

# **PHYSICAL AND CHEMICAL EFFECTS OF BRAN ON BROWN BREAD**

by

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Submitted in partial fulfillment of the requirements for the degree

PhD (Food Science)

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Pretoria

February, 2000



I declare that the thesis herewith submitted for the PhD (Food Science) degree at the University of Pretoria, had not been previously submitted by me for a degree at any other University

A handwritten signature in black ink, appearing to read 'J. Kock'.

## ABSTRACT

### PHYSICAL AND CHEMICAL EFFECTS OF BRAN ON BROWN BREAD

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Brown bread was produced by adding three bran fractions of different sizes (Pollard < 0.75 mm diam., Select > 0.75 mm < 1.8 mm and Digestive > 1.8 mm), from the same grist, to a common base white flour. The addition of bran caused loaf volumes to be depressed and crumb structures to be coarse. Bran components appeared to affect gluten functionality by changing its physicochemical characteristics through a subtle interplay of chemical and physical effects.

Pollard depressed loaf volumes the most, and Digestive bran the least. This could probably be attributed to differences in chemical composition. Pollard had the highest fat content, and therefore probably the highest lipoxygenase and glutathione concentrations, which adversely affected loaf volume. Subjecting the brans to a dry heat-treatment, which inactivated lipase and reduced the total reducing substances of which glutathione is part, increased loaf volume. This suggests that a chemical effect of the bran (probably the lipid metabolising enzymes lipase and lipoxygenase, as well as glutathione) is at least in part responsible for loaf volume depression. Heat treatment had the greatest effect on decreasing loaf volume depression in breads baked with Pollard and the least on breads Baked with Digestive bran, indicating a greater chemical effect in brans with smaller particle size.

A similar baking study was conducted with bran from 10 widely differing wheat samples (all of the same nominal particle size range). The different brans caused different levels of loaf volume depression. In all cases, dry heat-treatment of the brans decreased total reducing substances, inactivated lipase and increased loaf volume and height. However, the loaves still differed somewhat in volume. It is possible that differences in chemical composition of the different bran sources also accounted for these differences in loaf volume depression.

In addition to the difference in chemical compositions of the different brans, the higher loaf volumes of breads baked with Digestive bran, compared to those baked with Pollard, could also possibly be explained by the large, flaky Digestive bran particles trapping air bubbles in the dough. These air bubbles possibly provided extra nucleation sites for gas cells, as well as oxygen, which improved oxidation of the gluten and functioning of the oxidising agent ascorbic acid. The theory that Digestive bran particles trap air, could also probably explain why at low levels of addition, breads baked with Digestive bran had higher loaf volumes than the white bread controls. However, for large bran particles to be able to increase loaf volume, they have to be free of epicarp hairs.

Heat treatment did not result in all the brans producing loaves of the same volume, suggesting that a physical effect of the bran is also responsible for loaf volume depression. CAT scanning of proofing dough showed a uniform crumb structure in white bread dough in contrast with bubbles in brown bread dough, which were large and irregular. Bubbles became more elongated as proofing progressed. Bran probably ruptured the gas cell walls of the foam structure, leading to coalescence of the bubbles. Coalescence caused larger and irregular bubbles with lower internal pressures, probably resulting in lower loaf volumes.

It is concluded that there is a subtle interplay between the chemical and physical effects of bran on brown bread, which determines the extent of loaf volume depression. The addition of either large, epicarp hair free bran particles, or heat-treated smaller bran particles to white base flour are potential methods of optimising brown bread loaf size.



## UITTREKSEL

### FISIESE EN CHEMIESE EFFEKTE VAN SEMELS OP BRUINBROOD

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Bruinbrood is vervaardig deur die byvoeging van drie semelfraksies vanaf dieselfde maalkoring met verskillende groottes (Pollard < 0.75 mm diam., Select > 0.75 mm < 1.8 mm en Digestive > 1.8 mm), tot 'n basis witmeel. Die byvoeging van semels het laer broodvolumes en 'n growwe tekstuur tot gevolg gehad. Dit blyk dat semelkomponente die glutenfunksionaliteit beïnvloed het deur 'n subtiele wisselwerking tussen chemiese en fisiese effekte.

