THE INFLUENCE OF LIPID CHANGES IN BRAN AND OFFAL ON THE BAKING PROPERTIES OF WHEATEN FLOUR

by

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The content of this thesis represents my own work and any opinion expressed in this work is my own and not necessarily that of the Cape Technikon.

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Synopsis

Bread is an important commodity in South Africa for its nutritional value and contribution to the economy. As such anything that enhances consumption of bread is of economic importance.

Variation in bread volume influences its utility value and consumer acceptance of the product. The variation of brown bread volume is much greater than that of white bread. Bakers will benefit if they could control the variation in brown bread volume since consumer studies indicate that brown bread sales could surpass that of white bread in the near future.

The baking industry uses an automated, continuous baking process that is difficult to alter. Variance of flour thus causes variance in bread volume. Flour variance is caused by the availability of suitable wheat cultivars to blend the grist, the extraction rate of the flour, the amount of bran and germ material inclusion and the amount of cake flour divided off. Although millers strive to control variation in flour quality, they must operate their mills within constraints of profitability and wheat availability.

Deregulation is only applied to bread and excludes the raw material. Since the total deregulation of bread, the fixed price structure has been abolished. Bakers can now use more expensive additives to negate any shortfalls in flour quality. This could ensure standard bread quality at a slightly higher price. The problem at this stage is that very little is known about the factors that cause variable bread volume. In most cases decreased volumes are attributed to shortfalls in protein quality and quantity and bran content.

Baking quality of brown bread flour deteriorates during storage. The deterioration is more pronounced in flour blended with bran before storage. This study centres around the effects of changing lipid composition during storage on the baking quality of the flour.

A review of the literature, with respect to the formation of gluten and the lipid-protein interactions during this process, shows that the various authors have contradictory opinions. The effects of bran and its contribution to the baking process led to even more contradictions.

The research approach of this study differed from the approach published in the literature where the researchers use a specific sample of wheat and then generalise for wheat in total. In this study the samples were selected such that variation between samples are as high as possible. The lipids were extracted as total lipid, and were not separated into various fractions. This allowed the determination of the effect of the changed total lipid content on bread volume. The separation of the different flour samples, that was necessary in the analysis of the results, indicates that one or more important parameters were absent in the design.

With this approach it was shown that the changes in total lipids are caused by enzymatic action and that total lipid profiles correlate with bread volumes. It was however impossible to generalise for all the different samples of flour.

Samevatting

Brood is 'n belangrike handelsartikel in Suid-Afrika as gevolg van sy voedingswaarde en bydrae tot die ekonomie. Derhalwe sal enigiets wat die verbruik van brood stimuleer, van ekonomiese belang wees.

Variasie van broodvolume het 'n invloed op verbruikersaanvaarding en bruikbaarheid van die produk. Die volume van bruinbrood is meer varieerbaar as die van witbrood. Bakkers sal voordeel daaruit trek indien hulle die volumevariasie van bruinbrood kan beheer aangesien verbruikersstudies aantoon dat bruinbroodverkope die verkope van witbrood in die afsienbare toekoms kan oortref.

Die bakindustrie gebruik 'n geoutomatiseerde aaneenlopende bakproses wat moeilik verander word. Variasie in meelkwaliteit veroorsaak dus 'n gepaardgaande variasie in broodvolume. Die variasie in meel word veroorsaak deur die beskikbaarheid van geskikte koring kultivars om die gruismengsel saam te stel, die ekstraksiegraad van die meel, die hoeveelheid semel en kiemmateriaal teenwoordig in die meel asook die hoeveelheid koekmeel wat afgeskei is. Alhoewel meulenaars poog om variasie in meelkwaliteit te beperk, moet hulle egter die meul binne die beperkings van winsgewendheid en koringbeskikbaarheid bedryf.

Deregulasie is slegs van toepassing op brood en sluit nie die rou-produk in nie. Vandat brood totaal gedereguleer is, is die vaste verkoopsprys afgeskaf. Bakkers kan nou duurder additiewe gebruik om die tekortkomings in meelkwaliteit te oorbrug. Dit kan 'n standaard broodkwaliteit teen 'n ietwat duurder prys verseker. Die probleem op die stadium is egter dat baie min kennis oor die faktore wat

variasie in broodvolume veroorsaak, beskikbaar is. In die meeste gevalle word verminderde volumes toegeskryf aan onvoldoende proteïen-kwaliteit of -hoeveelheid asook semelinhoud.

Die bakkwaliteit van bruinbroodmeel verswak tydens opberging. Die verswakking is erger indien die meel met semel vermeng word voor opberging. Die studie sentreer om die veranderde lipiedsamestelling tydens opberging en die effekte hiervan op die bakkwaliteit van die meel.

'n Oorsig van die literatuur met verwysing na die vorming van glutien en die lipied-proteien interaksies gedurende die proses dui daarop dat die onderskeie outeurs weersprekende opinies het. Die effek van semel en die bydrae van semel op die bakproses het verdere weersprekings tot gevolg.

Die navorsingsbenadering van die studie verskil van die benaderings wat in die literatuur gepubliseer is, waar die navorsers 'n spesifieke koringmonster gebruik en die resultaat veralgemeen vir koring in geheel. In die studie is monsters so gekies dat die variasie tussen monsters so groot moontlik is. Die vet is as totale vet onttrek en nie in fraksies geskei nie. Dit het tot gevolg gehad dat die effek van die veranderings in totale vetinhoud op broodvolume bepaal kon word. Die vereiste dat die statistiek vir die verskillende monsters afsonderlik toepas moes word, dui daarop dat belangrike parameters in die ontwerp ontbreek het.

Met die benadering is egter aangetoon dat die veranderings in die totale vetinhoud deur ensiemaksie veroorsaak word en dat die totale vet profiele goed korreleer met broodvolume. Daar kon egter nie veralgemeen word vir al die verskillende monsters nie.

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Chapter 1

Introduction

1.1 Importance of bread

Bread is an important food item in the daily diets of numerous South Africans. Many people also earn their living by working in the bread and associated businesses, including farming, milling, baking and retailing.

South African bakeries that were regulated by the Wheat Board produced 821,7 million loaves of white bread and 755,6 million loaves of brown and whole wheat breads for the 1989-1990 season. These figures exclude bread baked by supermarkets and hot bread shops who produced approximately 185,0 million loaves of bread in the same period (S A Chamber of Baking, 1991). The total number of loaves produced was 1,76 billion with a retail value of R2,5 billion. This constitutes about 1% of the gross domestic product.

Any change in the market share of bread will not only influence the profits of the retailers and bakers, but also the profits of the farming and milling communities. The growth and continued well-being of these communities therefore depend on the bread industry retaining its competitive position.

1.2 Consumers' requirements

For bread to maintain its present status in the daily diets of general consumers, their needs must be determined. Once we know more or less what is required, we must strive to produce bread that satisfies these requirements.

Bread occupies a preferential position in the cereal market for its nutritional value. Many people still largely depend on bread to supply them with their daily energy and nutritional requirements.

1.2.1 Nourishment

Bread contributes to both the energy and protein requirements of the consumer. Brown bread also contains fibre that is essential in diets.

The energy value (van Heerden, *et al.*, 1990) of brown and whole wheat bread (9,29 kJ/g) is lower than that of white bread (10,0 kJ/g) since the increased fibre of the brown bread replaces some of the protein and carbohydrate of white bread.

The lysine and tryptophan content (van Heerden, *et al.*, 1990) of a 100g portion of whole wheat bread is about 0,238g and 0,109g respectively. To obtain the entire lysine and tryptophan requirement from whole wheat bread a person has to consume about 350 g/day. This is approximately 10 slices of bread.

The energy and protein value of brown bread is somewhat lower than that of white bread. Brown bread, however serves as a source of fibre that promotes elimination of digestive waste products from the gastro-intestinal tract. Low levels of dietary fibre (Pomeranz *et al.*, 1977) increases the incidence of colonic cancer. A high fibre diet (Dagher *et al.* 1987) is also more effective than a low carbohydrate diet in a diabetic dietary regimen and to control maturity onset diabetes.

1.2.2 Brown vs white bread

The selling price of bread increased after the bread subsidy was terminated earlier this year. The previous General Sales Tax system excluded all standardised breads while the current Value Added Tax system excludes only brown and whole wheat bread. This means that the selling price of brown bread is more than 10% lower than that of white bread.

Studies by Steyn (Steyn, *et al.*, 1990a; Steyn, *et al.*, 1990b) show that the urban community prefers brown bread. This correlates with studies undertaken in the First World Countries, (Collins, 1983; Catsberg *et al.*, 1990) where increased production of brown bread is reported.

The above-mentioned information, coupled with the difference in cost and the economic situation in the country, indicates a similar South African consumer swing from white bread to brown and whole wheat bread. This places more emphasis on the quality of brown bread.

1.2.3 Bread quality

Most consumers determine bread quality by the '*pressure test*' or '*buyers squeeze test*'. White loaves (Collins, 1983) are softer, with a better springiness in comparison to brown bread. The white loaves are also more uniform in size and shape. A loaf of bread with a small volume feels heavier and firmer than a bread with a larger volume. The consumer associates firmness with staleness. This is one of the reasons for many consumers' aversion to the product.

Bread volume (Collins, 1983) is an important quality parameter that influences consumer acceptance. The volume of bread also influences its utility. Oversize loaves do not fit into standard slicing machines, nor do they fit into standard toasters or lunch boxes.

1.3 Market share

From October 1990 to April 1991 the overall sales of bread decreased 6-10%. This is ascribed to consumer resistance to the price increase experienced over the same period (S A Chamber of Baking, 1991). Variable quality as perceived by customers, as a less than consistent final product, aggravates the situation.

This resistance can be overcome by product excellence. The quality of bread is regulated by statutory requirements rather than by competition for market share.

1.3.1 Statutory requirements

South African bread production has been subjected to regulation since the establishment of the Wheat Industry Control Board in 1938 (Fowler and Priestley, 1990). Even with the deregulation of February 1991, many influences of the previous system remain.

1.3.1.1 Previous system

Legislation created the Wheat Board as a statutory body to develop and enforce a system for controlling and marketing of wheat and wheaten products. As part of this regulatory system, the Wheat Board divided South African bread into six categories (Fowler and Priestley, 1990).

