Central University of Technology, Free State

DETERMINATION OF THE IMPACT OF VARIATION IN WHEAT (*TRITICUM AESTIVUM* L.) FLOUR QUALITY ON THE CONSUMER ACCEPTABILITY OF FROZEN DOUGH PRODUCTS

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DECLARATION OF INDEPENDENT WORK

I, MARIETA JOHANNA VAN DER WALT, do hereby declare that this research project submitted for the degree MAGISTER TECHNOLOGIAE: FOOD & NUTRITION, is my own independent work that has not been submitted before to any institution by me or anyone else as part of any qualification.

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SUMMARY

Following the deregulation of the wheat industry, a considerable diversification was observed in the retail of wheat dough products. The processing of frozen dough products, appears to be particularly promising as the convenient nature of the products complements the requirements of the small scale entrepreneur. The quality specifications of flour destined for frozen dough products appear not to have been specified in South Africa. Moreover, information on the effect of South African cultivars on the processing of frozen dough, as well as the consumer acceptance of such products, are virtually non-existent.

The primary objective of this study was to determine the impact of variation in flour quality on the sensory and thus marketing properties of a range of frozen products. The second objective was to identify criteria, or possibly a protocol, according to which flour types suited to the production of frozen dough products could be selected. The third objective was to identify the reological characteristics of flours suited to the production of frozen dough products.

Flour and dough quality were assessed by means of standardised rheological techniques to determine the rheological properties of five different wheat cultivars and a commercial flour. The flour sources used were derived from the commercial hard red wheat cultivars (*Triticum aestivum* L.) Molen, Gamtoos, Palmiet, Betta and Tugela. Four frozen dough products were produced and assessed by a consumer panel to indicate the impact of flour source. These products were Hamburger Buns, Fruit Buns, Wholewheat Buns and Standard Brown Loaves.

Flour from the cultivars, Tugela and Betta with their inherent strong dough quality features, were identified as being the most suitable for the production of frozen dough products. The introduction of AMMI, a multivariate statistical technique, in analysing the interaction between product and cultivar, diversified this study. According to AMMI-rankings, the visual texture of bran-containing products was identified as the most valuable sensory characteristic in predicting consumer acceptability. Canonical correlation analysis indicated that Mixograph Midline and Alveograph assessments could serve as valuable predictors in assessing the suitability of flour types for the production of frozen dough products.

OPSOMMING

Die deregulering van die koringbedryf het aansienlike uitbreiding in die beskikbaarheid van graanverwante produkte teweeg gebring. Die behoefte van die kleinskaalse entrepeneur kan veral deur die geriefswaarde van bevrore deegprodukte bevredig word. In Suid-Afrika bestaan daar egter geen kwaliteitspesifikasies met die oog op bevrore deegproduksie nie. Daar bestaan ook feitlik geen inligting oor die mate waartoe Suid-Afrikaanse koringkultivars die kwaliteit van gevriesde deegprodukte en verbruikersaanvaarding beïnvloed nie.

Die primêre doelwit van die studie was om die invloed van variasie in meelkwaliteit op die verbruikersaanvaarbaarheid van bevrore deegprodukte te bepaal. Die sekondêre doelwit was om norme, of 'n moontlike protokol, te identifiseer waarvolgens geskikte meeltipes vir die produksie van bevrore deegprodukte geselekteer kon word. Die derde doelwit was om die rheologiese eienskappe van geskikte meelsoorte vir die produksie van bevrore deegprodukte, te identifiseer.

Gestandaardiseerde rheologiese tegnieke is gebruik om meel- en deegkwaliteit te bepaal en sodoende die rheologiese eienskappe van vyf koringkultivars en 'n kommersiële meelbron, vas te stel. Meeltipes is verkry van die kommersiële harde koringkultivars (*Triticum aestivum* L.) Molen, Gamtoos, Palmiet, Betta en Tugela. 'n Verbruikerspaneel het deur sensoriese beoordeling die impak van meeltipe op vier bevrore deegprodukte: Hamburger-, Vrugte-, Heelgraanbroodrolletjies en Standaard Bruinbrode, bepaal.

Die kultivars Tugela en Betta, met hul oorerflik sterker deegkwaliteitseienskappe, het uit 'n verbruikersoogpunt die mees aanvaarbare produkte gelewer. Die aanwending van AMMI, 'n meerveranderlike statistiese tegniek, het ook met die interpretasie van die sensoriese interaksie tussen meelbron en produk 'n unieke dimensie aan die studie verleen. Met AMMI-resultate, is die visuele tekstuur van die semelbevattende produkte, as die mees betekenisvolle sensoriese eienskap vir die selektering van geskikte meeltipes geïdentifiseer. Kanoniese korrelasie analise het getoon dat Mixograaf Middellyn en Alveograaf data die hoogste voorspellingswaarde vir die kwaliteit van bevrore deegprodukte inhou.

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CHAPTER 1

INTRODUCTION AND PROBLEM STATEMENT

1.1 Introduction

The deregulation of the South African wheat industry introduced opportunities to trade a wide range of newly developed products. Within a free market system, the acceptability and profitability of these products are eventually being determined by the consumer. This development introduced the application of specialised production processes, which in turn appealed for the use of flours of different quality. Flour quality generally refers to flour functionality, and is determined by a multitude of biochemical and physical properties (Finney, Yamazaki, Youngs & Rubenthaler, 1987). The flour required for the production of bread, for example, would differ from the type of flour required for the production of cookies or pretzels (Bushuk & Scanlon, 1993). This implies that in optimising the economic efficiency of production, producers of baked products should have the capability to match the technology to their disposal with a specific type of flour quality.

Several studies have shown that the quality of wheat flour is determined by both inherent factors and the environment in which the wheat was grown (Van Lill, Wentzel, Smith & De Villiers, 1993; Van Lill, Purchase, Smith, Agenbach & De Villiers, 1995). The impact of the effects of genotype, environment or their interaction on quality parameters varies (Van Lill *et al.*, 1995; Van Lill & Smith, 1997). This implies that the breeders and producers of wheat should to some extent be capable of managing the quality of the wheat required by the processing sectors. In order to optimise the production of suitable wheat, it is of great importance to the wheat breeder to have information on the quality profiles required for the production of specific products. These profiles are used to develop protocols according to which the most suitable wheat lines in breeding programmes are selected (Van Lill & Smith, 1997).

Frozen dough products are associated with cost effectiveness and convenience (Best, 1995; Payne, 1997). Based on the number of articles on frozen dough published by the South African commercial or institutional catering trade press, it was concluded that the demand for frozen dough products has substantially increased. The information contained in these reviews, offered little consideration for either development in consumer satisfaction or for industry specific needs and characteristics (Payne, 1997; Penstone, 1997). At international level, most research reports appear to focus mostly on the mechanism of quality variation and also showed little or no relationship to consumer preferences (Gelinas, 1991; Inoue & Bushuk, 1991; Berglund & Shelton, 1993).

The lack of information on the suitability of South African wheat cultivars to frozen dough production affects both the wheat producing and processing industries. It was therefore envisaged that an investigation into the impact of variation in wheat flour quality on the consumer acceptability of frozen dough products, would add value to the quality framework of the breeders, producers, processors and the end-consumers of South African wheat.

1.2 Objectives

The objectives of the study were as follows:

a) To determine the impact of variation in flour quality on the consumer acceptability of frozen dough products.

b) To identify criteria, or possibly a protocol, according to which flour types suited to the production of frozen dough products could be selected.

c) To identify the rheological characteristics of flours suited to the production of frozen dough products.

CHAPTER 2

AN OVERVIEW OF WHEAT QUALITY AND SENSORY EVALUATION, WITH A FOCUS ON FROZEN DOUGH PRODUCTS

2.1 Introduction

The purpose of this overview is to introduce the integrated world of wheat quality. Even though some aspects, such as milling quality, were not directly linked to variation in frozen dough quality, a brief discussion was included to demonstrate wheat quality as a continued process in the consecutive stages of processing.

The conceptualisation of quality may relate to an appreciation of the finer things in life, similar to being able to admire the harmony flowing from different musical instruments tuned to the same pitch and intensity. On a more practical note, quality may relate to fitness for purpose, or simply put, those factors that the buyer finds attractive. Conceptualising the quality of baked goods, relates to a multitude of factors originating in the breeding of a wheat cultivar and being carried through the cycle of commercial production, being milled, baked and finally eaten. Small wonder that after decades of intensive research, wheat quality still demands the attention of the international wheat research community.

The complicated nature of the breeding of hard red wheat (*Triticum aestivum* L.) cultivars over a period of almost a decade, has been noted by Van Niekerk & Van Lill (1990). Besides the incorporation of agronomic factors contributing to improving yield across the harsh South African growth environment, wheat quality is considered as an equally essential feature in ensuring the competitiveness of a cultivar on the international wheat market. Quality refers to processibility which in turn determines the profitability of the milling and the baking sectors.

2.2 Milling quality

The quality of the grain intended for milling purposes affects both the efficiency of the milling process and the functionality of the flour produced. The miller buys wheat from the producer with the sole aim of maximising flour yield while meeting the requirements of the baker. The quality of wheat produced under field conditions, tends to be inconsistent. The first challenge of the miller is therefore, to combine different wheat sources to a relatively homogenous batch suited to the customer needs. This batch is commonly known as a grist (McWilliams, 1989).

After the wheat has been received, wheat classes are binned in different silos according to their quality attributes such as protein content and mixograph dough development time. In order to assess possible non-visual sprouting damage, Falling Number of milled grain samples is determined with a Hagberg Falling Number 1400 apparatus (AACC, 1983). The presence of excessive α-amylase signals unacceptability as it hydrolises the starch, resulting in a sticky bread crumb that cannot be sliced mechanically.

The milling of wheat involves optimising the separation of the endosperm from the bran ($\leq$ 80%) by means of consecutive milling phases. The degree of flour extraction varies according to the end use of the flour and the type of wheat being milled (Fowler & Priestley, 1990). For the production of white bread flour, the extraction level is aimed at about 75% and for the production of brown bread flour the extraction level may be increased to 80%. Flour colour, as well as differences in bread flavour relates to the extraction rate. Genotypic differences, for example, may also attribute to inherent colour variation in the endosperm.

During the first phase of milling, the break phase, the objective is to remove the bran by sifting or by an air classification system after being subjected to a brief tempering steam treatment to ease removal of the outer bran layers (McWilliams, 1989). Should the wheat be too hard, the normal 12 h period of tempering up to the moisture content required for effective milling (±16%), is increased beyond the limits of production schedule (Finney, *et al.*, 1987). The reduction phase which follows the break phase, is primarily concerned with the gradual reduction of the pieces of endosperm into particles of flour size by grinding on successive smooth roll stands (Bushuk & Scanlon, 1993).

A hard wheat of good milling quality should have normal bolting and sifting properties that can already be evaluated during wheat breeding. South African winter wheats with grain protein content ≥ 11% have been reported to be slightly harder when compared to samples having a lower protein content (Van Lill & Smith, 1997). Many research reports attribute to the fact that wheat hardness is primarily genetically determined. Environmental factors such as agronomic practices, also appear to have some effects on wheat hardness through variation in protein content. Irregular morphomology such as shrivelled, immature and broken kernels reduces milling performance by lowering flour yields (Fowler & Priestley, 1991).

A secondary measure of the efficiency of bran separation, is the ash content. The mineral content of wheat is primarily located in the bran and a higher ash content would relate to the increased presence of bran, signifying reduced milling efficiency and lower flour yields (Finney *et al.*, 1987).

The most suitable wheat will perform well when subjected to the physical operations of breaking, sifting and purifying.

2.3 Baking quality and dough characteristics

2.3.1 Protein content and protein quality

Wheat quality sets out with the breeding of superior wheat cultivars as the first step towards consumer satisfaction (Van Niekerk & Van Lill, 1990). Ultimately poor quality wheat reduces profitability, stressing that the consistent provision of flour with good quality is essential to maintain profitability in industrial bread-making (Van Lill, *et al.*, 1993). Both protein content and protein quality are essential elements in breadmaking. While protein content may vary from 8% to 25% (Van Niekerk & Van Lill, 1990), flour is normally milled from hard red wheats (*Triticum aestivum* L.) with a grain protein content (N x 5.7) in the range of 10-12% (Van Lill & Purchase, 1995). Protein quality refers to variation in the protein composition found among wheat genotypes, as well as the proportion of the various wheat protein classes. There are four protein classes namely glutenin, gliadin, globulin, albumin. Of primary importance in the breadmaking process are glutenins, providing elasticity and strength, with gliadins conferring extensiblity to a dough (Van Lill *et al.*, 1993).

Glutenins are the most important endosperm proteins related to quality properties of flour and play an important role in dough mixing tolerance. Gliadins have single polypeptide chains, whereas glutenins form polymers of protein subunits linked by interchain disulphide bonds. The glutenin subunits can be separated after reduction of disulphide bonds into high and low molecular weight groups which play an important role in dough mixing tolerance by providing the structural framework for the developed gluten matrix. The strength and mixing tolerance of the developed glutenin network depend on the ratio of the glutenins, comprising of strong covalent disulphide bonds, to gliadins, comprising of weak, non-covalent hydrogen bonds (Barnes & Hare, 1996). When compared to a weak flour, stronger flours have a greater number of disulphide bonds holding the coiled chains of protein together (Cheetham, 1990).

Within the field of baking quality, the study of deformation and flow of wheat dough is called rheology. The rheological properties of wheat dough relate to the force and the resultant deformation during mechanical processsing. The importance of rheological properties is that it changes dramatically during the baking process and contribute to effective transformations during baking (Bloksma, 1988). The rheological properties of greatest importance to the baker, are the mixing behaviour of the dough, especially its viscosity and rate of development, and its extensibility. Rheological data provides the baker with a valuable prediction of the processing quality of the flour (Simmonds, 1989).

2.4 Mechanical development processes of bread production

Bread-making may be divided into four basic manufacturing processes namely: mixing or dough formation, moulding of the dough product, dough development or fermentation and baking (oven spring). Bread quality may be influenced by the method of manufacturing and changes taking place during processing. The baker's requirements are largely determined by the type of product produced and technology employed in the bakery. Factors such as water absorption, dough mixing requirement and dough stability are related to the baker's profitability.

2.4.1 Dough mixing

According to Brown (1993), there are two types of dough mixing processes, namely the sponge-and-dough method and the straight dough method. The sponge-and-dough method is characterized by a pre-ferment, called the sponge, in which half of the total dough is subjected to twelve to sixteen hours to the physical, chemical and biological actions of the fermenting yeast. Compared to the straight dough method, this method has a longer processing time, as the dough, mixed with the rest of the ingredients, is then left for thirty minutes in bulk before being processed as required.

The Chorleywood Breadmaking Process involves the mixing of all ingredients into a single batch, with dough development being achieved by intense mechanical mixing of the dough in a short time. At an energy input of 11 Watt hours per kilogram dough in a high-powdered, high-speed mixer, the combined ingredients form a mass with visco-elastic properties (Brown, 1993). Mixing time can vary according to the resistance of the dough to the turning of the mixing impellor. Although the degree of dough development will remain the same for both soft and strong doughs, a strong dough (made with high protein flour), will take longer to consume the set energy level compared to soft doughs. Characteristics of the dough at the optimum point of mixing, involve acquired elastic properties and a smooth appearance with a dry surface. Mixing beyond this stage, produces a dough which is sticky and difficult to handle (Brown, 1993). The temperature of the mixed dough should also fall in the range of 28° C to 30° C to standardise the rate of fermentation.

Dough mixing is a complex process in which an optimum structure should be developed by combining flour, yeast, water, salt, fat and pre-mix (which usually comprises of emulsifiers and oxidants) to form a bread dough. The mixing properties of dough largely depend on the visco-elastic properties of flour proteins and the correct addition of the basic ingredients. Flours having low protein content (≤10%) require a longer mixing for full development of the gluten matrix. Higher protein levels (≥12%) are not known to affect mixing requirement. (Hoseney, 1985). According to Van Lill *et al.* (1995), wheat flours with high protein levels exhibited stronger dough features.

2.4.1.1 Wheat flour

When wheat flour is mixed with water to form a visco-elastic dough, the proteins, along with other constituents, rapidly hydrate. Individual hydrated flour particles are forced together by the mixing action, to form a continuous network of dough (Fowler & Priestley, 1991). The rheological properties of this network greatly depend on the number and type of cross-links between the protein molecules (Silaula, 1985). This gluten matrix displays the desirable combination of rheological properties for optimum expansion and gas retention during proof and baking (Fowler & Priestley, 1991). It was reported that mixing and kneading facilitated extensive intra and intermolecular association of the poly-peptide chains (Silaula, 1985). Overmixing causes a breakdown of the gluten network and weakening of the dough structure (Simmonds, 1989). Flour also contains starch which is partially hydrated with the dough water. During baking the dough protein coagulates and the hydrated starch partially gelatinises to form the structure of the bread (Brown, 1993).

2.4.1.2 Water

The amount of water required to produce a dough of standard consistency, is usually 58 - 65% of the flour mass. Factors like protein quality and content, damaged starch and bran in flour, may lead to a proportional increase of added water, especially in the Chorleywood Bread Process (3.5% more than normal, based on flour weight). A water phase, resulting from hydrated flour proteins which are partially absorbed by the flour starch, acts as a solution for sugars, salts and soluble proteins and dispersion of yeast cells (Brown, 1993).

2.4.1.3 Yeast

Yeast aerates dough by the production of carbon dioxide during the fermentation process. In this process, sucrose is rapidly converted to glucose and fructose, followed by the conversion of maltose to glucose. As a result of the conversion of all these monosaccharides, with enzymes playing a vital part, carbon dioxide and ethanol are formed to expand the dough during final proof and early stages of baking. During fermentation, yeast utilises reducing sugars which contribute to the Maillard reaction, resulting in conversing flavour to bread through the production of complex by-products of the fermentation process. A higher level of yeast, (2% on flour weight) is recommended for the Chorleywood Bread Process (Brown, 1993).

For the fermentation process, compressed baker's yeast is used. It has a moisture content of about 27 - 34% and a protein content (defined as Kjeldahl-N x 6.25) of about 42 - 56% (dry weight basis) (van Dam, 1988). To maintain a shelf life of three to four weeks, this type of yeast should be stored at temperatures between 0° C and 4° C (van Dam, 1988).

2.4.1.4 Salt

Salt not only contributes to the enhancement of flavour in bread dough, but also relates to inhibiting yeast activity and strengthening of the dough gluten (Chang, 1992).

2.4.1.5 Emulsifiers and oxidants

The baking industries rely on a wide range of chemical agents to modify the performance of flours and to improve the eating quality and shelf life of bread. Composite improvers may contain oxidizing and reducing agents, emulsifiers, fats and enzymes.

The pre-mix formula comprises of emulsifiers, oxidants and colourants. The commonly used emulsifiers (dough strengtheners) permitted for use in bread are the following: lecithin, monoglycerides, diacetyltartaric acid esters of monoglycerides (DATEM) and stearoyl lactylates (sodium salts SSL and calcium salts CSL) mostly used in powdered form. Dough strengtheners improve mixing tolerance, gas retention and resistance of dough collapsing during rough handling. They may also increase water absorption of the flour. In the finished product, dough conditioners improve loaf volume and give a resilient texture and fine grain, together with improved slicing properties (Tamstorf, Jonsson & Krog, 1988). The effects of most oxidizing and reducing agents on dough properties are dependant on their reaction occurring during dough mixing, consequently changing the process of mechanical development of the dough protein structure. Commonly used oxidants are: potassium bromate, L-ascorbic acid, L-cysteine hydrochloride and chlorine. Ascorbic acid requires oxygen for conversion to dehydroascorbic acid (Fitchett & Frazier, 1988).

2.4.1.6 Fat

The use of fats in yeast-leavened products, initiates a number of changes in the internal, as well as the external characteristics of the finished product. A larger volume, a finer and more uniform crumb structure and softer texture are related to the addition of fat (Stauffer,1993). During proofing and kneading, the liquid portion of the fat is retained within a matrix by the solid fat component, resulting in a stronger dough during proofing. Followed by the actual baking process, the fat acts as a lubricant on the gluten structure, ensuring a more extensible dough. The fat also reduces the rate of the carbon dioxide diffusion from the dough. All these factors may result in a larger loaf volume (Tamstorf, *et al.*, 1988). According to Brown (1993), fat is an essential ingredient in the Chorleywood

Bread Process and a normal addition of 0.7% of flour weight, ensures that sufficient solid fat is present at the end of the final proof.

2.4.2 Moulding process

The obvious purpose of the moulding in breadmaking is to shape the dough piece for proofing and baking. After mixing, the dough is scaled into individual loaf-sized pieces of predetermined weight and shaped by the moulder into cylindrical loaves. Moulding revolves around three distinct steps of sheeting the dough into a uniform thin layer, rolling the sheeted dough into cylindrical form and finally passing the rolled dough under a pressure board to seal its seams and give it the final required shape depending on the product being made.