Pollard het broodvolume die meeste onderdruk, en Digestive semels die minste. Dit kan moontlik toegeskryf word aan verskille in chemiese samestelling. Pollard het die hoogste vetinhoud gehad, en daarom moontlik ook die hoogste lipoksigenase en glutatation konsentrasies, wat die broodvolume nadelig beïnvloed het. Deur die semels aan 'n droë hittebehandeling bloot te stel, wat lipase geïnaktiveer het en totale reduserende stowwe, waarvan glutatation deel is, verminder het, is broodvolumes verhoog. Dit dui daarop dat 'n chemiese effek van die semels (waarskynlik die vetmetaboliserende ensieme lipase en lipoksigenase, sowel as glutatation) ten minste gedeeltlik verantwoordelik is vir broodvolume onderdrukking. Hittebehandeling, om broodvolume te onderdruk, het die grootste effek gehad in brode gebak met Pollard, en die minste in brode met Digestive semels, wat 'n groter chemiese effect in semels met kleiner partikelgrootte aandui.

'n Soortgelyke bakstudie is gedoen met semels van 10 verskillende koringmonsters (almal met dieselfde nominale partikelgrootte reeks). Die verskillende semels het verskillende vlakke van broodvolume onderdrukking tot gevolg gehad. Droë hittebehandeling van die semels het totale reduserende stowwe in al gevale verminder, lipase geïnaktiveer en broodvolumes and hoogtes verhoog. Tog het die broodvolumes nog ietwat verskil. Dit is moontlik dat verskille in chemiese samestelling van die verskillende semelbronne ook vir hierdie verskille in broodvolume onderdrukking verantwoordelik gehou kan word.

Bo en behalwe die verskille in chemiese samestellings van die verskillende semels, kan die hoër broodvolumes van brode gebak met Digestive semels, in vergelyking met die wat gebak is met Pollard, ook moontlik verklaar word deur die groot, vlokkige Digestive semelpartikels wat lugborrels in die deeg vasgevang het. Hierdie lugborrels kon moontlik ekstra nukleasie plekke vir gasselle verskaf het, sowel as suurstof, wat oksidasie van die gluten en werking van die oksideermiddel askorbiensuur verbeter het. Die teorie dat Digestive semelpartikels lug vasvang, kan moontlik ook verklaar waarom, teen lae byvoegingsvlakke, brode gebak met Digestive semels hoër volumes gehad het as die witbroodkontroles. Groot semelpartikels sal egter net in staat wees om broodvolumes te verhoog indien dit geen epikarphare bevat nie.

Hittebehandeling het nie veroorsaak dat al die semels brode met dieselfde volumes geproduseer het nie, wat aandui dat 'n fisiese effek van die semels ook verantwoordelik is vir broodvolume onderdrukking. CAT skandering van rysende deeg het 'n univorme tekstuur in die witbrooddeeg gewys, in kontras met gate in bruinbrooddeeg wat groot en onreëlmatig was. Gate het meer verleng geraak soos wat rysing verloop het. Semels het waarskynlik gasselwande van die skuimstruktuur gebreek, wat tot samesmelting van die gate gelei het. Samesmelting het groter and onreëlmatige gate met laer interne druk veroorsaak, wat waarskynlik laer broodvolumes tot gevolg gehad het.

Dit kan afgelei word dat daar 'n subtile wisselwerking tussen die chemiese en fisiese effekte van semels op bruibrood is, wat die mate van broodvolume onderdrukking bepaal. Die byvoeging van of groot, epikarhaarvry semelpartikels, of hittebehandelde kleiner semelpartikels tot witmeel, is moontlike metodes om bruinbroodgrootte te optimiseer.

## ACKNOWLEDGEMENTS

The author would like to express her sincere gratitude and appreciation to the following people and organisations for their help and assistance with this investigation:

Prof. John Taylor, my supervisor and mentor, for his constant motivation, invaluable guidance and expert advice.