The first three of these categories were the *'standardised breads'* that were government subsidised and had fixed selling prices. These subsidised breads were *white, brown and whole-wheat* bread. Only bakeries registered with the Wheat Board were allowed to produce these subsidised bread types. Most of the bakeries that produced subsidised breads are controlled by five milling groups (Fowler and Priestley, 1990).

The other three categories were *super, high protein* and *special* bread. They could be produced at any bakery, as long as the bread complied with specifications set by the Wheat Board (Fowler and Priestley, 1990).

1.3.1.2 New system

In February 1991 legislation changed to allow any bakery to produce any type of bread. Indeed, the classification scheme as sketched above, disappeared.

As a result, the role of the Wheat Board will inevitably also change. Fowler and Priestley (1990), predict that deregulation will diminish the Wheat Board's function as a controlling body. It will however still be important as a marketing body.

1.3.2 Marketing summary

South African consumers are becoming more urbanised with a concurrent rise in their social and economic status. This influences both their buying power and their freedom of choice in purchasing what they want.

For optimum utilisation of bread, volume is one quality parameter that influences consumer acceptance. The price structures can force increased usage of brown bread. Consumer awareness of health issues will promote greater usage of brown bread in preference to white bread.

The challenge is to find out which ingredients or processes influence the volume of bread, especially brown bread, and ways to solve the problem.

Chapter 2

Literature review

The industrial production process of bread is highly automated, leaving the baker limited scope for adjustment of the process after mixing. The baker can control bread quality by using either exactly the same quality flour or by adjusting the recipe.

2.1 Flour production

The quality and breadmaking potential of flour are associated with the characteristics of the wheat. The most important characteristics of the flour that are influenced by the wheat are the loaf volume that can be achieved as well as the mixing time for and water absorption of the particular flour during dough preparation (Pomeranz, 1991).

The factors that influence the quality and breadmaking potential of flour are determined by the area where wheat is produced, the specific climatic conditions, the protein content and value, and finally, the way in which the wheat is graded (Hemingway, 1985; Hemingway and Traut, 1988; Cheetham, 1990; Fowler and Priestley, 1990).

2.1.1 Milling

The miller blends various classes of wheat from the different wheat producing areas of the country. Blending is a prerequisite for milling a consistent flour (Inc. Nat. Ass. of British and Irish Millers, 1989). This wheat mixture is called a grist.

After blending, the wheat goes to the purifying and conditioning sections of the mill (Inc. Nat. Ass. of British and Irish Millers, 1989). The conditioning process controls the moisture absorption in the wheat kernel to yield a flexible bran without excessive moisture uptake by the endosperm.

After conditioning, the wheat is milled. During milling, the miller endeavours to produce good quality flour at the highest extraction rate possible.

Milling is the process of gradual separation and size reduction of the various components in the wheat (Inc. Nat. Ass. of British and Irish Millers, 1989). The combination of selected mill streams yields flour. When the miller combines all the high endosperm content mill streams to produce bread flour, the resulting flour is called '*straight run*' flour. With this method of flour production, quality of the wheat grist directly reflects in flour quality (Fowler and Priestley, 1990).

2.1.2 Flour

The composition of flour is influenced by the blending of different mill streams and the extraction rate of the flour. In South Africa, (Darby, 1990) the most common mill products are white bread flour and cake flour. The only economical way to produce the two products is by the divide method.

2.1.2.1 Divide method

The demand for cake flour in South Africa is seasonal (Cheetham, 1988; Darby, 1990). When this demand is high the miller divides a greater fraction of the higher quality endosperm off from the white bread flour to produce cake flour. This seasonal demand for cake flour causes the quality of the white bread flour to exhibit a commensurate seasonal fluctuation.

This inconsistency in quality (Vet, 1988) leads to serious problems for the baker. He has no prior knowledge of the amount of cake flour removed and therefore cannot anticipate the baking quality of the flour. This is one of the primary causes for the collapse of brown bread dough during the baking process. This leads to erratic bread volumes (Darby, 1990).

2.1.2.2 Extraction rate

The extraction rate for *straight run* white bread flour production in South Africa is 78% (Fowler and Priestley, 1990). This leaves the miller less choice for combining the desirable mill streams.

At this extraction rate, white bread flour contains a greater percentage of bran than the flours produced at lower extraction rates. Brown bread flour is produced at the mill by blending bran with white bread flour. The bran content is adjusted to between 10% and 15% as specified in the regulation (South Africa, 1988).

2.1.2.3 Bran

Bran consists of pericarp, testa and aleurone materials (Pomeranz, 1980). The addition of more than 7-10% fibre to flour causes major changes in the characteristics of bread. The bran dilutes the flour protein, causing weakening of the cell structure. Fibre cuts the gluten strands causing reduced gas retention. This

leads to the production of a smaller size bread. Addition of gluten solves these problems (Dubois, 1978).

Increasing the bran content reduces the loaf volumes (Pomeranz *et al.*, 1977; Shogren *et al.*, 1981). Up to a bran content of 5% the loaf depression is similar to the expected depression caused by dilution of the gluten proteins. At bran concentrations of 7% and higher, the reduction in bread volume is greater than the calculated reduction.

The gassing power of the dough (Pomeranz *et al.*, 1977) mixed with bran is higher than that of white bread flour. The decrease in volume caused by the addition of bran is the result of reduced gas retention rather than gas production. This is attributed to the disruptive action of the fibre on the gluten platelets.

Moder *et al.* (1984) repeated this experiment to determine the effect of bran addition on strong and mellow, hard red winter wheat. The mellow wheat gave significantly lower bread volumes with bran addition than the stronger variety. This is attributed to the dilution of the functional proteins in the bread dough.

2.1.2.4 Wheat germ in flour

during the milling process the germ which is a source of is flattened, the enzymes are lost during the process- and

Wheat germ is a source of protein, lipid and vitamins E and B. It also contains the amylases, lipid oxidase and proteases. The milling process flattens the germ with an associated release of germ oil and enzymes into the other mill fractions (Randall, *et al.*, 1989). During storage the free fatty acid level in the flour increases, with consequent decreases in bread volume (Cheetham, 1988; Randall, *et al.*, 1989).

which leads to oxidation

Analysis of brown bread flour samples show that the clean select bran is contaminated with aleurone and scutellum (Fowler and Priestley, 1990). Germ inclusion has a deleterious effect on the baking quality of the flour since flour with a high germ content yields bread with reduced volume and coarse texture (Randall, *et al.*, 1989).

By diverting some mill streams away from the flour the germ content of the final flour can be reduced with a minimum reduction in extraction rate. This would yield flour with a better bread making potential (Randall, *et al.*, 1989).

2.2 Baking technology

The protein quality and quantity are important parameters to describe the baking quality of flour. Protein content is easy to measure accurately, but protein quality is very difficult to measure (Wheatcroft, 1988; Fowler and Priestley, 1990).

All the components in the dough (Wheatcroft, 1988) contribute to the baking quality of the dough. The baker must consider the interaction of all the flour components during mixing and baking when relating protein quality to baking quality. Most of the measuring equipment available, measures the flow properties of the dough.

Bettge, *et al.* (1989) predict bread volumes accurately by using Alveograph data in combination with the amount of protein present. By using different variables for hard and soft wheat, descriptive algorithms are achieved that predict 84 to 90% of the volume variations.

2.2.1 Bread volume

The basic requirements for the bread making process (Inc. Nat. Ass. of British and Irish Millers, 1989) are the formation of a structure of gas bubbles inside the dough, the formation of a gluten network to retain the gas during expansion of the bubbles, and the presence of an active yeast to expand the gas bubbles.

All the factors (Inc. Nat. Ass. of British and Irish Millers, 1989) affecting gas production and retention in the dough will influence the final bread volume.

2.2.2 Baking

In South Africa most of the bread is produced in plant bakeries on a continuous production line (Howard, 1991). Bakers are able to adjust the ingredients used, the mixing time and the proof time to a limited extent (Vet, 1988).

2.2.2.1 Stages in breadmaking

The four main stages in breadmaking (Inc. Nat. Ass. of British and Irish Millers, 1989) are:

- During mixing of the ingredients, protein in the flour combines with water to form gluten. This forms a continuous network that binds flour particles together to form a dough.

- During dough development air bubbles are trapped in the dough. As mixing proceeds, these bubbles subdivide until the dough looks like a foam (Collins, 1988). The gluten network traps the air bubbles.

- During proofing the yeast starts to ferment the sugars in the dough and later the sugars released by enzyme action on the damaged starch granules. The products of fermentation are carbon dioxide and alcohol. The carbon dioxide mixes with the air bubbles, thereby expanding them.

- Baking the dough, sets and stabilises the expanded gluten network.

Dough preparation and development influences the final quality and volume of the bread. Baking enhances these characteristics.

2.2.2.2 Commercial baking

Approximately 30% of all the bakeries in South Africa (Howard, 1991) use the Chorleywood Bread Process (CBP) where dough ingredients are subjected to intense mixing that uses a large controlled amount of work. This process develops the dough in a couple of minutes (Collins, 1988). About 45% of the large baking plants and 15% of the small bakeries use an indigenous no-time dough system where semi-high speed spiral mixers develop the ingredients to a dough. A minimum rest (10 min) is allowed for further development assisted by chemical oxidants. Not nearly as much mechanical development is possible as in the CBP (Howard, 1991).

2.2.3 Dough additives

Bakers add some ingredients to aid the process and other ingredients to rectify problems associated with the particular flour used.

2.2.3.1 Enzymes

Alpha and beta amylase occur naturally in flour. Bread baked from flour with high amylase levels has a sticky crumb and is difficult to slice. Lack of amylase can be corrected by addition of fungal amylase. Bakers have no way to correct high amylase levels (Inc. Nat. Ass. of British and Irish Millers, 1989). South African wheat (Vet, 1988) has a shortage of cereal alpha amylase.

2.2.3.2 Oxidants

An oxidant such as potassium bromide, ascorbic acid or azodicarbonamide is added to improve the performance of flour used for the production of bread . The use of potassium bromide in bread was terminated in the UK in 1990 and indications are that Europe, Canada and the USA will terminate its use in the near future

(Dirndorfer, 1991). The oxidising agent in general use in South Africa is ascorbic acid.