The number and size of gas bubbles which are incorporated into the dough during mixing, has a major effect on the final bread character. Care must be taken in shaping the dough piece, not to damage the bubble structure in the dough as this will ultimately create the bread cell structure required (Cauvain, 1995).

2.4.3 Fermentation

Alcoholic fermentation is a biochemical process which involves the ensymatic conversion of carbohydrates into ethanol and carbon dioxide as the principle end product. Various enzymes, either naturally present in flour or added in the bread formula, may catalize numerous hydrolytic reactions, resulting in the progressive degradation of the starch, proteins and lipids. Enzymatic hydrolysis proceeds from the time the dough is mixed until the ensymes are inactivated by the oven heat (Chang, 1992).

2.4.4 Baking

Baking is the final step in breadmaking, characterised by several physical and biochemical interactions: Firstly, the expanding of the dough during the initial phase of baking, referred to as 'oven spring', where a 80% increase in the volume results from the increased production and expansion of carbon dioxide. The structure and strength of the dough must be such that it will expand under this internal pressure without collapsing (McWilliams, 1989). Following expansion, a crust forms, yeast and enzymatic activity accelerate, the protein coagulates, starch gelatinises and new flavour substances are formed. Raw dough is transformed into a light porous, readily digestible and flavourful product.

2.5 Assessment

In view of the end product, the assessment of the functionality of dough properties are determined through objective measurement with instruments such as the Farinograph, Mixograph, Extensograph and Alveograph. These instruments monitor dough changes through emulation of the three stages of the baking process namely dough mixing, fermentation and baking. The relationship between these instruments and the principle stages in the baking process, is demonstrated in Table 2.1.

Table 2.1 The principle phases[a] in the baking process

	Process	Evaluated property	Instrument
Phase 1	• Mixing • Dough formation	• Water absorption • Dough development time • Stability • Dough mixing tolerance	• Farinograph • Mixograph
Phase 2	Fermentation	• Resistance to extension	• Extensograph • Alveograph
Phase 3	Baking (oven spring)	• Pasting temperature Paste viscosity	• Amylograph

[a] Adapted from Rasper (1993)

2.5.1 Mixograph

The Mixograph and the Brabender Farinograph are instruments used for measuring dough-mixing behaviour and recording in graphical form, changes in the force required to mix a flour-water dough as it develops under standardised conditions (Simmonds, 1989).

The effect of quality and quantity of flour proteins on mixing properties can best be objectively determined by mixogrammes obtained on a Mixograph. The Mixograph provides valuable information on the time to peak dough development, dough consistency at peak dough development and the tolerance to overmixing (Finney *et al.,* 1987). Development may occur as the dough is mixed to obtain optimum hydration. Mixing tolerance is a function of the slope and width of the mixogramme after the peak and stability of mixogramme height on either side of the peak. Flour with low protein levels needs a longer mixing time due to the difficulty in forming a continuous phase of protein. A medium to medium-long mixing requirement of about four to five minutes, corresponding to the time to the peak, is generally the most desirable for dough handling properties and optimum bread production (Finney *et al.,* 1987). The graphical output from the Mixograph (the mixogramme) is predominantly used to deduct dough mixing requirements in breeding programmes and as a quality control measure of binning and milling of wheat

2.5.2 Farinograph

Dough development time, dough stability (plasticity and mobility) and water absorption are assessed with the Farinograph (AACC,1983), after been subjected to prolonged, relatively gentle mixing at a constant temperature (Finney *et al.,* 1987).

The consistency of the dough is strongly influenced by its water content. Flour water absorption is a linear function of protein content within a flour mixture. Variation in the relationship may occur when damaged starch and bran are added. Water absorption required to produce a dough of a certain consistency is affected by both protein quality and quantity (Bushuk & Scanlon, 1994). Every flour has its own optimum water absorption depending on its protein quality and quantity, flour particle size and the presence of mechanically damaged starch. Similar dough consistencies have to be used when comparing one flour against the other. Under-developed and over-developed doughs normally exhibit reduced optimum absorptions (Fowler & Priestley, 1991). The maximum resistance to the mixing force can be adjusted so that it is located at the centre line of the graph paper (500 Brabender units). Maximum forces above 500 units indicate that the dough is too dry and requires additional water. Maximum forces below 500 units indicate that the dough is too wet and a fresh dough must be made up using less water (Simmonds, 1989).

2.5.3 Extensograph

The Extensograph is used to determine the effects of inherent flour quality, processing and ingredients on the visco-elastic properties of wheat and flour doughs and indicates the boldness and stability of the dough (Kilborn & Preston, 1982). It measures both resistance to extension and extensibility to the point of rupture. The forces encountered by the hook of the instrument as it stretches the dough to the point of rupture, are recorded graphically through a dynamometer system in a similar manner to the Farinograph (Simmonds, 1989).

2.5.4 Alveograph

The Alveograph measures extensibility and resistance to expansion of dough. The height of the curve is a measure of the initial resistance of the dough to extension. The length of the curve is an index of dough extensibility and gas retention. The final curve is determined by averaging five replicate curves from a 250 g dough weight sample (Finney *et al.*, 1987).

2.5.5 Conclusion

The acceptability of baked products to the consumer, the production systems associated with these products and economic considerations are the major actors driving advances in baking technology. It became clear that different instruments, and sets of data are used to interpret quality variation, depending on the type of product being produced.

2.6 Sensory evaluation

While the assessment of dough focuses more on quality assurance during the production phase, sensory evaluation focuses more on determining the consumer's perception of the final product.

The need for sensory evaluation of food was supported by the consumer products industries since the early forties when sensory evaluation received additional impetus with research in food acceptance for the armed forces (Stone & Sidel, 1993). Industries have since recognised the value of sensory evaluation in their attempts for developing new products, entering new markets or competing with existing markets. A greater receptiveness to new approaches and new ways for anticipating and measuring the potential for the success of a product in the marketplace, are detected. The significant changes in the marketplace and the greater awareness of sensory evaluation coincide with the transformation by the food industry towards a consumer-orientated environment rather than the traditional production-orientated environment.

2.6.1 Sensory quality

Stone & Sidel (1993) defines sensory evaluation as a scientific discipline, used to evoke, measure, analize and interpret reactions to those characteristics of foods and other materials as they are perceived by the senses of sight, smell, taste, touch and hearing. These sensory qualities will largely dictate the success of a new product (Baker, Hahn & Roberts, 1988), by establishing whether product differences are acceptable or unacceptable and noticeable to the consumer (Lyon, Francombe, Hasdell & Lawson, 1992).

Sensory analysis is also important for the evaluation of quality. Quality is a composite of all the characteristics of a specific product and is used in determining the degree of acceptability of the product by the buyer (Baker *et al.*, 1988). Establishing product quality, is best achieved by using available information sources and including consumer preference information (Stone & Sidel, 1993). Product quality has a significant influence on consumer behaviour. The consumer's perception of quality often conflicts with that of the manufacturer, perhaps explaining the preoccupation of the European food sector with quality control and monitoring (Paquot, 1992). Sensory analysis provides a unique approach to identifying those product qualities that are important to the consumer (Stone, Mc Dermott & Sidel, 1991).

In a series of investigations concerning food quality, Stone *et al.*, (1991) observed that consumers tended to use quality and preference judgments interchangeably. The word "quality" was often used in the context of the sensory attributes of a product. It suggested that responses of consumers are influenced by physiological and psychological factors and by methods of product consumption (Smith & Cammarn, 1990). Therefore, a common understanding of the basic terms such as "quality", is essential for sensory evaluation of food.

2.6.2 The assessment of sensory characteristics

Food acceptance is regulated by the characteristics of the food object, the environmental surroundings of the food object, established food habits and intra-organic chemical conditions which themselves may or may not be directly related to metabolic needs (Amerine, Pangborn & Roessler, 1965).

When the acceptability of a food product is assessed by means of human sensory organs, the evaluation is sensory or subjective. Sensory properties are therefore manifested in the flavour, texture and appearance of products and these aspects, as well as functionality, if appropiate, should be evaluated as it would be used by the consumer (Mastrian, 1985). According to Meilgaard, Civille & Carr (1991), the attributes of a food item is perceived in the order of:

1. appearance;
2. odour / aroma / fragrance;
3. consistency and texture and
4. flavour (aromatics, chemical feeling factors, tastes such as salty, sweet, sour, bitter).

The surface characteristics, or appearance factors, could be the most important factors evaluated. Appearance factors which initially attract a person to a product, need to be evaluated as it is often related to the quality of the product and influence a decision to purchase or consume. The sense of vision has the advantage over the other senses in that an observer's appreciation of the appearance of an object can be recorded pictorially. Vision can be regarded as the process of seeing, whereas appearance is the recognition and assessment of properties like surface structure and colour, associated with the visual object (Hansen & Setser, 1990).

Of the various appearance characteristics of foods, colour is the most important. Colour involves both physical and psychological components (the wavelength distribution of light); size and shape; surface texture and the geometric attributes which include clarity, haze, and turbidity (Meilgaard *et al*., 1991). The colour of foods contributes to one's esthetic appreciation of it and is used to determine the quality of a number of foods.

The colour attribute for bakery products consists mainly of the browned lightness or darkness (colour value) and colour intensity. The colour value and colour intensity of the crust and the crumb should be assessed separately. Extremely light brown to extremely dark brown can be assessed as the colour value (Setser, 1993).

The odour of a product is detected when its volatiles enter the nasal passage and are perceived by the olfactory system. Odour of food is experienced by aroma and is the volatile, determinative characteristics of flavour. Aromas can be perceived separately from flavour, which includes both the aroma and taste of food (Meilgaard *et al.,* 1991).

Tastes include sweet, sour, salty, bitter and can stimulate, complement or mask one another (Setser, 1993).

Texture contributes to the overall acceptability of a food, as well as to the appearance and flavour. Texture is perceived by sensors in the mouth and can be defined as the sensory manifestation of the structure of foods as perceived by the senses (tactile) and muscles (kinesthetic) (Hansen & Setser, 1990).

Textural characteristics of baked products include terms such as hardness or firmness, crispness, adhesiveness, cohesiveness, gumminess and viscosity which are measured as mechanical properties by the fingers, tongue, jaw or lips. Grainy, gritty, crystalline, flaky and moisture properties, such as wetness, oiliness, moistness and dryness are measured as geometrical particles by the nerves in the surface of the skin of the hand, lips or tongue (Meilgaard *et al*., 1991). Physical properties may include size, shape, number, nature and a conformation of constituent structual elements (Brennan, 1988).

Flavour is the combined effects of the aromatics, tastes and chemical feelings stimulated by a substance in the mouth (Meilgaard *et al*., 1991).

Bread flavour may be affected by a wide variety of factors in the bread making procedure, including ingredients, fermentation and baking. Flour is the major ingredient in bread and contains many classes of flavour reactive compounds. Yeast fermentation is necessary for the development of bread flavour that results from the formation of alcohols, acids, esters and other precursors. Non-enzymatic browning reactions occurring during oven baking give rise to both volatile and non-volatile compounds that contribute to the flavour of bread. Increasing temperature results in a rapidly increasing rate of browning. Therefore, many of the flavour compounds in bread are formed in the crust (Chang, 1992).

Many attributes of bakery products can be measured only by sensory techniques. The sensory perception process and the interrelationships of sensory properties to acceptability, are fundamental to successful marketing of the finished bakery products. Appropriate measuring of the interrelated sensory properties will allow more successful product development, and set standards for raw materials, ingredients and finished products (Setser, 1993).

Sensory evaluation techniques provide a means of reducing out-of-spec products and reworking, thus contributing towards greater flexibility in manufacturing alternatives (Rutenbeck, 1985).

Food testing entails the sensory evaluation of a food product to identify specific sensory attributes, which may relate to product acceptance. Choosing the appropriate method of testing, determines the successful achievement of this goal.

2.6.3 Sensory evaluation tests

In the sensory evaluation process, suitable judges are selected as panelists to study the human perception of product attributes and concepts or to give an indication of their likes and dislikes. Trained or untrained panelists may be asked to discriminate between samples, describe or score the quality of a product, rate the acceptability of a product, or describe their preference for a product. To ensure that knowledge about sensory characteristics is related to consumer likes or dislikes about the product, appropriate analytical and affective tests are used (Lyon *et al.*,1992).

2.6.3.1 Analytical tests

Analytical tests reflect on differences among products, the specific nature of the differences, and their magnitudes. The two main types of analytical tests are: discriminative and descriptive, of which the latter is more useful. Discrimination tests determine whether products are perceived as different and the most frequently used discrimination tests are the sequential, paired difference, duo-trio and triangle tests (Stone & Sidel, 1995; Sidel, Stone & Bloomquist, 1980).

Descriptive tests which include flavour profile analysis, texture profile analysis and quantitative descriptive analysis, determine the specific similarities and differences among products and therefore provide considerably more information (Stone & Sidel, 1995). Descriptive analysis training involves defining and developing the nature of applicable sensory attributes, as well as the learning of a specific evaluation technique. Results from the descriptive test provide information about product similarities and differences in quantitative terms (Smith & Cammarn, 1990). According to Stone *et al.* (1991), typical descriptive analysis of an array of foods will yield about 40 attributes.

Both descriptive and discrimination tests require a well-trained and / or experienced panel. Potential panelists for analytical methods are screened for selected personal traits, interests, and their ability to discriminate between differences and generate reproducible results (Setser, 1993). The panelists must be able to recognize, identify, and recall sensory characteristics. The analytical panelists look at the simplest most atoministic sensory characteristics (how sweet, how firm) and no longer think in global terms that the consumer might use (how fresh, how creamy). Consumers, on the other hand, tend to view products more holistically, capturing an integrated response regarding the preference or likeness of the product (Lawless & Claassen, 1993).

2.6.3.2 Affective tests

Affective tests provide information about the degree of liking or the preferences for products. There are two types of tests namely, scaled and categorical, of which the former is more useful (Stone & Sidel, 1995).

Consumer sensory analysis (acceptance testing) are usually performed towards the end of the product development and will focus on the performance of products in the marketplace (Heymann, 1995). Consumer acceptance and preference are important and panelists are, therefore, everyday consumers of these products.

Generally, a large number of respondents (at least 50) are required (Lyon *et al.*,1992). The lack of experience of the consumer panel increases the experimental error and therefore necessitates a large number of judges (Campbell, Penfield & Grisworld, 1979). For affective judgements, like acceptability, the determination of how the population in general, and not just a few people, will respond to the product, is important (Setser, 1993). These panelists are not trained, but are selected at large to represent a target or potential target population. In consumer sensory analaysis the investigator is interested in whether the consumer likes the product, prefers it over another product or finds the product acceptable and whether this preference may lead to action in the form of buying the product (Heymann, 1995).

Panelists may be asked to evalute the product alone or to compare it with another. They may be asked to merely taste or view the product or may use it for months (Smith & Cammarn, 1990). Acceptance can be defined as a positive attitude after the tasting experience and actual utilization (purchase or eating) (Baker *et al.*, 1988).

In the establisment of a consumer panel, a number of factors should be considered. The consumer participating in a test should meet specific criteria such as product purchase and usage requirements, demographic criteria such as age, gender, income, education, economic or social level, health and household size. The latter ensures that the panel represents a known user group or approximate an anticipated user group in the case of a new product which is not currently on the market. With certain objectives in mind, a specific type of consumer will be delineated. Certain individuals must be identified and not be allowed to participate, while others who are important to the research, must be included (McDermott, 1990). According to McDermott (1990), a psychographic or lifestyle questionaire can also be designed to gather information regarding the person's personal views and beliefs. These questions might differentiate consumers in their food preferences, but are not considered standard recruiting criteria.

The quality of a product (or its ingredients) is a compromise between many factors, one of which is a high level of sensory appeal. Therefore, determination of product quality, requires two kinds of information: Sensory descriptive and preference/acceptance (quality judgements) (Setser, 1993).

According to Heyman (1995), there are three types of affective tests; paired-preference, ranking and rating:

Should the investigator aim to determine if one product is preferred to another, without the benefit of knowing the magnitude or liking, then the paired-preference method should be used (Stone & Sidel, 1995). Overall preference can be determined as well as preference of a particular attribute, such as sweetness or crunchiness of products (Setser, 1993). Two coded samples, normally A-B or B-A, are presented in a randomised format (Heymann, 1995) and the panelists are asked which one they prefer based on an attribute. The hypothesis assumes that one of the products will be preferred. A frequently used option allows the inclusion of "no preference" as a third choice, while another option allows inclusion of a fourth choice, "dislike both equally" (Stone & Sidel, 1993). Only one question has to be answered and panelists are not asked to justify their choice. This technique works very well when the consumer panelists have minimal reading and/or comprehensive skills and the panelists find it easy to do. A series of paired preferences can also be done, but the use of no preference options may give valuable information. Paired preference data can be analyzed using the Roessler Tables or the adjusted chi-square calculation or a Z calculation (Heymann, 1995). Ranking of a group of products is also contextual and will give relative preferences of more than two products (Setser, 1993).

A ranking test (ordinal scaling) can be used to discriminate among several products for a particular attribute and establish a magnitude of differences between samples (Setser, 1993). Panelists are asked to rank the products, within an internal reference frame, in either descending or ascending order of preference or liking. No ties in ranking are allowed and the resulting data will indicate the direction of the response for the product but give no idea of the relative differences between the rankings. Ranked data are ordinal and non-parametric and may be analyzed by using either Basker Tables or Friedman's Test (Heymann, 1995).

Scale ratings reflect a respondent's perceived intensity of a specified attribute under a given set of conditions. Different methods and various rating scales have been developed and used to determine and/or measure acceptance, including the hedonic and action rating scales (Lyon *et al.*, 1992).

Hedonic scales have been shown by several researchers to be reliable and to give valid data (Setser, 1993). The popular and most well-known scale in food research, is the nine-point scale, which was first devised in the 1940's (Heymann, 1995) (Table 2.2).

Table 2.2 The nine-point hedonic scale used for food acceptance and food preference

9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

(Meiselman, 1988)

This scale measures the level of liking (from extreme dislike to extreme like) for food products on a linear scale (semantic, numerical or both) and may be applied in testing for preference or acceptance (Heymann, 1995). The scale is used with untrained judges since trained ones are unlikely to give true affective responses (Land & Shepard, 1988). The method relies on the capacities of the test subjects to report, directly and reliably, their feelings of like and dislike by using the following nine categories: like extremely; like very much; like moderately; like slightly; neither like or dislike; dislike slightly; dislike moderately; dislike very much; dislike extremely (Heymann, 1995).

These data are "subjective" because they are influenced by each evaluator's food habits, cultural background, personality, interpretation of the scale, recent eating history, health, age, and all the factors interacting to influence a person's individual likes and dislikes (Setser, 1993). The scale is reliable and has a high stability of response that is independent of region and to some extent of panel size (Heymann, 1995). Samples may be tested monadically, paired against a standard, or in combinations dictated by statistical design. The monadic test method is appropriate for determining the acceptability of a new or unusual food product where there are no similar products for comparison. The scale is bipolar, that is, both ends of the scale may have descriptive adjectives that may not necessarily be opposite in sensory meaning (a semantic scale) (Gacula & Singh, 1983).

Variations of hedonic scaling can also be achieved by: substitution of the verbal categories by caricatures representing degrees of pleasure and displeasure (“smiley” or facial scales), which were devised for children or illiterate persons; a reduced number of rating categories, although not fewer than five is recommended; a greater number of "like" rating categories than "dislike"; omission of the neutral rating category; and use of a non-structured, non-numerical line scale anchored with "like" and "dislike" on opposite ends (Committee of the IFT Sensory Evaluation Division, 1981). After a seven-point scale (eliminating the 'like extremely' and 'dislike extremely' categories) and a five-point scale (eliminating the 'extremely' and 'slightly' categories) had been compared, the three survey lengths showed no difference in test - retest reliability. The nine-point category showed the highest test - retest reliability (0.96). A longer list length and a longer scale length produce better scale discrimination (Meiselman, 1988).

The results of the hedonic scale may be analyzed using parametric statistics like analysis of variance or the t-test. Hedonic scale ratings are converted to numerical scores. Computations will yield means, variance measures and frequency distributions by order of presentation and magnitude of difference betweeen products by the panel (Stone & Sidel, 1993). It is also possible to convert the hedonic results to paired preference or rank data (Heymann, 1995) by counting the number of subjects scoring one product higher than the other and analyze the result, i.e. testing the hypothesis that the probability $p=½$, for the binomial distribution, or that there is no difference in preference (Stone & Sidel, 1993). A hedonic rating test can yield both absolute and relative information about the test samples (Committee of the IFT Sensory Evaluation Division, 1981).

The Food action or attitude rating scale measures the level of acceptance of food products by a population. This scale is not applicable to the rating of specific characteristics, but is rather a measure of a general attitude towards a food product (Committee of the IFT Sensory Evaluation Division, 1981) and the subsequent action taken regarding the product. This method should be used to supplement the hedonic scale (Campbell *et al*, 1979).

