

The development and evaluation of measurements on spaghetti with diverse quality characteristics



Thesis presented in partial fulfilment of the requirements for the Master's degree of Science in  
Consumer Science (Foods) at the Stellenbosch University.

December 2005

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Co-Study Leader: Mrs SH Vorster

## DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or in any part, been submitted at any university of a degree.

Signature: \_\_\_\_\_

Date: \_\_\_\_\_



## SUMMARY OF THESIS

**TITLE:** The development and evaluation of measurements on spaghetti with diverse quality characteristics.

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**STUDY LEADER:** Dr MC Vosloo

**DEGREE:** Master of Science in Consumer Science (Foods)

**FACULTY:** Natural Science

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Pasta manufacturing is a process whereby wheat flour is converted into a shelf-stable food that is more desirable than native wheat flour. It can be fortified and may serve as a valuable source of nutrition in developing countries. Quality measures are of importance in the production process to ensure a consistent and acceptable finished product.

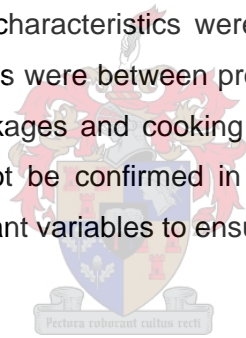
Literature provides information on many aspects of wheat types, milling techniques and processing of pasta. Protein content and quality of cultivated wheat varieties is of major importance to produce quality pasta products. Wheat types of lower protein content are more readily available than traditionally used durum wheat. As in all food products, the cost of final products is of major importance. Bread wheat is generally less expensive than durum wheat. However, product quality (and thus acceptability) may be lower. Direct measurements of product quality are currently limited to protein content, moisture content, colour analyses and certain other characteristics measurable in a laboratory, for example mechanical strength and firmness. Direct measurements of defects that may affect final product quality, such as cracks and fissures on the strands of spaghetti, different types of spots and lines on the strands, broken units, units sticking together and odd shapes are not well documented.

During the first part of this study, spaghetti quality evaluation techniques were reviewed, improved or developed and thereafter standardised. This developmental research was conducted to establish valid and reliable measures (with a high degree of repeatability) for the evaluation of dry and cooked pasta quality characteristics. A wide variety of available products on the South African market were evaluated for different quality characteristics. From this evaluation standards were drawn up, tested for validity and reliability by means of repeatability. Minimum sample sizes for the evaluation of different quality characteristics were calculated and presented in the study, together with reference photographs that can be used to evaluate spaghetti.

This study found that colour evaluation by means of commercially available apparatus needs revision. This study suggests the use of multiple layers when evaluating translucent food products for colour. The occurrence of fissures and flour spots are of importance for the quality of the final product. This study provides a set of valid and reliable measurements for measuring the quality of dry and cooked spaghetti. Simple techniques can therefore be used to detect the presence or absence of these defects.

Thereafter an empirical study was conducted to describe the differences between spaghetti prepared from durum and non-durum wheat, dried at different temperatures and at different relative humidity. Spaghetti samples of diverse perceived quality, from different manufacturers, were purchased and evaluated. Standard methods and the newly developed testing methods were used to test whether these methods effectively distinguish between spaghetti of diverse quality, reflecting on the validity of the methods. Correlations were calculated between dependent and independent variables in an attempt to find possible explanations for certain defects or quality differences, and to test certain theories in the literature.

Certain relationships between quality characteristics were found, while others were questioned. The most important proven relationships were between protein content and its effects on reducing quality defects such as fissures, breakages and cooking losses. The relationship between ash content and spaghetti colour could not be confirmed in this study. This study confirmed that protein remains one of the most important variables to ensure consistent quality spaghetti.



## OPSOMMING VAN TESIS

<b>TITEL:</b>	Die ontwikkeling en evaluasie van metings geneem op spaghetti met diverse kwaliteit eienskappe.
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Pastavervaardiging is 'n proses waartydens koring meel omskep word in a produk met 'n stabiele en lang rakleef tyd wat meer gewens is as die oorspronklike koring meel. Pasta kan gefortifiseer word and kan dien as a waardevolle voedingsbron in ontwikkelende lande. Om 'n konstante en aanvaarbare finale produk te verseker is kwaliteitmetings gedurende die produksie proses belangrik.

Die literatuur voorsien heelwat inligting rakende aspekte van belang vir pastakwaliteit, byvoorbeeld koringtipes, maaltegnieke en die vervaardigingsproses. Proteïnhoud en die kwaliteit daarvan is van groot belang tydens die produksie van hoë kwaliteit pasta. Koringtipes met 'n laer proteïnhoud is meer geredelik beskikbaar as tradisionele durumkoring. Soos met alle voedselprodukte, is die koste van die finale produk van groot belang. Oor die algemeen verhandel broodkoring teen laer pryse as durumkoring. Die produkkwaliteit en aanvaarbaarheid van pasta vervaardig van broodkoring kan egter laer wees as dié van durumkoring. Direkte metings van produkkwaliteit is tans beperk tot proteïnhoud, voginhoud, kleuranalise en sekere eienskappe meetbaar in 'n laboratorium, byvoorbeeld meganiese sterkte en fermheid. Die direkte meting van defekte wat finale produkkwaliteit kan beïnvloed, byvoorbeeld barste, krake, meel kolletjies, strepe op spaghetti-eenhede, gebreekte eenhede, eenhede wat aan mekaar kleef en ongewone vorms, is nie goed gedokumenteer nie.

Gedurende die eerste gedeelte van hierdie studie, is 'n oorsig van spaghetti evaluasie tegnieke beskikbaar in die literatuur gdoen, waarna sekere verbeter is, ander ontwikkel is en finaal gestandariseer is. Hierdie navorsing is uitgevoer om geldige en betroubare metings (met 'n hoë graad van herhaalbaarheid) vir die evaluasie van droë- en gaar pastakwaliteitseienskappe vas te stel. 'n Wye verskeidenheid van produkte beskikbaar op die Suid-Afrikaanse mark is ge-evalueer ten opsigte van verskillende kwaliteitseienskappe. Vanuit hierdie evaluasies is standarde saamgestel en getoets vir geldigheid en betroubaarheid deur middel van herhaalbaarheid. 'n Minimum steekproefgrootte per kwaliteitseienskap is bereken en word vermeld in hierdie studie. Daarmee saam word verwysingsfoto's aangebied wat gebruik kan word tydens die evaluasie van

spaghetti. Hierdie studie bied a stel geldige en betroubare meting vir die kwaliteit van droe en gaan spaghetti. Eenvoudige tegnieke kan dus gebruik word om die voorkoms van hierdie defekte te meet.

Met afloop van die verkennende studie, is 'n empiriese studie gedoen om die verskille te beskryf tussen pasta vervaardig van durum en brood koring, gedroog teen verskillende temperature en relatiewe humiditeit. Spaghettimonsters met oënskynlike diverse kwaliteit, vervaardig deur verskillende maatskappye, is aangekoop en ge-evalueer. Standaardmetings en nuutontwerpte metings is gebruik om te bevestig of die metings kan onderskei tussen spaghetti met uiteenlopende kwaliteit, wat reflekteer op die geldigheid van die metingsmetodes. Korrelasies is bereken tussen afhanklike en onafhanklike veranderlikes in 'n poging om moontlike verklarings vir sekere defekte of kwaliteitsverskille te vind, en ook om sekere teorieë in die literatuur te toets.

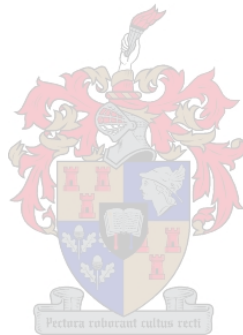
Die verband tussen sekere kwaliteitseienskappe is bevestig en bewys, terwyl ander bevraagteken was. Die mees belangrike verband was proteïnhoud en die effek daarvan om die voorkoms van defekte, soos barste, gebreke eenhede en kookverliese te verlaag. Die verband tussen asinhoud en spaghettkleur kon nie in hierdie studie bevestig word nie.

Hierdie studie het bevestig dat proteïen die mees belangrike veranderlike is wat oorweeg moet word wanneer 'n konstante hoë kwaliteit spaghettiproduk vervaardig word. Kleurevaluasie met behulp van kommersieel-beskikbare apparaat vereis hersiening. Hierdie studie stel voor dat tydens kleur evaluasie van voedsel wat lig deurlaatbaar is, dit in veelvoudige lae evalueer moet word. Die voorkoms van defekte soos barste, krake of meel kolletjies is van belang ten opsigte van finale produkkwaliteit. Hierdie studie bied riglyne vir die evaluasie van die genoemde defekte. Die voorkoms van hierdie defekte is van groter belang as die graad waarteen die defek voorkom. Eenvoudige tegnieke kan vervolgens gebruik word om die teenwoordigheid of afwesigheid van hierdie defekte te bepaal.

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by  
Elizabeth Mac Gregor

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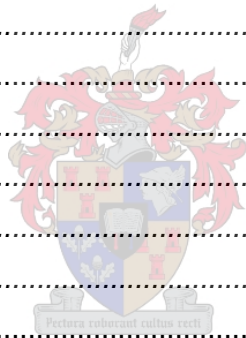
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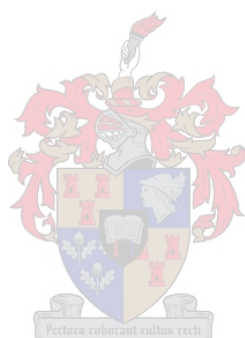
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## CHAPTER 1: INTRODUCTION

### 1.1 RATIONALE FOR THE STUDY

Pasta is a wheat-derived staple food, second in world consumption to bread (Mariani-Constantini, 1988:283). Worldwide acceptance of pasta is ascribed to a unique combination of properties, namely low cost, long shelf life, ease of preparation, palatability, versatility, desired nutritional properties, and the potential for fortification (Antognelli, 1980:140, Cubadda, 1988:227, Feillet, Abecassis, Autran & Laignelet, 1996:205). Pasta is recognised as having potential to an important staple food for developing countries, to minimise hunger and to improve the diets in these countries (Smolin & Grosvenor, 1999:73). Pasta products have a low water activity and long shelf life and may be fortified with proteins, vitamins and minerals without affecting the taste thereof. This appears unrealistic when one considers that durum wheat (*Triticum durum*), the primary ingredient in "Italian style" pasta, contributes only 5% of the world's wheat production. Internationally durum wheat trades at higher price than other wheat species, for example *Triticum aestivum* (Dick & Matsuo, 1988:509). If pasta can be produced from non-durum bread wheat the latter problem can be overcome. However, the poor sensory characteristics and cooked quality of non-durum wheat pasta products have dictated the use of durum wheat semolina in certain markets. The superior quality of pasta prepared from durum wheat is due to the superior protein quality and content, as well as the colour and hardness of the endosperm of durum wheat (Dalbon, Grivon & Pagani, 1998:17). Due to the non-availability of durum wheat and the lower cost of bread wheat, the latter is used in countries like South Africa to manufacture pasta on a commercial scale (Feillet *et al.*, 1996:207).

International research has focused on the use of durum semolina in Italian-style pasta, and only limited attention has been given to improving the quality of non-conventional raw materials. Newly developed technology enables the use of non-durum wheat to produce higher quality pasta. There is a lot of speculation in the literature on the use of bread wheat to manufacture pasta of high quality. This literature was reviewed (D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990:275,280, Novaro, D'Egidio, Mariani & Nardi, 1993:719, Marconi, Carcea, Schiavone & Cubadda, 2002:638) and the theories tested in this study. Research aimed at monitoring the quality of pasta produced from bread wheat is appropriate in countries such as South Africa. Literature reporting on the quality of pasta manufactured from bread wheat in South Africa is currently non-existent.

In formal markets the colour of foodstuffs is important from the consumers' point of view. Pasta is no exception to this rule. Pasta colour is mainly the result of the type of raw material used and by certain manufacturing techniques (Joppa & Williams, 1998:64, Atwell, 2001:119, Sissons & Hare,

2002:88). The mechanical strength of the dry product is also important, as it is an indication of how well the product will withstand handling during distribution. Mechanical strength of pasta is a function of the raw materials used (for example, protein content) and the manufacturing process (for example, drying defects which result in cracks) (Feillet & Dexter, 1998:116, Pollini, 1998:69, Gianibelli, Uthayakumaran, Sissons, Morell & Batey, 2000:642, Johnston, 2001:161, Sissons & Hare, 2002:83, Guler, Koksel & Ng, 2002:427).

Secondly, the quality of cooked pasta is of importance to consumers. The textural quality of cooked pasta is considered of critical importance when evaluating the overall quality of pasta. Cooked pasta should be firm, resilient and non-sticky (Grzybowski & Donnelly, 1979:380, Dick & Matsuo, 1988:538, Kovacs, Howes, Clarke & Leisle, 1998:47, Sissons & Hare, 2002:83). Variation in the quality of cooked pasta is due to the raw materials used and the manufacturing process (Abecassis, Faure & Feillet, 1989:480, Resmini & Pagani, 1983:1, De Stefanus & Sgrulletta, 1990:97, Dexter, Matsuo & Morgan, 1981:1741).

A need exists for the development and standardisation of methods to analyse the quality of dry and cooked pasta (Feillet *et al*, 1996:205). Standardised evaluation methods are essential to obtain sound statistical data. These evaluation methods may then also be used in an industrial pasta manufacturing plant as quality control measures, provided that they are valid, reliable and can be performed with ease. Therefore, after dealing with the theoretical underpinnings for the study in review chapters, the first phase of this research aimed at the development and standardisation of spaghetti quality evaluation measurements, which will have practical benefit in the pasta industry.

In formal markets, competitive products should have similar quality characteristics to compete successfully. Comparison of the quality characteristics of dry pasta manufactured from durum and bread wheat became essential to accurately describe any observed differences. The aim of the second phase of this research was therefore to compare the quality characteristics of dry pasta from three suppliers. Manufacturer A (Brand A) utilises the latest available manufacturing technology and a locally produced bread wheat flour (mixed cultivars SST57, SST88 and SST825). Manufacturer B (Brand B) utilises dated technology and durum wheat semolina. Manufacturer C is a well-established and internationally recognised pasta manufacturer producing high quality durum pasta, utilising the latest available manufacturing technology. The same was done for cooked pasta. When the aim of any production process is considered, namely the production of a consistent "high-quality" finished product that will stay in the market, and that will enjoy an ever-increasing market share, it becomes clear that comparison of opposing brands is essential.

The differences observed between brands could be explained bearing the various independent variables in mind. The third phase of this research therefore aimed at correlating the observed

spaghetti quality characteristics in an attempt to find possible explanations for certain defects or quality differences, and to test certain theories in the literature.

## 1.2 GOALS AND SUB-GOALS

Before undertaking the actual research during this study, the first goal was to establish a theoretical understanding of the pasta manufacturing process (Chapter 2), the milling and compositional factors influencing the suitability of raw materials for pasta manufacturing (Chapter 3) and also modern technologies enabling manufacturers to use non-traditional raw materials for the manufacture of pasta (Chapter 4).

Hereafter the research phases followed. This study had three research phases. Each phase was supported with a goal and sub-goals. The aim of the first research phase was the development of reliable and valid measurements for the evaluation of dry and cooked pasta quality characteristics respectively (Figure 1.1).

The sub-goals of Phase 1 (the developmental study) were thus to propose or improve measurements for the evaluation of dry and cooked spaghetti quality, which will contribute to the needs of the quality assurance team in the spaghetti industry in South Africa. The dry spaghetti quality evaluation methods were firstly reviewed and evaluated (Chapter 5). Dry quality characteristics included protein, ash, moisture, length, diameter, cracks, fissures, white spots, flour spots, dark spots, strands with bent shapes, strands with a white line, strands sticking together, strands with loops, breakages and colour. Secondly, the cooked quality characteristics were reviewed and investigated (Chapter 6). These cooked quality characteristics included cooking loss, rinse loss, water absorption, colour and resistance to over-cooking (Chapter 6). All these dry and cooked characteristics were measured repeatedly on spaghetti samples with diverse quality and the accuracy of measurements calculated. The dry and cooked characteristics became variables in the second phase of the research.



During Phase 2 (Chapter 7) data were collected over time, enabling the researcher to profile the bread wheat brand (Brand A), as well as that of the durum brands (Brands B and C), in terms of dry and cooked quality characteristics and hereby allow comparison between brands. For those measurements that reliability and validity could not be established during the first phase, it was further investigated in the second stage. The first sub-goal of the second research phase (empirical study) were to collect data over time, which enabled the researcher to compare dry and cooked spaghetti quality characteristics in terms of the variables listed under the previous bullet. Three brands were compared and included Brand A, Brand B and Brand C. The second sub-goal

of the second research phase was to establish the reliability and validity of those measurements for which reliability and validity could not be established in the first phase.

During Phase 3 (Chapter 8) the dry and cooked spaghetti quality characteristics were correlated. The first sub-goals of the third research phase were to pool the data across the three brands and correlate variables to determine whether there is interdependence between the quality characteristics. The second sub-goal of the third research phase were to further investigate the reliability and validity of measurements not proved in the first two phases.

The goals and sub-goals, representing the literature review and the three phases of the study, are depicted as a conceptual framework in Figure 1.1 (see next page).

### 1.3 HYPOTHESES

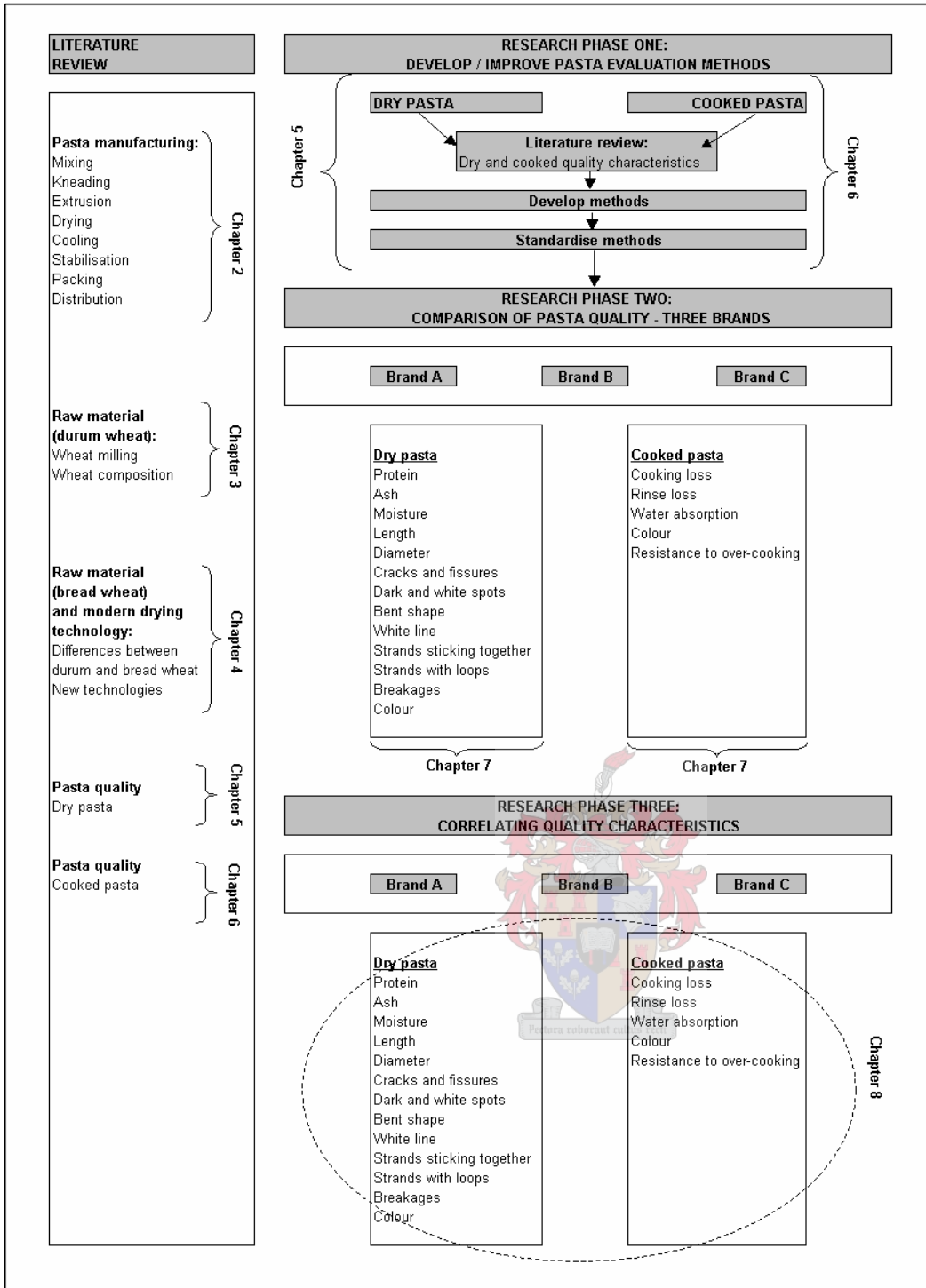
The developmental part of this empirical research (research Phase 1, partly Phase 2 and Phase 3), aimed at the development or improvement, and the standardisation of spaghetti quality evaluation methods, that are valid and reliable, to be used to monitor dry and cooked spaghetti quality characteristics, with the factual hypothesis that such developmental work can be done in order to progress to further phases of the research (See Chapters 5 and 6 and partly Chapters 7 and 8 for the report of the outcomes). These methods were essential to develop a reliable and valid tool for the second and third research phases of this study.

For research Phases 2 and 3, the following null-hypothesis were tested:

**H<sub>0</sub>1:** There will be no significant difference in the dry spaghetti quality characteristics (listed in Figure 1.1) of the bread wheat brand (Brand A) and that of the durum brands (Brands B and C) (See Chapter 7 for the report of the outcomes).

**H<sub>0</sub>2:** There will be no significant difference in the cooked spaghetti quality characteristics (listed in Figure 1.1) of the bread wheat brand (Brand A) and that of the durum brands (Brands B and C) (See Chapter 7 for the report of the outcomes).

**H<sub>0</sub>3:** There will be no correlation between spaghetti quality characteristics (See Chapter 8 for the report of the outcomes).



**FIGURE 1.1 CONCEPTUAL FRAMEWORK, AT THE SAME TIME ILLUSTRATING THE LAYOUT OF THIS STUDY**

## 1.4 VARIABLES

During the first research phase, control variables were identified from the literature and were borne in mind during the developmental study as these could have a great effect on the scores obtained when spaghetti quality is quantified. These control variables will be discussed in the relevant chapters (Chapters 5 and 6). Furthermore, dry and cooked quality characteristics were identified and further investigated for reliability and validity. These became variables in the research phases to follow and are illustrated in Table 1.1.

During the second research phase (Chapter 7), the quality of a bread wheat brand (Brand A) and that of the durum brands (Brands B and C) were compared and during the third research phase (Chapter 8) the interdependence between certain pasta quality characteristics was explored. The variables applicable to the second and third research phases are summarised in Table 1.1.

## 1.5 OUTLINE OF THESIS

In this chapter introductory perspectives pertaining to the rationale for the study were given. The goals and sub-goals, hypotheses were discussed and variables listed. A conceptual framework (Figure 1.1) served to illustrate the various phases of the study.

Before commencing the research, relevant literature was reviewed, covering all the aspects covered in the conceptual framework (Figure 1.1). These theoretical underpinnings are reported in Chapters 2, 3 and 4. Chapter 2 gives an overview of pasta manufacturing and serves as orientation towards the rest of the study. Hereafter Chapter 3 deals with wheat characteristics, with special reference to the suitability of durum for milling and pasta manufacturing, while Chapter 4 deals with bread flour and the use of modern technologies (high temperature drying technologies) to deal with inadequacies of bread flour for pasta manufacturing. These three chapters are necessary for the complete understanding of variables influencing pasta quality.

In Chapter 5, current and proposed methods for dry pasta quality evaluation are discussed. Thereafter, in Chapter 6, current and proposed measurements of cooked pasta quality are reported. In Chapter 7 those quality evaluation methods developed in the previous two chapters are summarised and applied for the comparison of dry and cooked pasta quality between three brands available in South Africa. In Chapter 8 correlations between pasta quality measurements are reported. In Chapter 9 final conclusions are drawn and recommendations are made.

**TABLE 1.1 VARIABLES IN RESEARCH PHASES TWO AND THREE**

<b>Research phase</b>	<b>Independent variables</b>	<b>Dependent variables</b>
<u>Phase 2</u> Evaluation of dry spaghetti quality characteristics	Brand A Brand B Brand C	Protein Ash Moisture Length Diameter Strands with bent shapes Strands with a white line Strands sticking together Strands with loops Breakages Colour
<u>Phase 2</u> Evaluation of cooked spaghetti quality characteristics	Brand A Brand B Brand C	Cooking loss Rinse loss Water absorption Colour Resistance to over-cooking
<u>Phase 3</u> Correlation of spaghetti quality characteristics	Protein Ash Moisture Length	Strands with bent shapes Strands with loops Strands with a white line* Strands sticking together* Breakages* Dry colour* Cooking loss Rinse loss Water absorption Cooked colour Resistance to over-cooking

\* These variables can either be dependent or independent during the statistical investigations depending on, with which other variable it is correlated (for example, if protein is correlated with strands sticking together, protein is the independent variable and strands sticking together the dependent variable. When strands sticking together are correlated with cooking loss, strands sticking together is the independent variable and cooking loss the dependent variable).

## 1.6 FORMAT

With regard to the technical aspects of this thesis, the “Guidelines for Authors” of the *Journal of Family Ecology and Consumer Science*, which is based on the Harvard reference system, was used. These guidelines can be accessed via the search engine “Google” with the key words “Family ecology” and “consumer science”. Although there are more appropriate journals for the content of this thesis, it was decided on a homogeneous technical style, to be adapted for applicable journals before submission.

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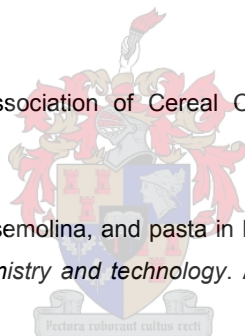
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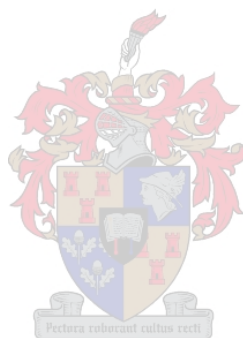
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## CHAPTER 2: PASTA MANUFACTURING

### 2.1 INTRODUCTION

Pasta usually consists of semolina (coarsely ground wheat, 150–600 micron) and water. Various forms of pasta are available on the market, varying from long pasta (such as spaghetti and tagliatelle) to pasta that is short (such as macaroni, penne or fucilli).

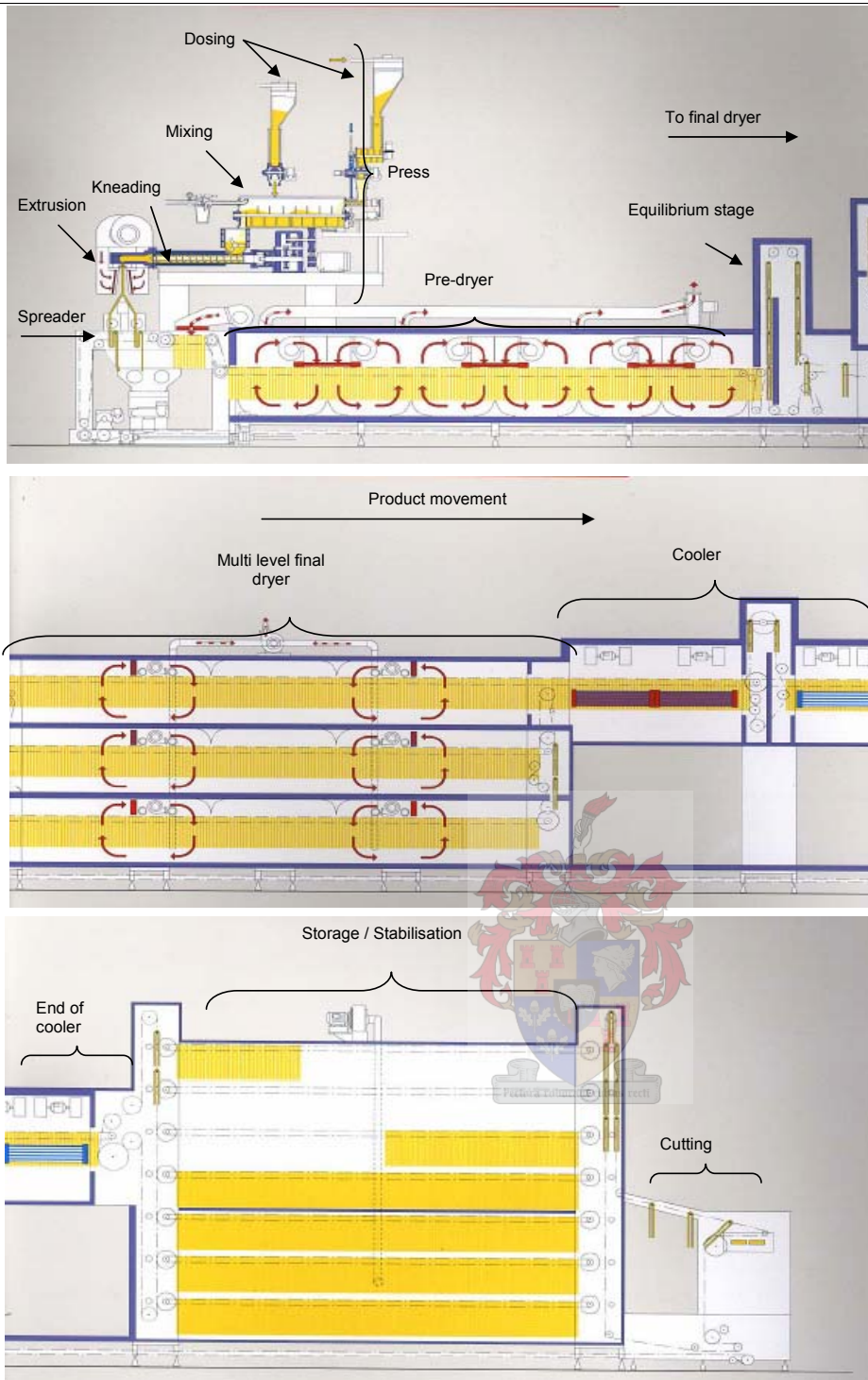
Literature on pasta processing and ingredient functionality is abundant, for instance Kill and Turnbull, 2001, Milatovic and Mondelli, 1991 and Kruger, Matsuo and Dick, 1998. However, a comprehensive guide relating to pasta quality and defects and the measurement thereof is not available. This overview is to explain the pasta-manufacturing process and how this relates to pasta quality.

### 2.2 THE PASTA-MANUFACTURING PROCESS

Pasta manufacturing can be divided into three main processes and are commonly referred to as the press, the dryer and the finishing units (see Figure 2.1). The press is designed to perform three major functions, i.e. mixing, kneading and extrusion (Baroni, 1988:191-216, Millatovic & Mondelli, 1991:69-97, Dalbon, Grivon & Pagani 1998:13-58, Dawe, 2001a:86-118). During the mixing stage the raw materials are added together and mixed into a homogeneous blend. This blend is then fed into a barrel containing a screw, which drives it forward. During this action the blend is kneaded and developed into dough. Lastly, the dough is extruded into its desired shape by pressing through a die in the extrusion head. After extrusion, spaghetti is neatly draped on drying sticks (equipment referred to as a spreader) and moved into a dryer (Baroni, 1988:191-216, Millatovic & Mondelli, 1991:98-174, Pollini, 1998:59-74, Johnston, 2001:158-173). Dryers are usually divided into three chambers namely a pre-dryer, an equilibration chamber and a final dryer. Upon the completion of the drying process, the pasta proceeds to the finishing units where it is stabilised (cooled under humidity control), cut and packed (Baroni, 1988:191-216, Varriano-Marston & Stoner, 1998:75-94).

#### 2.2.1 Mixing in the press

Semolina is transported from the silos to the mixing chamber of the press where it is blended with liquid (water and sometimes egg). The mixing chamber contains a high-speed rotating axle, with paddle-like extensions, which ensures homogeneous mixing (Dalbon *et al*, 1996:24). Mixing is carried out under vacuum (Dawe, 2001a:107). The main purpose of mixing under vacuum is to



**FIGURE 2.1 ILLUSTRATION OF A SPAGHETTI MANUFACTURING PLANT (ADAPTED FROM PAVAN, 2005)**

remove as much as possible air from the mixture. It also facilitates hydration and prevents the oxidation of the yellow carotenoid pigments (Dawe, 2001a:109) (see Section 2.2.2).

The main purpose of the mixing stage is to hydrate the semolina particles as evenly as possible, without the formation of dough (Dalbon *et al*, 1998:13). Upon proper mixing the product must have a granular structure resembling coarse crumbs similar to that of cooked couscous (see Figure 2.2).



**FIGURE 2.2 CORRECTLY HYDRATED SEMOLINA (MONDELLI, 2002:16)**

When semolina and water are mixed together, two fundamental reactions take place: the hydration of starch granules and the hydration of protein molecules (gliadin and glutenin). Although both starch granules and protein molecules have a high affinity for water, proteins have a greater affinity (bonding with up to 200 times its weight in water) (Dawe, 2001a:86, Pasta, 2002:13, Pasta 2004:43). This facilitates some gliadin-glutenin interaction, so that, at the end of mixing, the crumbs consist of hydrated starch granules dispersed in a matrix of unaligned (non-developed) gluten strands (see Figure 2.4). Except for some starch damage induced by mechanical action and enzyme activity, starch will not undergo any important structural changes during mixing (Antognelli, 1980:131, Dalbon *et al*, 1998:25, Dawe, 2001a:92). Factors affecting the success of the mixing stage include the hydration level, temperature and the time of blending.

**Hydration level.** The amount of liquid added is calculated on the basis of the moisture content of the semolina (max 14%) so that the moisture content of the resultant crumbs is approximately 28–31%. This should form a structure that will withstand kneading, extrusion and drying (Antognelli, 1980:145, Banasik, 1981:167, Hahn, 1990:386, Dalbon *et al*, 1998:20). The shape of the final product as well as the particle size of semolina influences the optimal amount of liquid to be added. Long shapes generally require less liquid to prevent excessive stretching of the dough during extrusion (Dalbon *et al*, 1998:21). Coarser semolina particles require less liquid than finer particles to hydrate to the required viscosity (Irvine, 1971:779).

The addition of either too much or too little water at the mixing stage causes uneven hydration of semolina, resulting in pasta with inferior appearance characteristics (dull colour, loss of opacity and the presence of unattractive white spots, the latter due to un-hydrated starch granules). With too much water, uneven hydration is caused by the tendency of semolina particles to form lumps (clusters of starch granules) allowing only the outer parts of these clusters to hydrate (few, but large white spots). Too little water, on the other hand, does not cause lumps, but only the outer parts of semolina particles will hydrate, resulting in a large number of small white spots (Debbouz & Donnelly, 1996:670, Dalbon *et al*, 1998:21, Dawe, 2001a:97, Pasta, 2003b:30). Excessive or insufficient hydration during the mixing stage also has a detrimental effect on dough development during the kneading and extrusion phase, which will result in an inferior finished product with poor cooking performance (see Section 2.2.2).

**Hydration temperature.** There is agreement that the temperature during mixing should not exceed 55°C to prevent denaturing of the gluten proteins, gliadin and glutenin (Milatovic & Mondelli, 1991:70, Pasta, 2004:45). When denaturing of proteins occurs during the mixing stage, the proteins agglomerate instead of forming a continuous gluten network. This phenomenon will be reflected in the final (cooked) pasta quality by the disintegration of the product (Milatovic & Mondelli, 1991:70).

Optimum hydration temperature during mixing is disputed. Some manufacturers advocate the use of low temperatures (2–10°C) at higher water quantities, 34–36% moisture as opposed to 28–31% moisture at higher temperatures, to protect the protein against denaturing. However, some authors caution that this practise will lead to uneven hydration, resulting in a final product with white spots (Pasta, 2003b:30). Other manufacturers, especially when using semolina with relatively coarse granulation, prefer to dose water at a temperature of 35–45°C, as it is absorbed more rapidly by the semolina (Antognelli, 1980:132, Dalbon *et al*, 1998:22, Dawe, 2001a:102). Most manufacturers, however, accept the ideal hydration temperature as being between 26–28°C. The temperature of the liquid and semolina should be taken into account to ensure that the temperature of the semolina crumbs entering the kneading barrel between 28 and 30°C (Dalbon *et al*, 1998:22, Mondelli, 2002:16).

**Hydration time.** It is important that starch molecules remain intact during the mixing phase. To prevent starch damage due to mechanical action and enzyme activity, mixing time should be as rapid as possible without compromising proper hydration (Lintas & D'Appolonia, 1973:567, Dalbon *et al*, 1998:22). Mixing time is normally between 10 and 15 minutes and is largely determined by hydration temperature and the particle size of semolina (Hahn, 1990:387). The lower the hydration temperature and the larger and more uneven the semolina particles, the longer the required time for mixing (Felleit & Dexter, 1998:116). In addition to these factors, a decrease in the protein



content and protein strength of semolina necessitates a decrease in mixing time (Gianibelli, Uthayakumaran, Sissons, Morell & Batey, 2000:642).

## 2.2.2 Kneading and extrusion in the press

Wet semolina is fed from the mixing chamber into the kneading barrel, containing a screw. The mixture is driven towards the extrusion head, while converting it into dough (see Figure 2.3). The dough then falls vertically into the extrusion head, from where it is forced through a die to obtain the desired shape. The kneading barrel and extrusion head operate under vacuum. They are equipped with water-cooling jackets (cooling system that circulates water at 27–32°C) to prevent excessive heat build-up in the unit and to maintain constant dough temperatures (Banasik, 1981:168, Hahn, 1990:387, Feillet & Dexter, 1998:110, Dawe, 2001a:106).