The amount of oxidants used (Potgieter, 1988) depends on the quality of the flour. Flour with a low protein content requires less oxidant than a high protein flour. Flour with weak protein will require more oxidation to strengthen the protein structure than flour with a strong protein.

2.2.4 Surfactants

The characteristic property of surfactants, (MacRitchie, 1983), is that their molecules contain hydrophilic and hydrophobic parts. Inclusion of surfactants produces a dough with more numerous and smaller air cells. The smaller air cells give better gas retention properties and a fine texture in baked loaves.

Surfactants (MacRitchie, 1983) contributes to the extension of shelf-life. The surfactants (Potgieter, 1988) used most frequently in South Africa are sodium-stearoyl-2 lactylate (SSL) and diacetylated tartaric acid esters of mono- and diglycerides (DATA esters).

2.2.4.1 Gluten

In Britain, it is general practise to add dried gluten (Collins, 1988) to flour to raise the protein level of the flour. Fortification of up to one percentage point is successful in improving white bread volume. Higher gluten fortification levels will yield only slightly increased bread volumes.

For brown bread, volume improvements caused by gluten addition are only half of the improvements experienced with white bread. The improvement in brown bread volume does however continue up to four percentage points. Gluten addition changes the brown bread, from the dense to a more expanded version. This

contributed to a marked increase in sales of this type of bread in Britain (Collins, 1988).

2.2.5 Fat in bread

Fat is a *desirable* ingredient in the bulk fermentation method of bread making, while it is an *essential* ingredient in the Chorleywood Bread Process to ensure adequate bread volume (Collins, 1983; MacRitchie, 1983).

The melting points of the fat and the amount of fat added, are important in relation to the dough processing temperatures. The most important is the temperature just before the bread enters the oven. There is a natural variation in the fat requirements for different flours (Collins, 1988). The fat requirement in the dough also increases with length of storage of the flour (Collins, 1983).

Mixing, incorporates air into the dough. The surface-active compound which forms at the interface between the air and the aqueous phase is compounded of lipids and proteins. In addition to affecting the formation of gas cells during mixing lipids play an important role in subsequent punching and moulding steps (MacRitchie, 1983).

The type of lipid (Pomeranz, 1980) present in the dough influences the mixing workability of the dough. Added shortening influences dough recovery considerably. Shortening also yields a '*machine friendly*' dough, from which bread with constant volume and desirable crumb texture is produced.

A fat with a high melting point extends the action of the fat. This delays loss of carbon dioxide during baking. The most important improving effect of fat on the developed dough occurs in the final stages of proving and the initial stages of baking when the greatest stress is placed on the dough structure (MacRitchie, 1983). The fat also enhances the slicing characteristics of the bread and helps to delay onset of staleness thereby improving the keeping quality of bread (Shogren, *et al.*, 1981; MacRitchie, 1983).

2.3 Changes in flour during storage

Bread volumes (Barnes and Lowy, 1986) decrease with an increase in age of the flour. Storage of wholemeal flour (Barnes and Lowy, 1986) at 20°C has a pronounced effect on the volume of the bread baked with it. Storing the wholemeal at -20°C reduced the effect of volume reduction. For white bread flour stored at -20°C the decrease in volume is statistically insignificant at the 95% confidence level. The authors give no results for white bread flour stored at 20°C.

During the storage time (Barnes and Lowy, 1986) the hexane-extractable fat rose progressively in the wholemeal sample stored at 20°C while it remained constant in the control wholemeal sample stored at -20°C. This difference is due to the storage temperature since all the other parameters remained constant.

This experiment included the effects of storage (Barnes and Lowy, 1986) at 20°C and -20°C on the various fractions. Table 2.1 gives the results for the different pre-storage and post-storage blends.

Table 2.1: Baking performance of flour blends after storage

Flour blend and storage Temperature (°C)			Loaf volume (cm^3)
Pre-blend -20			3157
Pre-blend +20			2310
Germ	Bran	Flour	
+20	-20	-20	3123
-20	+20	-20	3014
-20	-20	+20	3067
Post-blend +20			2747

Barnes and Lowy, 1986

The pre-blend stored at 20°C gave bread volumes significantly lower than that of the pre-blend stored at -20°C. Barnes and Lowy (1986) used the different fractions stored at 20°C and -20°C to prepare various post-blends. The post-blended samples containing only one fraction stored at 20°C had associated bread volumes only slightly lower than the pre-blend stored at -20°C. In the post-blend containing

fractions stored at 20°C, these fractions caused a higher volume depression. The changes in the lipid fraction account for part of the decrease in baking quality.

Storage of brown bread flour (Barnes and Lowy, 1986) at ambient temperatures causes an accumulation of free fatty acids while no change occurred during frozen storage. Table 2.2 gives the effect of storage temperature on the various components and blends of brown bread.

Table 2.2: Composition of fractions and blends

Sample	Storage temperature (°C)	Free fatty acid (% of fat)	Free fat (%)	Loaf volume (cm^3)
Germ	-20	14,7	3,4	
Germ	+20	38,6	3,3	
Bran	-20	18,8	3,0	
Bran	+20	50,4	2,2	
Flour	-20	12,5	1,0	
Flour	+20	28,9	0,9	
Pre-blend	-20	16,7	1,5	3157
Pre-blend	+20	46,1	1,2	2310
Post-blend	+20	44,4	1,4	2747

Barnes and Lowy, 1986

The volume of the bread (Barnes and Lowy, 1986) baked with these blends display a marked difference. The fatty acid composition for the three blends are similar in all respects except for a 1% variation in the linoleic acid (18:2) content.

The variance in bread volumes are explained as due to the accumulation of fatty acids as well as an unknown interaction taking place in the flour and during the bread making process (Barnes and Lowy, 1986). No comment is made about the difference in free fat content between the blends.

Basing the reported bread volumes in Table 2.2 on a free fat content of 1% by dividing the volumes with the given free fat content yielded calculated volumes of 1925cm^3 for the pre-blend and 1962cm^3 for the post-blend, both stored at 20°C and 2105cm^3 for the pre-blend stored at -20°C. These volumes are close enough to

conclude that the free fat content in the flour is directly proportional to bread volume.

This correlates to the storage studies on wheat flour done by Shearer and Warwick (1983). They were unable to demonstrate correlation between changes in baking quality and accumulation of free fatty acids.

2.4 Lipids

All the lipids contained in the various ingredients used to make the dough, contribute to the total lipid in the dough. The ingredients that contain lipids include flour, bran, full fat soya flour and shortening (Pomeranz, 1980; Nguyen-Brem *et al.*, 1983; Morrison, 1983; MacRitchie, 1983; Hoseney, 1986).

2.4.1 Lipids in wheat

The lipids found in wheat (Hoseney, 1986) consist of many chemical classes of compounds. The distribution of the classes of compounds differ in the various anatomical parts of the wheat. Table 2.3 gives the distribution of crude fats in the wheat kernel.

Table 2.3: Distribution of crude fats in wheat kernels

Kernel fraction	% Proportion	% Crude fat
Whole grain	100,0	1,8
Bran	15,0	5,4
Pericarp	7,0	1,0
Aleurone	6,0	8,0
Endosperm	82,0	1,5
Germ	2,5	28,5

Hoseney, 1986

The bran fraction consists of pericarp, aleurone and germ. The bran, aleurone and germ fractions contain high concentrations of fat varying between 5,4 and 28,5%.

Lipids (Hoseney, 1986), vary in their fatty acid composition. This composition is more or less standard for a species of grain. Table 2.4 gives the distribution of fatty acids in wheat and its fractions.

Table 2.4: Fatty acid composition (%) of wheat lipids

Wheat	Fatty acid					
Fraction	16:0	16:1	18:0	18:1	18:2	18:3
Whole wheat						
Total	20	1	1	15	57	4
Non-polar	20	-	-	22	53	3
Polar	18	-	-	15	62	4
Bran	19	1	2	20	50	4
Germ	21	<1	2	13	55	6
Flour						
Non-starch	19	-	<2	12	63	4
Starch	40	-	<2	11	48	2

16:0=palmitic 16:1=palmitoleic 18:0=stearic
18:1=oleic 18:2=linoleic 18:3=linolenic

Hoseney, 1986

Most of these fractions show a consistent pattern, except the lipids associated with the starch fraction of the flour.

The lipids of oven dried and milled white bread dough (Nguyen-Brem *et al.*, 1983) contain about 60% linoleic acid, 26% palmitic acid, 0,7% stearic acid and 11% oleic acid.

The fatty acid profile in the gluten (Nguyen-Brem *et al.*, 1983) is 57% linoleic acid, 29% palmitic acid, 1% stearic acid and 1% oleic acid. The largest difference is in a reduced oleic acid content in gluten compared to the content in dough.

2.4.2 Flour lipids

The lipids in white flour (Pomeranz, 1980) are present in concentrations of 1,4-2,0%. Of these 0,8-1,0% are present as free lipid and 0,6-1,0% as bound lipid. The free lipid fraction consists of 0,6-0,7% non-polar lipids and 0,2-0,3% polar lipids. The bound lipid fraction consists of 0,2-0,3% non-polar lipid and 0,4-0,7%

polar lipid. The total lipids are thus evenly distributed between non-polar (50,9%) and polar lipids (49,1%).

The common definition (Hoseney, 1986) of a non-polar lipid is that material which chloroform can elute from a silicic acid column. This includes free fatty acids and triglycerides. Methanol elutes the polar lipids from the silicic acid column. The polar lipids include phospholipids and glycolipids. Whole wheat lipids contain about 70% non-polar lipids, 20% glycolipids and 10% phospholipids. The polar lipids occur mostly as bound lipids while the non-polar lipids are mostly present as free lipids.

Pericarp lipids (Morrison, 1983) consist of partial glycerides, triglycerides and sterylesters. The lipids occurring in the aleurone and germ are identical, and consist of 72-85% triglyceride and other non-polar lipids, 14-18% phospholipid and very little glycolipid. The lipid contribution of the bran to the flour blend comprises mostly of non-polar lipid.

MacRitchie (1983) reports that non-polar lipids are detrimental to the baking performance of the wheat, while polar lipids are beneficial.

This generalisation is taken to explain the reduction of loaf volume in brown bread. Bran is contaminated with germ and both the bran and the germ increase the non-polar lipid compounds.

