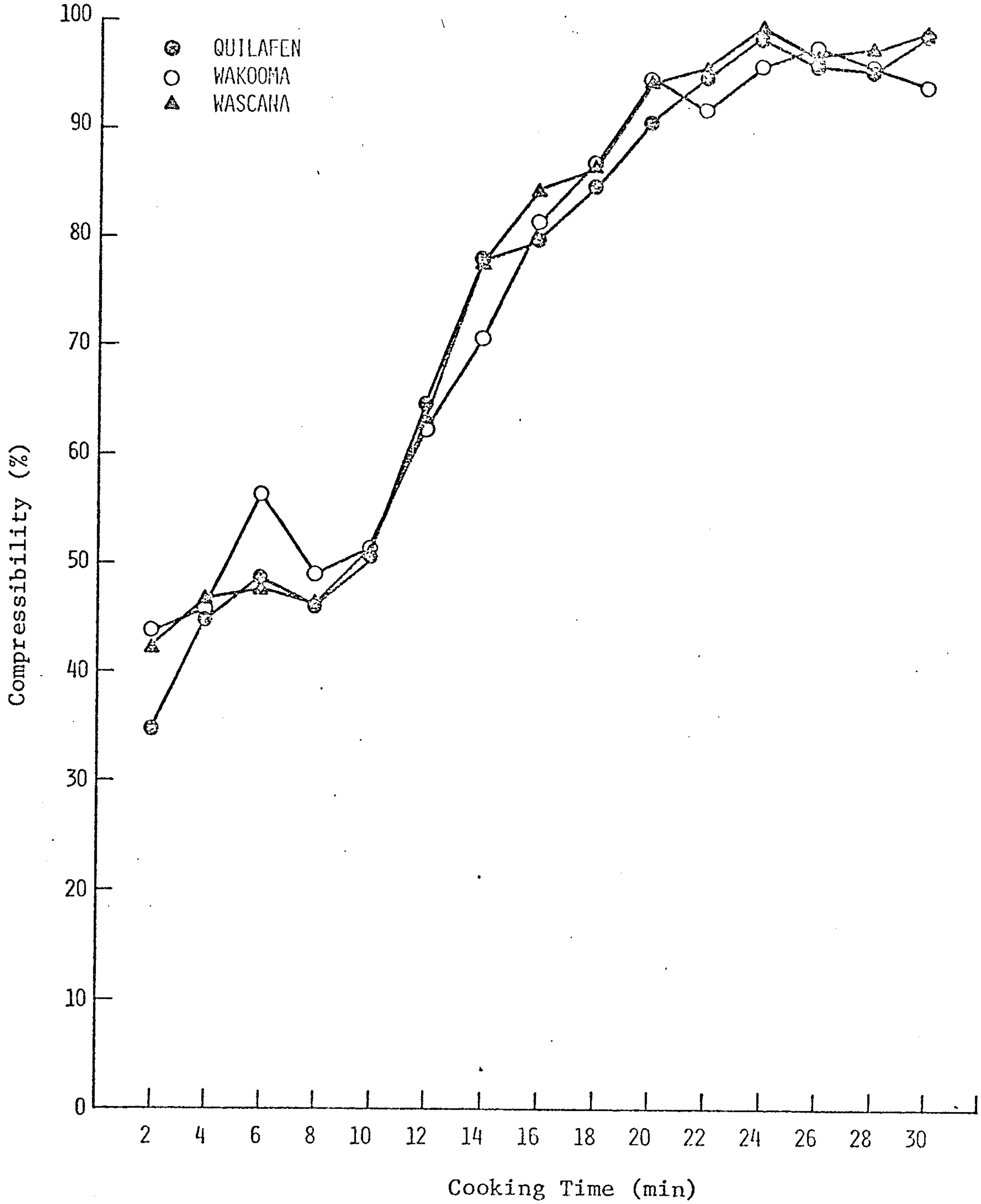


Figure 7. Effect of length of cooking time and durum variety on instrumentally assessed compressibility of spaghetti cooked at 82°C.

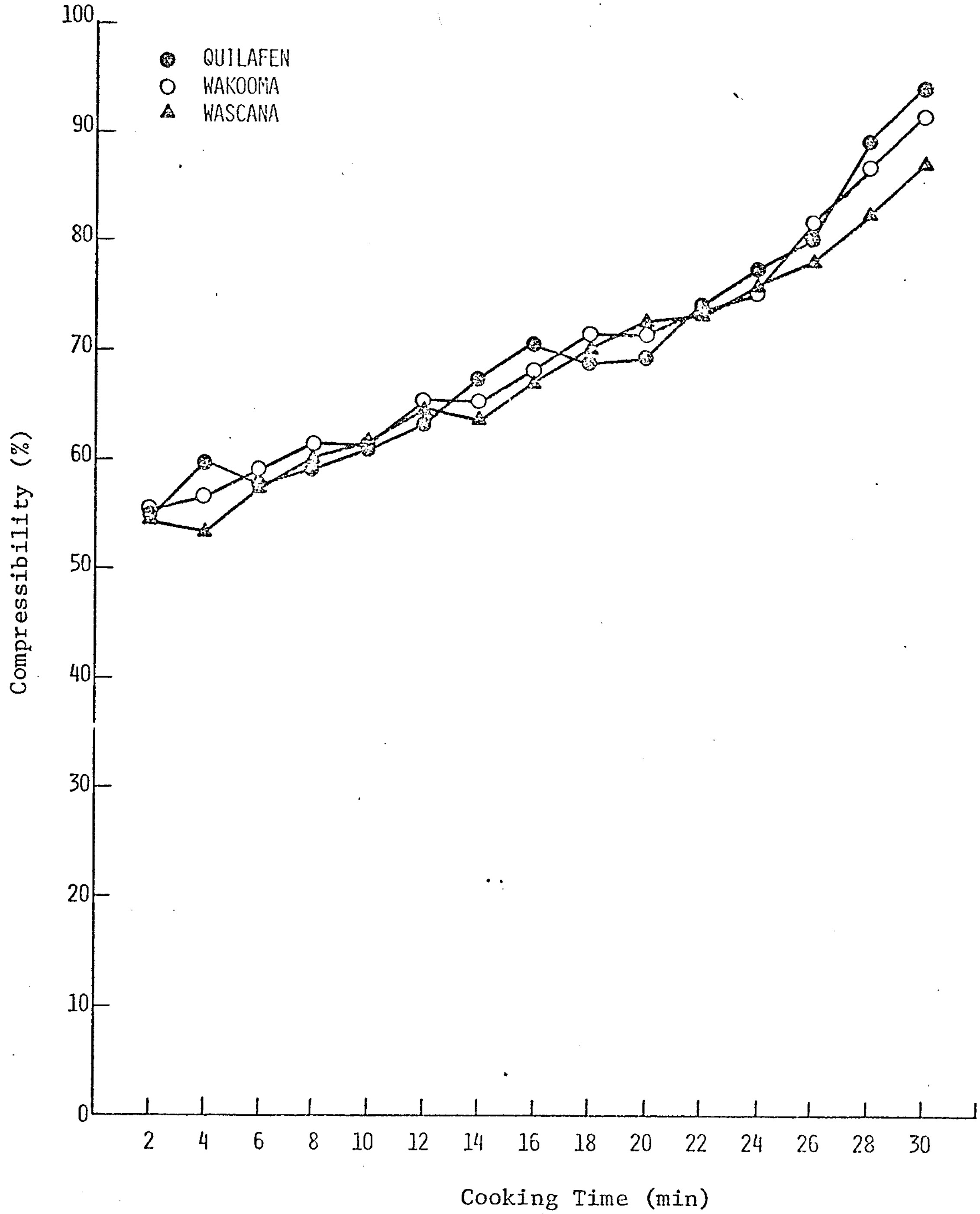


Figure 8. Effect of length of cooking time and durum variety on instrumentally assessed compressibility of spaghetti cooked at 58.5°C.

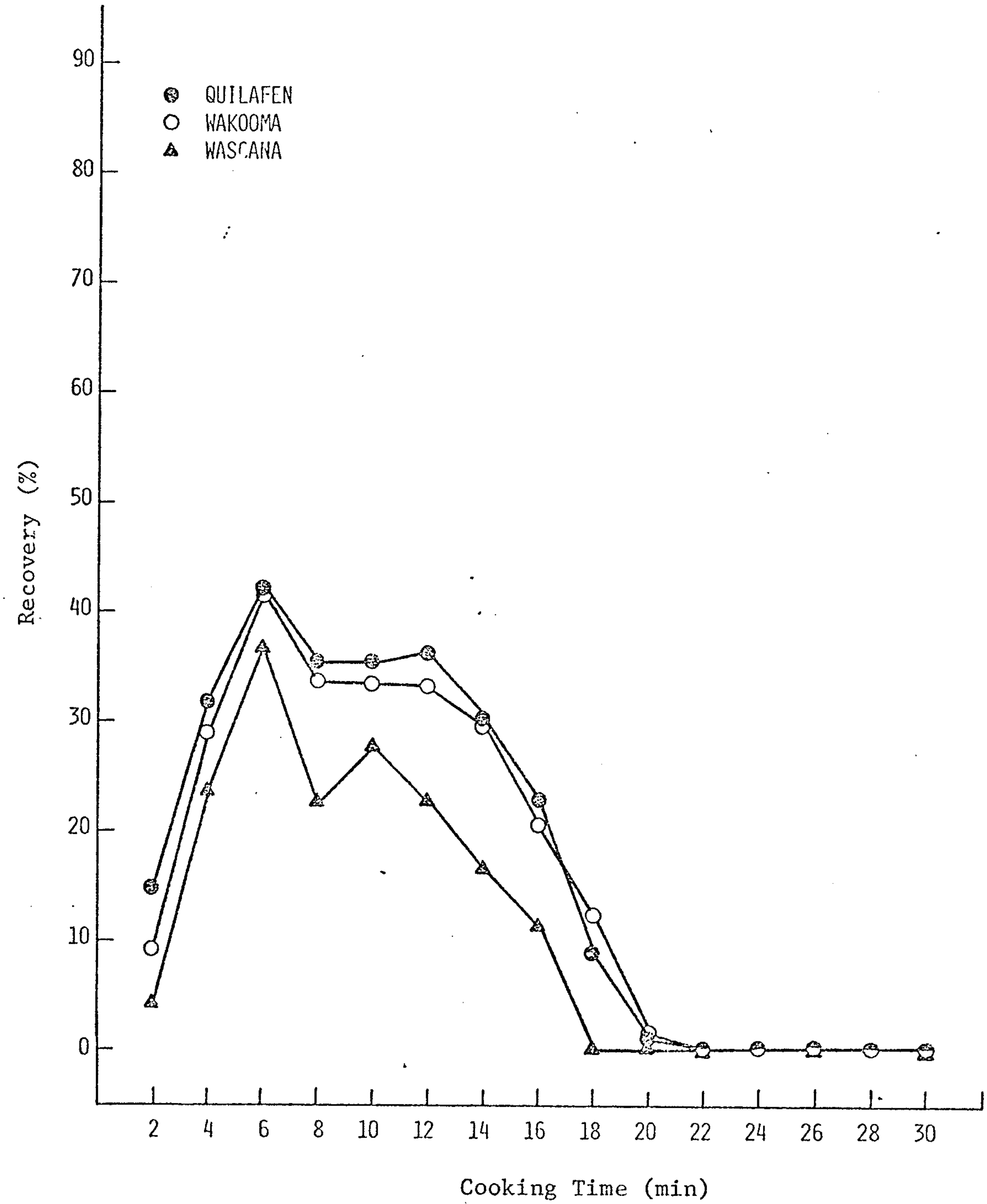


Figure 9. Effect of length of cooking time and durum variety on instrumentally assessed recovery of spaghetti cooked at 98.5°C.

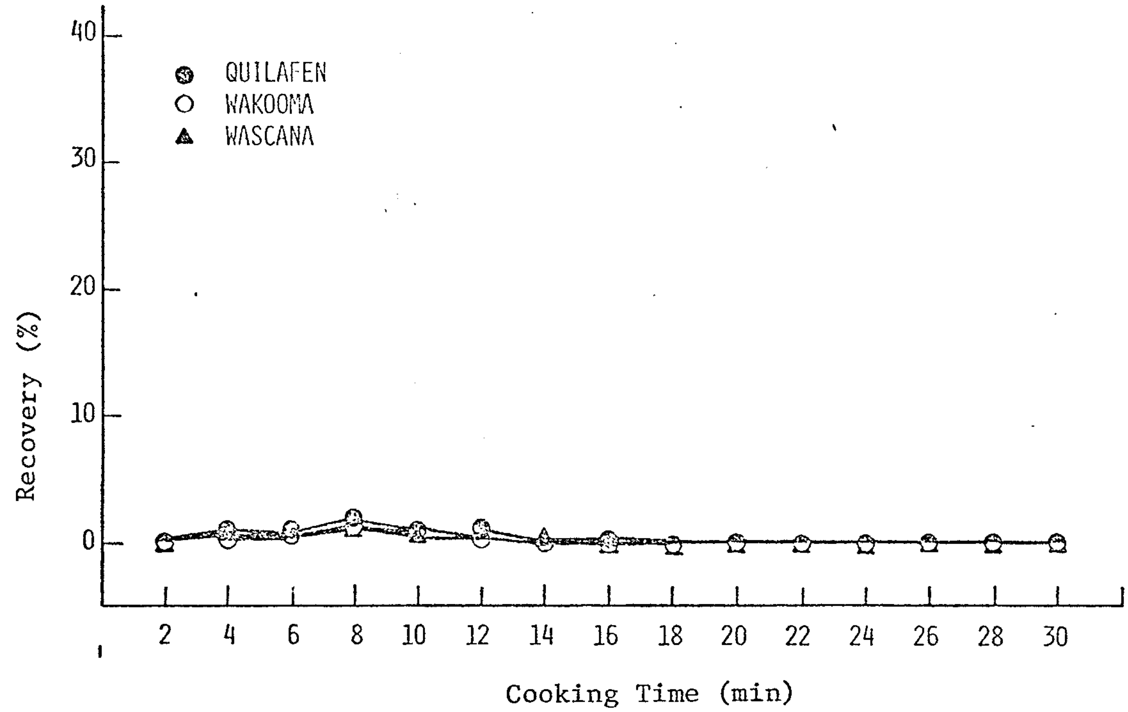


Figure 10. Effect of length of cooking time and durum variety on instrumentally assessed recovery of spaghetti cooked at 82°C.

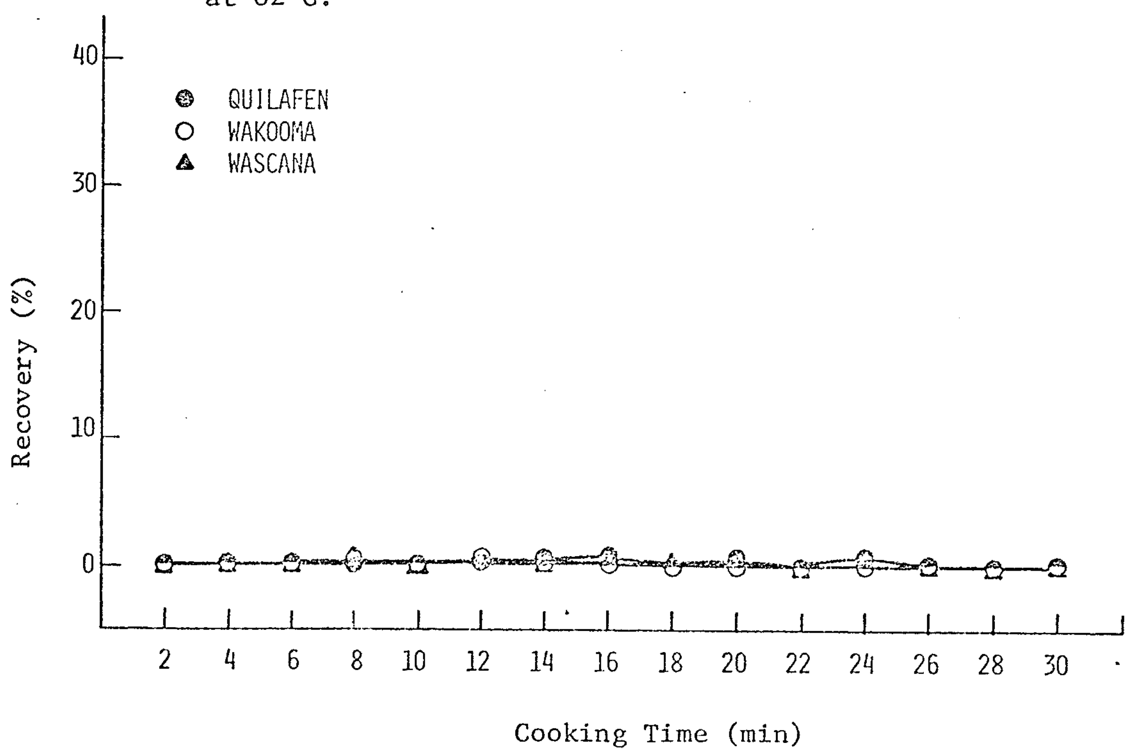


Figure 11. Effect of length of cooking time and durum variety on instrumentally assessed recovery of spaghetti cooked at 58.5°C.

samples were produced from pure varieties varying fairly widely in protein content, it seemed surprising that no major differences were noted. In attempting to explain this lack of difference, protein determinations were done on the spaghetti samples. These results were then compared with the protein levels previously determined for the semolinas. From Table 6 it is evident that mixing of the varieties must have occurred during processing. Since samples were produced on a continuous processing regimen, this was highly possible. The results suggest that the varieties were processed in the order of Wascana, Wakooma and Quilafen, thus only Wascana was likely to be a pure sample.

Figures 12 to 20 show the effect of time and temperature on texture, within each variety. Considering Figures 12 to 14, all 3 varieties when cooked at 82°C, tend to be softer for at least the middle time range, than those cooked at 58.5°C or in boiling water. This observation not withstanding, samples cooked at 98.5°C reached the al dente stage, that is no longer evidenced a white core, 6 min before those cooked at 82°C and 18 min before those cooked at 58.5°C. Samples cooked at 58.5°C were the firmest at any given time period up to 28 min since they were not fully hydrated. At 30 min this observation held true for Wascana, however, tenderness values for Wakooma and Quilafen were highest for 82°C and 98.5°C samples, respectively. The differences in texture due to time in this study, suggest that samples should be cooked to al dente rather than for a specified length of time, to insure optimum textural characteristics for testing purposes.

The observations as to the effect of temperature also suggest that a certain amount of heat is required for rapid water penetration and that even more heat is required to maximize the textural qualities after

Table 6. Comparison of protein content of semolina and uncooked spaghetti used and produced commercially for variety study.

	Protein (%)[1]	
Variety	Semolina	Spaghetti
Wascana	11.7	11.7
Wakooma	13.8	12.8
Quilafen	12.3	12.7

[1] 14% moisture basis.