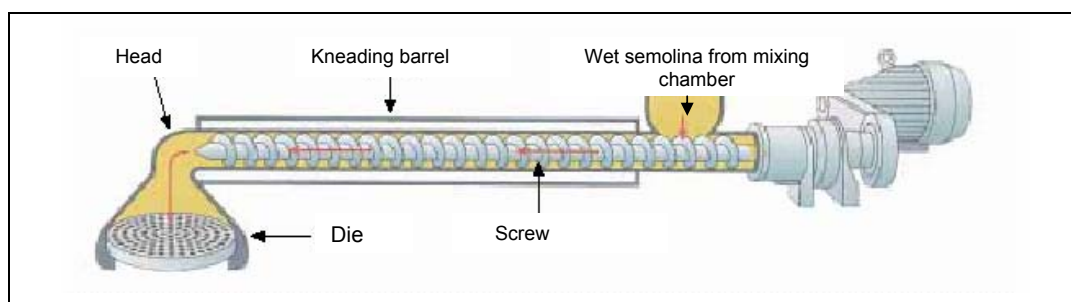
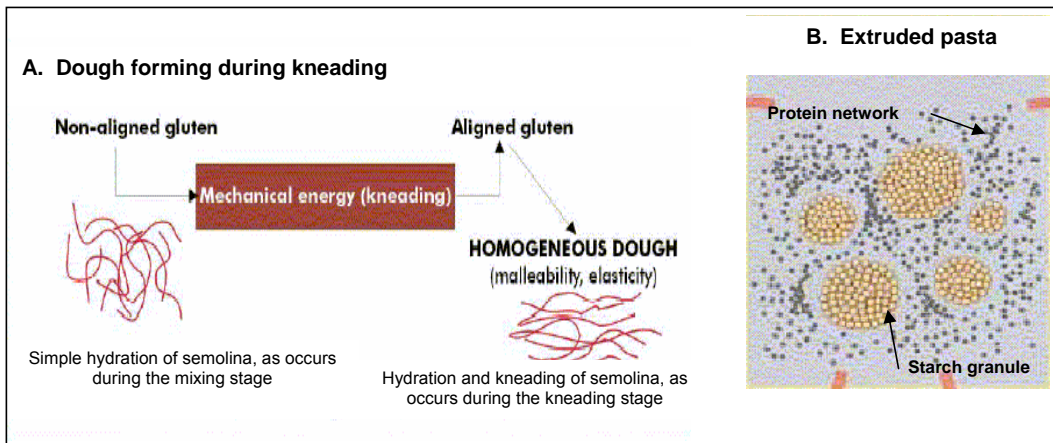


FIGURE 2.3 THE KNEADING BARREL (PASTA, 2004:39)

The main function of the kneading phase is to convert the wet semolina into dough that is fit for extrusion. This is brought about by the mechanical action (friction) of the screw and the pressure that is built up by the forward driving action; all of which generates the energy required for dough development. Extrusion under high pressure (which can reach levels of up to 100 kg/cm<sup>2</sup>) causes further shearing and tearing of dough and increases its compactness, all of which strengthens the dough (gluten structure) of the extruded pasta (Dalbon *et al*, 1998:45). By the time the dough leaves the press the surface of the freshly extruded pasta should consist of a continuous protein (gluten) film, while the inner portion is a compact structure of starch granules embedded in an amorphous gluten matrix aligned in layers parallel to the protein film (Figure 2.4, part A and B) (Antognelli, 1980:133, Banasik, 1981:168, Resmini & Pagani, 1983:5, Hahn, 1990:387, Dalbon *et al*, 1998:32, Feillet & Dexter, 1998:110, Pasta, 2004:38).





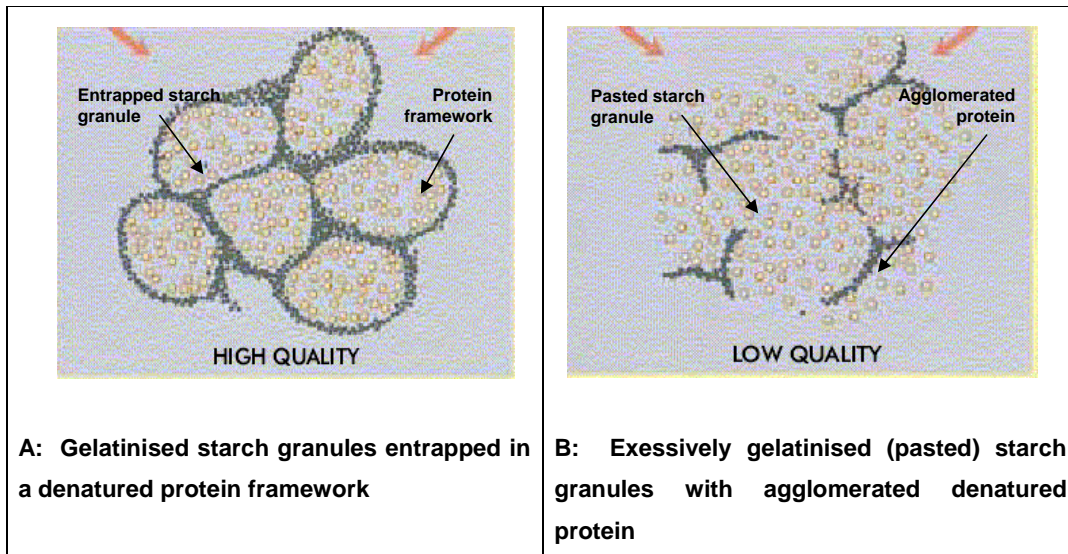
**FIGURE 2.4 DOUGH FORMATION DURING MIXING AND KNEADING – PICTORIAL PRESENTATION (PASTA, 2002:13, PASTA, 2004:43)**

Good cooking performance is dependent on the creation of this structure during kneading and extrusion and the preservation thereof during the drying process (Dawe, 2001a:86). During cooking the gluten framework denatures around the starch granules and restricts water absorption by the inner starch granules, thereby preventing excessive starch gelatinisation and pasting (Resmini & Pagani, 1983:1). In good quality pasta, gelatinised starch particles are therefore trapped in a denatured protein network, which promotes the firmness and eating quality of cooked pasta (see Figure 2.5A). The gluten structure is disrupted in low quality pasta either by protein denaturing or starch gelatinisation, which leads to proteins that form aggregated masses rather than a continuous matrix. Without a continuous protein matrix, starch gelatinisation will occur unrestricted and pasting will result (see Figure 2.5B). Starch pasting is highly undesirable because it results in a sticky product with an unacceptable texture (Grzybowski & Donnelly, 1977:1305, Resmini & Pagani, 1983:1, Feillet, 1984:551, Pagani, Gallant, Bouchet & Resmini, 1986:122, Fardet *et al*, 1998:699, Vansteelandt & Delcour, 1998:2501).

Optimum dough development is dependent on the degree of vacuum, kneading time, the interrelationships between dough temperature and dough viscosity and the condition of the die.

**Vacuum.** Vacuum conditions ensure close contact between particles, which facilitate proper bonding of gliadin and gluten molecules to form dough (gluten strands). These conditions also favour osmosis between the more hydrated granules and the less hydrated granules, thus inhibiting the formation of white spots. Furthermore, this prevents the oxidation of carotene pigments in semolina, thereby preserving the typical yellow colour of pasta, and removing air bubbles to ensure a compact, non-aerated dough structure (Hahn, 1990:387, Dalbon *et al*, 1998:58, Feillet & Dexter, 1998:110). If not removed, air bubbles will give the finished product a

chalky white (instead of translucent yellow) appearance with poor mechanical strength and a greater tendency to cracking during drying and cooking (Abecassis *et al*, 1994:247, Smewing, 1997:8, Dalbon *et al*, 1998:58, Feillet & Dexter, 1998:110).



**FIGURE 2.5 STARCH-GLUTEN STRUCTURE IN COOKED PASTA AND ITS EFFECTS ON QUALITY – PICTORIAL PRESENTATION (PASTA, 2004:43)**

**Kneading time.** The kneading time is dependent on the screw speed. By increasing the screw speed, kneading time is reduced, causing temperature and pressure to rise (Abecassis *et al*, 1994:253). Optimum kneading time (screw speed setting) is determined by dough viscosity. With increased viscosity (dough stiffness), increased kneading times are required.

The screw speed is normally fixed to ensure constant flow rate and plant throughput. Under these conditions it is of utmost importance that both dough temperature and dough viscosity be maintained at constant levels (Abecassis *et al*, 1994:252, Antognelli, 1980:133). A change in dough temperature brings about changes in dough viscosity, which affects the pressure in the kneading barrel and consequently changes the flow behaviour of the dough over the die (Dawe, 2001a:103). Tests have shown that a temperature increase of 1°C in the dough has the same effect as an increase of 1% in the dough moisture, i.e. increase in dough viscosity (Dawe, 2001a:105).

**Dough temperature.** The importance of dough temperature has been researched and reviewed extensively (Antognelli, 1980:133, Banasik, 1981:168, Hahn, 1990:387, Abecassis *et al*, 1994:252, Dalbon *et al*, 1998:35, Feillet & Dexter, 1998:110, Dawe, 2001a:105, Marchesani & Soncini, 2002:13, Johnston, 2001:160). In summary, wet semolina enters the kneading barrel at a

temperature of 26–28°C. Heat generated by friction of the kneading action and pressure build-up during the forward drive of the mixture to the extrusion head will cause an increase in temperature. The process must be carefully controlled to prevent dough temperature from rising above 50–55°C. At these high temperatures the gluten proteins (the backbone of pasta quality) will denature and the starch granules will gelatinise. These undesirable changes reduce the pliability and strength of dough, which will easily break upon extrusion. The finished product will be inferior in terms of mechanical strength and cooking performance.

Due to the compactness and temperature of the dough during this stage (vacuum and high pressure) amolytic enzyme activity, which may cause excessive starch damage, are more pronounced. It is therefore advisable to operate the kneading stage at a dough temperature either above or below the temperature at which the enzyme systems are most active. Dough should be either below 30°C or above 42°C, but never exceed 50–55°C (Antognelli, 1980:133, Mondelli, 2002:15, Pasta, 2003a:16).

**Dough viscosity.** Since dough viscosity affects dough temperature, it is of utmost importance that wet semolina enters the mixing barrel at the optimum moisture level of 28–31%. With too little water (insufficient hydration) the dough that forms will be too stiff. To maintain a constant flow rate (fixed screw speed), screw movement will generate more friction and pressure than normal (Dawe, 2001a:103). This mechanical energy will be dissipated into increased heat generation, which can have a detrimental effect on dough quality as denaturing of the protein structure and partial gelatinisation of starch granules are likely to occur (Dawe, 2001:107).

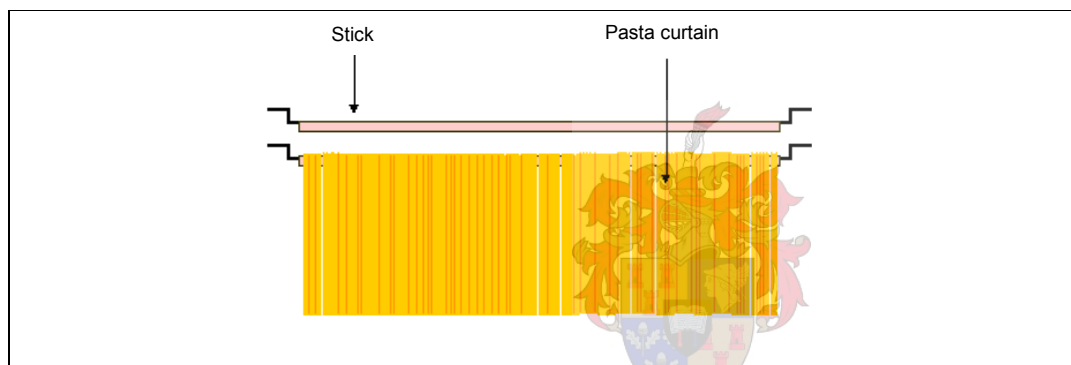
With too much water (excessive hydration) the lumpy, instead of crumbly, semolina entering the kneading barrel will develop into dough that will be too soft, with screw movement generating less friction and pressure (energy) than normal. Under these conditions dough temperature will not be adversely affected, but the energy will be insufficient to develop a proper protein network. The extruded pasta will tend to lose its shape and stick together resulting in difficulties during the drying phase (Dalbon *et al*, 1998:38, Dawe, 2001a:104)

**Die condition.** The inside surface of the die is an important factor in the maintenance of consistent quality. The two most frequently used die types are bronze dies and those with Teflon inserts in the die holes. The latter is mostly preferred, as it allows higher extrusion speeds and produces a product that is smooth and that appears more yellow (Dalbon *et al*, 1998:44, Dawe, 2001b:120, Pasta, 2004:41). The condition of the die is directly related to the smoothness of the pasta surface. A damaged die will leave streaks on the final extruded product (white lines along the spaghetti strand). Excessive die wear can also cause the formation of cracks as well as deviant product diameter (Turnbull, 2001:217). Spaghetti diameter affects the mechanical strength

of the product as well as the cooking time (Holliger, 1963:239, Turnbull, 2001:217, Sissons & Hare, 2002:83). An increase in wall thickness of 0.1 mm could result in an increase of 1 minute cooking time. Increasing or non-uniform product diameter is an indication of wear of the die (Turnbull, 2001:217).

### 2.2.3 Spreading

After extrusion, a curtain of spaghetti strands descends that is subsequently spread on sticks. A synchronised movement first folds and then cuts the pasta curtain, so that the two sides of the curtain resting on the stick are the same length (see Figure 2.6). The even distribution of spaghetti on these sticks is of critical importance since overlapping strands may adhere to one another or become misshapen (Pasta, 2003b:32). The pasta curtains are ventilated with hot air to lightly dry the surface of the pasta to keep the individual strands from sticking together (Antognelli, 1980:134, Pollini, 1998:61, Pasta, 2003a:15). When hanging on these drying sticks, the product is placed under considerable stress and here the well developed gluten structure (formed during kneading and extrusion) is of specific relevance to support the weight of the pasta and to prevent the product from breaking and falling off the sticks (Dick & Matsuo, 1988:529).



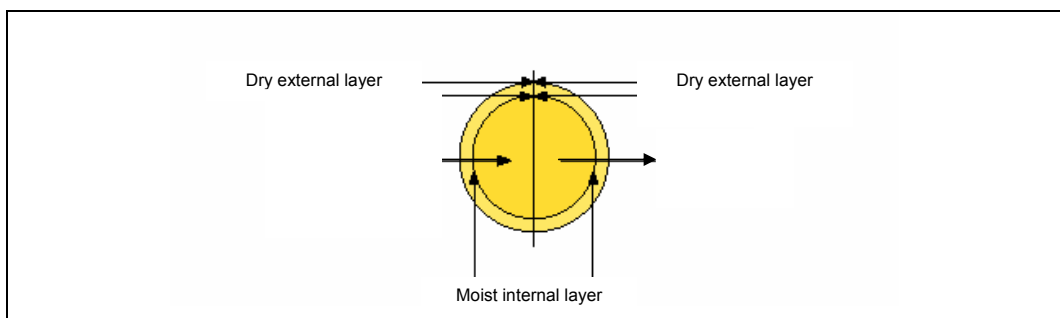
**FIGURE 2.6 PASTA CURTAIN HUNG OVER THE DRYING STICK BY THE SPREADER (PROFESSIONAL PASTA, 2005)**

### 2.2.4 Drying

After conditioning in the spreader, the pasta immediately moves into the pre-dryer and is conveyed throughout the rest of the drying process. The main function of the drying process is to reduce the moisture content from 30 to 10–12%, without the creation of non-uniform moisture gradients between the interior and exterior of the pasta and without causing changes in the gluten-starch structure that has been developed during kneading and extrusion. If carried out successfully, the product will become hard (dry) without losing its shape or elasticity; will not develop cracks or

fissures and will produce a finished product with good cooking performance, which can be stored for a long period of time without danger of microbiological attack (Holliger, 1963:233, Banasik, 1981:168, Milatovic & Mondelli, 1991:100, Smewing, 1997:8).

**Moisture gradient.** Temperature, humidity, airflow rate and time spent in drying must be carefully controlled during each phase of the drying process to prevent the creation of non-uniform moisture gradients between the interior and exterior of the pasta (Figure 2.7). As pasta shrinks upon moisture loss, the dry surface will contract onto the wet core with the result that the surface of the pasta will be under tension and the core under compression (Dick & Matsuo, 1988:538, Smewing, 1997:9, Johnston, 2001:158).



**FIGURE 2.7 NON-UNIFORM MOISTURE DISTRIBUTION IN SPAGHETTI (MONDELLI, 2003:37)**

During the early stages of drying, while pasta is still moist and pliable, these forces may cause shape deformations. In the later stages of drying, when pasta has become dryer and stiffer, these forces will cause cracks (networks of superficial splits or breaks) and fissures (deep longitudinal breaks or splits) as described by Johnston (2001:159). Cracks and fissures compromise the gluten framework formed during kneading and extrusion, thereby reducing the mechanical strength of the dry product causing immediate or delayed shattering of the product and reduced cooking performance (Dick & Matsuo, 1988:538, Feillet & Dexter, 1998:105,116, Pasta, 2003b:33). The time before cracking and fissuring appears will depend on the storage temperature and the relative humidity, which will control the extent of any further moisture losses. The product can either crack or fissure during or immediately after drying, or it can crack and fissure after it has been packaged and sold (Hahn, 1990:386). Cracks and fissures vary in depth depending on the degree to which the drying error occurred. Low levels of cracks and fissures will be visually unattractive. In its severest form cracked and fissured pasta will simply fall apart when cooked (Turnbull, 2001:217).

**Low-temperature drying.** Traditionally, pasta is dried at temperatures below 60°C, which requires a relatively long drying period of up to 40 hours (Milatovic & Mondelli, 1991:100). Drying conditions (temperature, humidity, airflow rate and time spent in drying) vary on the basis of the thickness of each shape as well as with the volume to surface-area ratio of the product (Pasta,

2004:42). In the case of long strands, drying is a particularly critical operation (Pollini, 1998:61). Typical conditions for the drying of spaghetti is summarised in Table 2.1 (Milatovic & Mondelli, 1991:100).

**TABLE 2.1 TRADITIONAL DRYING STEPS AND CONDITIONS FOR SPAGHETTI**

Drying steps	Drying Temperature (°C)	Relative Humidity (%)	Drying Time (h)	Product Moisture (%)
Pre-drying	53	81	4	20,6
Equilibration	37	90	4	20,6
Final drying	40–55	70–90	32	11,8

Pre-drying stage. Due to the high moisture content of freshly extruded pasta it loses water rapidly (Pasta, 2004:41). The pre-dryer consists of one drying tunnel on a single level, wherein pasta loses about 30–32% of its initial moisture content over a period of one to two hours (Pollini, 1998:60, Banasik, 1981:168, Pasta, 2003a:15). At the end of the pre-drying stage the product moisture level is approximately 16–20% (Milatovic & Mondelli, 1991:100, Pasta, 2004:41). The main functions of the pre-drying stage are to dry the pasta superficially shortly after extrusion, to set the shape, prevent the pasta pieces from sticking together and to prevent deformation during the remaining drying stages (Hahn, 1990:388, Pollini, 1998:60).

The moisture loss that occurs during this stage is due to the fact that the pasta is still placid and possesses capillary porosity (Banasik, 1981:168, Pollini, 1998:60). The pre-dryer is divided into zones. From one zone to the next, the temperatures are gradually increased and humidity controlled (Johnston, 2001:166). At the end of the pre-drying stage, moisture levels within the product are not homogeneous, similar to that illustrated in Figure 2.6. The exterior of the pasta is much dryer (15%) than the inner layers. The core moisture content is close to that of recently extruded pasta (Pasta, 2004:41). Continued exposure of pasta to heat and ventilation will not cause evaporation of the water in the core, but would rather over-dry the external layer. This in turn will cause these layers to shrink and this may lead to the formation of cracks. To avoid the occurrence of this particular defect the product must undergo a resting period in an atmosphere with suitable relative humidity, as discussed in the next stage (Milatovic & Mondelli, 1991:100, Pasta, 2004:42).

Equilibration stage. From the pre-dryer, the spaghetti is conveyed to the equilibration unit (sometimes referred to as tempering) of which the main function is to preserve the surface porosity through moisture equilibration at high relative humidity (Milatovic & Mondelli, 1991:100, Pollini, 1998:61). Under these conditions the water from the interior is able to spread slowly to the



surface. Only once the water particles have been redistributed evenly, the pasta may be exposed to ventilation and heat once again (Pasta, 2004:42). This stage therefore has its main influence on dehydrating the inner layers of the pasta product. If performed incorrectly, fissures will be manifested hours or days after the manufacturing process (Banasik, 1981:168, Pollini, 1998:60).

*Final-drying stage.* From the equilibrium stage the spaghetti is conveyed into the multi-level final dryer. During final drying the spaghetti moisture level is reduced to its final value of below 12.5% (Pasta, 2003a:17). The final dryer is a multi-level tunnel. The time of final drying of pasta is much longer than during pre-drying, which implies that the overall length of the dryer is significantly longer, despite the use of multiple levels.

The critical control in the final dryer is to gradually lower the temperature in order to avoid internal stresses in the pasta (Pollini, 1998:62, Pasta, 2002:27, Mondelli, 2003:41). As the pasta proceeds inside the drying tunnel, it is alternately subjected to periods of ventilation and resting. During ventilation water evaporates from the pasta surface. During resting, equilibration between the core water and surface water takes place. Surface porosity of spaghetti is hereby maintained, which in turn favours moisture loss without cracking (Pollini, 1998:62, Pasta, 2002:27, Mondelli, 2003:41).

Improper drying during the final stages may cause superficial blemishes and cracks to appear in the pasta while in the dryer, or almost immediately after removal from the dryer (Pollini, 1998:60, Felleit & Dexter, 1998:116).

### **2.2.5 Stabilising and cutting**

On leaving the dryer the pasta enters the cooler tunnel fitted with a heat exchanger, which rapidly reduces the temperature of the product to just above ambient temperature (Johnston, 2001:167, Pasta, 2003a:17). In the case of long strands an additional dehumidification zone between the final dryer and the cooler is required to reduce the moisture gradient between the core and the surface of the product to a minimum. Defects during the cooling stage are normally reflected in the final product as superficial cracks (Pasta, 2003b:35). Pasta is left in cooler to cool off completely before cutting and packing.

A stripper saw removes the dried spaghetti curtain from the support stick and cuts it into 25 cm long strands. The cut spaghetti is transferred to the scales that feed the packaging machines, while the empty sticks are returned to the spreader (Boroni, 1988:191, Milatovic & Mondelli, 1991:250, Pasta, 2003a:17,18, Pasta, 2003b:35).

Uniform strand length is important from the consumers' point of view (Turnbull, 2001:216). Defective strand lengths are due to defective cutter settings in the production line, or due to breakages caused by poor mechanical strength or poor handling practises.

### 2.2.6 Packaging

After stabilising pasta it may be packed by automated packing machines into either plastic or cardboard packaging material. The function of packaging is to keep the product free from contamination, to protect it from damage during the distribution process and to display favourably (Banasik, 1981:169). Long pasta products are packaged mostly in plastic bags (for moisture-proof protection) or in cardboard boxes (Banasik, 1981:169, Boroni, 1988:212, Milatovic & Mondelli, 1991:250). Packing in cardboard boxes serves two purposes, namely for easy shelf stacking and for the protection of fragile pasta products (Banasik, 1981:169).

### 2.3 CONCLUSIONS

Pasta manufacturing is a delicate procedure during which the raw materials and processing conditions, namely time, temperature and humidity, are of critical importance. The manufacturing process is designed to develop gluten into a network encapsulating ungelatinised starch granules. Upon cooking, this protein framework denatures around the starch granules and prevents pasting of the starch granules. In good quality pasta starch particles are therefore trapped in a protein network ensuring firmness of cooked pasta (Grzybowski *et al*, 1977:1305, Resmini & Pagani, 1983:1, Feillet, 1984:551, Pagani *et al*, 1986:122, Fardet *et al*, 1998:699, Vansteelandt & Delcour, 1998:2501). With an understanding of pasta quality the critical control measures will be evident to ensure consistent quality.

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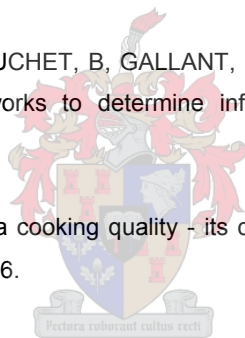
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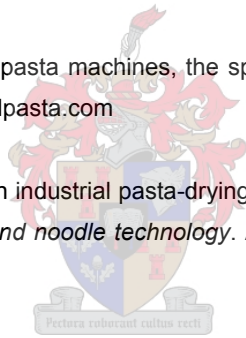
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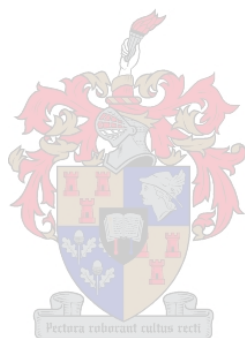
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## CHAPTER 3: IMPORTANCE OF WHEAT MILLING AND COMPOSITIONAL PROPERTIES IN TRADITIONAL PASTA MANUFACTURING

### 3.1 INTRODUCTION

Traditionally, pasta could only be made successfully with semolina milled from durum wheat cultivars. Innovations in ingredient and production technology, introduced since the 1970s, have made it possible to produce satisfactory pasta from materials milled from the more common bread wheat cultivars. Durum wheat semolina, however, remains the preferred raw material because of its intrinsic superior pasta-making properties.

An understanding of the structural and compositional differences between durum wheat (*Triticum durum*) and bread wheat (*Triticum aestivum*) as well as the effect of milling on functionality enables manufacturers to optimise raw material specifications and product formulations according to manufacturing conditions.

Table 3.1 provides a comparison between durum wheat and bread wheat. Bread wheat has a lower protein content, produces a more extensible rather than strong dough, which is ideal for gas retention during the leavening process. When durum semolina is replaced with bread wheat flour in pasta making, the protein fractions found in bread wheat do not have the ability to become firm and rigid upon denaturing to the same extent than that of durum wheat. For this reason egg addition is sometimes advised. Bread wheat also has a softer endosperm and it lacks yellow colour (being slightly reddish) (Banasik, 1981:167, Pylar, 1988:130, Dexter, Preston, Marchylo, Clarke & Carcea, 2000:662, Wiseman, 2001:18, Marconi, Carcea, Schiavone & Cubadda, 2002:636). When comparing the starch derived from durum and bread wheat, the differences are small and do not contribute to pasta quality as much as protein (Vansteelandt, 2000. Sung & Stone, 2003:65). The lipid content of all wheat flours or semolina is generally below 1% and plays a negligible role in determining the cooked quality of pasta (Youngs, 1988:139).

The most important properties of durum wheat are the composition and the hardness of the endosperm. Durum wheat has a yellow colour, a high protein content and yields a strong dough (Banasik, 1981:167, Pylar, 1988:130, Feillet & Dexter, 1998:96, Dexter, Preston, Marchylo, Clarke & Carcea, 2000:662, Marconi & Carcea, 2001:522, Wiseman, 2001:18, Marconi, Carcea, Schiavone & Cubadda, 2002:636).

**TABLE 3.1 DIFFERENCES BETWEEN *TRITICUM DURUM* AND *TRITICUM AESTIVUM* RELEVANT TO PASTA MANUFACTURING**

Quality characteristics	Wheat species	
	<i>Triticum durum</i>	<i>Triticum aestivum</i>
Traditional application	Pasta	Bread
<u>Milling variables</u>		
Endosperm hardness	Hard endosperm	Soft endosperm
Milling product	Semolina	Flour
<u>Compositional variables</u>		
Protein content (db)	High (>13%)	Low (<13%)
Protein quality	Strong dough	Extensible dough
Colour pigments	Yellow	Brown-red

### 3.2 STRUCTURAL AND COMPOSITIONAL FACTORS

The superior pasta-making aptitude of durum wheat is a function of its unique genetic character as expressed in kernel hardness and type and amounts of molecular constituents such as proteins, starch, lipids, colour pigments and enzymes.

#### 3.2.1 Kernel hardness

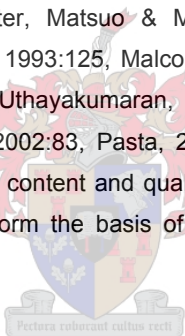
Durum wheat differs from bread wheat in that it has a very hard kernel structure (Hoseney, Wade & Finley, 407). Upon milling, durum wheat is readily converted into semolina, a grainy material with a coarse particle size of 150–600  $\mu\text{m}$ . In contrast, bread wheat with its softer kernel structure is more readily milled into flour, a powdery material with a fine particle size of less than 150  $\mu\text{m}$ . Semolina, as opposed to flour, represents a smaller surface to volume ratio. Starch molecules in semolina are therefore more intact and protected from enzymatic breakdown than those in flour, making it ideally suited for pasta-making (Antognelli, 1980:127, Dalbon, Grivon & Pagani, 1998:17, Turnbull, 2001a:56). It is possible to adjust the milling process to produce semolina from bread wheat but only durum wheat lends itself to cost-effective milling into semolina (see Section 3.3.2).

#### 3.2.2 Proteins

Wheat proteins are highly heterogeneous, including the insoluble gliadins and glutenins and the soluble albumins and globulins and the. It can be sub-divided into the gluten-forming and non-gluten-forming proteins. The gluten-forming proteins consist of glutenin and gliadin sub-units (Rao, Mulvaney, Dexter, Edwards & Peressini, 2001:217, Shewry, 2003:2). Glutenin is insoluble in alcohol and soluble in dilute acids, alkali, hydrogen and in hydrophobic bond-breaking solvents.

Gliadin is soluble in 70% ethanol. The non-gluten-forming proteins, also referred to as the soluble fractions, consist of globulin (soluble in neutral salt solutions), albumin (soluble in water) and proteases. The quantities of the last three constituents are very little and do not play a major role in pasta quality. Gluten-forming wheat proteins glutenin and gliadin are of primary importance in pasta manufacturing (Walsh & Gilles, 1971:553, Antognelli, 1980:129, Wall & Huebner, 1981:120, Feillet, 1984:553, Feillet, 1988:95, Milatovic & Mondelli, 1991:49, Marchesani & Soncini, 2002:20, Shewry, 2003: 2).

Albumins and globulins are cytoplasmic proteins with enzymatic activity, and foaming and emulsifying properties (Feillet, 1988:100). Gliadins, known for their medium molecular weight (25 000–100 000) and their high extensibility, and glutenins, known for their high molecular weight (100 000–3 000 000) and their high elasticity, associate with each other to form gluten which imparts unique viscoelastic properties to dough (Feillet, 1988:100, Pylar, 1988:115). One of the most critical success factors in pasta-making is the formation of a strong (elastic) gluten network with enough viscous flow (extensibility to encapsulate starch granules) (Feillet, 1988:102). A strong gluten network reduces the risk of shape deformations, increases the mechanical strength and may reduce cracking of dry pasta. Proper encapsulation of starch granules retards starch gelatinisation reduces leaching thereof into cooking water and increases the resistance of the product to over-cooking. This prevents pasta from becoming sticky and losing its typical firm texture (Matsuo, Bradley & Irvine, 1972:711, Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Wyland & D'Appolonia, 1982:200, Dexter, Matsuo & Morgan, 1983:1545, Hahn, 1990:394, Edwards, Izydorczyk, Dexter & Biliaderis, 1993:125, Malcolmson, Matsuo & Balshaw, 1993:420, Feillet & Dexter, 1998:116, Gianibelli, Uthayakumaran, Sissons, Morell & Batey, 2000c:642, Rao *et al*, 2001:217, Sissons & Hare, 2002:83, Pasta, 2003b:31). The viscoelastic properties of dough (gluten) are affected by both the content and quality of proteins in the milled wheat and for this reason, protein measurements form the basis of grain quality in marketing (Feillet, 1988:100, Pylar, 1988:115, Shewry, 2003:2).



### **3.2.2.1 Protein content**

The protein content of wheat varies widely from 6–20% (dry basis) and is primarily determined by environmental conditions during growth (Feillet, 1984:553, Feillet, 1988:103, Pylar, 1988:128, Halverson & Zeleny, 1988:25).

Various studies showed that, regardless of wheat species, type and cultivar, pasta-making properties increase as total protein content increases. It is easy to understand why high protein content is favourable to good pasta quality: the polypeptide chains are more numerous, and the chances for proteins to interact and to form a continuous network able to entrap starch granules -

are higher. Good quality pasta, especially long pasta goods, such as spaghetti, can only be manufactured with milled wheat having a protein content of 13% (Feillet, 1988:101). However, manufacturers are able to produce pasta of acceptable quality with materials having as little as 11% protein. Milled wheat with a protein content below 11% will yield pasta with poor mechanical strength and cooking performance (Feillet, 1988:101). Durum wheat, in general, has higher protein content (ranging from 9–18%, with typical average of 13%) than bread wheat (ranging from 8–16% with typical average of 12%) and this explains in part its superior pasta-making potential (Matsuo *et al*, 1972:711, Grzybowski & Donnelly, 1979:380, Dick & Matsuo, 1988:529, Bergman, Gualberto & Weber, 1994:625, Turnbull, 2001b:186).

Protein content can be increased by addition of protein from other sources but it is important to remember that not all proteins improve the cooked quality (Matsuo *et al*, 1972:711). Various proteins have been tested such as wheat gluten, rapeseed protein, fish protein and egg albumin. Of these only wheat gluten and egg albumin improved the cooked pasta quality (Matsuo *et al*, 1972:711).

Increased protein content improves pasta quality, regardless of the processing conditions (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter *et al*, 1983:1545, Hahn, 1990:394, Edwards *et al*, 1993:125, Malcolmson *et al*, 1993:420, Feillet & Dexter, 1998:116, Gianibelli *et al*, 2000c:642, Sissons & Hare, 2002:83). In dry pasta it increases mechanical strength and there is also some evidence that it reduces cracking. When cooking pasta it increases cooking time, the firmness of the cooked product, and resistance to over-cooking, while decreasing stickiness, cooking loss, and water absorption. Additionally, it was also found that low protein content can lead to shape defects or to units of spaghetti sticking together (Pasta, 2003:31).

### **3.2.2.2 Protein quality**

Various studies showed that at any particular protein level (manipulated by agronomical conditions) some wheat cultivars consistently perform better in pasta-making than other. The superior pasta-making properties of these varieties are believed to be the result of differences in the proportion and composition (number, types and sequence of amino acids) of the various protein fractions – all of which are determined by genetic factors. This will be discussed and referenced below.

**Gluten-forming proteins:** Gluten-forming proteins (gliadin and glutenin) can be separated into numerous fractions, which are closely related, but none the less distinct and different protein aggregates (Pylar, 1988:115). The identification and classification of these fractions is an ongoing field of study.



Gliadins that comprises 40–50% of the total wheat proteins refers to a mixture of about 50 different single-chained polypeptides which can be classified into  $\alpha$ -;  $\beta$ -;  $\gamma$ - and  $\omega$ -fractions (Feillet, 1988:102, Pylar, 1988:115, Wrigley & Bietz, 1988:165). The  $\alpha$ -;  $\beta$ - and  $\gamma$ -gliadins are very similar in overall amino acid composition (rich in sulphur-containing amino acids) and have molecular weights ranging from 32 000–42 000. The  $\omega$ -fractions differ considerably in overall amino acids composition (poor in sulphur containing amino acids) and have molecular weight ranging from 44 000–74 000. The polypeptide chains of these relatively small, monomeric proteins tend to have compact globular configurations, which are held together mainly by relatively weak hydrophobic and hydrophilic bonds (Feillet, 1988:102, Pylar, 1988:115, Wrigley & Bietz, 1988:165). Their surface area, however, can be greatly increased when tension is applied and will not recoil to regain their original configurations to the same extent as glutenins when the tension is removed (Pylar, 1988:116). This explains why gliadins, upon hydration and mixing, produce a cohesive syrupy mass that is highly extensible. Gliadins have a softening effect on gluten and reduce the cooking performance of pasta by increasing starch leaching (pasting) and decreasing pasta firmness (Feillet, 1984:556, Feillet, 1988:101,103, Wrigley & Bietz, 1988:168, Walsh & Gilles, 1971:553, Matsuo *et al*, 1972:710, Rao *et al*, 2001:217, Shewry, 2003:2)

Glutenins refer to relatively large, multi-chained low molecular weight (LMW) Glu I and high molecular weight (HMW) Glu II fractions, which consist of a heterogeneous mixture of at least 15 different polypeptide sub-units (Feillet, 1988:102, Pylar, 1988:120, Wrigley & Bietz, 1988:165). These sub-units can be classified into two main groups: HMW sub-units that refer to a small group of four to six sub-units with molecular weight ranging from 95 000–136 000 and the more numerous LMW sub-units with molecular weight ranging from 36 000–44 000 (Feillet, 1988:102, Pylar, 1988:120, Wrigley & Bietz, 1988:165). Thus, depending on the number and type of sub-units, glutenins are very polydisperse in size with molecular weight ranging from as low as 50 000 to as high as 15 million. The acetic acid soluble Glu I fractions with molecular weights ranging from 36 000–44 000 comprise 10–20% of the total wheat proteins and consist mainly of LMW sub-units, which are joined together by non-covalent forces. The acetic-acid insoluble Glu II fractions with molecular weight of more than 100 000 comprise 17–35% of the total wheat proteins and consists mainly of HMW sub-units, which are joined head-to-tail by strong covalent disulphide bonds. The polypeptide chains of these large, polymeric proteins have less compact, more random configurations, which provide ample opportunity for molecular associations. These structures can be stretched out of its native state upon application of tension, but will recoil to regain its original configurations when tension is removed (Feillet, 1988:102, Pylar, 1988:120, Wrigley & Bietz, 1988:165, Shewry, 2003:2). It is therefore not surprising that glutenins, upon hydration and mixing, form a strong, rubbery mass, which is highly elastic (resistant to extension) in nature. Glutenins have a strengthening effect on gluten and improve the cooking performance of pasta. During the cooking of pasta, glutenins coagulate and become firm and rubbery. This

retards the penetration of water into pasta, thereby preventing excessive starch gelatinisation and pasta surface disintegration; all of which decrease starch leaching (causing stickiness) and increase pasta firmness (Walsh & Gilles, 1971:553, Matsuo *et al*, 1972:710, Kasarda, Bernardin & Nimmo, 1976:165, Huebner, 1977:30, Khan & Bushuk 1978:14, Wall & Huebner, 1981:117, Feillet, 1984:553, 556, Feillet, 1988:95,101,103,105, Wrigley & Bietz, 1988:168, Pomeranz, 1988:331, Pylar, 1988:111,116, Schofield, 1988:200, Milatovic & Mondelli, 1991:55, Dawe, 2001:86, Rao *et al*, 2001:217, Shewry, 2003:2).