2.4.3 Enzymes

In wheat (Galliard, 1983) lipase is associated with both the bran and germ fractions. Lipase causes de-esterification of the glycerides leading to an increase in free fatty acids with an associated decrease in triglycerides.

The lipase activity (Galliard, 1983) is seven times greater in bran and 4 times greater in germ than the activity in white bread flour. The shorter storage life of high-extraction flours is consistent with the fact that the lipid-degrading enzymes occur in the bran and germ fractions of the wheat.

Lipoxygenase in wheat catalyses the oxidation of polyunsaturated fatty acids. The enzyme oxidises free fatty acids as well as the fatty acids in mono- and triglycerides but these to a limited extent (Galliard, 1983; Hoseney, 1986). Hydrophobic surfaces readily absorb this enzyme. Lipoxygenase therefore absorbs on to the glutenin fraction of wheat proteins (Galliard, 1983). Approximately 50% (Kretovich *et al.*, 1980) of the total lipoxygenase activity in flour is present in gluten. This enzyme (Galliard, 1983) is '*self-destructive*' in dough and does not have any influence during dough making since it is inhibited by its hydroperoxide products.

2.4.4 Lipid summary

Flour contains equal amounts of polar and non-polar lipids. Polar lipids, because of their hydrophobic-hydrophilic nature, are reported to be beneficial in breadmaking (MacRitchie, 1983). Bran and germ material contain mainly non-polar lipids (Hoseney, 1986). Inclusion of this material dilutes the polar lipid fraction with consequent detrimental effects.

Flour, bran and germ material also contain lipase that catalyses de-esterification of glycerides (Galliard, 1983). The high concentration of lipase in bran explains the detrimental effect on the baking performance of pre-blended brown bread flour after storage.

2.5 Protein

During dough preparation ~~an elastic compound~~, namely gluten, forms. Gluten has the ability to form fine membranes around gas cells and to stretch as these cells enlarge during proofing.

The formation of a true lipoprotein (Marion *et al.*, 1987) such as found in membranes does not occur in gluten. Gluten is regarded as a system containing stabilised micro emulsions. The lipid vesicles embed themselves in the protein matrix, giving slip planes.

2.5.1 Gluten

Dry gluten (Khan and Bushuk, 1979) consists of 75% to 85% protein, depending on the thoroughness of washing, and 5% to 10% lipids. Occluded starch makes up most of the remainder of the dry material.

2.5.1.1 Gliadin

The gliadin group of proteins (Bietz and Wall, 1972; Khan and Bushuk, 1979) are soluble in 70% aqueous ethanol and constitute 35% to 40% of the flour proteins. Gliadin imparts the viscous component to the viscoelastic properties of gluten.

Gliadin (Bietz and Wall, 1972) has an average molecular mass of 36000 dalton. The amino acid composition has a high glutamine content which promotes hydrogen bonding in the gluten complex.

Gliadin (Bietz and Wall, 1972) also contains a high level of proline which creates kinks or bends in the polypeptide chain. This results (Khan and Bushuk, 1979) in disruption of the regular secondary structure. Contrary to expectation, gliadin proteins have compact tertiary structures similar to those of globular proteins.

2.5.1.2 Glutenin

Glutenin (Khan and Bushuk, 1979) is that fraction of the gluten proteins that is insoluble in 70% aqueous ethanol but soluble in dilute acid or alkali. It comprises 35% to 45% of the wheat endosperm proteins.

Glutenin (Khan and Bushuk, 1979) imparts the elastic component to the viscoelastic properties of gluten. The glutenin group of proteins are large molecules with an average molecular mass of millions and contain high proportions of glutamine which promotes intra- and inter-molecular hydrogen bonds.

Glutenin (Khan and Bushuk, 1979) also contains a relatively high proportion of hydrophobic amino acids. The non-polar side chains of leucine can interact with each other in an aqueous environment to form hydrophobic bonds. When many of these weak bonds form they will stabilise the glutenin aggregates.

2.5.2 Lipid-protein interactions

Dough and gluten formation (Latztity, 1980) proceed in aqueous media. The thermodynamic tendency points towards a linking of the non-polar groups with each other or with other non-polar groups like lipids. Up to a certain temperature limit, the strength of hydrophobic bonds increase with increasing temperature. The hydrophobic bonds are therefore particularly important for the thermal stability of gluten.

Decreasing the hydrophobic environment (Genot *et al.*, 1984) of the proteins by delipidation of the flour alters the lipid-protein interactions. This changes both the gluten structure and the aromatic amino acid environment.

Lipids constitute (Genot *et al.*, 1984) approximately 2% of soft wheat flour. Apolar organic solvents extract about 60% of the total lipids, directly. This fraction

constitute the so called *'free lipids'*. A part of the free lipids (Nishiyama *et al.*, 1981) change into bound lipids during gluten formation. The lipid fraction distributes itself between vesicles in the gluten and protein bound lipid.

Polar lipids, especially glycolipids bind preferentially to the gliadin proteins (Zawistowska *et al.*, 1985), whereas the non-polar lipids associate more strongly with glutenins. The extractable lipid content of dry gluten consists of equal amounts of polar and non-polar lipids (Carlson *et al.*, 1979).

The proteins of the bran consist of 31% gliadins and no glutenin (Pyler, 1982). This causes an increased ratio of gliadin to glutenin in brown bread flour. The increased gliadin produces a more viscous dough (Bietz and Wall, 1972). Increasing the amount of fat used in the recipe, reduces the viscosity (Collins, 1983).

2.5.2.1 Lipid requirement

Any change in lipid (Carlson *et al.*, 1979) will affect the lipid-water phases with subsequent drastically different functional properties of the gluten. After storage of flour, (Collins, 1983) bakers add increased amounts of fat into the dough to preserve loaf volume. It is important that the melting point of the baking fat is higher than the temperature reached by the dough at the end of the final proof (MacRitchie, 1983).

2.5.2.2 Fatty acids

Fatty acids (Latztity, 1980) affect the rheological properties of gluten. The interaction of the more strongly hydrophobic compounds with proteins, cause the relaxation time observed by the use of the longer chain fatty acids. This interaction could result in the rupture of existing hydrophobic bonds. Oleic acid causes a crumbling disintegrating gluten mass since it interacts with a preferred side chain on the proteins.

The free fatty acids (MacRitchie, 1983) are the components present in the non-polar lipid fraction responsible for loaf volume depression. Linoleic acid constitutes more than half of the free fatty acids present in wheat flour lipids. Addition of linoleic acid to defatted and intact flour depresses loaf volume significantly. The addition of sufficient lard negates this loaf volume depression.

2.5.2.3 Additives

Additives in the dough influence the composition of the lipid fractions in dough and gluten. Ascorbic acid addition depresses the amount of linoleic acid in both the gluten and the dough. Lipoxygenase causes a bigger depression of the linoleic acid level in the dough and gluten. A combination of lipoxygenase and lipase have the greatest effect on the linoleic acid in the dough and gluten, but do not affect the other fatty acids (Nguyen-Brem *et al.*, 1983).

2.6 Literature summary

Bread volume is an important quality parameter that influences consumer acceptance of the product. Bread volume is influenced by the method of flour production, the protein content of the flour and baking. Control of the bran content, the presence of wheat germ material, the amount of cake flour divided off during milling and the quality of the protein will benefit the baker.

During breadmaking operations the protein content can be altered by gluten additions. Addition of oxidants and surfactants improve proper dough development. The amount of bran present influences the mixing time, water absorption, gassing power and gas retention of the dough. Notice must also be taken of the lipid composition of the flour to ensure the addition of the right amount and type of fat to ensure maximum stability of gluten during baking.

Changes taking place in flour lipids during storage have a significant influence on bread volume. Enzymatic activity in the flour during storage affects the bread making potential of the flour. The contribution of the bran content to these changes is significant.

Flour contains equal amounts of polar and non-polar lipids (Pomeranz, 1980). Polar lipids, because of their hydrophobic-hydrophilic nature, are reported to be beneficial in breadmaking (MacRitchie, 1983). Bran and germ material contains mainly non-polar lipids (Morrison, 1983). Inclusion of this material dilutes the polar lipid fraction with consequent detrimental effects.

Flour, bran and germ material also contain lipase that catalyses de-esterification of glycerides (Galliard, 1983). The high concentration of this enzyme in bran explains the detrimental effect on the baking performance of pre-blended brown bread flour after storage (Barnes and Lowy, 1986; Cheetham, 1988). The enzyme has the ability to catalyse the formation of non-polar lipids from the polar lipids thereby increasing the non-polar lipid content with an associative decrease in polar lipid content (Galliard, 1983).

Bran contains only gliadins (Pyler, 1982). Polar lipids associate with gliadin while non-polar lipids associate with glutenin (Nishiyama *et al.*, 1981; Latztity, 1980; Zawistowska *et al.*, 1985). The polar lipid requirement of brown bread dough is thus enhanced.

Addition of non-polar fat improves the baking quality of the dough (Pomeranz, 1980; MacRichie, 1983; Collins, 1983). The added fat binds preferentially to the glutenin (Nishiyama *et al.*, 1981; Latztity, 1980; Zawistowska *et al.*, 1985). Non-polar lipids in flour are detrimental to the baking performance (MacRichie, 1983).

The contradictory aspects of the detrimental or beneficial aspects of polar and non-polar lipid composition influenced the design of the experiment described in

Chapter 3. In the experiment the lipid was extracted as total lipid with no fractionation.

Chapter 3

Experimental objectives and design

3.1 Objectives

Industrial bread making recipes contain more lipid in the flour and bran than the fat added as shortening. The literature is contradictory as to the effects of polar and non-polar lipids on baking performance (Pomeranz, 1980; MacRichie, 1983; Collins, 1983; Nishiyama *et al.*, 1981; Latztity, 1980; Zawistowska *et al.*, 1985). Because of this, it was decided to study the changes in the *total lipid* composition of flour and bran during storage.

The primary objective was to determine if changes in the fatty acid composition of the flour and bran have significant interaction with bread volume. The statistical significance of changes in fatty acid composition in the flour and bran fractions on bread volume were therefore calculated.

The secondary objective was to determine whether the lipid changes were caused by enzymatic action. The literature abounds with references to the effects of natural enzymes on lipids (Hoseney, 1986; Galliard, 1983; Kretovich *et al.*, 1980). These enzymes occur in both the flour and the bran. Since bran constitutes only a small percentage of brown bread flour, its contribution to the total enzyme content of the flour is limited. The reduced baking performance of brown bread flour after

storage can therefore not be explained by enzymes only. Oxidative changes during storage must also be taken into account.