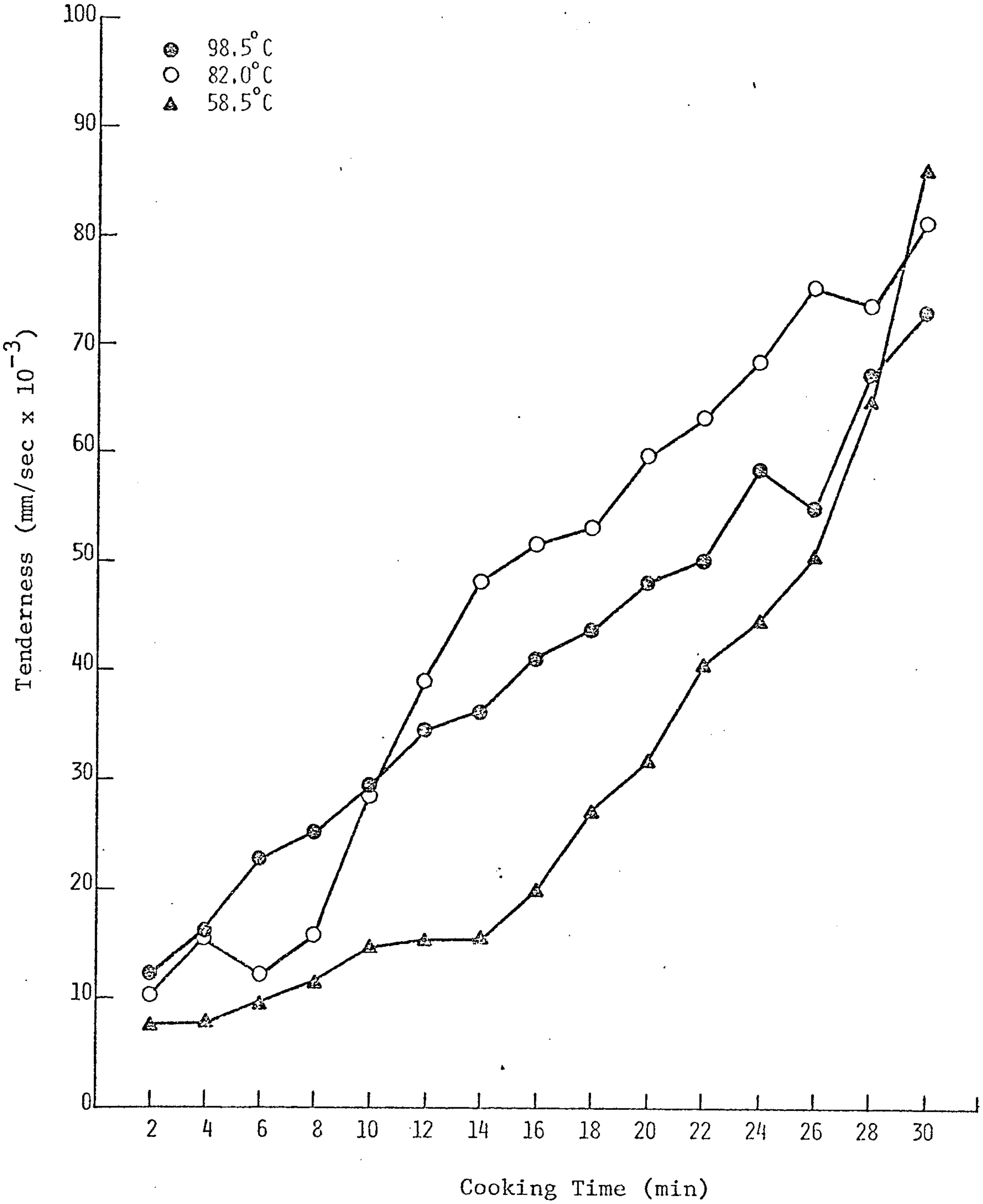


Figure 12. Effect of length of cooking time and cooking water temperature on instrumentally assessed tenderness of spaghetti made from Quilafen semolina.

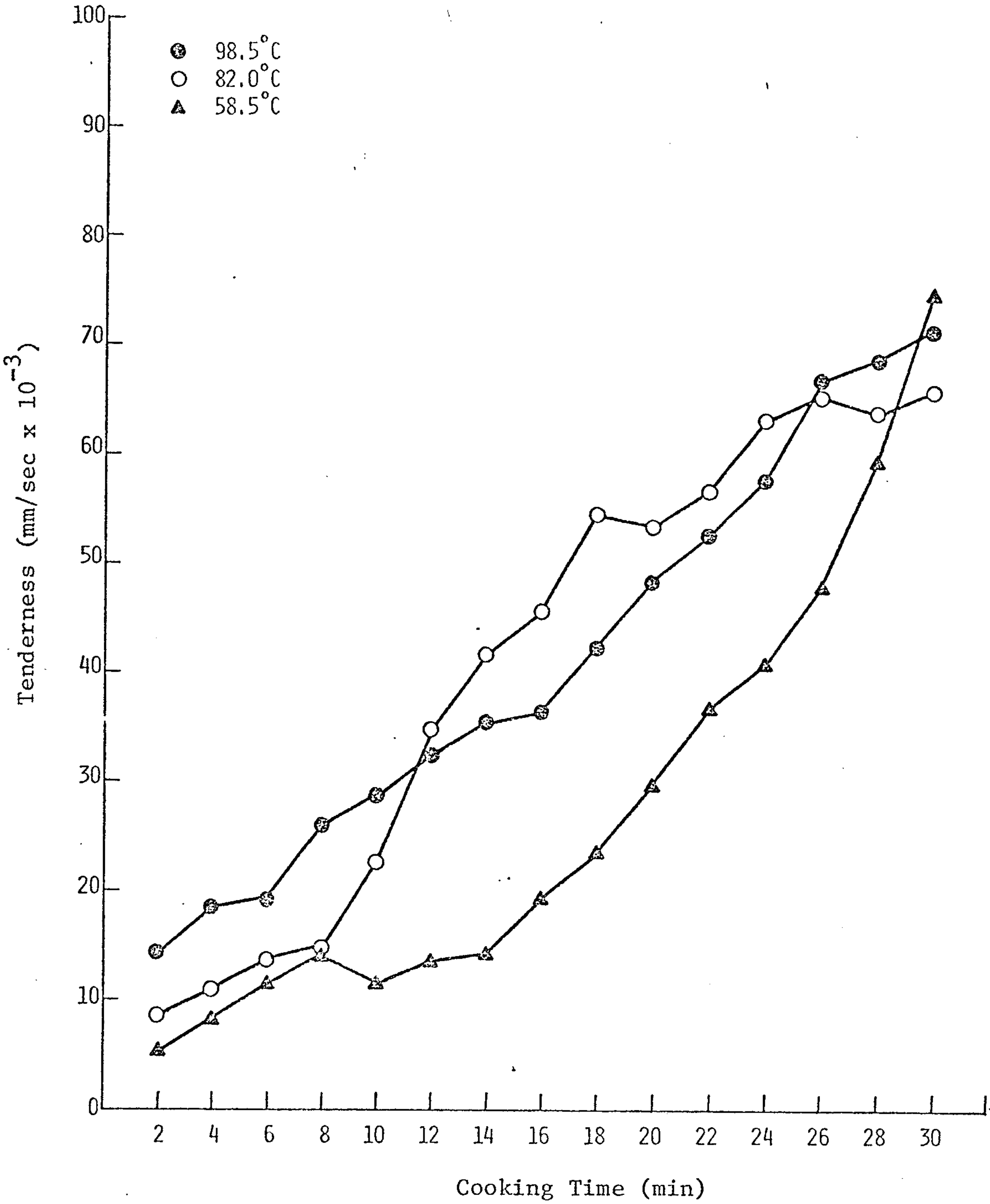


Figure 13. Effect of length of cooking time and cooking water temperature on instrumentally assessed tenderness of spaghetti made from Wakooma semolina.

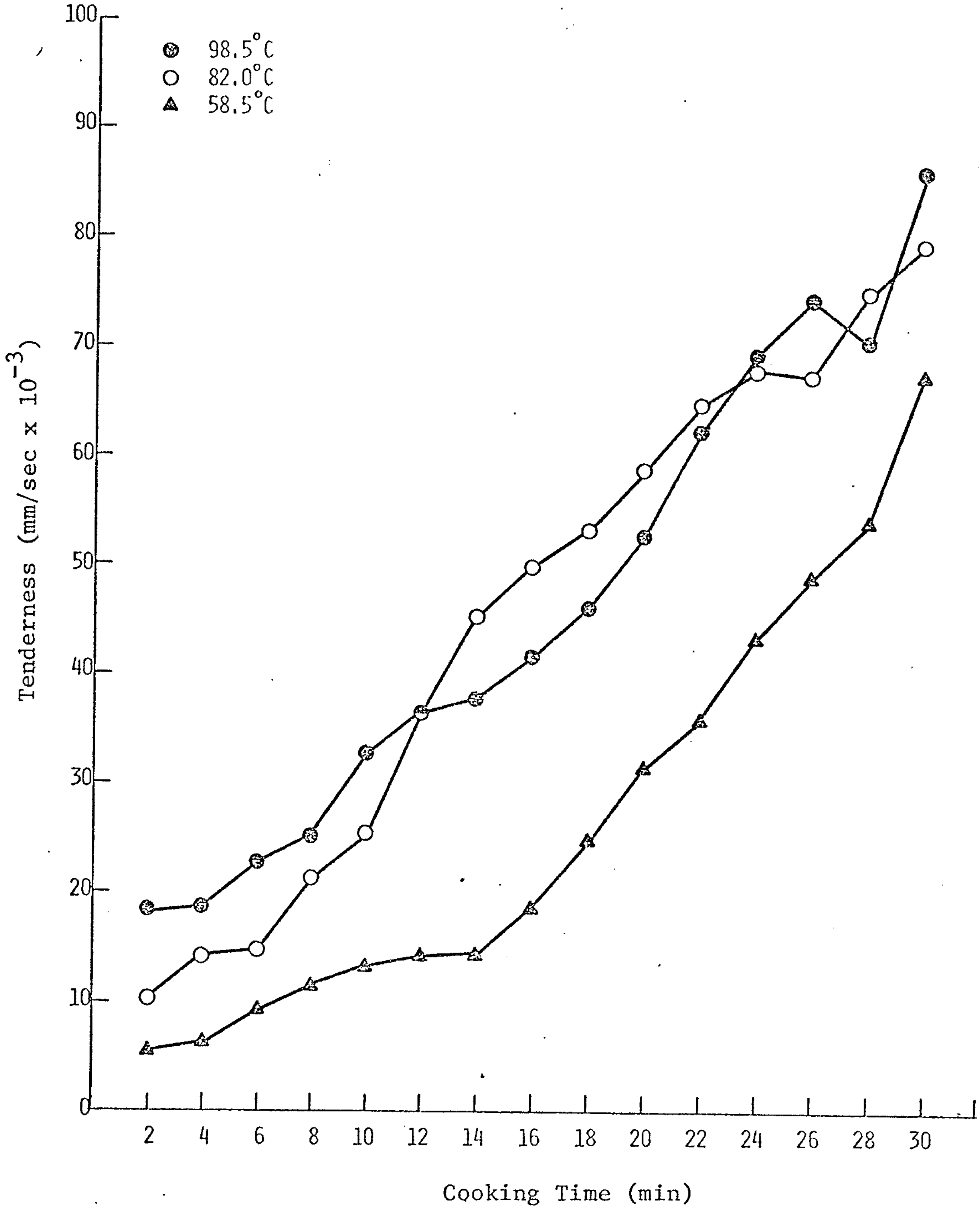


Figure 14. Effect of length of cooking time and cooking water temperature on instrumentally assessed tenderness of spaghetti made from Wascana semolina.

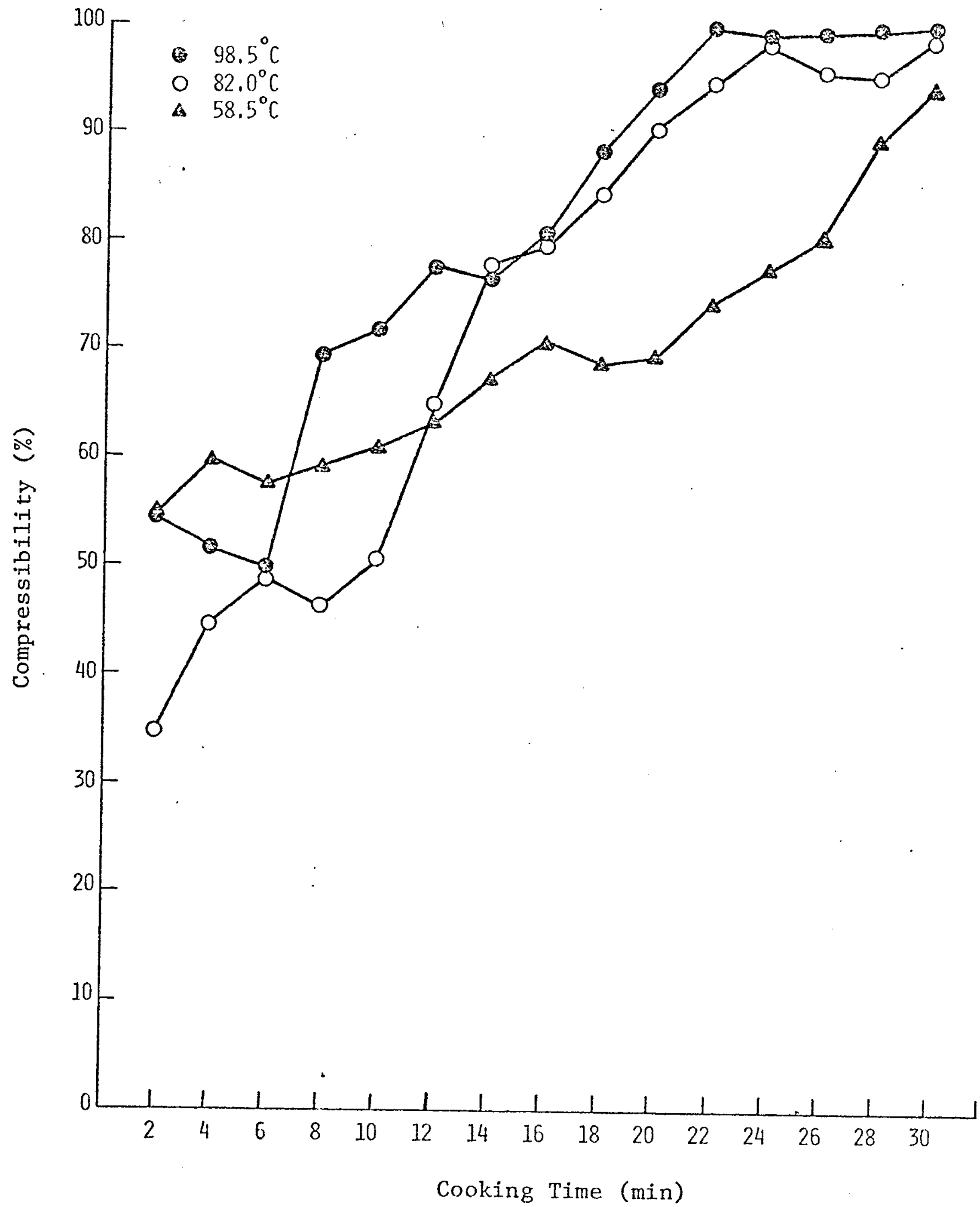


Figure 15. Effect of length of cooking time and cooking water temperature on instrumentally assessed compressibility of spaghetti made from Quilafen semolina.

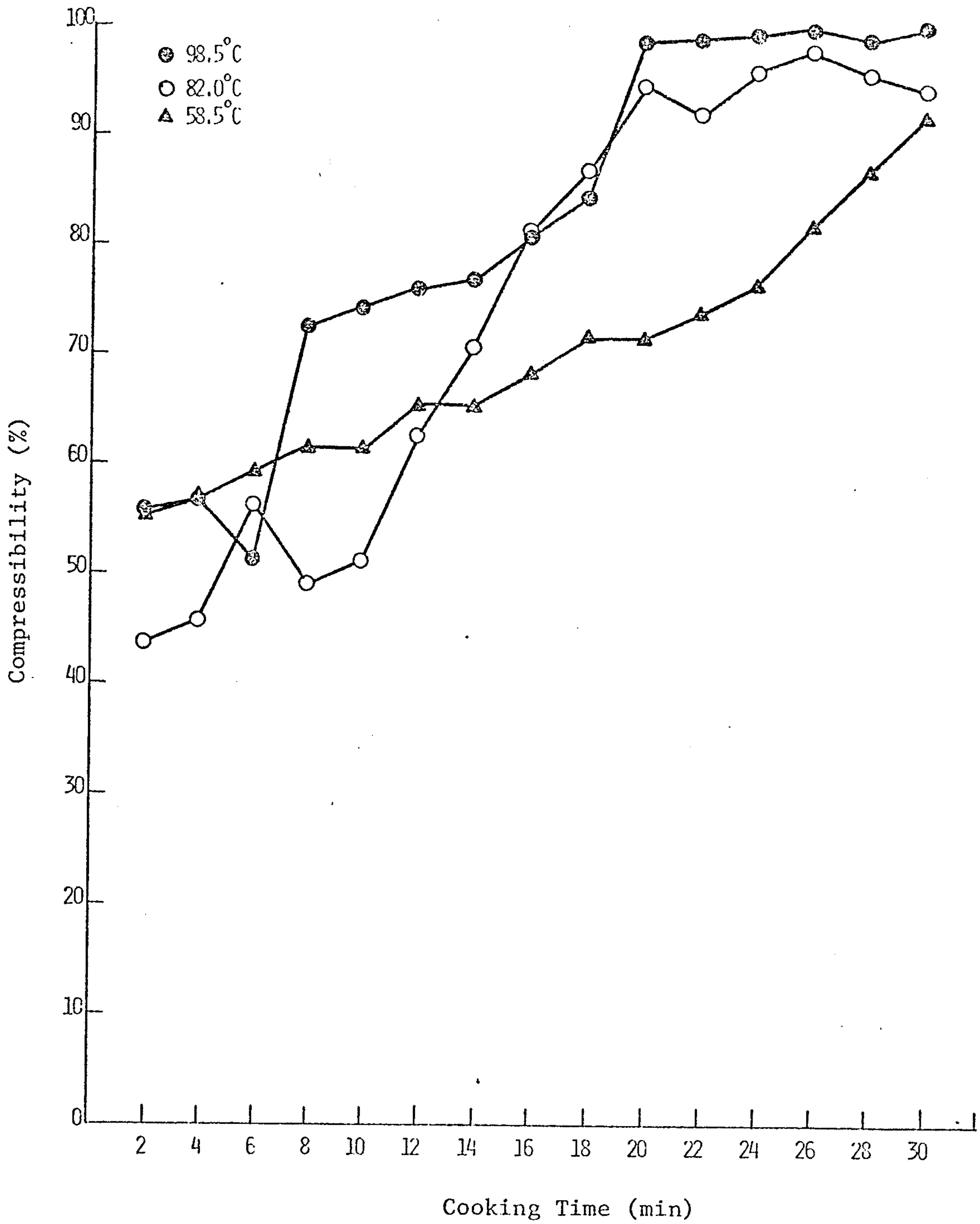


Figure 16. Effect of length of cooking time and cooking water temperature on instrumentally assessed compressibility of spaghetti made from Wakooma semolina.