Hydration and kneading of milled wheat result in the uncoiling and rearrangement of gliadins and glutenins from separate configurations to stretched out polypeptide chains linked together by sulphhydryl-disulphide interchange and association of secondary bonds (hydrogen, ionic and hydrophobic) into a continuous network of thin gluten films which surround the starch granules and other cell particles, hereby forming a dough with unique viscoelastic properties (Wall & Huebner, 1981:120, Feillet, 1984:553, Feillet, 1988:95).

Despite the fact that no clear difference between durum wheat and common wheat can be found in the total amounts of gliadin and glutenin proteins, gluten from durum wheat tends to be more elastic and less extensible than gluten obtained from bread wheat. Durum wheat proteins are more hydrophobic than other wheat species and yield a strong instead of extensible dough, making it very suitable for pasta manufacturing (Feillet, 1988:105). The superior pasta-making potential of durum wheat, therefore, appears to be a function of the ratio in which the various gliadins ( $\alpha$ -,  $\beta$ -,  $\gamma$ - and  $\omega$ -fractions) and glutenins (Glu I and Glu II) occur in the milled wheat. It is known that the glutenins in hard wheat have a higher molecular weight than softer wheats. It is also known that these HMW units are responsible for the increased dough strength (Pylar, 1988:116, Dick & Matsuo, 1988:530). The gluten of a strong dough consists of larger, more compact protein aggregates that are more resistant to stretching, whereas the gluten of a weak dough, contains smaller, less compact protein aggregates which stretch easily (Pylar, 1988:116, Bloksma & Bushuk, 1988:157, Milatovic & Mondelli, 1991:28).



When selecting durum cultivars, a high glutenin to gliadin ratio and a high percentage of insoluble protein is preferred as it is linked to good cooked pasta quality. Cultivars of durum wheat containing  $\gamma$ -45 gliadin and  $\gamma$ -42 gliadin have also been linked to pasta quality. These are used as genetic markers as it bond with specific LMW glutenin sub-units, through this mechanism they influence pasta quality. Gliadin band  $\gamma$ -45 has been linked with strong dough properties whereas gliadin band  $\gamma$ -42 was linked to intermediate dough strength (Dick & Matsuo, 1988:120, Feillet & Dexter, 1998:120).

Durum wheat is therefore preferred to bread wheat since it generally has a higher protein content and has a better protein quality in that the protein sub-units compete more effectively with starch gelatinisation. This is due to the specific amino acid composition of durum wheat proteins, which renders the gluten more hydrophobic than that of other wheat species. The starch granules are also better encapsulated by the protein framework (Sgrulletta & De Stefanis, 1989:219). Under traditional pasta manufacturing practises, the protein content and the quality of the proteins are of equal importance in relation to the cooking performance of pasta (D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990:275,280, Novaro, D'Egidio, Mariani & Nardi, 1993:719, Feillet, Abecassis, Autran & Laignelet, 1996:206, Marconi *et al*, 2002:638).

**Non-gluten-forming proteins.** Although present in very small quantities in native wheat, it has been indicated that the addition of albumins and globulins influence the cooking performance of pasta (Matsuo *et al*, 1972:711). Albumins increase firmness and decrease starch leaching. It was found that albumin is more functional in improving pasta quality than gliadin. For this reason the addition of egg to flour milled from non-durum wheat is a common pasta-manufacturing practise. Globulins decrease firmness and increase starch leaching (Walsh & Gilles, 1971:550, 553, Matsuo *et al*, 1972:710, Feillet, 1988:103, Milatovic & Mondelli, 1991:60).

### 3.2.3 Starch

Starch granules comprise 60–70% of wheat endosperm (semolina or flour) (Biliaderis, 1991:61). Starch is the major storage carbohydrate of all higher plants and these granules are mainly composed of  $\alpha$ -D-glucose polymers. The granules contain small amounts of non-carbohydrate components, particularly lipids, proteins and phosphorus (Biliaderis, 1991:61). The functionality of starch can be ascribed to the two major high molecular weight carbohydrate components, namely amylose and amylopectin, as well as to the physical organisation of these macromolecules into the granular structure (Biliaderis, 1991:61). Starch molecular composition, starch gelatinisation behaviour, starch granule size and starch damage affect pasta quality.

#### 3.2.3.1 Molecular composition

Wheat starch consists of approximately 25% linear amylose and approximately 75% branched amylopectin (Feillet, 1984:558, Thomas & Atwell, 1999:6). Amylose is known for ability to form a gel after the starch granule has been cooked and amylopectin are considered non-gelling and have a typically cohesive and gummy texture (Thomas & Atwell, 1999:6). Other carbohydrate compounds are sucrose (0,2%), glucose (0,1%), fructose (0,6%), and dextrans (0,2%) (Antognelli, 1980:128). In wheat a protein framework holds this entire starch structure together.

Starch contributes to the quality of Japanese white noodles (Oda, Yasuda, Okazaki, Yamauchi & Yokoyama, 1980:254). Starch with low amylose content produces softer noodles, which is preferable in noodles, but not in pasta (Oda *et al*, 1980:254, Konik, Miskelly & Gras, 1992:404, Batey, Curtin & Moore, 1997:499). It has been shown that waxy starches (high amylopectin) from various sources (maize, wheat and barley) produced pasta of extremely poor quality. Amylopectin causes pasta to be less firm and more sticky, but with reduced cooking losses (Gianibelli, Sissons, Morell & Batey, 2000b:631, Grant, Dick & Shelton, 1993:676). High amylose starch improves the overall quality of pasta reflected by higher firmness and lower stickiness. However, amylose increases cooking losses (Dexter & Matsuo, 1979:194, Grant *et al*, 1993:676, Gianibelli *et al*, 2000b:631,632).

When comparing durum wheat to other wheat species it appears to have a marginally higher proportion of amylose; approximately 27% as apposed to approximately 25% for non-durum species (Medcalf & Gilles, 1965:558, D'Appolonia, Gilles, Osman & Pomeranz, 1971:277, Lii & Lineback, 1977:138, Feillet, 1984:558, Lintas, 1988:123).

### **3.2.3.2 Granule size**

The size of starch granules ranges between 1–100  $\mu\text{m}$  and is dependent on the wheat species, type and cultivar (Biliaderis, 1991:61). Smaller starch granules are beneficial to pasta quality. Smaller starch granules have a larger surface to volume ratio than the larger granules and hence have more interaction surface per unit weight than the larger granules. Smaller granules are more easily encapsulated in the gluten matrix (physical inclusion) during processing (Vansteelandt & Delcour, 1998:2500). Ghiasi, Hosney and Varriano-Marston (1982:258) noted that starch granule size influence the gelatinisation temperature. Smaller granules have a 3°C higher gelatinisation temperature than larger starch granules and are preferred in pasta manufacturing (Ghiasi *et al*, 1982:258).

Durum wheat has smaller starch granules than non-durum wheat. Therefore, durum wheat has a higher gelatinisation temperature, rendering it more resistant to breakdown during manufacturing and cooking of the final pasta product (Resmini & Pagani, 1983:2).

### **3.2.3.3 Gelatinisation, pasting and retrogradation**

Raw, dry starch granules (<55°C) have a rigid semi-crystalline structure (Dawe, 2001:87). When heated in excess water, starch granules loses this rigid structure as the starch granules absorb water and swell (gelatinise) until they rupture and release the content thereof into the water, a process referred to as pasting (Thomas & Atwell, 1999:26, Dawe, 2001:87). Gelatinisation and

pasting affects pasta quality. Starch requires a temperature of over 50°C and a moisture content of at least 40% for gelatinisation to occur (Marchesani, 2003:15). No gelatinisation takes place when the moisture content is below 30% (Ghiasi *et al*, 1982:258). This implies that pasta should undergo limited starch gelatinisation during manufacturing since the dough moisture is approximately 30%.

The gelatinisation behaviour of durum and non-durum wheat starches differs. The final degree of gelatinisation and rate of gelatinisation in non-durum starch is higher than that of durum. It leaches more amylose and has a slightly lower pasting temperature than durum wheat (Gianibelli, Bangur, Lafiandra, Molfese, Seghezzi, Morell & Batey, 2000a:655, Vansteelandt, 2000, Turhan & Gunasekaran, 2002:6, Sung & Stone, 2003:65). Other than the fact that durum wheat has a higher proportion amylose to amylopectin and smaller starch granules, durum wheat starch granules are covered with a more extensive protein layer, which is not the case in non-durum wheat starch (Turhan & Gunasekaran, 2002:6). The endosperm cells are also more closely packed in durum wheat (Turhan & Gunasekaran, 2002:6).

The gelatinisation temperature of durum and non-durum wheat starch is in the same region, between 50 and 70°C (Gianibelli *et al*, 2000a:656, Thomas & Atwell, 1999:27). Durum wheat starch has a higher water binding capacity than non-durum wheat starch according to Feillet (1984:558). However, Sung and Stone (2003:65) reported no significant differences between the water absorption capacities of starches from the different wheat sources. Differences in water absorption between the flours derived from different wheat sources were ascribed to differences in the protein matrix surrounding the starch granules by the latter authors. It was also indicated that soft wheat starch, when compared to hard wheat and durum starch, swell more rapidly at high temperatures. This may, in part, explain the higher cooking losses observed with soft wheat types. They argued that the protein network formation is more effective in preventing cooking losses than the differences in starch characteristics. The character of starch is considered negligible on pasta quality (Sung & Stone, 2003:65).

Retrogradation is another process that may affect pasta quality. When gelatinised starch is cooled, the solubilised starch polymers and the remaining insoluble granular fragments have a tendency to reassociate, which is referred to as retrogradation (Thomas & Atwell, 1999:26). Retrogradation is especially evident when amylose-containing starches are cooled. It results in the formation of crystalline aggregates and a gelled texture. It is speculated that these changes in the packing arrangement of starch molecules are likely to contribute to pasta quality by reducing cooking losses and increasing firmness of pasta (Yue, Rayas-Duarte & Elias, 1999:543, Pagani, Gallant, Bouchet & Resmini, 1986:126).

### 3.2.4 Lipids

The lipid content of wheat is below 3%, with the bran being richer in lipids than the endosperm (Youngs, 1988:139). Durum wheat has a slightly higher lipid content than other wheat species, also containing a higher proportion of non-polar lipids than other wheat species (Youngs, 1988:139, Milatovic & Mondelli, 1991:26,28). The lipid content of wheat endosperm is usually below 1%. The lipid content plays a negligible role in cooked pasta quality (Youngs, 1988:139). Lipids and surfactants are sometimes added to pasta to improve cooking texture, to prevent dough strands from adhering to one another and to prevent over-drying of the surface (Niihara, Yonezawa & Matsuo, 1998:280).

Free or non-polar lipids improve pasta quality, with monoglycerides having the larger effect, whereas polar lipids have little effect on pasta quality (Matsuo, Dexter, Boudreau & Daun, 1986:484,486). Triglycerides (45%), free fatty acids (25%), and diglycerides (20%) are the predominant components of non-polar wheat semolina lipids, whereas monoglycerides constitute only 5% of the total non-polar lipids (Matsuo *et al*, 1986:486). Neither commercial coconut oil nor commercial sunflower oil (triglycerides) has any effect on spaghetti stickiness, while the addition of 0,5% monoglycerides to semolina significantly decreased the surface stickiness of cooked spaghetti and improved the resistance to over-cooking (Matsuo *et al*, 1986:484). However, Grant *et al* (1993:676) pointed out that the addition of monoglycerides only decreases pasta stickiness under high-temperature processing conditions.

Of the solids lost from pasta during cooking, the highest contribution comes from amylose (Matsuo *et al*, 1986:487, Sung & Stone, 2003:61). The leached solids on the surface of pasta make the cooked pasta sticky. Amylose forms a water-insoluble complex with certain types of lipids, in particular monoglycerides. This complex reduces the solubility of amylose, which results in amylose remaining in the starch granule, which, in turn, inhibits swelling and gelatinisation. The net result is decreased surface stickiness and cooking loss, increased firmness and resistance to over-cooking. This can be explained by reduced free amylose bound by lipids, rendering it insoluble (Matsuo *et al*, 1986:487, Sung & Stone, 2003:61). In contrast to this theory, Sung and Stone (2003:68) have found that when monoglycerides are added to pasta, which contains only starch (no non-starch constituents e.g. protein), the cooking losses and stickiness increased dramatically, indicating that the beneficial effect cannot be explained by starch-lipid interactions, but rather by protein-lipid interactions.

### 3.2.5 Enzymes

Lipoxygenases, peroxidases and polyphenoloxidases (oxidative enzymes), amylases (amylolytic enzymes) and lipases, present in semolina, are of importance during pasta manufacturing. Semolina with no enzymatic activity would be ideal for pasta manufacturing (Antognelli, 1980:130). On the other hand, proteases increase gluten-formation capacity and improve the final product quality by decreasing stickiness. The addition of water to semolina allows various enzymatic changes to occur, mainly oxidative and amylolytic phenomena (Feillet, 1984:561).

Oxidative enzymes (lipoxygenases, peroxidases and polyphenoloxidases) require the presence of oxygen to exert their action on the semolina constituents (Dalbon *et al*, 1998:25). The mechanism of the action is not yet fully understood (Dalbon *et al*, 1998:25). Spaghetti colour is affected not only by the level of xanthophylls in the semolina, but also by the amount of lipoxygenases and by processing conditions. Lipoxygenase activity plays an important role in determining pasta colour by oxidising carotenoid pigments, thereby decreasing the yellowness of the pasta (Irvine, 1965:330, Dalbon *et al*, 1998:25, Marchesani & Soncini, 2002:21). This enzyme is active at temperatures between 61 and 90°C and is inactivated by temperatures exceeding 90°C (Pollini, 1998:70). The reaction can therefore be inhibited by processing under vacuum (anaerobe) and high temperatures (>90°C) or by adding anti-oxidants such as L-ascorbic acid (Joppa & Williams, 1998:64, Johnston, 2001:161). This enzyme could also be very effective to maintain gluten at a non-oxidised state, which has a negative effect on cooked quality (Feillet, 1984:561). Peroxidases and polyphenoloxidases have been identified as major role players in determining pasta colour and seem to give a brownish colour to pasta products (Dalbon *et al*, 1998:25, Feillet, 1984:561). These enzymatic systems oxidise mono- and polyphenols. It causes darkening of vegetable products (Marchesani & Soncini, 2002:22). Temperatures above 70°C inactivate peroxidases and polyphenoloxidase enzymes, preventing the darkening (browning) of pasta (Milatovic & Mondelli, 1991:94).

The action of amylolytic enzymes (especially  $\alpha$ -amylase) increases starch damage and is especially pronounced where wheat has germinated or when wheat is milled incorrectly (Dick & Matsuo, 1988:531, Dalbon *et al*, 1998:25, Feillet, 1984:561, Turnbull, 2001b:192). During germination  $\alpha$ -amylase is released from the germ into the endosperm to break down starch to sugars for easy assimilation for growth (Turnbull, 2001b:192).

The enzyme  $\alpha$ -amylase splits the  $\alpha$ -1,4 glycosidic bonds of the starch molecules to yield sugars and reduces the cooked quality of the product (Kruger & Matsuo, 1982:27, Matsuo, Dexter & MacGregor, 1982:468, Dick & Matsuo, 1988:529, Turnbull, 2001b:192). Very high levels of sugars cause extrusion problems as the dough becomes very soft (Turnbull, 2001b:192). When



manufacturing long pasta it will break and fall off the drying rods (Dick & Matsuo, 1988:531). The enzyme  $\alpha$ -amylase is active between temperatures ranging from 61–80°C (Pollini, 1998:70).

Starch is mechanically damaged during milling and during the first steps of processing. This provides a suitable substrate for amylolytic enzymes during the drying period and damaged starch is transformed to maltose by these enzymes (Turnbull, 2001b:192). This is followed by a conversion of maltose into glucose. Especially during the initial stages of spaghetti drying, the humidity and temperature conditions are ideal for enzymatic activity and, as a result, the amylolytic enzymes are probably responsible for the observed increase in solubilised starch and damaged starch (Lintas & D'Appolonia, 1973:567). This results in reduced mechanical strength of dried pasta and a final product with increased cooking losses, being less firm more sticky (Lintas & D'Appolonia, 1973:566, Matsuo & Dexter, 1980:117, Kruger & Matsuo, 1982:26, Matsuo *et al*, 1982:468, Dick & Matsuo, 1988:529, Grant *et al*, 1993:684).

Falling Number is a measurement of  $\alpha$ -amylase activity of wheat and the test indirectly measures starch hydrolysis by  $\alpha$ -amylase. The Falling Number measures the time it takes for a probe to fall through a semolina/flour–water slurry (Turnbull, 2001b:192). Hydrolysed starch is not as viscose as intact starch, reducing the time for the probe to completely fall through the slurry. If the Falling Number is below 250 seconds, problems during pasta production is experienced (Dick & Matsuo, 1988:531, Turnbull, 2001b:192). A Falling Number below 400 seconds is an indication that some amylose damage, ascribed to the action of  $\alpha$ -amylase, has occurred (Dick & Matsuo, 1988:531).

**Comment [IT1]:** This does not make sense. Perhaps a better explanation of the number values will clarify this.

Enzymes can also be added to pasta to improve the cooked quality, especially that of non-durum pasta. Treatment with lipase results in an increased formation of amylose-lipid complexes. These complexes inhibit the swelling of the starch granules, especially in the outer layer of the noodle or spaghetti strands, resulting in a firmer texture and smoother surface (Lustenberger & Qi Si, 2000). Another potential mode of action may be interactions of lipase with gluten, whereby strengthening of the gluten takes place. The addition of fungal lipase reduced spots on noodles. Lipase improves the brightness of the cooked product, reduces stickiness and improves firmness and resistance to over-cooking (Lustenberger & Qi Si, 2000).

It is known that durum wheat in its mature state tends to have a slightly higher  $\alpha$ -amylase activity than non-durum wheat and, as a result, has a somewhat higher content of various sugars. Durum wheat has a lower lipoxidase activity, which will influence the yellowness favourably (Buhler Laboratories, 1998).



### 3.2.6 Yellow pigment

Consumers prefer a golden, bright yellow colour in pasta (Abecassis, Abbou, Chaurand, Morel & Vernoux, 1994:251, Feillet & Dexter, 1998:112,115). The manufacturing process has little or no effect on the colour of the finished product. The colour of pasta is largely due to the colour of the wheat used. The colour of wheat is a genetic variable, with only a few genes with several alleles that control this character (Atwell, 2001:119). The desired colour of semolina is a clear bright yellow colour, imparted mainly by xanthophylls, a carotenoid pigment (Joppa & Williams, 1998:64). It is therefore understandable that the colour has become a selection criterion in cultivation programs worldwide (Abecassis *et al*, 1994:251, Joppa & Williams, 1998:64, Sissons & Hare, 2002:81). To optimise the colour of pasta products, wheat species or cultivars with a high carotenoid pigment content, a low polyphenol oxidase activity, and a low lipoxygenase activity, are preferred (Dexter, Matsuo & Morgan, 1981:1742, Dick & Matsuo, 1988:537, Feillet & Dexter, 1998:112,115). Spaghetti colour is also affected, to a lesser degree, by the amount of lipoxygenases and by processing conditions. Durum wheat is well known for its extremely high carotenoid pigments when compared to non-durum species, thereby rendering it more suitable for pasta manufacturing (Banasik, 1981:167, Wiseman, 2001:18, Marconi *et al*, 2002:636).

The apparent colour of semolina is a function of a number of physical characteristics such as particle size, particle shape and bran content, which influence dry colour more significantly than the  $\beta$ -carotene level (Feillet & Dexter, 1998:108, Turnbull, 2001b:189). Spectrophotometric techniques, expressing the colour of semolina used to manufacture pasta, do exist and are used widely. Colour is expressed in terms of "L" (brightness), "a" (red or brown) and "b" (yellow) values. The "a" value shows good correlation with bran contamination, whereas the "L" and "b" reflect how bright and yellow the final cooked pasta will be (Turnbull, 2001b:189).

### 3.3 RAW MATERIAL SELECTION AND MILLING

The functionality of durum semolina as reflected in moisture content, ash content, and particle size distribution, are affected by milling techniques and should be carefully monitored by the manufacturer or the miller.

#### 3.3.1 Raw material quality

Wheat kernels that are improperly cleaned and damaged by smudge, mildew or black point, can cause black spots in the final pasta product (Feillet & Dexter, 1998:106, Turnbull, 2001a:44, Turnbull, 2001b:190). The number of spots in the milled product should be less than 10 per 100

cm<sup>2</sup> (Turnbull, 2001b:190). When present in pasta it is very noticeable and undesirable (Dalbon *et al*, 1998:15, Turnbull, 2001a:44, Turnbull, 2001b:190).

### 3.3.2 Milled endosperm granulation (particle size distribution)

There is no general consensus regarding ideal particle size (granulation) for optimum pasta quality. When durum semolina is blended with cheaper bread wheat, particle size can be used to detect such adulteration (Turnbull, 2001a:44, Dawe, 2001:91). The coarser particle size of semolina requires less water to form dough, thereby shortening the drying process (Irvine, 1971:779). However, machine manufacturers strive to reduce mixing times, favouring the use of smaller particles that hydrate faster (Milatovic & Mondelli, 1991:75, Dalbon *et al*, 1998:17, Dawe, 2001:91, Turnbull, 2001b:191).

Course particles, over 500 µm, do not absorb water adequately during the kneading stage and may cause white spots in dried pasta. On the other hand, excess fineness (150 µm) may lead to thermal stresses during processing, which may cause protein to denature prematurely (Antognelli, 1980:128). However, smaller particles render more proteins on the surface of the granule, leading to better hydration and better gluten and dough formation (Milatovic & Mondelli, 1991:460).

With a reduction in particle size the solids leaching from pasta during cooking and stickiness increase as a result of increased starch granule damage (Dexter *et al*, 1983:1548, Evers & Stevens, 1985:330). The enzyme  $\alpha$ -amylase degrades damaged starch granules more readily than less damaged granules and larger particles (Dexter *et al*, 1981:1741, Evers & Stevens, 1985:330).

There is currently agreement that raw material particle size between 150–350 µm is preferred to ensure shorter mixing times and reduced white spots (Antognelli, 1980:128, Milatovic & Mondelli, 1991:75, Dalbon *et al*, 1998:17, Turnbull, 2001a:57, Turnbull, 2001b:191). More importantly, particle size distribution should be homogeneous (Banasik, 1981:167, Dalbon *et al*, 1998:18, Turnbull, 2001a:44, Turnbull, 2001b:191, Dawe, 2001:91, Pasta, 2003:30). In the case where granulation is uneven, the smaller particles will absorb the available water more rapidly than coarser particles (Dawe, 2001:91, Banasik, 1981:167), resulting in white spots. To prevent this, the mixing time must be increased or the kneading action intensified (Banasik, 1981:167, Dawe, 2001:91). Intensified kneading can result in heat generation and protein denaturing prior to drying. Instead of forming an extensive protein network, proteins agglomerate and, as a result, reduce cooked quality (Banasik, 1981:167, Dawe, 2001:91).

Uneven raw material granulation has been implicated in other defects, such as increased cooking losses, stickiness and decreased firmness (Matsuo & Dexter, 1980:117, Banasik, 1981:167, Dexter *et al*, 1983:1545, Dalbon *et al*, 1998:18, Dawe, 2001:91, Turnbull, 2001b:191). A world-renowned equipment supplier for the milling and pasta manufacturing industry, Buhler (Pty) Ltd (Uzwil, Switzerland) recommends a particle size distribution as illustrated in Table 3.2.

**TABLE 3.2 INDICATION OF PARTICLE SIZE DISTRIBUTION FOR PASTA MANUFACTURING**

Particle size	Particle distribution
>400 $\mu\text{m}$	0%
$\leq 400 \mu\text{m}; >315 \mu\text{m}$	1–3%
$\leq 315 \mu\text{m}; >200 \mu\text{m}$	40–60%
$\leq 200 \mu\text{m}; >125 \mu\text{m}$	20–40%
$\leq 125 \mu\text{m}$	<30%

### 3.3.3 Extraction rate (ash content)

The objective of milling wheat is to separate the endosperm from the bran layers with minimal contamination of the endosperm. The effectiveness of this process is referred to as the extraction rate. The ash content of milled wheat is a measure of how well this process was performed (Feillet & Dexter, 1998:106). The mineral content in the bran layer is very high compared to the endosperm. Therefore, the ash content can be used to quantify the contamination rate of milled wheat. Ash content is a measure of the inorganic material remaining when all the organic material has been removed by combustion at very high temperature (Turnbull, 2001b:184).

Semolina or flour with the lowest ash content is that from the core of the grain (endosperm), where the ash content could be as low as 0,6%. Endosperm nearer to the mineral rich aleurone layer (bran layer) could have an ash content of as high as 1,5% (Turnbull, 2001a:44, Turnbull, 2001b:184). Semolina of too high a milling extraction has a higher ash content and a high amount of bran specks (Dick & Matsuo, 1988:538). These specks are brown in colour and visible in dried pasta (Feillet & Dexter, 1998:106), although not as visible as black spots caused by unclean wheat (Turnbull, 2001a:44, Turnbull, 2001b:190). The high number of brown spots obscures the yellow colour of pasta and the result is greater dullness, both in the dry and cooked form. Unlike black spots, brown spots are usually numerous and cannot be counted (Dexter & Matsuo, 1978:841, Dexter *et al*, 1981:1742, Feillet & Dexter, 1998:106, Turnbull, 2001a:44, Turnbull, 2001b:190).

To yield translucent durum pasta with a yellow colour, the ash content should be below 1% (dry basis). If it is above 1% the colour may be darker (Antognelli, 1980:130, Milatovic & Mondelli, 1991:2, Turnbull, 2001b:181).

### 3.3.4 Moisture

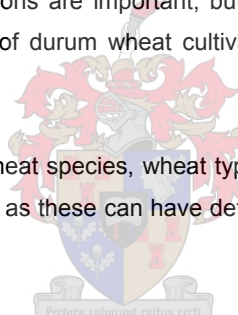
During the milling process the dry wheat is rehydrated before milling and the moisture is reduced later during the process. Milled wheat moisture should be in the region of 12–14% (Turnbull, 2001b:186). The moisture content is important from a safety point of view and should be constant to prevent continuous water adjustments during pasta manufacturing. Semolina with varying moisture contents will lead to dough inconsistency and therefore inconsistent pasta quality (Dalbon *et al.*, 1998:18).

### 3.4 CONCLUSIONS

The raw materials used in pasta are limited to wheat flour or semolina and water. Nevertheless, the constituents of these ingredients and the interactions occurring between and within these constituents are important in pasta quality. It is clear that the quality, content and bonds of wheat protein are very important in pasta quality.

In the traditional manufacturing process (as described in Chapter 2) the protein content and the protein quality are both of major importance to ensure consistent product quality. The nature of the starches may be important, but are over-shadowed by the importance of protein. Native lipids do not play a role in pasta quality. Enzymatic reactions are important, but controllable by external factors such as temperature. The yellow colour of durum wheat cultivars remains important in traditionally prepared pasta.

It remains crucial that the other factors, namely wheat species, wheat type, wheat cultivar, milling characteristics and ash content, not be underestimated as these can have detrimental effects on pasta quality.



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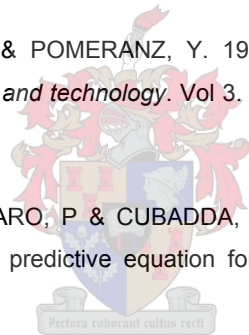
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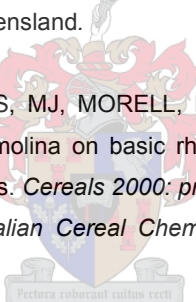
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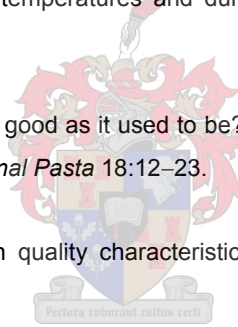
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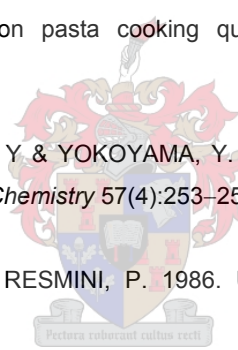
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## CHAPTER 4: USING BREAD FLOUR FOR PASTA MANUFACTURING: HIGH-TEMPERATURE DRYING TECHNOLOGY

### 4.1 INTRODUCTION

Traditionally pasta was strictly produced from durum wheat semolina and pasta manufactured from bread wheat was inferior (Dalbon, Grivon & Pagani, 1998:17. Fortunately for countries that do not grow durum wheat, innovations in pasta-drying technology have made it possible to produce satisfactory pasta from softer bread wheat (*Triticum aestivum*). Not only has these innovations in pasta drying technology improved pasta quality, but the drying time has been reduced, implying higher plant through-put, therefore making the process of pasta manufacture more economical.

### 4.2 NEW TECHNOLOGIES

Traditionally, pasta drying was performed at temperatures below 60°C, referred to as low temperature (LT) drying, and required long drying periods (Table 4.1). During the 1970s the major equipment manufacturers began designing tunnels that made it possible to use shorter drying times by increasing drying temperatures, and thus referred to as high-temperature (HT) and very high-temperature (VHT) drying emerged which is seen as one of the most significant improvements in pasta processing (Pollini, 1998:59). Temperatures vary between 60 and 100°C (Pollini, 1998:66, Pasta, 2004:43).

**TABLE 4.1 DRYING TECHNIQUES USED IN THE PREPARATION OF PASTA**

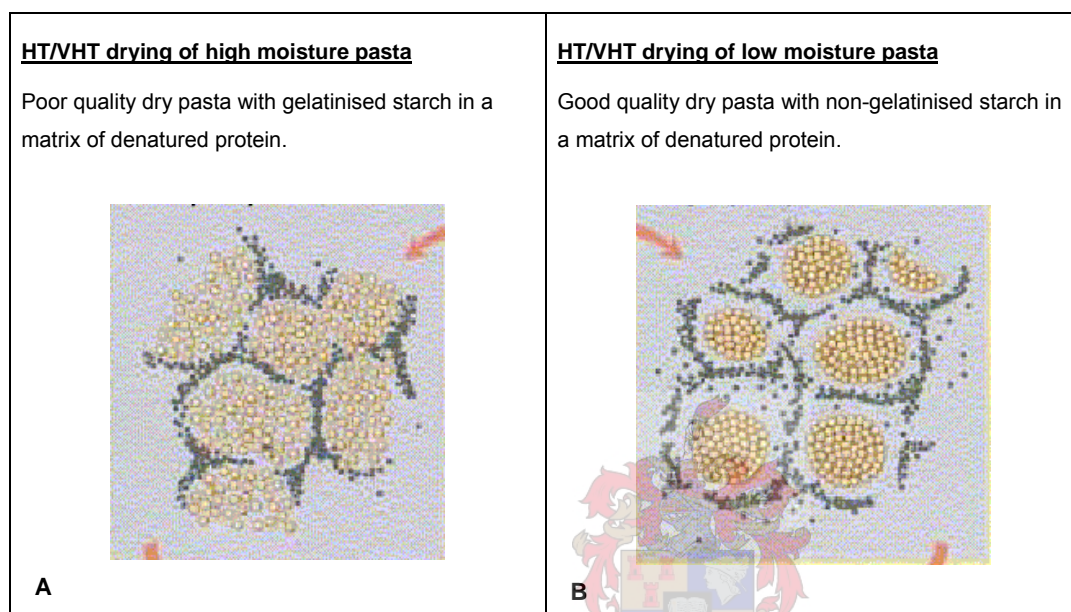
Drying temperature	Temperature range (°C) across the whole drying process	Relative humidity (%)	Drying time (hours)
Low-temperature (LT)	40–60	70–80	18–28
High-temperature (HT)	60–84	74–82	8–11
Very high-temperature (VHT)	>84	74–90	2–5

Other than slowing down the production process, LT drying increases the risk of microbiological proliferation as pasta remains at high moisture levels for extended periods of time (Marconi & Carcea, 2001:525, Pasta, 2004:43). Of importance is the modifications brought about in the protein-starch structures when increased temperatures are used (Marconi & Carcea, 2001:525, Pasta, 2004:43). HT application leads to protein denaturing without starch gelatinisation prior to the cooking process. This has brought about the potential for producing pasta from less expensive bread wheat (Abecassis, Abbou, Chaurand, Morel & Vernoux, 1994:247, Marconi & Carcea, 2001:525, Pasta, 2004:43). Today, HT and VHT drying are applied in most pasta factories and are

divided into certain approaches (see Section 4.2.1) of temperature application (Feillet, Abecassis, Autran & Laignelet, 1996:206).

#### 4.2.1 Approaches to HT and VHT drying

The water activity of pasta when applying HT (or VHT) is very important (Dexter, Matsuo & Morgan, 1981:1741, Boroni, 1988:191, Feillet, 1988:93). There are two approaches, the application of HT (or VHT) during pre-drying (pasta with high moisture content), or during the later stage of drying (pasta with a low-moisture content) (Milatovic & Mondelli, 1991:76, Zweifel, Conde-Petit & Escher, 2000:645).



**FIGURE 4.1 PROTEIN-STARCH STRUCTURE OF PASTA DRIED WITH HT/VHT APPLIED TO HIGH MOISTURE PASTA VERSUS LOW MOISTURE PASTA – PICTORIAL PRESENTATION (PASTA, 2004:43)**

The application of HT (or VHT) during pre-drying risks simultaneous starch gelatinisation and protein denaturing (Pollini, 1998:68). This will disrupt the formation of a continuous denatured protein network (Figure 4.1A). Starch gelatinisation during manufacturing is brought about when too much water (>30%) is available at temperatures above 50°C (Dexter *et al*, 1981:1746). The second approach utilises pre-drying temperatures similar to those used in LT drying (<60°C), followed by final drying at HT (Pollini, 1998:67). The latter approach is more effective in improving the cooked quality of pasta, as no starch gelatinisation occurs (Figure 4.1 B) (Abecassis, Faure & Feillet, 1989:480, Resmini & Pagani, 1983:1, De Stefanus & Sgrulletta, 1990:97, Dexter *et al*, 1981:1741). This drying technique reduces cooking losses, cooked weight and stickiness

(Abecassis *et al*, 1989:480). The improvement of pasta quality when applying HT on low moisture pasta is especially pronounced when manufacturing pasta from poor quality raw material (Abecassis *et al*, 1989:480). Figure 4.1A illustrates an amorphous, gelatinised starch structure and Figure 4.1B illustrates a crystalline, non-gelatinised starch structure.

### 4.3 IMPACT OF NEW TECHNOLOGY ON PASTA QUALITY

The quality of pasta dried at HT is superior to that dried at LT (Pollini, 1998:69, Johnston, 2001:161) and the best quality is obtained when using VHT drying technology (Guler, Koksel & Ng, 2002:427). Dry pasta colour and mechanical strength is improved. Cooked pasta quality is improved by a reduction of cooking loss, rinse loss, cooked weight and an increase in firmness and cooking time. This technology enabled manufacturers to produce good quality pasta from inferior wheat cultivars and non-durum species, which lack gluten strength (Dexter *et al*, 1981:1745, Wyland & D'Appolonia, 1982:200, Dexter, Kilborn, Morgan & Matsuo, 1983:141, Dexter, Matsuo & Morgan, 1983:1545, Resmini & Pagani, 1983:1, Pagani, Gallant, Bouchet & Resmini, 1986:118, Duzkiewicz-Reinhard, Khan, Dick & Holm, 1988:281, Abecassis *et al*, 1989:480, Milatovic & Mondelli, 1991:71, Grant, Dick & Shelton, 1993:684, Malcolmson, Matsuo & Balshaw, 1993:420, Marconi, Carcea, Graziano & Cubadda, 1999:25, Marconi, Graziano & Cubadda, 2000:138, Zweifel *et al*, 2000:650, Guler *et al*, 2002:427, Sissons & Hare, 2002:83, Zweifel, Handschin, Escher & Conde-Petit, 2003:159).

When HT technology is applied to raw materials of good versus poor quality, the positive effects of this technology are much more pronounced when using poor (low protein content of inferior protein quality) raw materials (Dexter *et al*, 1981:1745, Abecassis *et al*, 1989:480, Wyland & D'Appolonia, 1982:200, Malcolmson *et al*, 1993:420, Sissons & Hare, 2002:83). It is reported that the quality of non-durum pasta may indeed approach that of durum pasta provided that the protein content is sufficient (Milatovic & Mondelli, 1991:5). Other studies confirmed that when HT or VHT drying technology is used, good quality pasta could be produced from bread flour or poor quality durum semolina if the protein content is above 11% (db) (Wyland & D'Appolonia, 1982:200, D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990:279, Malcolmson *et al*, 1993:417, Marconi *et al*, 2002:638). The effect of increased drying temperatures on pasta quality is explained by the effect that increased temperatures have on protein, protein-starch interactions, starch, enzymes and microbes.

