THE UNIVERSITY OF MANITOBA

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

by

SUSAN GLENISE MARSHALL

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PLANT SCIENCE

WINNIPEG, MANITOBA

May, 1974

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

by

SUSAN GLENISE MARSHALL

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

ACKNOWLEDGEMENTS

The author wishes to thank Dr. G. N. Irvine for his help and encouragement during the research for and writing of this thesis and Dr. W. Bushuk and Mrs. M. Vaisey for their continued interest in the progress of the project.

Thanks also to Dr. G. N. Irvine, Dr. R. R. Matsuo, Mr. C. Rhymer, Mrs. B. Thompson and Mrs. M. Vaisey for their contribution as panelists. A special acknowledgement is due to Mr. J. Bradley and Mr. R. Daniel for excellent technical assistance and to the many other members of the Grain Research Laboratory and Department of Plant Science staffs for their valuable contributions in other areas. The author also wishes to thank Dr. J. Meredith and Dr. J. Brewster for their assistance in the statistical analyses involved in this project.

Thanks are also due to Mrs. S. Kusmider for the competent typing of this manuscript and to Mr. W. Stevenson for assistance with the proofreading.

Research for this thesis was supported through funds from a National Research Council Scholarship, a University of Manitoba summer stipend and a research grant from the Department of Plant Science.

TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	v
LIST OF FIGURES	viii
ABSTRACT	xi
REVIEW OF LITERATURE	1
Contribution of Chemical Components to Quality	1
Starch	1
Protein	5
Quality Measurements	9
Instrumental assessment of quality	9
Sensory assessment of quality	14
Contribution of External Influences to Quality	17
Processing conditions	17
Cooking conditions	21
METHODS	24
Spaghetti Production	24
Micro scale laboratory samples	24
Temperature-pressure variations	25
Sensory panel samples	25
Commercial samples	26
Cooking Method	27
Regular method	27

PAGE

Blanching 27

Temperature and duration of cooking time effects 28

Evaluation of Texture 29

Instrumental 29

Sensory 29

Volume Increase 33

Starch Gelatinization During Processing and Cooking 33

RESULTS AND DISCUSSION 36

Effects of External Influences on Cooking Quality 36

Blanching 36

Temperature and duration of cooking time effects 38

Volume increase with cooking time 64

Effects of processing conditions 65

Instrumental Evaluation of Texture 77

Range in commercial samples 77

Evaluation of samples to be used for sensory testing 84

Sensory Evaluation of Texture 86

Starch 101

GENERAL DISCUSSION 121

SUMMARY AND CONTRIBUTIONS TO KNOWLEDGE 131

LITERATURE CITED 136

LIST OF TABLES

TABLES		PAGE
1	Comparison of the nutritional composition of spaghetti, rice and potatoes	2
2	Comparison of texture of blanched and unblanched spaghetti samples	37
3	Average instrumental results for spaghetti made from Quilafen and cooked at 58.5°, 82°C and boiling water for 2 to 30 min	39
4	Average instrumental results for spaghetti made from Wakooma and cooked at 58.5°, 82°C and boiling water for 2 to 30 min	40
5	Average instrumental results for spaghetti made from Wascana and cooked at 58.5°, 82°C and boiling water for 2 to 30 min	41
6	Comparison of protein content of semolina and uncooked spaghetti used and produced commercially for variety study	51
7	Comparison of average 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	62
8	Comparison of average 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	63
9	Average volume increase over time, for 3 spaghetti samples	66
10	Average results for firmness, compressibility and recovery of spaghetti produced from Stewart 63 semolina	71
11	Average results for firmness, compressibility and recovery of spaghetti produced from Hercules semolina	72

TABLE		PAGE
12	Comparison of analysis of variance results for spaghetti samples made from Stewart 63 and Hercules under different processing conditions	73
13	Comparison of means for the instrumental textural parameters of spaghetti made from Hercules semolina	74
14	Average results of cooking tests done on 6 brand name spaghettis using the GRL spaghetti tenderness testing apparatus	78
15	Average instrumental results for textural parameters of spaghetti used for sensory panel work	85
16	Average instrumental results for spaghetti samples containing 0.5 to 2.0% egg albumin	87
17	Average ratio estimation values for firmness of spaghetti samples containing added egg albumin	90
18	Typical panel results (replicate 2) for sensory evaluation of spaghetti	91
19	Multiple linear regression analysis of logs of panel and instrumental data	93
20	Comparison of observed and predicted panel scores for firmness of commercial spaghetti samples	96
21	Instrumental values for commercial pastas for prediction formula testing study	97
22	Instrumental values for commercial pastas used as a check against Table 21	99
23	Results of amylograph analysis of semolina, ground spaghetti and cooked spaghetti	102
24	Comparison of the degree of gelatinization of starch in laboratory produced spaghettis of varying protein levels as determined by polarized light microscopy	104