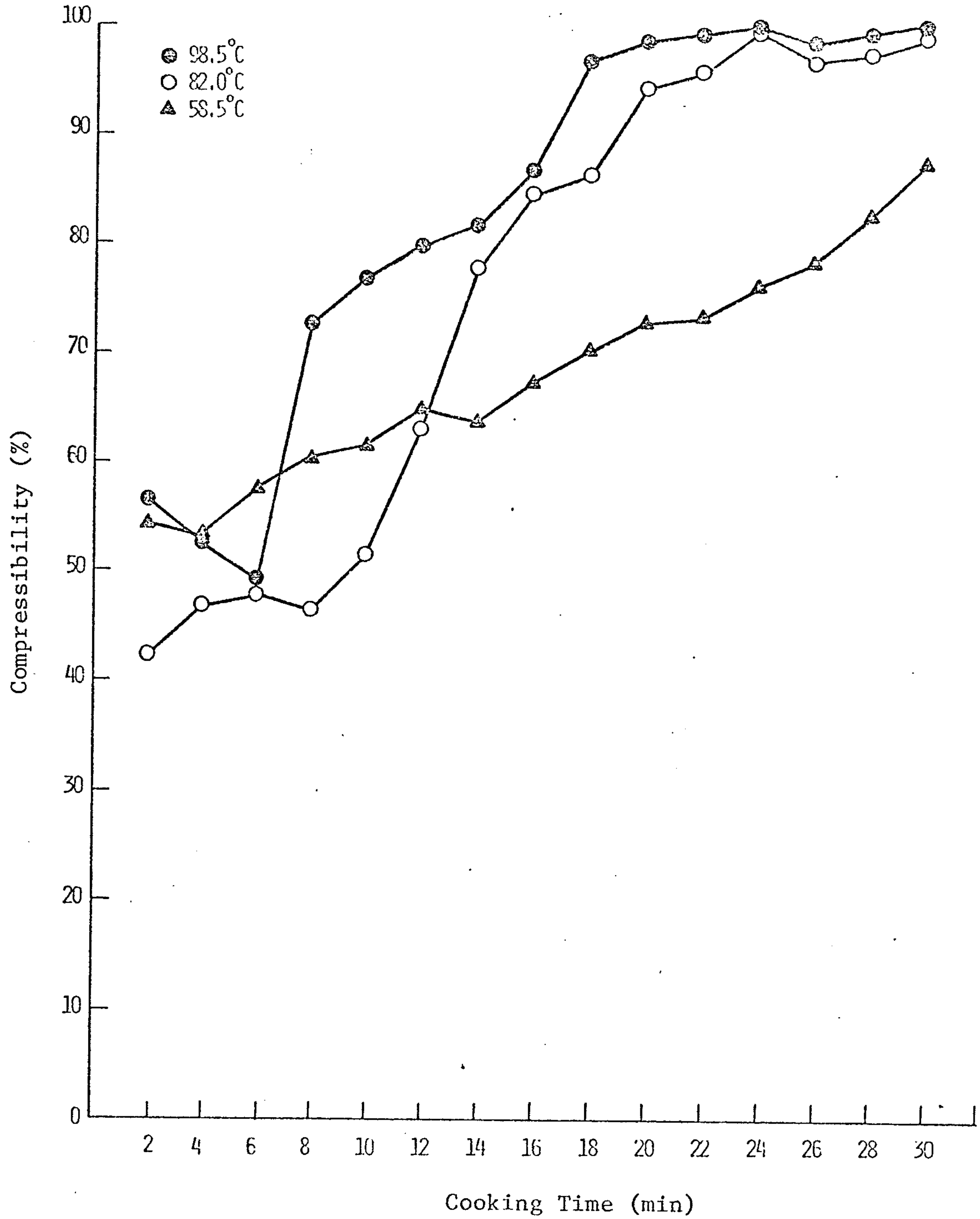


Figure 17. Effect of length of cooking time and cooking water temperature on instrumentally assessed compressibility of spaghetti made from Wascana semolina.

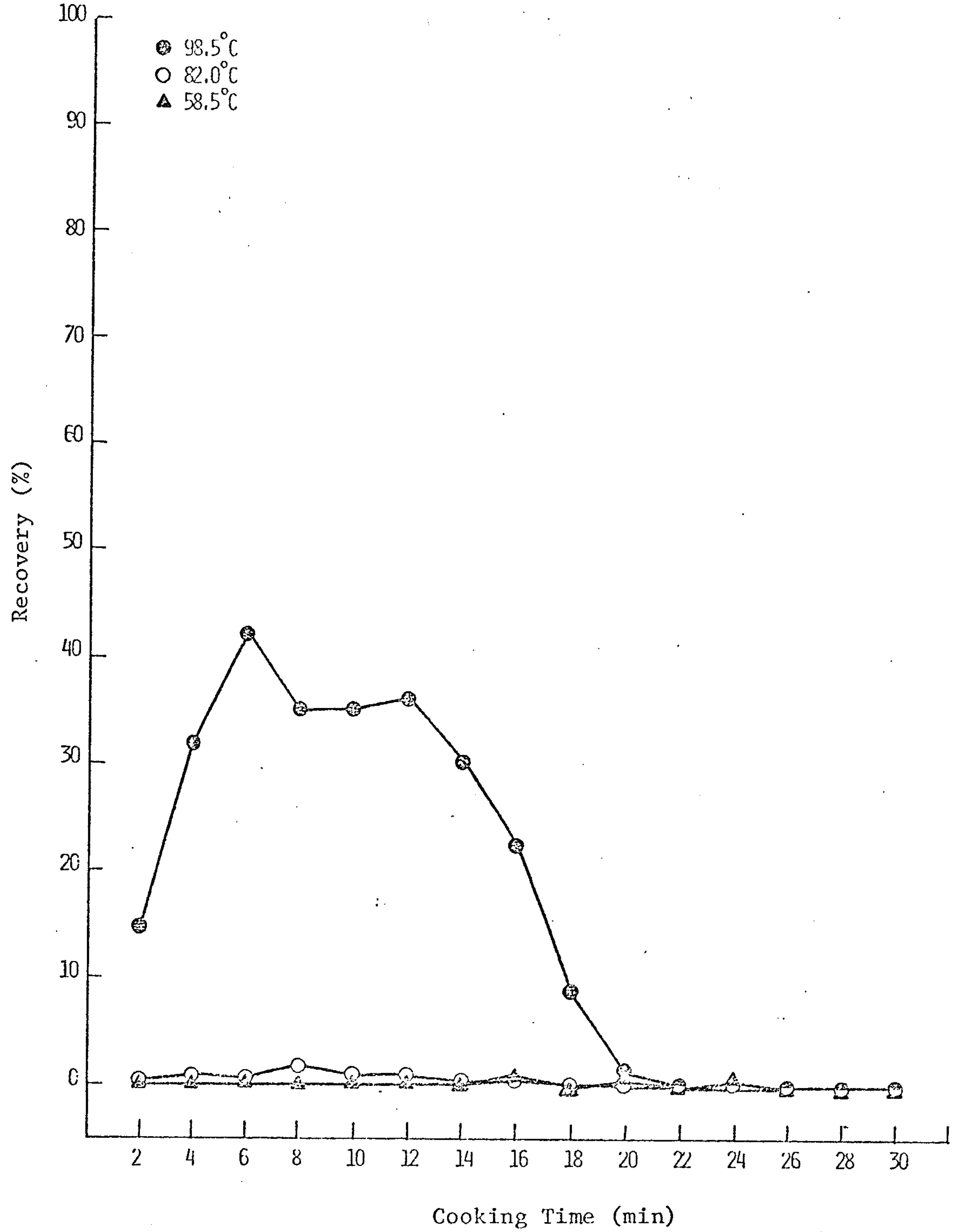


Figure 18. Effect of length of cooking time and cooking water temperature on instrumentally assessed recovery of spaghetti made from Quilafen semolina.

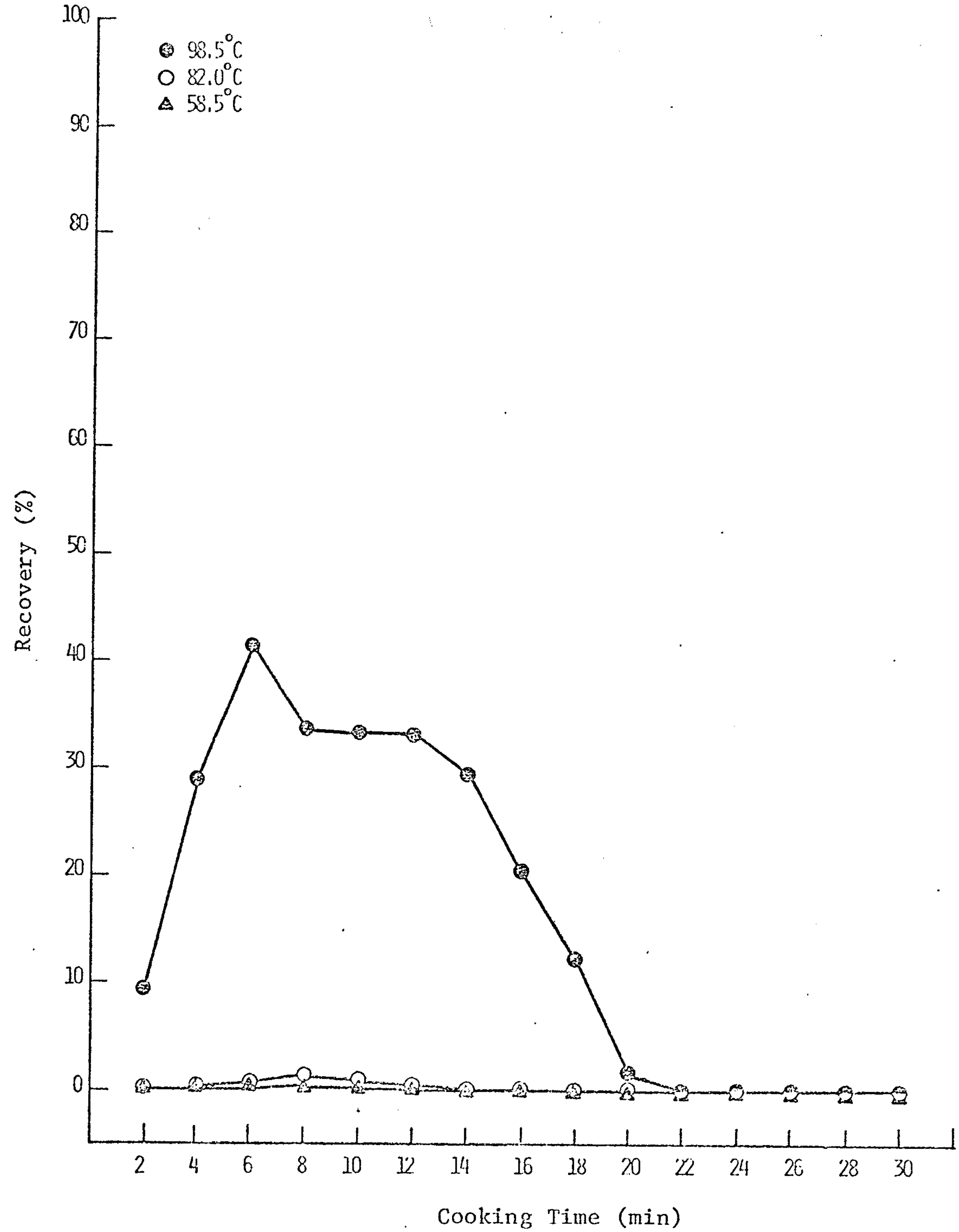


Figure 19. Effect of length of cooking time and cooking water temperature on instrumentally assessed recovery of spaghetti made from Wakooma semolina.

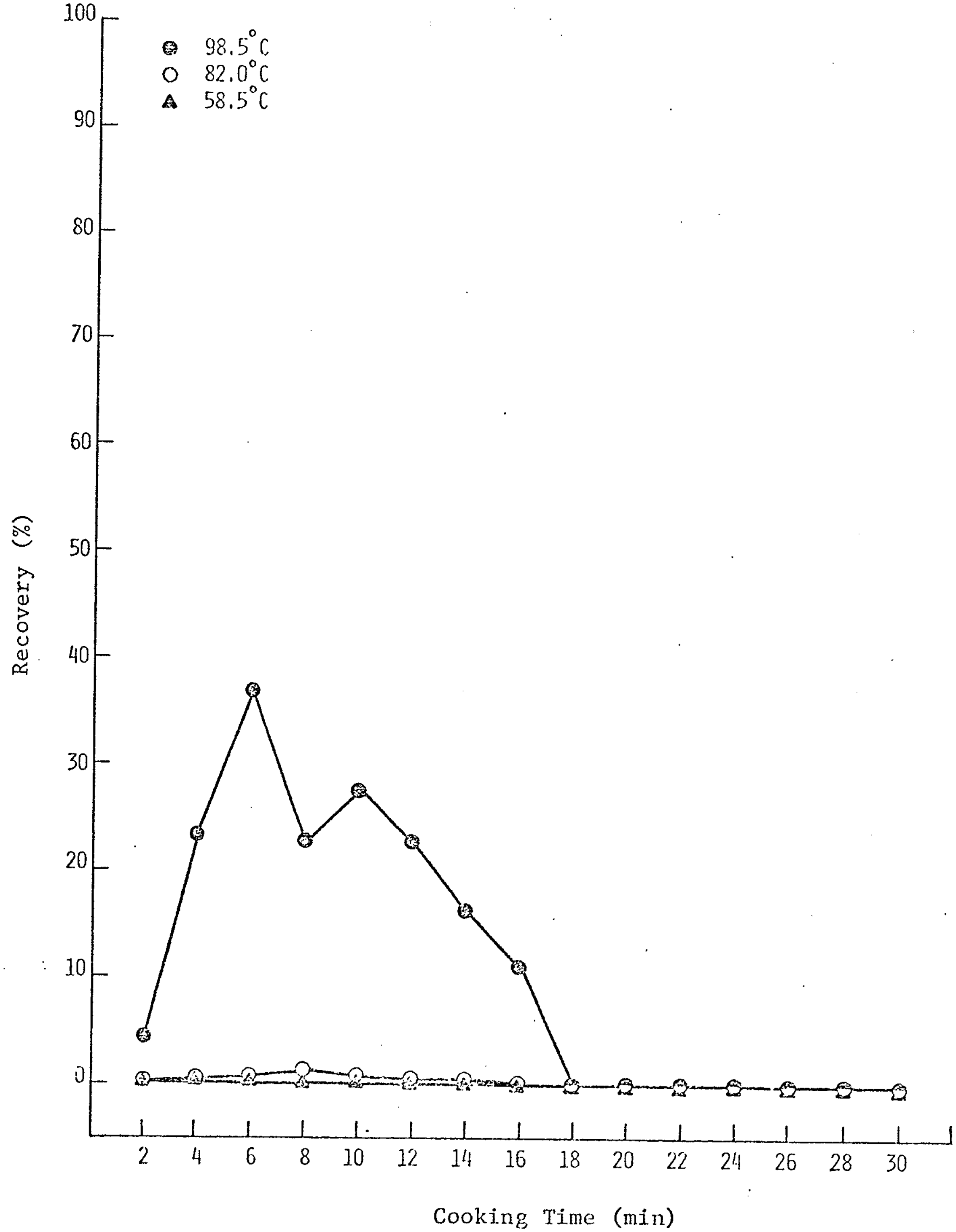


Figure 20. Effect of length of cooking time and cooking water temperature on instrumentally assessed recovery of spaghetti made from Wascana semolina.

this penetration has occurred. This appears to be especially true for the recovery parameter where the effect of heat is very dramatic. A decrease of 16^{o} in cooking water temperature results in a drop in recovery from approximately 40% to less than 1%. Since this change is effected in the region of 82^{o} to 98^{o}, it may be possible that gelatinization of starch is responsible for the recovery attribute of a sample. This drastic temperature dependence does not occur for tenderness or compressibility and it is likely that these parameters are protein influenced rather than starch influenced. The suggestion that these textural parameters are not starch dependent is borne out by the fact that when samples cooked for 30 min at $58.5^{o}C$ were placed in boiling water for 5 sec, they exhibited almost the same degree of firmness and compressibility as shown by samples cooked to al dente in boiling water (Table 7). The percent recovery, however, did not change to the same degree. Further studies were done to determine the effect of the length of time that the spaghetti was cooked in boiling water following cooking for 30 min at $58.5^{o}C$. These tests were done only on Wakooma samples since varietal differences with respect to textural quality appeared to be negligible. When samples were placed in boiling water for 30, 60, 90 and 120 sec, further improvements in texture were noted (Table 8). At 60 sec, tenderness and compressibility appeared to be almost identical to the comparable values derived from samples cooked to al dente in boiling water (Table 7). The recovery of the sample, after 60 sec was approximately one half the value exhibited by al dente samples cooked in boiling water. Cooking the $58.5^{o}C$ samples for more than 60 sec in boiling water, did not improve the textural characteristics any further and by the time they had been cooked for 120 sec, the results were

Table 7. Comparison of average[1] results for tenderness, compressibility and recovery of spaghetti samples cooked at boiling temperature (98.5°C), at 58.5°C and at 58.5°C plus 5 sec boiling water.

Variety	Treatment[2]	Tenderness mm/sec x 10^{-3}	Compressibility %	Recovery %
Quilafen	boiling water (12 min)	34.7	77.6	36.0
	58.5°C (30 min)	86.4	94.2	0.0
	58.5°C (30 min) + 5 sec boiling	44.2	82.5	2.9
Wakooma	boiling water (12 min)	32.4	76.0	33.0
	58.5°C (30 min)	74.6	91.7	0.4
	58.5°C (30 min) + 5 sec boiling	36.3	77.7	2.5
Wascana	boiling water (12 min)	36.3	79.8	22.6
	58.5°C (30 min)	67.4	87.2	0.0
	58.5°C (30 min) + 5 sec boiling	35.6	75.4	2.8

[1] Average of 3 replicates.

[2] Samples cooked in boiling water and at 58.5°C were cooked to al dente as determined by the Braibanti test.

Table 8. Comparison of average[1] results for tenderness, compressibility and recovery of Wakooma spaghetti samples cooked at 58.5°C for 30 min then immersed in boiling water (98.5°C) for 30, 60, 90 and 120 sec.

Treatment	Tenderness mm/sec x 10^{-3}	Compressibility %	Recovery %
30 min at 58.5°C + 30 sec boiling	37.18	82.43	6.71
30 min at 58.5°C + 60 sec boiling	32.72	77.23	16.49
30 min at 58.5°C + 90 sec boiling	32.83	80.90	15.82
30 min at 58.5°C +120 sec boiling	35.62	85.73	15.51

[1] Average of 3 replicates.

beginning to indicate deterioration in quality. The fact that starch gelatinization may be involved in these observed effects is further supported by the fact that samples cooked for 30 min at 58.5°C, when examined under polarized light, showed approximately 95% of the starch granules to be birefringent. After 30 sec in boiling water, only 10% of the granules appeared to be totally birefringent, the remaining 90% were partially gelatinized. Samples boiled for 60 sec and longer showed almost total loss of birefringence. Thus it was not until gelatinization had taken place that most of the textural qualities were restored. Starch gelatinization appears to take place in stages, with initial swelling occurring at temperatures between 55° and 70°C followed by a rapid increase in viscosity from about 71° to 93°C (Crossland and Favor, 1948). Since it has been shown that starch gelatinization plays a specific role in bread baking, in relation to the texture of the product (Sandstedt, 1961), it is highly possible that it may also fulfil a similar function in relation to the cooking quality of spaghetti. The results of these tests suggest that this is so, at least as far as percent recovery is concerned.

In view of the effect on texture of blanching as well as of cooking water temperature and length of cooking time, the standardization and control of these conditions is essential for acceptable results.

Volume increase with cooking time. Volume increase in samples with respect to length of cooking time was also investigated. The diameter of the stands of spaghetti can have an effect on instrumental assessment of texture and it is possible that it might also affect sensory texture perception. Increase in weight or volume of cooked spaghetti was also linked with cooking quality in the literature reviewed (Binnington *et al.*,

1939) thus measuring this increase over time might be a simple way of predicting quality. The average volumes for the 3 varieties tested are shown in Table 9. As can be seen, there was very little difference among varieties at any one specific cooking time, and plots of volume against cooking time were practically superimposable as shown in Figure 21. This suggests that there is very little value in using this method for prediction of cooking quality. However, the fact that the volume continued to increase even after 10 min overcooking indicates that it might be considered in relation to the effect of strand diameter on texture measurement.

Plotting the 3 instrumental parameters against volume, as seen in Figures 22, 23 and 24, gives curves similar to those obtained by plotting these parameters against cooking time. This is because volume increase is almost linear with cooking time.

Effects of processing conditions. The effects of temperature and pressure applied during the resting period of spaghetti production on firmness, compressibility and percent recovery of samples made from Stewart 63 and Hercules semolinas, are shown in Tables 10 and 11. The analyses of variance for these results are presented in Table 12. In all cases, F values for temperature were significant at the 1% level of probability. Application of Tukey's hsd test to the results for Hercules are shown in Table 13. Since F values for batch were significant for Stewart 63, it was not permissible to apply Tukey's test to the temperature results, however, the results tended to be in the same direction as those for Hercules. Examination of the data in Table 13 indicates that the two higher temperatures tend to effect negative changes in the texture of cooked spaghetti, whereas the 2 lower tempera-

Table 9. Average[1] volume increase over time, for 3 spaghetti samples.