#### 4.3.1 Effect of HT and VHT on protein and protein-starch interactions

When cooking pasta, starch pasting is highly unwanted as this will result in a sticky product with a high cooking loss. To prevent this pasting, starch gelatinisation must be restricted. The only way



to achieve this is to ensure that a denatured protein framework is formed around the starch granules before excessive gelatinisation occurs (see Figure 4.2). However, when a protein network is extensively denatured in a protein-starch matrix, before subjected to cooking, it will take longer for water to penetrate the protein network. It will therefore take longer to reach the starch granules and for the starch to gelatinise (Sung & Stone, 2003:67). Under LT conditions proteins are not denatured upon completion of the drying process, whereas during HT and VHT treatments the proteins are denatured. Therefore, when cooking LT dried pasta, protein denaturing and starch gelatinisation occur simultaneously and competitively. When cooking HT and VHT manufactured pasta, starch gelatinisation does not compete with protein denaturing but gelatinises within the already denatured protein framework. In the case of VHT, the starch swelling is more effectively constrained than in HT. This pre-denatured gluten matrix physically constrains the starch swelling (gelatinisation) more effectively than proteins entering the cooking process undenatured (Guler *et al*, 2002:427).

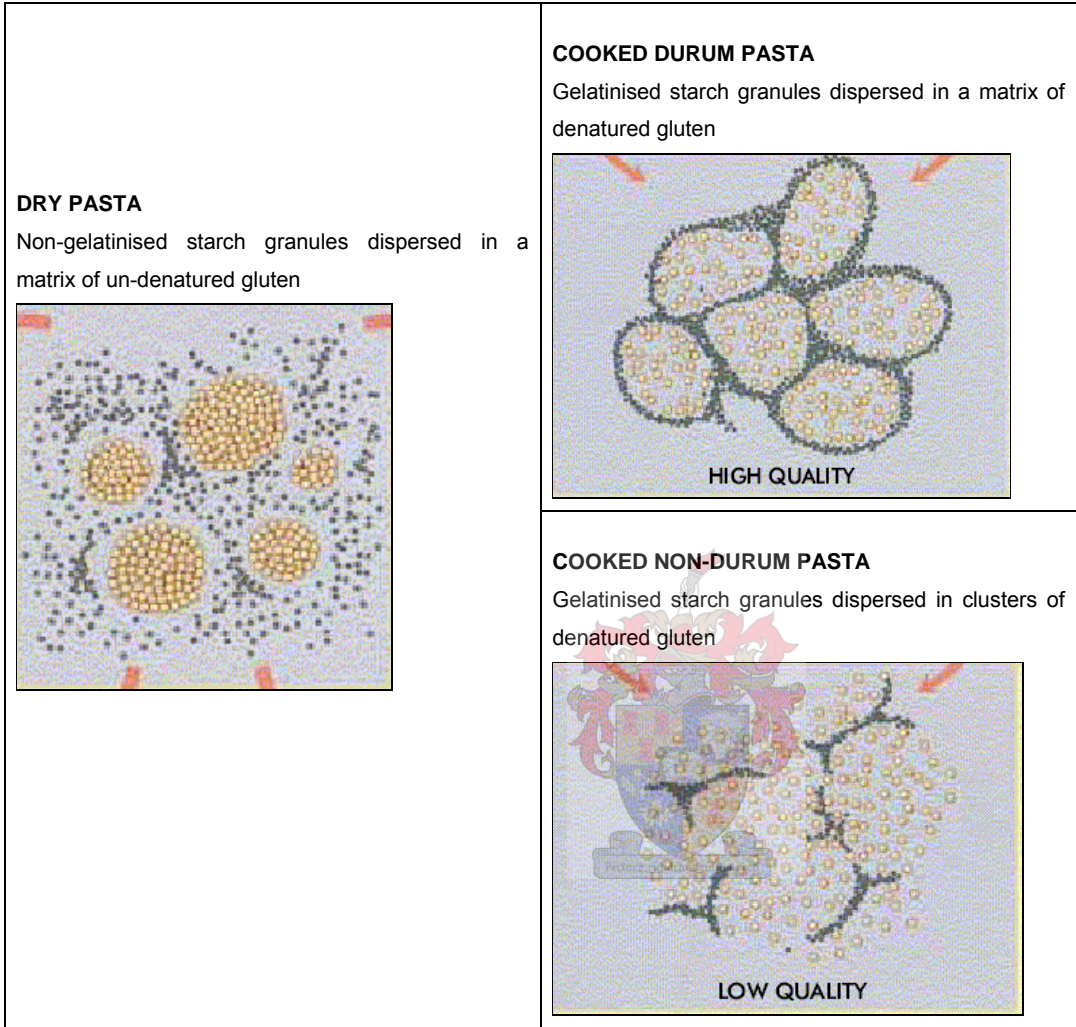
During LT drying proteins do not denature. Non-denatured glutenin and albumin can form continuous denatured frameworks during cooking, encapsulating starch granules (i.e. effectively compete with starch gelatinisation). Gliadin does not possess this ability and denatures in masses (Figure 4.2) rather than networks (Matsuo, Bradley & Irvine, 1972:711). Similarly, the protein fractions present in durum pasta can form continuous denatured frameworks during cooking, encapsulating starch granules, whereas that of bread wheat does not possess this ability (Matsuo, Bradley & Irvine, 1972:711). The implication of this is that the proteins found in bread wheat do not form a continuous protein network, hereby not encapsulating starch granules and are, in fact, in competition with starch gelatinisation (Wyland & D'Appolonia, 1982:200). If protein denaturing took place prior to cooking (i.e. during drying, without starch swelling), gluten from both durum and non-durum wheat denature in a continuous matrix, encapsulating starch granules. Additionally, when proteins denature in the absence of starch gelatinisation, they may cover a larger surface area. Ingredients with lower protein content can therefore effectively encapsulate more starch granules, which means that wheat with lower protein content can be used. The HT and VHT drying techniques therefore eliminate, to a certain degree, the effect of protein quality on final product quality (Wyland & D'Appolonia, 1982:200, Feillet & Dexter, 1998:119). Therefore non-traditional raw materials can be used to produce good quality pasta.

In summary, when using HT and VHT drying techniques on low-moisture pasta, starch will remain ungelatinised, while protein is denatured. During the cooking process, gelatinisation will take place within the relatively hydrophobic insoluble denatured protein framework (Dexter *et al*, 1981:1746, Grzybowski & Donnelly, 1977:1304, Grzybowski & Donnelly, 1979:383, Wyland & D'Appolonia, 1982:200, Feillet, 1984:558, Resmini & Pagani, 1983:9, Turhan & Gunasekaran, 2002:7, Sung &



Stone, 2003:66). This gluten framework may also lead to improved product colour (Wyland & D'Appolonia, 1982:200).

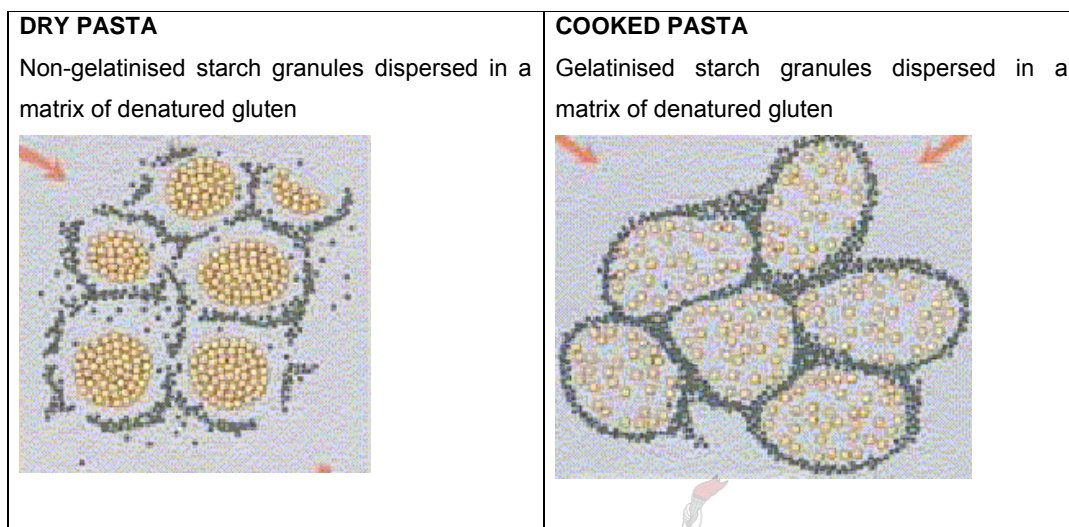
When using VHT drying, it was further found that proteins in dried spaghetti surround the starch granules where a water coat (at least 30 nm) surrounds the starch granules in LT-produced spaghetti (Resmini & Pagani, 1983:1, Pagani *et al*, 1986:122, Vansteelandt & Delcour, 1998:2500).



**FIGURE 4.2 THE PROTEIN-STARCH STRUCTURE OF DRY AND COOKED PASTA DRIED WITH LT TECHNOLOGY – PICTORIAL PRESENTATION (PASTA, 2004:43)**

Dexter and Matsuo (1977:717), Dexter *et al* (1981:1741), Wyland and D'Appolonia (1982:199) as well as Resmini and Pagani (1983:1) reported on the importance of protein quality versus protein content. With LT-drying (<60°C) the protein content and quality are of equal importance. With HT-

drying (>60°C), the importance of protein quality is minimised (D'Egidio *et al*, 1990:280,275, Novaro, D'Egidio, Mariani & Nardi, 1993:719, Marconi *et al*, 2002:638). Currently it is generally accepted that the protein content is the vital factor for good cooked pasta quality (Feillet *et al*, 1996:206, D'Egidio *et al*, 1990:275, Novaro *et al*, 1993:716, Marconi *et al*, 2002:638). This also applies to pasta manufactured from bread wheat flour with lower protein content (D'Egidio *et al*, 1990:275, Novaro *et al*, 1993:716, Marconi *et al*, 2002:638). Consensus is that with the use of new drying technologies, protein content contributes to two thirds of variability in pasta quality, whereas protein quality to one third (Feillet & Dexter, 1998:119).



**FIGURE 4.3 THE PROTEIN-STARCH STRUCTURE OF DRY AND COOKED PASTA DRIED WITH HT TECHNOLOGY (PASTA, 2004:43)**

#### 4.3.2 Effect of HT and VHT on starch granules

Pasta dried at high temperatures (HT and VHT) is more resistant to cooking since it has an increased amylose to amylopectin ratio; requires higher temperatures for gelatinisation (starch granules are less permeable and thus more rigid, which implies increased cooking times); has lower water absorption capacity; has less soluble components leaching out during gelatinisation (lower cooking losses); contains more retrograded starch (resistant starch); and contains less damaged starch (enzyme inactivation).

All of the above effects on starch have positive effects on pasta quality. However, the majority of the positive effects of increased temperature drying (HT and VHT) are ascribed to the effects on the proteins (Dexter & Matsuo, 1979:194, Dexter, Matsuo & MacGregor, 1985:39, Pagani *et al*, 1986:126, De Stefanus & Sgrulletta, 1990:103, Grant *et al*, 1993:676, Vansteelandt & Delcour,

1998:2499, Yue, Rayas-Duarte & Elias, 1999:543, Zweifel *et al*, 2000:650, Gianibelli, Sissons, Morell & Batey, 2000:632, Vansteelandt, 2000. Guler *et al*, 2002:424,426, Zweifel *et al*, 2003:159).

#### 4.3.3 Effect of HT and VHT on microbiological organisms and enzymes

When using HT and VHT drying techniques, the temperature at the equilibrium stage (referred to as the “Rhototherm”) is 100°C, which effectively reduces microbiological loads (Banasik, 1981:167, Milatovic & Mondelli, 1991:94, Pollini, 1998:62) and causes inactivation of enzymes, especially in pasta with small diameter (1,7–1,8 mm) (Milatovic & Mondelli, 1991:107). The enzymes include lipoxygenase (causing carotene-oxidation),  $\alpha$ -amylase (increasing starch damage) and polyphenoloxidase (causing pasta darkening). This technology is therefore extremely important for the preservation of the yellow colour of pasta and prevention of starch damage (Dexter *et al*, 1981:1742, Dick & Matsuo, 1988:538, Milatovic & Mondelli, 1991:107, Pollini, 1998:69, Johnston, 2001:161). Drying at high temperatures (HT and VHT) implies that raw materials of finer particle size, such as flour, can be used for pasta manufacturing without risking increased starch damage by  $\alpha$ -amylase, while under LT drying conditions (39°C), the finer the particle size, the poorer the cooked spaghetti (increased cooking loss and stickiness) due to increased starch damage by enzymes (Dexter *et al*, 1983:1548, Evers & Stevens, 1985:330).

Therefore, there is no difference between the cooking loss of pasta prepared from semolina and flour when HT is applied, explained by the fact that  $\alpha$ -amylase is denatured during HT drying (Dexter *et al*, 1981:1741). The reduction of semolina particle size had no effect on the cooked quality of spaghetti in terms of cooking loss, firmness, resistance to over-cooking and stickiness (Grant *et al*, 1993:681, Evers & Stevens, 1985:330).

#### 4.4 CONCLUSIONS

With the application of high-temperature drying, protein content is largely responsible for the improvement of pasta quality. The effect of the protein quality is diminished, which is of particular interest when manufacturing pasta from bread wheat. The effect of heat on starch and enzymes also play a role in the final quality of pasta.

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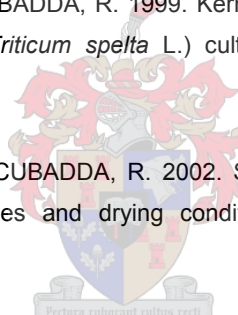
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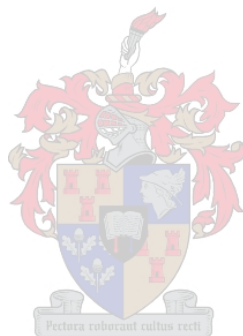
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## CHAPTER 5: REVIEW, IMPROVEMENT AND STANDARDISATION OF DRY SPAGHETTI QUALITY MEASUREMENTS

### 5.1 INTRODUCTION

Consumers that are familiar with spaghetti have certain expectations of the product. Although not defined, these expectations may be described as a product with a certain visual appeal, colour, diameter, minimum length, textural properties, mouth feel and taste. Processors must ensure that products meet these expectations. In the foregoing chapters the intrinsic factors of the raw material sources were discussed, as well as alternative production methods. Processors can control the quality of their products by adhering to certain predetermined standards (for raw material, manufacturing and final product) with set upper and lower limits. This does not entirely eliminate the need for final product evaluations or quality control inspections, since processing deviations may have an effect on product quality. Methods of final product evaluation to ensure consistent quality are described in the literature and are discussed below.

With the introduction of high-temperature drying and the use of non-durum wheat as raw material, current methods (e.g. AACC 14-22, 2000) of evaluation may not suffice to ensure consistent quality. Additionally, there is a lack of an internationally accepted definition of overall spaghetti quality, which hampers accurate communication between manufacturers and the trade. Additional measures and standards may be useful for this purpose, as was successfully implemented for rice in the United States of America (USDA 2001:9, USDA 2002:5). Standards defining spaghetti quality need to be drawn up and a detailed review of the current evaluation methods and the possible shortfalls thereof are required. Additional methods of evaluation that are designed to detect defects, not adequately described by the current methods, needs to be developed. To establish the need for such evaluations, a detailed study of competitive products is required to set standards for these defects.

The validity of standard testing methods may be compromised by the use of alternative raw materials and drying techniques. All evaluation methods need to be adequately described and tested for validity and repeatability. In addition to this, the tests should yield quick results and be practical to carry out in a production environment.

The measurement of certain spaghetti quality characteristics is well documented (protein, moisture and ash content) (AACC 08-02, 2000, AACC 14-22, 2000, AACC 46-30, 2000). Although colour is measured accurately, the translucency of certain brands may obscure accurate measurements (Good, 2002:8). Mechanical strength measurement is well documented (Holliger, 1963:233, Dick & Matsuo, 1988:537), but it is not common practise due to high cost of instrumentation (Hahn, 1990:385, Dick & Matsuo, 1988:538). Measurement of other defects such as optimal length,

diameter, breakages and other defects (cracks, spots, lines, fissures and odd shapes) have not received much attention (Smewing, 1997:8). Standard methods to evaluate such defects need to be developed, since it may provide useful information relating to formulation and processing errors.

The purpose of this study was to identify and define dry spaghetti quality variables to develop methods for the direct measurement of defects and to test these methods for repeatability. To achieve this, the study was performed in two phases.

## **5.2 LITERATURE REVIEW**

### **5.2.1 Protein content**

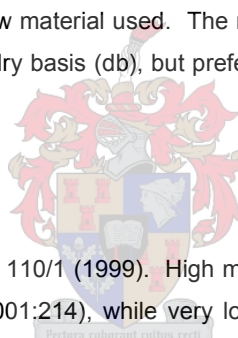
Protein content is determined by either the combustion method or the Kjeldal method, as described in detail in the AACC methods 46-30 and 46-10 (2000) respectively. Of all pasta quality measurements protein content is accepted as the most important variable that affects pasta quality. Higher protein content yields spaghetti with higher mechanical strength and with reduced cooking loss (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter, Matsuo & Morgan, 1983:1545, Hahn, 1990:394, Edwards, Izydorczyk, Dexter & Billiaderis, 1993:125, Malcomson, Matsuo & Balshaw, 1993:420, Feillet & Dexter, 1998:116, Gianibelli, Uthayakumaran, Sissons, Morell & Batey, 2000:642, Sissons & Hare, 2002:83). Dry spaghetti protein content is directly dependent on the protein content of the raw material used. The raw material should have a protein content of at least 11% expressed on a dry basis (db), but preferably 13% (db) (Matsuo, Bradley & Irvine, 1972:711, Turnbull, 2001:186).

### **5.2.2 Moisture content**

Moisture content is determined by the ICC method 110/1 (1999). High moisture content (>12.5%) may lead to microbiological spoilage (Turnbull, 2001:214), while very low moisture content may impair mechanical strength (Holliger, 1963:233).

### **5.2.3 Ash content**

The AACC method 08-02 (2000) is generally used to determine ash content. High levels of ash are indicative of bran contamination. It may affect colour negatively (usually a browner product) and should be kept below 1% (Feillet & Dexter, 1998:106).



## 5.2.4 Colour

Pasta colour can be measured subjectively or objectively. The latter methods are preferred by most scientific evaluations (Good, 2002:5). Absorbency values and Hunter L, a and b and/or CIE L\*, a\* and b\* scales are often reported in the literature (Walsh, Gilles & Shuey, 1969:7, Dexter & Matsuo, 1977:717, Dick & Matsuo, 1988:537, AACC 14-22, 2000. Good, 2002:6). "L" is an indication of lightness, ranging from 0 (black) to 100 (white), "a" represents the red/green axis (negative values are green and positive values are red) and "b" represents the yellow/blue axis (negative values are blue and positive values are yellow).

Since it is accepted that pasta should have a yellow colour, a yellowness index (YI) was calculated, as proposed by Hunter ColorFlex User manual (1999:10-9). YI is calculated by means of X, Y and Z CIE tri-stimulus values by using of the following equation, Equation 1:

$$YI=[100 (1.275X - 1.057Z)] / Y \quad (1)$$

The yellowness is mainly dependent on the presence of carotenoids (Sissons & Hare, 2002:81) and is a function of wheat species and cultivars (Dick & Matsuo, 1988:537).

Due to the translucency of certain food products, such as rice, it is recommended that one should use multiple-layers of the food for this type of evaluation (Good, 2002:6). The AACC method 14-22 (2000) is most commonly used to evaluate colour. A possible shortfall thereof is the use of single-layers for pasta evaluation.

Between repetitions, observed differences of measured colour can be expressed by  $\Delta E$ , where

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (2)$$

as described by Good (2002:6) (in Equation 2). The difference between repetitions is deemed to be too large when  $\Delta E > 0,11$ . More readings are then required per repetition in order to reduce  $\Delta E$  to  $\leq 0,11$  (L, a and b values are average values within repetitions). The purpose of the analysis is to determine how many repetitions will be required to reach a  $\Delta E \leq 0,11$ . It is apparent from the nature of the equation that more readings per repetition will lead to a reduction in  $\Delta E$ . Meeting the above requirements one can then determine the amount of repetitions required per food product being evaluated.

### 5.2.5 Length

Uniform strand length is important to consumers. Deviating strand length will affect actual mass versus declared mass. Defective cutter settings, poor mechanical strength and poor handling may cause variation in strand length (Turnbull, 2001:216). The target length in South Africa is assumed to be  $250\pm 10$  mm, estimated from the length of the most popular brands that are currently successfully retailed in this country. Length measurement can be done accurately in millimetre.

### 5.2.6 Diameter

Spaghetti diameter affects the mechanical strength and the cooking time (Holliger, 1963:239, Turnbull, 2001:217, Sissons & Hare, 2002:83). An increase in wall thickness of 0,1 mm can result in an increased cooking time of one minute (Turnbull, 2001:217). An increase in spaghetti diameter is an indication of die-wear encountered during extrusion. Spaghetti diameter can be determined by physical measurement with a micrometer (Turnbull, 2001:216).

### 5.2.7 Breakages and cutting defects

Breakages during processing are caused by poor mechanical strength due to cracking or other formulation and processing errors. Other causes may include poor handling after packing. Breakages contribute to inconsistency within a package that may lead to poor consumer acceptance (Turnbull, 2001:216). No literature could be found that accurately describes a method of quantifying breakages.

### 5.2.8 Translucency and surface defects

The physical appearance of pasta should be translucent (free from white or dark spots) and should have a smooth surface, free from cracks, fissures and lines (Dick & Matsuo, 1988:537). Not only do these characteristics influence the consumer acceptance of pasta (Feillet & Dexter, 1998:116), but also disclose a considerable amount of information about the manufacturing process (such as mixing and drying procedures) and raw material quality. These measurements are therefore of importance to pasta processors.

White spots are caused by air bubbles included in the dough during dough formation or the inclusion of unhydrated flour particles (Banasik, 1981:167, Dawe, 2001:91). Cracks and fissures were suggested to be drying defects (Dick & Matsuo, 1988:538, Feillet & Dexter, 1998:105,116, Pasta, 2003:33). White lines on spaghetti are caused by defects such as small particles adhering to the die (Turnbull, 2001:217). The measurements of these defects lack standardisation.

Measurements used to quantify mechanical strength of pasta are well established (Smewing, 1997:9). Mechanical strength of pasta is normally considered to be a factor of all the above-mentioned defects (Holliger, 1963:240, Matsuo *et al*, 1972:708, Antognelli, 1980:126, Banasik, 1981:168, Hahn, 1990:387, Abecassis, Abbou, Chaurand, Morel, & Vernoux, 1994:247, Smewing, 1997:8, Dalbon, Grivon & Pagani, 1998:23, Feillet & Dexter, 1998:110). Mechanical strength may therefore be an indirect measurement of errors in the manufacturing process or the raw material used (Holliger, 1963:240, Matsuo *et al*, 1972:708, Banasik, 1981:168, Dick & Matsuo, 1988:538, Hahn, 1990:387, Smewing, 1997:8-9, Dalbon *et al*, 1998:30, Feillet & Dexter, 1998:105, Atwell, 2001:119, Turnbull, 2001:206). It is clear that it will be more informative to measure the individual defects that affect mechanical strength.

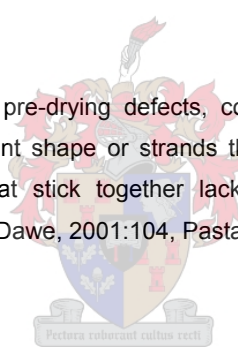
No guidance on quantifying these physical defects could be found in the literature, except for cracks. Turnbull (2001:217) suggested that the percentage defects (cracks) may be measured by separations of strands with cracks and weighing thereof. Most laboratories have their own method of quantifying cracks. One such measurement involves counting the number of cracks per spaghetti strand on each of 30 units. The average is calculated and used to classify products into three categories ranging: Category 1=1 crack, Category 2=2 cracks, Category 3  $\geq$  3 cracks (S. Momus, *Eurogerm*, cereal product development company, personal communication).

#### **5.2.9 Bent shapes and units sticking together**

Too high moisture content, spreader defects or pre-drying defects, compromise the aesthetic appeal of spaghetti by causing strands with a bent shape or strands that stick together. The measurements for bent shapes and strands that stick together lack standardisation (Hahn, 1990:388, Dalbon *et al.*, 1998:38, Pollini, 1998:60, Dawe, 2001:104, Pasta, 2003:32).

#### **5.2.10 Strands with loops**

Defective products with loops may occasionally be present in packed spaghetti. These loops are formed when pasta is left to hang over the drying stick and with subsequent defective cutting. No reference to this defect could be found in the literature, but it was observed in a pasta processing plant.



## 5.3 METHODOLOGY

### 5.3.1 Phase 1A

The first objective of this phase was to identify and define spaghetti quality variables. The second objective is to develop and propose evaluation methods for variables lacking standard evaluation methods or to propose improvements for evaluation methods with shortfalls.

#### 5.3.1.1 Materials and sampling

Two sets of samples were used in Phase 1A. The first set of samples was collected over a period of three months: three 500 g packets of five different brands (Brands A to E) of spaghetti were purchased weekly for 12 weeks from various stores either in Cape Town or Johannesburg. Great care was taken that the batch codes differed with every weekly purchase. The three packets purchased weekly were combined within brands and coded A1 to E12 (A to E referring to Brand and 1 to 12 referring to batch), yielding 60 samples (5 brands x 12 batches each). The sampling details are summarised in Addendum A. These samples were used for initial observations of quality differences between commercially available spaghetti brands.

The brands selected for this study are freely available in South Africa. Stores with fast stock rotation were selected in order to obtain different batches of the same brands with every purchase. It was known that the specific brands differed considerably in quality. According to the ingredients declarations the spaghetti of different brands were manufactured from a range of raw materials such as durum semolina, bread wheat semolina and bread wheat flour.

Below a short description of the typifying characteristics (of importance in this study) of each of the brands:

- Brand A: Local bread wheat flour, overall poor quality, packed in low density polyethylene
- Brand B: Imported durum wheat semolina, average quality, packed in a cardboard box
- Brand C: Imported durum wheat semolina, excellent quality, packed in a cardboard box
- Brand D: Local bread wheat semolina, small diameter (0,67 mm), very translucent, packed in low density polyethylene
- Brand E: Imported durum wheat semolina, good quality, packed in low density polyethylene

The second set of samples were drawn from five commercial batches of 8 mt (metric ton) each, prepared with varying amounts of durum wheat in the formulations (stepwise 0 to 100%, in increments of 25%). These samples visually ranged between being brownish (100% bread wheat

flour) to bright yellow (100% durum semolina). These samples were used to test the discriminating ability of two colour evaluation methods (proposed method – see Section 5.3.1.2).

### **5.3.1.2 Methods**

Samples A1 to E12 were visually and physically examined. Noticeable differences between samples were recorded as variables (for e.g. colour) and included in the study. The length and diameter of 10 strands of each of the 60 samples were measured and recorded. Length was measured to the nearest 1 mm, using a transparent ruler. Diameter was measured in the middle of the strand with a vernier calliper to the nearest 0.02 mm.

Reference photographs were taken of selected strands from samples A1 to E12, depicting the typifying defects. More strands with no visual damage or defects were selected and photographed as base or zero value for comparison with defects.

The recommendations by Good (2002:6) were tested, since it was suspected that possible variations in strand diameter and translucency might have an influence on the colour measurements. Evaluation in multiple-layers will eliminate the possible effect that the black background, used during measurements, may have on colour measurements as proposed by AACC method 14-22 (2000). This method of evaluation is also more representative of the observation of consumers when purchasing spaghetti at store level. The validity of measuring spaghetti in single versus multiple-layers was compared by measuring the colour of spaghetti with five different levels of durum wheat semolina. For this purpose five measurements were recorded on each batch of the 8 mt prepared product with varying durum wheat semolina both in single-layer and multiple-layers (90 mm wide, 20 mm deep).

Colour was measured in terms of L, a and b values with a *Hunter ColorFlex spectrophotometer* model 45 ° / 0 ° (Hunter Lab ColorFlex TM User Guide, 1999:10-9). From these values the yellowness index was calculated, Equation 1 (Hunter Lab ColorFlex TM User Guide, 1999:10-9). Five measurements were taken on the middle section of spaghetti strands.

### **5.3.1.3 Statistical procedures**

Data of the products prepared with five different levels of durum wheat semolina were subjected to difference testing by means of LSD (least significant different) values. The least significant difference was calculated (Snedecor & Cochran, 1976:272).

#### 5.3.1.4 Results and discussion

Results of Phase 1A are reported here, as they impact on the sampling method in Phase 1B. From visual and physical examination of samples, spaghetti quality variables were identified. Length and diameter were variables. Further observations were made regarding breakages and the variation in the length of broken units was noted. Colour differences were evident and varied between being light brown to deep yellow, particularly between brands. Translucency differed considerably between brands.

It was noted that the frequency of the presence of white lines was extremely low. This may imply that they either do not occur as defects at the plants where the selected brands were manufactured, or that quality control personnel removed such strands before packing. Other forms of easily recognisable defects, such as strands with bent shapes, strands sticking together and strands with loops, were moderately higher. Considerable variation was noted in the presence of the defects, namely cracks, fissures and spots, both between brands and within brands (between batches).

**Strand length, cutting defects and breakages.** A category classification table (Table 5.1) was constructed to classify the different lengths of strands and the amount of broken units. This was done in consultation with manufacturing personnel with many years of experience in the industry. Such experienced personnel maintain that certain lengths may indicate different production variance, although no reference to this could be found in the literature.

Considering spaghetti presentation in supermarkets (packed bundles of 500g in translucent packaging material) and consumer expectations, uniformity of strand length is important, as is the amount (quantity) of broken units. Strands exceeding the target length and those below the target length are unattractive and must be quantified by counting those strands out of specification. Since there are several hundred strands in a 500 g packet, it is proposed that 60 strands are randomly selected and divided into categories B1–B3 (Table 5.1). Smaller uncountable units should be weighed and quantified by expressing their occurrence by mass percentage. To increase the accuracy of measurement (weighing), the contents of at least three 500 g packets were combined before sifting and sampling of the 60 longer units.

Since breakages generally occur after packing, measurement of length of unbroken units is of value to identify cutting defects. Therefore, it is proposed that only strands allocated to category B3, Table 5.1, be included in determining the average length of strands. It is proposed that strand length is determined by measurement of individual strands with a calibrated transparent ruler. One measurement was taken per strand.



**TABLE 5.1 CATEGORIES FOR STRAND LENGTH AND BREAKAGES, RANGES AND QUANTIFICATION OF SPAGHETTI STRANDS**

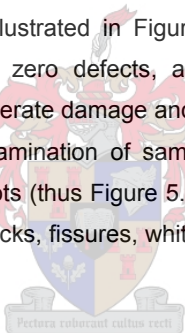
Categories	Definition	Quantification*
B1	≥ 260 mm	Unit percentage
B2	< 260 mm and ≥ 240	Unit percentage
B3	< 240 mm and ≥ 120 mm	Unit percentage
B4	< 120 mm and ≥ 5.5 mm	Mass percentage
B5	< 5.5 mm	Mass percentage

\* Units percentage=number of defect units / total number of strands (n=60 strands) X 100; Mass percentage=mass of broken units / total sample mass (n=3 x 500 g=1 500 g) X 100,

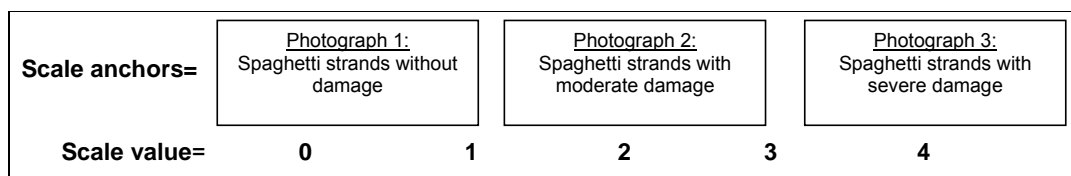
**Strands with white lines, bent shape and strands with loops.** For evaluating each of these variables, it is proposed that 60 strands are randomly selected and those strands with the defect be counted and expressed as a unit percentage.

**Diameter.** Diameter is to be measured with a vernier calliper (to the nearest 0.02 mm), one measurement taken in the middle of each strand.

**Cracks, fissures and spots.** From the photographs taken of selected strands, specific pictures were selected as reference photographs and are illustrated in Figure 5.2 to Figure 5.6. The selection firstly included one photograph depicting zero defects, and secondly included two photographs per identified defect - one indicating moderate damage and one photograph indicating extreme damage. Defects identified during the examination of samples (A1 to E12) included cracks, fissures, flour spots, white spots and dark spots (thus Figure 5.2 to Figure 5.6 respectively depicting the *Likert* scale for judging the degree of cracks, fissures, white spots, flour spot and dark spots).



To measure these defects, *Likert* scales were constructed, by means of reference photographs, for the classification of defects (see Figure 5.1 for detail). It is proposed that spaghetti be evaluated by viewing against a black background, through a sieve-counting lens (x 10 magnification). Defects are then categorised according to the severity of damage (Figure 5.1 to Figure 5.6 and Table 5.2).



**FIGURE 5.1 MODEL DIAGRAM USED FOR LIKERT SCALE DEVELOPMENT FOR THE DEFECTS, NAMELY CRACKS, FISSURES, FLOUR SPOTS, WHITE SPOTS AND DARK SPOTS**

Table 5.2 defines the defects and their respective *Likert* scale intervals. The *Likert* scales were used to categorise ordinal data obtained by judge scores on five possible responses per defect, as suggested by Gregory (2000:123). There is no real zero point and equal intervals cannot be assumed, although ranking can be obtained from these scales (Gregory, 2000:119). The data can be used to estimate both the degree of damage and the proportion of damaged strands by binomial interpretation of the data.

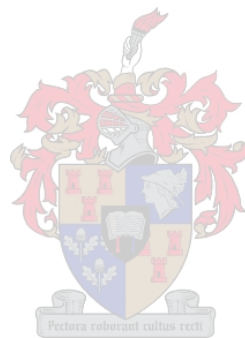
**TABLE 5.2 LIKERT SCALE INTERVALS AND DESCRIPTIVE TERMS FOR DEFECTS**

Defect	Description	Degree of damage	Likert scale interval	Figure	Quantification of defects
No damage	Strands without any defects	None	0	Figure 5.2–5.6	<i>Likert</i> scale intervals no damage=0, moderate damage=2, and severe damage=4
Cracks	A network of fine breaks or splits in the pasta surface	Moderate	2	Figure 5.2	
		Severe	4	5.2	
Fissures	Longitudinal breaks or splits in the pasta surface	Moderate	2	Figure 5.3	
		Severe	4	5.3	
Flour spots	White spots present on the surface of the pasta strand	Moderate	2	Figure 5.4	
		Severe	4	5.4	
White spots	White spots within the pasta strand, seen from the outside	Moderate	2	Figure 5.5	
		Severe	4		
Dark spots	Brown and black spots present in and on pasta strands	Moderate	2	Figure 5.6	
		Severe	4		

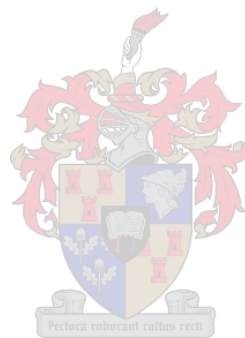
**FIGURE 5.2 LIKERT SCALE FOR JUDGING THE DEGREE OF CRACKS**



**FIGURE 5.3 LIKERT SCALE FOR JUDGING THE DEGREE OF FISSURES**



**FIGURE 5.4 LIKERT SCALE FOR JUDGING THE DEGREE OF FLOUR SPOTS**



**FIGURE 5.5 LIKERT SCALE FOR JUDGING THE DEGREE OF WHITE SPOTS**

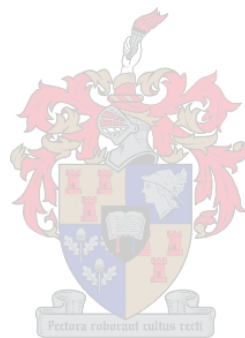
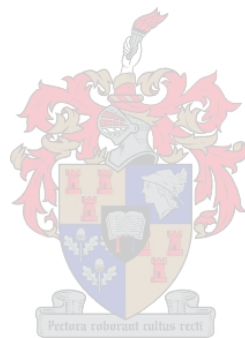


FIGURE 5.6 LIKERT SCALE FOR JUDGING THE DEGREE OF DARK SPOTS



**Colour.** The means and standard deviations for single and multiple-layer colour analyses are presented in Table 5.3. From the results in Table 5.3 it is clear that when packed in single-layer, differences between different samples were obscured. This may be due to the translucent nature of the product measured. Multiple-layer results are more discriminate than single-layer results with particular reference to the yellowness index value (Table 5.3). Less evident, but with significant difference between methods, the b values are also more discriminate (Table 5.3). This may reflect on the validity of colour analysis as currently practised.

Based on the evidence presented, it is recommended that multiple-layer colour analyses be used on translucent material such as spaghetti.

**TABLE 5.3 COMPARISONS BETWEEN COLOUR MEASUREMENTS OF SINGLE VERSUS MULTIPLE-LAYERED SPAGHETTI**

MEASUREMENT	SINGLE-LAYER					LSD Std. err.	MULTIPLE-LAYER					LSD Std. err.
	% DURUM						% DURUM					
	0	25	50	75	100		0	25	50	75	100	
L-value	a	a	b	b	c		a	a	b	bc	c	
Avg	43,06	43,14	44,80	44,82	45,35	0,52	46,37	46,67	50,00	51,04	51,12	1,21
Std. dev.	0,22	0,30	0,35	0,37	0,21	0,19	0,74	1,28	0,17	0,19	0,36	0,44
a-value	e	d	c	a	b		d	c	b	a	b	
Avg	-0,12	-0,85	-1,65	-2,23	-1,90	0,17	3,20	2,70	2,17	1,64	2,25	0,12
Std. dev.	0,04	0,17	0,07	0,09	0,03	0,06	0,01	0,11	0,05	0,08	0,04	0,04
b-value	a	a	b	c	d		a	b	c	d	e	
Avg	17,47	17,65	18,76	19,34	20,74	0,25	20,68	21,33	23,34	24,60	25,82	0,54
Std. dev.	0,16	0,11	0,14	0,16	0,12	0,09	0,25	0,62	0,04	0,06	0,12	0,19
Yellowness Index	a	a	a	b	c		a	b	c	d	e	
Avg	72,35	71,73	72,24	73,41	78,46	0,64	84,65	85,83	86,54	88,43	93,42	0,69
Std. dev.	0,38	0,30	0,55	0,32	0,13	0,23	0,40	0,59	0,34	0,18	0,30	0,25

<sup>a-e</sup> Values with the same row within columns with different superscripts differ ( $P \leq 0,05$ )



### 5.3.2 Phase 1B

The objective of Phase 1B was to determine the repeatability of measurements proposed in Phase 1A. Repeatability analysis was performed by calculating the number of measurements required to per batch (repetition) for each sample.