For the purpose of this study, an affective testing method would be more applicable, since consumer acceptance of the intended products will be the major determining factor of success. Acceptance and preference testing may appear to be identical, but the difficulty in consumer research is not in measuring opinion, but in interpreting that opinion into a course of action. If people like a product it does not necessarily follow they will buy it or use it (Meiselman, 1994). In addition to determining the likeability or preference for the different samples of frozen dough products, differences in responses to the individual frozen dough products can be detected with the hedonic scale.

2.7 Frozen doughs

Retail baking is highly labour intensive and the demand for skill- or labour-saving convenience products is broadening. The incorporation of frozen dough products into bakery production lines, especially in in-store bakeries, may be more profitable, less time consuming and may result in productivity improvement in the face of declining young unskilled workers.

The first frozen bread dough was introduced to the industry in 1962 following an incident where a Californian baker accidentally placed some dough into a freezer overnight and found that it had baked well after thawing. The concept of frozen dough has been internationally implemented for several years, and is already an integral part of bakery sales and production (Best, 1995). At present the South African market for frozen dough products is so small that there are no formal statistics relating to its size or value. The frozen dough market in South Africa, represents approximately less than 1% of national bakery produce (L Watters, General Manager, Just Baked - Personal communication) and is therefore considered as a niche market. According to Penstone (1997), there is currently a demand for frozen dough products by consumer groups in the medium- to high-income brackets (especially confectionery) and secondly by South Africa's township and rural population.

Best (1995) described the selling of frozen bread products in three forms: Refrigerated or frozen doughs that must be thawed, proofed and baked ("bake-off"); fully baked products that are frozen, thawed and either slightly reheated or sold ready-to-eat ("thaw-and-sell"); and partially baked, frozen, thawed and baked ("par-baked"). Par-baked products are already available in most of South African supermarkets and are also considered by caterers as enhancing the perception of freshness. For these reasons, the "bake-off" production will be emphasised in this study.

The following advantages of using frozen dough products were noted:

- The customer may be served with a broader range of products including fresh bread which will be more rapidly available being baked at retail outlets (Gelinas,1991).

- The use of frozen dough by retail bakers for production of fresh bread, rolls and other products, offers economic advantages and convenience as compared with the traditional practice of normal baking.

- Improvements in frozen dough quality have made its use increasingly attractive. Any responsible worker can properly proof and bake-off frozen dough products.

- The frozen dough manufacturer can practice economics of scale that are not available to the small baker. Even with the added costs of freezing and frozen storage and transportation, the final product cost to the baker is likely less than the similar scratch product if the costs of labour and overhead are taken into account (Stauffer, 1993).

- By using frozen dough, the baker eliminates wastage in his store by simply baking as much as he requires. The baker is also guaranteed of better consistency, for each batch will adhere to the same quality standards (Payne, 1997).

The problem however, is that the overall quality, and in particular, dough strength of bread baked from frozen dough, deteriorates gradually during frozen storage (Inoue & Bushuk, 1992). The deteriorated gluten was shown by scanning electron microscopy (SEM) and Extensograph measurements on frozen, thawed doughs. The factors observed in this deterioration of frozen dough during storage, were as follows:

- Decreased gasing power due to the gradual loss of yeast activity during frozen storage (Inoue, Sapirstein, Takayanagi & Bushuk, 1994).

- Weakened dough (gradual loss of dough strength). This is the result of an increase of disulphide reducing substances leached from dead yeast cells which would cause a reduction of gluten protein. It has also been proposed that ice crystals formed during freezing, physically disrupt many of the gluten membranes and ice patches can occur (Inoue *et al.*, 1994).

- Relatively short shelf life (up to three months), which could be improved by higher oxidant levels (Stauffer, 1993).

- The loss of product quality by mishandling the frozen dough products while being loaded, transported or kept in display units (Wang & Ponte, 1994; Lorenz & Kulp, 1995).

- Extended frozen and freeze thaw cyles cause inferior dough because the gluten network becomes ruptured, thinner and separates from the starch granules (Wang & Ponte, 1994).

- Water retention is reduced (Wang & Ponte, 1994).

All these factors result in an extended proofing time, lower loaf volume, a flattened top combined with a mushroom appearance, open harsh grain and grummy textures (Wang & Ponte, 1994). Prooved loaves show progressively less oven spring and the internal structure of the baked bread becomes coarser (Stauffer, 1993). The firming of bread crumb and staling has also been recognized as one of the most important factors in reducing acceptability to the consumer (Berglund & Shelton, 1993).

2.7.1 Frozen dough quality

Wang & Ponte (1994) defined frozen dough quality as the ability of a thawed dough to proof in an acceptable period of time and to bake into a loaf with normal volume and desirable organoleptic characteristics.

Frozen dough technology comprises of two major steps: Dough preparation (structure building) and dough processing (freezing and storing) (Best,1995). The measures to be considered in ensuring a stable dough for the production of frozen doughs, are listed in Table 2.3.

Table 2.3 Favourable conditions for processing frozen doughs

1.	Reduced water absorption
2.	Reduced dough mixing temperature
3.	High level of shortening
4.	High level of yeast
5.	High level of surfactant
6.	Straight-dough no-time baking method
7.	Freezing of dough immediately after mixing
8.	Suitable packaging having moisture and oxygen barriers
9.	Freezer temperature of -23° C

(De Stefanis, 1995)

Ingredients for frozen doughs are essentially the same as for conventional bread production, namely flour, yeast, pre-mix (emulsifiers, oxidants enzymes colourants, salt), fat, and water. Frozen dough is more sensitive to ingredients and processing conditions and is, therefore, more complex than conventional dough. When a processed dough is frozen for long periods, two problems often emerge: Dough destabilization (weakness), resulting in a low loaf volume and coarse grain; yeast inactivation, resulting in long proofing. In reviewing the literature on frozen doughs (Inoue & Bushuk, 1991; Inoue & Bushuk, 1992; Best, 1995), it became clear that the quality of bread baked from frozen dough depends strongly on the characteristics of the yeast and the flour, as well as the activity of the yeast after thawing. Another key ingredient, oxidants (commonly known as "bread improvers"), also has a great effect on the behaviour of frozen doughs during and after storage.

2.7.1.1 Flour

To obtain high quality bread from frozen doughs, the level of dough strength must exceed that required for standard bread production from non-frozen doughs. This can be achieved by deliberately breeding wheat cultivars suited for the frozen-dough market (Inoue & Bushuk, 1991). Stronger wheat varieties produce stronger flour which performs better in the frozen-dough procedure than flours with dough strength that is considered optimal for convenient baking, although a dough that is excessively strong, may not produce the best quality product (Wang & Ponte, 1994). The phenomenon appears to be due to their ability to maintain higher oven spring during baking even after losing some of their intrinsic strength on freezing and frozen storage (Inoue & Bushuk, 1991).

High protein flours also improve dough stability during storage (Best, 1995). It has been shown that gluten-fortified frozen dough, which increases protein content by one to five percent, related into increased dough strength, improved loaf volume and a strong enough dough with enough gasing power to provide good volume bread with a fine grain (Wang & Ponte, 1994). More tolerant freeze / thaw cycles were also noted. High quality protein flour with good protein quality and tolerance can provide enough strength to counteract the weakening effects of freeze damage on gluten (Wang & Ponte, 1994).

2.7.1.2 Yeast

For frozen dough applications it is often recommended to use a compressed yeast as fresh as possible (Van Dam, 1988). According to Stauffer (1993), yeast levels in frozen dough formulations are higher (4 - 6% yeast on a 100% flour basis), compared to the normal usage of about 3% for the production of commercial bread. The higher initial concentration of yeast cells compensates for the inevitable partial loss of fermentation capability during freezing and storage (Stauffer, 1993). To achieve yeast stability during frozen storage, it is necessary to eliminate yeast activity before freezing (Van Dam, 1988; Inoue & Bushuk, 1991), as freezing destroys some of the yeast. According to Cauvain (1990), the two critical temperatures are -18° C and 38° C. If storage time increases, more yeast cells continue to die. This loss of yeast activity can be seen as a loss of gasing power when the dough pieces are defrosted and prooved. Resulting in a weakened gluten, reduced yeast activity causes one of the major problems in frozen dough products namely the vulnerability of the yeast cell to freezer damage. Reduced yeast activity at low temperatures might be more suitable for bread produced from frozen dough. (Stauffer, 1993).

2.7.1.3 Shortening

Shortening is 100% fat, is solid at room temperature and often comprises of hydrogenated vegetable oils or animal fats. The shortenings traditionally used in bakery production are animal products namely butter and lard which often contribute to a certain distinctive flavour of the product. At least 1% to 2% saturated or partially saturated shortening in the formulation of frozen dough is preferred to improve dough processing and crumb properties (De Stefanis, 1995).

2.7.1.4 Dough conditioners and enzymes

Dough conditioners and enzymes generally modify dough and bread properties. By adding appropiate oxidants the dough may be strengthened (De Stefanis, 1995). Higher levels of oxidants are used in frozen doughs compared to fresh doughs to counteract the damaging affects of processing and freezing on the gluten structure (Stauffer, 1993). Careful selection of the amount and type of oxidant lowers the proof time and provides oven spring during baking which results in a better appearance (De Stefanis, 1995). A combination of ascorbic acid and potassium bromate compared with ascorbic acid alone, was found to improve the baking potential of frozen dough (Inoue & Bushuk, 1991). Dough conditioners such as sodium stearol lactylate (SSL) may be added to reduce dough weakening and dough dryers like calcium peroxide can be added to prevent excessive water absorption. Crumb softeners may also be included to ensure good crumb quality (Penstone, 1997).

2.7.2 The production of frozen doughs

2.7.2.1 The mixing and moulding process

The frozen dough industry seems to prefer the straight-dough procedure of batch mixing the dough to full development in a high-speed dough mixer. To prevent fermentation throughout preparation it is recommended that the ingredients and the dough itself, must be kept at very cold temperatures during the mixing process. The fully developed dough must be rapidly moulded and frozen to ensure dough stability and baking quality (Penstone, 1997).

2.7.2.2 The freezing process

A blast freezer is preferable to a retarder or freezer, because cold air at about -35°C is blown over the products. Fast freezing relates to intracellular freezing in contrast with slow freezing where intracellular water is transferred to external ice (Lorenz & Kulp, 1995). The freezing process is called "soak freezing" with the dough comprising of an internal temperature of -7° C. (J Butler, confectionery technologist, Just Baked - Personal communication) According to Lorenz & Kulp (1995), solid freezing is not recommended, since this will shorten the freezer storage life of the product and eventually lengthen proof times. Thorough freezing of the product occurs during an equilibration period (the packaging and frozen storage), where yeast activity is least. Dough, being a relatively good insulator, causes continuous fermenting until the completion of the freezing process, while the centre of the dough piece tries to expand. At this stage the frozen surface of the dough piece which has no room for expansion, results in cracks forming, which are carried through to the final product where they appear as baked scars (Cauvain, 1990).

2.7.2.3 Frozen storage

Freezer storage is limited from five to a maximum of sixteen weeks at temperatures ranging from -18° C to - 23° C (Penstone, 1997). Storage conditions should be changed as little as possible and tight storage of dough and packages are recommended to minimise temperature changes. According to Brümmer (1995), dough pieces appear to be mechanically sturdy after a core temperature of -15° C has been reached. Due to physical and enzymatic processes during storage, however, changes may occur in the dough which not only affect the extensibility of the dough, but also reduce the functionality of the wheat gluten. Packaging in synthetic bags, sacks or containers is recommended to prevent dehydration on the surface (Brümmer, 1995).

2.7.2.4 Thawing, proofing and baking

The successful thawing and proofing of frozen dough products, implies careful control of both humidity and temperature. Recommended times for thawing vary from 12 to 16 h for full development of flavour compounds. Humidity levels during proofing should not exceed 75%, and temperatures in the proover should range from 32° C to 40° C, depending on product and size (Lorenz & Kulp, 1995; Penstone, 1997).

Smaller frozen products (± 50 g), based on wheat flours, require a thawing period of 2 h at room temperature with an additional proofing time of 40 - 50 minutes in a proover, followed by baking for 20 minutes at 240° C. (J Butler, confectionery technologist, Just Baked - personal communication). An extended proofing time for frozen doughs is due to the cooler temperature at the core of the dough piece (15° C) (Brümmer, 1995), compared to that of fresh doughs (25 - 27° C) when entering the proover (Lorenz & Kulp, 1995).

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CHAPTER 3

EXPERIMENTAL

3.1 Experimental design

Little information is available on the suitability of South African wheat cultivars for the production of frozen dough products with acceptable sensory characteristics. Quality specifications of flour destined for the production of frozen bread dough products also appear not to have been specified.

The primary objective of this project was to determine the extent to which qualitative differences in wheat flours would affect the sensory and thus marketing properties of a range of frozen dough products. In order to extend our findings to wheat breeding and procurement, five of the flour sources were obtained from single cultivars. The application of a multivariate statistical technique, known as the Additive Main Effects and Multiplicable Interaction (AMMI) model, was also employed for this purpose. To our knowledge, the AMMI model has never been applied in assessing the interaction beween flour type and consumer perceptions.

The second objective was to identify a protocol according to which flour types suited to the production of frozen dough products could be selected.

The third objective of this project was to estimate the quality profile of flour most suited to the commercial production of frozen dough products. This information could serve as a valuable guideline to both wheat breeders and officials involved in wheat procurement.

Data was generated in four consecutive phases.

(a) Assessment of dough quality;

(b) processing of flours from cultivars with different rheological profiles into four different frozen dough product types;

(c) standardisation of the test bake procedures prior to experiential evaluation and

(d) sensory evaluation of the baked products by a consumer panel.

Dough quality was assessed by means of standardised rheological techniques (AACC, 1983) to determine the dough properties of five different wheat cultivars and a commercial flour which served as the control. The data obtained was similar to the assessment procedure prescribed for wheat lines prior to final release. Sensory evaluation was based on crust colour, crumb colour, crumb texture, mouthfeel, taste and after taste.

3.1.1 Frozen dough products

Four frozen dough products were used to assess the impact of flour source by a consumer panel. These products were Hamburger Buns, Fruit Buns, Wholewheat Buns and Standard Brown Loaves. The Hamburger Buns and Fruit Buns were processed from white flours (extraction rate = 74%), whereas the other products were based on high extraction flours (86%). The assumption was made that these four products were most likely to be sold in micro business enterprises.

3.2 Materials and Methods

3.2.1 Flour sources

The flour types used were derived from the commercial hard red wheat cultivars (*Triticum aestivum* L.) Palmiet, Gamtoos, Molen, Betta and Tugela. These five cultivars represented the range of quality types typically grown in South Africa. It is also likely that these grain types represent the quality range normally found among early generation wheat lines, implying that more knowledge may be gained on the selection of wheat lines suited for the production of frozen dough products. Pure grains were obtained from wheat cultivar trials grown at the Small Grain Institute in Bethlehem during 1996. The aim was to produce grains with a protein content of above 12% to optimize the expression of qualitative differences among genotypes (Van Lill & Purchase, 1995). Eventually, high protein content flours varying from a minimum of 13.1% to a maximum of 13.9% protein content, were obtained. In addition, a standard commercial wheat flour was included as an additional source of variation and to serve as a commercial reference. The commercial flour source was referred to as the 'control.'

3.2.1.1 Palmiet

After being released in 1982, Palmiet was produced in the Western-Cape (Swartland and Ruens) as well as in the irrigated areas of Northern Cape, North-West and Mpumalanga. According to Mrs A Enslin, (Manager, South African Grain Information Service (SAGIS) - personal communication) the national production for the 1996/97 season amounted to 580 303 metric tons. This cultivar is presently in the process of being phased out because of poor baking performance at lower grain protein levels (<11%) (Van Lill, 1994). The Glu-1 score, reflecting the High Molecular Weight glutenin composition of this cultivar, was determined as seven (Randall, Manley, Meiring & McGill, 1992), which confirmed the tendency towards poorer quality.

3.2.1.2 Gamtoos

Gamtoos is a higher yielding cultivar, especially under irrigated conditions. According to Mrs A Enslin, (Manager, SAGIS - personal communication) the production of Gamtoos was not that significant for the 1996/97 season, being in the order of 507 metric tons. Being a high yielder, Gamtoos is normally associated with a lower protein content as well as poor dough quality linked to the presence of rye derived chromatin in the genomic structure. Van Lill, Howard & van Niekerk (1990) demonstrated that the presence of the 1B/1R-carrying chromosome translocation caused the formation of a particular dough stickiness, rendering the cultivar unsuitable for commercial bread production. According to Randall *et al.* (1992), the Glu-1 score of Gamtoos amounts to six, confirming the above statement. At present, this cultivar is also being phased out.

3.2.1.3 Molen

The wheat cultivar Molen was released in 1986 and is produced throughout the Free State. It produced above the regional average, 86 627 metric tons during the 1996/97 season (A Enslin, Manager, SAGIS - personal communication). Molen is characterised by a shorter dough development time (Mixograph dough development time of about 2.2 min), therefore requiring less energy to be fully developed. This cultivar is extremely suitable for the Chorleywood Baking Process (CBP) where an energy input of about 11 $Wh.kg^{-1}$ dough is optimal. Dough produced from Molen, is softer, smoother in appearance and posesses an excellent gas retention capacity. This cultivar obtained a Glu-1 score of seven (Randall *et al.*, 1992).

3.2.1.4 Betta

Considering a national production of 34 625 metric tons during the 1996/97 season (A Enslin, Manager, SAGIS - personal communication) Betta is a cultivar with an average, but stable yield. It tends towards slightly stronger dough properties when compared to that of Molen. The Mixograph dough development time of Betta was in the order of 2.5 min while its Alveograph P/L-ratio has been reported as about 1.2 (Van Lill & Smith, 1997). The Glu-1 score obtained by this cultivar was nine (Randall *et al.*, 1992), indicating the tendency towards producing better quality dough, when compared to Molen.

3.2.1.5 Tugela

The national production of Tugela during the 1996/97 season amounted to 93 733 metric tons (A Enslin, Manager, SAGIS - personal communication). Tugela was released in 1992 and is better adapted to higher yielding environments. In addition of a protein content above the average, the cultivar is inherently inclined towards a level of dough strength considered as undesirable for the CBP. Problems observed during processing, include increased dough temperature, increasing batch-to-batch cycle time and loaf volumes that exceed pan capacity (Van Lill & Purchase 1995). The controversial nature of these problems, probably lead to this cultivar being phased out. According to Randall *et al.* (1992), Tugela also related to a high Glu-1 score of ten, predicting a higher loaf volume compared to the other cultivars.

3.2.2 Determination of flour quality characteristics

Grain samples of approximately 50 g were milled with a Falling Number KT-120 laboratory mill (1.0 mm sieve). To assess possible sprouting damage, the falling number of samples was determined with a Hagberg Falling Number apparatus (AACC,1983). Flour protein and moisture contents were determined by using a Technicon Infra Alyser 300, calibrated against Kjeldahl nitrogen and air oven moisture determinations (AACC, 1983). Five kg wheat samples were tempered to a moisture content varying between 15.0% and 15.5% moisture content depending on the vitreousness of the grain. After being tempered, the wheat was milled with a Buhler 202 experimental mill to straight grade flour (AACC, 1983) at an extraction rate of approximately 74%.

3.2.3 Assessment of dough quality

Mixogrammes were prepared with a 35 g National Mixograph (Finney & Shogren, 1972). Mixogrammes were digitally analysed, using the MIXSCAN software (Walker & Walker, 1992). This programme is based on scanner technology where raw data is converted and parameters such as peak, height, width and area are reported. Farinograph characteristics (dough development time, dough stability, water absorption) were measured with a 50 g Brabender Farinograph (AACC, 1983). Other rheological analyses were done with the Chopin Alveograph (dough strength, the ratio of stability to distensibility) and the Brabender Extensograph (dough strength, the ratio of maximum resistance to extensibility). Baking strength index (BSI) refers to the loaf volume of a flour sample as a proportion (%) of that which can be expected from a reference cultivar (Van Lill, 1994). In this study the cultivar Betta, was considered as the quality standard and the BSI was calculated according to the formula:

$$BSI = \frac{(LFV_{\text{Experimental flour sample at } x \text{ percent FPC}})}{(LFV_{\text{Betta at } x \text{ percent FPC}})}$$

where $LFV_{\text{Betta at x percent FPC}} = 24.94\,(x) + 756$.

3.2.4 Test baking

For each flour sample test loaves (100 g) were baked in duplicate, using the optimized straight dough method of Finney (1984). The dough was proofed at a relative humidity of 85% for 90 min, moulded and rested for 30 min at 34° C and baked at 215° C for 24 min. Loaf volume was determined by means of the displacement of turnip seed directly after baking, using a pup-loaf volumeter.