Cooking time min	Average volume (ml) Variety		
	Quilafen	Wakooma	Wascana
0	0.08	0.09	0.08
2	0.16	0.16	0.15
4	0.20	0.20	0.20
6	0.25	0.24	0.23
8	0.26	0.25	0.26
10	0.29	0.29	0.27
12	0.30	0.31	0.32
14	0.34	0.33	0.33
16	0.35	0.35	0.36
18	0.37	0.38	0.35
20	0.40	0.38	0.39
22	0.42	0.40	0.41
24	0.44	0.42	0.44
26	0.44	0.43	0.45
28	0.46	0.46	0.48
30	0.46	0.48	0.45

[1] Average of 3 replicates.

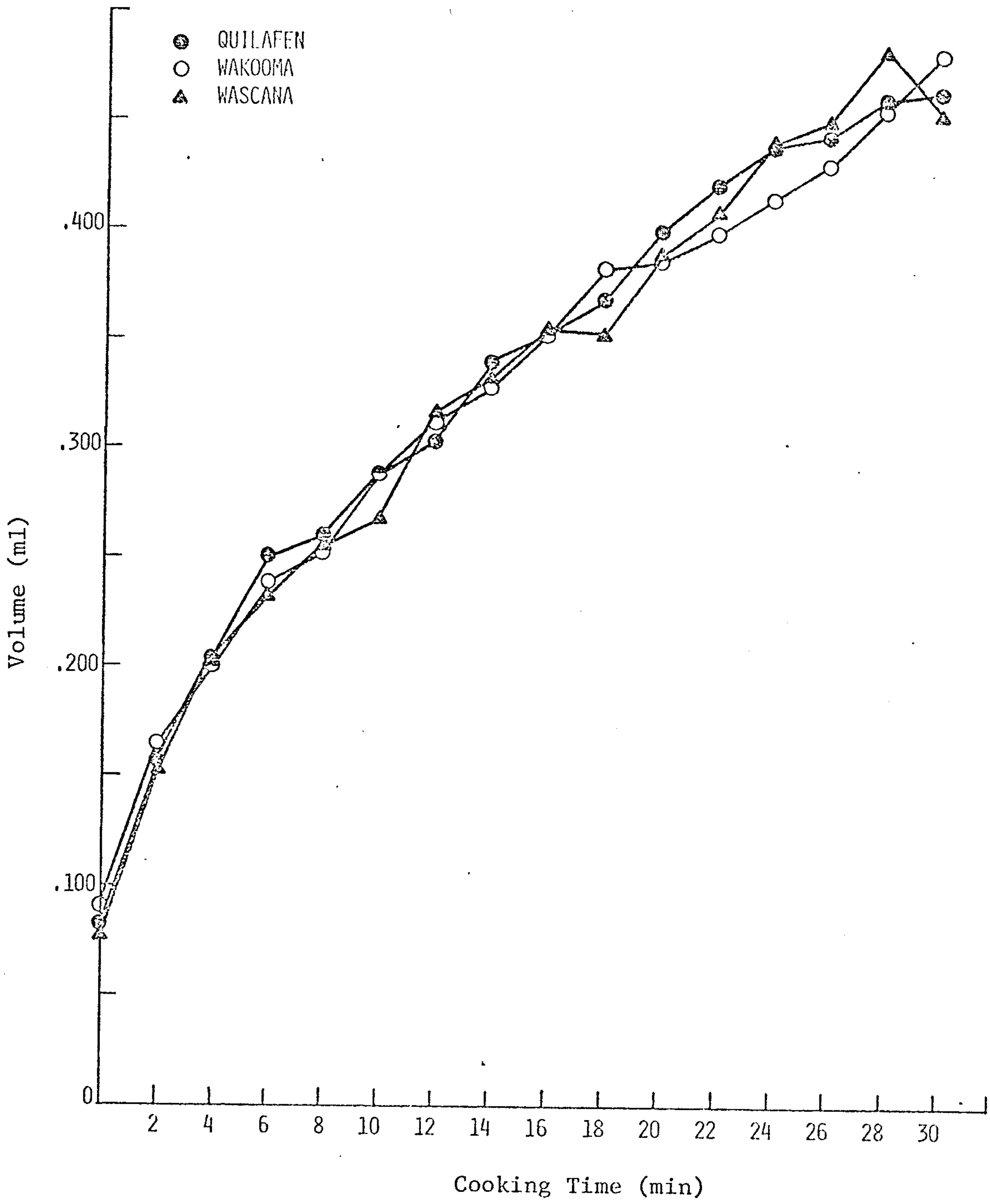


Figure 21. Effect of variety on the relationship between volume increase of cooked spaghetti and length of cooking time.

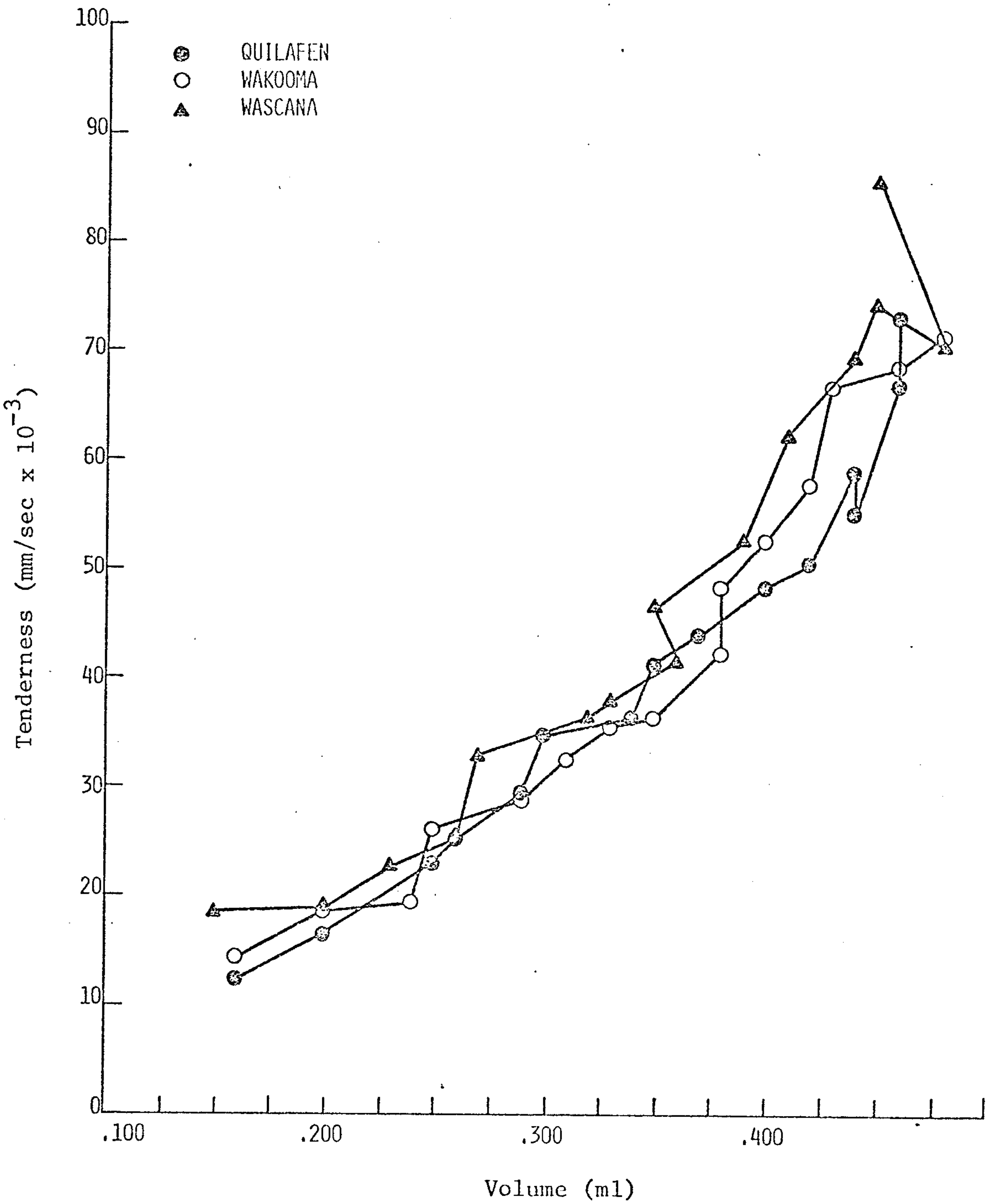


Figure 22. Effect of variety on the relationship between instrumentally assessed tenderness and volume of cooked spaghetti.

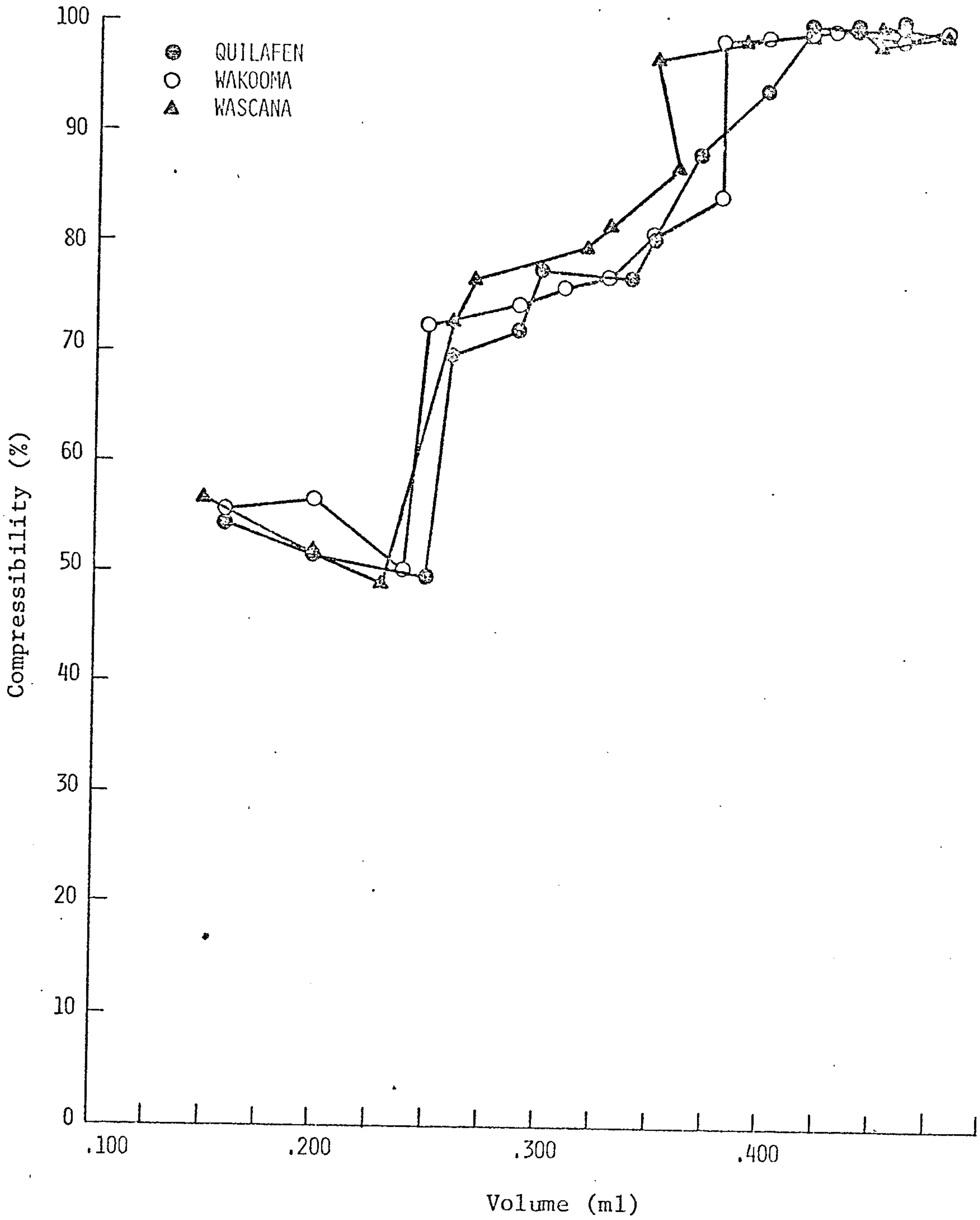


Figure 23. Effect of variety on the relationship between instrumentally assessed compressibility and volume of cooked spaghetti.

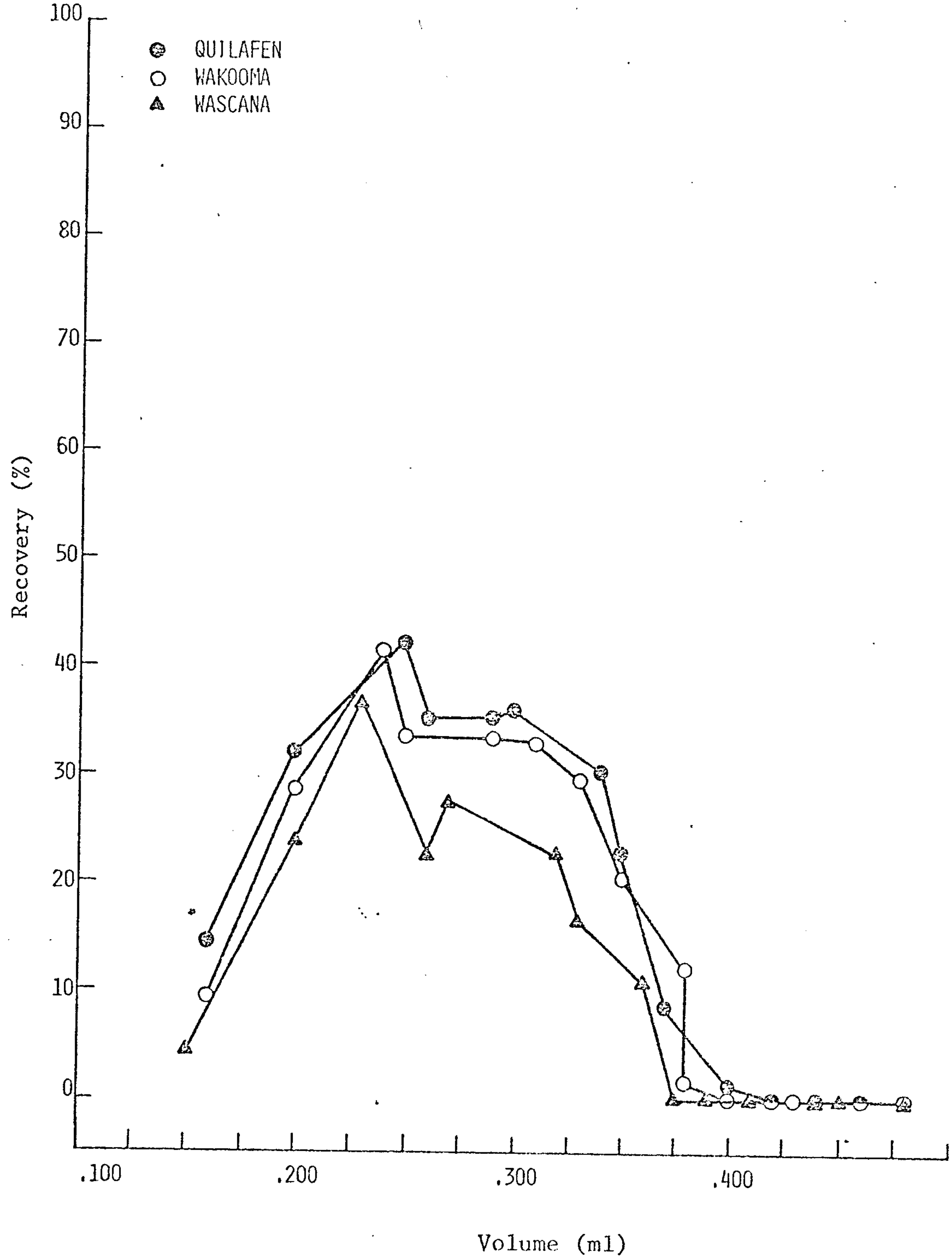


Figure 24. Effect of variety on the relationship between instrumentally assessed recovery and volume of cooked spaghetti.

Table 10. Average[1] results for firmness, compressibility and recovery of spaghetti produced from Stewart 63 semolina.

Temp °C	Press psi	Duplicate	Textural Parameter: Tenderness mm/sec x 10^{-3}	Compressibility (%)	Recovery (%)
25	0	1	40.0	75.8	23.7
		2	41.6	77.4	20.0
	1000	1	39.8	75.3	23.2
		2	40.4	77.8	22.6
	2000	1	38.5	74.6	24.5
		2	39.6	79.2	25.8
	5000	1	42.2	78.1	21.6
		2	39.1	77.3	22.6
40	0	1	39.2	76.3	34.3
		2	36.8	72.2	31.4
	1000	1	37.8	75.3	33.2
		2	37.8	74.4	26.1
	2000	1	37.4	73.2	31.2
		2	36.1	73.8	30.6
	5000	1	37.0	73.3	25.5
		2	38.1	75.3	25.9
60	0	1	39.3	75.4	25.1
		2	40.1	78.0	24.2
	1000	1	43.8	82.8	16.6
		2	42.6	78.6	18.5
	2000	1	40.3	77.7	18.4
		2	41.6	78.7	20.3
	5000	1	39.5	76.7	24.2
		2	41.1	76.9	20.5
80	0	1	44.4	78.6	12.8
		2	44.4	80.9	11.4
	1000	1	49.8	81.1	14.8
		2	44.3	81.1	9.0
	2000	1	46.4	82.0	10.8
		2	50.2	80.4	12.5
	5000	1	43.8	77.0	10.9
		2	47.5	84.0	4.9

[1] Average of 3 replicates.

Table 11. Average[1] results for firmness, compressibility and recovery of spaghetti produced from Hercules semolina.

Temp °C	Press psi	Duplicate	Textural Parameter: Tenderness mm/sec x 10^{-3}	Compressibility (%)	Recovery (%)
25	0	1	36.4	74.7	30.4
		2	34.6	72.8	30.1
	1000	1	35.1	75.2	31.7
		2	33.0	73.7	31.3
	2000	1	36.4	75.0	25.4
		2	33.4	76.2	26.6
	5000	1	35.3	73.4	30.0
		2	34.8	74.7	29.3
40	0	1	33.5	75.0	36.2
		2	35.2	76.0	26.3
	1000	1	35.4	73.9	28.8
		2	36.9	73.0	27.0
	2000	1	36.0	73.8	28.9
		2	37.4	75.5	30.1
	5000	1	35.7	73.4	31.5
		2	34.2	78.4	23.5
60	0	1	37.1	76.5	28.0
		2	34.2	75.0	27.9
	1000	1	41.1	80.3	22.0
		2	42.5	78.8	18.2
	2000	1	40.5	80.8	16.8
		2	39.3	81.9	18.3
	5000	1	40.8	80.9	15.6
		2	42.0	80.9	19.8
80	0	1	39.5	78.5	18.7
		2	40.4	77.2	21.4
	1000	1	45.0	79.3	18.0
		2	38.7	76.2	15.6
	2000	1	43.9	79.7	15.4
		2	44.1	77.2	15.5
	5000	1	38.9	77.9	14.6
		2	42.2	76.9	21.2

[1] Average of 3 replicates.

Table 12. Comparison of analysis of variance results for spaghetti samples made from Stewart 63 and Hercules under different processing conditions.

			MS			F value		
Variety	Source	df	Tenderness	Compressibility	Recovery	Tenderness	Compressibility	Recovery
Stewart 63	Temp	3	340.03	168.78	1468.77	39.36**	13.30**	90.11**
	Press	3	6.48	8.96	50.87	0.75	0.71	3.12
	TXP	9	10.56	6.00	33.29	1.22	0.47	2.04
	Batch	16	8.64	12.69	16.30	1.93*	2.04*	0.62
	Error	64	4.47	6.23	26.42			
Hercules	Temp	3	221.51	136.09	830.95	31.83**	22.87**	34.22**
	Press	3	27.08	15.35	123.07	3.89*	2.58	5.07*
	TXP	9	8.71	11.75	31.08	1.25	1.97	1.28
	Batch	16	6.96	5.95	24.28	0.53	0.59	1.33
	Error	64	13.09	10.14	18.28			

* $p < 0.05$

** $p < 0.01$

Table 13. Comparison of means for the instrumental textural parameters of spaghetti made from Hercules semolina.