3.2 Design

Flour samples with the highest possible variation between them were used. To achieve this the flour samples were obtained from two different companies in different geographical locations. This was done in an attempt to reach valid generalisations.

Bran samples were taken on the same day with the flour samples. Half of the bran samples were treated such that their enzymes were denatured. The changes in the brown bread flour mixed with untreated bran could thus be checked against a blank brown bread sample.

The samples were stored in paper bags with no barrier properties to allow free transfer of oxygen. They were also stored at ambient temperature to allow maximum enzyme action. The trial experiment showed that pre-storage mixing of the brown bread flour gave the greatest changes. For subsequent experiments only pre-storage mixing were used.

The total lipid content of each of the samples were extracted from them after one or two weeks storage and again after ten weeks storage.

On the same day that the lipids were extracted, baking tests were performed. The samples used in the baking tests and for extraction were therefore similar. Direct correlation of the lipid analyses and baking results were possible.

During the initial design phase it was assumed that the changes in fatty acid profiles would be similar for all the samples. This would lead to a decrease in the

unsaturated long chain fatty acids with an associative increase in short chain fatty acids. Correlation of these changes with bread volume should be high.

Preliminary results indicated that this was the wrong assumption and a more powerful statistical technique namely multivariate regression analysis had to be used.

3.3 Materials

Five normal production run flour samples were taken such that the grists were different for each sample. Three of the samples were taken at a mill in Paarl and two at different mills in Johannesburg. The three Paarl samples varied in extraction rate and treatment. This was done to ensure variation in flour quality due to mill settings, grist composition, extraction rate, oxidative treatments and geographical wheat availability.

Three different samples of bran and offal were collected at the same time that the flour samples were taken. The bran and offal samples were identical to that used to blend with the white flour to produce brown bread flour. The bran samples were split into two fractions. One fraction was heat treated in an oven at 80°C for four hours. Nearly all enzymes are irreversibly destroyed by heating to 80°C (Sumner and Somers, 1943). Any lipid changes in the heat treated bran samples and blends after storage were caused by lipase and lipoxidase in the flour or oxidation by air.

Baking tests were done on white flour and flour containing either 10% untreated or 10% treated bran. This was repeated after ten weeks storage.

The pilot experiment was done with 78% extraction rate flour from the Paarl mill where the flour was oxidised with chlorine dioxide at 25 mg/kg. The effects of pre-storage and post-storage blending of the flour was included in this experiment. The samples were analysed after one and ten weeks storage. All the analyses for

this experiment were done in duplicate. Results from this experiment were used to alter the design for the rest of the samples.

The subsequent two experiments were done on Paarl and Johannesburg samples. The Paarl samples were bread flour and cake flour of 78% and 72% extraction rate respectively. One bran sample was taken at the same time. The Johannesburg samples were 78% extraction rate bread flour, taken at Newtown and Isando mills. One sample of bran was taken at the Newtown mill. This was used for both the flours to prepare the blends. In this experiment only pre-storage blending was used. These samples were analysed after two and ten weeks storage. Lipid extraction was done on single samples. All the other analyses were done in duplicate.

3.4 Methods

3.4.1 Baking tests

The baking tests of the Paarl samples were done at a local test bakery in Paarl and the Johannesburg samples were test baked in a test bakery in Newtown. The basic recipes used are similar in most respects although the proofing time for the two methods are different. Table 3.1 lists the recipes.

Table 3.1: Breadbaking recipes

Ingredient	Paarl	Newtown
Flour	100,0	100,0
Water	57,0	60,0
Yeast	2,2	2,2
Salt	2,0	2,0
Sugar	1,0	1,8
Shortening	0,25	0,20
SSL	0,20	0,30
Soya flour	0,20	0
Mould inhibitor	0,10	0,23
Ascorbic acid	Yes	Yes
Alpha amylase	Yes	No

Table 3.2 lists the fatty acid composition of the shortening used in the two methods.

Table 3.2: % Fatty acid composition of the shortenings used

Fatty acid	Paarl	Newtown
Lauric (12:0)	0,0	5,5
Myristic (14:0)	6,0	5,5
Palmitic (16:0)	20,0	17,0
Palmitoleic (16:1)	9.0	6,0
Stearic (18:0)	9.0	12,0
Oleic (18:1)	16,0	33,0
Linoleic (18:2)	5,0	2,0
Higher fatty acids		
Saturated	7,0	3,2
Unsaturated	14,0	7,2
Poly-unsaturated	14,0	6,0

The proof time for each test is given in the tables of results. For the Paarl samples proof height and total loaf height were measured at the highest point on the loaf. Oven spring was calculated as the difference between loaf height and proof height. Total volume was measured with seed displacement.

For the Johannesburg samples only final volume was measured since the test bakery was not equipped to do proof height and oven spring.

3.4.2 Lipid extraction and analysis

Total lipid extraction was done on the same day as the different baking tests. Samples of the flour, flour blends and bran were extracted to determine the fatty acid profiles of the samples.

The lipids were extracted according to the method of Folch as quoted by Davidson *et al.* (1986). The fatty acid methyl esters were prepared according to the method of Moscatelli as quoted by Davidson *et al.* (1986) using boron trifluoride: methanol.

A 1 micro litre sample was applied to a 6 m x 2,5 mm inside diameter stainless steel chromatography column. The packing material for the column was Chromosorb WP 100/120 mesh containing 10% SP 2330 as stationary phase. Helium was used as carrier gas. The gas chromatograph used was a Varian 4270

with a flame ionisation detector. It ran isothermally at 195°C, with the detector and injector temperatures set at 225°C.

3.4.3 Statistical analysis

The first statistical analyses were done using correlation coefficients. The correlation coefficient (R) is an index of linear relationship between two variables (McCuen, 1985). Bread volume was used as dependent variable in all cases. The fatty acids were used as independent variables. Since correlation coefficients between individual fatty acids and bread volume was found to be low, a more powerful analytical technique had to be used.

The first test considered was analysis of variance (ANOVA). This test is a comparison of means (McCuen, 1985). For multiple comparisons the null hypothesis is rejected if at least one pair of group means are unequal (McCuen, 1985). Since the samples were selected for high variation, this test was not suitable.

Multivariate regression analysis is a method of obtaining a set of coefficients for an equation and it can be used to assess the relative importance of predictor (independent) variables (McCuen, 1985). Bettge *et al.* (1989) used this method to predict bread making properties of wheat.

Multivariate regression analysis was then performed. The coefficient of determination, R^2, is equal to the percentage of variance in the criterion variable (bread volume) that is explained by the predictor variable (fatty acids). R^2 is therefore a meaningful indicator of the accuracy of predictions (McCuen, 1985).

Chapter 4

Experimental Results and Discussion

Results are presented in chronological order to allow the reader to follow the observations and conclusions, as well as the reason for the ensuing analyses.

4.1 Baking tests

4.1.1 Paarl oxidised bread flour

The first test bake results were for the Paarl oxidised bread flour. Samples of pre- and post-storage mixing of the brown bread flour were included. Table 4.1 lists the results obtained in this baking test.

Table 4.1: Paarl oxidised flour: baking results

Measurements	POX[a]	POX+B[b]	POX+TB[c]
Week 1			
Proof time = 60 minutes			
Proof height (mm)	136	130	130
Oven spring (mm)	18	7	4
Total height (mm)	154	137	134
Volume (cm^3)	3350	3000	2956

Mixed		pre-storage		post-storage	
Measurements	POX[a]	POX+B[b]	POX+TB[c]	POX+B[b]	POX+TB[c]
Week 10					
Proof time = 70 minutes					
Proof height (mm)	121	120	122	121	125
Oven spring (mm)	-6	-8	-12	-7	-13
Total height (mm)	115	112	110	114	112
Volume (cm^3)	2492	2467	2467	2492	2530
Proof time = 85 minutes					
Proof height (mm)	136	137	140	129	140
Oven spring (mm)	-3	-15	-13	-9	-10
Total height (mm)	133	122	127	120	130
Volume (cm^3)	2930	2780	2897	2680	2917

a POX = Paarl oxidised white bread flour
b B = Bran
c TB = Heat treated bran

Differences between the week 1 results and the week 10 results were calculated, for pre- and post-storage flour blends. Table 4.2 contains these results.

Table 4.2: Differences between week 1 and week 10 results

Mixed		pre-storage		post-storage	
Measurements	POX[a]	POX+B[b]	POX+TB[c]	POX+B[b]	POX+TB[c]
Proof time = 70 minutes					
Proof height (mm)	15	10	8	9	5
Oven spring (mm)	24	15	16	14	17
Total height (mm)	39	25	24	23	22
Volume (cm^3)	858	533	489	508	426
Proof time = 85 minutes					
Proof height (mm)	0	-7	-10	1	-10
Oven spring (mm)	21	22	17	16	14
Total height (mm)	21	15	7	17	4
Volume (cm^3)	420	220	59	320	39

a POX = Paarl oxidised white bread flour
b B = Bran
c TB = Heat treated bran

The oven spring for all the samples baked after 10 weeks storage were negative. The longer proof time made a considerable difference in the total height of the various loaves with a corresponding improvement of loaf volume. Pre-storage mixing of the flour and treated bran caused a diminished effect on the bread volume depression with proof times of 85 minutes. The effects of the treatment of the bran with 70 minutes proof times showed improvement only with post-storage blending.

4.1.2 Paarl Standard and Cake Flour

Table 4.3 lists the results obtained from the SASKO baking tests on the standard bread flour (STD) and the cake flour (CF). Proof times for week 2 were 60 minutes and 70 minutes for week 10.