3.2.5 Frozen dough production

All frozen dough products were developed under industrial conditions at the Just Baked factory in Johannesburg. Although a large degree of resemblance exists between the production of frozen doughs and the production of loaves aimed at direct comsumption, the main difference lies in the fact that for frozen products, the dough preparation phase requires cold conditions.

All ingredients were kept in a walk-in fridge at a temperature of 4° C. A controlled temperature of 8° C in the factory also contributed to the restriction of fermentation before mixing. The dry ingredients were weighed on a bench scale and mixed in 5 kg batches in a Diosna spiral mixer (Diosna, Osnabrück, Germany). The baking formula is presented in Table 3.1.

Table 3.1 Formula used for frozen dough production

Basic components		Percentage (%,m/m)
Flour (5 kg)		100
Yeast		6
Pre-mix	(Emulsifiers, enzymes, oxidants, colourant, milk powder and sugar.)	0.2
Blendomix	(Commercial emulsifiers, fats and oxidants.)	2
Salt	(Only added to brown loaves.)	1.8
Water	(Depending on the product type.)	50 - 64
Additional components		
Crushed wheat and bran	(For the production of the Wholewheat Buns and Brown Loaves, emulating an extraction rate of 86%)	12
Mixed fruit	(Added at the end of the mixing period to the fruit buns)	40
Sugar		2

The production of the four products were initiated with a two minute slow mixing time, which allowed the ingredients to blend, followed by different fast mixing times for the various cultivars until the doughs were optimally developed.

During mixing, the dough development of each dough batch was continuously monitored by the production manager. As dough development proceeded, small pieces of dough were subjected to a stretching action by the fingers to ensure that the desired consistency was achieved and that the water absorption was optimized.

A flimsy and torn stucture indicated that the dough was under developed and mixing was continued. When the dough showed a silky and non-sticky membrane, it was considered as being fully developed. Following, the dough was individually transferred by hand to an industrial Winkler roll moulder (Winkler, Villingen, Germany) with eight lines for the scaling, sheeting and moulding of the different products. The Standard Brown Loaves were scaled, remoulded with a Benier Status rounder (Benier, Hertogenbosh, The Netherlands) into six round doughs and transferred to a proover in which each dough was rotated six times between proofing bags at intervals of three minutes. The doughs were then pressed through rollers into oval shapes of 30 cm in diameter and one cm thickness.

Following sheeting, the products were conveyored into a AGA Frigoscandia spiral blast freezer, rapidly chilled and frozen for 40 minutes to a core temperature of -7° C. During the packaging and storage of the products at the factory care was taken to maintain a maximum temperature of -7° C.

3.2.6 Packaging , storage and transport of the frozen products

The frozen products were packed into plastic bags, automatically weighed and counted, packed in boxes, sealed and marked for easy identification. The boxes containing the frozen products were temporarily stored in the walk-in freezer of the factory with a temperature of -23° C for two days and were transported to the walk-in freezer of the Cook Freeze kitchen in Bloemfontein without a change in temperature. Storage took place for three months before the baking studies commenced. The objective was to maximise the possibility of deterioration of yeast viability and activity and the gas-retention properties as previously reported for frozen doughs.

3.2.7 Thawing, proofing and baking of the frozen products

Optimisation of the preparation of the frozen dough products for sensory evaluation was conducted in a food laboratory at Technikon Free State. Care was taken that the conditions emulated the micro business enterprises where these products are likely to be sold.

One product at a time was drawn from storage facilities and stored in a household freezer at a temperature of -18° C for the duration of the evaluation. The buns were positioned on four sheet pans in batches of 20 per cultivar and left for two hours at room temperature to thaw until an internal temperature of 22° C was reached. After thawing, the buns were proofed for 40 minutes in an eight rack Bakbar Proover (Moffat, Christchurch, New Zealand) with adjustable temperature and humidity levels.

Proofing of the buns took place at a humidity level of 75 - 80% and a temperature of 40° C. The fully proofed frozen buns were then baked in a E32 Bakbar turbofan convection oven (Moffat, Christchurch, New Zealand) with four racks for 20 minutes at a temperature of 200° C. The process was repeated to facilitate another four pans which were thawed and proofed accordingly. A total of 160 buns were baked daily from the six cultivars. The process was repeated for three consecutive days for each type of product.

The processing of the Standard Brown Loaves was conducted slightly different from that of the buns. Doughs, individually wrapped in plastic, were left overnight in a fridge at a temperature of 4° C to thaw. After being removed from the fridge, the doughs were left at a room temperature to reach an internal temperature of 22° C. The doughs were kneaded by hand, rested for ten minutes, shaped into loaves and proofed for 1 h in similar conditions as the buns. Once again, care was taken to standardise the panning of the doughs. After proofing, the loaves were baked for 28 minutes at a temperature of 210° C. Four loaves from each of the six cultivars were baked daily and the process was repeated for three days.

3.2.8 Volume measurements

The product volume was determined by the displacement of turnip seed directly after baking, averaging six repetitions. The visual appearance and internal crumb structure of each product were photographed to serve as a later reference.

The frozen dough products were allowed to cool for 2 h at room temperature. Buns were presented intact for the sensory evaluation process. Due to the impracticality of providing a loaf of bread for each panelist, the Standard Brown Loaves were presented in four cm slices for easy identification of crust colour.

3.2.9 Sensory evaluation of the frozen products

The quality of each product was evaluated by a consumer panel consisting of 20 panelists per session, for twelve consecutive sessions. Sensory evaluation was determined in a central location and the panelists had no interaction with one another. Instructions and interactions with the panelists were verbal. At each session, panelists were given a marked sheet on which the six products, made from the six different cultivars, were presented in random order (Cochram & Cox, 1957), a demographic questionnaire (Appendix A), a response sheet (Appendix B), a knife, a pencil, a serviette and a glass of tap water. Panelists were instructed to rate the acceptability of each characteristic of the product, namely, crust colour, crumb colour, crumb texture, mouthfeel, taste and after taste in the appropriate box, according to Meiselman's (1988) hedonic nine-point scale varying from like extremely (9) to dislike extremely (1). The categories were not numbered on the response sheet. The same rating procedure followed for each product on a separate response sheet. For each panelist, the experimental session with instructions, lasted about 20 minutes.

3.2.10 Statistical analysis

All statistical analyses were performed using the GENSTAT 5 statistical program (GENSTAT 5 Committee, 1997). The data was analysed in the following order.

1. The relative effects of product and flour source on consumer acceptability were estimated using the mean squares to compare the relative magnitude of main effects and variances. The purpose of this approach was to identify which aspects of interpretation should be emphasised. The use of these techniques had been demonstrated by Peterson, Graybosch, Baenziger & Grombacher (1992). The applicability of this technique to South African studies of wheat quality was demonstrated by Van Lill and Smith (1997).

2. One of the newer and well-tested (Smith, 1991) statistical methodologies for understanding the true pattern in complex interactions, is the model known as the Additive Main Effects and Multiplicative Interaction or AMMI model. Univariate ANOVA provides an overall test for interaction, which is quite often ignored as the overall test for significance rejects the interaction as being significant.

The AMMI statistical model, on the other hand, combines the classical ANOVA and principle component analysis (PCA). AMMI first fits the additive main effects of cultivars and products by the usual ANOVA and then describes the non additive part, the cultivars x products interaction by PCA, averaged over the replicates.

After fitting the AMMI model, usually one interaction PCA (IPCA) component is retained and the rest is discarded as a residual or noise (Zobel, Wright & Gauch 1988; Gauch 1992; Smith 1991; Smith & Smith 1992). It is this reduction of noise that makes AMMI-esimates more reliable than the usual interactive means. For each cultivar and product, IPCA scores are obtained from which the interaction effect is estimated. Biplots of these IPCA scores versus the cultivar and product means are a visual representation of the main effects, as well as interaction effects. The closer points are together, the more similar they are in overall response. A score close to zero is an indication of stability or insensitivity.

Furthermore, the AMMI-estimates of each cultivar are ranked for each product and form this more reliable selections of cultivars, suited to each product, can be made (Gauch, 1992; Smith, 1991).

3. Canonical correlation analysis (CANCOR), was conducted to examine whether the data from a set of rheological traits could significantly account for the variation in frozen dough products as observed by a consumer panel. Canonical correlation analysis sets out to find linear combinations of the two sets of variables for the cultivars, such that the linear combinations have maximal correlation (Digby & Kempton, 1987). In this manner, the combination of rheological variables could be identified that best correlate with combinations of sensory variables, so that sensory variation may be predicted from rheological variation on site. This technique has also been used to demonstrate the relationship between a range of biochemical and quality characteristics in South African wheat (Van Lill *et al.*, 1995).

CHAPTER 4

RESULTS

4.1 Rheological profiles of the various flour sources

The rheological profiles for the various flour sources are summarised in Table 4.1 (see page 42).

4.2 Processing characteristics of frozen dough products

The processing characteristics of the various flour sources are presented in Table 4.2.

Table 4.2 Processing characteristics in the production of frozen dough products from various flour sources

	PRODUCT TYPE							
	Hamburger Buns		Brown Loaves		Fruit Buns		Wholewheat Buns	
Cultivar	DDT[a]	WBS[b]	DDT	WBS	DDT	WBS	DDT	WBS
Control	11	54	13	62	11	54	13	52
Molen	9	50	11	62	9	50	11	54
Gamtoos	9	54	10	60	9	54	10	60
Palmiet	8	55	11	63	8	55	11	60
Betta	12	53	14	60	12	53	14	56
Tugela	14	50	20	60	14	50	20	51

[a] DDT = Dough development time (min)
[b] WBS = Water absorption (%)

From Table 4.2 it could be seen that the processing characteristics of the various flour sources differed under commercial conditions. This observation probably related to the differences in the quality profiles observed in Table 4.1.

Table 4.1 Quality characteristics of flours used to stu[illegible]en dough production

Flour source	Wheat quality characteristics[a]																
	Mixogramme Envelope Analysis					Mixogramme Midline Analysis			Farinograph			Alveograph		Extensograph		Baking strength	
	FPC	MED	MEL	MER	MEA	MMD	MML	MMR	FRD	FRS	FRW	APL	AST	EXR	EXS	LFV	BSI
Control	13.2	2.6	35.7	-9.1	34.1	2.6	12.0	-4.5	10.7	13.8	65.7	1.6	66	14.6	132	1040	98
Molen	13.1	2.1	27.5	-13.4	32.0	2.0	14.6	-6.1	6.0	13.5	60.6	0.6	48	10.1	152	1020	94
Gamtoos	13.8	1.9	26.5	-17.1	19.6	1.7	17.8	-10.2	9.2	8.0	67.9	1.2	46	11.8	107	1025	93
Palmiet	13.2	2.3	24.5	-21.8	20.0	2.2	10.0	-7.0	9.4	11.0	66.1	0.5	62	10.9	118	1110	102
Betta	13.7	2.3	32.9	-10.6	36.4	3.0	9.0	-5.6	12.4	15.0	64.1	1.2	70	13.5	148	1128	103
Tugela	13.8	3.5	28.7	-6.1	43.5	4.0	1.4	0.0	18.0	16.5	70.6	1.9	75	14.4	178	1200	109

[a] FPC = Flour protein content (%), MED = Mixogramme envelope development time (min), MEL = Mixogramme envelope left-of-peak ($\%.min^{-1}$), MER = Mixogramme envelope right-of-peak ($\%.min^{-1}$), MEA = Mixogramme envelope area (cm^2), MMD = Mixogramme midline development time (min), MML = Mixogramme midline left-of-peak ($\%.min^{-1}$), MMR = Mixogramme midline right-of-peak ($\%.min^{-1}$), FRD = Farinograph dough development time (min), FRS = Farinograph dough stability (min), FRW = Farinograph water absorption (%), APL = Alveograph P/L ratio, AST = Alveograph strength(cm^2), EXR = Extensograph ratio (R_{max} at 5 cm / Extensibility (mm), EXS = Extensograph strength (cm^2), LFV = Loaf volume (ml), BSI = Baking strength index

4.3 Demographics of the consumer panel used for sensory evaluation

Table 4.3 The demographic composition of the consumer panel for sensory analysis

Category		Hamburger Buns	Standard Brown Loaves	Fruit Buns	Wholewheat Buns
Age	18 - 29	102	144	222	168
	30 - 39	90	72	66	72
	40 - 49	83	78	48	66
	>50	85	66	24	54
Gender	Male	48	78	54	96
	Female	312	282	306	264
Occupation	Student	60	24	120	6
	Retailer	12	6	0	0
	Foodservice	54	42	36	102
	Housewife	108	48	36	42
	Other	126	240	168	210
Personal Preference	Brown Bread	174	234	222	174
	Wholewheat Buns	84	66	60	108
	Hamburger Buns	90	30	60	66
	Fruit Buns	6	0	0	12
	Never buy any	6	30	18	0
Normal shopping venue	In-store bakery	294	282	306	252
	Supermarket (no bakery)	18	30	12	18
	Bakery/ Bread shop	48	48	42	90
Previously subjected to frozen dough products	Yes	120	90	30	78
	No	240	270	330	282
Would consider buying frozen products	Yes	238	257	254	264
	No	122	103	106	96

The composition of a consumer panel demonstrated the inclusion of panelists with a wide range of interests or previous exposure to products derived from frozen doughs.

4.4 Evaluation of sensory characteristics

Table 4.4 Mean squares for the analysis of variance of sensory qualities of frozen dough products

		Mean squares for Sensory Characteristics[a]					
Source of variation	**df[b]**	**CTC**	**CBC**	**VTX**	**MTF**	**TST**	**ATS**
Product (P)	3	13.28**	10.44**	3.60**	2.72NS	3.04NS	6.75NS
Flour source (S)	5	7.85**	17.29**	34.42**	13.58**	10.57**	12.44**
P x S	15	8.56**	3.79**	3.46**	4.05**	5.37**	5.92**
Error	1416	1.76	1.36	1.67	2.12	2.16	2.60

[a] CTC = Crust colour, CBC = Crumb colour, VTX = Visual texture, MTF = Mouthfeel, TST = Taste, ATS = After taste
[b] df = degrees of freedom
** $P \leq 0.01$, NS = Non-significant

It can be seen in Table 4.4 that flour source and product both contributed to sensory variation. The magnitude of variation, however, varied among sensory characteristics.

4.5 Variance ratios of sensory characteristics

Table 4.5 Variance ratios of sensory characteristics

Characteristics	Ratio (P/S)[a]	Ratio P/(PxS)[b]
Crust colour	1.7	1.6
Crumb colour	0.6	2.8
Visual texture	0.1	1.0
Mouthfeel	0.2	0.7
Taste	0.3	0.6
Aftertaste	0.5	1.1

[a] Ratio of the effect of product (P) to that of flour source (S)
[b] Ratio of the effect of product (P) to that of the interaction of product by flour source (PxS)

The results contained in Table 4.5 indicated that the perceptions of the consumer panel were mostly influenced by variation in flour source. For crust colour, however, this tendency was not observed.

4.6 The influence of flour source on the sensory variation of four frozen dough products

The influence of flour source on the sensory variation assessed for four frozen dough products, are presented in Table 4.6.

Table 4.6 The influence of flour source on the sensory variation assessed for four frozen dough products[a]

Products and Flour sources	**Crust colour**	**Crumb colour**	**Visual texture**	**Mouth feel**	**Taste**	**After taste**
Hamburger Buns						
Control	7.12	6.90	6.78	6.67	6.52	6.27
Molen	6.92	7.10	7.02	6.90	6.87	6.58
Gamtoos	7.28	6.92	6.68	6.67	6.67	6.48
Palmiet	6.67	6.80	6.85	6.68	6.37	5.98
Betta	7.92	7.73	7.62	7.38	7.47	7.22
Tugela	6.90	7.25	7.58	7.22	7.03	6.67
Product mean	7.14	7.12	7.09	6.92	6.82	6.53
Standard Brown Loaves						
Control	7.20	7.42	7.30	6.70	6.70	6.63
Molen	7.55	7.45	7.42	7.05	7.03	6.83
Gamtoos	7.33	7.13	6.70	6.42	6.32	6.12
Palmiet	7.88	7.70	7.38	7.07	7.23	7.05
Betta	7.53	7.43	7.40	6.72	6.87	6.70
Tugela	7.70	7.67	7.53	7.62	7.55	7.47
Product mean	7.53	7.47	7.29	6.93	6.95	6.80
Fruit Buns						
Control	7.05	6.75	6.63	6.73	6.80	6.57
Molen	6.98	6.95	7.22	7.07	6.87	6.65
Gamtoos	7.32	6.83	6.67	7.05	7.27	7.03
Palmiet	7.07	7.20	7.07	7.28	7.07	6.78
Betta	7.30	7.52	7.40	6.98	7.05	6.95
Tugela	7.00	7.40	7.42	7.22	7.17	7.07
Product mean	7.12	7.11	7.07	7.06	7.04	6.84
Whole Wheat Buns						
Control	7.38	7.43	7.37	7.27	7.15	6.92
Molen	7.37	7.45	7.05	6.98	7.00	6.77
Gamtoos	6.25	6.42	6.10	6.43	6.53	6.32
Palmiet	7.15	7.20	6.95	7.18	6.82	6.47
Betta	7.53	7.50	7.73	7.37	7.10	7.05
Tugela	7.80	7.78	7.70	7.30	7.28	6.95
Product mean	7.25	7.30	7.15	7.09	6.98	6.74
Flour source effects (mean over products)						
Control	7.19	7.13	7.02	6.84	6.79	6.60
Molen	7.20	7.24	7.18	7.00	6.94	6.71
Gamtoos	7.05	6.83	6.54	6.64	6.70	6.49
Palmiet	7.19	7.23	7.06	7.05	6.87	6.57
Betta	7.57	7.55	7.54	7.11	7.12	6.98
Tugela	7.35	7.53	7.56	7.34	7.26	7.04
LSD_T Flour source($P \leq 0.01$)	0.41	0.36	0.40	0.45	0.45	0.50
LSD_T Product ($P \leq 0.01$)	0.31	0.27	0.30	0.34	0.34	0.37
LSD_T Product x Flour source ($P \leq 0.01$)	0.97	0.85	0.94	1.06	1.07	1.18

[a] Mean acceptability score on a nine point hedonic scale, varying from 9 (like extremely) to 1 (dislike extremely)

Considering that the predominant patterns have been established by means of variance ratios, the interpretation of the data presented in Table 4.6, could be directed towards identifying tendencies for specific flour sources.

4.7 The AMMI analysis of variance for sensory characteristics

Table 4.7 AMMI analysis of variance for six sensory characteristics baked from six flour sources for four frozen dough products

		Characteristics[a]					
Source	**df[b]**	**CTC**	**CBC**	**VTX**	**MTF**	**TST**	**ATS**
Total	1439	2691.9	2096.0	2594.2	3133.0	3204.9	3841.9
Treatment	23	207.4	174.6	234.8	136.8	142.5	171.3
Flour source	5	39.3	86.4	172.1	67.9	52.8	62.2
Product	3	39.8	31.3	10.8	8.2	9.1	20.3
Interaction	15	128.3	56.9	51.9	60.7	80.5	88.8
PCA 1	7	86.3	34.0	34.8	28.3	45.7	60.0
Residual	8	42.0	22.9	17.2	32.5	34.8	28.8
Error	1416	2484.5	1921.4	2359.4	2996.2	3062.4	3670.7

[a] CTC = Crust colour, CBC =Crumb colour, VTX = Visual texture, MTF = Mouthfeel, TST = Taste, ATS = After taste
[b] Degrees of freedom

The presentation of sums of squares in Table 4.7 provided more insight into the interactive effect by means of principle components analysis. Following the reduction of statistical noise in the interpretation of interactive effects, it became easier to select flour sources suited to specific products.