	Textural parameter											
	Tenderness (mm/sec x 10^{-3})				Compressibility (%)				Recovery (%)			
Temperature (°C)	25	40	60	80	25	40	60	80	25	40	60	80
Mean value	35.7^{a}	36.4^{a}	40.0^{b}	42.2^{b}	74.5^{a}	74.9^{a}	79.4^{b}	77.9^{b}	29.4^{a}	29.0^{a}	20.8^{b}	17.6^{b}
Pressure (psi)	0	1000	2000	5000	0	1000	2000	5000	0	1000	2000	5000
Mean value	37.1^{a}	38.9^{a}	39.6^{b}	38.8^{a}	75.7^{a}	76.3^{a}	77.5^{a}	77.1^{a}	27.4^{a}	24.2^{ab}	22.1^{b}	23.2^{b}

abc Numbers in the same row bearing different superscripts are significantly different ($p < 0.01$) based on Tukey's hsd test.

tures effect positive changes. In general, compressibility appears to vary directly with temperature while firmness and recovery vary inversely.

The effect of processing temperature was also seen during cooking. Samples processed at 80^{o}, when cooked for testing purposes, left a large amount of residue in the cooking water, while those samples processed at the lower temperatures showed fairly clear cooking water. The surface of the 80^{o} samples following cooking and blanching, was uneven and appeared to be coated with a sticky residue. For all the other treatments, the sample surfaces were smooth and slippery. The sticky coating plus poor textural attributes made samples produced at 80^{o} the least desirable.

For the Hercules samples, pressure effects were significant for tenderness and recovery, however, the level of probability for significance was 5% rather than 1% as observed for temperature effects. No significance was found for any of the textural parameters when the pressure effect on Stewart 63 samples was examined. In the case of this variety, batch effects were significant ($p < 0.05$) for tenderness and compressibility but not for recovery. These batch effects were probably responsible for the lack of apparent significant pressure effects.

The significant pressure effects and the fact that low pressures tended to produce more desirable products suggests that sufficient pressure was exerted by the mixer blades on the dough, during mixing and that additional pressure during resting was therefore not necessary or might even be detrimental. These findings do not agree with the results reported by Martin _et al_. (1946), who developed the micro method for producing macaroni. These authors reported that resting the dough under pressure was done to simulate conditions of commercial processing and to obtain maximum efficiency during extrusion. Since the latter was important for good surface characteristics, pressure was used during the rest period. At the time that this paper (Martin et al., 1946) was published, the textural qualities of cooked samples were not being assessed. Surface characteristics, however, were and pressure was found to have a positive effect on these since it reduced the number of air bubbles in the dough. With the introduction of the application of vacuum during mixing, the use of high pressures during the rest period no longer appears to be as crucial. On the basis of these results, it may be possible to reduce the level of pressure applied, or delete it completely from the micro scale method.

Although both varieties showed the same trends as far as treatments were concerned (Table 10 and 11), in almost all cases, Hercules appeared to produce a product of better cooking quality than Stewart 63. In addition, Hercules seemed to have a greater tolerance to variation in processing than did Stewart 63. It would appear therefore, that the varietal role in cooking quality cannot be completely obscured by variation in processing conditions.

To determine whether surface characteristics of a spaghetti sample could be related to cooking quality and hence serve as a tool for its prediction, samples of spaghetti produced from Stewart 63 and Hercules semolinas were examined using a scanning electron microscope (SEM). All the Stewart 63 samples were examined, however, no obvious differences could be seen among any of the treatments. For this reason, only a few of the Hercules samples were examined and the same appeared to be true for them. Thus, while the scanning electron microscope is of interest in studying the surface characteristics of spaghetti samples, it does not appear that these characteristics are sufficiently different among treatments to be used for prediction of differences in cooking quality.

As a result of these studies, the recommendation is made that samples be processed at 40°C and low pressure for optimum development of textural characteristics. Since the standard micro technique employed by GRL uses 50°C and 2000 psi, observed differences in quality are likely to be due to variety or to the physical or chemical composition of the semolina, rather than to the processing conditions imposed on the sample in this method.

Instrumental Evaluation of Texture

Range in commercial samples. When testing experimentally produced samples, it is useful to know the range of values occurring in standard samples so that the experimental results may be evaluated in this light. Work reported by Matsuo and Irvine (1970) suggested that a range in tenderness index of 35 to 45, as determined using the GRL spaghetti tenderness testing apparatus, was representative of good cooking quality. To examine the range in texture of spaghettis available commercially, 6 brand name samples were cooked and tested. The results of these tests are shown in Table 14. As is evident, the tenderness values for these brands are fairly close to the range suggested by Matsuo and Irvine (1970) as desirable. No numerical ranges of acceptibility, however, were specified by these authors for compressibility and recovery. Instead, the suggestion was made that low compressibility and high recovery were preferable. For these samples then, considering all 3 textural parameters, Agnesi brand would be the most desirable and Constant the least, with all the other brands intermediate to these two.

Scanning electron microscope studies were also done on these

Table 14. Average[1] results of cooking tests done on 6 brand name spaghettis using the GRL spaghetti tenderness testing apparatus.

Brand	Textural Parameter		
	Tenderness mm/sec x 10^{-3}	Compressibility %	Recovery %
Agnesi	32.2^{a}	67.8^{a}	46.3^{c}
Barilla	37.7^{b}	76.2^{a}	27.9^{b}
Catelli	38.3^{b}	69.8^{a}	20.5^{b}
Constant	41.3^{c}	93.0^{b}	2.4^{a}
Creamette	36.7^{b}	74.7^{a}	18.4^{b}
Primo	36.4^{b}	73.5^{a}	23.4^{b}

[1] Average of 4 replicates.

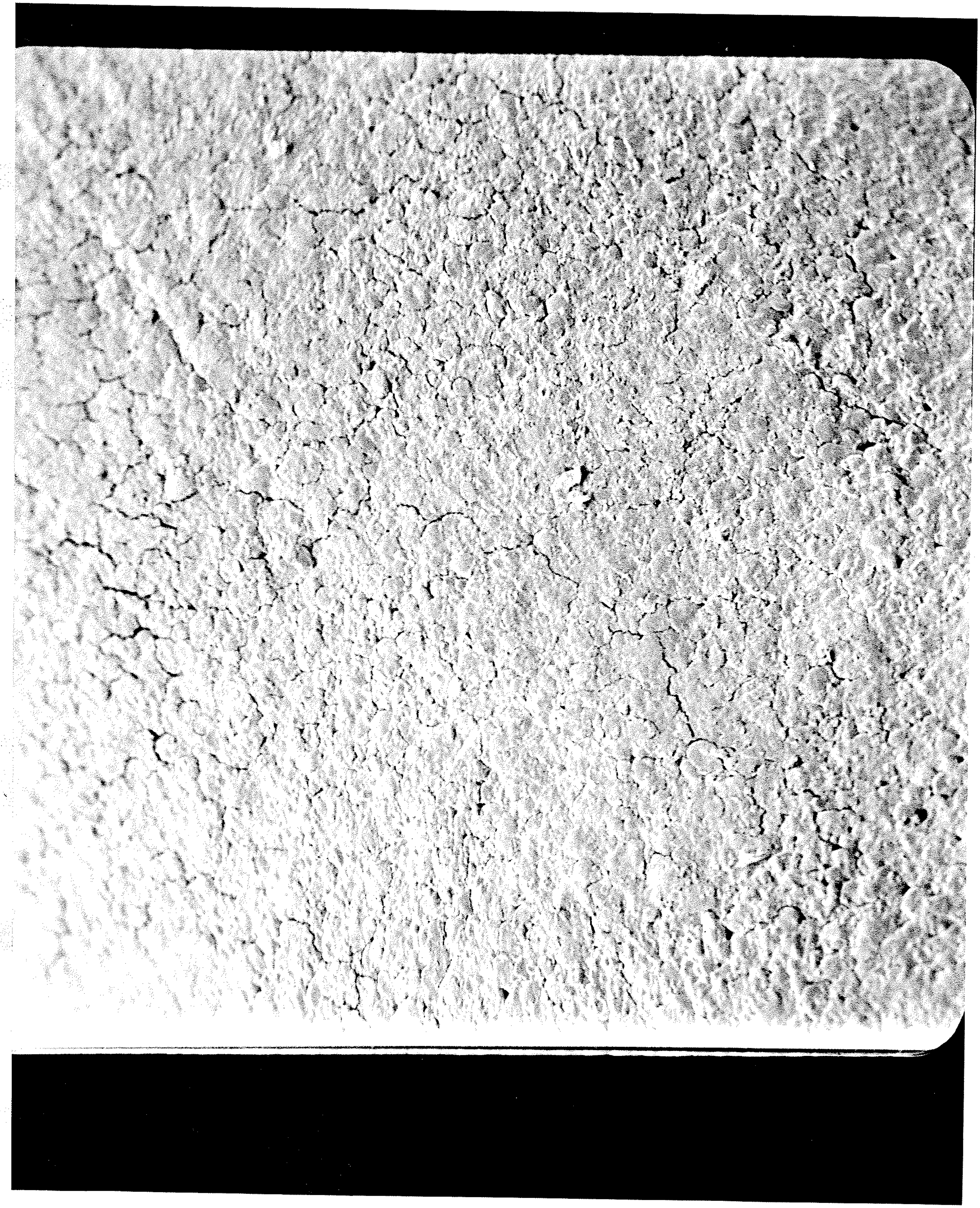
[abc] Numbers in the same column bearing different superscripts are significantly different at the 5% level of probability, based on Tukey's hsd test.

commercial samples. These studies showed some distinct differences between the sample of poorest cooking quality, Constant, and the rest of the samples, however, no major differences were visible between the intermediate samples and the best one. Figures 25 and 26 are included to illustrate the differences found. Figure 25 shows the surface of a strand of Constant brand spaghetti, Figure 26 that of Barilla at the same magnification. Individual starch granules and a fairly rough surface characterize the Constant sample. The starch granules appear to be coated, the sample is more compact and the surface much smoother in the Barilla sample. A number of reasons, including the type of wheat, type of extrusion die and processing conditions used, may explain the differences between brands. Whatever the explanation, however, for these samples, the surface characteristics seem to have some relationship to cooking quality for these samples. Poor cooking quality might possibly be due to many of the starch granules being lost from the surface or to water penetration being too rapid due to the looseness of the structure, or to the looseness of the structure itself which might offer less resistance to shearing and/or compression than a more compact structure such as that seen in the Barilla sample.

Although samples of spaghetti produced from Stewart 63 and Hercules, under varying processing conditions showed few differences when examined under the SEM, commercially produced samples did. Since the commercial samples were presumably produced from different varieties of durum and possibly even from wheat other than durum, it is possible that the SEM might be of more use in predicting quality differences due to the starting material rather than to the processing conditions employed. From this point of view it could be of use in quality assessment.

Figure 25. Scanning electron micrograph showing the surface characteristics of an uncooked sample of Constant brand spaghetti (1,125 X).

Figure 26. Scanning electron micrograph showing the surface characteristics of an uncooked sample of Barilla brand spaghetti (1,125 X).



Evaluation of samples to be used for sensory testing. Although, consideration of the surface characteristics of a sample may assist in the prediction of its cooking quality, much more than this is required for adequate assessment of the sample. The use of an instrument to measure the physical manifestations of quality is helpful, however, even the measurements from a machine such as the GRL spaghetti tester, would be more useful if the results could be manipulated to provide a single figure for comparison purposes. Table 14 shows that based on analysis of variance and application of Tukey's test, one brand is superior to all the others and one is inferior. However, nothing is indicated with regard to the 4 remaining intermediate samples. They may be ordered according to the magnitude of their results, however, this order is different for each of the 3 textural parameters.

To establish the relationship among the textural parameters assessed by the GRL spaghetti tester and to determine the correlation of this instrument with evaluation by human subjects, a series of samples of varying texture were analyzed by machine and by a taste panel. The variation in texture was achieved by adding different amounts of egg albumin. This was one of the two protein additives which Matsuo et al. (1972) showed would improve the textural parameters without detrimental effects to some other aspect of cooking quality. The instrumental results for these samples are presented in Table 15. As can be seen, addition of egg albumin increased the firmness and recovery and decreased the compressibilities of the pastas. These changes, futhermore, were in the same direction as the amount of albumin added and tend to support the observations of Matsuo et al. (1972) that increasing the protein content improves the cooking quality of spaghetti. It must be

Table 15. Average[1] instrumental results for textural parameters of spaghetti used for sensory panel work.

Sample	Textural parameter		
	Tenderness mm/sec x 10^{-3}	Compressibility %	Recovery %
2CWAD semolina + 0.0% egg albumin	50.9^{b}	65.8^{b}	28.3^{c}
2CWAD semolina + 2.5% egg albumin	30.8^{c}	53.2^{c}	64.4^{ab}
2CWAD semolina + 5.0% egg albumin	24.1^{cd}	43.0^{d}	70.4^{a}
2CWAD semolina + 7.5% egg albumin	19.3^{de}	43.9^{d}	58.7^{b}
2CWAD semolina + 10.0% egg albumin	16.8^{de}	36.2^{de}	62.8^{ab}
2CWAD semolina + 12.5% egg albumin	14.7^{e}	31.5^{e}	66.3^{ab}
2CWAD semolina + 15.0% egg albumin	13.0^{e}	28.0^{e}	63.8^{ab}
Standard sample-commercial Catelli	58.1^{a}	89.9^{a}	1.4^{d}

[1] Average of 3 replicates.

[abc] Numbers bearing different superscripts in the same column are significantly different ($P < 0.05$) based on Duncan's multiple range test.

noted, however, that after a certain point, the change in texture levels off regardless of the percent protein added. The greatest quality improvement was caused by the initial addition of 2.5% albumin. In panel work done with these samples, judges noted that the textural characteristics of samples containing large amounts of added protein, exceeded the levels which they expected to encounter and in some cases were almost objectionable. In order to determine whether there was a minimum level for egg albumin addition which would effect optimum improvements in the textural quality of spaghetti, 4 additional spaghetti samples were made. These samples contained 0.5, 1.0, 1.5 and 2.0% egg albumin and were assessed instrumentally but not by the panel. Results for these samples are shown in Table 16 and suggest that additions of 1.5 to 2.0% would be sufficient to optimize the cooking quality, in the case of egg albumin. It is also interesting to note that when percent addition of egg albumin is plotted against each of the 3 textural parameters measured mechanically (Figure 27), there appears to be a direct and continuing relationship between concentration and improvement of results for firmness and compressibility. In the case of recovery, initial increases in concentration are reflected in increases in this parameter to the 2.0% level of addition after which the values tend to remain the same. Again it appears that the protein component may be linked with tenderness and compressibility but not necessarily with recovery. This work also suggests that additions of egg albumin need not exceed 1.5 to 2.0% when it is being added to improve cooking quality.

Sensory Evaluation of Texture

To determine the relationship between the GRL spaghetti tester and human assessment of firmness, a series of texture evaluation panels were

Table 16. Average[1] instrumental results for spaghetti samples containing 0.5 to 2.0% egg albumin.

Sample	Textural parameter		
	Tenderness mm/sec x 10^{-3}	Compressibility %	Recovery %
2CWAD semolina + 0.5% albumin	38.9	77.3	41.4
2CWAD semolina + 1.0% albumin	32.2	70.1	55.6
2CWAD semolina + 1.5% albumin	30.2	65.9	65.6
2CWAD semolina + 2.0% albumin	28.7	63.4	73.3

[1] Average of 3 replicates.

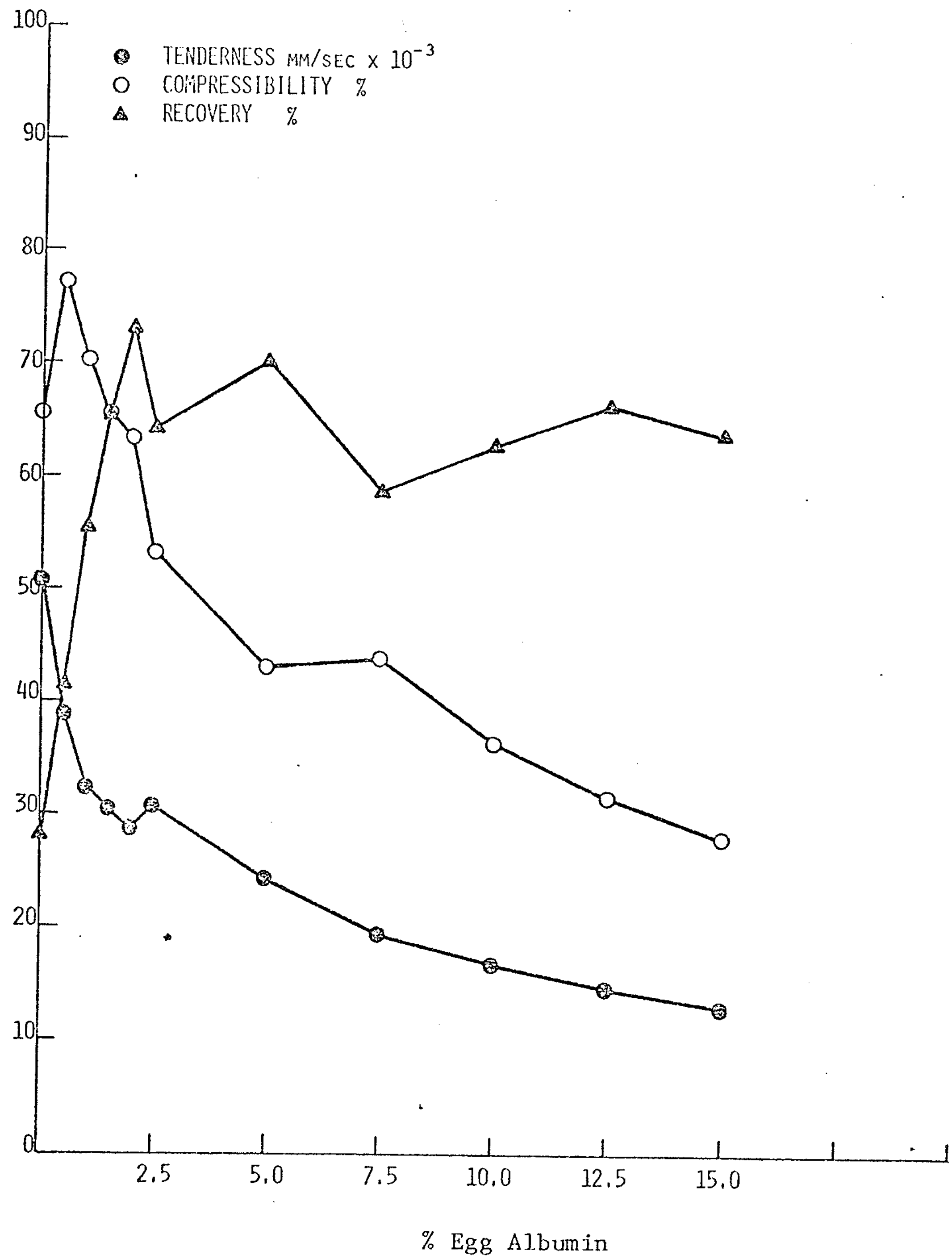


Figure 27. Relationship between percent egg albumin added to spaghetti and the 3 textural parameters measured by the GRL spaghetti tester.

conducted. Five panelists, instructed in the method of ratio estimation, used this technique to assess the firmness of the same samples tested on the instrument. The results from these judges are shown in Table 17. Duncan's multiple range test showed significant differences ($p < 0.05$) among the treatments, however, these differences were not exactly the same as those for any of the 3 parameters measured mechanically. This is most easily explained by the fact that human perception of firmness involves the assessment and integration of all 3 textural attributes measured by the instrument. In order to relate the instrumental results to the sensory ones, it was therefore necessary to perform a multiple linear regression analysis. Analysis of variance applied to the panel results indicated a significant difference ($p < 0.05$) among replicates. While this difference was far outweighed by the highly significant ($p < 0.01$) treatment differences, it was felt that for prediction purposes, the results should be handled as 24 distinct observations rather than as 3 sets of 8. Most of the differences among replicates is probably due to the method of sample preparation and the method of presentation. It was not possible to control the length of cooking time to the second, and the length of time between sampling and testing varied with the time required by the panelist to complete his evaluation. Panelists tended to be fairly consistent as illustrated in Table 18 which shows the results of a typical replicate. Results from this table indicate that the judges could identify the coded standard as shown by the fact that they rated it equal to the known standard. Results among panelists were fairly consistent for the samples containing small additions of egg white. At higher levels, greater variation was observed. Much of this variation, however, was due to the magnitude of the scale which each

Table 17. Average[1] ratio estimation values for firmness of spaghetti samples containing added egg albumin.