#### 5.3.2.1 Materials and sampling

Two sets of samples were used. The first set applied to the variables, namely length, diameter, breakages, cracks, fissures, flour spots, white spots and dark spots. Due to the observed variability of these variables within or between brands, Brands A, B and C were selected. Of each



of these brands fresh batches were purchased (3 x 500 g) and used for repeatability evaluations of the above characteristics. These were coded Sample A13, B13 and C13 (see Addendum A).

The second set of samples was used for testing the repeatability of the improved colour evaluation method. Particular batches of Phase 1A (Samples B4 and D6) with extreme deviations in colour were selected (see Addendum A). All factors that may affect apparent colour, namely diameter, translucency and discolouration, were considered in this selection.

### 5.3.2.2 Methods

The repeatability of methods proposed in Phase 1A was calculated. Data required to calculate the variation introduced by either the sample or the measurement was collected by repeated measures as described below.

**Cutting defects and breakages** The method and sampling applied was as proposed in Phase 1A per sample (Samples A13, B13 and C13). Three 500 g packets were combined per sample and procedure followed, as described in Section 5.3.1.4.

**Strands with white lines, bent shape and strands with loops.** The method described in Section 5.3.1.4 was followed. Per sample 60 strands were randomly drawn and visually inspected for the listed defects. Those strands with defects were expressed as a unit percentage.

**Length.** The length of 30 randomly drawn strands was recorded per sample (Samples A13, B13 and C13) as described in Section 5.3.1.2. A calibrated transparent ruler was used and measurements taken to the nearest 1 mm.

**Diameter.** The diameter of 30 randomly drawn strands was recorded per sample (Samples A13, B13 and C13) as described in Section 5.3.1.2. A vernier caliper was used and measurements taken to nearest 0.02 mm in the middle of each strand.

**Cracks and fissures and spots.** To determine *judge repeatability*, a single judge scored 50 spaghetti strands from three samples (Samples A13, B13 and C13) in two sessions for each of the defects, namely cracks, fissures, white spots, flour spots and dark spots (five defects). The 50 strands per sample were randomly drawn from the combined packs of three each. Strands were randomly numbered and evaluated. After the first session, the spaghetti strands were assigned new random numbers, which were used in the second session. Judge repeatability was calculated by correlating results obtained in Session 1 and Session 2 for the five defects.

Measurement repeatability was determined by binomial interpretation of the results obtained when judge repeatability was determined. The proportion of damage was determined. Instead of calculating the number of repetitions required per batch, the confidence intervals of a specified sample size were determined. The specified sample size (N) was selected as 100 (i.e. measurements required per batch), as more readings per repetition would be impractical for a single judge. This was substituted into the equation presented in the next section and the confidence intervals, per defect, determined. The severity (=scale interval or category) in which damage had occurred per defect and per batch was determined by calculating the “average category” for strands evaluated. These “average categories” are not descriptive but serve as an indication of ranking.

**Colour.** It was decided to use multiple-layered samples in this study. Three measurements were taken on the middle section of spaghetti strands per sample (Samples B4 and D6). To determine whether three measurements were sufficient when evaluating colour, the L, a and b values were applied in Equation 2 (Good, 2002:6).

### 5.3.2.3 Statistical procedures

**Length, diameter, breakages, white lines, bent shape and stands with loops, colour.** According to Snedecor and Cochran (1976:516) the sample variance is used to determine the number of measurements required per batch (one repetition, at a chosen confidence limit of 95%) and is calculated with the following equation (Equation 3) (higher numbers of measurements required per batch, implies a lower degree of repeatability):

$$n=(S^2 \times 1.96^2)/L^2 \quad (3)$$

where “n” is the number of measurements required (i.e. required sample size) per batch (repetition), “S<sup>2</sup>” is the sample variance, and “L” is the error allowed per batch (repetition) as specified by the study (Snedecor & Cochran, 1976:516).

For colour, the required sample size was calculated by Equation 1 as described by Good (2002:6).

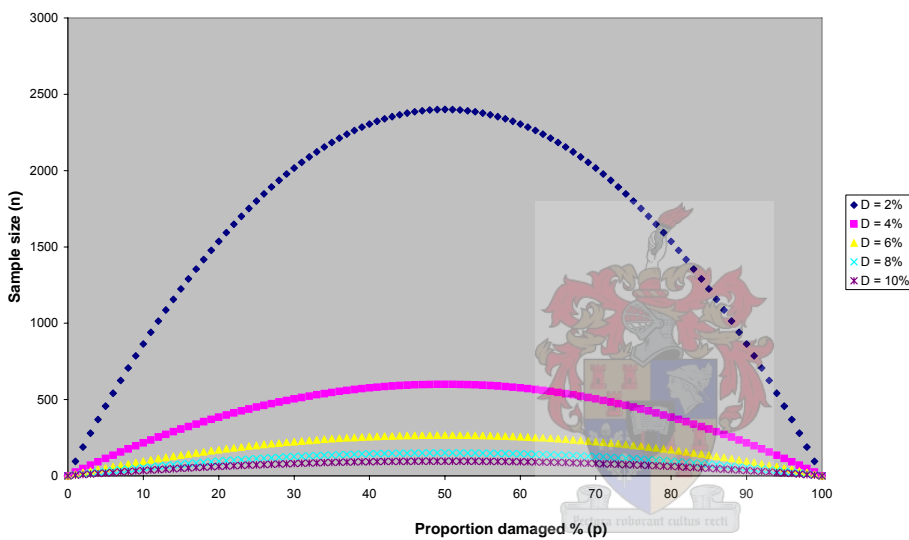
**Cracks, fissures and spots.** Judge repeatability was determined by correlation analysis according to *Spearman's* rank correlation coefficient, which is a measure of correlation between two ordinal data sets (Spearman, 1904 as cited by SAS, 1999). Measurement repeatability was also determined (Snedecor & Cochran, 1976:210). *Ordinal data* (*Likert* scale categories for appearance defects) were categorised as binomial data - zero defects (*Likert* scale interval zero) and those with defects (*Likert* scale intervals one to four). The number of measurements required

per batch (one repetition) was calculated by means of Equation 4 for a chosen confidence limit of 95% and for a chosen confidence interval for p (Snedecor & Cochran, 1976:210):

$$n=(1.96^2pq)/(D^2) \tag{4}$$

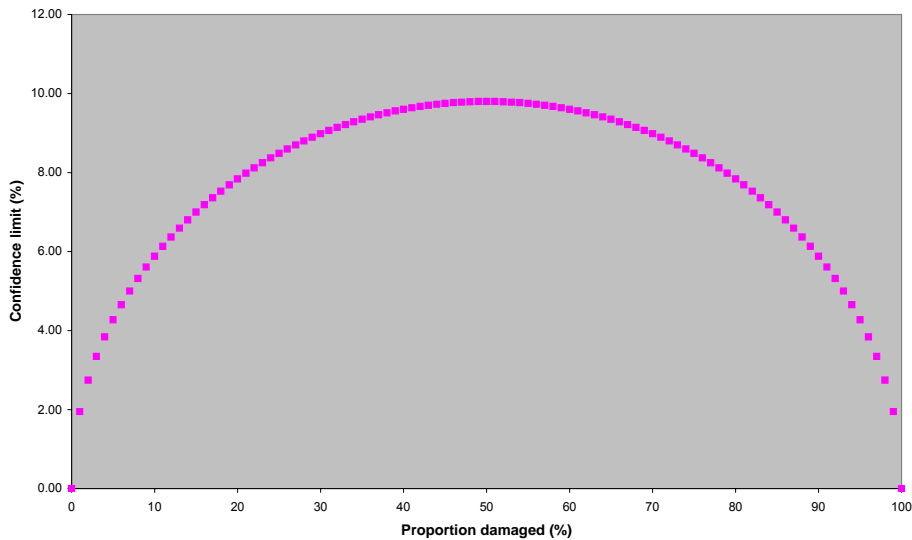
provided that:  $np(1-p) > 9$  (see Figure 5.7).

where “n” is the number of measurements required per batch (repetition) for a specific confidence limit of 95%, “p” is the proportion of damage, “q”=“1-p” (proportion not damaged) and “D” is the confidence interval (specified precision - i.e. the difference between the value p and the boundary of the confidence interval). The proportion of damage (p) is denoted by:  $p+D \geq p \geq p-D$  provided that “ $np(1-p) \leq 9$ ”. Crow (1956:439) provided tables with 95% confidence limits for the binomial distribution. It is evident from Figure 5.7 that the sample size required is highest when the proportion damage is closest to 50%.



**FIGURE 5.7 SAMPLING FROM A BINOMIAL DISTRIBUTION WHEN CONFIDENCE INTERVAL (D) IS SPECIFIED (CROW, 1956:430)**

Instead of determining the number of measurements required per repetition, “n” in Equation 4 can be specified (N) and the confidence interval calculated for a specific proportion (see Figure 5.8). Seeing that it is not practical for a single judge to evaluate more than 100 strands per repetition (batch), “n” was specified in this study and referred to as N=100. From Figure 5.8 it can be seen that the confidence interval cannot be less than 10% when N is limited to 100 strands with 50% thereof damaged.



**FIGURE 5.8 CONFIDENCE INTERVAL (D) FOR A PROPORTION (P) IF THE SAMPLE SIZE IS SPECIFIED (N) TO BE 100 (CROW, 1956:430)**

***Criteria for accepting or rejecting validity and reliability of testing methods***

Based on the information gathered from the preceding analyses and the descriptions of validity of measurements and the reliability of such measurements (Bless & Higson-Smith, 2000:126) the following procedures were followed in this study:

1. Great care was taken to select measurements that directly measure the degree of damage (or variance) for all selected quality defects (or measurements).
2. The reliability of the measurements is reflected by the degree in which repeated measurements will yield the same or very similar results and the ability of the method to effectively distinguish between obvious differences. This was tested by repetitions of the testing methods for each variable measured.
3. Estimates of the population means, selected errors for the estimate of the mean (L), chosen probabilities (5%) that the error will not exceed L and chosen confidence limits (95%) were used to calculate the minimum sample size to meet this criteria.
4. Testing methods yielding the lowest sample size required, or a feasible sample size, to meet the chosen confidence and probability limits, were selected as those with the highest repeatability, reflecting on the highest reliability and validity of the method, with Point 1 above a prerequisite.

Note: Measurements that are absolutely repeatable will yield estimates of  $\sigma$  (S) equal to zero. Such measurements hardly ever occur. Measurements that are less repeatable will yield estimates of  $\sigma$  larger than zero. A possible method that can be used as a preliminary estimate of the repeatability of a testing method is to express the estimate of  $\sigma$  in relation to the estimate of  $\mu$  (mean), commonly known as the coefficient of variation (CV). However, the magnitude of  $\sigma$  is duly taken into account following the suggested procedures described above.

## 5.4 RESULTS AND DISCUSSION

### 5.4.1 Cutting defect and breakages, strands with white lines, bent shape and with loops

Due to the low frequency of these variables, it was not possible to determine repeatability of these measurements within the scope of this study. This part of the research only serves as a potential model for defining and evaluating these defects. During the application of these measurements on a larger population, in the next part of the research (Chapter 7), comments will be made on the validity and reliability of methods.

### 5.4.2 Length

Repeatability analysis (Table 5.4) indicated that at a confidence limit of 95% and an allowed error of 3 mm, an average of 10 measurements would be sufficient per batch (repetition).

**TABLE 5.4 REPEATABILITY DATA FOR PASTA STRAND LENGTH**

Pasta variety (n=30)	Sample A	Sample B	Sample C
Mean (mm)	250,47	247,25	249,35
Variance ( $S^2$ )	20,33	16,46	9,26
Measurements required per batch *	9,03	7,32	4,12

\* The number of measurements required per batch at a confidence limit of 95% and allowed error (L) of 3 mm per batch

### 5.4.3 Diameter

Repeatability analysis (Table 5.5) indicated that if a representative average were to be obtained at a confidence limit of 95% and an allowed error of 0,02 millimetres, and average of nine measurements, would be required per repetition (batch).

**TABLE 5.5 REPEATABILITY DATA FOR PASTA STRAND DIMENSIONS**

Pasta variety (n=30)	Sample A	Sample B	Sample C
Mean (mm)	1,67	1,86	1,68
Variance (S <sup>2</sup> )	0,0009	0,0003	0,0007
Measurements required per batch *	8,75	3,24	7,37

\* The number of measurements required per batch at a confidence limit of 95% and allowed error (L) of 0,02 mm per batch

#### 5.4.4 Cracks and fissures and spots

Results obtained in Sessions 1 and 2 for the five defects were correlated. Per session a total of 750 measurements were recorded (50 strands x 3 samples x 5 defects). Refer to Table 5.6 for the descriptive statistics of these sessions.

**TABLE 5.6 DESCRIPTIVE STATISTICS OF CORRELATION BETWEEN SESSIONS EVALUATING THREE SAMPLES FOR FIVE DEFECTS**

Variable	Minimum score	Maximum score	n	Mean	Standard Deviation	Median
Session 1	0	4	750	1,868	1,058	2,000
Session 2	0	4	750	1,880	1,056	2,000

Correlation results are presented in Table 5.7. A correlation coefficient (r) equal to 0,98 is considered to be highly repeatable (refer to Table 5.7). The highly significant P-value (P < 0,0001) confirmed the validity of the correlation coefficient (r=0,98). The judge therefore evaluated the same spaghetti strand equally in both sessions.

**TABLE 5.7 DETERMINATION OF JUDGE REPEATABILITY BY CORRELATION COEFFICIENTS (R)**

Spearman Correlation Coefficients (r)		
	Session 1 (n=750)	Session 2 (n=750)
Session 1	1,000	0,986 (P < 0,0001)
Session 2	0,986 (P < 0,0001)	1,000

Measurement repeatability for the defects, namely cracks, fissures, flour spots, white spots and dark spots are presented in Table 5.8. According to the proportion of damage found in the 150 strands (n=3 samples x 50 strands=150) evaluated per session, with a specified sample size (N=100) the confidence interval (accuracy) of the measurements were calculated.

**TABLE 5.8 MEASUREMENT REPEATABILITY ANALYSIS WHEN SAMPLING FROM A BINOMIAL DISTRIBUTION (LIKERT SCALE CATEGORIES 0 VERSUS 1-4) – CALCULATING CONFIDENCE INTERVAL (D) FOR A PROPORTION (p) AT A 95% SIGNIFICANCE, WHEN SAMPLE SIZE IS SPECIFIED TO BE 100 (N)\***

	SESSIONS									
	Session 1 (50 strands)					Session 2 (50 strands)				
Defect (0="no damage"; 4="severe damage")	Cracks	Fis- sures	Flour spots	White spots	Dark spots	Cracks	Fis- sures	Flour spots	White spots	Dark spots
<b>Sample A13</b>	<b>Session 1</b>					<b>Session 2</b>				
Proportion (p) damaged **	0,48	0,50	0,16	0,98	1	0,48	0,52	0,20	0,98	1
Np(1-p)	25	25	13	2	0	25	25	16	2	0
Confidence interval (D) (%)	10	10	7	3,5	2	10	10	8	3,5	2
Severity of damage (Likert scale category)	1,13	2,64	1,00	1,04	2,00	1,21	2,58	1,00	1,04	2,00
Variance (S <sup>2</sup> )	0,20	1,49	0,00	0,04	0,00	0,24	1,53	0,00	0,04	0,00
<b>Sample B13</b>	<b>Session 1</b>					<b>Session 2</b>				
Proportion (p) damaged **	0,16	0,10	0,14	1	1	0,16	0,10	0,22	1	1
Np(1-p)	13	9	12	0	0	13	9	17	0	0
Confidence interval (D) (%)	7	6,5	7	2	2	7	6,5	8	2	2
Severity of damage (Likert scale category)	3,88	1,80	1,00	1,88	3,00	3,88	1,80	1,00	1,86	3,00
Variance (S <sup>2</sup> )	0,13	1,70	0,00	0,11	0,00	0,13	1,70	0,00	0,12	0,00
<b>Sample C13</b>	<b>Session 1</b>					<b>Session 2</b>				
Proportion (p) damaged **	0,12	0	0	1	1	0,12	0	0	1	1
Np(1-p)	11	0	0	0	0	11	0	0	0	0
Confidence interval (D) (%)	6	2	2	2	2	6	2	2	2	2
Severity of damage (Likert scale category)	1,00	0	1,00	1,00	1,04	1,00	0	0	1,00	1,06
Variance (S <sup>2</sup> )	0,00	0	0,00	0,00	0,04	0,00	0	0	0,00	0,06

\* Calculating the confidence interval (D) at a confidence limit of 95% when sampling from a binomial distribution, when  $Np(1-p) \geq 9$  or when  $Np(1-p) \leq 9$

\*\* % of 150 spaghetti strands (n=150) categorised in Likert scale categories 0–4

In the worst-case scenario, i.e. where the proportion of damaged is 50% of the total sample, and 100 measurements are taken per batch (repetition), the accuracy of the measurement (confidence interval D) is 10% (i.e.  $50\% \pm 10\%$ , Figure 5.8). A damage proportion of 50% is likely to occur (Table 5.10) when bread flour pasta (Sample A13) is evaluated. This therefore reflects on the reliability of the measurement.

#### 5.4.5 Colour

After analysis of averaged colour values per batch (repetition) for Sample B4 (Table 5.9) and Sample D6 (Table 5.10), three measurements proved to be sufficient to obtain a repeatable value per batch (repetition) for each of the samples evaluated (Samples B4 and D6), as the  $\Delta E$  amounted to less than 0,11 (Good, 2002:6). This proposed measurement of colour proved to be repeatable.

**TABLE 5.9 COLOUR OF SAMPLE B4 (TRANSLUCENT, WITH A DIAMETER OF 0,67 MM)**

Sample B4	L value	a value	b value
Mean 1 (n=3)	58,05	0,03	26,07
Mean 2 (n=3)	58,12	0,08	26,09
$\Delta E$ *	0,09		

\* $\Delta E \leq 0,11$  implies sufficient measurements

**TABLE 5.10 COLOUR OF SAMPLE D6 (DISCOLOURED, WITH A DIAMETER OF 0,88 MM)**

Sample D6	L value	a value	b value
Mean 1 (n=3)	45,36	3,44	22,85
Mean 2 (n=3)	45,41	3,54	22,89
$\Delta E$ *	0,11		

\* $\Delta E \leq 0,11$  implies sufficient measurements

#### 5.5 CONCLUSIONS AND RECOMMENDATIONS

An improved measurement of dry pasta colour is proposed, since the AACC method 14-22 (2000) posed problems when samples with differing translucency and diameter were compared. This study proved that spaghetti colour could be measured with a high degree of repeatability on multiple layers of spaghetti as long as the number of readings per batch proposed in this study is adhered to. Therefore when pasta colour is measured, the AACC prescribed method (AACC 14-22, 2000) should be adapted to include the evaluation of multiple-layers of samples instead of single-layers of spaghetti. It was determined that when colour is measured, at a confidence limit of 95% and an allowed error (L) of 0,5 yellowness units, an average of three measurements per batch is required.

Spaghetti strand dimensions (strand length and diameter) can be measured reliably if the number of readings per batch proposed by this study is adhered to. Strand length repeatability analysis indicated that at a confidence limit of 95% and an allowed error of 3 mm, an average of 10 readings per batch are required. When determining strand diameter nine readings per batch are required.



The repeatability of measuring the defects namely, breakages, white lines, units sticking, bent shape and strands with a loop could not be determined since the sample size in this study was not adequate. To obtain enough data to determine measurement reliability, the measurements should be applied on a larger population, during the next phase of the research (Chapter 7).

Defects, namely cracks, fissures, flour spots, white spots and dark spots were defined with reference photographs and measurements were proposed. From this study it can be concluded that judges can be trained to score pasta quality with regard to these quality attributes. The repeatability of these measurements is subject to the proportion of damage and the specified sample size (in this case 100). It was found that a proportion of 50% damage is likely in bread wheat pasta (Sample A13), implying measurement accuracy of  $50\% \pm 10\%$ . Validity of these measurements can only be vouched for once this proposed measurement is tested on a large population, in which the distribution of data across the proposed scale can be evaluated (Chapter 7), thereby determining whether the scales are representative of pasta quality. Correlation of these measurements with other measurements will vouch for the validity of the measurements and will be dealt with in Chapter 8.

The number of measurements required per batch, or the confidence limits within which the results are true, was determined based on the sample variance found within a single batch of pasta drawn from three brands on the South African market. The number of measurements required per batch might change if more or less variance occurred within a single batch than that tested in this study. The samples included in this study, were selected in such a manner to include the most variance. Low quality bread flour pasta and high quality durum pasta were used.

For those measurements that repeatability could not be proven, further review by implementation within a large-scale study with a larger sample size is required. For measuring pasta colour, it is recommended that the AACC prescribed method (AACC 14-22, 2000) be adapted to include multiple-layers of spaghetti strands. It is recommended that the various causes of compromised mechanical strength, such as white and flour spots, dark spots, cracks and fissures be measured individually as more information about the process may be revealed.

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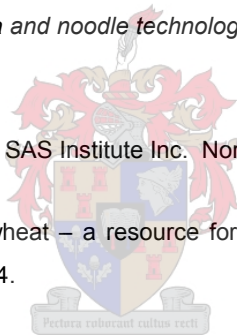
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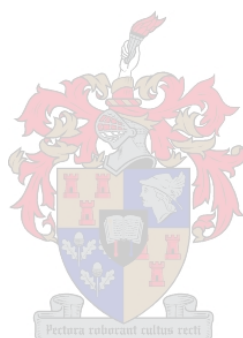
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## CHAPTER 6: REVIEW, IMPROVEMENT AND STANDARDISATION OF COOKED SPAGHETTI QUALITY MEASUREMENTS

### 6.1 INTRODUCTION

Cooked spaghetti quality refers to many physical and chemical tests of which cooking loss percentage (CL), rinse loss percentage (RL) (stickiness), water absorption (WA), firmness, resistance to over-cooking and cooked colour is of greatest importance (Grzybowski & Donnelly, 1979:380, Dick & Matsuo, 1988:538, Debbouz & Doetkott, 1996:674, Kovacs, Howes, Clarke & Leisle, 1998:47, Sissons & Hare, 2002:83). A number of authors have also described successful instrumental measurements of cooked spaghetti quality, such as firmness, stickiness and resilience to compression (Matsuo & Irvine, 1969:3, Matsuo & Irvine, 1970:554, Walsh, 1971:204, Voicy & Larmond, 1973:127, AACC 16-50, 2000).

Sensory evaluation is probably the most valid measurement of quality, but it is time consuming, expensive and sometimes biased. The limitations of taste panels have led testing laboratories to develop controlled cooking procedures and objective measurements, which have been correlated to sensory evaluation. Spaghetti quality should preferably be evaluated in a laboratory since the methods are more objective than sensory evaluation (Dexter, Matsuo & Morgan, 1983:1545, Smewing, 1997:9).

Various tests to determine cooked spaghetti quality have been developed and applied in research facilities, but their application as quality assurance procedures in the industry have not received recognition, mostly due to the cost of instrumentation (Hahn, 1990:385). The AACC method for measuring spaghetti firmness is repeatable and correlates well with the subjective test of cooking quality (AACC method 16-50, 2000). Although it is a fast and precise method, the cost of the instrumentation is high to use as a quality assurance procedure (Hahn, 1990:385). The development of inexpensive measurements with the required precision is therefore necessary.

The purpose of this study was to test and improve on the accuracy of quality measurements recorded on cooked spaghetti and was performed in two phases.

The purpose of the first phase (Phase 1D) was to:

1. Standardise CL and RL measurements by calculating the number of repetitions required per batch, when different drying techniques (during the evaporation of cooking and rinse water) were used.

2. Standardise colour evaluation. The repeatability of colour measurement was calculated when five measurements were taken per batch.

The purpose of the second phase (Phase 1E) was to:

1. Validate cooking methods (sample preparation) identified from literature. Cooking methods (or methods of sample preparation) were compared in terms of its ability to discriminate between spaghetti of different quality.
2. Determine repeatability of valid cooking methods (methods of sample preparation). The cooking method yielding the most consistent quality measurements for CL, RL and WA is preferred.

## 6.2 LITERATURE REVIEW

### 6.2.1 Cooking loss percentage (CL) and rinse loss percentage (RL)

CL is defined as the material released from spaghetti during the cooking process. The CL is a reflection of spaghetti breakdown during cooking and is strongly negatively correlated to overall spaghetti quality (D'Egidio & Nardi, 1998:139), protein content and starch damage (Resmini & Pagani, 1983:1, Matsuo, 1988:259), i.e implying validity of the measurement. According to Holliger (1963:239), CL determination is not a sufficient measurement to discriminate between the cooked qualities of spaghetti samples of diverse quality. It was suggested that the cooked quality of spaghetti rather be determined by direct physical examination of the texture of the cooked products, using, for example, a texture analyser.

RL is defined as the surface material released from cooked spaghetti during exhaustive rinsing. RL is correlated to the stickiness of spaghetti (Dexter, Matsuo & MacGregor, 1985:43), i.e. implying validity of the measurement.

According to literature (AACC method 16-50, 2000, Miskelly, 1998:266, Dexter *et al*, 1985:43) CL and RL can be measured by two techniques: either by evaporating the entire cooking water and rinse water respectively or only a portion thereof. The latter method is often used because it requires shorter drying times, but may be inaccurate.

### 6.2.2 Water absorption (WA)

WA is defined as the amount of water spaghetti absorbs during the cooking process. It is expressed as the cooked spaghetti weight in relation to the dry spaghetti weight. This

measurement corresponds to the mass of the meal available to the consumer (yield). WA is negatively correlated to firmness and can therefore be used as an indirect estimation of firmness (Abecassis, Faure & Feillet, 1989:478, Grant, Dick & Shelton, 1993:684, Debbouz & Doetkott, 1996:674, Lustenberger & Qi Si, 2000), thus eliminating direct texture analysis. The WA capacity of spaghetti can be described by the water absorption factor (WAF) and the weight increase percentage (WIP). The WAF is determined by dividing the cooked mass by the dry mass (as is moisture basis) of the sample, giving the increase in meal size after the dried product has been cooked.

WIP is determined by expressing the difference between cooked and dry spaghetti mass, as a percentage of the dry spaghetti and should ideally be in the region of 160 to 180% for spaghetti (Holliger, 1963:233, Feillet & Dexter, 1998:95, Miskelly, 1998:265, *Buhler Laboratories*, 1998). This value is reported on a moisture free basis of the original dry samples, facilitating the accuracy of comparisons.

### 6.2.3 Cooking time

Spaghetti can be cooked to either the optimum cooking time or the tolerance cooking time. Optimum cooking time is defined as the precise time at which the ungelatinised core of the spaghetti disappears. This state is also referred to as "*al dente*" and is determined according to the AACC method 16-50 (2000). Tolerance cooking time is traditionally defined as the optimum cooking time plus five or ten minutes, in which case the spaghetti is over-cooked. The flaw in this definition is that it gives no consideration to what the optimum cooking time is. A product with a shorter optimal cooking time will be more over-cooked proportionally when compared to one with a longer optimum cooking time. It is therefore suggested that the tolerance cooking time be defined as a factor of the optimal cooking, whereby the optimal cooking time is increased proportionally to derive the tolerance cooking time. During this study, tolerance-cooking time was defined as 1,5 times that of the optimum cooking time, also referred to as over-cooking.

### 6.2.4 Resistance to over-cooking

The resistance of spaghetti to over-cooking is defined as the rate of spaghetti breakdown during over-cooking, therefore illustrating how well the product resists the cooking process (Matsuo, Malcolmson, Edwards & Dexter, 1992:29, Batey, Sissons & Bangur, 2000:692). Resistance to over-cooking is measured on over-cooked spaghetti in comparison to optimally cooked results to thereby illustrate the rate of spaghetti breakdown (Matsuo *et al*, 1992:29, Batey *et al*, 2000:692).



## 6.2.5 Colour

The AACC method 14-22 (2000) describes a method for determining cooked spaghetti colour with a reflectance colorimeter and is sufficiently standardised. When measuring cooked spaghetti colour, sample treatment after cooking and time elapsing between cooking and colour measurement, play the largest role in the measurement (Good, 2002). These variables should therefore be strictly controlled during colour evaluation. Upon cooking spaghetti it loses its translucency; therefore single layer evaluation is accepted. Between repetitions observed differences of measured colour can be expressed by  $\Delta E$  as described in Chapter 5, Equation 2. In the case of cooked pasta the value of  $\Delta E$  should be smaller or equal to one (Personal communication, H. Williams, Hunter Lab, 2002).

## 6.2.6 Cooking method

The AACC method 16-50 (2000) describes a spaghetti cooking method. This method requires the cooking of 25 g spaghetti samples in 300 ml artificially hardened water for the designated time. The ratio of cooking water to spaghetti sample must be at least 10:1, hereby ensuring rapidly boiling water after adding the spaghetti sample. This method also requires that the cooking water be topped up during the cooking process, which is obviously labour intensive. It is suggested that the length of the spaghetti strands are kept constant by cutting to 5 cm pieces (Grant *et al*, 1993:678). These methods lack detail regarding heating-plate temperature, spaghetti treatment during cooking and the specifications of the cooking container.

Heating-plate temperature and distribution of heat on the plate surface is of importance. Plate temperature determines the vigour with which water boils. Distribution of heat across the plate determines how evenly the product is cooked. Even heat distribution across the hotplate surface is not possible. Therefore stirring during cooking is required.

When cooking spaghetti for an extended period, spaghetti tends to stick to the bottom of the cooking flask. Possible solutions may be to stir spaghetti during cooking, or by making use of a stainless steel perforated cooking basket (Holliger, 1963:233).

The cooking container is of importance since flat-bottomed flasks maximise the area of contact with a plate to ensure a uniform boiling rate. The vigour with which water boils may affect the amount of material leaching into the cooking water. With non-uniform beakers, the volume of cooking water after cooking will also vary (Matsuo *et al*, 1992:28).

Although the cooking method (control variable) used greatly affects the subsequent quality measurements, cooking methods vary between laboratories. Standardisation is required.

### 6.3 PHASE 1D

During Phase 1D, methodology for CL and RL were developed and tested for repeatability. The methods were tested for the ability to discriminate between optimal and tolerance cooked spaghetti, both in terms of CL and RL. The methods with the highest repeatability and that could distinguish best, were applied in Phase 1E.

#### 6.3.1 Materials and methods

##### 6.3.1.1 Materials

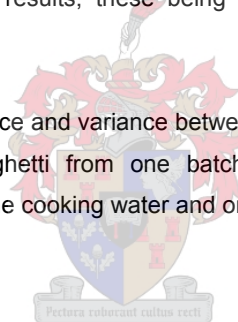
Sample D12, compiled of three 500 g packets (See Addendum A), was selected for its known low protein content (see Results, Table 6.1) and the known correlation of protein with CL and RL (D'Egidio & Nardi, 1998:139, Dexter *et al*, 1985:4). Spaghetti with poor cooked quality (for example, low firmness and high stickiness) will lead to greater CL and RL and would also be expected to result in larger variances within data (Dexter *et al*, 1985:43, D'Egidio & Nardi, 1998:139). Poor quality spaghetti leads to more cooked defects (more variation) and would need a more accurate technique to obtain consistent results, these being the means for selecting Sample D12.

Variance generally has two sources, sample variance and variance between samples. To illustrate variance introduced by the measurement, spaghetti from one batch was used. Eighteen repetitions were performed per drying method on the cooking water and on the rinse water.

##### 6.3.1.2 Methods

Protein, ash and moisture were determined in duplicate according to standard methods by the South African Grains Laboratory (SAGL), AACC methods 46-30 (2000), 08-02, (2000) and ICC Standard no. 110/1 (1999) respectively.

The AACC method 16-50 (2000) describes a spaghetti cooking method. This formed the basis for the developmental work done during this study. A single temperature-controlled ceramic-top *Gerhardt Ceran* hotplate (200 °C) was used to cook all 25 g spaghetti samples in 400 ml artificially hardened (pH 7) boiling water (AACC 16-50, 2000). Water was contained in a 600 ml flat-bottomed Griffin beakers (85 mm in diameter and 125 mm high). As opposed to the AACC



method, an increased amount of water, 400 ml, was used to eliminate the need to top up the water during cooking (AACC 16-50, 2000). Spaghetti was cooked in a cooking basket since it was argued that only those solids smaller than the basket mesh size (2 mm) would land up in the cooking and rinsing water.

Optimum cooking times were determined and tolerance cooking times were defined as 1,5 times the optimum cooking time, as opposed to the time required for optimum cooking, plus a fixed amount of time as reported in the literature. This method of calculating tolerance cooking time was preferred to prevent over-cooking of spaghetti that requires shorter cooking to the optimal state. All samples were cooked for both optimum and tolerance cooking times in order to determine CL, RL and WA (WAF & WIP). Colour was only measured after cooking to the optimum time. Five measurements were taken per sample and subjected to difference testing (Equation 2, in Chapter 5) to establish whether five measurements would suffice.

After cooking and draining for 90 seconds through a *Büchner* funnel the spaghetti was allowed to rest for 10 minutes and then weighed for WA determination. The cooking water was collected in pre-dried drying pans (weighed to the nearest 0,001 g). The spaghetti was placed in 150 ml distilled water for 10 minutes to rinse, while stirring for the first 30 seconds only. Thereafter the spaghetti was drained through a 250  $\mu\text{m}$  nylon sieve for 90 seconds and colour evaluation was performed immediately. Colour was measured with a *Hunter ColorFlex spectrophotometer model 45°/0°* (Hunter Lab ColorFlex TM User Guide, 1999:10-9, AACC 14-22, 2000). The rinse water was collected in drying pans (weighed to the nearest 0,001 g).

One of these three drying methods (DM) were used for drying the cooking and rinse water:

- 1) Drying method 1 (DM1): 3 x 5 ml aliquots in drying dishes with 5 g – 2 mm glass beads;
- 2) Drying method 2 (DM2): 3 x 5 ml aliquots in drying dishes without glass beads;
- 3) Drying method 3 (DM3): complete sample in a drying dish with 10 g – 2 mm glass beads.

The drying pans containing the water samples were placed into a temperature-controlled convection oven at 103°C. Aliquots were evaporated for 60 minutes and the entire cooking and rinse water were evaporated for 24 hours. These times proved sufficient to ensure complete dryness. Drying times were determined by taking mass recordings at 30 minute intervals during drying and defined as the time at which mass readings stabilised. CL, RL and WA were calculated and expressed as a proportion of the ingoing uncooked spaghetti mass (on dry basis).

The order of the tests were randomised and completed in nine consecutive days. Eighteen repetitions were performed per day for the specific test allocated to that day. All quality measurements of the cooked spaghetti (CL, RL, WA and colour) were determined after cooking the

samples to the optimum cooking times and tolerance cooking times respectively, with the exception of cooked colour, which was only measured when optimally cooked.

### 6.3.1.3 Statistical procedures

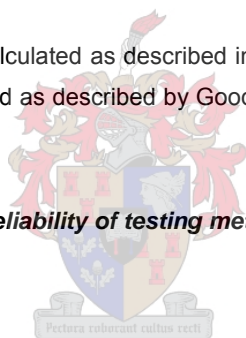
**Test for normality.** Since many standard statistical techniques (for example ANOVA and LSD) are based on the assumption of normality (Snedecor & Cochran, 1976:84), normality was tested with the *Shapiro-Wilk* test for non-normality;  $P < 0,05$  is an indication of non-normality (Shapiro & Wilk, 1965). Non-normality can be due to kurtosis or scewness (Snedecor & Cochran, 1976:86). The normal distribution has a kurtosis value of  $\leq 3$  and scewness value = 0 (Snedecor & Cochran, 1976:86). Kurtosis has no effect on the means and therefore further statistical analysis can continue (Shapiro & Wilk, 1965). Normality was computed using the SAS statistical package (SAS, 1999).

**Analysis of variance (ANOVA).** The GLM procedure of SAS was used to construct ANOVA tables for variables measured where applicable.

**Least significant difference test (LSD).** The LSD was calculated according to Snedecor and Cochran (1976:272) using the SAS statistical package, calculating the *Students' t*-LSD at  $P = 0,05$  (SAS, 1999).

**Sample size determination.** Sample size was calculated as described in Chapter 5, Equation 3. For colour the required sample size was determined as described by Good (2002:6), Equation 2 in Chapter 5 for cooked pasta, but for  $\Delta E \leq 1$ .

**Criteria for accepting or rejecting validity and reliability of testing methods.** Refer to Chapter 5, Section 3.3.2.3.



### 6.3.2 Results and discussion

The first phase consisted of six experimental treatments for CL and RL determination, cooked to optimum cooking time and tolerance cooking time. CL and RL were determined by three different drying methods, namely DM1, DM2 and DM3. From the results presented in Table 6.1 it is clear that protein content of Sample D12 was very low (negative correlated with high CL and RL).

**TABLE 6.1 ANALYTICAL DATA**

Measurements (%)	Sample D12
Moisture	10,25
Protein (12% moisture basis)	10,41
Ash (dry basis)	0,46

**6.3.2.1 Cooking loss percentage (CL)**

Treatments were the degree of cooking (optimal or tolerance) by drying method (DM1, DM2 or DM3). Eighteen repetitions were performed (2 degrees of cooking x 3 drying methods x 18 repetitions=108). The data were not distributed normally ( $P<0,05$ ). This was ascribed to kurtosis (4,32) and therefore further analysis could be done. The constructed ANOVA table is presented in Table 6.2. It is clear that there were treatment differences ( $P<0,01$ ). The differences could therefore be further investigated to determine which DM was most accurate (Table 6.3).