4.8 Biplot of product and flour source means and PCA scores of crust colour

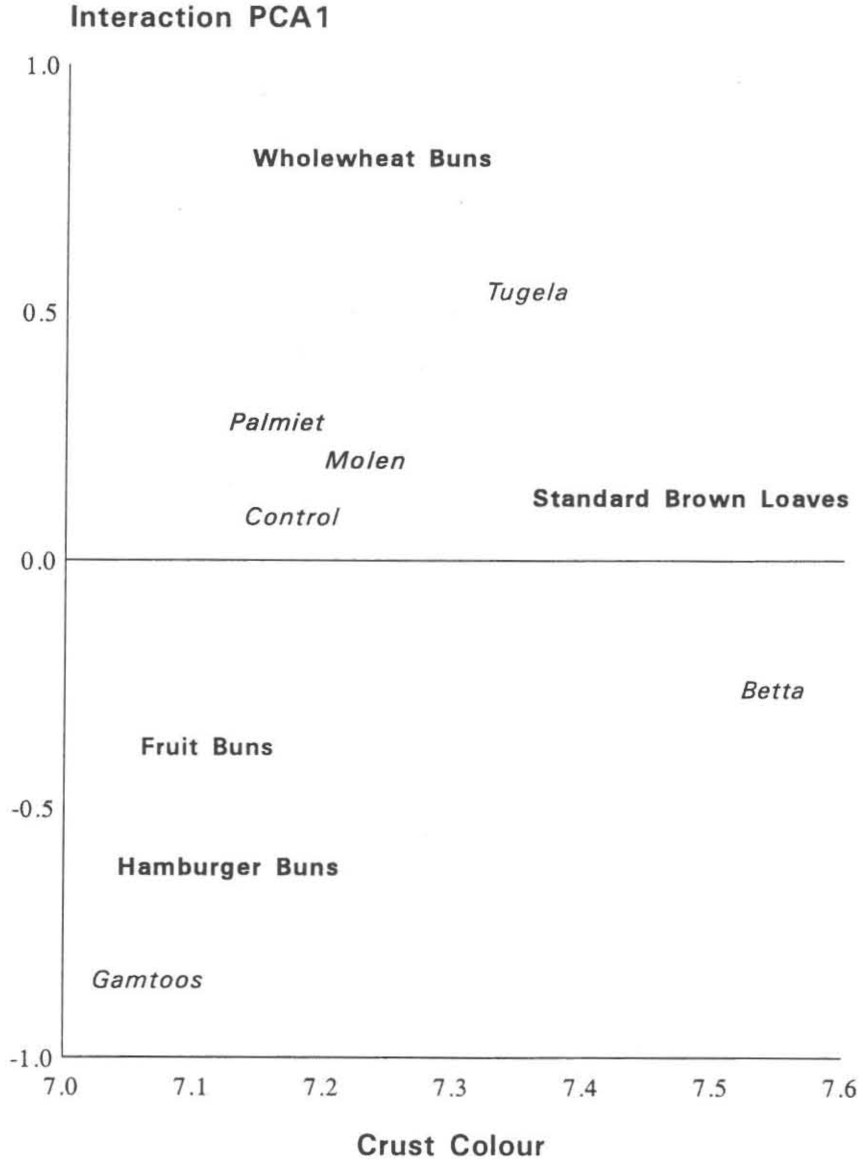

Figure 4.1 Biplot of product and flour source means and PCA scores of crust colour.

Figure 4.1 depicts the interaction between flour source and product type for crust colour. It appeared that flour from the cultivars Gamtoos had greater impact on crust colour than all the other flour sources. It also appeared that the presence of bran in products induced variation in preference for crust colour.

4.9 Biplot of product and flour source means and PCA scores of crumb colour

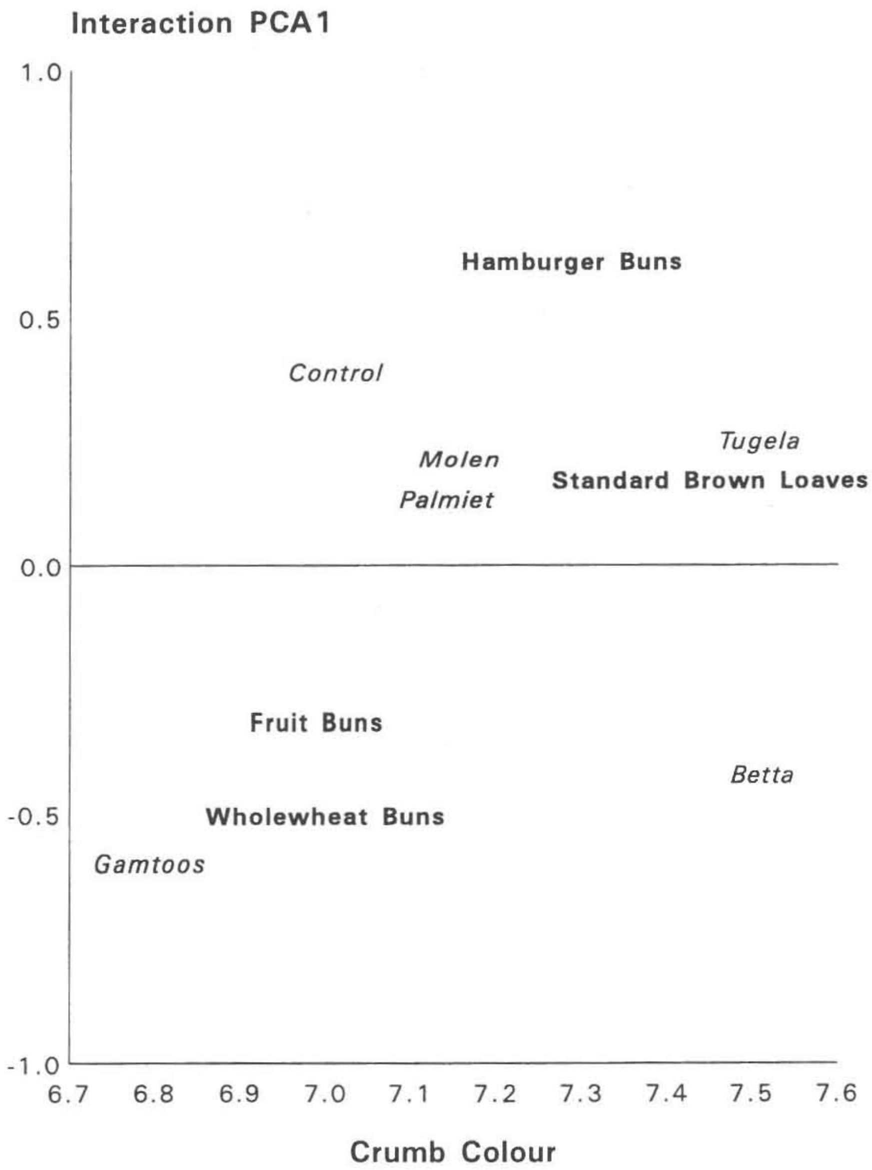

Figure 4.2 Biplot of product and flour souce means and PCA scores of crumb colour.

From Figure 4.2 it became clear that the crumb colour was mostly influenced by flour source effects. The crumb colour obtained through flours from Tugela and Betta were preferred.

4.10 Biplot of product and flour source means and PCA scores of visual texture

Figure 4.3 Biplot of product and flour source means and PCA scores of visual texture.

Figure 4.3 showed that visual texture was most susceptible to the effects of flour source. From the manner in which the data clustered, it was also evident that interactive effects between flour source and product were most pronounced. Wholewheat buns formed a pattern different to that of other products. Gamtoos, for example, showed the most sensitive response.

4.11 Biplot of product and flour source means and PCA scores of mouthfeel

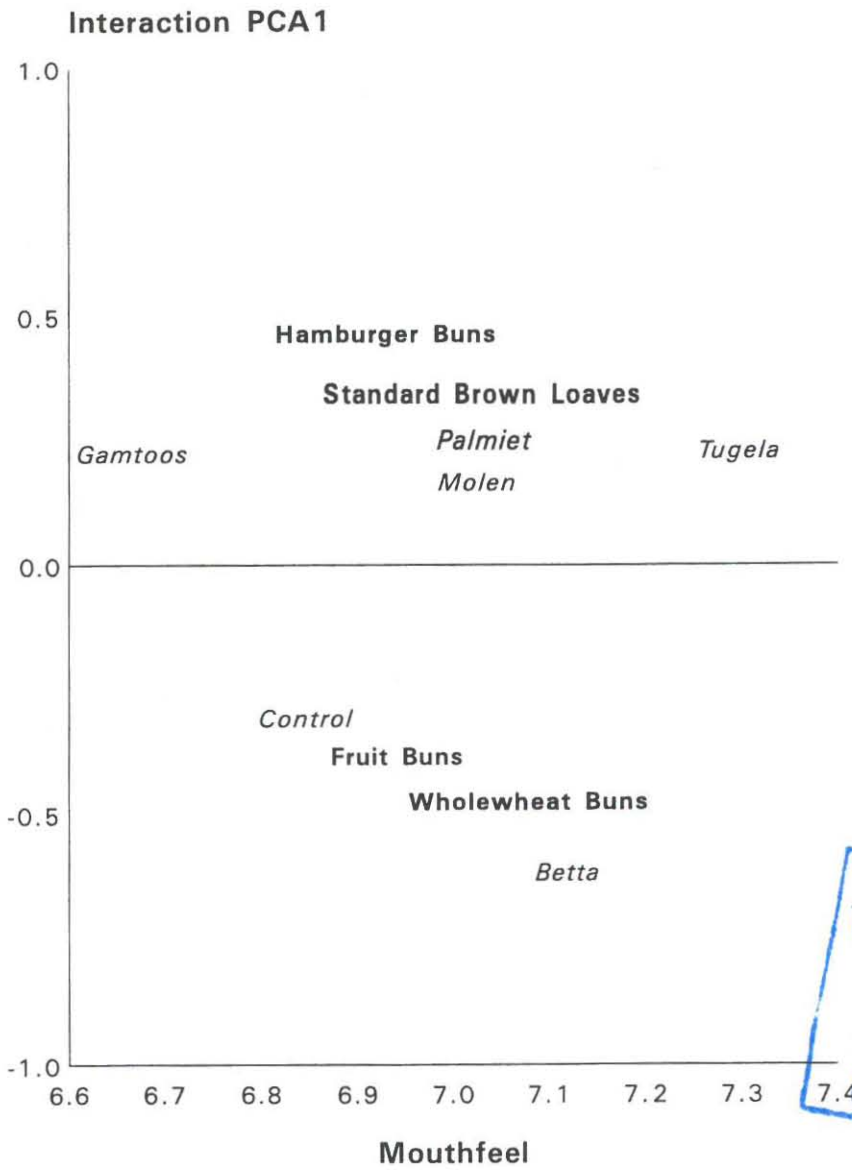

Figure 4.4 Biplot of product and flour source means and PCA scores of mouthfeel.

From Figure 4.4 it became clear that mouthfeel was mildly subjected to interactive effects. Even though no strong patterns could be distinguished, it could be concluded that the consumer panel preferred the mouthfeel of products made from Betta and Tugela flour.

4.12 Biplot of product and flour source means and PCA scores of taste

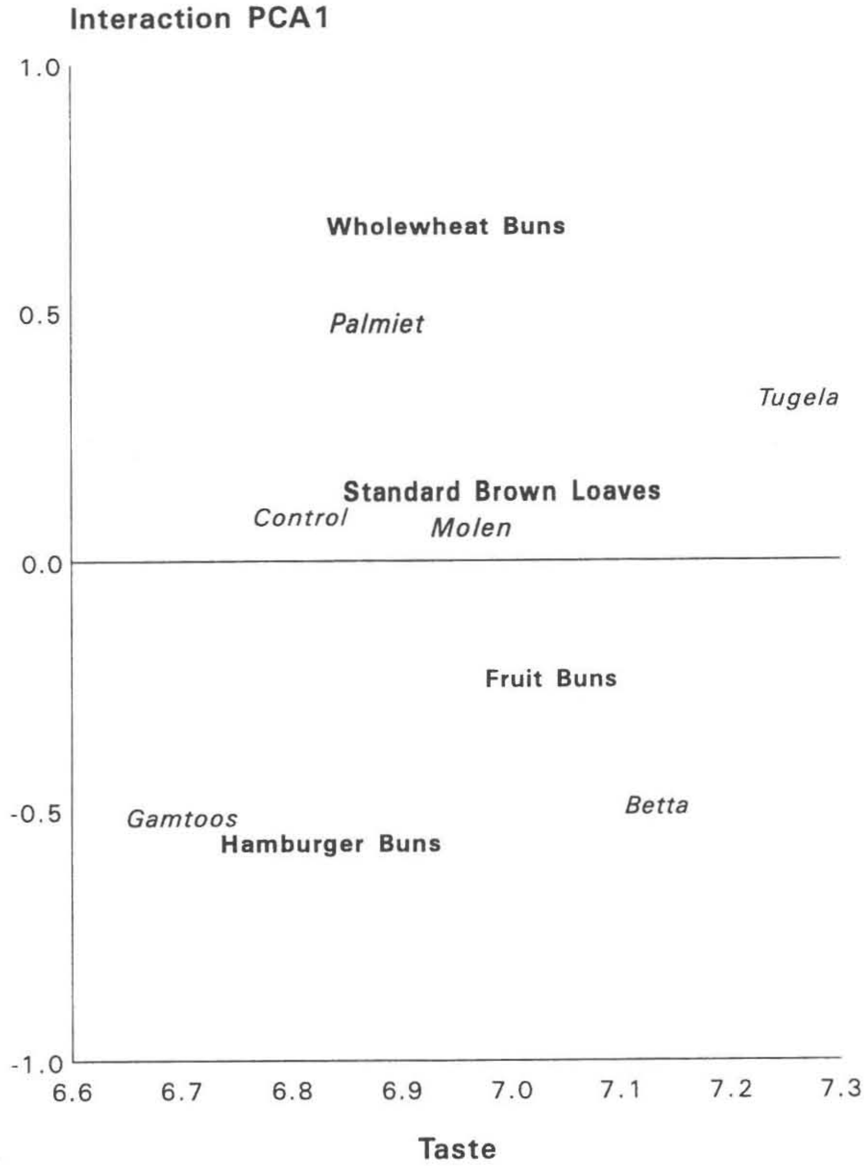

Figure 4.5 Biplot of product and flour source means and PCA scores of taste.

From Figure 4.5 it became clear that the interactive effects for taste were of minor influence. Fruit Buns were preferred more than the other products, and Tugela and Betta flours once again showed better results.

4.13 Biplot of product and flour source means and PCA scores of after taste

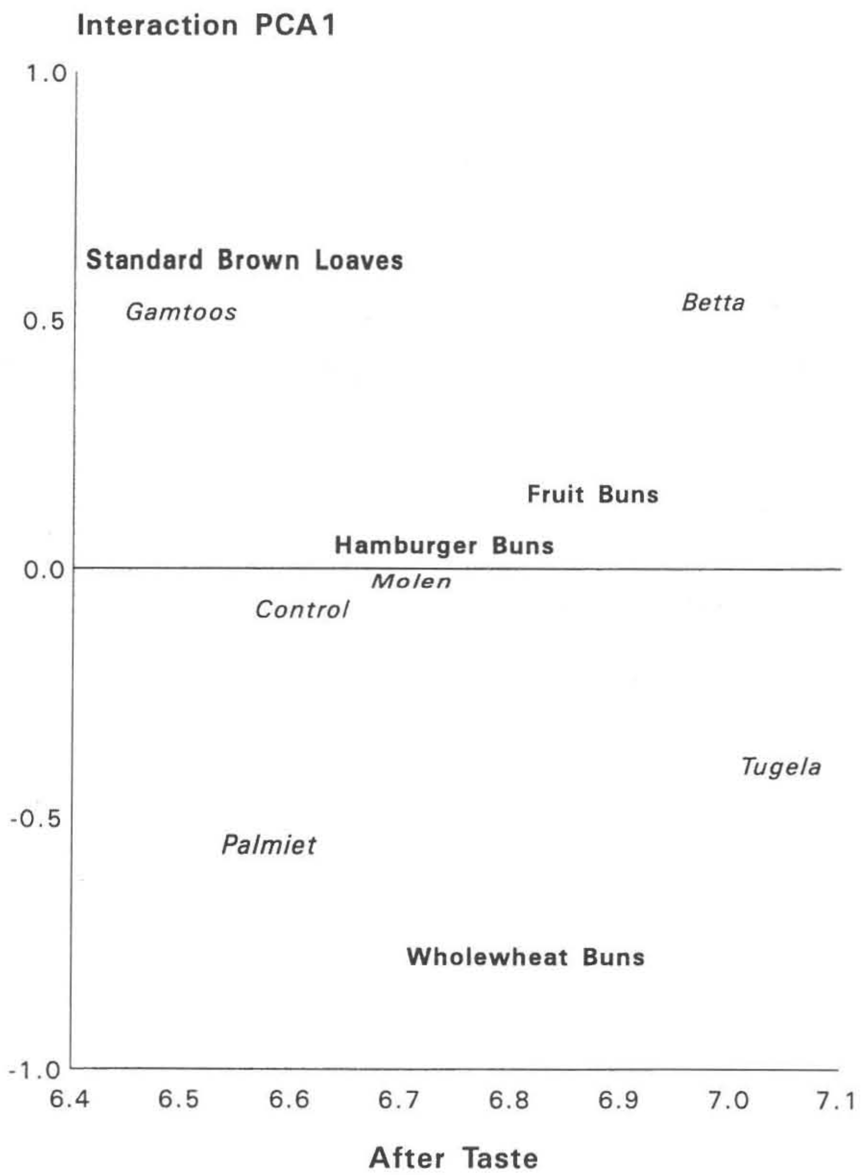

Figure 4.6 Biplot of product and flour source means and PCA scores of after taste.

Figure 4.6 showed that after taste was to a larger extent the product of interaction between product and flour source. Despite interactive effects, Betta and Tugela were once again associated with better results.

4.14 Photographs of sections through the four frozen dough products baked from different flour sources

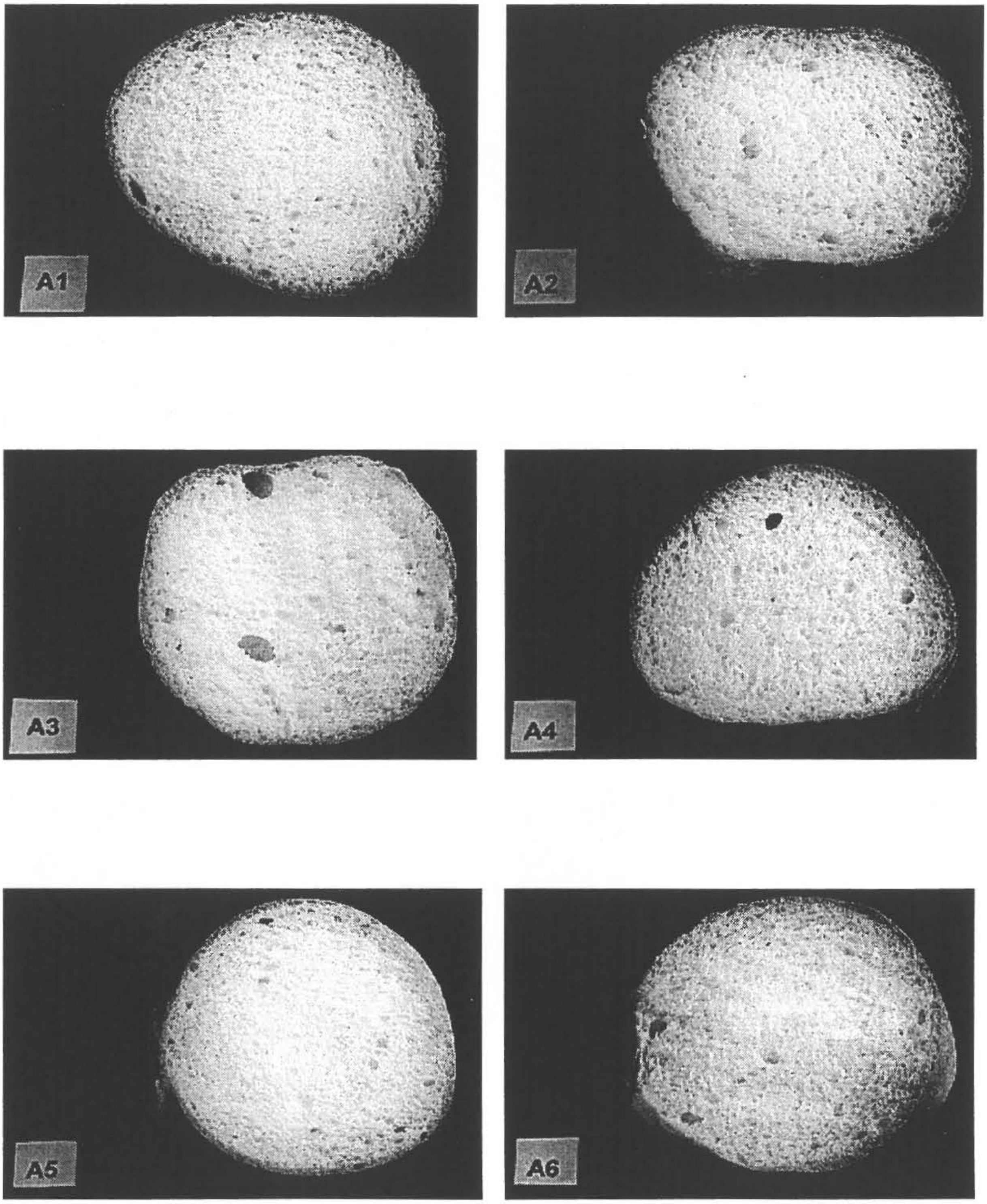

Figure 4.7 Photographs of sections through Hamburger Buns baked from six flour sources
A1 = Control, A2 = Molen, A3 = Gamtoos, A4 = Palmiet, A5 = Betta, A6 = Tugela