Sample	Rep. 1	Rep. 2	Rep. 3	Overall Avg.
Standard sample-commercial Catelli	.88	1.04	0.95	0.96[a]
2CWAD semolina + 0.0% egg albumin	1.32	1.24	1.15	1.24[ab]
2CWAD semolina + 2.5% egg albumin	1.99	1.89	2.10	1.99[b]
2CWAD semolina + 5.0% egg albumin	3.02	3.08	3.10	3.07[c]
2CWAD semolina + 7.5% egg albumin	4.10	3.60	4.60	4.10[d]
2CWAD semolina + 10.0% egg albumin	4.48	5.10	6.00	5.19[e]
2CWAD semolina + 12.5% egg albumin	5.70	5.00	6.10	5.60[ef]
2CWAD semolina + 15.0% egg albumin	6.20	5.20	7.60	6.33[f]

[1] Average of results for 5 panelists.

[abc] Numbers bearing different supercripts are statistically different at the 5% level of probability based on Duncan's multiple range test (F = 54.40 7, 14 df).

Table 18. Typical panel results (replicate 2) for sensory evaluation of spaghetti.

Sample	Panelist 1	2	3	4	5
Standard sample-commercial Catelli	1.0[1]	1.0	1.0	1.0	1.2
2CWAD semolina + 0.0% egg albumin	1.5	1.2	1.0	1.5	1.0
2CWAD semolina + 2.5% egg albumin	3.0	1.5	1.5	1.75	1.7
2CWAD semolina + 5.0% egg albumin	4.0	5.0	2.0	2.5	1.9
2CWAD semolina + 7.5% egg albumin	7.0	3.5	2.0	3.5	2.0
2CWAD semolina + 10.0% egg albumin	6.0	9.0	3.0	5.0	2.5
2CWAD semolina + 12.5% egg albumin	8.0	7.0	4.0	3.0	3.0
2CWAD semolina + 15.0% egg albumin	8.0	4.0	5.0	5.0	4.0

[1] Ratio estimation values.

judge chose to use. For statistical analysis purposes, panel results were transformed into log form since it has been reported (Moskowitz, 1970), that sensory scales tend to be of a logarithmic nature. Results of multiple linear regression analysis of the sensory and instrumental data from these samples is shown in Table 19. On the basis of these results, the following equation may be constructed for predicting sensory values when instrumental ones are known.

$$\log S = 2.784 - 0.928(\log T) - 0.617(\log C) - 0.033(\log R)$$

where T = tenderness
C = compressibility
R = recovery

Using this equation, predicted sensory results for the instrumental results shown in Table 15, would be as follows:

	Predicted Value
Standard sample (commercial - Catelli)	1.09
2CWAD semolina + 0.0% egg albumin	1.28
2CWAD semolina + 2.5% egg albumin	1.66
2CWAD semolina + 5.0% egg albumin	2.64
2CWAD semolina + 7.5% egg albumin	3.21
2CWAD semolina + 10.0% egg albumin	3.86
2CWAD semolina + 12.5% egg albumin	4.12
2CWAD semolina + 15.0% egg albumin	5.75

The corrected multiple r for these results is 0.97, which is significant at the 1% level of probability (df, 6). The corrected multiple r^2 value is 0.94 indicating that the 3 textural parameters measured mechanically explain 94% of the variability in the sensory response. β values reflect the relative importance of the independent variables

Table 19. Multiple linear regression analysis of logs of panel and instrumental data.

Regression coefficient	tenderness	-0.928
	compressibility	-0.617
	recovery	-0.033
β values	tenderness	-0.719
	compressibility	-0.331
	recovery	-0.109
Intercept		2.784
Corrected multiple r		0.968
Corrected multiple r^2		0.938
Standard error of estimate		0.078
F value (df 3,20)		111.222***

*** $p < 0.001$

for this set of data. Since these values are dimensionless, it is possible to compare their relative sizes and hence determine their relative importance in prediction of the sensory results. In this case, tenderness is about twice as important as compressibility and 6.5 times as important as recovery in predicting human perception of firmness, and compressibility is approximately 3 times as important as recovery. This relationship is also suggested by the sizes of the regression coefficients for this equation.

As mentioned in the literature review, the relationship between sensory perception and instrumental evaluation of an attribute of the sample in question, takes the form

$$S = kI^n$$

with the exponent n indicating how rapidly sensory magnitude grows with increases in physical intensity (Moskowitz et al., 1972). If the exponent is less than 1.0, as it is for each of the 3 textural parameters in this study, it indicates that subjective magnitude grows more slowly than physical intensity and that the range of subjective intensity is narrower than that measured physically. That is, the instrument is more sensitive to sample variation than is the human. Since this is true, and there is a good correlation between panelist and machine, it means that this instrument may be used with confidence for routine laboratory testing.

To test the prediction equation for the range of samples most commonly found in laboratory analysis, a second set of tests was conducted. In this case, commercially available samples were cooked and assessed mechanically and by the panelists. The instrumental results were then substituted into the prediction formula and panel scores predicted.

Table 20 shows the observed and predicted scores; the predicted values are similar to the observed ones, although slightly higher in most cases. The prediction formula places the samples in the same order as the panel results except for Catelli and Lancia. However, since these two samples are not significantly different for either form of assessment this does not affect formula use. The prediction for Catelli and Creamette are furthest from the observed. The major problem encountered here is that values of 0.0 were recorded for recovery for these samples. This is shown in Table 21 along with the rest of the instrumental results. Because 0 cannot be expressed logarithmically, a small value such as 0.01 must be used. This results in the incorporation of a fairly large negative number in the analysis, which, when multiplied by a negative coefficient, markedly affects the predicted score. In an attempt to solve this problem, a number of values ranging from -1.0 to -3.5 were substituted into the equation. Best fit was obtained using a value of -2.5 and for all subsequent calculations this value was used as representative of the log of 0. Because the use of this value results in a predicted score larger than expected, calculations involving 0% recovery may be somewhat suspect.

Analysis of variance applied to the instrumental values (Table 21) indicated significance at the 1% level of probability for tenderness ($F = 18.18$, df 4,4) but no significant differences for compressibility and recovery. Because tenderness is the greatest factor in human perception of firmness, the panelists were still able to distinguish differences among the samples.

The lack of significance in regard to the values for compressibility and recovery is likely due to the results for Catelli and Creamette. For

Table 20. Comparison of observed and predicted panel scores for firmness of commercial spaghetti samples.

Sample	Panel scores		
	Observed[1]	Predicted[2]	
		Set 1[3]	Set 2
Agnesi	1.36 1.67[b]	1.93 1.87[a]	2.52 2.06[a]
Buitoni	2.14 2.24[a]	1.98 2.27[a]	2.68 2.45[a]
Catelli	1.01 1.48[bc]	1.63 1.93[ab]	1.70 1.57[b]
Creamette	0.87 0.84[c]	1.35 1.28[c]	1.52 1.56[b]
Lancia	1.28 1.34[b]	1.48 1.59	1.71 1.50[b]

[1] Average of results from 5 panelists.

[2] Calculated using prediction formula from multiple linear regression.

[3] Set 1 predicted using instrumental values in Table 21, Set 2 predicted using instrumental values in Table 22.

[abc] Pairs of numbers in the same column bearing different letters are significantly different ($p < 0.05$) based on Duncan's multiple range test.

Table 21. Instrumental values for commercial pastas used for prediction formula testing study.

Textural parameter	Rep	Brand					F value
		Agnesi	Buitoni	Catelli	Creamette	Lancia	
Tenderness	1	26.7	29.7	30.3	43.0	35.7	18.18**
(mm/sec x 10^{-3})	2	30.0_c	26.8_c	29.5_{bc}	40.2_a	33.0_b	
Compressibility	1	64.3	52.0	70.9	95.5	66.0	-
(%)	2	56.1	48.6	94.6	68.0	66.8	
Recovery	1	67.1	80.2	48.1	0.0	36.8	-
(%)	2	78.8	72.9	0.0	54.2	26.5	

[abc] Brands bearing different subscripts are significantly different ($p < 0.05$) based on Duncan's multiple range text.

** $P < 0.01$ (4,4 df).

both these samples, a large value and a very small value were recorded for each parameter. When the data were compiled for analysis the order of these values for one brand was balanced by that of the other, therefore neither duplicate nor treatment differences were significant. Despite the fact that tenderness testing was done on the same samples, no wide range for duplicate values was noted for this parameter. To determine whether the range in values was due to faulty working of the instrument or to the samples themselves, a second set of samples was cooked and tested.

With the exception of the values for compressibility and recovery for the Catelli and Creamette samples, instrumental values for the second set, as shown in Table 22, were not very different from those recorded for the samples used for sensory evaluation (Table 21). Reconsideration of the curves used to calculate the data for the first set of samples, showed that Catelli and Creamette samples had both cooked and overcooked strands. This phenomenon was most likely due to variation in strand diameter within the sample. At the point where al dente was reached for most of the strands, many of the thinner ones would be overcooked. Since the GRL instrument has been shown to be more sensitive to textural variation than human judges, these differences would be recorded mechanically but not necessarily noted by the panelists. Analysis of variance of the second set of data indicated the same type of grouping as shown in Table 21. Predicted panel scores (Table 20) from these data were larger than those observed by the panelists, however, analysis of variance and application of Duncan's multiple range test showed significant differences ($p < 0.05$) in the same direction and, similar grouping of the samples.

Instrumental results for samples containing 0.5 to 2.0% egg white

Table 22. Instrumental values for commercial pastas used as a check against Table 21.

Textural parameter	Rep	Brand					F value
		Agnesi	Buitoni	Catelli	Creamette	Lancia	
Tenderness mm/sec x 10^{-3}	1	22.83	22.83	30.00	30.33	29.50	19.47^{**}
	2	25.67_b	23.67_b	32.00_a	29.50_a	23.17_a	
Compressibility %	1	52.45	47.39	69.60	86.54	69.29	119.55^{**}
	2	60.78_c	52.18_d	71.20_b	88.98_a	72.17_b	
Recovery %	1	76.50	71.09	26.37	9.32	37.49	276.73^{**}
	2	73.45_a	69.67_a	31.13_c	5.38_d	35.26_b	

abc Brands bearing different subscripts are significantly different ($p < 0.05$) based on Duncan's multiple range test.

** $P < 0.01$ (4,4 df).

were also substituted into the prediction formula to determine more accurately which level, if any, produced the greatest overall improvement in texture. The predicted values were as follows:

	Predicted panel score
2CWAD semolina + 0.5% egg albumin	1.23
2CWAD semolina + 1.0% egg albumin	1.54
2CWAD semolina + 1.5% egg albumin	1.69
2CWAD semolina + 2.0% egg albumin	1.81

Comparison of these values with the predicted scores on page 92 indicate that the spaghetti containing 2.0% added protein gave a higher value than that resulting from the 2.5% addition. The predicted score for the 2.0% sample was also higher than that for samples containing lower amounts of egg albumin. These results suggest that addition of egg albumin at the level of 2.0% is sufficient to produce a spaghetti of good textural quality. Additions in excess of 2.0% are wasteful since they do not produce proportionate improvements in quality and at levels above 7.5% may even be detrimental. Additions of less than 2.0% produce less marked improvements in texture.

Since there is a good correlation between sensory evaluation of firmness and the GRL spaghetti tenderness tester, it may be used with confidence to assess samples for quality testing. This instrument appears to be more sensitive to textural differences than the human, requires less sample and is less likely to have 'off' days. In addition, it is not subject to brand name loyalty or cultural bias and thus may be used to assess any type of spaghetti desired. By using the prediction equation, it is possible to reduce the 3 textural parameters to a single value which may then be compared to results for other samples, if ranking of samples is desired. The weighting included in the equation also permits comparison of samples which have the same value for one parameter, such as tenderness, but different values for the other two.

Starch

Changes in starch during processing and cooking of spaghetti were studied to determine the relationship existing between textural quality and gelatinization.

Samples of semolina, ground spaghetti and cooked spaghetti were tested using an amylograph, to determine peak height and the temperature at which this peak occurred. The results for the 3 varieties tested are presented in Table 23. By comparison of these results and those in Table 7 for samples cooked in boiling water, it can be seen that the higher the percent recovery, the lower the amylograph peak height. Although there is a range in peak heights for all 3 forms of the samples tested, and although within any one treatment, the samples follow the same order, this order is not the same as that for either tenderness or compressibility.

Peak height is a measure of the increasing viscosity of a starch mixture and hence indicates the degree of gelatinization. The greater the height, the more gelatinization has occurred during the testing period, thereby indicating either little starch damage or more starch present. In this study, samples of ground spaghetti gave higher peak heights than did semolina. This is not in agreement with the results reported by Lintas and d'Appolonia (1973) who found that semolina samples gave a higher reading than did spaghetti samples. The work done by these authors, however, was done on starch extracted from the semolina or spaghetti whereas analysis done in this study was on the actual ground spaghetti or semolina. In the present study, not only the starch but also the

Table 23. Results of Amylograph analysis of semolina, ground spaghetti and cooked spaghetti.

Sample		Temperature of peaking °C	Height of peak B. U.[1]
Semolina	Quilafen	89	110
	Wakooma	92	130
	Wascana	94.5	300
Ground Spaghetti	Quilafen	89	170
	Wakooma	87	350
	Wascana	89	490
Cooked Spaghetti	Quilafen	95	20
	Wakooma	95	25
	Wascana	93	30

[1] Brabender Units.

other components present, could influence peak height. This could be especially true with the samples of ground spaghetti. As has been shown, the volume of spaghetti increases with cooking time, thus in the amylograph studies, it is highly possible that this increase could cause a considerable viscosity increase which would be registered as an increase in peak height. It is interesting to note that the temperature at which maximum peak height was reached, was lower for the ground pasta than for the semolina. This would further support the idea that peak height, expecially for ground spaghetti, was not related solely to starch gelatinization. In the case of cooked spaghetti, peak height was very small and occurred at $95^{o}C$, the temperature most frequently quoted as being the optimum for gelatinization. With these samples, much of the volume increase would have already taken place, thus the peak seen should be indicative of gelatinization. Since it was so small, it appears likely that most of the gelatinization of starch takes place during the cooking of the spaghetti and it is therefore possible that this component could indeed affect the quality of the cooked product.

Further investigation of the process of starch gelatinization during spaghetti cooking was done using a polarized light microscope. Ungelatinized starch granules when examined by this method, exhibit birefringence and loss of this property was used as a measure of gelatinization (Radley, 1968). Starch granules from spaghetti samples soaked in water for 4 hr at room temperature, as well as from spaghetti cooked for 5 min and to al dente were examined. The results are shown in Table 24 and 25. Table 24 shows the effect of protein level on samples produced under laboratory conditions. Figures 28 to 33 are photographs taken of various samples under bright and polarized light to serve as an illustration to

Table 24. Comparison of the degree of gelatinization of starch in laboratory produced spaghettis of varying protein levels as determined by polarized light microscopy.

Treatment	Sample		% Birefringent starch granules	time to al dente
Raw spaghetti soaked 4 hr	Leeds 8% protein		90	
	17% protein		90	
	Tunisian 8% protein		90	
	17% protein		90	
	2CWAD + 2.5% egg albumin		90	
	2CWAD + 15.0% egg albumin		90	
Cooked spaghetti 5 min	Leeds 8% protein	core	80	
		outer zone	10	
	17% protein	core	90	
		outer zone	10	
	Tunisian 8% protein	core	80	
		outer zone	10	
	17% protein	core	90	
		outer zone	10	
	2CWAD + 2.5% egg albumin	core	80	
		outer zone	10	
	2CWAD + 15.0% egg albumin	core	90	
		outer zone	10	
al dente	Leeds 8% protein		<1	13' 00"
	17% protein		1	14' 30"
	Tunisian 8% protein		<1	13' 05"
	17% protein		1	14' 30"
	2CWAD + 2.5% egg albumin		1	13' 10"
	2CWAD + 15.0% egg albumin		1	14' 30"

Table 25. Comparison using polarized light microscopy of the degree of gelatinization of starch in commercially produced spaghetti from 3 varieties.

Treatment	Sample		% Birefringent starch granules	Textural parameters: Tenderness mm/sec x 10^{-3}	Textural parameters: Compressibility %	Textural parameters: Recovery %
Semolina soaked 4 hr	Quilafen		99			
	Wakooma		99			
	Wascana		99			
Raw spaghetti soaked 4 hr	Quilafen		70			
	Wakooma		70			
	Wascana		70			
Cooked spaghetti 5 min	Quilafen	core	70	19	50	38
		outer zone	10			
	Wakooma	core	50	19	53	36
		outer zone	2			
	Wascana	core	60	20	50	31
		outer zone	<1			
al dente	Quilafen		1	35	78	36
	Wakooma		1	32	76	33
	Wascana		<1	36	80	23

Figure 28. Bright light photomicrograph of starch granules in the outer zone of a spaghetti sample cooked for 5 min (630 X).

Figure 29. Polarized light photomicrograph of starch granules in the outer zone of a spaghetti sample cooked for 5 min (630 X).

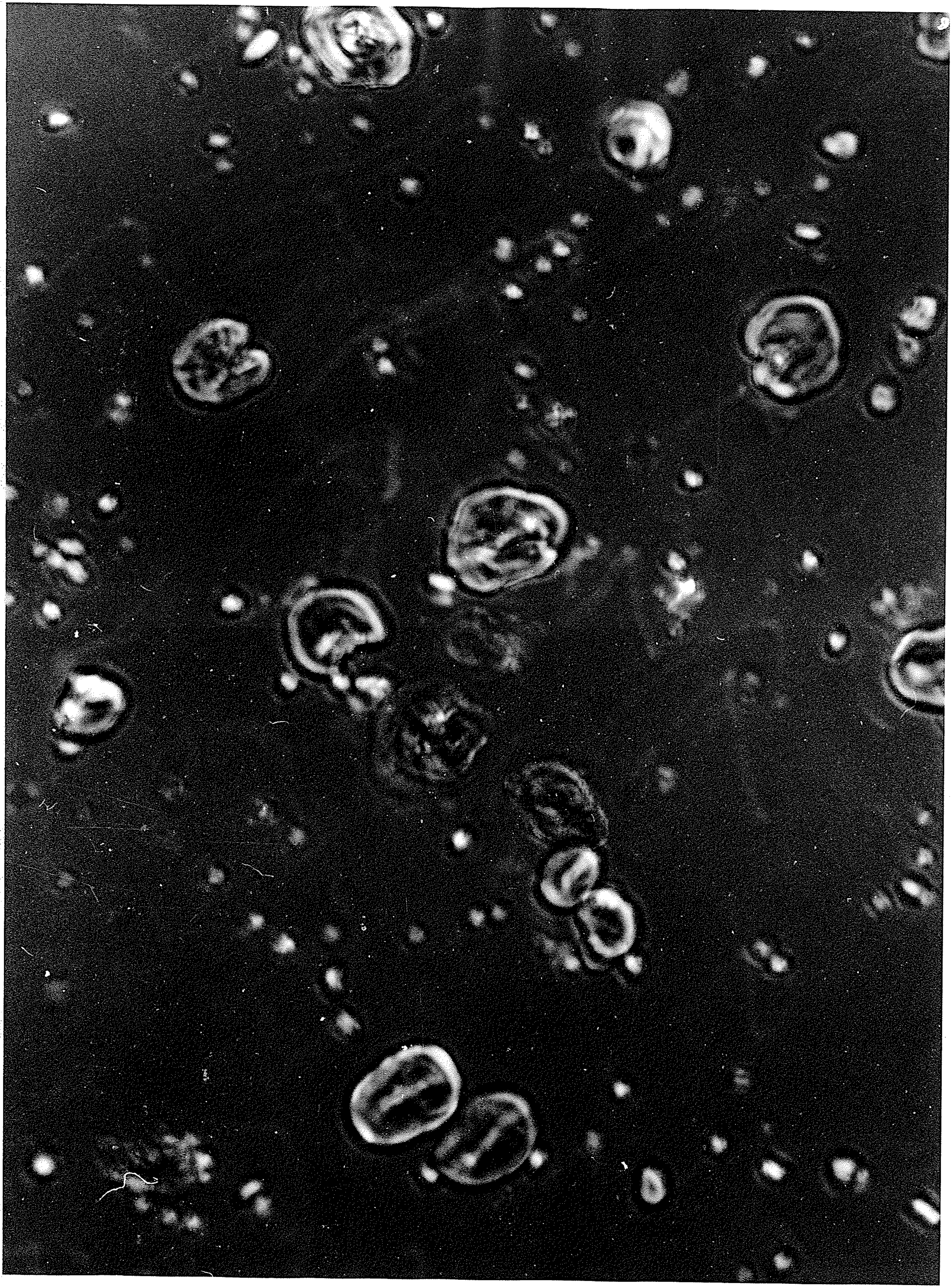


Figure 30. Bright light photomicrograph of starch granules in zone 2 of a spaghetti sample cooked for 5 min (630 X).