Table 4.3: Paarl standard and cake flour: baking results

Measurements	STD[a]	STD+B[b]	STD+TB[c]	CF[d]	CF+B[b]	CF+TB[c]
Week 2						
Proof height (mm)	125	126	115	119	118	117
Oven spring (mm)	7	2	1	18	12	11
Total height (mm)	132	128	116	137	130	128
Volume (cm^3)	3175	3075	2912	3225	3065	3025
Proof height (mm)	123	119	117	122	120	117
Oven spring (mm)	8	8	6	18	10	12
Total height (mm)	131	127	123	140	130	129
Volume (cm^3)	3100	2987	2912	3275	3087	3050
Week 10						
Proof height (mm)	120	119	121	123	122	121
Oven spring (mm)	4	0	2	7	3	5
Total height (mm)	124	119	123	130	125	126
Volume (cm^3)	2850	2775	2852	3000	2950	2950
Proof height (mm)	122	119	122	125	123	121
Oven spring (mm)	6	3	1	5	4	0
Total height (mm)	128	122	123	130	127	121
Volume (cm^3)	2962	2800	2837	2962	2925	2850

a STD = Paarl standard white bread flour
b B = Bran
c TB = Heat treated bran
d CF = Paarl cake flour

The differences between week 2 and week 10 baking results were calculated. Table 4.4 lists the results.

Table 4.4: Average differences between week 2 and week 10 results

Measurements	STD[a]	STD+B[b]	STD+TB[c]	CF[d]	CF+B[b]	CF+TB[c]
Proof height (mm)	3,0	3,5	-5,5	-3,5	-3,5	-4,0
Oven spring (mm)	2,5	3,5	2,0	12,0	7,5	9,0
Total height (mm)	5,5	7,0	-3,5	8,5	4,0	5,0
Volume (cm^3)	231,5	243,5	67,5	269,0	138,5	137,5

a STD = Paarl standard white bread flour
b B = Bran
c TB = Heat treated bran
d CF = Paarl cake flour

The influence of the storage time was less, but still significant. For the standard flour, a slight decrease of volume after storage for brown bread baked with heat treated bran was observed. The volume of these breads compared favourably with the volumes of white bread baked with the same flour after storage.

The bread volume achieved with the cake flour are slightly higher for the breads baked with cake flour blended with bran than the volumes achieved for bread baked with bread flour blended with bran. After storing the flour samples, very small differences in the volumes achieved by the different cake flour samples were observed.

4.1.3 Johannesburg, Newtown and Isando flours

Table 4.5 lists the volumes of bread achieved with the recipe of the Newtown test bakery. The flour was milled at the Isando (ISAN) and Newtown (NEW) mills. The week 2 samples were proved for 30 minutes and the week 10 samples for 45 minutes.

Table 4.5: Isando and Newtown baking results

Sample	Week 2 Volume (cm^3)	Week 10 Volume (cm^3)	Average Difference
NEW[a]	3403	3405	16,5
NEW	3410	3375	
NEW+B[b]	2988	3092	-118,5
NEW+B	3038	3171	
NEW+TB[c]	3008	3142	-64,5
NEW+TB	3077	3072	
ISAN[d]	3434	3508	-64,5
ISAN	3443	3498	
ISAN+B[b]	3053	3020	37,5
ISAN+B	3097	3055	
ISAN+TB[c]	3088	3083	15,5
ISAN+TB	3087	3061	

a NEW = Newtown white bread flour
b B = Bran
c TB = Heat treated bran
d ISAN = Isando white bread flour

The volumes of the bread baked from white bread flour were higher than that achieved with brown bread flour in all cases. The brown breads baked with the Newtown samples had significantly higher volumes after storage. Differences between the volumes for brown bread baked with normal and treated bran after storage were small.

For the Isando samples, the differences between the week 2 and week 10 samples, were also very small in all respects.

4.2 Fatty acid analysis

All the fatty acids were expressed as a percentage of the total amount of fatty acids present. The total lipid content of the samples were extracted, so no distinction was made between free fatty acids or fatty acids from polar or non-polar lipids.

4.2.1 Paarl oxidised flour fatty acids

Table 4.6 gives the fatty acid composition of the fat in the Paarl oxidised flour samples (POX).

Table 4.6: Paarl oxidised flour fatty acids

Sample	16:0	18:0	18:1n9	18:2n6
Week 1				
Bran (B)	0,0	26,25	3,95	69,8
Treated bran (TB)	0,0	26,2	4,0	69,8
POX	21,25	0,0	9,1	69,75
POX+B	18,8	2,6	9,2	69,4
POX+TB	19,13	2,62	8,59	69,76
Week 10				
Bran (B)	0,1	18,9	11,05	70,05
Treated bran (TB)	0,0	27,0	3,9	69,1
POX	20,65	0,0	10,55	68,9
POX+B[a]	18,59	1,89	10,60	69,02
POX+B[b]	18,8	1,9	11,0	68,3
POX+TB[a]	18,59	2,7	9,89	68,92

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid
a mixed post-storage
b mixed pre-storage

For the untreated bran a decrease in stearic acid with an associated increase in oleic acid was observed after storage. These changes were absent in the treated bran sample.

The white bread flour sample gave a smaller increase in oleic acid with associated decreases in both palmitic and linoleic acid. The oleic acid in the white bread flour mixed with treated bran after storage, changed in the same ratio as the changes that occurred in the white flour.

The white bread flour mixed with untreated bran, had different fatty acid profiles for the samples mixed before and after storage. In the sample mixed before storage, all the changes were larger. Both the stearic and linoleic acid levels decreased with an associated increase in oleic acid.

4.2.2 Paarl standard and cake flour fatty acids

The brown bread flour samples were mixed before storage. Table 4.7 gives the fatty acid analysis for the Paarl standard (STD) and cake flour (CF).

Table 4.7: Fatty acid analysis for Paarl STD and CF flours

Sample	16:0	18:0	18:1n9	18:2n6
Week 2				
Bran (B)	0,0	24,8	5,6	69,6
Treated bran (TB)	0,0	25,4	4,5	70,1
STD	22,1	0,0	9,6	68,3
STD+B	18,2	5,3	7,5	69,0
STD+TB	17,5	5,5	8,1	68,9
CF	21,1	0,0	9,4	69,5
CF+B	17,7	5,4	7,8	69,1
CF+TB	17,1	5,7	7,9	69,3
Week 10				
Bran (B)	0,0	19,7	9,2	71,1
Treated bran (TB)	0,0	22,6	4,0	73,4
STD	20,7	0,0	10,1	69,2
STD+B	17,7	3,7	9,2	69,4
STD+TB	17,9	5,1	8,0	69,0
CF	23,3	0,0	9,2	67,5
CF+B	17,9	3,6	9,4	69,1
CF+TB	17,6	5,4	7,8	69,2

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid

Results similar to those obtained in table 4.6, for the treated and untreated bran fractions were observed.

The oleic and linoleic acid levels increased in the standard flour sample, with an associated decrease in palmitic acid. Increases in both the oleic and linoleic levels in the standard flour, mixed with untreated bran were observed. The profile in the sample mixed with treated bran, indicated a slight increase in palmitic acid with an associated decrease in stearic acid.

The palmitic acid increased in the cake flour with associated decreases in both oleic and linoleic acid. In the cake flour sample mixed with untreated bran, the oleic acid level increased, with an associated decrease in stearic acid. For the sample mixed

with treated bran, an increase in palmitic acid with associated decreases in stearic, oleic and linoleic acid was observed.

4.2.3 Johannesburg samples fatty acids

Table 4.8 contains the fatty acid analysis for the Newtown (NEW) and Isando (ISAN) samples.

Table 4.8: Fatty acid analysis for NEW and ISAN samples

Fatty acid	16:0	18:0	18:1n9	18:2n6
Week 2				
Bran (B)	0,0	24,8	5,0	70,2
Treated bran (TB)	0,0	24,7	4,6	70,7
NEW	21,7	0,0	9,8	68,5
NEW+B	17,1	5,2	7,6	70,1
NEW+TB	17,3	5,6	8,0	69,1
ISAN	20,8	0,0	9,6	69,6
ISAN+B	17,5	6,3	8,2	68,0
ISAN+TB	17,4	6,4	7,9	68,3
Week 10				
Bran (B)	0,0	19,9	9,9	70,2
Treated bran (TB)	0,0	23,9	4,9	71,2
NEW	21,9	0,0	9,6	68,5
NEW+B	17,4	3,0	10,7	68,9
NEW+TB	17,9	5,8	8,1	68,2
ISAN	21,2	0,0	9,6	69,2
ISAN+B	17,2	3,4	10,2	69,2
ISAN+TB	17,8	5,4	7,6	69,2

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid

For the untreated bran sample, the amount of oleic acid increased with an associated decrease in stearic acid. For the treated bran sample, the oleic and linoleic acid levels increased with an associated decrease in stearic acid. These changes were small.

The Newtown white flour fatty acid profile changed very slightly during storage. Addition of untreated bran to this sample, caused an increase in oleic acid, with associated decreases in stearic and linoleic acid, during storage. Addition of treated

bran to the flour, caused increases in palmitic, stearic and oleic acid with an associated decrease in linoleic acid, during storage.

The fatty acid profile in Isando white flour changed very little during storage. A slight increase in palmitic acid was observed with an associated decrease in linoleic acid. Addition of untreated bran to this flour caused increases in oleic and linoleic acid with associated decreases in palmitic and stearic acid, during storage. Mixing the flour with treated bran caused increases in palmitic and linoleic acid with associated decreases in stearic and oleic acid.

4.2.4 General observations about the fatty acids

From tables 4.6, 4.7 and 4.8, distinct differences between the fatty acid profiles of the untreated and treated bran samples after 10 weeks storage were observed. In the untreated bran samples the oleic acid increased perceptively with associated decreases in stearic acid. There was very little change in the heat treated bran samples.

The experimental design was such that the only difference between the treated and untreated bran samples were in their enzyme activity. The enzyme systems in the flour were active. Oxygen permeation through the storage bags were possible. ***Through elimination it was shown that the changes that occurred in the bran and flour blends are caused by enzymes situated in the bran fraction.*** The observed changes were not catalysed by lipase or lipoxygenase. The observed decrease in stearic acid with associated increased oleic acid levels is a new finding with significant consequences. It is however not described in any of the cereal literature. ***Some hereto unknown de-saturase system was responsible for these changes.*** The exact nature of this enzyme system is beyond the scope of this work. This is a topic that should be studied later.

These changes were smaller in the flour blends. There were however distinctive differences between the flour blended with treated bran and untreated bran. In the

flour samples blended with bran the oleic acid increased with associated decreases in stearic acid. In the flour samples blended with treated bran the changes in the oleic and stearic acid levels were less obvious. For all the samples the levels of palmitic and linoleic acid were affected by storage time to a lesser degree.