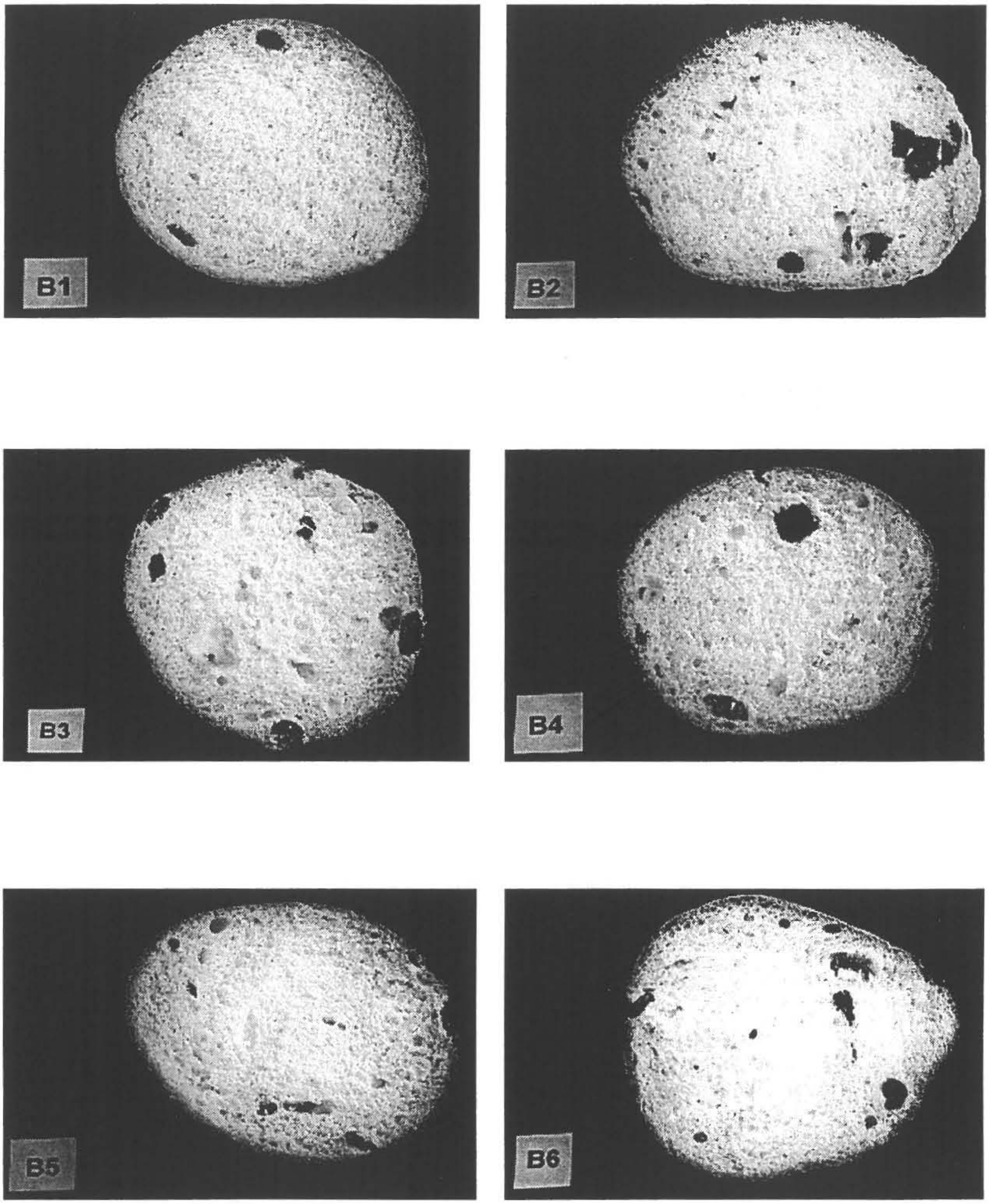

Figure 4.8 Photographs of sections through Fruit Buns baked from six flour sources.
B1 = Control, B2 = Molen, B3 = Gamtoos, B4 = Palmiet, B5 = Betta, B6 = Tugela

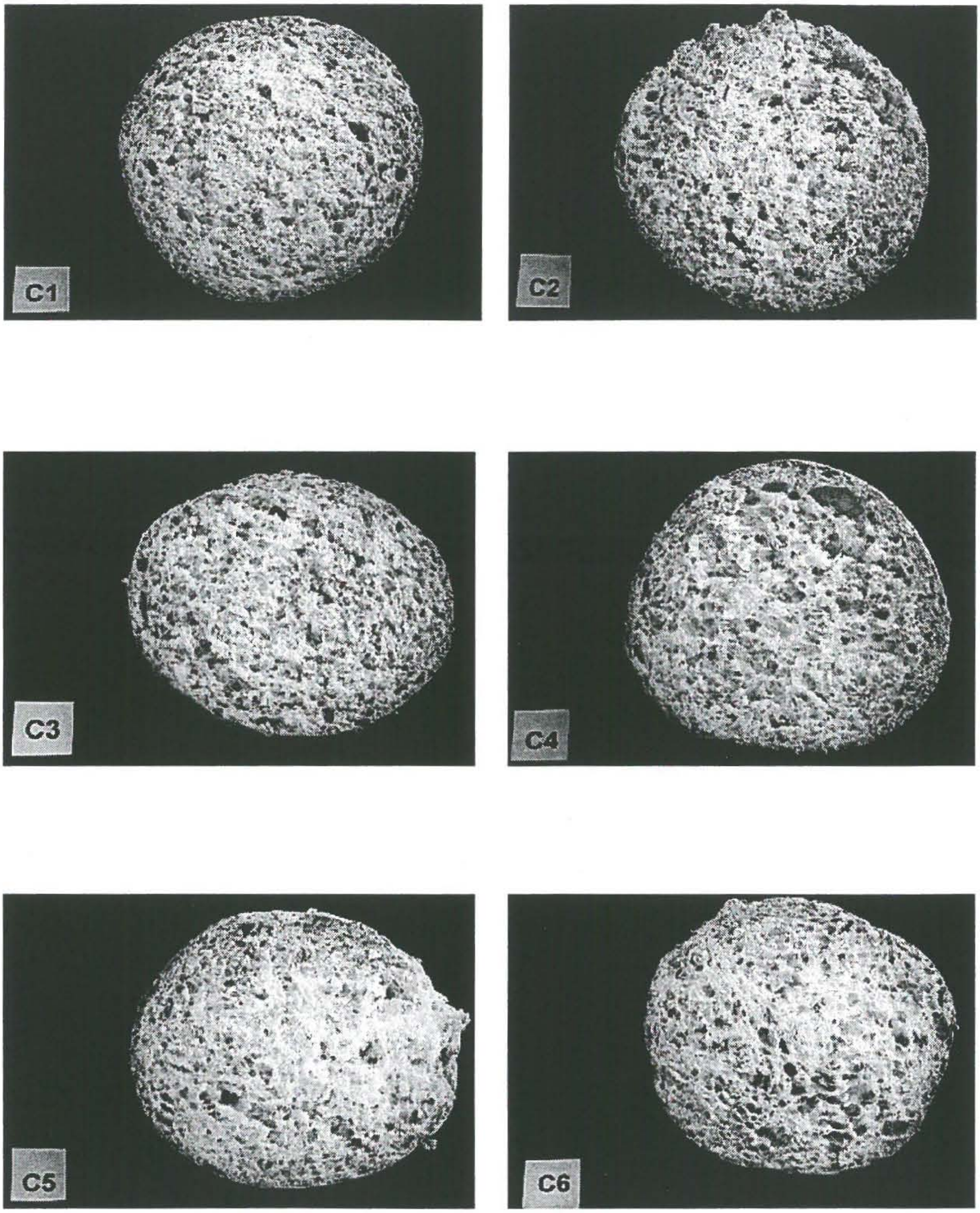

Figure 4.9 Photographs of sections through Wholewheat Buns baked from six flour sources. C1 = Control, C2 = Molen, C3 = Gamtoos, C4 = Palmiet, C5 = Betta, C6 = Tugela.

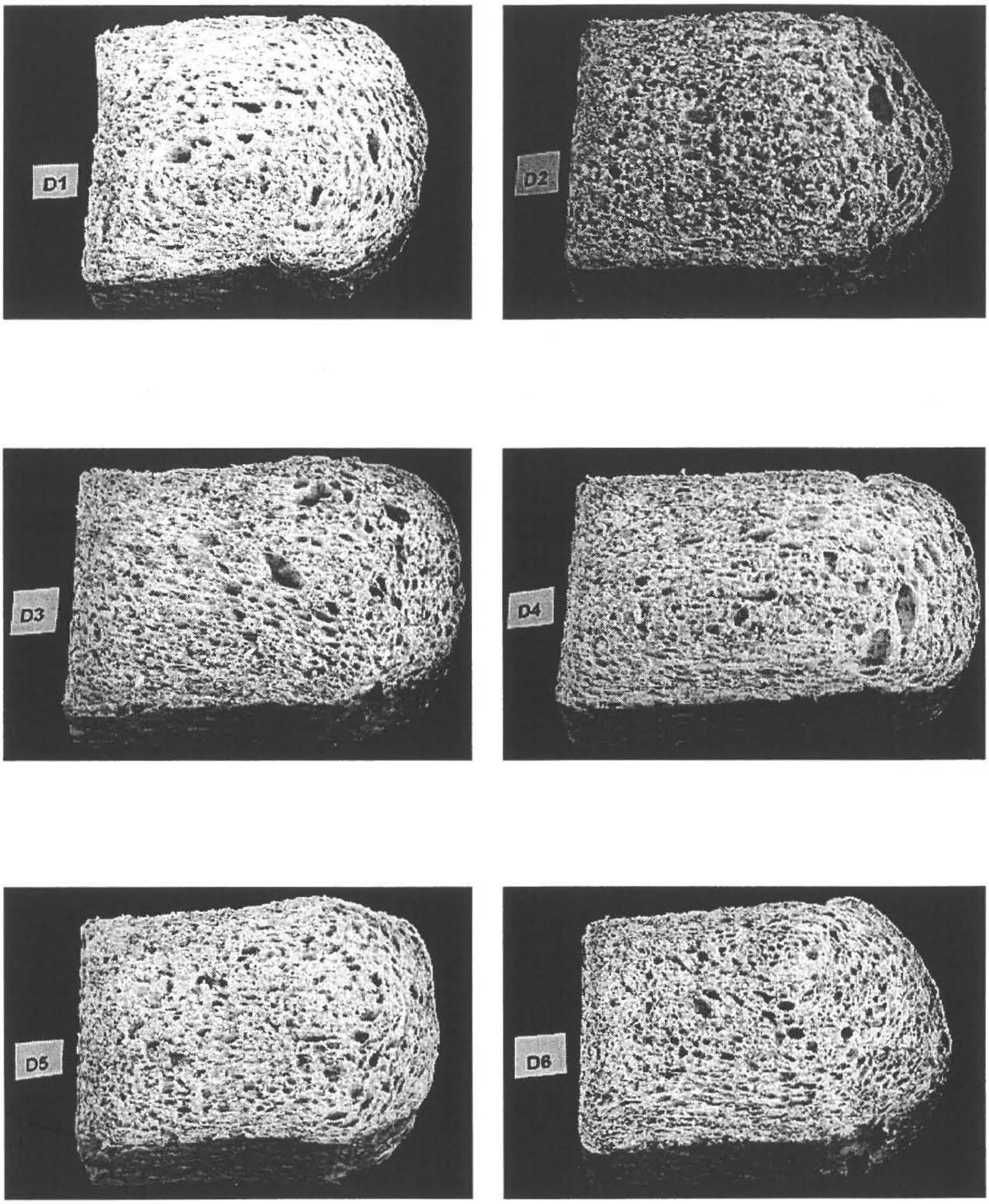

Figure 4.10 Photographs of sections through Standard Brown Loaves baked from six flour sources.
D1 = Control, D2 = Molen, D3 = Gamtoos, D4 = Palmiet, D5 = Betta, D6 = Tugela

The photographs of sections through the four frozen dough products baked from different frozen dough sources in Figure 4.7 to 4.10 provided an impression of the differences observed by the consumer panel. The greatest differences could be observed in the comparison of Wholewheat Buns. The general pattern is that products made from the flour of Betta and Tugela showed a more regular gas cell structure, which in turn was preferred by the consumer panel.

4.15 AMMI flour source selections for four frozen dough products

Table 4.8 demonstrates how AMMI can be used to select most suitable cultivars. Data is presented on the noise levels caused by various sensory attributes, as well as rankings of the suitability of flour sources. It became clear that visual texture was a more accurate technique in the determination of consumer acceptability. In addition, it appeared that flour derived from the cultivars Tugela and Betta generally performed better than the other flour sources.

Table 4.8 AMMI cultivar selections for six sensory cha six different flour sources for four frozen dough products

Characteristic	Product	Product mean	IPCA I Score[a]	AMMI Rankings
Crust colour	Whole Wheat Buns	7.25	0.81	Tugela, Molen, Palmiet, Betta, Control, Gamtoos
(Noise level: 20.2 %)	Standard Brown Loaves	7.53	0.18	Betta, Tugela, Molen, Palmiet, Control, Gamtoos
	Fruit Buns	7.12	-0.37	Betta Gamtoos Control Tugela, Molen, Palmiet
	Hamburger Buns	7.13	-0.62	Betta, Gamtoos, Control, Molen, Palmiet, Tugela
Crumb colour	Hamburger Buns	7.12	0.62	Tugela, Control, Molen, Palmiet, Betta, Gamtoos
(Noise level: 13.1 %)	Standard Brown Loaves	7.47	0.17	Tugela, Betta, Molen, Palmiet, Control, Gamtoos
	Fruit Buns	7.11	-0.30	Betta, Tugela, Palmiet, Molen, Control, Gamtoos
	Whole Wheat Buns	7.30	-0.49	Betta, Tugela, Palmiet, Molen, Gamtoos, Control
Visual texture	Fruit Buns	7.07	0.45	Tugela, Betta, Molen, Palmiet,Gamtoos, Control
(Noise level: 7 %)	Hamburger Buns	7.09	0.17	Tugela, Betta, Molen, Palmiet, Control, Gamtoos
	Standard Brown loaves	7.29	-0.10	Tugela, Betta, Molen, Palmiet, Control, Gamtoos
	Whole Wheat Buns	7.15	-0.72	Betta,Tugela, Control, Molen, Palmiet,Gamtoos
Mouthfeel	Hamburger Buns	6.92	0.47	Tugela, Palmiet, Molen, Betta,Gamtoos, Control
(Noise level: 23.7 %)	Standard Brown Loaves	6.93	0.35	Tugela, Palmiet, Molen, Betta, Control, Gamtoos
	Fruit Buns	7.06	-0.38	Betta, Tugela, Control, Palmiet, Molen, Gamtoos
	Whole Wheat Buns	7.09	-0.44	Betta, Tugela, Control, Palmiet, Molen, Gamtoos
Taste	Standard Brown Loaves	6.95	0.68	Tugela, Palmiet, Molen, Control, Betta, Gamtoos
(Noise level: 24.4 %)	Whole Wheat Buns	6.98	0.13	Tugela, Betta, Molen, Palmiet, Control, Gamtoos
	Fruit Buns	7.04	-0.24	Betta, Tugela, Molen, Gamtoos, Control, Palmiet
	Hamburger Buns	6.82	-0.58	Betta, Tugela, Gamtoos, Molen Control, Palmiet
After taste	Standard Brown Loaves	6.80	0.62	Betta, Gamtoos, Tugela, Molen, Control, Palmiet
(Noise level: 16.8 %)	Fruit Buns	6.84	0.14	Betta, Tugela, Molen, Control, Gamtoos, Palmiet
	Hamburger Buns	6.53	0.02	Tugela, Betta, Molen, Control, Palmiet, Gamtoos
	Whole Wheat Buns	6.75	-0.78	Tugela, Palmiet, Molen, Control, Betta, Gamtoos

[a] IPCA 1 Score = Interaction PCA_1

4.16 Linear correlation coefficients among sensory and rheological characteristics

Table 4.9 Linear correlation coefficients[a] among sensory and rheological characteristics[b]

	[b]CTS	CBC	VTX	MTF	TST	ATS
CTC	1.00					
CBC	-	1.00				
VTX	0.41	0.70	1.00			
MTF	0.55	0.61	***0.98***	1.00		
TST	0.74	0.41	***0.87***	***0.94***	1.00	
ATS	0.55	0.27	0.66	0.76	***0.88***	1.00
MED	-	0.71	0.58	0.44	-	-
MEL	0.55	0.40	0.24	0.27	0.33	-
MER	0.30	0.65	0.62	0.60	0.57	0.44
MEA	-	***0.85***	0.78	0.74	0.64	0.50
MMD	-	0.77	0.82	0.73	0.51	0.23
MML	-	-0.78	-0.77	-0.64	-0.36	-
MMR	-	***0.89***	0.68	0.56	0.32	-
FRD	-	0.48	0.69	0.60	0.40	-
FRS	-	***0.97***	0.80	0.74	0.58	0.41
FRW	-	-	-	-	-	-0.35
APL	0.24	0.29	0.38	0.34	0.29	-
ALS	-	0.74	0.70	0.59	0.36	-
EXR	0.36	0.41	0.42	0.38	0.30	-
EXS	-	***0.86***	0.82	0.76	0.61	0.57
BSI	-0.23	0.69	0.76	0.63	0.36	-

[a] All coefficients are reported at P≤0.001, Coefficients ≥0.8 are all indicated in **bold** and ***Italic***

[b] CTC = Crust Colour, CBC = Crumb Colour, VTX = Visual Texture, MTF = Mouthfeel, TST = Taste, ATS = After taste, MED = Mixogramme envelope development time (min), MEL = Mixogramme envelope left-of-peak (%.min^{-1}), MER = Mixogramme envelope right-of-peak (%.min^{-1}), MEA = Mixogramme envelope area (cm^2), MMD = Mixogramme midline development time (min), MML = Mixogramme midline left-of-peak (%.min^{-1}), MMR = Mixogramme midline right-of-peak (%.min^{-1}), FRD = Farinograph dough development time (min), FRS = Farinograph dough stability (min), FRW = Farinograph water absorption (%), APL = Alveograph P/L-ratio, ALS = Alveograph strength(cm^2), EXR = Extensograph ratio (R_{max} at 5 cm / Extensibility (mm), EXS = Extensograph strength (cm^2), BSI = Baking strength index

The linear coefficients contained in Table 4.9 showed that almost all coefficients indicated significant correlations between variables. This result demonstrates that simple linear relationships can not be used in the interpretation of complex data sets. In order to derive at more helpful information, a multivariate statistical approach (Van Lill *et al.*, 1995) should be followed.

4.17 Canonical correlation analysis of sensory and quality characteristics

The results in Table 4.10 showed the interelatedness between the set of rheological data and the sensory data obtained in this study. The results did not present a clear cut pattern which could be employed by wheat breeders. At least it appeared that dough with stronger rheological features, such as associated with the cultivars Tugela and Betta, gave most desirable results.