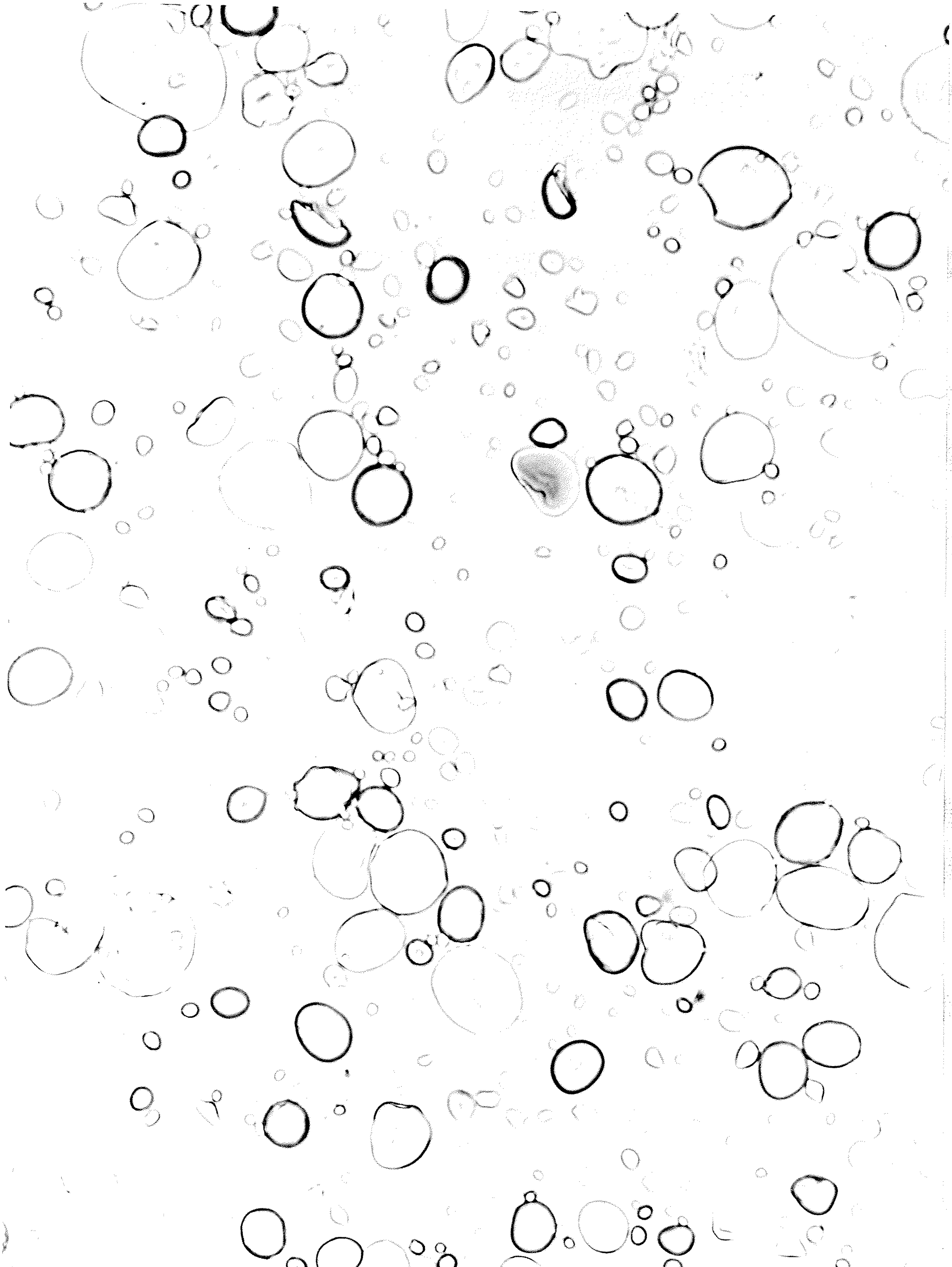


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Figure 31. Polarized light photomicrograph of starch granules in zone 2 of a spaghetti sample cooked for 5 min (630 X).

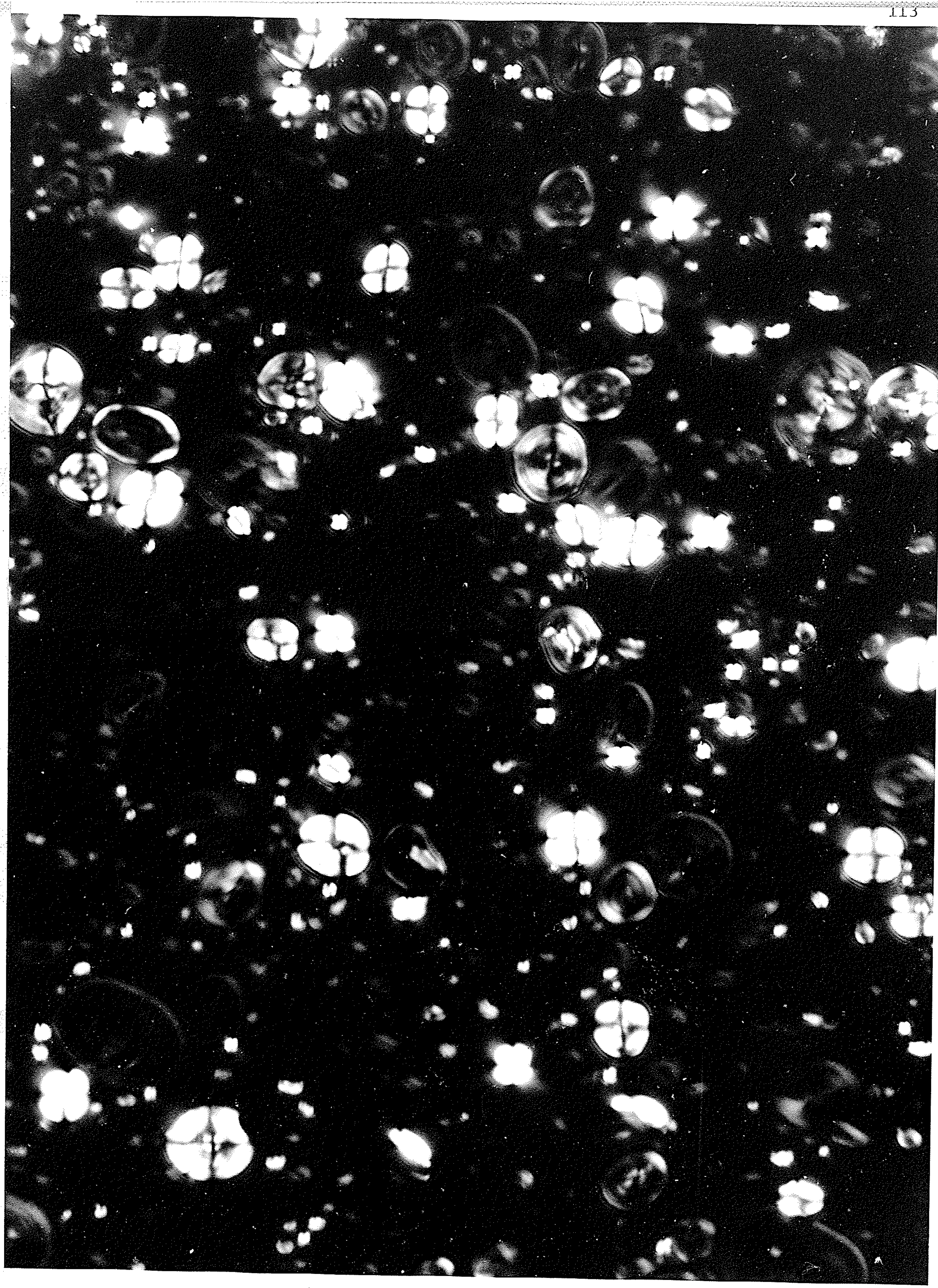

Figure 32. Bright light photomicrograph of starch granules in the core of a spaghetti sample cooked for 5 min (630 X).

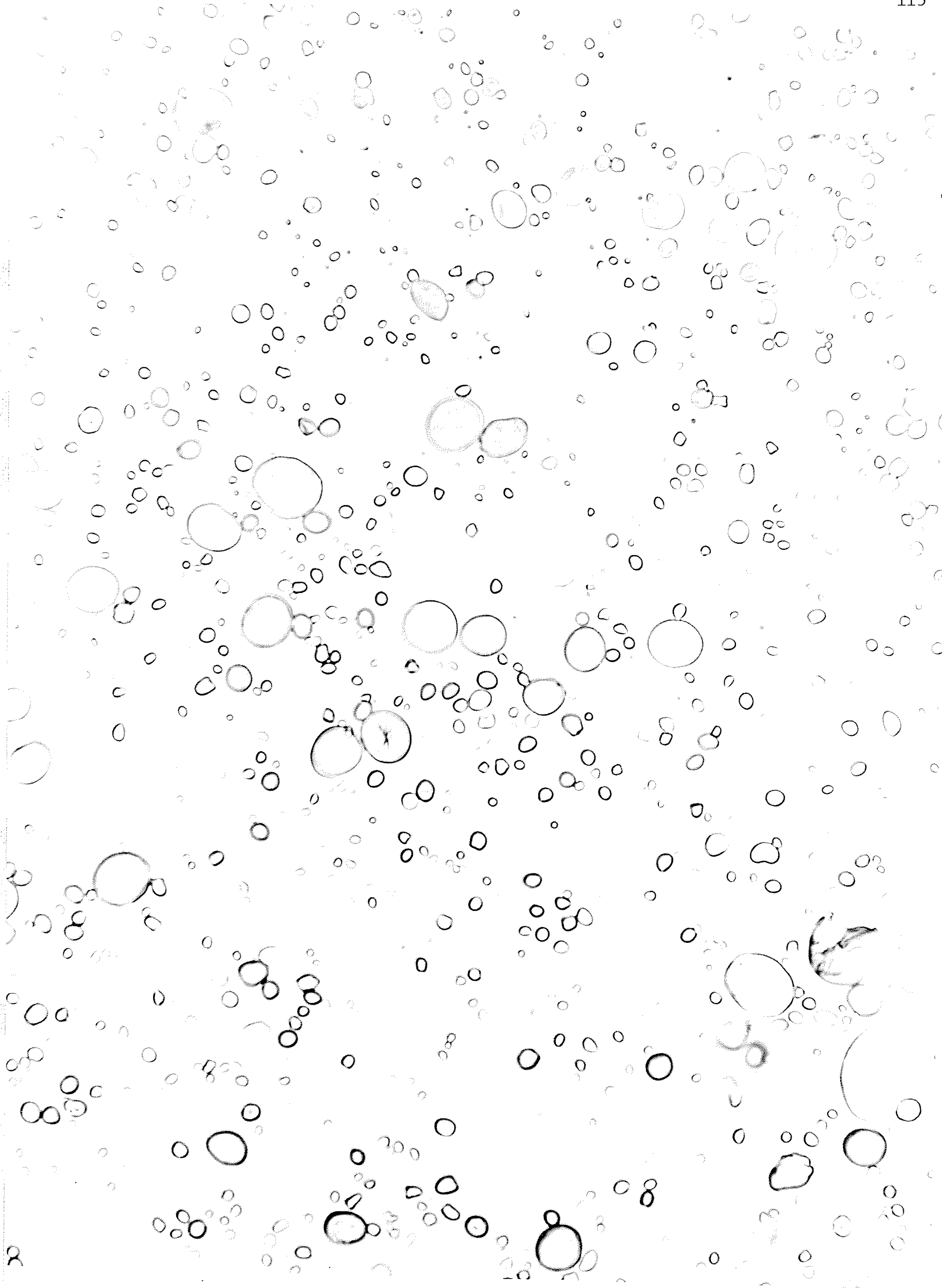

Figure 33. Polarized light photomicrograph of starch granules in the core of a spaghetti sample cooked for 5 min (630 X).

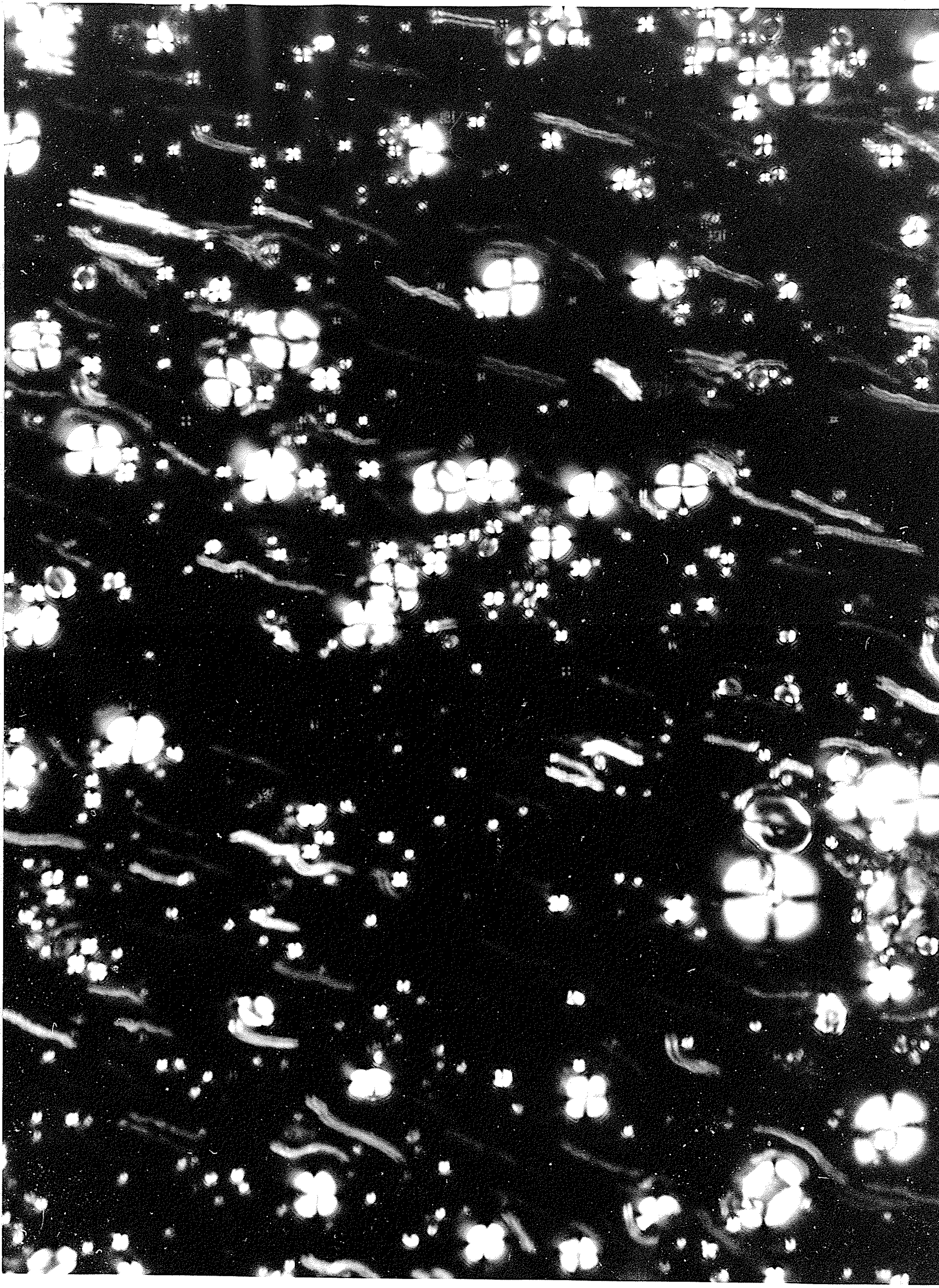

Table 24.

The fact that all samples soaked for 4 hr showed 90% of the starch granules as being birefringent, suggests that little gelatinization of the sample takes place during processing under laboratory conditions. Most of the gelatinization, as well as the main effect of protein level is seen during the cooking period. Examination of samples after 5 min cooking showed 2 or 3 zones of cooking depending on sample protein content. These zones are illustrated in Figure 34. Low protein samples showed 2 zones while the higher protein ones showed 3. For all samples, the outer zone showed almost total loss of birefringence and the inner core showed very little loss. Zone 2 starch granules showed losses intermediate to those of zones 1 and 3. The loss for the inner core varied with the protein level, with samples having lower protein levels exhibiting less birefringence. Samples cooked to al dente showed almost total loss of birefringence and the only difference observed among samples at this point was the length of cooking time required to reach al dente. The high protein samples took approximately 1½ min longer to be completely cooked. From these results, it appears that the gelatinization process takes place in an inward direction and that water penetration, and hence cooking, is more rapid at lower protein levels. The rate of water penetration is indicated by the presence of 1 more zone in the high protein samples cooked for 5 min than in the low protein samples cooked for the same length of time.

Table 25 shows the effect of commercial production of spaghetti from 3 durum varieties, on the gelatinization of starch. Comparison of results for semolina and raw pasta which were soaked in water at room temperature for 4 hr showed a considerable loss of birefringence, presumably due to

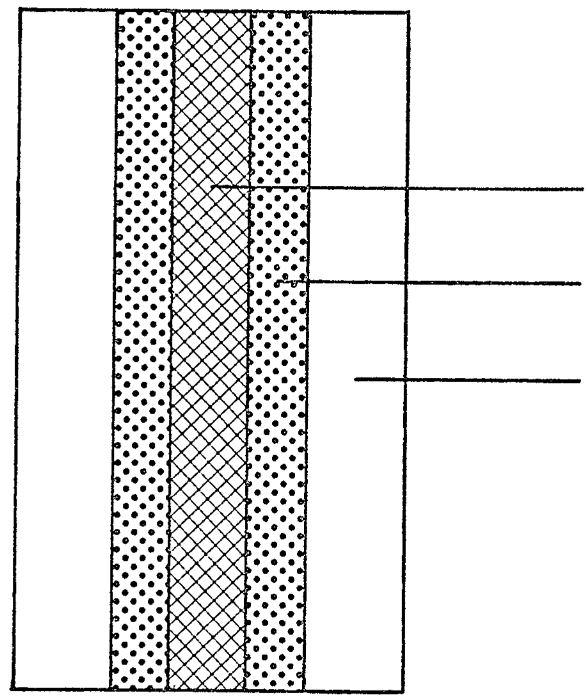

Figure 34. Zones of cooking seen in spaghetti samples cooked for 5 min then squeezed between 2 plexiglass plates.

the commercial processing regimen. Comparison of the percent starch gelatinized, with tenderness, compressibility and recovery results for samples cooked for 5 min and 12 min (Figures 3, 6 and 9), suggests that as well as being related to recovery, starch gelatinization may also have some bearing on compressibility. The values for these textural parameters have been included in Table 25 for comparison purposes. It appears that the greater the loss of birefringence the larger the value for percent compressibility and the smaller the value for percent recovery. In this case, cooking time to al dente was almost the same for all 3 varieties and protein levels were also similar.