**TABLE 6.2 ANOVA FOR COOKING LOSS PERCENTAGE (CL)**

Source	df	MS	P
Treatment	5	6,24	<0,01
Error	102	0,74	
Corrected total	107		

It is clear from Table 6.3 that DM3 showed the largest difference (1,19% units) between optimum and tolerance cooking. This difference was significant at  $P\leq 0,05$ . This method can therefore be described as the most accurate method when determining CL. Since reliability is a measure of accuracy, this method was selected as the most appropriate or valid measure to use. Although DM1 yielded significant differences, these differences were of smaller magnitude (0,71% units), while DM2 failed to demonstrate differences at  $P\leq 0,05$ .

**TABLE 6.3 MEAN VALUES FOR COOKING LOSS PERCENTAGE (CL) BETWEEN TREATMENTS**

TREATMENTS	DRYING METHOD		
	DM1 (aliquots cooking water with beads)	DM2 (aliquots cooking water without beads)	DM3 (complete cooking water with beads)
Optimum	6,90 <sup>bc</sup>	6,37 <sup>dc</sup>	5,93 <sup>d</sup>
Tolerance	7,61 <sup>a</sup>	6,92 <sup>bc</sup>	7,12 <sup>ab</sup>

<sup>a-d</sup>Means (n=18) with the different superscripts differ ( $P\leq 0,05$ ,  $LSD=0,57$ )

The addition of glass beads seemed to have had a positive effect on the results. Faulty sampling of suspended particles may be responsible for the smaller differences obtained when analysing aliquots in comparison to analysis of the complete sample.

The required sample size per drying method was the lowest for DM3 (two measurements). Sample size was calculated at a confidence limit of 95% and an accepted error of 1% (L). DM3 is therefore the most reliable (Snedecor & Cochran, 1974:516). See Table 6.4 for results.

**TABLE 6.4 DETERMINATION OF A SAMPLE SIZE WHEN MEASURING COOKING LOSS PERCENTAGE (CL)**

TREATMENTS		CL			
DRYING METHOD	DEGREE OF COOKING	n	Mean	Std. Dev.	Measurements required *
DM1 (aliquots cooking water with beads)	Optimum	18	6,90	1,27	6,43
	Tolerance	18	7,61	1,06	4,49
DM2 (aliquots cooking water without beads)	Optimum	18	6,37	0,55	1,22
	Tolerance	18	6,92	0,94	3,53
DM3 (complete cooking water with beads)	Optimum	18	5,93	0,41	0,67
	Tolerance	18	7,12	0,61	1,51

\* The number of measurements required per batch at a confidence level of 95% and allowed error (L) of 1% per batch

### 6.3.2.2 Rinse loss percentage (RL)

Treatments were the degree of cooking (optimal or tolerance) by drying method (DM1, DM2 or DM3). Eighteen repetitions were performed (2 degrees of cooking x 3 drying methods x 18 repetitions=108). The data were distributed normally (P=0,97). An ANOVA table was constructed and is presented in Table 6.5. It is clear that there were treatment differences (P<0,01). The differences could therefore be further investigated to determine which DM was most accurate (Table 6.6).

**TABLE 6.5 ANOVA FOR RINSE LOSS PERCENTAGE (RL) BETWEEN TREATMENTS**

Source	df	MS	P
Treatment	5	5,62	<0,01
Error	101	0,35	
Corrected total	106		

It is clear from Table 6.6 that all drying methods distinguished between RL of optimum-cooked and tolerance-cooked samples. This difference was significant at  $P \leq 0,05$ . These methods can therefore be described as accurate methods when determining RL. Since reliability is a measure of accuracy, any one of these methods could be selected as an appropriate or valid measure. The addition of glass beads had no noticeable effect on measurements.

**TABLE 6.6 MEAN VALUES FOR RINSE LOSS PERCENTAGE (RL) BETWEEN TREATMENTS**

TREATMENTS	DRYING METHOD		
	DM1 (aliquots rinse water with beads)	DM2 (aliquots rinse water without beads)	DM3 (complete rinse water with beads)
Optimum	1,41 <sup>b</sup>	1,18 <sup>b</sup>	1,07 <sup>b</sup>
Tolerance	2,42 <sup>a</sup>	2,10 <sup>a</sup>	2,07 <sup>a</sup>

<sup>a-b</sup>Means (n=18) with the different superscripts differ ( $P \leq 0,05$ , LSD=0,40)

**TABLE 6.7 DETERMINATION OF A SAMPLE SIZE WHEN MEASURING RINSE LOSS PERCENTAGE (RL)**

Treatments		RL			
DRYING METHOD	DEGREE OF COOKING	n	Mean	Std dev	Measurements required *
DM1 (aliquots rinse water with beads)	Optimum	18	1,41	0,26	0,28
	Tolerance	18	2,42	0,72	2,07
DM2 (aliquots rinse water without beads)	Optimum	18	1,18	0,29	0,34
	Tolerance	18	2,10	0,50	1,02
DM3 (complete rinse water with beads)	Optimum	18	1,07	0,34	0,47
	Tolerance	18	2,07	1,03	4,27

\* The number of measurements required per batch at a confidence level of 95% and allowed error (L) of 1% per batch

The required sample size per drying method was the lowest (two measurements) for DM2. Sample size was calculated at a confidence limit of 95% and an accepted error of 1% (L). DM2 was therefore the most reliable (Table 6.7). DM2 was selected for rinse loss measurements since this method was the simplest to perform (requires no glass beads), has a short drying time and required the smallest sample size.

### 6.3.2.3 Water absorption (WA)

The sample size required when determining WA when cooking according to this particular cooking method (cooking basket), is indicated Table 6.8. DM does not affect WA measurements, therefore

all measurements across three drying methods and 18 repetitions were used when calculating sample size ( $3 \times 18 = 54$ ). When an accepted error of 0,1% and 5% is allowed for the WAF and the WIP respectively, at a confidence level of 95%, two and seven measurements (repetitions) are respectively required per batch for WAF and WIP (Table 6.8).

**TABLE 6.8 DETERMINATION OF A SAMPLE SIZE WHEN MEASURING WATER ABSORPTION (WA) WITH A COOKING BASKET**

MEASUREMENT	DEGREE OF COOKING	n	Mean	Std dev	Measurements required *
WAF	Optimum	54	2,53	0,04	0,53
	Tolerance	54	3,00	0,06	1,34
WIP	Optimum	54	182,10	4,05	2,63
	Tolerance	54	234,42	6,46	6,67

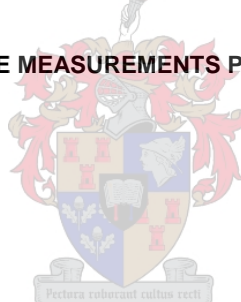
\* The number of measurements required per batch at a confidence level of 95% and allowed error (L) of 0,1% for the "WAF", and an error of 5% for the "WIP" per batch.

### 6.3.2.4 Colour

In Table 6.9,  $\Delta E$  was calculated for five measurements per batch. Neither DM nor CM introduces variance in colour measurements; therefore all measurements across three drying methods and 18 repetitions were pooled and used when calculating sample size ( $n=3 \times 18=54$ ). From the  $\Delta E$  value it is clear that the five measurements were sufficient to yield a  $\Delta E \leq 1$ .

**TABLE 6.9 COLOUR VALUES AND  $\Delta E$  FOR FIVE MEASUREMENTS PER BATCH**

MEASUREMENT	Mean (n = 54)
L value	60,27
a value	-4,46
b value	7,78
Yellowness Index	17,80
$\Delta E$	0,52*



\* $\Delta E \leq 1$  is sufficient to provide repeatable results

### 6.3.3 Implications for Phase 1E

Under the conditions of this study, it was concluded that the CL should be measured by drying the total cooking water in a dish containing 10 g – 2 mm glass beads, and when measuring RL, 5 ml aliquots should be dried in a dish without glass beads.



The number of repetitions required per batch when measuring CL, RL and WA (i.e. “W1” and the “WAF”), is true only when the specific cooking method is used. The number of measurements required for colour determination, is true irrespective of cooking method.

## **6.4 PHASE 1E**

This phase (Phase 1E) follows on the results of the previous phase, and focused on the various cooking methods. Firstly, the cooking method should not obscure differences between samples that are different. It should secondly allow consistent results in quality measurements.

### **6.4.1 Materials and methods**

#### **6.4.1.1 Materials**

Three composite spaghetti samples A13, B13 and C13 (3 x 500 g each) were selected on known formulation and quality differences (See Addendum A). Anticipated protein content differences were confirmed (see Results, Table 6.10). Protein content is correlated with CL and RL, therefore variation is expected in cooked quality (D'Egidio & Nardi, 1998:139, Dexter *et al*, 1985:4).

#### **6.4.1.2 Methods**

The ability of cooking methods to discriminate between spaghetti samples of diverse quality was determined (validity). Thereafter, valid tests were evaluated for repeatability.

Protein, ash and moisture were determined in duplicate according to standard methods by the South African Grains Laboratory (SAGL), AACC methods 46-30 (2000), 08-02, (2000) and ICC Standard no. 110/1 (1999) respectively.

To determine whether the methods could effectively distinguish between brands (based on differences in protein content), four repetitions were performed. Spaghetti samples of diverse quality were cooked with each of the developed cooking methods. The measurements obtained were used to determine the validity.

All spaghetti samples were cooked as described in Phase 1D, with cooking method being the only variable. CL (DM3, see results) and RL (DM2, see results) measurements were performed as summarised in Section 6.3.3 and the variability introduced by the cooking method was measured by deviations in CL, RL and WA. The three cooking methods (CM) were:

- 1) Cooking method 1 (CM1): in a basket with no agitation;
- 2) Cooking method 2 (CM2): not in a basket with manual stirring;
- 3) Cooking method 3 (CM3): not in a basket with magnetic stirring

CM1 was performed by placing samples in a cooking basket, submerging into 400 ml artificially hardened boiling water, stirring for the first 30 seconds. CM2 was performed by directly adding spaghetti to 400 ml artificially hardened boiling water, manually stirring continuously for the first 30 seconds and thereafter periodically stirring every 30 seconds. CM3 was performed by directly adding samples to boiling water, while continuously stirring with a magnetic stirring bar ( $\pm 100$  rpm). In all cooking tests samples were cooked to both optimum and tolerance cooking times.

Secondly, after the identification of valid cooking tests, these were evaluated for repeatability. Within 6 consecutive days, 16 repetitions of the valid cooking tests were done (in randomised order). The sample of poorest quality, as identified during the validity analysis, was used during repeatability analysis.

#### 6.4.1.3 Statistical procedures

Refer to description in Phase 1D.

#### 6.4.2 Results and discussion

From the results presented in Table 6.10 differences are noted in analytical measurements (most importantly protein content).

**TABLE 6.10 ANALYTICAL RESULTS**

Measurements (%)	Sample A13	Sample B13	Sample C13
Moisture	9,43	8,97	8,44
Protein (12% moisture basis)	10,69	11,25	12,01
Ash (dry basis)	0,83	1,60	1,42

##### 6.4.2.1 Validity determination

An average of four measurements per pasta sample were calculated and compared to determine whether the respective cooking method could discriminate between diverse spaghetti brands A13, B13 and C13 (Table 6.11). CM3 (not in a basket, with magnetic agitation) proved to be the most discriminate, followed by CM2 (not in a basket, with manual stirring) (Table 6.11). CM1 (in a basket, without agitation) was invalid, as it does not discriminate between samples, i.e. the use of a

cooking basket is not advised. CM2 and CM3 were subjected to repeatability testing considering their ability to discriminate between diverse spaghetti samples.

**TABLE 6.11 COMPARISON BETWEEN COOKING METHOD VALIDITY**

COOKING TEST	CM1: COOKING BASKET				CM2: HAND STIRRING				CM3: MAGNETIC STIRRING			
	SAMPLE			LSD	SAMPLE			LSD	SAMPLE			LSD
MEASUREMENTS (n = 4)	A13	B13	C13		A13	B13	C13		A13	B13	C13	
WAF Optimum	b	a	c		a	a	b		a	b	c	
Mean	2,48	2,33	2,79	0,10	2,64	2,66	3,15	0,08	2,49	2,62	3,11	0,10
Std dev	0,07	0,03	0,01		0,03	0,05	0,03		0,046	0,025	0,056	
WAF Tolerance	b	a	c		a	b	c		a	b	c	
Mean	2,83	2,71	3,24	0,10	2,80	2,99	3,63	0,21	2,62	2,72	3,59	0,10
Std dev	0,03	0,04	0,06		0,16	0,02	0,05		0,036	0,048	0,051	
WIP Optimum	b	a	c		a	a	b		a	a	b	
Mean	172,91	155,99	203,75	11,12	190,57	190,5	243,63	9,38	175,3	185,8	239,44	11,09
Std dev	7,55	3,68	1,58		3,15	5,25	3,83		4,966	2,229	6,578	
WIP Tolerance	b	a	c		a	a	b		a	b	c	
Mean	211,50	196,76	252,49	10,90	212,06	228,3	297,17	24,44	188,8	199,2	292,10	10,52
Std dev	2,81	4,90	6,21		18,04	2,36	4,77		4,185	4,386	5,364	
CL Optimum	a	a	a		b	a	a		b	a	a	
Mean	7,28	6,92	7,21	0,40	10,08	7,08	7,98	1,80	13,30	8,81	7,89	1,25
Std dev	0,24	0,16	0,12		1,08	0,35	0,79		0,881	0,372	0,064	
CL Tolerance	a	a	a		b	a	a		c	b	a	
Mean	8,26	7,83	8,29	0,62	15,02	9,71	8,80	4,05	20,80	16,57	9,72	3,04
Std dev	0,19	0,35	0,26		2,63	1,66	0,23		0,387	2,205	0,684	
RL Optimum	a	a	a		b	a	a		b	b	a	
Mean	1,80	1,52	1,70	0,54	3,29	1,52	1,52	0,89	3,41	3,06	2,04	0,99
Std dev	0,17	0,09	0,37		0,67	0,09	0,12		0,165	0,725	0,165	
RL Tolerance	b	a	a		b	b	a		b	ab	a	
Mean	2,93	1,48	1,55	1,29	4,19	3,43	1,84	1,49	4,57	3,84	2,53	1,87
Std dev	0,93	0,09	0,33		1,10	0,18	0,30		0,75	1,10	0,53	

<sup>a-c</sup>Means (n=4) with the different superscripts differ ( $P \leq 0,05$ ,  $LSD=0,40$ )

#### 6.4.2.2 Reliability determination

Results summarised in Table 6.12 indicated that CM3 (not in a basket, with magnetic agitation) would require four measurements per batch when cooked optimally, whereas five measurements would be required if CM2 (not in a basket, with manual stirring) were used. When over-cooked, CM3 required five measurements per batch and CM2 required nine measurements per batch. CM3 has proved to be valid and most repeatable.

**TABLE 6.12 COMPARISON BETWEEN COOKING METHOD REPEATABILITY**

COOKING TEST	CM2: HAND STIRRING		CM3: MAGNETIC STIRRING	
	Result	Measurements required*	Result	Measurements required*
WAF Optimum				
Mean	2,61	0,91	2,48	0,78
Std dev	0,05	(L=0,1)	0,04	(L=0,1)
WAF Tolerance				
Mean	2,78	1,72	2,58	0,69
Std dev	0,13	(L=0,1)	0,04	(L=0,1)
WIP Optimum				
Mean	187,91	4,46	174,37	3,79
Std dev	5,28	(L=5)	4,87	(L=5)
WIP Tolerance				
Mean	207,13	8,41	185,10	3,38
Std dev	14,75	(L=5)	4,60	(L=5)
CL Optimum				
Mean	10,65	4,99	13,40	3,46
Std dev	1,12	(L=1)	0,93	(L=1)
CL Tolerance				
Mean	17,50	5,54	22,32	4,02
Std dev	1,77	(L=1,5)	1,50	(L=1,5)
RL Optimum				
Mean	3,51	2,44	3,42	2,86
Std dev	0,82	(L=1)	0,89	(L=1)
RL Tolerance				
Mean	4,70	4,98	4,36	4,80
Std dev	1,17	(L=1)	1,15	(L=1)

\* The number of measurements required per batch at a confidence level of 95% and allowing an error (L) as indicated in brackets

## 6.5 CONCLUSIONS AND RECOMMENDATIONS

When cooking spaghetti in a cooking basket, no differences were found between diverse quality spaghetti samples. This is in agreement with the findings of Holliger (1963:232). Large distinctions were found in measurements of CL, RL and WA, when cooked without the cooking basket. In contrast to the recommendations of Holliger (1963:232), CL measurement may be a valid measurement of spaghetti quality. A possible explanation for this finding is that when cooking in a basket, spaghetti is protected from mechanical damage due to reduced movement during cooking. This simple determination of CL may be used to distinguish between samples of different quality if CM3 is used.

When measuring CL and RL, DM3 (not in a basket, with magnetic agitation) and DM2 (not in a basket, with manual stirring) should be used, respectively. If cooked spaghetti quality is measured in terms of CL, RL and WA it is recommended that CM3 be used. For the determination of optimally cooked spaghetti quality, four measurements are required per batch and for the determination of tolerance cooked spaghetti quality, five measurements are required per batch. This cooking test proved to be reliable and valid as it distinguished between optimally and tolerance cooked measurements of CL, RL and WA, as well as between samples of diverse quality.

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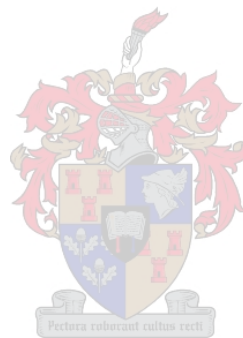
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## CHAPTER 7: A COMPARISON OF DRY AND COOKED QUALITY OF THREE SELECTED PASTA BRANDS READILY AVAILABLE ON THE SOUTH AFRICAN MARKET

### 7.1 INTRODUCTION

The quality of pasta in the South African market is diverse. Pasta is imported, and also produced locally from durum and bread wheat. The preferred pasta raw material, durum wheat, is not grown in South Africa. Importing durum wheat or semolina for local pasta production is more expensive than to import the final pasta product. To be competitive with imported durum pasta, bread wheat must be used as raw material. Bread wheat trades at a competitive price, is readily available and South African mills are designed specifically to mill bread wheat, while a dedicated mill is required to mill durum wheat.

Most scientific studies cited in this chapter investigated either the effect of different drying temperatures on a particular cultivar of wheat (Dexter, Matsuo & Morgan, 1981, De Stefanis & Sgrulletta, 1990, Novaro, D'Egidio, Mariani & Nardi, 1993) or quality measurements on different cultivars of wheat (Matsuo, Dexter, Kosmolak & Leisle, 1982, D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990, De Stefanis & Sgrulletta, 1990). Limited attention has been given to durum wheat pasta in comparison to bread wheat pasta, though the following authors have reported such work: Wyland & D'Appolonia, 1982:200, Marconi, Carcea, Graziano & Cubadda, 1999, Marconi & Carcea, 2001, Marconi, Carcea, Schiavone & Cubadda, 2002.

Various articles describe the advantages of higher drying temperatures, as reviewed by Feillet, Abecassis, Autran and Laignelet, 1996. No direct comparisons between bread wheat pasta dried at very high-temperatures (VHT), durum semolina pasta dried at high-temperature (HT), and durum semolina pasta dried at VHT are reported in the literature. However, literature suggests that VHT has a more pronounced effect on lower protein content raw materials, such as in bread wheat, than on higher protein raw materials, such as in durum wheat (Feillet *et al*, 1996).

The first aim of this study was to select three brands of different perceived quality and to compare the dry and cooked quality of these brands. The brands were evaluated to highlight the quality differences between brands. Difference between brands may be due to the use of durum versus bread wheat, the composition and milling of the raw material, due to the use of HT versus VHT drying technology, as well as defects caused by the manufacturing process and distribution chain. This information is required to plan business strategy and brand positioning.

The problem of this experimental design is that there are far more variables than there are products. The variables include the raw material used, the composition (e.g. protein content) and

state of the raw material (e.g. starch damage, flour versus semolina etc), the manufacturing process (e.g. high versus low temperature drying), the quality control during manufacture, packaging material and conditions of transport. Of these variables only a limited number could be controlled and measured. This information is nevertheless required to highlight the differences currently existing between spaghetti brands and provides the manufacturer with information that will define where the quality of their product require attention. Once this information is at hand, the manufacturer can start planning product improvement and decide whether more in-depth research is required.

The second aim was to test the validity of the proposed quality measures that could not be evaluated in the preceding chapters due to either the low occurrence of defects or the small sample size used. If quality measurements distinguish between brands and the data is distributed normally, it reflects on the validity of the measurement. This objective specifically refers to measurements of strands that are bent, strands that stick together, strands with a white line, strands with loops, measurement of broken, cracks, fissures, white spots, flour spots and dark spots.

## 7.2 MATERIALS AND METHODS

The three brands were selected on the grounds of their perceived quality, ranging from low (bread wheat flour, VHT, Brand A) through medium (durum wheat semolina, HT, Brand B) to excellent quality (durum wheat semolina, VHT, Brand C). Packaging material varied between brands. Brand A was packed in low density polyethylene sheeting. Brands B and C were packed directly into cardboard boxes. Sixteen batches of each brand were used for the representation of each brand. Each batch consisted of three 500 g spaghetti packets. Refer to Addendum A for sampling; Brand A comprised of samples A14–30, Brand B of samples B14–30 and Brand C of samples C14–30. Batch numbers were used to distinguish between batches and samples were purchased from retail outlets in either Cape Town or Johannesburg.

Methods proposed in Chapters 5 and 6 were used to measure the quality characteristics of dry and cooked spaghetti and is summarised below. First a composite sample was prepared by combining the three 500 g packets per batch; whereafter the evaluation was conducted as follows:

1. **Breakages:** The composite sample (1500 g) was sifted (mesh 5.5 mm) and small broken units removed and allocated to breakage category B5 (units < 5.5 mm). Thereafter the rest of the broken units, allocated to breakage category B4 (units < 120 mm and  $\geq$  5.5 mm) were removed. Broken units were weighed and expressed as mass percentages. See section 5.3.1.4, Table 5.1, for more detail.

2. **Sample division:** From the spaghetti that was left-over, the following samples were randomly drawn:

- 2.1. 4 samples each consisting of 60 strands
- 2.2. 1 sample consisting of 10 strands
- 2.3. 5 samples each consisting of 100 strands
- 2.4. 1 sample of 200 g
- 2.5. 1 sample of 350 g
- 2.6. Left-over sample kept separately

3. **Breakages and cutting defects / cutter settings and strand length:** One of the 60 strand samples (Point 2.1) were divided into strand length categories B1 (strands  $\geq 260$  mm), B2 (target range, strands  $< 260$  mm and  $\geq 240$  mm) and B3 (strands  $< 240$  mm and  $\geq 120$  mm). Per category strands were counted and expressed as a unit percentage. See section 5.3.1.4, Table 5.1, for more detail.

From those strands divided into Category B2 (target range), 10 strands randomly drawn. The average strand length was determined by measuring the length of these 10 strands with a calibrated ruler to the nearest 1 mm.

4. **Strand diameter:** The average diameter was determined by measuring the diameter of 10 randomly drawn strands (Point 2.2) with a vernier caliper to the nearest 0.02 mm. One measurement was taken in the middle of each strand.

5. **Strands with a white line, bent shape and loops:** From the additional three 60 strand samples (Point 2.1), units with white lines, bent shape and those with loops were removed from a specific sample. One sample was used for each of the defects mentioned. Defects were expressed as a unit percentage.

6. **Cracks, fissures, white spots, flour spots and dark spots:** The five 100 strand samples (Point 2.3) were used to determine the degree of cracking, fissuring, white spots, flour spots and dark spots, one sample for each of the defects mentioned. Each of the 100 strands was inspected individually, against a black background and viewed through a sieve counting lens. Each strand was categorised according to the degree of damage present. Categorisation was done against reference photographs presented in Figures 5.2 to 5.6. Refer to Section 5.3.1.4 for more detail.

7. **Protein, moisture and ash:** One 200 g sample was used for protein, ash and moisture analysis (Point 2.4). Analyses were done in duplicate by the South African Grains Laboratory (SAGL) according to the AACC methods 46-30 (2000) and 08-02, (2000) and, ICC Standard no. 110/1 (1999) respectively.
8. **Dry colour:** The left-over sample (Point 2.6) was used for dry colour evaluation. Per batch, three colour measurements were taken in multiple layers (90 mm wide, 20 mm deep). A *Hunter ColorFlex spectrophotometer model 45 ° / 0 °* (Hunter Lab ColorFlex TM User Guide, 1999:10-9, AACC 14-22, 2000) was used to measure L, a and b values and to calculate the yellowness index (see Section 5.2.4).
9. **Cooking:** The 350 g sample (Point 2.5) was cut into 5 cm pieces and used for the evaluation of cooked pasta. Two cooking times were used: time to reach the optimal state and time to over-cook (tolerance cooking) and referred to as the degree of cooking (DC).

From the 350 g sample, 4x25 g samples was drawn and used to determine the cooking time. Optimum cooking times were determined as described by AACC method 66-50 (2000) and tolerance cooking times were defined as a 1,5 factor of the optimum cooking time. A further four samples of 25 g was drawn and each cooked independently for the optimal cooking time, whereafter CL, RL, WA and colour were measured. Another four 25 g samples were drawn and each cooked independently to the tolerance cooking time, whereafter CL, RL and WA was measured.

A single temperature-controlled ceramic-top *Gerhardt Ceran* hotplate (200 °C) was used to cook all 25 g spaghetti samples in 400 ml artificially hardened (pH 7) boiling water (AACC 16-50, 2000). Water was contained in 600 ml flat-bottomed Griffin beaker (85 mm in diameter and 125 mm high).

After cooking and draining for 90 seconds through a *Büchner* funnel the spaghetti was allowed to rest for 10 min and then weighed (to the nearest 0.01) for WA determination (as described in Section 6.2.2). The total cooking water was collected in pre-dried drying pans (weighed to the nearest 0,001 g) containing 10 g glass beads and evaporated. The spaghetti was placed in 150 ml distilled water for 10 minutes to rinse, while stirring for the first 30 seconds only. Thereafter the spaghetti was drained through a 250 µm nylon sieve for 90 seconds and colour evaluation was performed immediately. Colour was measured with a *Hunter ColorFlex spectrophotometer model 45 ° / 0 °* (Hunter Lab ColorFlex TM User Guide, 1999:10-9, AACC 14-22, 2000) and five measurements taken per sample.

Of the left-over rinse water, 3x5 ml aliquots were pipetted into drying pans (weighed to the nearest 0,001 g) without glass beads and evaporated to dryness. The drying pans containing the water samples (cooking water and rinse water) were placed into a temperature-controlled convection oven at 103°C. Rinse water aliquots (5 ml) were evaporated for 60 minutes and the total cooking were evaporated for 24 hours. These times proved sufficient to ensure complete dryness. Drying times were determined by taking mass recordings at 30-minute intervals during drying and defined as the time at which mass readings stabilised. CL, RL and WA were calculated and expressed as a proportion of the ingoing uncooked spaghetti mass (on dry basis) as described in Sections 6.2.1 and 6.2.2.

### 7.2.1 Statistical analyses

Since many standard statistical techniques (e.g. ANOVA, LSD) are based on the assumption of normality, the normality of datasets is of interest (Snedecor & Cochran, 1976:84). Normality was tested with the *Shapiro-Wilk* test for non-normality. Non-normality can be assumed when  $P < 0,05$  (Shapiro & Wilk, 1965). Non-normality can be due to kurtosis or scewness (Snedecor & Cochran, 1976:86). The normal distribution has a kurtosis value three or less and a scewness value of zero (Snedecor & Cochran, 1976:86). Kurtosis has no effect on the means and therefore allows standard statistical analysis (Shapiro & Wilk, 1965). The test for normality was computed on the SAS statistical package (SAS, 1999). Outliers were identified as values exceeding sample means by more than three standard deviations and removed as a standard statistical procedure, resulting in  $n < 16$  in some cases.

The GLM procedure of SAS was used to construct analysis of variance (ANOVA) tables for the measured variables. Where applicable, interactions were calculated. Thereafter, the least significant differences (LSD) were calculated (Snedecor & Cochran, 1976:272) by means of the SAS statistical package, calculating the *Students' t*-LSD at  $P = 0,05$  (SAS, 1999).

## 7.3 RESULTS AND DISCUSSION

### 7.3.1 Comparison of dry spaghetti quality

The ANOVA tables for dry variables are presented in Tables 7.1 to 7.16. The variables are individually discussed and their means, standard deviations and LSD values summarised in Table 7.17 (see at the end of the report on dry spaghetti quality). Significant differences are indicated in the latter table.

**Protein.** Protein data (%) were distributed normally ( $P=0,6375$ ) and the ANOVA indicated that brands differed in protein content ( $P<0,0001$ , Table 7.1). The protein content of all three brands differed significantly (Table 7.17). Brand A had the lowest protein content (11,09%), followed by Brand B (11,52%), and Brand C had the highest protein content (12,08%). This was also the order of perceived quality and is in agreement with the literature that quality is a function of protein content (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter, Matsuo & Morgan, 1983:1545, Hahn, 1990:394, Edwards, Izydorczyk, Dexter & Biliaderis, 1993:125, Malcolmson, Matsuo & Balshaw, 1993:420, Feillet & Dexter, 1998:116, Gianibelli, Uthayakumaran, Sissons, Morell & Batey, 2000:642, Sissons & Hare, 2002:83).

**TABLE 7.1 ANOVA FOR PROTEIN CONTENT (%)**

Source	DF	MS	P
Product	2	3,6	<0,0001
Error	41	0	-
Corrected total	43	-	-

Durum wheat generally contains more protein than bread wheat and is also reflected in final spaghetti protein content of this study. This is also in agreement with literature (Banasik, 1981:167, Pylar, 1988:330, Feillet & Dexter, 1998:96, Dexter, Preston, Marchylo, Clarke & Carcea, 2000:662, Marconi & Carcea, 2001:522, Wiseman, 2001:18, Marconi *et al*, 2002:636).

**Ash.** Ash data (%) were distributed normally ( $P=0,0737$ ). The ANOVA for ash suggested that there were differences between brands ( $P<0,0001$ , Table 7.2).

**TABLE 7.2 ANOVA FOR ASH CONTENT (%)**

Source	DF	MS	P
Product	2	1.3	<0,0001
Error	45	0	-
Corrected total	47	-	-



From the comparison of means (Table 7.17), it is clear that the two durum semolina brands (Brands B and C) contained significantly more ash (1,29% and 1,29% respectively) than the bread wheat flour brand (0,79% for Brand A). No other comparisons of this nature could be found in literature. However, it can be expected that the milling process of durum wheat normally yields higher ash content in comparison to bread wheat, since durum wheat is harder and more difficult to mill (Turnbull, 2001a:44, Dawe, 2001:91).

**Moisture.** The data for moisture (%) were distributed normally ( $P=0,3963$ ). The ANOVA presented evidence that there were differences between brands ( $P<0,0001$ , Table 7.3). All three brands differed significantly from one another (Table 7.17). Brand A had the highest moisture content,

namely 10,28%, followed by Brand B with an intermediate level of 9,89%, and Brand C with 9,35%. However, all values were below the 12% critical upper limit, but exceeded 9% (Table 7.17). These moisture levels may be described as acceptable levels (Holliger, 1963:233, Turnbull, 2001b:214).

**TABLE 7.3 ANOVA FOR MOISTURE CONTENT (%)**

Source	DF	MS	P
Product	2	3,5	<0,0001
Error	45	0,2	-
Corrected total	47	-	-

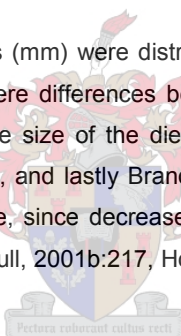
**Length.** Spaghetti strand length measurements (mm) were not distributed normally ( $P=0,0119$ ), but this was due to the kurtosis effect (2,65) and analysis of variance was possible (scewness=0,9). The P value of <0,0001 is evidence that brands differed (Table 7.4).

**TABLE 7.4 ANOVA FOR STRAND LENGTH (MM)**

Source	DF	MS	P
Product	2	234	<0,0001
Error	44	4,7	-
Corrected total	46	-	-

These differences were statistically significant, but of no real value, since all three brands were within the target length of  $250 \pm 10$  mm (Table 7.17).

**Diameter.** Spaghetti strand diameter measurements (mm) were distributed normally ( $P=0,8104$ ) and the ANOVA ( $P<0,0001$ ) indicated that there were differences between brands (Table 7.5). The diameter of spaghetti is determined by the plate size of the die. Brand B had the largest diameter (1,79 mm), followed by Brand A (1,72 mm), and lastly Brand C (1,68 mm, Table 7.17). These differences were significant and of importance, since decreased diameter leads to higher surface to volume ratio, affecting cooking time (Turnbull, 2001b:217, Holliger, 1963:239, Sissons & Hare, 2002:83) and possibly cooking losses.



**TABLE 7.5 ANOVA FOR STRAND DIAMETER (MM)**

Source	DF	MS	P
Product	2	0	<0,0001
Error	41	0	-
Corrected total	43	-	-

**Bent shapes, white lines, units sticking together, and units with loops.** These variables, expressed in percentage, are attribute data sets. Tests for normality showed that only the data set for bent shapes were distributed normally ( $P=0,187$ ). This therefore reflects positively on the validity of the measurement.

The other listed defects occur very infrequently and therefore the data was not distributed normally. Non-normality was attributed to the kurtosis effect and ANOVA analysis was done. Kurtosis values for defects were 42,47 for white lines, 6,45 for units sticking together and 42,87 for loops. Even though data was not distributed normally, these methods may be valid considering the kurtosis effect.

The ANOVAs illustrated no differences between brands for strands with a bent shape (Table 7.6), strands with white lines (Table 7.7), or strands with loops (Table 7.9). This may be due to brands not being significantly different or it may be due to the measurement technique not being able to distinguish between brands that are in fact different (should the latter be the case, the measurement technique is inaccurate). Considering the distribution of data (test for normality) the evidence suggest that the measurements may indeed be valid and used to quantify spaghetti quality.

Of significance is the occurrence of units sticking together in the spaghetti prepared from bread wheat flour ( $P < 0,003$ , Table 7.9).

**TABLE 7.6 ANOVA FOR STRANDS WITH BENT SHAPE (%)**

Source	DF	MS	P
Product	2	127	0,3219
Error	45	109	-
Corrected total	47	-	-

**TABLE 7.7 ANOVA FOR STRANDS WITH WHITE LINES (%)**

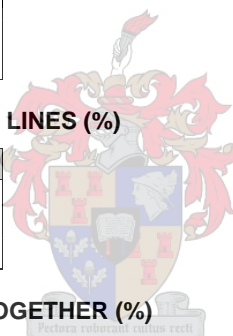
Source	DF	MS	P
Product	2	0,1	0,351
Error	44	0,1	-
Corrected total	46	-	-

**TABLE 7.8 ANOVA FOR STRANDS STICKING TOGETHER (%)**

Source	DF	MS	P
Product	2	18	0,003
Error	43	2,7	-
Corrected total	45	-	-

**TABLE 7.9 ANOVA FOR STRANDS WITH LOOPS (%)**

Source	DF	MS	P
Product	2	0,1	0,288
Error	44	0,1	-
Corrected total	46	-	-





Only Brand A had units sticking together (1,91%, Table 7.17). This was most likely due to spreader defects caused by inadequate airflow (Pasta, 2003a:15, Pasta, 2003b:32). Another cause may be that the moisture content was too high directly after extrusion, increasing the risk of sticking when different strands make contact with one another (Antognelli, 1980:134, Hahn, 1990:388, Dalbon, Grivon & Pagani, 1998:38, Pollini, 1998:61, Dawe, 2001:104, Pasta, 2003a:15, Pasta, 2003b:32). Irrespective of the wheat species, type or cultivar, flour will require more water than semolina to hydrate to a predetermined viscosity (Irvine, 1971:779). Similarly, milled bread wheat requires more water than milled durum wheat to hydrate to a predetermined viscosity, irrespective of particle size. In the current study, only spaghetti prepared from bread wheat flour (which requires the more water than durum semolina), showed units that were sticking together. In theory, higher moisture content directly after extrusion may lead to a higher frequency of units sticking together when the units make contact on the spreader. If this defect is caused by higher moisture content, the frequency of bent shapes is also expected to be higher, which was not the case in the current study. The observed differences between the brands could therefore not be explained by moisture content and is therefore most likely to be due to inadequate airflow in the spreader. The measurement of units sticking together distinguishing between brands, suggests that the measurement may be valid.

**Breakages.** Different lengths (fineness) of broken units are caused by poor mechanical strength of the product, different manufacturing errors or poor handling practises. Since the brands that were compared were commercially purchased, the packaging material must also be considered. It is expected that packing in plastic sheeting versus cardboard boxes, will yield more broken units.

Breakages were divided into five categories of damage (Categories B1–B5). Of these categories, only the data in Category B4 ( $P=0,0927$ ) were distributed normally. Data in the other categories were not distributed normally and ascribed to the kurtosis effect. Further analysis was therefore possible (Shapiro & Wilk, 1965). Kurtosis values for the quality characteristics were as follows: Category B1=19,03, Category B2=2,17, Category B3=3,26 and Category B5=1,70. This kurtosis effect was expected since these defects occur very infrequently and will therefore necessitate the evaluation of an extremely large sample per batch to obtain enough measurements that may be distributed normally.

Considering the normality of datasets per breakage category and the ability of measurements to distinguish between brands (Table 7.17), evidence strongly suggests that these measurements may be valid.

Category B1–B3: When cutting spaghetti, the blades are set to cut according to specification (250 mm [ $\pm 10$  mm] in the current study). During cutting, these blades may move and yield strand

lengths that are out of specification. ANOVA analysis indicated variation across brands only for data in Category B3 (Table 7.10 to Table 7.12).