Table 4.10 Canonical correlation analysis of sensory and quality characteristics[a] aimed at the production of frozen dough products

Canonical Correlation	r	Variation explained %	Q-set: Rheological Characteristics				P-set: Sensory characteristics					
Hamburger Buns												
Mixogramme Envelope Analysis			**MED**	**MEL**	**MER**	**MEA**	**CTC**	**CBC**	**VTX**	**MTF**	**TST**	**ATS**
CC_1	0.30	46	0.12	-0.14	0.08	-0.03	-1.75	-1.16	1.25	-1.29	1.78	-0.19
CC_2	0.26	39	1.11	0.09	-0.03	-0.08	-0.08	-0.33	0.64	-0.85	0.78	-1.43
Mixogramme Midline Analysis			**MMD**	**MML**	**MMR**							
CC_1	0.31	58	-1.51	-0.14	0.22		0.38	0.57	-0.95	5.47	-5.26	1.24
CC_2	0.21	38	0.83	-0.07	-0.24		-0.31	-0.71	1.55	-0.16	1.12	-1.27
Farinograph Analysis			**FRD**	**FRS**	**FRW**							
CC_1	0.27	46	-0.49	0.32	0.42		-0.79	0.39	-0.29	-3.16	2.20	-0.12
CC_2	0.25	43	-0.18	0.26	0.10		0.64	1.35	-1.22	1.88	-2.26	1.17
Alveograph + BSI Analysis			**APL**	**ALS**	**BSI**							
CC_1	0.30	50	0.29	-0.10	0.14		-1.58	-1.09	0.82	-2.21	2.37	0.15
CC_2	0.18	29	-0.03	0.04	-0.14		0.68	0.59	-1.22	-1.45	0.49	0.53
Extensograph + BSI Analysis			**EXR**	EXS	BSI							
CC_1	0.30	44	0.09	-0.02	0.07		0.17	-0.47	1.16	-0.38	0.84	-1.78
CC_2	0.18	36	-0.09	0.01	0.05		-0.26	0.05	0.38	2.49	-1.78	0.35
Fruit Buns												
Mixogramme Envelope Analysis			**MED**	**MEL**	**MER**	**MEA**						
CC_1	0.35	52	-1.12	-0.12	-0.00	0.09	-0.53	-2.33	3.71	-1.30	2.98	-2.06
CC_2	0.17	25	-0.66	0.99	-0.07	0.04	0.55	0.27	0.03	-0.57	-3.15	1.44
Mixogramme Midline Analysis			**MMD**	**MML**	**MMR**							
CC_1	0.30	50	-0.34	0.13	0.33		0.48	-1.99	0.01	1.27	-6.16	5.34
CC_2	0.18	31	-0.32	-0.11	0.02		0.22	1.47	-1.46	1.32	-2.06	1.59
Farinograph Analysis			**FRD**	**FRS**	**FRW**							
CC_1	0.29	52	0.47	-0.43	-0.38		0.36	0.93	-0.24	-0.68	1.80	-0.47
CC_2	0.18	32	-0.30	0.20	0.34		-0.13	0.38	-1.93	1.06	0.74	0.36
Alveograph + BSI Analysis			**APL**	**ALS**	**BSI**							
CC_1	0.35	48	0.36	-0.10	0.15		-0.84	-2.26	2.49	-0.92	5.69	-3.15
CC_2	0.15	31	0.36	0.02	-0.12		0.62	-1.74	0.07	0.01	-3.80	3.78
Extensograph + BSI Analysis			**EXR**	EXS	BSI							
CC_1	0.30	51	0.14	-0.02	0.05		0.53	2.98	-3.37	0.71	-1.17	0.69
CC_2	0.18	34	0.18	-0.00	-0.09		0.78	-1.46	-0.35	0.18	-4.53	4.43
Wholewheat Buns												
Mixogramme Envelope Analysis			**MED**	**MEL**	**MER**	**MEA**						
CC_1	0.43	56	0.70	-0.04	0.20	-0.12	-3.31	-0.45	3.95	-2.65	6.20	-4.75
CC_2	0.18	23	-0.39	-0.13	0.14	-0.06	0.87	0.55	-0.15	-1.18	0.22	-0.89
Mixogramme Midline Analysis			**MMD**	**MML**	**MMR**							
CC_1	0.38	59	0.19	0.16	0.28		-0.21	-0.87	0.07	-1.33	1.50	1.94
CC_2	0.15	23	0.21	0.13	0.05		0.50	-0.55	-2.35	0.65	-2.39	5.07
Farinograph Analysis			**FRD**	**FRS**	**FRW**							
CC_1	0.42	66	0.33	-0.28	-0.20		-3.11	0.98	3.91	-1.30	4.52	-6.34
CC_2	0.17	26	0.28	-0.11	-0.30		0.82	0.79	-0.63	0.38	-1.24	1.33
Alveograph + BSI Analysis			**APL**	**ALS**	**BSI**							
CC_1	0.37	58	1.03	-0.05	0.06		-3.07	0.05	3.65	-3.01	5.96	-4.34
CC_2	0.15	23	0.12	-0.06	0.04		1.50	0.14	-1.63	-0.55	-1.45	1.35
Extensograph + BSI Analysis			**EXR**	EXS	BSI							
CC_1	0.39	60	-0.18	0.01	-0.05		3.53	0.18	-3.42	0.08	-3.86	3.73
CC_2	0.18	27	0.15	0.02	-0.07		-0.60	-0.20	0.52	-1.65	1.93	1.28
Standard Brown Loaves												
Mixogramme Envelope Analysis			**MED**	**MEL**	**MER**	**MEA**						
CC_1	0.27	40	-0.52	-0.09	0.27	-0.11	-2.10	-2.95	-0.47	1.01	1.54	0.19
CC_2	0.18	26	0.30	0.14	-0.03	-0.05	0.68	4.09	-0.35	-2.33	-1.35	-0.95
Mixogramme Midline Analysis			**MMD**	**MML**	**MMR**							
CC_1	0.27	62	-1.56	-0.26	-0.01		1.16	2.10	-0.99	-0.03	-0.68	0.83
CC_2	0.15	35	-0.18	0.05	0.24		-2.07	-0.65	-0.29	-0.20	1.81	0.51
Farinograph Analysis			**FRD**	**FRS**	**FRW**							
CC_1	0.27	61	0.53	-0.39	-0.52		2.80	-1.19	4.42	-0.28	-0.81	-3.98
CC_2	0.14	33	0.18	-0.28	-0.13		1.04	1.57	-1.11	0.03	-0.59	-0.93
Alveograph + BSI Analysis			**APL**	**ALS**	**BSI**							
CC_1	0.23	53	0.85	-0.06	0.04		-2.38	-2.65	-1.73	1.39	1.56	1.24
CC_2	0.13	31	0.00	0.09	-0.19		-0.23	1.50	0.43	-1.61	-0.96	-0.05
Extensograph + BSI Analysis			**EXR**	EXS	BSI							
CC_1	0.27	60	0.16	0.01	-0.11		-2.12	-3.35	0.12	0.73	0.46	1.79
CC_2	0.12	26	0.14	-0.02	0.00		0.78	4.84	-1.47	-2.02	-0.82	-1.60

[a] Refer to Table 4.9

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CHAPTER 5

DISCUSSION

5.1 Rheological profiles of the various flour sources

The results contained in Table 4.1 indicated that the flour protein content (FPC) of the flours sourced from the pure cultivars varied from a minimum of 13.1% (Molen) to a maximum of 13.8% (Tugela, Gamtoos). At these levels of higher than 12% protein content, the qualitative differences among cultivars were likely to be enhanced (Van Lill & Purchase, 1995).

Analysis of the mixogramme envelope involves the information gleaned from the upper and lower traces of the curve. Mixogramme midline analysis focuses on the middle of the curve, and is considered a more consistent source of information (Walker & Walker, 1992).

Regardless of the assessment technique, Gamtoos consistently showed the shortest dough development time (MED), followed by Molen, Palmiet, Betta and the control, all varying between two to three min. Tugela consistently showed the longest dough development time ($\geq$ 3.5 min).

The left-of-peak (MEL) and right-of-peak (MER) slopes reflect the tolerance and the sensitivity of a flour to mixing time. Very steep left-of-peak and right-of-peak slopes are undesirable. Envelope analysis (MEA) of these slopes showed a comparable rate of dough development as the left-of-peak slope varied between 25 and 36 $\%.min^{-1}$. The right-of-peak figures however, contrasted Tugela against Palmiet and Gamtoos (average = $-19.5\%.min^{-1}$). The other cultivars showed an intermediate result (average = $-11\%.min^{-1}$), indicating weaker dough types.

Analysis of the mixogramme midline left (MML) and right-of-peak (MMR) slopes, depicted Tugela as having a slower ascendance towards the peak, probably reflecting a slower rate of water absorption. The absence of a right-of-peak, indicated an extremely high tolerance to overmixing.

Similar comparisons of the midline peak slopes indicated that the dough tolerance of

Control, Molen, Palmiet and Betta were comparable. Gamtoos, in contrast, showed a rapid rate of dough development as well as breakdown, predicting undesirable dough quality. This confirmed the unsuitability of Gamtoos for commercial bread production as previously demonstrated by Van Lill *et al.* (1990).

The area of the curve, as determined through envelope analysis, estimates the energy required to mix the dough and is to some extent indicative of baking strength. Having the largest envelope area, Tugela was identified as the strongest dough when compared to Betta, Control and Molen (average = 34.2 cm^2). Gamtoos in contrast, was identified as the cultivar with the least strength.

The Farinograph measures dough development time (FDT), dough stability (FRS) and water absorption (FRW) when dough is subjected to a prolonged, relatively gentle mixing action at a constant temperature. Resistance offered by the dough to mixing blades is transmitted through a dynamometer to a pen that traces a curve on a kymograph chart (Finney *et al.*, 1987). The curve can be divided into two sections indicating dough development time, (starting from the bottom of the chart to the turning point of the curve) and dough stability, (duration time of the curve on the center line of the graph paper). The longer the duration time of the curve on the center line, the higher the resistance of the dough. When a dough has been mixed to maximum dough development time, optimum hydration of protein and starch has occurred.

According to the guidelines laid down by the South African breadmaking industry, the optimum value for FDT varies from four to five min (Van Lill & Purchase, 1995). FRS should be limited to a maximum of 16 min in order to meet the requirements of the Chorleywood Breadmaking Process (Van Lill & Purchase, 1995). Tugela showed the longest dough development time and the highest dough stability when compared to the control and Betta (FRD average = 11.6 min, FRS average = 14.4 min), indicating strong dough features. The dough development time of Molen was less than that of Gamtoos and Palmiet (average = 9.3 min), while Gamtoos showed the least stability. Compared to the suggested volume of water required to produce a dough of standard consistency (58 - 65%), the majority of the cultivars showed an acceptable water absorption (average = 64.8%). The water absorption level of Tugela was the highest, confirming the interrelated nature of longer dough development times, higher dough stability times and higher levels of water absorption (Van Lill & Smith, 1997).

The Alveograph employs air pressure to blow a bubble from a disc of dough. A recording manometer monitors the expansion of the bubble to the point of rupture. The height of the curve (P) on the Alveogramme measures the initial resistance of the dough to extension as measured during the formation of the bubble. The length of the curve (L) serves as an index of dough extensibility and gas retention. The P/L-ratio determines a definite description of protein functionality, intergrating data on the extensibility and resistance to extension. In view of the CBP, a P/L-ratio of 1.2 is considered as acceptable. The area under the curve resembles dough strength, referring to the capacity to withstand mechanical strains during fermentation (Finney *et al.*, 1987).

Tugela showed both the highest P/L-ratio and curve area, indicating a higher dough stability and strength when compared to that of Betta. Molen and Palmiet produced the smallest ratios, indicating less resistance to extension and weaker doughs. The control and Gamtoos both showed an acceptable average P/L-ratio (average = 1.4) when compared to the suggested P/L-ratio of 1.2.

The forces encountered by the hook of the Extensograph as it stretches the dough to the point of rupture, measures both resistance to extension (Brabender Units) and extensibility (mm). The results are recorded graphically through a dynamometer system similar to that of the Farinograph (Simmonds, 1989). Weak doughs exhibit lengthy and flowy Extensogramme curves, while less extensible, stiff doughs yield a high but narrow curve. An acceptable extensogramme curve reflects a good balance between extensibility and resistance to extension as a function of time, indicating boldness and stability of dough during fermentation.

Studies by Van Lill & Smith (1997), showed that maximum averages EXR values of 25 were obtained for stronger cultivars like Tugela while intermediate averages ranged from Molen (EXR = 12) to Betta (EXR = 17). A similar tendency of EXR values were observed in this study, confirming that Extensograph measurements (R_{max} at 5 cm along the baseline) were efficient when comparing qualitative differences among flours (Simmonds, 1989; Van Lill & Smith, 1997). Maximum average EXR values of 15 were obtained for Tugela and the control, while intermediate averages ranged from Molen (EXR = 10), to Betta (EXR = 14). This indicated that cohesive and partially elastic doughs with high resistance were formed. Extensograph strength, however, was dominated by Tugela, indicating a higher level of dough tolerance to mechanical breakdown and a higher potential for loaf volume when compared to the other cultivars, varing from a maximum of 178 cm^2 (Tugela) to a minimum of 107 cm^2 (Gamtoos).

The collective results obtained from the Farinograph, Alveograph and Extensograph clearly contrasted cultivars in terms of weak versus strong dough characteristics. The weaker dough type of cultivars such as Gamtoos, Palmiet and Molen as depicted by a shorter dough development time, lower water absorption and lower resistance to overmixing, contrasted against the stronger dough qualities exhibited by cultivars such as Tugela and Betta. As previously found by Van Lill & Purchase (1995), Betta could be considered as a relatively strong dough type. For the cultivar Tugela, a level of dough strength that exceeded CBP conditions was predicted by FRD and FRS. The performance of the commercial flour source was considered as being intermediate.

The baking strength index (BSI) is a relative measure of protein quality as it expresses actual loaf volume (LFV) as a percentage of the volume that can be expected of a cultivar with acceptable quality (Tipples & Kilborn, 1974). The value of the BSI therefore lies in eliminating the influence of varying protein levels in quality assessments. A BSI of 100 implies that the baking quality is equal to that of the quality standard which in this study was the cultivar Betta. The BSI of Tugela was 6% higher than the standard. The average BSI scores of Molen, Palmiet, Gamtoos and Control amounted to six percent less than Betta.

The data in Table 4.1 were grouped and analysed in three sections: Mixogramme envelope and midline analysis; Farinograph, Alveograph and Extensograph analysis; BSI and Glu-1 scores. Results showed that the strength of Tugela's dough quality features dominated all the other cultivars. Similar to previous findings (Van Lill & Smith, 1997), Tugela exhibited strong dough characteristics, having a relatively long dough development time (MED > 2.5 min), a high tolerance to overmixing (FRS > 15 min) and a very high water absorption (FRW > 65%). Tugela also related to a strong baking strength index.

Considering the study of Inoue & Bushuk (1992), which indicated that flours from stronger wheat varieties performed better in the frozen dough procedures, the expectation was that Tugela would be the cultivar most suitable for the manufacturing of frozen dough products.

5.2 Comparison of processing characteristics of the frozen dough products

5.2.1 Processing characteristics

The dough development times and water absorptions for the various wheat cultivars used in the production of four frozen dough products are listed in Table 4.2.

The production manager at Just Baked recommended a minimum water absorption level of 50% and 60% for rolls and brown loaves respectively. These levels were adjusted during mixing as required. Extended dough mixing times for frozen doughs should be minimized as it generates heat and enhances fermentation (Kulp, 1995). The data contained in Table 4.2 indicated that strong flours, as well as the presence of bran, tended towards a higher water absorption. Previous studies by Nelles (1997) and Van Lill (1994) also related the presence of bran to increased water absorption in the order of 2%.

5.3 Demographics of the consumer panel used for sensory evaluation

The demographic composition of the consumer panel employed for sensory analysis is summarised in Table 4.3.

The sensory evaluation survey comprised of 240 participating panelists. Each panelist evaluated six baked units per product; each unit representing a different flour source.

The majority of panelists (44%) were in the age group of 18 to 29 while the remainder were evenly distributed. Mostly females (80%) participated in the survery.

The occupations of the panelists varied. Of all the panelists, 15% were students, 32% were housewives and representatives of the Foodservice Industry, while the majority (52%) did not specify their occupation.

Regarding the preference of the different products, 56% of the panelists indicated that they regulary purchased Standard Brown Loaves. Wholewheat Buns were preferred by 22% of the panelists, followed by Hamburger Buns (17%) and Fruit Buns (1%). Only 4% of the consumers indicated that they have never before bought any of these types of products on a regular basis.

Data from the sensory evaluation survey indicated that almost 80% of the panelists bought bread related products from supermarkets with in-store bakeries. Bakeries or bread shops were indicated as second choice (15%), followed by supermarkets without in-store bakeries (5%).

It also appeared that almost 80% of the panelists perceived frozen dough products as a new concept. Following their first exposure to frozen dough products, 70% of the consumers indicated that they would now consider buying these products. Wholewheat Buns (4% above average) and Standard Brown Loaves (1% above the average) were slightly more popular compared to the other products, probably reflecting a health related preference for products containing bran.

5.4 Evaluation of sensory characteristics

5.4.1 Crust colour

From the analysis of variance (ANOVA), it appeared that the effects of product, flour source and their interaction contributed to variation of crust and crumb colour and visual texture (Table 4.4). Product did not contribute to variation in mouthfeel, taste or after taste. Interactive effects of Product (P) and Flour source (S) were noted for all sensory characteristics.

The magnitude of the respective effects of product, flour source and their interaction was examined by comparison of variance components. These variance components primarily served as relative predictors of interaction of sensory characteristics. The variance ratios for each sensory characteristic, are shown in Table 4.5. A similar method of interpretation was also followed by Van Lill *et al.* (1995); Van Lill & Smith (1997), in the interpretation of genotype and environment interaction.

From the P/S-ratio, it became clear that the panel preference for crust colour was predominantly influenced by the type of product evaluated. This tendency was also confirmed by the ratio of P/(PxS).

From the data of product means presented in Table 4.6, it appeared that the crust colour of the Standard Brown Loaves (mean= 7.53), was considered more acceptable, when compared to that of the Hamburger Buns, Fruit Buns and Wholewheat Buns (mean= 7.17).

Assessment of differences among flour source means, indicated that the crust colour of Betta was most preferable, while the crust colour of Gamtoos was least acceptable.

As far as the PxS - interaction is concerned, Gamtoos and Betta presented the most acceptable crust colour for Hamburger Buns, whereas for Standard Brown Loaves and Fruit Buns no significant interaction was observed. The interaction effects for Wholewheat Buns indicated the crust colour of Gamtoos as being most acceptable.

In addition to ANOVA, the interaction of cultivar by product was further investigated by means of the AMMI-model (Additive Main Effect And Multiplicative Interaction). AMMI combines the additive main effects of the analysis of variance (ANOVA) with the interaction effects of principal components analysis (PCA). This approach is particularly useful for analysis of two-way data (genotype x product effects) as it highlights particular patterns of the interaction (Zobel *et al.*, 1988; Barnard, Purchase, Smith & Van Lill, 1997) as previously noted for wheat types and environment and also for sensory attributes of meat (Results unpublished, M.F. Smith, Director Agrimetric Statistics, ARC - personal communication).

The second advantage of AMMI is the partitioning of the data into a model containing the effects of treatment (Treatment Sum of Squares) and noise (Residual Sum of Squares indicating observational variance) in the data. In the final analysis of the multiplicative interaction the noise is discarded, causing some AMMI estimates to differ from treatment means. The AMMI analysis of variance for the sensory characteristics studied, is presented in Table 4.7. For this study, the ultimate aim of the interpretation of product by flour source interaction, was the selection of flour sources suited to the production of a specific product. AMMI analysis also provided tabulated AMMI rankings per product, thereby simplifying the selection process.

The noise level for crust colour (Sum of $\text{Squares}_{\text{Residual}}$ / Sum of $\text{Squares}_{\text{Treatment}}$) was 20% (Table 4.8), which confirmed the human nature of a typical consumer panel. In the analysis of standardised cultivar adaptation trials, for example, a noise level of 5% is normally observed (Barnard *et al.*,1997). The first interaction component captured 67% of the interaction SS in 47% of the interaction degrees of freedom (7/15). After discarding noise effects, it appeared that flour source and product contributed equally (19%, $P < 0.01$) to variation in crust colour. The strong evidence of interactive effects ($P<0.01$), explained 62% of the variation.

Product and flour source means for crust colour, as well as their first interaction PCA scores (PCA 1) are presented in Figure 4.1. In this biplot, the main effects (crust colour means) are presented on the horizontal axis and the interaction effects on the vertical axis.

According to the biplot, the most stable flour sources (least influence on product type, PCA 1 < ± 0.27) were Control, Molen, Palmiet and Betta, whereas, Tugela and Gamtoos induced most variation within products. The previously noted contrast of products containing bran with products made from a white flour basis, was also confirmed. The largest contrast of PCA 1 scores for product and flour source (Gamtoos versus Wholewheat Buns), indicated that Gamtoos tended to reduce the crust colour preference of Wholewheat Buns by the consumer panel.

The product means, their PCA 1 scores and a ranking of flour source acceptability for each product is shown in Table 4.8. It appeared that Betta and Gamtoos were the most acceptable flour sources to achieve an acceptable crust colour for Fruit Buns and Hamburger Buns. Tugela was most acceptable for the production of bran containing products. Molen produced an acceptable crust colour for Wholewheat Buns.

5.4.2 Crumb colour

The variance ratio of P/S, (Table 4.5), indicated that the panel's preference for crumb colour was predominantly determined by flour source effects.

Crumb colour differences among various products (Table 4.6) followed a similar tendency to that of crust colour. The flour sources Palmiet, Molen, Tugela and Betta were more favourably perceived when compared to Gamtoos and the control.

The interaction of product by flour source showed that for Hamburger Buns, Betta's crumb colour was preferred. The crumb colour of Palmiet was least acceptable, with the other flour sources being comparable. For Wholewheat Buns, the crumb colour of Tugela, Betta, Molen and Control (mean = 7.54), was preferred above that of Gamtoos. The interactive effects for the crumb colour of Standard Brown Loaves and Fruit Buns were insignificant.

The AMMI analysis of variance for crumb colour indicated a noise level of about 13%. From Table 4.7 it appeared that the effects of flour source and product respectively contributed to 49% and 18% of the variation, while the PCA1 captured 60% of the interactive SS. When comparing these results with the variance ratios calculated from ANOVA, it became evident that the AMMI analysis was more sensitised to detecting interactive effects.