4.3 Statistical analysis

4.3.1 Phase 1: Raw data

The first analysis was done using all the results. Correlation analysis between individual fatty acids and bread volume were done to determine if any fatty acid shows dominant correlation with bread volume. The results are given in table 4.9.

Table 4.9: Correlation of each fatty acid and bread volume

Fatty acid	Correlation coefficient
C16:0	0,4005
C18:0	0,2995
C18:1n9	0,0157
C18:2n6	0,6036

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid
d.f. = 55 $P_{.01}$ = 0,340 $P_{.05}$ = 0,262

For palmitic and linoleic acid the correlations were significant at 99% level. Stearic acid was significant at 95% level. The oleic acid was not significant. In the next analysis the Paarl and Johannesburg groups of data were separated. Table 4.10 gives the results for the Johannesburg group of samples.

Table 4.10: Johannesburg samples: Correlation coefficient of each fatty acid vs. volume

Fatty acid	Correlation coefficient
C16:0	0,9531
C18:0	0,9056
C18:1n9	0,5271
C18:2n6	0,0000

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid
d.f. = 22 $P_{.01}$ = 0,515 $P_{.05}$ = 0,404

The correlation coefficients, between palmitic and stearic acid and bread volume, were very good. The result of no correlation between linoleic acid and bread volume was suspect since MacRichie (1983) states that linoleic acid depresses bread volume significantly. A negative correlation was therefore expected.

The Paarl samples did not follow the same pattern. Table 4.11 gives the correlation coefficient for the Paarl samples.

Table 4.11: Paarl samples: Correlation coefficient of each fatty acid vs. volume

Fatty acid	Correlation coefficient		
	Volume	Proof height	Oven Spring
C16:0	0,2876	0,3239	0,2173
C18:0	0,0970	0,4225	0,0436
C18:1n9	0,3682	0,3960	0,4175
C18:2n6	0,0592	0,0332	0,1603

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid
d.f. = 31 $P_{.01}$ = 0,437 $P_{.05}$ = 0,339

All these correlation coefficients were different for the individual fatty acids as those presented in table 4.10. All these coefficients were low. The next step was to separate the various Paarl samples and to repeat the analysis. Table 4.12 gives the results for this correlation analysis.

Table 4.12: Paarl samples: Separate correlations

Fatty acid	Correlation coefficient		
	Volume	Proof height	Oven Spring
Paarl oxidised samples (POX)			
C16:0	0,4112	0,1995	0,6042
C18:0	0,1817	0,0332	0,3336
C18:1n9	0,6601	0,3055	0,6925
C18:2n6	0,6699	0,1612	0,8543
d.f. = 7 $P_{.01}$ = 0,798 $P_{.05}$ = 0,666			
Paarl standard samples (STD)			
C16:0	0,6513	0,5559	0,6378
C18:0	0,3768	0,4118	0,4917
C18:1n9	0,0436	0,4899	0,2659
C18:2n6	0,3332	0,6322	0,5667
d.f. = 10 $P_{.01}$ = 0,708 $P_{.05}$ = 0,576			
Paarl cake flour samples (CF)			
C16:0	0,2871	0,6206	0,1857
C18:0	0,4334	0,5992	0,3056
C18:1n9	0,2540	0,6348	0,1136
C18:2n6	0,3332	0,6322	0,3673
d.f. = 10 $P_{.01}$ = 0,708 $P_{.05}$ = 0,576			

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid

The correlation coefficients in table 4.12, indicated variation of specific fatty acids with volume, proof height and oven spring. Splitting of the Paarl group into the three different flours resulted in greater confusion about the effect of a particular fatty acid on bread volume.

The next trial was to split the Paarl samples into a before storage group and an after storage group. Table 4.13 lists the analysis for these groups.

Table 4.13: Paarl samples: Two groups

Fatty acid	Correlation coefficient		
	Volume	Proof height	Oven Spring
Before storage			
C16:0	0,7113	0,5237	0,3838
C18:0	0,7320	0,5550	0,4750
C18:1n9	0,6185	0,3921	0,4134
C18:2n6	0,1772	0,3870	0,4085
d.f. = 15	$P_{.01}$ = 0,606	$P_{.05}$ = 0,482	
After storage			
C16:0	0,2161	0,1503	0,2553
C18:0	0,0566	0,2526	0,0283
C18:1n9	0,4243	0,3750	0,4831
C18:2n6	0,2975	0,1676	0,5206
d.f. = 18	$P_{.01}$ = 0,561	$P_{.05}$ = 0,444	

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid

The results in table 4.13 indicated a pattern similar to that of the Johannesburg samples (table 4.10) for the fresh samples, although the correlation coefficients were not as high for palmitic and stearic acid against volume. The pattern was however completely different for the samples after storage. The results showed no significant linear relationship between any fatty acid and bread volume in the after storage samples.

The changes in lipid composition of the different flours are directly dependent upon the flour. The problem was re-examined. Flour contributes to the total lipid in the dough but the other ingredients also contribute some lipids and should therefore be included in the design.

4.3.2 Phase 2: Total fatty acids in the dough

The total fatty acids in the dough had to be calculated, since no lipid extraction of the dough was done. For the calculations only the palmitic, stearic, oleic and linoleic acids, were considered since only these are present in the flour. Tables of fatty acid data and composition were used to calculate the contribution of full-fat soya flour. Table 4.14 gives the calculated fatty acid composition in gram of the various dough mixtures.

Table 4.14: Fatty acid composition in dough

Sample	C16:0	C18:0	C18:1n9	C18:2n6
Before storage	g	g	g	g
STD	2,252	0,142	1,142	6,189
STD+B	2,325	0,726	1,129	7,819
STD+TB	1,992	0,748	1,195	7,808
CF	1,795	0,142	0,960	5,078
CF+B	1,991	0,652	1,039	6,742
CF+TB	1,935	0,681	1,048	6,761
POX	2,178	0,142	1,098	6,316
POX+B	2,425	0,429	1,250	7,900
POX+TB	2,424	0,429	1,250	7,907
NEW	2,070	0,138	1,226	5,939
NEW+B	2,056	0,704	1,207	7,651
NEW+TB	2,078	0,748	1,251	7,542
ISAN	1,992	0,138	1,209	6,034
ISAN+B	2,100	0,824	1,272	7,422
ISAN+TB	2,089	0,835	1,240	7,455
After storage				
STD	2,130	0,142	1,186	6,268
STD+B	2,270	0,550	1,316	7,863
STD+TB	2,292	0,704	1,184	7,819
CF	1,950	0,142	0,946	4,938
CF+B	2,010	0,482	1,190	6,742
CF+TB	1,982	0,652	1,039	6,752
POX	2,125	0,142	1,225	6,241
POX+B	2.369	0,351	1,470	7,818
POX+TB	2,369	0,440	1,393	7,810
NEW	2,087	0,138	1,209	5,939
NEW+B	2,089	0,465	1,544	7,520
NEW+TB	2,144	0,769	1,261	7,444
ISAN	2,027	0,138	1,209	5,999
ISAN+B	2,067	0,508	1,490	7,553
ISAN+TB	2,133	0,726	1,207	7,553

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid

For the next analysis correlation coefficients between the gram mass of individual fatty acids in the dough and bread volume were calculated. Table 4.15 gives the correlation coefficients for the various combinations of samples.

Table 4.15: Correlation coefficients of each fatty acid mass with volume for various combinations of samples

	Fatty acids			
Sample	**C16:0**	**C18:0**	**C18:1n9**	**C18:2n6**
Combined	0,4334	0,3068	0,2227	0,4900
Johannesburg	0,5692	0,9057	0,3453	0,9703
Paarl	0,4204	0,1278	0,6972	0,4665
POX	0,1120	0,1855	0,6853	0,2404
STD	0,1269	0,3771	0,7643	0,5228
CF	0,8409	0,4331	0,4792	0,4807
Combined	d.f. = 55	$P_{.01}$ = 0,340	$P_{.05}$ = 0,262	
Johannesburg	d.f. = 22	$P_{.01}$ = 0,515	$P_{.05}$ = 0,404	
Paarl	d.f. = 31	$P_{.01}$ = 0,437	$P_{.05}$ = 0,339	
POX	d.f. = 7	$P_{.01}$ = 0,798	$P_{.05}$ = 0,666	
STD	d.f. = 10	$P_{.01}$ = 0,708	$P_{.05}$ = 0,576	
CF	d.f. = 10	$P_{.01}$ = 0,708	$P_{.05}$ = 0,576	

16:0 Palmitic acid 18:0 Stearic acid
18:1n9 Oleic acid 18:2n6 Linoleic acid

Each flour investigated (table 4.15) has a particular combination of fatty acids that correlates significantly with bread volume. However, no single set of fatty acids prevails for all flours.

With reference to the work of Bettge *et al.* (1989) it was decided to use multivariate regression.

4.3.3 Phase 3: Multivariate regression

Comparing the values in table 4.15, to the values in tables 4.9 to 4.13, the correlation coefficients improved noticeably. Since none of the fatty acids showed dominant correlation with bread volume, multivariate regression analyses of the gram content of all the fatty acids in the dough against volume were done. Table 4.16 gives the correlation coefficients (R) and coefficients of determination (R^2) for the multivariate analyses.

Table 4.16: Correlation for multivariate analysis

Sample	R	R^2	d.f.	Constant
Combined	0,5402	0,2918	52	4210,791
Paarl	0,7918	0,6269	28	4355,064
Johannesburg	0,9723	0,9455	19	5087,076
NEW	0,9832	0,9667	7	3356,693
ISAN	0,9961	0,9923	7	3542,461
POX	0,8445	0,7132	4	-54020,500
STD	0,8374	0,7013	7	4046,490
CF	0,8528	0,7274	7	5510,842

R = Correlation coefficient
R^2 = Coefficient of determination
d.f. = Degrees of Freedom

The results in table 4.16 show a high linear association between the mass of the fatty acids in the dough and the bread volume. The coefficient of determination (R^2) indicated that the predictor (independent) variables do not explain a large percentage of the variance in the combined samples. When the analysis was repeated on the individual samples, the coefficients of determination indicate that the total amount of the individual fatty acid combination in dough explain 70,13% to 99,23% of the variance in the bread volumes.