**TABLE 7.10 ANOVA FOR STRANDS THAT ARE TOO LONG IN CATEGORY B1 (%)**

Source	DF	MS	P
Product	2	2	0,062
Error	44	0,7	-
Corrected total	46	-	-

**TABLE 7.11 ANOVA FOR STRANDS IN THE TARGET RANGE IN CATEGORY B2 (%)**

Source	DF	MS	P
Product	2	89	0,072
Error	43	32	-
Corrected total	45	-	-

**TABLE 7.12 ANOVA FOR STRANDS THAT ARE TOO SHORT IN CATEGORY B3 (%)**

Source	DF	MS	P
Product	2	166	0,0006
Error	42	19	-
Corrected total	44	-	-

Comparison of means (Table 7.17) indicated that there was less than 0,7% occurrence of strands that were too long (Category B1). Considering that, in all cases, strands within the target length range (Category B2) were above 90%, control in the plants producing the specific brands is good. Category B3 (strands that are too short) were lowest for Brand C (0.95%) and differed significantly from Brands A and B (5,62% and 7,56% respectively). The differences observed between brands in all three categories can most likely be ascribed to the degree of control over these defects in the different plants.

Category B4: Assuming good quality control, breakages occur after packing (relatively long broken units). Since the control applied to proper handling during transit is not known, but assumed to be equal (brands bought in similar stores), it must be accepted that higher mechanical strength may reduce the occurrence of this defect. In this category, breakages are expected to increase as protein and moisture content decreases, since both decreased protein content and moisture content is correlated to decreased mechanical strength (Malcolmson *et al*, 1993:420, Feillet & Dexter, 1998:116, Gianibelli *et al*, 2000:642, Sissons & Hare, 2002:83). ANOVA analysis indicated variation across brands ( $P < 0,0001$ , Table 7.13).

**TABLE 7.13 ANOVA FOR BROKEN STRANDS IN CATEGORY B4 (%)**

Source	DF	MS	P
Product	2	1,9	<0,0001
Error	42	0,1	-
Corrected total	44	-	-

LSD analysis (Table 7.17) indicated that bread wheat, Brand A (with the lowest protein and moisture content), had significantly higher percentage broken units (1,56%) compared to the durum brands Brand B (0,99%) and C (0,28%), which also differed significantly from one another. Another reason for the higher breakages in Brand A may be due to the non-protective packaging material (polyethylene) used for this brand. Increased mechanical strength has also been correlated to higher drying temperatures. The durum pasta dried by means of HT had higher percentage breakages than that dried by means of VHT.

Category B5: The broken units of this category are fractions of spaghetti that split off during the cutting process. ANOVA analysis indicated no variation across brands ( $P=0,0227$ , Table 7.14).

**TABLE 7.14 ANOVA FOR BROKEN STRANDS IN CATEGORY B5 (%)**

Source	DF	MS	P
Product	2	0	0,0227
Error	42	0	-
Corrected total	44	-	-

Although the percentage of units in this category was extremely low ( $<0,05\%$ , Table 7.17), the observed differences were significant between Brands B and C, but Brand A did not differ from either of these two brands. This may be due to the effect of VHT compared to HT on mechanical strength.

**Colour.** Higher L-values (lightness) indicate lighter coloured products. The higher the yellowness index (YI) value, the more yellow the product is. Both the lightness (L-values) data ( $P=0,0752$ ) and yellowness (YI) data ( $P=0,3802$ ) were distributed normally (Shapiro & Wilk, 1965). The ANOVA for lightness ( $P<0,0001$ ) suggested that there were differences between brands (Table 7.15), as did the ANOVA for the yellowness data ( $P<0,0001$ , Table 7.16).

**TABLE 7.15 ANOVA FOR LIGHTNESS (L-VALUE) OF DRY SPAGHETTI**

Source	DF	MS	P
Product	2	48	$<0,0001$
Error	45	1	-
Corrected total	47	-	-

**TABLE 7.16 ANOVA FOR YELLOWNESS INDEX (YI) OF DRY SPAGHETTI**

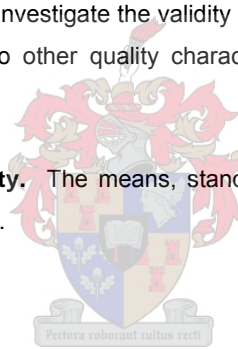
Source	DF	MS	P
Product	2	548	$<0,0001$
Error	44	3,1	-
Corrected total	46	-	-

With the observed higher ash content of the durum brands (Brands B and C) it was expected that these brands would be darker in colour than the bread wheat brand (Brand A). However, this was not the case (LSD analysis, Table 7.17). Brands A and B had similar values (45,86 and 46,57, respectively) and Brand C was significantly lighter in colour (49,14). These aspects warrant further investigations in an in depth study, comparing flour and semolina of similar particle size (assuming that the bran particles will also differ) of the two wheat varieties, HT and VHT and two moisture levels during mixing and kneading. It was observed during the current study that finely ground bran has a larger darkening effect on the product than coarsely ground bran. Maillard reactions may also be affected by the protein content as such, the amount the moisture available needed for these reactions and the reaction (drying) temperature.

Regarding yellowness, all three brands differed significantly (see Table 7.17). Durum wheat has higher carotenoid (yellow pigment) content. Comparing durum brands, Brand C had a higher YI than Brand B, possibly due to VHT inactivation of enzymes oxidising carotenoids (Feillet, 1984:561, Milatovic & Mondelli, 1991:94, Marchesani & Soncini, 2002:22).

**Cracks, fissures, white spots, flour spots and dark spots.** For these measurements no statistical analyses were possible since data was not distributed normally. Non-normality was due to screwiness. This phenomenon may be due to low frequency of measurements and large variation between batches and brands. To further investigate the validity of this evaluation method in predicting pasta quality, it will be correlated to other quality characteristics in the following chapter.

**Summary of the results of dry spaghetti quality.** The means, standard deviations and LSD values are presented in Table 7.17 (see next page).



### 7.3.2 Comparison of cooked spaghetti quality

The ANOVA tables for all cooked results are presented in Tables 7.18 to 7.23. The individual ANOVAs are presented and discussed below. A summary of the comparison between brands is presented in Table 7.24 and observed differences are discussed. The means, standard deviations and LSD values for cooked spaghetti are presented in the latter table.

**Cooking loss percentage (CL).** CL data were not distributed normally ( $P < 0,0001$ ). This was due to the kurtosis effect (3,65) and further analysis was done. The ANOVA indicated that interaction was present between degrees of cooking (DC) and Brand ( $P < 0,0001$ , Table 7.18).

Brands differed significantly, with Brand A having the highest CL and Brand C the lowest CL. It was observed that the differences between CL for optimally cooked product and tolerance cooked product increased as CL for optimally cooked product increased. This increase was therefore more pronounced in lower quality spaghetti (Brand A) than in good quality spaghetti (Brand C). This result may be ascribed to the lower protein content of Brand A and the higher protein content of Brand C (Table 7.17, reported under dry quality characteristics). Other explanations may include differences in starch damage and the use of various drying techniques.

With an increase in cooking time (optimal cooking versus tolerance cooking, DC), the lower CL of Brand C may be due to better protein encapsulation of starch during cooking, therefore better water holding in the starch granules and the prevention of leaching of starch from the granules (Resmini & Pagani, 1983:1, D'Egidio *et al*, 1990:279). The significant differences of the main effect of DC on CL (Table 7.24) across brands is due to the increased exposure of starch to water and heat leading to a higher degree of gelatinisation and subsequent pasting (Atwell, 2001:18). The significant differences between brands (Table 7.24) for optimally cooked and tolerance cooked products may be ascribed to the differences in protein content.

**TABLE 7.17 COMPARISON OF MEANS OF DRY SPAGHETTI BETWEEN BRANDS**

MEASUREMENT	BRANDS									LSD
	A			B			C			
	n*	Mean	± Std dev	n*	Mean	± Std dev	n*	Mean	± Std dev	
Protein (%)	14	11,08 <sup>c</sup>	± 0,31	15	11,52 <sup>b</sup>	± 0,14	15	12,08 <sup>a</sup>	± 0,16	0,159
Ash (%)	16	0,79 <sup>b</sup>	± 0,03	16	1,29 <sup>a</sup>	± 0,19	16	1,29 <sup>a</sup>	± 0,25	0,130
Moisture (%)	16	10,28 <sup>a</sup>	± 0,44	16	9,89 <sup>b</sup>	± 0,55	16	9,35 <sup>c</sup>	± 0,47	0,350
Length (mm)	16	250,09 <sup>b</sup>	± 2,74	16	248,24 <sup>c</sup>	± 1,75	15	255,74 <sup>a</sup>	± 1,83	1,559
Diameter (mm)	14	1,72 <sup>b</sup>	± 0,02	15	1,79 <sup>a</sup>	± 0,04	15	1,68 <sup>c</sup>	± 0,01	0,020
Bent shape (unit %)	16	20,21	± 10,31	16	25,53	± 8,65	16	22,92	± 12,07	7,433
White line (unit %)	15	0,11	± 0,43	16	0,00	± 0,00	16	0,00	± 0,00	0,175
Sticking (unit %)	14	1,91 <sup>a</sup>	± 2,99	16	0,00 <sup>b</sup>	± 0,00	16	0,00 <sup>b</sup>	± 0,00	1,198
Loops (unit %)	15	0,00	± 0,00	16	0,10	± 0,42	16	0,00	± 0,00	0,176
<b>Breakages</b>										
Category B1 (unit %)	16	0,10 <sup>ab</sup>	± 0,42	16	0,00 <sup>b</sup>	± 0,00	15	0,67 <sup>a</sup>	± 1,38	0,588
Category B2 (unit %)	15	94,11 <sup>ab</sup>	± 5,15	15	91,67 <sup>b</sup>	± 6,55	16	96,46 <sup>a</sup>	± 5,12	4,106
Category B3 (unit %)	16	5,62 <sup>a</sup>	± 5,05	15	7,56 <sup>a</sup>	± 5,19	14	0,95 <sup>b</sup>	± 1,26	3,180
Category B4 (mass %)	14	1,56 <sup>a</sup>	± 0,39	15	0,99 <sup>b</sup>	± 0,44	16	0,28 <sup>c</sup>	± 0,19	0,259
Category B5 (mass %)	16	0,02 <sup>ab</sup>	± 0,01	15	0,03 <sup>a</sup>	± 0,02	14	0,01 <sup>b</sup>	± 0,01	0,011
<b>Colour</b>										
Lightness (L-value)	16	45,86 <sup>b</sup>	± 1,03	16	46,57 <sup>b</sup>	± 0,94	16	49,14 <sup>a</sup>	± 1,06	0,720
Yellowness index (YI)	16	87,64 <sup>c</sup>	± 1,31	16	92,04 <sup>b</sup>	± 2,54	15	99,44 <sup>a</sup>	± 1,04	1,273

<sup>a-c</sup> Means with different superscripts in the same row differ at  $P \leq 0,05$

\* n=batches (repetitions). Outliers were identified as values exceeding sample means by more than 3 standard deviations and removed as standard statistical procedure, resulting in n<16 in some cases.

**TABLE 7.18 ANOVA FOR COOKING LOSS PERCENTAGE (CL)**

Source	DF	MS	P
Degree of cooking (DC)	1	329,152	<0,0001
Brand	2	279,565	<0,0001
DC x Brand	2	40,792	<0,0001
Error	90	2,24465	-
Corrected total	95	-	-

**Rinse loss percentage (RL).** RL data were distributed normally ( $P=0,0586$ ) and the ANOVA indicated interaction ( $P<0,05$ ) and significant differences ( $P<0,0001$ ) between treatments (Table 7.19).

**TABLE 7.19 ANOVA FOR RINSE LOSS PERCENTAGE (%)**

Source	DF	MS	P
Degree of cooking (DC)	1	2,87	<0,0001
Brand	2	9,618	<0,0001
DC x Brand	2	0,615	0,0194
Error	90	0,149	-
Corrected total	95	-	-

A similar trend for RL as for CL was observed regarding the differences between DC for brands, i.e. less pronounced differences between the observed values with an increase in protein content (Table 7.24). With the exception of Brand C, the RL increased significantly as cooking time increased. This implies increased stickiness as cooking time is prolonged. Brand C had a better ability to withstand increased cooking time, i.e. better resistance to over-cooking. RL also differed significantly across brands. The relationship between RL and protein is similar than between CL and protein. There is also evidence that starch damage increases RL. Flour has higher starch damage values than semolina, which may be a further reason why Brand A has a higher RL than Brands B and C (D'Egidio & Nardi, 1998:155).

**Water absorption (WA).** The WA of spaghetti was measured as a water absorption factor (WAF) and weight increase percentage (WIP). WA data were distributed normally for both WAF ( $P=0,8104$ ) and WIP ( $P=0,3886$ ) and the ANOVA indicated that interaction was present ( $P<0,01$ ) and that there were differences ( $P<0,0001$ ) between treatments (Tables 7.20 and 7.21 respectively).

**TABLE 7.20 ANOVA FOR WATER ABSORPTION FACTOR (WAF)**

Source	DF	MS	P
Degree of cooking (DC)	1	2,525	<0,0001
Brand	2	0,401	<0,0001
DC x Brand	2	0,049	0,0014
Error	90	0,007	-
Corrected total	95	-	-

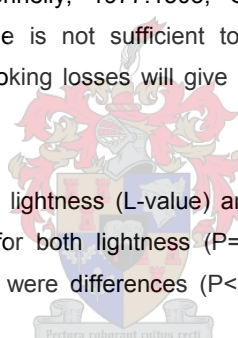
**TABLE 7.21 ANOVA FOR WEIGHT INCREASE PERCENTAGE (WIP)**

Source	DF	MS	P
Degree of cooking (DC)	1	31194,7	<0,0001
Brand	2	3587,76	<0,0001
DC x Brand	2	551,332	0,0025
Error	89	85,81	
Corrected total	94		

The interaction trend was reversed in comparison to CL and RL, i.e. the values for WA increased across brands as protein content increased (Table 7.24). The LSD analysis indicated that as cooking time increased, the WA values (WIF and WIP) increased for all brands (Table 7.24). When cooked optimally Brand C had the highest WA. Although Brand A had a slightly lower WA than Brand B, the difference is not significant. When tolerance cooked, Brand C has the highest WA, followed by Brand B. Brand A had the lowest WA. In contrast to literature, as the protein content increased the WA values also increased (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter *et al*, 1983:1545, Hahn, 1990:394, Edwards *et al*, 1993:420, Feillet & Dexter, 1998:116, Gianibelli *et al*, 2000:642, Sissons & Hare, 2002:83). This is likely to be due to protein encapsulation of starch during cooking, therefore better holding of water in the starch granules and preventing leaching of starch and water from the starch granule.

According to the literature, the WA is correlated to the firmness of the cooked product, an important eating quality characteristic (Grzybowski & Donnelly, 1977:1305, Grzybowski & Donnelly, 1979:383). However, WA (WAF and WIP) alone is not sufficient to estimate softness (not measured in this study), since variation in the cooking losses will give misleading results of the amount of moisture absorbed.

**Colour.** The colour of spaghetti is presented as lightness (L-value) and yellowness index (YI) values. Colour data were distributed normally for both lightness (P=0,1345) and yellowness (P=0,4599) and the ANOVA indicated that there were differences (P<0,0001) between brands (Table 7.22 and 7.23 respectively).

**TABLE 7.22 ANOVA FOR COOKED LIGHTNESS (L-VALUE) OF COOKED SPAGHETTI**

Source	DF	MS	P
Product	2	3,416	<0,0001
Error	45	0,129	-
Corrected total	47	-	-

**TABLE 7.23 ANOVA FOR COOKED YELLOWNESS INDEX (YI) OF COOKED SPAGHETTI**

Source	DF	MS	P
Product	2	257,8805	<0,0001
Error	42	2,274959	
Corrected total	44	611,3092	

The bread wheat spaghetti (Brand A) was the darkest of all when cooked (LSD analysis, Table 7.24). Although Brand A had a similar lightness value when compared to Brand B when dry, Brand B was significantly lighter in colour than Brand A when cooked. Brand B was significantly lighter than Brand C when cooked, although the opposite applied in the dry form. This may be due to the leaching of certain components, or differences in the translucency of the products.

The YI values differed significantly - true to expectation; the durum brands were more yellow than Brand A. The durum brand produced under VHT drying conditions was more yellow than that produced under HT drying conditions, which is in accordance with literature (Malcolmson *et al*, 1993:420, Marconi *et al*, 1999:25, Marconi, Graziano & Cubadda, 2000:138, Zweifel, Conde-Petit & Escher, 2000:650, Guler, Koksel & Ng, 2002:427, Sissons & Hare, 2002:83, Zweifel, Handschin, Escher & Conde-Petit, 2003:159).

**TABLE 7.24 COMPARISON OF MEANS OF COOKED SPAGHETTI BETWEEN BRANDS AND DEGREE OF COOKING**

MEASUREMENT	DEGREE OF COOKING	BRANDS						
		A		B		C		
		n	Mean $\pm$ Std dev	n	Mean $\pm$ Std dev	n	Mean $\pm$ Std dev	
CL (%) (LSD=1,052)	Optimum	16	10,420 <sup>b</sup> $\pm$ 1,082	16	8,318 <sup>c</sup> $\pm$ 0,460	16	6,797 <sup>d</sup> $\pm$ 0,385	
	Tolerance	16	16,645 <sup>a</sup> $\pm$ 2,925	16	11,155 <sup>b</sup> $\pm$ 1,680	16	8,665 <sup>c</sup> $\pm$ 0,742	
RL (%) (LSD=0,272)	Optimum	16	2,050 <sup>b</sup> $\pm$ 0,454	16	1,554 <sup>c</sup> $\pm$ 0,192	16	1,238 <sup>d</sup> $\pm$ 0,182	
	Tolerance	16	2,692 <sup>a</sup> $\pm$ 0,641	16	1,858 <sup>b</sup> $\pm$ 0,366	16	1,330 <sup>cd</sup> $\pm$ 0,272	
WAF (LSD=0.059)	Optimum	16	2,583 <sup>e</sup> $\pm$ 0,051	16	2,586 <sup>e</sup> $\pm$ 0,060	16	2,716 <sup>d</sup> $\pm$ 0,084	
	Tolerance	16	2,828 <sup>c</sup> $\pm$ 0,108	16	2,911 <sup>b</sup> $\pm$ 0,095	16	3,119 <sup>a</sup> $\pm$ 0,087	
WIP (%) (LSD=6,544)	Optimum	16	188,027 <sup>e</sup> $\pm$ 5,279	16	186,986 <sup>e</sup> $\pm$ 7,045	16	199,597 <sup>d</sup> $\pm$ 8,853	
	Tolerance	15	215,526 <sup>c</sup> $\pm$ 13,097	16	223,214 <sup>b</sup> $\pm$ 10,246	16	243,835 <sup>a</sup> $\pm$ 9,389	
Colour	Lightness (L-value) (LSD=0,257)	Optimum	16	57,545 <sup>c</sup> $\pm$ 0,269	16	58,465 <sup>a</sup> $\pm$ 0,377	16	58,081 <sup>b</sup> $\pm$ 0,417
		Yellowness index (YI) (LSD=1,113)	Optimum	14	29,168 <sup>c</sup> $\pm$ 1,466	15	33,697 <sup>b</sup> $\pm$ 2,024	16

<sup>a-e</sup> Means with different superscripts within measurements (WAF, WIP, CL, RL) differ at  $P \leq 0,05$

\* n=batches (repetitions). Outliers were identified as values exceeding sample means by more than 3 standard deviations and removed as standard statistical procedure, resulting in  $n < 16$  in some cases.

## 7.4 CONCLUSIONS AND RECOMMENDATIONS

When comparing brands in the dry form by means of the suggested measurements, durum Brand C, with the highest perceived quality, was consistently evaluated superior by all measurements. It had the highest protein content, the least defects, the lightest and most yellow colour. Additionally it had the smallest diameter and longest strands.



Durum Brand B had a higher amount of breakages than Brand C, even though it was packed in similar packaging material. It also had a darker dry colour and was not as yellow. The differences in colour may be due to different drying techniques applied, which result in enzyme inactivation, as ash analysis did not differ significantly. This brand had the largest diameter and the shortest strand lengths.

Bread wheat Brand A had an inferior colour compared to the durum brands. Lightness and yellowness differed. It had a higher percentage of breakages and units sticking together. Other defects occurred in similar percentages as the durum brands. Brand A also had the lowest protein content. It had a diameter and strand length between that of the two durum brands.

There was a vast difference in the cooked quality of the three brands, likely due to a difference in the protein content, starch damage and drying techniques. As the protein content increased across the three brands (A, B and C), CL and RL decreased while WAF and WIP increased. These decreases in CL and RL implied a cooked product with a more appealing quality and being less sticky. It is also quite likely that the starch damage increased across the three brands (from Brand A to Brand C). Brand A was manufactured from flour, generally having more starch damage than semolina. Also, Brand B manufactured under lower drying temperatures than Brand C, which will be favourable for enzyme activity, resulting in higher starch damage values for Brand B.

Durum brands B and C had a better cooked quality than bread wheat Brand A. VHT dried Brand C had a better cooked quality than HT dried Brand B. It is well known that increased drying temperatures deactivates enzymes leading to increased starch damage (increasing CL and RL) and also improves the protein structure resulting in improved starch encapsulation during cooking (Guler *et al.*, 2002:427).

When bread wheat Brand A was compared to durum Brands B and C the quality was inferior. In the dry form, manufacturing techniques may be adapted to prevent units sticking. Packaging material may be changed to cardboard to reduce breakages. To improve the colour,  $\beta$ -carotene may be used to increase yellowness. If the lightness (L-value) of the product can be reduced the effects of added carotene will be more pronounced as follows: the use of bread wheat semolina (lower ash content) instead of flour, with added  $\beta$ -carotene, will yield a colour comparable to that of durum wheat spaghetti. However, the use of bread wheat semolina instead of flour will reduce the cooked quality of the spaghetti as at low protein levels coarser particles do not have the ability to form a gluten network to the same degree than finer particles do (Antognelli, 1980:128, Milatovic & Mondelli, 1991:460).

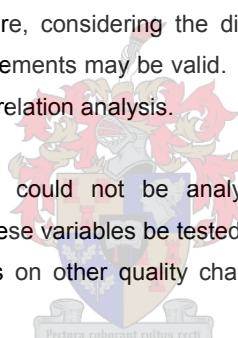
The cooked quality of Brand A also requires improvement. CL and RL will have to be reduced and WA increased. The addition of approximately 2% vital wheat gluten may improve the CL, RL and WA, although gluten addition may reduce the lightness of the product. Albumin or egg may also be used as protein source, but is more expensive than gluten. Additionally, both albumin and egg will require an additional allergen to be declared on the label (albumin) and egg poses food safety concerns (salmonella). If semolina is used, further protein addition will be required. An increase in diameter (decreased surface to volume ratio) may also improve CL, RL and WA.

The quality of Brand A may therefore be similar to that of durum brands if bread wheat semolina is used instead of flour, and  $\beta$ -carotene and gluten is added. However, milling semolina from bread wheat on a flour-mill is not cost effective due to lower yields. Should long term benefits of a special plant not be considered, it is recommended that the least cost options are applied, i.e. an increase in diameter, addition of gluten and carotene and changes in the packaging material to limit breakages.

The quality of Brand B may be similar to that of Brand C if VHT drying techniques are used. Additional gluten will also reduce the relatively high cooking loss.

This research confirmed that spaghetti strands that are bent, strands that stick together, strands with a white line, strands with loops and that are broken occur in spaghetti and some of these measurements vary between brands. Furthermore, considering the distribution of data in this study, evidence suggest that the proposed measurements may be valid. Further investigation into the validity of measurements may be done with correlation analysis.

The occurrence of cracks, fissures and spots could not be analysed statistically. It is recommended that the importance of measuring these variables be tested in a correlation analysis, which will illustrate the effects on these variables on other quality characteristics (reflecting on validity).



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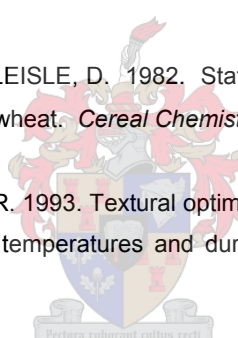
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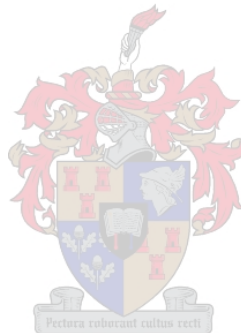
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## CHAPTER 8: CORRELATIONS BETWEEN PASTA QUALITY MEASUREMENTS

### 8.1 INTRODUCTION

Correlations between some spaghetti quality characteristics are well documented (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter, Matsuo, Morgan, 1983:1545, Hahn, 1990:394, Edwards, Izydorczyk, Dexter & Biliaderis, 1993:125, Malcolmson, Matsuo & Balshaw, 1993:420, Feillet & Dexter, 1998:116, Gianibelli, Uthayakumaran, Sissons, Morell & Batey, 2000:642, Sissons & Hare, 2002:83) and mostly focus on analytical measurements on the raw material quality which is correlated to the cooked quality of pasta. The effects of low protein content, poor protein quality and starch damage, which all manifest in defects such as reduced mechanical strength and increased cooking losses, rinse losses and increased water absorption are well documented (Matsuo, Bradley & Irvine, 1972:711, Wyland & D'Appolonia, 1982:200, Dexter *et al*, 1983:1547, Malcolmson *et al*, 1993:420). The correlation of pasta colour with raw material properties are also well documented in the literature listed above.

The effects on the dry quality measures, such as cracks, fissures, and damage caused by units sticking together and spots were neglected in research (Edwards *et al*, 1993:125, Malcolmson *et al*, 1993:420, Feillet & Dexter, 1998:116). The amount of variation in these variables needs to be quantified by measurements of the variation in other variables.

Theoretically, surface damage to the dry spaghetti, such as cracks, fissures and units sticking together may decrease mechanical strength and increase the water penetration potential and absorption into the pasta, as well as the leaching of solids during cooking and subsequent rinsing. Other defects may increase the surface to volume area of spaghetti. Apart from the obvious controllable effect of product diameter on this aspect, defects like cracks and fissures may also increase this ratio. This, in turn, may lead to shorter cooking times, higher water absorption and leaching of solids during different degrees of cooking. Variation in moisture content and spots may lead to variation in cracks and fissures. The variation in ash content may reflect on the amount of variation of dark spots in particular. Both ash content and dark spots may therefore lead to colour differences (Antognelli, 1980:130, Milatovic & Mondelli, 1991:2, Turnbull, 2001b:181). Wheat species and type, fineness of flour (in particular the bran particles) and processing techniques affect dry and cooked product colour, yet this aspect and the importance thereof needs to be quantified.

The nature of non-durum wheat spaghetti is not well documented. It is not known whether the same factors of importance in the production of spaghetti from durum wheat will apply to the same extent to that produced from non-durum wheat (e.g. bread wheat). Only pooled analyses across



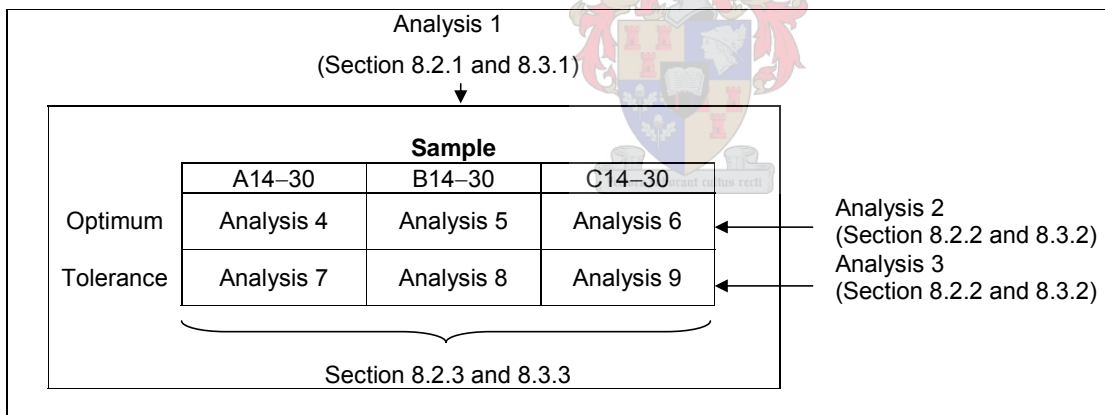
brands (different raw materials, different drying techniques) and specific analyses within degree of cooking, as well as analyses between brands can provide these answers.

The first aim of this study was to determine which measurable characteristics are correlated with important quality characteristics and to test other theories regarding the importance of certain deviations and the effect that these deviations may have on final quality.

The second aim of this study is to further investigate the validity of the developed quality measurements (see Section 7.3.1), with special reference measurement of cracks, fissures, white spots, flour spots and dark spots, which could not be investigated in the previous chapter.

## 8.2 MATERIALS AND METHODS

Data collected on the quality measurements of samples A14–30 (Brand A), B14–30 (Brand B) and C14–30 (Brand C), as described in Chapter 7 (3 brands x 16 samples), were used to calculate correlation coefficients ( $r$ ) between all the variables by means of the CORR Procedure of SAS (SAS, 1999). The *Likert* scale values for cracks, fissures, white spots, flour spots and dark spots were included in the analyses. For these variables, the collected data was also converted to attribute data, i.e. the number of strands without any cracks versus the number of strands with different degrees of cracks out of 100 strands inspected within a batch (16 batches x 3 brands). This was done to determine whether the magnitude of a particular defect would be reflected in the magnitude of other defects, or whether defects, irrespective of magnitude, affected other defects. The various correlation matrixes calculated, are summarised in Figure 8.1.



**FIGURE 8.1 EXPERIMENTAL LAYOUT FOR THE CALCULATION OF CORRELATION MATRIXES**

### **8.2.1 Analysis 1 (pooled data)**

Initial analysis was done on the pooled data, irrespective of cooking degree or brands. Pooled data were analysed as a representative sample of the population of spaghetti of different quality grades available on the South African market, to establish whether certain variables are correlated or not correlated.

### **8.2.2 Analyses 2 and 3 (pooled data per degree of cooking)**

The data were further analysed for each degree of cooking, ignoring brand. Analysis 2 (optimum) and Analysis 3 (tolerance) were performed to test whether correlation coefficients for selected variables increase without cooking degree as variable.

### **8.2.3 Analyses 4 to 9 (pooled data per brand per degree of cooking)**

Individual analyses for brands were performed to test whether correlation coefficients for selected variables increased (or decreased) without brand as variable.

## **8.3 RESULTS AND DISCUSSION**

### **8.3.1 Analysis 1 (pooled data)**

The correlation matrix of the pooled data (Analysis 1) yielded low r-values, thus very little variation in the Y-values could be explained by the variation in X-values. In a limited number of cases the r-values were higher and the probability of non-zero slope (P-value) significant. However, these cases were mostly for measurements such as cooking time and water absorption. Such values are correlated by the nature of the test and the characteristics of starch products. It is of interest to evaluate different product qualities (brands) for these aspects within a specific degree of cooking (i.e. Analyses 2 and 3). Other correlations in Analysis 1 that was of interest are summarised in Table 8.1. The correlations included in Table 8.1 were either selected due to their higher r-value and non-zero slope (P-value), or because they were not supported by the literature.

**TABLE 8.1 CORRELATION COEFFICIENTS (r) AND THEIR PROBABILITIES (P) FOR SELECTED DRY (n=48) AND COOKED (n=96\*) MEASUREMENTS**

Independent variable	Dependent variable	n	r-value	P-value
Ash	Lightness	48	0,396	0,0003
Ash	Yellowness	48	0,522	0,0001
Ash	Dark spots	48	0,098	0,3398
Dark spots	Lightness	48	0,129	0,2107
Dark spots	Yellowness	48	0,259	0,122
Protein	Lightness	48	0,490	<0,0001
Protein	Yellowness	48	0,699	<0,0001
Fissures	Breakages Category B4	48	0,429	<0,0001
Fissures	Breakages Category B5	48	0,331	0,001
Protein	Fissures	48	-0,507	<0,0001
Protein	Units sticking together	48	-0,437	<0,0001
Protein	Fissures	48	-0,507	<0,0001
Protein	Cooking loss	96	-0,664	<0,0001
Protein	Rinse loss	96	-0,743	<0,001
Fissures	Cooking loss	96	0,524	<0,0001
Fissures	Rinse loss	96	0,505	<0,0001
Dry yellowness	Cooked yellowness	48	0,856	<0,0001
Cooking time	Cooked colour	48	-0,348	0,015
Cooking loss	Rinse loss	96	0,802	<0,0001

\* All cooked measurements were taken on both optimally (n=48) and tolerance (n=48) cooked samples (total n=96). The only exception being cooked colour measurements, which was only taken on optimally cooked samples (n=48).

### 8.3.1.1 Dry correlations

**Colour.** The relationship between colour, ash and dark spots were of interest. Although ash content is emphasised in the literature and mainly ascribed to the occurrence of dark spots (bran) (Dexter & Matsuo, 1978:841, Dexter, Matsuo & Morgan, 1981:1742, Dick & Matsuo, 1988:538, Feillet & Dexter, 1998:106, Turnbull, 2001a:44, Turnbull, 2001b:190), no such correlations could be demonstrated in the current study, even with a wide distribution in ash content of 0,79 to 1.29% (see Chapter 7, Table 7.1). The effect of ash content on colour could also not be demonstrated. Contrary to the literature (Antognelli, 1980:130, Milatovic & Mondelli, 1991:2, Turnbull, 2001b:181), ash was positively correlated with lightness, although this relationship was low ( $r=0,396$ ,  $P=0,0003$ ). Ash content was also positively correlated with yellowness ( $r=0,522$ ,  $P<0,0001$ ). Ash and dark spots were not correlated ( $r=0,098$ ,  $P<0,3398$ ). A negative correlation would be expected between dark spots and colour, since increased dark spots may reduce the lightness (L-

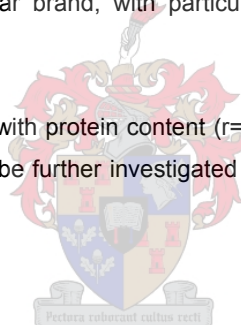
value) and yellowness (YI) value. However, dark spots were not correlated with the dry lightness ( $r=0,129$ ,  $P=0,2107$ ) and dry yellowness ( $r=0,259$ ,  $P<0,122$ ). Protein content and colour was correlated positively, both reflected in lightness ( $r=0,490$ ,  $P<0,0001$ ) and yellowness ( $r=0,6999$ ,  $P<0,0001$ ). It is known that durum wheat contains more protein and that it is more yellow in colour than bread wheat cultivars (Marconi & Carcea, 2001:522, Wiseman, 2001:18, Marconi, Carcea, Schiavone & Cubadda, 2002:636). The correlation between protein and colour is more likely to be the effect of wheat species.

**Breakages.** Contrary to predictions from literature (Dick & Matsuo, 1988:538, Feillet & Dexter, 1998:105,116, Pasta, 2003:33), no correlations were found between breakages and cracks or fissures, except for breakages in the smaller sized categories with total fissures (Category B4,  $r=0,429$ ,  $P<0,0001$ , and Category B5,  $r=0,331$ ,  $P=0,001$ ). This correlation suggests that the measurement of fissures is valid and that its occurrence may decrease the mechanical strength of the spaghetti (causing breakages).

**Surface defects.** Other relationships of interest are between protein content (irrespective of protein source) and certain quality characteristics. In agreement with literature (Gianibelli *et al*, 2000:642, Sissons & Hare, 2002:83) total fissures were negatively correlated with protein content ( $r=-0,507$ ,  $P<0,0001$ ). The variation in protein content therefore explained 25% of the variation in fissures in Analysis 1. Seeing that drying errors are the main cause of cracks and fissures, it is more likely that the drying process of a particular brand, with particular protein content, was ineffective (Mondelli, 2003:37).

Units sticking together were negatively correlated with protein content ( $r=-0,437$ ,  $P<0,0001$ ). This suggests that the measurement is valid and it will be further investigated in the analyses to follow (Table 8.5).

### 8.3.1.2 Dry and cooked correlations



**Protein.** Total fissures were negatively correlated with protein content ( $r=-0,507$ ,  $P<0,0001$ ), which was expected. Cooking loss was negatively correlated with protein content ( $r=-0,664$ ,  $P<0,0001$ ), similarly, rinse loss ( $r=-0,743$ ,  $P<0,001$ ). This is due to protein encapsulation of starch granules, which protects starch from excessive gelatinisation and subsequent pasting (Matsuo *et al*, 1972:711, Dexter *et al*, 1983:1547, Malcolmson *et al*, 1993:422, Wyland & D'Appolonia, 1982:200). In the pooled data analysis no correlations were found between protein content and WA.

**Fissures, cracks and spots.** Both cracks and fissures may increase cooking loss as the protein structure of the spaghetti is damaged, resulting in increased solids leaching during cooking

(Turnbull, 2001b:217). Total fissures were positively correlated with cooking loss ( $r=0,524$ ,  $P<0,0001$ ) and rinse loss ( $r=0,505$ ,  $P<0,0001$ ). However, considering the negative correlation between total fissures and protein content ( $r=-0,507$ ,  $P<0,0001$ ), this may be due to a particular brand having a low protein content, causing increased CL and RL, at the same time having a high amount of fissures. Cooked measurements were also poorly correlated with measurements of cracks and spots.

**Colour.** Cooked and dry yellowness was highly correlated ( $r=0,856$ ,  $P<0,0001$ ), as would be expected, since yellowness is an effect of raw material selection (durum).

**Diameter.** In the pooled data analysis no correlations were found between diameter and WA, which is in contrast with the literature (Turnbull, 2001b:217).

### **8.3.1.3 Cooked correlations**

**Cooking time.** Cooking time and cooked colour, particularly yellowness, showed a low negative correlation ( $r=-0,348$ ,  $P=0,015$ ) and may rather be an effect of different raw materials used and drying temperatures for the different brands (Milatovic & Mondelli, 1991:107, Banasik, 1981:167, Wiseman, 2001:18).