The biplot of product and flour source means versus PCA 1 scores for crumb colour is presented in Figure 4.2. The lower values of the PCA 1 scores (< ± 0.30) for the flour sources Molen, Palmiet, Tugela and Betta contrasted against the higher score of Gamtoos, designating Gamtoos as contributing to inconsistency of crumb colour. It was also observed that the crumb colour of Hamburger Buns and Standard Brown Loaves were contrasted against that of Fruit Buns and Wholewheat Buns, but could not be explained.

From the AMMI rankings in Table 4.8 it appeared that regardless of product type, Tugela and Betta produced the most acceptable crumb colour.

5.4.3 Visual texture

From the P/S-ratio presented in Table 4.5 it was concluded that of all sensory characteristics, visual texture was the most sensitive to flour source effects. Furthermore, the P/(PxS) ratio presented evidence of a definite interactive effect between flour source and product type.

Comparing the visual texture means between flour sources (Table 4.6) contrasted Tugela (most acceptable) against Gamtoos (least acceptable). No signifcant textural differences were noted among product types. For Hamburger Buns, Standard Brown and Fruit Buns, no interactive effects could be detected, while Gamtoos clearly reduced the visual acceptability of the texture of Wholewheat Buns.

From the data in the AMMI analysis of variance for sensory characteristics (Table 4.7), it became clear that the noise level for visual texture was the lowest of all sensory characteristics (7%), indicating the evaluation of visual texture by the consumer panel as most consistent. The first interaction component captured 67% of the interaction SS. After discarding noise effects, it appeared that flour source contributed 73% and product only 5% ($P < 0.01$) to variation in texture. Visual texture was therefore identified as the most valuable sensory characteristic for selecting genotypes suited to the production of frozen dough products.

According to the biplot in Figure 4.3, of the flour source by product interaction PCA 1 scores, the flour sources Tugela and Betta provided the combination of most consistent and highest scores for visual textures (mean = 7.55) regardless of the type of product. The flour source Gamtoos induced most of the variation in visual texture and also gave the poorest results (mean = 6.54) when compared to the other flour scores (mean = 7.27). The AMMI analysis also ranked Tugela and Betta as being most suitable for the production of baked products with an acceptable visual texture (Table 4.8).

Of particular interest, was the contrast in PCA 1 scores between the Wholewheat Buns and the other three products, indicating that this product was most susceptible to flour source effects. Considering that the bran content of Wholewheat Buns and the Standard Brown Loaves were similar, it is likely that the intensified mechanical handling of a smaller dough volume could have advanced the presentation of quality defects.

Photographs showing the texture of the four products (Figures 4.7 to 4.10) supported the findings previously discussed. For products without added bran (Figures 4.7 and 4.8), no major differences could be observed among flour sources. Clearer variation was depicted for Wholewheat Buns (Figure 4.9) and Standard Brown Loaves (Figure 4.10). For both products, Gamtoos (C3, D3) and Palmiet (C4, D4) showed signs of an irregular crumb structure and a crumbly appearance. Even though texture is known to comprise of a number of variables, the consumer's association of a firm crumb structure with freshness is well known (Spies, 1990). It is likely that the consumer panel perceived the crumb structure produced by Gamtoos and Palmiet as sub-standard when compared to that of the other entries.

5.4.4 Mouthfeel

The variance ratios for mouthfeel (Table 4.4) indicated that flour source effects dominated. Further investigation into the nature of the P/(PxS) ratio, showed that mouthfeel was mildly subjected to the interaction of product and flour source.

No significant differences in mouthfeel were detected among the products. For flour sources, Betta and Tugela produced better results, whereas the mouthfeel of Gamtoos was worse than the best flour sources. Investigation of the interaction between product and flour source showed that for Standard Brown Loaves only, the mouthfeel achieved by the flour source Tugela was preferred above that of Gamtoos.

The AMMI analysis of variance for mouthfeel (Table 4.7) indicated a noise level of 24%. As was previously concluded by means of the variance ratios, flour source effects dominated (50%, $P < 0.01$) those of products (6%, $P<0.01$). For the interactive effects of product by flour source, the SS in PCA 1 explained 47% of the variation.

The biplot of product and flour source means versus PCA 1 scores for mouthfeel (Figure 4.4) showed relatively consistent PCA 1 scores (mean = ± 0.23) for the cultivars Gamtoos, Molen, Palmiet, Tugela and the control. The flour source Betta, appeared to contribute positively to the mouthfeel of Fruit Buns and Wholewheat Buns.

The rankings provided by the AMMI-analysis classified Tugela as being the most acceptable flour source for the production of Hamburger Buns and Standard Brown Loaves. Betta was selected as being most suitable for the production of Fruit Buns and Wholewheat Buns.

5.4.5 Taste

The variance ratios for taste (Table 4.4) also indicated dominant flour source effects, while the P/(PxS) ratio, showed that interactive effects for taste were of minor influence.

Differences among the products were insignificant. Even though the presence of fruit and a higher sugar content in Fruit Buns increased its preference slightly; the emphasis remained on differences among flour sources. Differences among flour sources indicated that the taste of products made from Tugela was preferred. Interactive effects highlighted that Betta improved the taste of Hamburger Buns, while Tugela significantly enhanced the taste of Standard Brown Loaves.

Analysis of variance by means of the AMMI model (Table 4.7) indicated a noise level of about 24% characterising the perception of taste by consumers as variable. Flour source effects were smaller (37%) when compared to visual texture of mouthfeel, while the impact of product was in the same order. Evidence of interactive effects amounted to 57%.

The biplot of product and flour source means versus PCA 1 scores for taste is presented in Figure 4.5. The control and Molen had the least influence on the determination of taste (PCA 1 scores < 0.1), while the other flour sources appeared to induce some variation. Of particular interest was the contrast between bran containing products and the buns made from a white flour base. It appeared that Tugela and Palmiet would contribute to better-tasting Wholewheat Buns, while Gamtoos and Betta would enhance the taste of Hamburger Buns.

The AMMI-rankings (Table 4.8) rated Tugela and Palmiet as being the most acceptable flour sources for the production of Standard Brown Loaves, while for all the other products, Betta and Tugela were considered most appropriate.

5.4.6 After taste

From assessment of the variance ratio for P/S calculated from the ANOVA, it appeared that the consumer panel's perception of after taste was also strongly influenced by flour source effects, while the effect of product type overshadowed the impact of interactive effects. The data pattern was therefore comparable to that observed for taste. As for taste, differences among products were insignificant, while Tugela was considered as being most acceptable over products.

Analysis of variance by means of the AMMI model (Table 4.7) indicated a noise level of about 17%. Flour source effects were also smaller (36%) when compared to visual texture and mouthfeel, while the impact of product was 6% more when compared to that of taste. Evidence of interactive effects amounted to about 68%.

The biplot of product and flour source means versus PCA 1 scores for after taste (Figure 4.6) contrasted Wholewheat Buns against the other products. In contrast with the data for taste, it occurred that Betta and Gamtoos would enhance the after taste of Standard Brown Loaves, while Tugela and Palmiet would improve the after taste of Wholewheat Buns.

Despite more variation in the selection of the top two cultivars for after taste by AMMI (Table 4.8), it appeared that the two cultivars Betta and Tugela, previously noted for their stronger dough characteristics, would improve after taste.

5.4.7 Conclusion

Assessment of data derived from ANOVA variance ratios, showed that crust colour was predominantly influenced by product choice while in all the the other characteristics genotypic variation appeared to be dominant. From the results of AMMI analysis for sensory characteristics, visual texture appeared to be the most consistent, compared to that of the other characteristics. Comparing the results of the ANOVA variance ratios with that of the AMMI analysis, it became evident that the AMMI analysis was more sensitised to detecting interactive effects.

Strong evidence of interactive effects between product and flour source were noted. Visual texture was identified as the most valuable characteristic contributing toward the selection of genotypes more suitable for the production of frozen dough products.

In the selection of flour sources suited for the production of a specific product, the flour sources Betta and Tugela featured prominently as most suitable for the production of the range of frozen dough products evaluated in this study. The flour source Gamtoos, mostly produced poorer results when compared to the other flour sources and generally reduced consumer acceptability.

A secondary aim of the study was to identify a rheological profile of flour samples suited to the production of frozen dough products. Such information could be of value to frozen dough manufacturers in the procurement of flour, or to wheat breeders in the selection of suitable wheat lines. Following, an investigation of the relationship between the rheological profiles of product and flour source acceptability was conducted by means of canonical correlation analysis.

5.5 Identification of rheological characteristics of flour suited to the production of frozen dough products

Previous studies by Van Lill *et al.* (1995) have demonstrated the use of multivariate techniques, such as canonical correlation analysis, in identifying relationships between different sets of data. A similar approach was followed to determine whether a rheological profile could be derived from the data set presented in this study.

The simple linear correlation coefficients among sensory and rheological characteristics and sensory characteristics are shown in Table 4.9. Since almost all coefficients indicated highly significant relationships, the principal tendencies were considered as those explaining at least 70% of the variation ($r \geq 0.83$).

As far as relationships among sensory characteristics were concerned, the correlation between visual texture and mouthfeel (r=0.98) verified the integrated nature of these attributes as reported by Hansen & Setser (1990) and Meilgaard *et al.* (1991). Taste in turn, related closely to texture, mouthfeel and after taste. The only correlations found among sensory and rheological characteristics were crumb colour being related to dough strength (Mixogramme Envelope area, Mixogramme tolerance, Farinograph stability and Extensograph strength), but could not be adequately explained.

Van Lill *et al.* (1995) have demonstrated that complex, interrelated data sets could not be sufficiently interpreted only by means of simple linear correlations. This finding was also applicable to this study as the interrelated nature of variables did not contribute to helpful information.

Since this study required the interpretation of two sets of data (rheological and sensory), canonical correlation analysis was considered most adequate. The data applicable to each product was separately interpreted for five rheological data packages, namely; a) digital analysis of the Mixogramme envelope, b) digital analysis of the Mixogramme midline, c) Farinograph analysis, d) analysis of a combination of data obtained from the Alveograph and BSI, and finally, e) a package containing Extensograph and BSI data. The aim was to determine which set of rheological characteristics would serve as the best predictor of the sensory quality of the various frozen dough products. An arbitrary coefficient of $\geq$0.8 was considered as indicating tendencies from which a screening procedure could be derived.

5.5.1 Hamburger Buns

Significant canonical relationships were found between rheological and sensory characteristics for Hamburger Buns (Table 4.10). The first and second canonical correlations (CC_1, CC_2) accounted for a total of 85% of the variation between rheological factors (R_1, R_2) and sensory factors (S_1, S_2). In these response domains, canonical correlations of 0.30 and 0.26 were observed between the respective canonical vectors. The extent to which an individual parameter contributed to a canonical variate is indicated by the magnitude of its canonical coefficient. Although all parameters in S_1 with the exception of after taste showed coefficients of substantial magnitude, no significant trends could be observed for the rheological coefficients. In the second response domain, longer dough development times reduced the acceptability of mouthfeel and after taste.

It was, therefore, concluded that data obtained from digital analysis of the Mixogramme envelope would be of some value in predicting sensory variation of Hamburger Buns.

The data derived from digital analysis of the Mixogramme Midline explained 58% of the variation in the first response domain (CC_1) with a canonical correlation of 0.31 between the vectors. The magnitude of the coefficient for MMD in R_1, indicated that most of the rheological variation related to doughs having a lower dough development time. The coefficients in S_1, reflected that such doughs tended to reduce the acceptability of visual texture and taste in combination with an improvement of mouthfeel and after taste. The vectors contained in CC_2 explained an additional 38% of the variation. In this domain, longer dough development times were exclusively related to an improved texture. It appeared that longer dough development times would enhance the textural characteristics of Hamburger Buns. This result aligned to previous findings (AMMI-analysis, Table 3.8), indicating a preference for the cultivars Betta and Tugela with their respective Mixogramme dough development times ranging from three to four min (Table 4.1).

It was, therefore, concluded that Mixogramme Midline Analysis would serve as the most accurate predictor of the sensory quality of Hamburger Buns, when compared to Mixogramme Envelope analysis. The preference for flour samples with a longer dough development time (>3 min), probably reflects that increased dough strength maintains the dough structure during the storage period as noted by Inoue & Bushuk (1992).

Assessment of results obtained from combinations of Farinograph, Extensograph and Alveograph and BSI data yielded no meaningful results since the canonical coefficients for rheological parameters were insignificantly low.

5.5.2 Fruit Buns

With the exception of MEA, the canonical correlations between rheological and sensory characteristics for Fruit Buns were insignificant. Data obtained from the Mixogramme Envelope Analysis explained 52% of the variation between rheological and sensory factors in the first canonical correlation (CC_1) and 25% in the second response domain (CC_2). Canonical correlations of 0.35 and 0.17 were observed between the rheological and sensory variates. Doughs with shorter development times as observed in S_1, reduced the acceptability of crumb colour, mouthfeel and after taste, while the acceptability of visual texture and taste was more approved of. In the second domain (CC_2), increased left of peak values reduced taste and enhanced after taste. These tendencies could not be explained.

Assessing the canonical coefficients for rheological parameters from Mixogramme Midline and Farinograph Analysis and combinations of Extensograph, Alveograph and BSI, data were unavailing. In the interpretation of Alveograph and BSI data, the magnitude of the canonical correlations for sensory characteristics could not be associated with any significant results from the rheological coefficients.

It was concluded that Mixogramme Envelope Analysis could be utilised to a lesser extent in predicting the sensory quality of Fruit Buns with a shorter dough development time (± 1.9 min) being less acceptable.

5.5.3 Wholewheat Buns

Accessible canonical relationships between rheological and sensory characteristics for Wholewheat Buns, were only found for Alveograph and BSI Analysis. In this response domain, canonical correlations of 0.37 and 0.15 were observed between the respective canonical vectors. The first and second canonical correlations (CC_1 and CC_2), accounted for 81% of the variation. From the assessment of the coefficients in S_1, it appeared that doughs with a higher Alveograph P/L-ratio, would enhance texture and taste, whereas crust colour, mouthfeel and after taste, were perceived less favourably. Finney *et al.* (1987), considered an Alveograph P/L ratio of 1.2 as being acceptable, while a higher P/L-ratio in the order of more than 2.0 would reflect a less extensible dough (Van Lill & Smith, 1997). Based on the results obtained in this study, it appeared that flour samples with a ratio of 1.2 – 1.9 (Table 4.1) would secure acceptable results in producing frozen doughs.

5.5.4 Standard Brown Loaves

Significant canonical relationships between rheological and sensory characteristics for Standard Brown Loaves were found for Mixogramme Midline Analysis, as well as the combination of Alveograph and BSI Analysis. A canonical correlation of 0.27 between the vectors in the first response domain of the Mixogramme Midline Analysis was observed. The variation of 62% mostly related to doughs with shorter development times. It appeared that the acceptability of visual texture, mouthfeel and taste was reduced by doughs with shorter dough development times (± 1.9 min).

Analysis of Alveograph and BSI data, accounted for 53% of the variation in the first response domain, with a canonical correlation of 0.23 between vectors. As noted for Wholewheat Buns, higher Alveograph P/L-values (1.2 – 1.9) were associated with improved mouthfeel, taste and after taste.

5.5.5 Conclusion

Little applicable information could be derived from the analysis of data by means of canonical correlations between rheological and sensory characteristics. It is possible that the inclusion of a wider range of cultivars over a range of protein contents, could improve this assessment. While most sensory parameters showed coefficients of substantial magnitude, most of the response domains yielded insignificant results.

The following guidelines in the selection of flours suited for frozen dough production were derived:

1. Data obtained from the digital analysis of the Mixogramme Midline, was preferred to that of Mixogramme Envelope Analysis.

2. Results obtained by means of the Mixograph and Alveograph, were of most value in predicting sensory variation.

3. Shorter Mixogramme dough development times ($\leq$1.9 min) reduced sensory acceptability, whereas longer dough development times (± 2.3 – 3.5 min) improved the sensory value.

4. Higher Alveograph P/L-ratios (1.2 - 1.9) were associated with improved sensory characteristics.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to determine the impact of variation in flour quality on the consumer acceptability of frozen dough products. The second aim was to identify criteria, or possibly a protocol, according to which flour types suited to the production of frozen dough products could be selected. The third objective was to identify the rheological characteristics of flours suited to the production of these frozen products. This profile could assist both the procurers of flour, as well as wheat breeders. Sensory evaluations among cultivars were related to sensory variation by means of multivariate statistical techniques such as AMMI and canonical correlation analysis.

6.1 The impact of variation in flour quality on the consumer acceptability of frozen dough products

Assessment of variance ratios derived from ANOVA, indicated genotypic effects as being mostly dominant. At this stage it could be concluded that the cultivars, Tugela and Betta, provided more acceptable results. This finding related to existing knowledge that stronger dough properties would support gas retention during freeze-thaw cycles.

Compared to results obtained through ANOVA, it appeared that AMMI was of more value in the interpretation of interactive (product x flour source) effects. This approach provide a much more user friendly, and more objective method to identify flour sources suited to the production of specific frozen dough products.

6.2 The identification of criteria, or possibly a protocol, according to which flour types suited to the production of frozen dough products could be selected

The interactive effects between product and flour source, identified visual texture as the most consistent predictor in the evaluation of products made from frozen doughs. This feature should therefore be considered as an evaluation parameter in the development of a profile for assessing the suitability of flours for frozen dough production.

Of further interest, was that bran-containing products were more susceptible to exhibiting defects. The visual texture of Wholewheat Buns and Standard Brown Loaves provided clear visual differences among cultivars when compared to the other products.

6.3 The identification of the rheological characteristics of flours suited to the production of frozen dough products

Canonical correlation analysis was found as an appropriate method to explain the relationship between variation in rheological and sensory characteristics. Even though some relationships were observed, it is likely that the inclusion of a wider range of flour types would have enhanced the validity of the information.

In the evaluation of Mixograph results by means of digital analysis, the effectivity of analysing the envelope was compared to that of analysing the midline. It was found that Midline analysis provided a more reliable result.

Besides Mixograph Midline analysis, Alveograph data was also found to be of predictive value. Of particular interest was, that longer dough development times (>2.3 – 3.5 min) and higher Alveograph P/L-ratios (>1.2 – 1.9) yielded more acceptable frozen dough products. It, therefore, appears that the combined interpretation of Mixograph and Alveograph data would be of value to the wheat breeder. Otherwise, selection on the basis of Mixograph dough development time only, could influence the perception of the dough quality profile of a breeding programme.

This study focused on qualitative differences among flour sources, implying that the variation induced by variation in protein content, was not taken into account. In view of further studies, we suggest that the sensory variation of a wider range of cultivars over protein levels be evaluated. Such a study may improve the applicability of the information derived.

It is essential that a breeder's direction of the quality profile of a breeding programme should relate to the requirements of the milling and baking industries. Most of the South African breeding programmes are aimed at the selection of genotypes suitable to eventually being baked according to the Chorleywood Breadmaking Process. This technology is compatible with softer dough features, for example, such as being exhibited by the cultivar, Molen. While a cultivar like Tugela might not be acceptable for bread-making purposes in

South Africa, it may hold commercial value for the production of frozen dough products. Considering the rapid development of the market for frozen dough products, it may be beneficial for breeders to modify their breeding strategies to accommodate niche markets.

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APPENDIX A: Frozen products survey

Frozen products survey

Thank you for taking the time to complete this questionnaire. The purpose of this survey is to investigate the acceptability of frozen dough products for use by you, the consumer.

Please circle the applicable number of each question

Age:
1. 18 - 29
2. 30 - 39
3. 40 - 49
4. > 50

☐

Gender:
1. Male
2. Female

☐

Full time occupation:
1. Student
2. Retailer
3. Foodservice / Chef / Food Education
4. Housewife
5. Other ....

☐

Which one of the following bread or bread products do you buy most often?

1. Standard brown bread
2. Whole wheat buns
3. Hamburger buns
4. Fruit buns
5. Never buy any of above

☐

Where do you usually buy your bread or bread products?

1. Local Supermarket / Café with in-store bakery
2. Local Supermarket / Café without in-store bakery
3. Bread shop / Bakery

☐

Have you ever used frozen dough bread products?

1. Yes
2. No

☐

APPENDIX B: Response sheet for the sensory evaluation of products baked from frozen dough.

Date:	
Judge no:	
Sample Code:	
Product:	

Please rate the acceptability of the product by marking (✓) in the appropriate box

	Like extre-mely	Like very much	Like mode-rately	Like slightly	Neither like or dislike	Dislike slightly	Dislike mode-rately	Dislike very much	Dislike extre-mely
Appearance: Crust colour									
Appearance: Crumb colour									
Visual appearance: product texture									
Mouthfeel when chewing									
Taste when chewing									
After taste									

Will you buy this product?	YES	NO