TABLE PAGE

25 Comparison using polarized light microscopy of the degree of gelatinization of starch in commercially produced spaghetti from 3 varieties 105

LIST OF FIGURES

FIGURE		PAGE
1	Classical GRL spaghetti tenderness testing apparatus curves and formulae for calculation of textural parameters	30
2	Questionnaire used for sensory evaluation of pasta firmness	32
3	Effect of length of cooking time and durum variety on instrumentally assessed tenderness of spaghetti cooked at 98.5°C	42
4	Effect of length of cooking time and durum variety on instrumentally assessed tenderness of spaghetti cooked at 82°C	43
5	Effect of length of cooking time and durum variety on instrumentally assessed tenderness of spaghetti cooked at 58.5°C	44
6	Effect of length of cooking time and durum variety on instrumentally assessed compressibility of spaghetti cooked at 98.5°C	45
7	Effect of length of cooking time and durum variety on instrumentally assessed compressibility of spaghetti cooked at 82°C	46
8	Effect of length of cooking time and durum variety on instrumentally assessed compressibility of spaghetti cooked at 58.5°C	47
9	Effect on length of cooking time and durum variety on instrumentally assessed recovery of spaghetti cooked at 98.5°C	48
10	Effect of length of cooking time and durum variety on instrumentally assessed recovery of spaghetti cooked at 82°C	49
11	Effect of length of cooking time and durum variety on instrumentally assessed recovery of spaghetti cooked at 58.5°C	49

FIGURE PAGE

12 Effect of length of cooking time and cooking water temperature on instrumentally assessed tenderness of spaghetti made from Quilafen semolina 52

13 Effect of length of cooking time and cooking water temperature on instrumentally assessed tenderness of spaghetti made from Wakooma semolina 53

14 Effect of length of cooking time and cooking water temperature on instrumentally assessed tenderness of spaghetti made from Wascana semolina 54

15 Effect of length of cooking time and cooking water temperature on instrumentally assessed compressibility of spaghetti made from Quilafen semolina 55

16 Effect of length of cooking time and cooking water temperature on instrumentally assessed compressibility of spaghetti made from Wakooma semolina 56

17 Effect of length of cooking time and cooking water temperature on instrumentally assessed compressibility of spaghetti made from Wascana semolina 57

18 Effect of length of cooking time and cooking water temperature on instrumentally assessed recovery of spaghetti made from Quilafen semolina 58

19 Effect of length of cooking time and cooking water temperature on instrumentally assessed recovery of spaghetti made from Wakooma semolina 59

20 Effect of length of cooking time and cooking water temperature on instrumentally assessed recovery of spaghetti made from Wascana semolina 60

21 Effect of variety on the relationship between volume increase of cooked spaghetti and length of cooking time 67

FIGURE		PAGE
22	Effect of variety on the relationship between instrumentally assessed tenderness and volume of cooked spaghetti	68
23	Effect of variety on the relationship between instrumentally assessed compressibility and volume of cooked spaghetti	69
24	Effect of variety on the relationship between instrumentally assessed recovery and volume of cooked spaghetti	70
25	Scanning electron micrograph showing the surface characteristics of an uncooked sample of Constant brand spaghetti	81
26	Scanning electron micrograph showing the surface characteristics of an uncooked sample of Barilla brand spaghetti	83
27	Relationship between percent egg albumin added to spaghetti and the 3 textural parameters measured by the GRL spaghetti tester	88
28	Bright light photomicrograph of starch granules in the outer zone of a spaghetti sample cooked for 5 min	107
29	Polarized light photomicrograph of starch granules in the outer zone of a spaghetti sample cooked for 5 min	109
30	Bright light photomicrograph of starch granules in zone 2 of a spaghetti sample cooked for 5 min	111
31	Polarized light photomicrograph of starch granules in zone 2 of a spaghetti sample cooked for 5 min	113
32	Bright light photomicrograph of starch granules in the core of a spaghetti sample cooked for 5 min	115
33	Polarized light photomicrograph of starch granules in the core of a spaghetti sample cooked for 5 min	117
34	Zones of cooking seen in spaghetti samples cooked for 5 min then squeezed between 2 plexiglass plates	119

ABSTRACT

MARSHALL, SUSAN GLENISE, Ph.D. The University of Manitoba, March 1973.

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 electro-

phoresis (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,