**Cooking loss percentage (CL), rinse loss percentage (RL) and water absorption (WA).** Cooking loss was highly correlated with rinse loss ( $r=0,802$ ,  $P<0,0001$ ). CL and RL values could not explain the variance in WA values.

### **8.3.2 Analyses 2 and 3 (pooled data per degree of cooking)**

#### **8.3.2.1 Dry and cooked correlations**

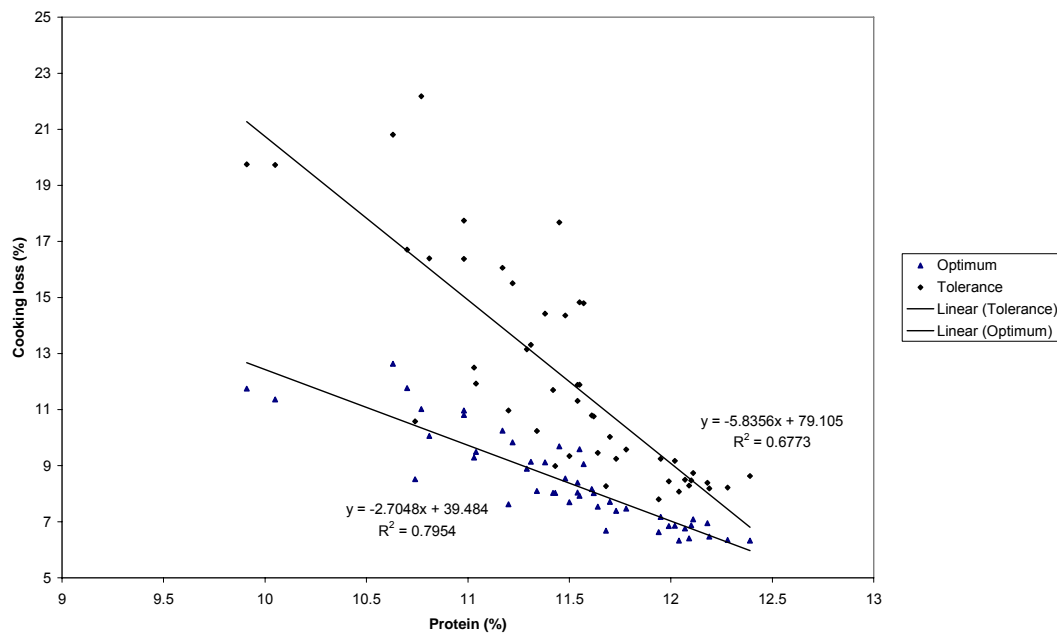
The correlation coefficients for protein, total cracks, total fissures and diameter with cooked measurements are presented in Table 8.2. All the correlation coefficients in these analyses were higher than in Analysis 1. According to literature, protein is positively correlated with good cooked pasta quality, whereas cracks and fissures are negatively correlated with good cooked spaghetti quality. (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter *et al*, 1983:1545, Hahn, 1990:394, Feillet & Dexter, 1998:116, Gianibelli *et al*, 2000:642, Sissons & Hare, 2002:83). Increased protein content leads to an increased cooking times, decreased RL, CL and WA. Cracks and fissures may lead to decreased mechanical strength and increased CL and RL.

**TABLE 8.2 CORRELATION COEFFICIENTS (r) AND THEIR PROBABILITIES (P) FOR SELECTED DRY AND COOKED MEASUREMENTS (n=48)**

DEGREE OF COOKING		OPTIMUM					TOLERANCE				
Cooked measurement	Dry measurement	Cooking time	CL	RL	WAF	WIP	Cooking time	CL	RL	WAF	WIP
		(sec)	(%)	(%)	(%)	(%)	(sec)	(%)	(%)	(%)	(%)
Protein	r	-0,230	-0,892	-0,824	0,571	0,519	-0,227	-0,823	-0,777	0,722	0,550
	P	0,115	<0,001	<0,001	<0,001	<0,001	0,121	<0,001	<0,001	<0,001	<0,001
Cracks total	r	-0,008	0,245	0,425	-0,056	-0,035	0,001	0,274	0,456	-0,255	-0,248
	P	0,956	0,094	0,003	0,704	0,814	0,995	0,059	0,001	0,079	0,089
Fissures total	r	0,030	0,698	0,568	-0,343	-0,282	0,002	0,654	0,522	-0,459	-0,252
	P	0,840	<0,001	<0,001	0,017	0,052	0,988	<0,001	<0,001	0,001	0,084
Diameter	r	0,540	0,021	0,023	-0,558	-0,546	0,540	-0,031	0,030	-0,345	-0,325
	P	<0,001	0,889	0,875	<0,001	<0,001	<0,001	0,831	0,840	0,017	0,024

**Protein.** Contrary to literature, no relationship were found between protein content and cooking time (Grzybowski & Donnelly, 1979:380, Dexter *et al*, 1983:1545, Edwards *et al*, 1993:125). Protein content was negatively correlated with CL and RL (both optimum and tolerance) in agreement with the literature (Dexter *et al*, 1983:1545, Edwards *et al*, 1993:125, Malcolmson *et al*, 1993:420, Feillet & Dexter, 1998:116, Gianibelli *et al*, 2000c:642, Sissons & Hare, 2002:83). Protein content was positively correlated with WAF and WIP (both optimum and tolerance) in these analyses, which is not in agreement with literature (Grzybowski & Donnelly, 1979:380). In Chapter 7 it was suggested that protein encapsulation of starch restricts starch pasting and increases the ability of the starch to retain amylose and amylopectin molecules dispersed in water. The correlations between protein content and WA, CL and RL respectively support the arguments for the differences observed between brands in Chapter 7.

The important role of protein content on cooking losses in spaghetti is further illustrated in Figure 8.2 for optimum and tolerance cooked products. It is clear from the slope of the linearly fitted regressions that the importance of protein is more pronounced in tolerance cooking than in optimum cooking.



**FIGURE 8.2 THE RELATIONSHIP BETWEEN PROTEIN CONTENT (%) AND COOKING LOSS (%) OF SPAGHETTI COOKED TO THE OPTIMUM AND TOLERANCE STATE**

**Cracks.** Spaghetti strands with cracks showed evidence of higher RL than those without. This may be explained in terms of the higher surface to volume ratio of strands with cracks and reflects positively of the validity of the measurement. Cracks were not correlated to any of the other cooked measurements.

**Fissures.** CL and RL were positively correlated with total fissures (Table 8.2), as would be expected. The correlation coefficients are low to intermediate, but higher than in Analysis 1. This provides weak evidence that more solids may be leaching out of spaghetti strands with fissures, since these strands did not absorb more water during cooking and may even have absorbed less water than those without fissures (Table 8.2). It also suggests that the measurement may be valid.

**Diameter.** Diameter was positively correlated with cooking time. This is in support of the findings reported by Turnbull (2001b:217); increase in pasta wall thickness of 0,1 mm could result in an increase of one minute in cooking time. Diameter was negatively correlated with WAF and WIP. This is expected since products with larger diameter have lower surface to volume ratios, increasing cooking time required to reach the optimal stage, while decreasing WA by the excessive loss of solids.

### 8.3.2.2 Cooked correlations

From Analysis 1 (pooled data) it appeared that cooking time, CL, RL, WAF, WIP and cooked colour are correlated. The correlation coefficients for these measurements by Analyses 2 and 3 are presented in Table 8.3. These coefficients differ from those obtained by Analysis 1. It was the purpose of Analyses 2 and 3 to specifically investigate the correlation coefficients across brands within degree of cooking. It appears from the data in Table 8.3 that Analyses 2 and 3 yielded correlation coefficients that differed largely from those obtained by Analysis 1. These correlation coefficients can be used to better explain certain observations than those of Analysis 1.

**TABLE 8.3 CORRELATION COEFFICIENTS (r) AND THEIR PROBABILITIES (P) FOR SELECTED MEASUREMENTS (n=48) OF OPTIMALLY AND TOLERANCE COOKED PRODUCTS**

DEGREE OF COOKING		OPTIMUM					TOLERANCE				
Cooked measurements		CL	RL	WAF	WIP	Cooked	Cooked	CL	RL	WAF	WIP
		(%)	(%)	(%)	(%)	L-value	YI	(%)	(%)	(%)	(%)
Cooking time	r	0,273	0,271	-0,234	-0,258	0,047	-0,348	0,264	0,276	-0,248	-0,161
	P	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	0,070	0,058	0,090	0,275
CL	r	1	0,857	-0,541	-0,481	-0,410	-0,810	1	0,802	-0,777	-0,515
	P	1	<0,001	<0,001	<0,001	0,003	<0,001	1	<0,001	<0,001	<0,001
RL	r		1	-0,514	-0,457	-0,298	-0,622		1	-0,755	-0,585
	P		1	<0,001	<0,001	0,040	<0,001		1	<0,001	<0,001

**Cooking time.** Only a minor proportion of the variance in CL, RL, WAF, WIP, cooked lightness and cooked yellowness could be explained by variance in cooking time to reach the different degrees of cooking. Cooking time was negatively correlated with WAF and WIP. This was not the case in Analysis 1. It can be explained by the loss of solids during cooking, with a resultant reduction in cooked mass and not by actual lower water absorption. Cooking time is also negatively correlated to cooked yellowness, which can be expected since increased loss of colour pigments is expected during cooking.

**Cooking loss percentage (CL) and rinse loss percentage (RL).** CL and RL were positively correlated and the correlation coefficients were higher than in Analysis 1. CL and RL were negatively correlated with WAF and WIP, but is most likely due to the interrelationship between CL, RL and protein content. The correlation of CL and RL with colour is most likely due to the differences between brands manufactured from different raw materials with different colour and different protein content.



### 8.3.3 Analyses 4 to 9 (pooled data per brand per degree of cooking)

Dry measurements of variables reflecting on mechanical strength, such as cracks and fissures, may be correlated with defects such as breakages. In Analyses 2 and 3 these correlations were not evident and it was argued that the difference in raw materials and differences in drying technology obscured the relationships between these variables. Analyses 4–9 were specifically performed to establish whether these variables are correlated to different degrees within wheat species and drying technique (i.e. brands).

#### 8.3.3.1 Independent variables leading to cracks and fissures

Not all brands indicated presence of cracks, fissures, flour spots and white spots. Brand A had no white spots, Brand B had no cracks, and Brand C had no cracks, fissures or flour spots.

**TABLE 8.4 CORRELATION COEFFICIENTS (r) AND THEIR PROBABILITIES (P) FOR SELECTED DRY MEASUREMENTS (n=48) WITH CRACKS AND FISSURES**

Brand	Dry measurements	Brand A		Brand B		Brand C	
		Cracks	Fissures	Cracks	Fissures	Cracks	Fissures
Protein	r	-0,304	-0,037	n.a.	0,213	n.a.	n.a.
	P	0,253	0,892	n.a.	0,431	n.a.	n.a.
Moisture	r	0,046	0,428	n.a.	0,505	n.a.	n.a.
	P	0,867	0,098	n.a.	0,045	n.a.	n.a.
Flour spots	r	0,528	0,592	n.a.	n.a.	n.a.	n.a.
	P	0,0019	0,015	n.a.	n.a.	n.a.	n.a.
White spots	r	n.a.	n.a.	n.a.	0,212	n.a.	n.a.
	P	n.a.	n.a.	n.a.	0,431	n.a.	n.a.

**Protein.** Increased protein increases mechanical strength and there is some evidence that it may reduce cracks and fissures (Dexter & Matsuo, 1977:724, Grzybowski & Donnelly, 1979:380, Dexter *et al*, 1983:1545, Hahn, 1990:394, Feillet & Dexter, 1998:116, Gianibelli *et al*, 2000:642, Sissons & Hare, 2002:83). In the current study (Table 8.4) neither cracks or fissures were significantly correlated with protein content, although the values were negative for Brand A in support of the literature. According to Johnson (2001:159) defective drying in the later stages are also responsible for the formation of cracks and fissures. The observed weak correlations between protein and fissures may be the result of defective drying.

**Moisture.** There is weak evidence in the current study that moisture may be positively correlated with fissures (Table 8.4). This finding cannot be extrapolated to moisture levels outside the

perimeters of the current study, since the different brands differed very little regarding moisture content (9.4–10,3%).

**Flour spots and white spots.** Flour spots and white spots (air bubbles) can increase cracks and fissures, leading to poor mechanical strength (Holliger, 1963:240, Irvine, 1965:330, Matsuo *et al*, 1972:708, Antognelli, 1980:128, Banasik, 1981:168, Hahn, 1990:387, Abecassis, Abbou, Chaurand, Morel & Vernoux, 1994:247, Smewing, 1997:8, Dalbon, Grivon & Pagani, 1998:23, Dick & Matsuo, 1988:538, Feillet & Dexter, 1998:105,110,115, Pasta, 2003:32). In Brand A, flour spots were positively correlated with total cracks. Although Brand B exhibited white spots, this brand had no cracks.

### 8.3.3.2 Independent variables leading to breakages

The correlation coefficients for cracks, fissures, flour spots and white spots with breakages are presented in Table 8.5. Reduced mechanical strength leads to increased breakages (Turnbull, 2001b:216). White spots caused by air bubbles or the inclusion of unhydrated flour particles (Banasik, 1981:167, Dawe, 2001:91) and cracks and fissures, caused by drying defects (Dick & Matsuo, 1988:538, Feillet & Dexter, 1998:105,116, Pasta, 2003:32), may decrease mechanical strength and therefore increase breakages (Holliger, 1963:240, Irvine, 1965:330, Matsuo *et al*, 1972:708, Antognelli, 1980:130, Banasik, 1981:168, Dick & Matsuo, 1988:538, Hahn, 1990:387, Abecassis *et al*, 1994:247, Smewing, 1997:8,9, Dalbon *et al*, 1998:23,30, Feillet & Dexter, 1998:110,105, Atwell, 2001:119, Turnbull, 2001b:206).

**TABLE 8.5 CORRELATION COEFFICIENTS (r) AND THEIR PROBABILITIES (P) FOR CRACKS, FISSURES, FLOUR SPOTS AND WHITE SPOTS WITH BREAKAGES (n=48)**

Brand	Dry measurements	Brand A		Brand B		Brand C	
		B4*	B5*	B4*	B5*	B4*	B5*
Total cracks	r	-0,146	0,191	n.a.	n.a.	n.a.	n.a.
	P	0,589	-0,478	n.a.	n.a.	n.a.	n.a.
Total fissures	r	-0,287	-0,448	0,094	0,178	n.a.	n.a.
	P	0,280	0,082	0,728	0,510	n.a.	n.a.
Flour spots	r	-0,214	0,671	-0,180	0,000	n.a.	n.a.
	P	0,427	0,004	0,505	1,000	n.a.	n.a.
White spots	r	n.a.	n.a.	0,386	0,122	-0,290	-0,293
	P	n.a.	n.a.	0,140	0,652	0,277	0,272

\* Categories for breakages

**Cracks and fissures.** Cracks and fissures were not correlated with breakages in the current study. The cracks and fissures depicted by reference photographs may be too superficial to impact on mechanical strength.

**Flour spots and white spots.** Larger semolina particles ( $> 500 \mu\text{m}$ ) are more likely to form white spots (Antognelli, 1980:128). Ideal particle size varies between  $150\text{--}350 \mu\text{m}$  (Antognelli, 1980:128, Milatovic & Mondelli, 1991:75, Dalbon *et al*, 1998:17, Turnbull, 2001a:57, Turnbull, 2001b:191). It is therefore anticipated that pasta produced from semolina (Brands B and C) should have more flour spots than that from flour (Brand A) and therefore more breakages caused by this defect. In the current study the opposite was true. In Brand A (Table 8.5) total flour spots were positively correlated with broken units in Category B5 ( $<5\text{mm}$ ) ( $r=0,671$ ,  $P=0,004$ ). Flour spots may therefore increase brittleness of strands, leading to spaghetti fragments splitting during cutting.

No correlations were found between white spots and breakages. It can therefore not be conclusively said measurement is valid. It can therefore not be conclusively said measurement is valid. It may also be that this measurement does not impact on other quality measurements.

**Dark spots:** No correlations were found between dark spots with any other measurements. It can therefore not be conclusively said measurement is valid. It may also be that this measurement does not impact on other quality measurements, and may still be valid tool to measure the appearance of the product.

#### 8.3.3.3 *Dry and cooked correlations*

**Cracks.** From the results presented in Table 8.6 there is evidence that when cracks occur in a particular brand that this may lead to increased rinse loss (stickiness) when the product is over-cooked. This correlation proves that the measurement of the amount of strands displaying cracks was valid and can be used in a quality control environment.

**Fissures.** No correlation of fissures with cooked quality measurements was found in Analyses 4 to 9, which is a negative reflection on the validity of the measurement.

**Units sticking together.** Units sticking together are caused by spreader defects (Pasta, 2003:32) when the moisture content upon extrusion is too high (Dalbon *et al*, 1998:38, Dawe, 2001:104), or pre-drying defects (Hahn, 1990:388, Pollini, 1998:60). These defects are plant specific rather than formulation specific. Units sticking together were only observed in Brand A and, when cooked to the optimum point, correlated with CL and RL. This increase in cooking loss may be avoided by

adjustments to equipment and is probably not dependent on the fact that bread wheat was used. This correlation also suggests that the measurement of units sticking together is valid.

**TABLE 8.6 CORRELATION COEFFICIENTS (r) AND THEIR PROBABILITIES (P) FOR SELECTED DRY AND COOKED MEASUREMENTS (n=48)**

BRAND		Brand A			Brand B			Brand C		
Cooked measurements		Dry Measurements								
OPTIMUM		Cracks	Fissures	Sticking*	Cracks	Fissures	Sticking	Cracks	Fissures	Sticking
CL	r	0,025	0,336	0,504	n.a.	-0,098	n.a.	n.a.	n.a.	n.a.
	P	0,927	0,209	0,047	n.a.	0,715	n.a.	n.a.	n.a.	n.a.
RL	r	0,425	0,165	0,498	n.a.	-0,109	n.a.	n.a.	n.a.	n.a.
	P	0,103	0,540	0,049	n.a.	0,686	n.a.	n.a.	n.a.	n.a.
WAF	r	0,140	-0,383	-0,012	n.a.	0,410	n.a.	n.a.	n.a.	n.a.
	P	0,605	0,433	0,964	n.a.	0,115	n.a.	n.a.	n.a.	n.a.
WIP	r	0,133	-0,365	-0,015	n.a.	0,564	n.a.	n.a.	n.a.	n.a.
	P	0,625	0,165	0,956	n.a.	0,023	n.a.	n.a.	n.a.	n.a.
TOLERANCE		Cracks	Fissures	Sticking*	Cracks	n.a.	Sticking	Cracks	Fissures	Sticking
CL	r	0,109	0,191	0,154	n.a.	-0,164	n.a.	n.a.	n.a.	n.a.
	P	0,689	0,479	0,569	n.a.	0,544	n.a.	n.a.	n.a.	n.a.
RL	r	0,526	-0,014	0,193	n.a.	-0,180	n.a.	n.a.	n.a.	n.a.
	P	0,036	0,960	0,473	n.a.	0,505	n.a.	n.a.	n.a.	n.a.
WAF	r	-0,255	-0,169	-0,383	n.a.	0,155	n.a.	n.a.	n.a.	n.a.
	P	0,340	0,532	0,143	n.a.	0,565	n.a.	n.a.	n.a.	n.a.
WIP	r	-0,228	0,070	-0,370	n.a.	0,106	n.a.	n.a.	n.a.	n.a.
	P	0,395	0,796	0,158	n.a.	0,696	n.a.	n.a.	n.a.	n.a.

\* Correlation coefficient for units sticking with protein content:  $r=-0,247$ ,  $P=0,3556$

#### 8.4 CONCLUSIONS AND RECOMMENDATIONS

The correlation coefficients calculated in this study were generally low ( $r<0,5$ ) with the exception of protein content with cooked pasta quality ( $r>0,8$ ). The other correlation coefficients with non-zero slopes were relatively low ( $r=\pm 0,5$ ).

This study provides evidence that the proposed measurements of cracks, fissures and flour spots may be valid measures of spaghetti quality. These measurements can be used, to a certain degree of effectiveness, to predict cooked pasta quality, but require further investigation in a study with fewer variables. The occurrence of these defects is of importance, but this study could not prove that the magnitudes of these defects are of interest. Although the *Likert* scales are of some value to quantify defects, the presence of these defects should rather be noted in quality control to

make immediate adjustments to the causes of such defects. The total amount of fissures may indicate an increase in CL (over-all quality) and RL (stickiness), and surface cracks may indicate increased RL (stickiness) of the cooked product. Flour spots may lead to increase cracking and fissuring with increased breakages (Category B5). This study could not prove that the measurements of white spots and dark spots are valid or that it impacts on other quality characteristics.

Furthermore it has been proved that occurrence of defects such as units sticking together have an influence on the cooked quality of the product and that it can be measured as proposed in the previous chapter.

It has been confirmed that strict control must be placed on incoming raw materials, with particular reference to protein content. The importance of ash in determining final product colour could not be confirmed by this study. Particular attention should also be given to moisture content of the raw materials and the correct calculation of the amount of water required to hydrate this material to the correct degree. This will yield pasta of acceptable quality without excessive stretching (a characteristic of bread wheat proteins), without flour spots and units sticking together, which all leads to subsequent decreases in the cooked quality.

It is recommended that those measurements on dry spaghetti that show evidence of having a negative influence on cooked pasta quality, be further investigated. In such a study the experimental design may be improved by either including a similar amount of total spaghetti samples (batches) from more brands (for example, 8 brands x 6 batches); or more batches from a single brand.

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## CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

During this study the theory underlying spaghetti quality was thoroughly reviewed. The theoretical underpinnings of the manufacturing process, the raw material milling and composition and modern technologies enabling the use of bread wheat for pasta manufacturing was well established.

After thoroughly reviewing the above literature, the quality characteristics of dry and cooked pasta were also reviewed and measurements used to measure quality were investigated. During this study some of the existing quality measurements were improved. For those quality characteristics having no standard measures, methods were developed. These improved and developed measurements were standardised and evaluated for reliability and validity.

Reliable and valid measurements of dry spaghetti quality include protein, ash, moisture, strand length and diameter, cracks, fissures, flour spots, strands with bent shapes, strands with a white line, strands sticking together, strands with loops, breakages and colour. Of these measurements, those for cracks, fissures, flour spots, strands with bent shapes, strands with a white line, strands sticking together, strands with loops and breakages required development. The standard AACC method for colour measurement required improvement.

Of specific relevance in this study, was the development of standard reference methods for cracks, fissures and flour spots during this study for the measurement of the magnitude of these defects on dry spaghetti. This study found that the occurrence of a particular defect exceeds the importance of the magnitude of the defect. The total amount of fissures may indicate a decrease in the overall quality of spaghetti (increased CL) and increased stickiness (RL). Surface cracks may be an indication of increased stickiness (RL) of the cooked product. Total flour spots may lead to an increase in cracks and fissures with increased breakages. These correlations imply that these measures may be reliable and valid. These measurements can be useful to adjust processing equipment when these control measures exceed predetermined limits. This study could, however, not prove that the measurements of white spots and dark spots are valid or that they impact on other quality characteristics. It is recommended that those measurements providing evidence of validity be implemented in a study where independent variables are better controlled e.g. packaging material. Such a study would be able to conclusively prove or disprove the validity of these measurements.

When measuring cracks, fissures and flour spots, certain control variables were identified and should be kept in mind during evaluation. These include evaluating samples against a black background and the use of a sieve counting lens.

It was proved that the occurrence of defects such as strands with bent shapes, strands with a white line, strands sticking together, strands with loops, and breakages can be measured repeatably. Of special interest is strands sticking together, which was correlated to cooking loss, implying a valid measure.

Considering that colour is of importance, the accurate measurement of colour is a prerequisite in pasta manufacturing. The translucency of good quality pasta, results in inaccurate measurement of true pasta colour. This study proved that the use of multiple layer colour evaluations results in better distinction between true differences. It is therefore recommended that the AACC method be adapted accordingly.

Reliable and valid measurements of cooked spaghetti included cooking loss, rinse loss, water absorption, colour and resistance to over-cooking. When measuring the cooked quality of spaghetti, measurements of CL, RL and WA, as standardised in this study, are reliable measurements of spaghetti quality. Measurements of CL and RL were improved and so was the method of cooking spaghetti (sample preparation) before measuring the applicable variables.

Although CL and RL were highly correlated with each other and both highly correlated with protein content, there is evidence that other measurements influence the two measurements differently. Examples include the correlation between CL and units sticking together and the correlation between RL and cracks. It is therefore recommended that both measurements be taken. When calculating WA, it is recommended the cooked mass be expressed in relation to the moisture free dry product.

This study proved the effects of cooking method (sample preparation) on cooked quality measurements. The adjusted and standardised cooking method, as described in this study, has proved to be valid and reliable and its use is recommended. Control variables include the use of a cooking basket versus agitation of sample during cooking. This study proved that cooking in a cooking basket obscured differences between samples that are different. It is recommended that controlled agitation, using a magnetic stirring bar, be applied during cooking.

It is recommended that spaghetti quality measurements as summarised in the methodology of Chapter 7, with the exception of white spots and dark spots, be used to evaluate the quality of spaghetti. These measurements were proved repeatable and could effectively distinguish between samples that were different. These measurements are therefore valid and reliable. These measurements and the sample size requires per batch, are summarised in Addendum B.

Pasta manufacturers strive to manufacture spaghetti of comparable quality by utilising different raw materials. Therefore three brands freely available in the South African market place were compared. One of these brands was manufactured from bread wheat, the most readily available raw material for spaghetti manufacturing in the Western Cape of South Africa. The other two brands were manufactured from durum wheat. During the comparison of brands, partly to test developed methods and partly to obtain information of variability between brands, clear distinctions were noted between durum and bread wheat pasta. Although the milling of the raw material (flour versus semolina), the composition of the raw material and the processing techniques differed between brands, some differences may be explained.

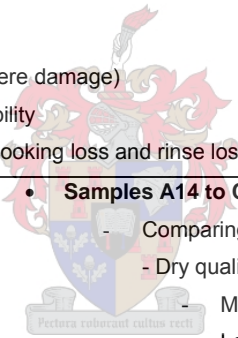
The manufacture of bread wheat spaghetti, even with the latest very high temperature technologies, without the addition of colourants, does not have the same yellow colour as durum pasta. This may be manipulated by using bread wheat semolina instead of flour (which will increase the lightness) and by adding colourants (to increase yellowness).

Furthermore, spaghetti manufactured from bread wheat flour had increased amounts of dry units sticking together. The surface of this product was also more cracked and fissured. Adjustments in the manufacturing line may address some of these problems (cracks, fissures and strands sticking). However, for the consumer, the cooked quality of the product is of the greatest importance and demands a product that is firm and non-sticky (as indicated by low CL and low RL). The bread wheat brand had a higher CL and RL, due to solids leaching from the product during cooking. This study reiterated the role of protein in protecting spaghetti against disintegration during cooking (decreased CL). Comparing the two durum brands, the brand with the highest protein content and manufactured at higher temperatures, had the best quality. There is also evidence that the effect of protein content is of special importance when spaghetti is over-cooked. This will be of particular interest to the catering industry, where products are known to be subject to more abuse than a normal household setting. It must be noted that the effect of protein content on spaghetti quality may have been compounded by other effects such as protein quality and starch damage, not measured in this study.

Even though the effects of protein content overshadowed the effects of other standard measures such as ash content and moisture in this study, it can be said that when the moisture content is maintained between 9% and 12%, breakages, cracks and fissures are not affected. In this study it was found that exceeding the recommended ash content of 1% is not detrimental to pasta quality. The upper limit for ash content in spaghetti manufactured from alternative raw materials should still be established.

**ADDENDUM A: COMMERCIAL SAMPLES PROCURED AND THEIR USE IN THE STUDY**

	Brands				
Batch	A	B	C	D	E
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13				No samples	
14-30					

<ul style="list-style-type: none"> <li>• <b>Sample A1 to E12 (Chapter 5 and 6)</b> <ul style="list-style-type: none"> <li>- Reference photographs (No damage, moderate damage and severe damage)</li> <li>- Sample B4 and D6 – Dry colour repeatability</li> <li>- Sample D12 – Measuring technique for cooking loss and rinse loss</li> </ul> </li> </ul>	
<ul style="list-style-type: none"> <li>• <b>Samples A13, B13, C13 (Chapter 7 and 8)</b> <ul style="list-style-type: none"> <li>- Protein, moisture and ash determination</li> <li>- Method repeatability dry                             <ul style="list-style-type: none"> <li>- Length, diameter</li> <li>- Breakages</li> <li>- Bent shape, sticking, white line, loops</li> <li>- Cracks, fissures and spots</li> </ul> </li> <li>- Method repeatability cooked                             <ul style="list-style-type: none"> <li>- Colour</li> <li>- Water absorption</li> <li>- Cooking loss</li> <li>- Rinse loss</li> </ul> </li> </ul> </li> </ul>	 <ul style="list-style-type: none"> <li>• <b>Samples A14 to C30 (Chapter 7 and 8)</b> <ul style="list-style-type: none"> <li>- Comparing brands</li> <li>- Dry quality                             <ul style="list-style-type: none"> <li>- Moisture, protein, ash</li> <li>- Length, Diameter</li> <li>- Breakages</li> <li>- Bent shape, sticking, white line, loops</li> <li>- Cracks, fissures and spots</li> </ul> </li> <li>- Cooked quality                             <ul style="list-style-type: none"> <li>- Colour</li> <li>- Water absorption</li> <li>- Cooking loss</li> <li>- Rinse loss</li> </ul> </li> </ul> </li> </ul>

## ADDENDUM B: RELIABLE AND VALID MEASUREMENT OF DRY AND COOKED SPAGHETTI QUALITY – METHOD AND SAMPLE SIZE REQUIREMENTS PER BATCH

### Definition

This method determines the dry quality of spaghetti.

### Scope

This method is applicable to dry spaghetti, manufactured from durum or bread wheat.

### Literature required

1. AMERICAN ASSOCIATION OF CEREAL CHEMISTS (AACC). 2000. *Approved Methods of the American Association of Cereal Chemists*. 10th Edition. AACC METHOD 14–22, 2000: Color of alimentary pastes – Reflectance colorimeter method. Method reapproved 3 November 1999. AACC. St Paul, Minnesota.
2. AMERICAN ASSOCIATION OF CEREAL CHEMISTS (AACC). 2000. *Approved Methods of the American Association of Cereal Chemists*. 10th Edition. AACC METHOD 16–50, 2000: Pasta cooking quality – firmness. Method reapproved 3 November 1999. AACC. St Paul, Minnesota.

### Apparatus required

1. Apparatus as described by AACC Method 14–22, 2000 or an apparatus able to measure colour in terms of L, a and b-values
2. Calibrated vernier calliper–accuracy 0.02 mm
3. Calibrated translucent ruler–accuracy 1 mm
4. Mesh with 5.5 mm aperture
5. Sieve counting lense (X10 magnification)
6. Reference photographs presented in Figures 5.2 to 5.6
7. Apparatus required for protein, moisture and ash analysis–as standardised widely.
8. Hotplate (200 °C) with stirring function (100 rpm)
9. Magnetic stirring bar (55 mm long, 9 mm diameter)
10. Long plyers
11. *Büchner* funnel
12. Glass beakers, 600 ml flat-bottomed Griffin beakers, 85 mm in diameter and 125 mm high
13. Temperature-controlled convection oven (103°C)
14. 2 mm glass beads
15. Drying pans 400 ml
16. Drying pans 5 ml



## Procedure

Draw a 1500 g dry spaghetti sample from one batch.

### 1. Determination of breakages

- Sift the complete sample (1500 g) over the mesh (5.5 mm aperture)
- Weigh sieving and express as a percentage of the total sample (1500 g)
- This is allocated to category B5 in Table 1.

**TABLE 1. CATEGORIES FOR BREAKAGES**

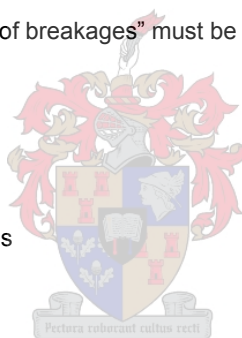
Categories	Definition	Quantification	Sample size
B4	< 120 mm and $\geq$ 5.5 mm	Mass percentage	1500 g
B5	< 5.5 mm	Mass percentage	1500 g minus B4

- From the sample remaining, remove all units shorter than 120 mm, weigh and express as a percentage of the total sample (1500 g).
- This is allocated to category B4 in Table 1.

### 2. Sample division

- The spaghetti left-over after “the determination of breakages” must be divided into the following samples and should be drawn randomly:

- 2.1. 4 samples each consisting of 60 strands
- 2.2. 1 sample consisting of 10 strands
- 2.3. 5 samples each consisting of 100 strands
- 2.4. 1 sample of 200 g
- 2.5. 1 sample of 350 g
- 2.6. Left-over sample kept separately



### 3. Determination of cutting defects, cutter settings and strand length

- Select one of the 60 strand samples (Point 2.1).
- Divide the sample into strand length categories B1 (strands  $\geq$  260 mm), B2 (target range, strands < 260 mm and  $\geq$  240 mm) and B3 (strands < 240 mm and  $\geq$  120 mm) as presented in Table 2.
- Count the strands in each category and express the amount of strands per category as a percentage of the original sample (60 strands).

**TABLE 2. CUTTING DEFECTS, CUTTER SETTINGS AND STRAND LENGTH**

Categories	Definition	Quantification	Sample size
B1	≥ 260 mm	Unit percentage	One 60 strand sample
B2	< 260 mm and ≥ 240	Unit percentage	
B3	< 240 mm and ≥ 120 mm	Unit percentage	

**4. Determination of the average strand length**

- From those strands divided into Category B2 (Table 2), randomly draw 10 strands.
- Measure the length of these 10 strands with a calibrated transparent ruler to the nearest 1 mm.
- Calculate the average.

**5. Determination of the average strand diameter**

- Measure the diameter of 10 strands (Point 2.2) with a vernier caliper to the nearest 0.02 mm.
- One measurement is to be taken in the middle of each strand.
- Calculate the average.

**6. Determination of strands with a white line, bent shape and loops**

- Select one of the 60 strand samples (Point 2.1) for each defect.
- Inspect each strand for the defect under investigation.
- Remove all strands that present the defect.
- Count the strands with the defect and express as a percentage of the original sample (60 strands).
- Repeat for each defect.

**7. Determination of cracks, fissures, white spots\*, flour spots and dark spots\***

- Select one of the 100 strand samples (Point 2.3) for each defect.
- View each strand against a black back-ground through a sieve counting lens.
- Inspect each strand for the defect under investigation in comparison to the applicable reference photographs presented in respective Figures 5.2 to 5.6.
- Remove all strands that present the defect.
- Count the strands with the defect, irrespective of the degree of damage and express as a percentage of the original sample (100 strands).

\* *The validity and reliability of these measurements was not proved in this Thesis.*

**8. Determination of protein, moisture and ash**

- Use one 200 g sample for the analysis of protein, ash and moisture analysis.

- Analysis should at least be done in duplicate, with standard methods, by an accredited laboratory.

#### **9. Determination of dry spaghetti colour**

- Use the left-over sample (Point 2.6) for colour determination.
- Follow the procedure as prescribed by the AACC method 14–22, 2000 with exception to sample preparation. Spaghetti samples must be packed in multiple layers, 90 mm wide and 20 mm deep.
- Take three colour measurements per sample and calculate the average for each measurement (e.g. L, a and b-values).

#### **10. Determination of the cooked quality of spaghetti**

- Cut the 350 g spaghetti sample (Point 2.5) into 5 cm pieces.
- In all cases listed, 25 g samples are cooked in 400 ml artificially hardened (pH 7) boiling water as prescribed by AACC 16–50, 2000.
- Water must be contained in 600 ml flat-bottomed Griffin beaker, 85 mm in diameter and 125 mm high.
- Each Griffin beaker should contain a magnetic stirring bar.
- Water is brought to the boil on a hotplate set at 200 °C with the stirring function set to rotate the stirring bar at 100 rpm.
- When water reaches a rolling boil, spaghetti samples must be added and cooked for the designated time.

#### **Determination of cooking time**

- Determine the optimum cooking time of the spaghetti as described by AACC method 16–50, 2000.
- Repeat this procedure four times and calculate the average time.
- Calculate the tolerance cooking time as 1,5 factor of the optimum cooking time.

#### **Determination of optimum cooking loss (CL), rinse loss (RL), water absorption (WA) and colour**

- Cook 25 g spaghetti to the optimum cooking time according to the prescribed procedure.
- Upon cooking drain spaghetti for 90 seconds through a *Büchner* funnel.
- Allow to rest for 10 min and then weighed (to the nearest 0.01).
- Calculate the WA by expressing the difference between the cooked and dry spaghetti mass (dry basis), as a percentage of the dry spaghetti mass.
- Collect the total cooking water in pre-dried drying pans (weighed to the nearest 0,001 g) containing 10 g glass beads and evaporate in a convection oven at 103 °C for 24 hours until



dry. Weigh the dried dishes and calculate CL by expressing the mass of the dry solids as a percentage of the dry sample mass (dry basis).

- After weighing, place spaghetti in 150 ml distilled water for 10 minutes to rinse, while stirring for the first 30 seconds only.
- Drain through a 250  $\mu\text{m}$  nylon sieve for 90 seconds and measurement the colour directly afterwards as described by AACC method 14–22, 2000.
- Pipette 3x5 ml aliquots of rinse water into drying pans (weighed to the nearest 0,001 g) and evaporate in a convection oven at 103 °C for 60 minutes until dry. Weigh the dried dishes and calculate RL by expressing the mass of the dry solids as a percentage of the dry sample mass (dry basis).
- Repeat this four times and calculate the average CL, RL, WA and colour.

#### **Determination of tolerance cooking loss (CL), rinse loss (RL) and water absorption (WA)**

- Cook 25 g spaghetti to the tolerance cooking time according to the prescribed procedure. After cooking follow the procedure described for the “Determination of optimum cooking loss (CL), rinse loss (RL) and water absorption (WA)” with the exception of colour evaluation.