The results of these tests confirm the findings with the amylograph, that most of the gelatinization of starch occurs during cooking, rather than during processing, and this appears to be true regardless of whether samples are produced in the laboratory or commercially.

GENERAL DISCUSSION

As was noted in reviewing the literature, some method of quality measurement of spaghetti is necessary before assessment can be adequately made of the role of various biochemical constituents in a sample. In addition, since texture is an important attribute of food where human consumption is concerned, the measurement of quality in terms of textural parameters is also important. In this study, it has been shown that the spaghetti tenderness testing apparatus developed at GRL (Matsuo and Irvine, 1969; 1971) can adequately fulfil this role. It measures the 3 textural parameters; tenderness, compressibility and recovery; is simple and rapid to operate; requires a minimum amount of sample and its results are fairly reproducible. All these attributes are useful when an instrument is to be considered for research work or for routine laboratory analysis. However, one other criterion must be met if the researcher is to have confidence in the use of results for quality prediction purposes. This criterion is that of good correlation of instrumental results with those of human subjects asked to judge the same type of samples. Experiments in this thesis, done to study this relationship, showed that the 3 textural parameters measured by the GRL spaghetti tester explained for 94% of the variation in the human judgement of firmness. The multiple correlation coefficient between the instrument and sensory panel was found to be 0.97, which is highly significant ($p < 0.01$). The textural parameter, tenderness, made the greatest contribution to the prediction of human assessment of firmness, while the recovery parameter made the least. Application of multiple linear regression analysis to sensory and instrumental results provides a formula for predicting human response on the basis of instrumental results. Since the instrument was also shown to be more sensitive to textural changes than the human, its use and the application of the prediction formula to its results, therefore, provide an effective tool, not only for quality testing of samples, but also for comparison of results and prediction of human response to sample texture. This instrument may therefore be used for quality assessment of plant breeders' varieties as well as for determining the effect on quality of substituting one biochemical component for another.

Once the researcher has established the reliability of an instrument for quality assessment, it is also necessary to determine the effects of preparation techniques on sample quality. In the case of spaghetti, it is necessary to consider the effect of cooking water temperature and length of cooking time as well as the effect of blanching, on samples, in relation to the instrumental results obtained. Studies of these effects indicated that all 3 of these treatments affected the apparent textural quality of spaghetti samples. The temperature of the cooking water, studied at 58.5°, 82°C and boiling temperature (98.5°C) affected all 3 of the textural parameters measured with the GRL spaghetti tester. Samples cooked in boiling water produced the most desirable cooked products. The use of temperatures of 82°C and lower resulted in increased tenderness and compressibility to undesirable levels, and decreased recovery to zero. These samples also took longer to cook to al dente.

At all temperatures, tenderness and compressibility increased with increases in the length of cooking time. For samples cooked in boiling water, recovery increased during the first 6 min, was roughly constant for the next 6 min then dropped rapidly to zero after the al dente stage had been reached. Recovery results were so small or non existant for samples cooked at 58.5° and 82°C, that time effects could not be adequately assessed.

These effects of time and cooking water temperature on textural quality of cooked spaghetti are important considerations when a method is being developed for sample preparation. Textural characteristics may be mechanically measured on any cooked sample, however, in order to compare sample results especially when single strand measurements are involved, it becomes obvious that preparation conditions must be standardized. This standardization of techniques is also necessary to insure that measurements are made when quality is at its maximum. It has been noted previously that there are two schools of thought in respect to length of time samples should be cooked prior to quality testing. Some researchers (Feillet, 1970) prefer to cook all samples for a specified time, for example 10 min, while others suggest that all samples be cooked to al dente. The results of studies reported in this thesis tend to support the latter group. The length of cooking time to al dente varied with the sample, therefore, if all the samples are cooked for a specific time length, some will be undercooked, some overcooked and some cooked to al dente. Because of this, cooking to a specified time may also result in misleading prediction of potential consumer acceptance of samples. Since spaghetti testing is often conducted with a mind to selecting the most economically promising samples, errors in prediction could prove to be financially embarrassing.

The effect of blanching on the textural quality of spaghetti samples was investigated primarily from a functional point of view. Samples not blanched prior to testing changed their textural characteristics at an extremely rapid and undesirable rate. Blanching was found to reduce these changes, thus improving the testing technique.

Differing slightly from cooking techniques, but nonetheless still under the category of preparation techniques affecting quality, are the actual processing methods used to produce a spaghetti sample from semolina. Processing conditions and their effects on quality have been studied previously, however, only with respect to such quality attributes as color, handling properties and surface characteristics (Anderson and Cunningham, 1943; Cunningham and Anderson, 1943; Martin et al., 1946). More recently, work published by Walsh et al. (1971), indicated that application of high vacuum during mixing improved firmness and that high absorption levels had adverse affects on this textural property.

In the study encompassed in this thesis, the effect of both temperature and pressure during the rest period, were examined to determine what contribution, if any, they made to the textural qualities of cooked pasta. These parameters were chosen since they had been previously shown to affect quality characteristics such as handling properties of the dough and surface characteristics of the extruded product. The temperature and pressure treatments were applied to 2 varieties; Hercules, which tends to give a spaghetti of fairly high cooking quality, and Stewart 63, a variety which produces spaghetti of inferior cooking quality. In these tests it appeared that Hercules was less affected by processing conditions than was Stewart 63. This confirms the fact that in addition to the conditions under which a sample is processed, its genetic or biochemical constitution is also a factor in determining its quality.

For both varieties, temperature effects were highly significant ($p < 0.01$) with lower temperatures of 25° and $40^{\circ}C$ producing better quality products in terms of instrumentally assessed tenderness, compressibility and recovery. Pressure effects were significant, however, only for Hercules samples and at a lower level ($p < 0.05$) of significance than temperature. Low pressures appeared to have the least detrimental effect on textural quality, suggesting that it may be possible to delete pressure application during the rest period of laboratory scale spaghetti production. Pressure was originally included in the method since it improved the plasticity of the dough and hence its surface characteristics after extrusion and because it caused bubbles incorporated in the dough during mixing, to coalesce and therefore improved the translucency of the product. With the introduction of vacuum during mixing, air bubbles are no longer a problem during processing. In addition, the use of Teflon coated dies produces a much smoother surface than did the brass dies previously used, thus the plasticity of the dough, as well, is no longer a critical consideration.

In summarizing the effects of external influences on the textural quality of pasta, it appears that temperature is the most critical factor involved, both in the production process where low to moderate temperatures are desirable and in the cooking procedure where high temperatures (98.5^{o}C) are necessary.

In addition to the effects of external influences, the biochemical constitutents of the semolina used for spaghetti making have also been implicated in sample cooking quality. As was noted in the literature review, different varieties of wheat produced spaghettis of varying quality (Sheu et al., 1967). This is generally attributed to their chemical or genetic composition, however, no component has yet been proven to be the quality controlling one. To date, most of the investigations on the relationship of chemical components to cooking quality have been carried out on the protein fraction. Both quantity and quality of this component present in the spaghetti sample appear to affect its textural qualities. In this study, the effect of addition of different amounts of protein, in the form of egg albumin, was considered. These additions were made primarily for the purpose of producing samples with a range of textural qualities large enough for human judges to be able to differentiate among them. Although this purpose was adequately served, a second benefit was also derived, that of being able to assess the effect of protein additions on tenderness, compressibility and recovery of the samples. It was found that the most effective change in these textural parameters occurred with the addition of 2.0% albumin. From this level upwards to 15.0%, the improvement in texture was almost linear but relatively small. This finding is of economic importance to spaghetti producing companies wishing to improve the quality of their products by protein supplementation, since the addition of egg white is fairly costly.

Since considerable work has been reported on studies of protein and pasta quality but little on starch and quality, this latter component was considered at greater length. Starch and its gelatinization process have been implicated in bread baking quality by several authors (Sansdtedt, 1961; Jongh et al. 1968). Since bread and spaghetti are both derived from wheat, it was felt that starch might also contribute to spaghetti texture. This idea was supported by a number of observations made during the examination of the effect of external influences on spaghetti textural quality. Cooking water temperature and cooking time tests suggested that some component other than protein was involved in cooking quality. This was especially true for the textural parameter recovery and the component implicated in this case was starch. Samples cooked at temperatures below

$82^{\circ}C$ showed little or no recovery regardless of the variety used. Since starch gelatinization is greatest at temperatures around $95^{\circ}C$ and samples cooked in boiling water showed good recovery, it is possible that gelatinization is necessary for this parameter to become measureable. Cooking samples for 30 min at $58.5^{\circ}C$ then placing them in boiling water for 60 sec resulted in tenderness and compressibility readings comparable to those of samples cooked to al dente in boiling water. Recovery results, on the other hand, remained considerably lower than those observed for al dente samples suggesting that the component responsible for this parameter was in some way lacking. This might have been due to its diffusion out of the sample or to destruction by some other means during the period that the sample was being held at $58.5^{\circ}C$. In fact, if amylose, the fraction of starch responsible for gel formation (Griswold, 1962) does contribute to recovery in the sample, it is conceivable that lack of recovery could be due to its diffusion into the cooking water, since it is quite soluble in water, especially at temperatures between 60° and $80^{\circ}C$.

In this respect, it is possible that one of the roles of protein in pasta cooking quality is to coat the starch granules, thereby preventing losses due to diffusion. Commercial samples examined with the scanning electron microscope showed distinct surface differences. Loose starch granules and rough surfaces were characteristic of the poorer quality samples. Those having good cooking qualities showed fairly smooth surfaces and the starch granules appeared to be coated or embedded in the structural material. In future work it might be useful to examine both the chemical structure of the cooked spaghetti as well as the chemical composition of the cooking water residue. In this way it might be possible to establish whether cooked spaghetti is a starch or protein gel or whether there is an interaction between these components which is responsible for textural quality.

Starch is composed of two main fractions, amylose and amylopectin and it is possible that the ratio of these fractions in pasta might also affect its cooking quality. Amylopectin does not possess the ability to form gels as amylose does, thus it might be that samples having high levels of amylopectin might also prove to be inferior in texture.

It is also feasible that there could have been some enzymic degradation of starch in samples held at $58.5^{\circ}C$ since α-amylase would still be somewhat active at this temperature. The presence of this enzyme, however, and its survival of the processing regimen, would likely be small since pasta is generally produced from sound rather than germinated wheat.

Further study of the nature of the starch during processing and cooking was done with both the amylograph and polarized light microscope. Results of amylograph testing of semolina, ground spaghetti and cooked spaghetti samples indicated that most of the gelatinization of starch occurred during sample cooking rather than processing. Peak heights appeared to vary inversely with recovery but showed no relation to tenderness or compressibility results. Peak heights for ground spaghetti samples were greater than those for semolina, however, the peaks occurred at lower temperatures. These results might be explained by the fact that while some starch gelatinization occurred during processing, this was masked by the presence of other components in the pasta which swelled during cooking, thereby increasing the apparent viscosity and giving a greater peak height than expected. Because these results were complicated by the presence of components other than starch, samples were also examined under polarized light. Results of these studies supported the observations that gelatinization did in fact occur largely during the cooking period rather than during processing. In addition, studies of spaghetti samples cooked at $58.5^{o}C$ and in boiling water, indicated that high temperatures were necessary to cause this gelatinization during cooking. Samples cooked at $58.5^{o}C$ for as long as 30 min still showed 90% birefringent starch granules when examined under polarized light, while those cooked at $98.5^{o}C$ for 12 min showed less than 1% of the granules as being birefringent. Commercially produced spaghetti samples showed more gelatinization during processing than laboratory produced ones, most likely due to the higher temperatures used under commercial conditions. Samples containing high percentages of protein showed the same process of gelatinization during cooking as did low protein samples, only they required a greater length of time to be cooked to al dente. Examination of samples after 5 min cooking and at al dente, showed that starch gelatinization takes place in an inward direction and at a rate which appears to be directly related to protein level.

In conjunction with the examination of starch during the various phases of cooking, it is interesting to note that although many authors have attributed cooking quality of spaghetti to the nature of its protein fraction, it appears to be the starch component which determines the optimum cooking time. The basis for determination of the al dente point of a sample during cooking, is the disappearance of its white core. This core may be examined by cutting the sample in half with a sharp knife, or, as in the Braibanti technique, squashing the sample between 2 plexiglass plates. Whatever the method chosen to determine this end point, the fact remains that it is apparently the process of starch gelatinization which is being examined and which determines the point at which the textural quality of the sample will be the most desirable.

Thus the sensitivity of the GRL spaghetti tenderness testing apparatus and its high correlation with human perception of firmness provides a useful tool for spaghetti texture assessment. With this instrument it should now be possible to analyze the quality attributes required in durum wheats for export and hence to assist in programs to assess pastas and to design products to fit either domestic or foreign consumer demands. In addition, it should prove useful in testing of plant breeders samples and in further study of the roles of the various chemical fractions in pasta quality. Other fields of study which might prove useful in clarifying the problem of cooking quality include chemical analysis of pasta cooking water for starch or protein residues, microscopic examination of cooked pasta to determine the nature of its physical structure and the production and testing of starch or protein-free spaghetti samples to further examine the contribution of these components to quality.

SUMMARY AND CONTRIBUTIONS TO KNOWLEDGE

1. A study was undertaken to determine the effect of blanching with cold water, on sample texture. Upon instrumental evaluation blanched samples showed greater firmness and recovery and less compressibility than samples which were not blanched immediately after cooking. In addition, blanching reduced the variability among instrumental readings for a single sample.

2. The temperature of the cooking water and duration of cooking time were examined to determine their contribution to the textural quality of cooked spaghetti. The lower the temperature of the water used, the longer the time required before al dente was reached. In conjunction with this, samples taking longer to cook were softer, more compressible and showed little or no recovery. The effect of temperature on the recovery parameter of a sample is very dramatic and, since temperatures in excess of 82°C were necessary before the sample evidenced this parameter to any degree, it was suggested that starch and its gelatinization during cooking made a significant contribution to cooking quality. Time and temperature effects do not appear to be variety dependent. Differences in textural quality due to time suggest that samples should be cooked to al dente rather than to a specified time, to insure that all measurements are taken when firmness, compressibility and recovery are at their optimum.

3. Increases in volume of cooked spaghetti, with length of cooking time were found not to be variety dependent and hence this technique was rejected as a tool for quality differentiation. The fact that this increase continued, however, even after 10 min overcooking, is an important

consideration for methods of testing where sample diameter is critical.

4. The effects of variety and processing conditions on textural quality were assessed using Stewart 63 and Hercules semolinas. Pressures of 0, 1000, 2000 and 5000 psi and temperatures of 25^{o}, 40^{o}, 60^{o} and $80^{o}C$ were applied in all possible combinations during the resting period of the micro scale spathetti making method. Temperature effects were highly significant ($p < 0.01$) for both varieties, with 40^{o} and 25^{o} producing the better products. Temperature varied directly with compressibility and inversely with tenderness and recovery. Pressure effects were significant at the 5% level of probability for Hercules but not for Stewart 63, the latter possibly due to confounding by significant ($p < 0.05$) batch differences. Analysis of the pressure effects suggested that low pressures produced products with better textural characteristics.

The effects of these treatments on the 2 varieties chosen were similar, however, Hercules samples seemed less sensitive to processing variations and in all cases produced better quality spaghetti than did Stewart 63. Better inherent cooking quality appears to confer better tolerance to processing conditions.

Results of these studies suggest that blanching, temperature of cooking water, length of cooking time and processing conditions must be carefully controlled if sample results are to be compared.

5. Instrumental assessment of the textural quality of 6 commercial brands of spaghetti showed fairly good agreement with the values reported by Matsuo and Irvine (1970). Scanning electron microscope studies of these samples suggested a relationship between visible surface characteristics and cooking quality. Samples having a relatively smooth, compact surface showed better cooking quality than those with rough surfaces,

many starch granules visible and exhibiting a fairly loose structure. Application of this technique to samples varying in quality and produced in the laboratory, however, showed no significant differences among samples. The use of this method, therefore, appears to be of academic interest rather than of practical use for quality prediction purposes.

6. The effect of protein content on cooking quality was measured using a series of spaghetti samples containing from 0.5 to 15.0% added egg albumin. Instrumental assessment was done using the GRL spaghetti tenderness tester. An increase in firmness and recovery and a decrease in compressibility were observed and these changes were in the same direction as the increase in egg albumin added. The greatest improvement in texture occurred with the addition of 2.0% albumin. Although improvement in textural qualities continued up to the addition of 15% albumin, the suggestion is made that addition is not necessary in excess of 2.0% since levels greater than this may affect sensory acceptibility.

7. To establish the relationship between the GRL spaghetti tenderness testing apparatus and human perception of firmness, samples containing 2.5 to 15% added egg albumin assessed using this instrument were also tested by a sensory panel of 5 judges. Panelists were asked to rate the firmness of the samples in comparison with a reference sample by using the method of ratio estimation. Multiple linear regression analysis applied to the results produced a corrected multiple r of 0.97 which is significant at the 1% level of probability (df 6). The corrected multiple r^2 was 0.94, indicating that the instrumental results could account for 94% of the variability in sensory results. Further examination of the analysis showed that the instrumental parameter, tenderness, was the most valuable in predicting human reaction, while percent recovery

was the least useful.

8. Based on the multiple linear regression analysis, it was possible to construct the following formula for predicting sensory assessment of firmness.

$$\log S = 2.784 - 0.928(\log T) - 0.617(\log C) - 0.033(\log R)$$

where S = sensory value
T = tenderness
C = compressibility
R = recovery

This equation was tested using commercial spaghetti samples. Predicted values calculated from instrumental results of analysis of the samples, were very close to the results observed for panel assessment. Thus, the equation may be used to integrate all 3 textural results derived from the GRL instrument for the purposes of ranking test samples or for comparing samples having identical values for one parameter but differing for the other two. Inspection of the coefficients involved in this equation indicate that the instrument is more sensitive to variation in texture than are humans. Thus it may be used with confidence for laboratory analysis of spaghetti cooking quality both for testing plant breeders varieties and for routine quality test work.

9. Using an amylograph, gelatinization studies were conducted on semolina, ground spaghetti and cooked spaghetti processed from 3 different durum wheat varieties. Comparison of peak height with percent recovery, as measured mechanically, indicated a direct relationship and suggested that the starch component is responsible for this parameter. This relationship was not observed for the tenderness and compressibility parameters. Ground spaghetti samples showed greater peak heights than

the semolina samples, however, these peaks occurred at a lower temperature. This observation was attributed to the presence of components other than starch which swell on cooking and thus increase the viscosity of the mixture. Samples of cooked spathetti had the lowest peak heights, indicating that most of the starch gelatinization occurs during this stage.

10. The course of gelatinization of starch during cooking was also examined by polarized light microscopy. Starch granules in various spaghetti samples soaked for 4 hr at room temperature, remained birefringent as did those in semolina. Examination of ground, uncooked spaghettis showed a 10% loss in birefringence, indicating some gelatinization during processing. Commercially produced samples showed greater losses of birefringence than did samples produced under laboratory conditions. These differences were most likely due to the more rigorous conditions applied to the samples during commercial processing. Samples cooked to al dente showed almost complete gelatinization, as indicated by the presence of fewer than 1% birefringent granules. In cooking samples to al dente, some of the spaghetti was removed at 5 min. When these samples were squeezed between plexiglass plates, a white core was seen. The starch granules in this core were almost completely birefringent, while those around the outside of the strands were 99% gelatinized indicating that the gelatinization process takes place in stages, from the outside of the strand, inwards. Examination of high protein (17%) samples revealed slower water penetration and gelatinization than for low protein (8%) samples. The degree of gelatinization did not appear to be variety dependent, however, the rate was influenced by the amount of protein present.

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