For the Johannesburg samples the correlation coefficient indicate a significance of more than 99,9%. With the exclusion of the Paarl oxidised flour (POX), with a significance of 95%, the other Paarl samples are better than 99% significance.

The X coefficients (A - D) and constants are given in table 4.17.

Table 4.17: Regression line coefficients for the different samples

	A	B	C	D	Constant
POX	52753,4	9625,2	10568,3	-11164,1	-54020,5
STD	-401,2	-2021,4	-3642,6	703,7	4046.5
CF	-1495,2	-640,7	-799,1	251,0	5510,8
NEW	488,6	-44,2	203,7	-204,7	3356,7
ISAN	904,5	-8,0	64,7	-326,8	3542,5

POX - Paarl oxidised flour
STD - Paarl standard bread flour
CF - Paarl cake flour
NEW - Johannesburg Newtown standard bread flour
ISAN - Johannesburg Isando standard bread flour

The regression lines for the bread volume of the flour samples are given by:

$$\text{Bread volume} = (AX_1) + (BX_2) + (CX_3) + (DX_4) + \text{Constant}$$

Where X_1, X_2, X_3 and X_4 represents the gram mass of palmitic, stearic, oleic and linoleic acid in the dough respectively.

4.4 Projected volume calculations

Using the regression line formulas, the volumes of the bread were calculated for each group of samples. Table 4.18 contains the results of these calculations.

Table 4.18: Projected vs. measured volume

Sample	Weeks storage	Average measured volume (cm^3)	Projected volume (cm^3)
1 POX	1	3350	3335
2 POX	10	2711	2718
3 POXB	1	3000	3335
4 POXB	10	2586	2585
5 POXTB	1	2956	2919
6 POXTB	10	2724	2718
7 STD	2	3138	3052
8 STD	10	2906	2996
9 STDB	2	3056	3036
10 STDB	10	2788	2764
11 STDTB	2	2912	2877
12 STDTB	10	2845	2894
13 CF	2	3250	3243
14 CF	10	2981	2988
15 CFB	2	3076	2978
16 CFB	10	2938	2938
17 CFTB	2	3038	3041
18 CFTB	10	2900	2994
19 NEW	2	3407	3396
20 NEW	10	3390	3401
21 NEWB	2	3013	3010
22 NEWB	10	3132	3132
23 NEWTB	2	3043	3050
24 NEWTB	10	3107	3103
25 ISAN	2	3439	3449
26 ISAN	10	3503	3492
27 ISANB	2	3075	3092
28 ISANB	10	3038	3036
29 ISANTB	2	3088	3069
30 ISANTB	10	3072	3075

This data is graphically presented in Figure 4.1. The numbers on the graph refer to the sample numbers in Table 4.18.

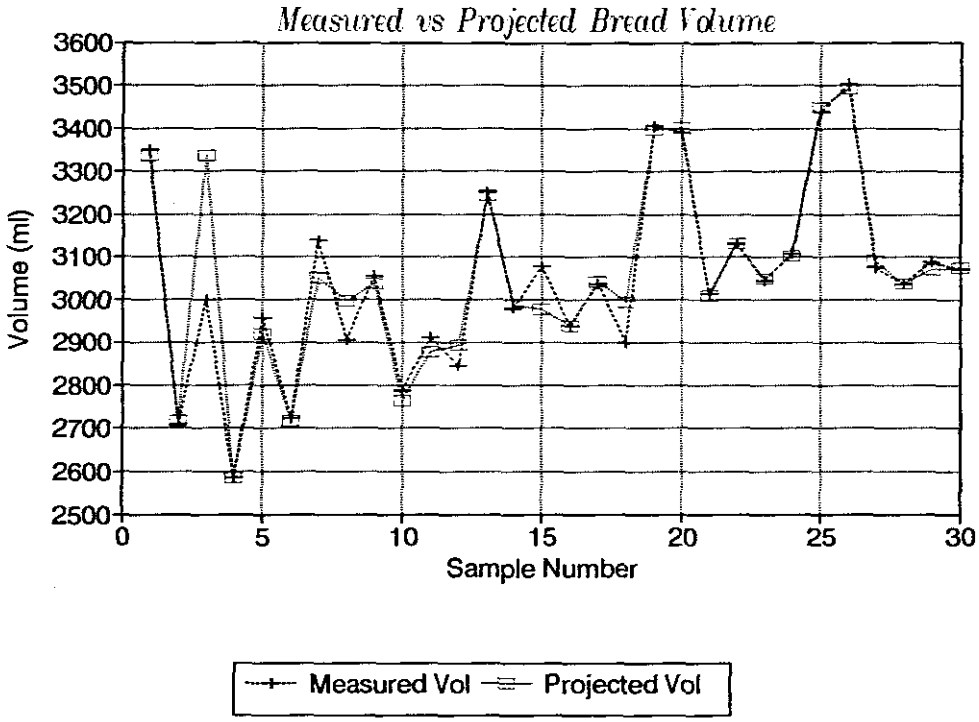

Figure 4.1: Graph of volume overlayed with projected volume

The calculated correlation coefficient between the measured volume and the calculated volume for all the samples is 0,9461. This value has better than 99,9% significance.

This confirms the expected significant interaction between the fatty acid content of flour and the volume of bread. ***Any change in the fatty acid profile of flour alters the fatty acid profile of dough that will exhibit commensurate changes in bread volume that can be achieved with the flour.***

Chapter 5

Conclusions

Throughout the various chapters aspects were identified that are important to the baking industry. The industry can benefit if they take cognisance of this to alleviate their most immediate problems and to stay competitive.

5.1 Milling

Millers would be well advised to control the amount of bran and germ material in the flour, even though this reduces the extraction rate somewhat. The size and composition of the bran particles, influence the volume of bread. The optimum bran size and composition should be determined to allow the baker to specify standards for this raw material.

The total amount of cake flour divided off from the run, has serious consequences on the quality of the bread flour, blended from the remaining streams. The industry will benefit if they determine the maximum amount of cake flour that can be divided off from a run, such that the bread flour produced, still have all the desired baking properties.

5.2 Bread volume

A combination of factors, rather than one single factor, are responsible for changes in bread volume. In the body of scientific and technical literature, many references are found that indicate bran as the specific factor responsible for volume reduction. Bran dilutes the protein and starch content of the flour. A decrease in volume is therefore expected.

Using the recipes given in Table 3.1, the flour used to produce 950g dough were 575,8g for white bread and 518,2g flour and 51,8g bran for brown bread. Basing the experimental bread volumes on available white flour content, it was found that the ratio of white flour: bread volume was higher in the case of brown bread than the ratio for white bread. The amount of flour in brown bread therefore out-performed the flour present in white bread. Assuming that the amount of gluten present in the dough is directly proportional to the amount of white flour in the dough, it can be assumed that the gluten in brown bread performed better than the same amount of gluten in white bread. Table 5.1, contains the results for the average ratios.

Table 5.1: Ratio of Bread Volume / Flour Content

Sample	Average Volume	Flour	Ratio
Combined	cm^3	g	cm^3/g
White flour	3199,8	575,8	5,56
White flour+bran	2965,8	518,2	5,72
White flour+treated bran	2968,9	518,2	5,73
Week 1 and 2 samples			
White flour	3312,8	575,8	5,75
White flour+bran	3043,3	518,2	5,87
White flour+treated bran	3012,8	518,2	5,81
Week 10 samples			
White flour	3098,2	575,8	5,38
White flour+bran	2896,0	518,2	5,59
White flour+treated bran	2929,4	518,2	5,65

In the fresh samples the ratio for untreated bran samples are 0,06 cm^3/g higher than the ratio for treated bran samples. After ten weeks storage, this phenomena is reversed. The ratios of the samples mixed with bran and treated bran, are consistently higher than those of white flour samples. The calculated volume depressions for bran concentrations of 10% were therefore greater than the measured depressions.

These results oppose the earlier research findings described in Chapter 2 where significant volume depressions are reported with more than 7% bran additions (Dubois, 1978; Moder *et al.*, 1984; Pomeranz *et al.*, 1977; Shogren *et al.*, 1981). Pomeranz *et al.* (1977) calculated an expected volume depression, and found the depression to be consistent up to bran concentrations of 7%. At higher bran concentrations, they found the volume depression to be greater than expected. These findings correlate with the findings of Shogren *et al.* (1981) who found improvement of bread volumes with additions of vital gluten, additional shortening and various blends of surfactants.

The discrepancy between the measured results and those published can be attributed to the type of flour and bran that were used or the use of different amounts of oxidants and improvers in the white bread. This aspect should be controlled and further investigated in the future.

5.3 Lipids

The literature abounds with studies done on lipids in wheat, and their effect on bread. Most of these studies are complicated, since the research teams separated and fractionated the lipids into various classes of compounds. These studies, paved the way for researchers to become embroiled in detail, thereby losing sight of the original problem.

In this study lipid was extracted as total lipid, and was not separated into various fractions. This allowed the determination of the effect of the total lipid content on bread volume. With this approach it was shown that the bread volume was significantly influenced by changes in lipid composition of the dough. The lipid spectrum changes with storage in such a way that bread volume is reduced. The coefficients of determination indicate that one or more important parameters were absent in the experimental design.

5.4 Future research

Future studies should include bran, total lipid and protein content of flour as additional variables. Protein content could be expressed as total protein, total gluten, or one of the descriptive techniques used in dough rheology. A further modification would include descriptive data of bread texture.

Better control of the ingredients in dough and processing parameters that affect bread volume will allow determination of the way in which fatty acids influence bread volume. Once this objective has been reached it would be possible to manipulate bread volume to a desired size by controlling the fatty acid composition of the fat used in baking formulations.

The changes in the fatty acid profiles during storage are inconsistent. The chemical and enzymatic factors in the flour and bran that cause the changes in fatty acid profiles are not described in the literature. From Tables 4.6, 4.7 and 4.8 the increase in oleic acid with decrease in stearic acid in samples mixed with untreated bran, indicate the presence of an enzyme system causing de-saturation of stearic acid. The presence of such a system is still unknown, although it will explain the deterioration in flour during storage (Pomeranz, 1991).

The void in scientific knowledge regarding the '*new*' enzyme system hampers understanding of the inconsistent changes as experienced. Research to alleviate this

lack of information and work on the kinetics involved in this system is essential to describe what happens to flour during storage.

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