The Wheat Board and the NRF for financial support.

Ruto Mills, for providing raw materials.

Janet Taylor of the Department of Food Science, University of Pretoria, for her technical support and invaluable contribution to this project.

Alan Fowler and Klaas Dumas of Ruto Mills and Dave Carroll of Albany Bakery, for supplying valuable information and guidance.

Cora Hendriks of the Wheat Board, for her technical support and expert baking advice.

Alan Hall and Andre Botha of Electron microscopy, University of Pretoria, for their invaluable assistance in scanning electron microscopy, photography and image analysis.

Trudie Ferreira of the Technikon Witwatersrand, for her valuable input on CAT scanning.

Wendy Bubb and Tanya Reynolds, radiographers of Johannesburg General Hospital, for giving up their Saturdays to CAT scan the breads.

Corinda Erasmus of Foodtek, CSIR, for her technical assistance in image analysis.

Adriaan and Maria Van Zyl for helping me “Excel” in this project.

My admirable parents, Danie and Vrede de Kock, for their unconditional love and constant support.

My wonderful husband, Craig, for always believing in me, and for his love, encouragement and support.

## **INTERESTING FACTS ABOUT BREAD....**

1. More than 98% of convicted felons eat bread.
2. Half of all children in bread-consuming households score below average on standardised tests.
3. More than 90% of violent crimes are committed within 24 hours of eating bread.
4. Primitive tribal societies that have no bread exhibit a low incidence of cancer, Alzheimer's and Parkinson's disease, as well as osteoporosis.
5. Bread has been proven to be addictive. Subjects deprived of bread and given only water, begged for bread after as little as two days.
6. Newborn babies can choke on bread.
7. Bread is baked at temperatures as high as 230°C. This heat can kill an adult in less than one minute.
8. Most bread eaters are utterly unable to distinguish between significant scientific facts and meaningless statistical babbling!

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## **CHAPTER 1: INTRODUCTION**

### **1.1 STATEMENT OF THE PROBLEM**

Brown bread is an important staple food in many countries (Gan, Ellis, Vaughan & Galliard, 1989; Cauvain, 1998a) and in some, e.g. South Africa, it accounts for more than 46% of bread produced (Randall, Wessels & Traut, 1995). Annually, 3-3.5 billion loaves of brown bread are sold in South Africa. This equates to 4-5 slices of bread per capita per day (Mr. P.J. Cownie, Executive Director, South African Chamber of Baking - Personal communication). The high production of brown bread can be attributed to an increase in demand for food products containing elevated levels of dietary fibre (Galliard, 1986a), and also in the case of South Africa the lower selling price of brown bread. Epidemiological observations that several diseases of "civilisation", such as coronary heart disease, diabetes, and some colon diseases are most prevalent in western countries, have heightened interest in the inclusion of more fibre in our diets (Pomeranz, Shogren, Finney & Bechtel, 1977; Johnson & Southgate, 1994).

Brown bread is bread made from part or all of the pericarp of wheat, in addition to the endosperm. The non-endosperm components (germ, bran and epicarp hairs) of the wheat caryopsis are known to be responsible for producing the low specific volume and dense crumb structure of traditional wholemeal bread (Gan, Galliard, Ellis, Angold & Vaughan, 1992). Their effect cannot be explained solely in terms of the dilution effect on the gluten-forming proteins and the precise reason for the decrease in loaf volume, caused by their addition, is not known (Bloksma & Bushuk, 1988).

The chemical effects of bran on baking quality have been studied extensively (Sullivan, Howe & Schmalz, 1936; Hullet & Stern, 1941; Warwick, Farrington & Shearer, 1979; Bell, Daniels & Fisher, 1979; Barnes & Lowy, 1986; Galliard, 1986a; Galliard 1986b; Tait & Galliard, 1988; Stear, 1990; Schofield & Chen, 1995; Nelles, Randall & Taylor, 1998). From these studies it can be concluded that the reduction in baking performance may be due mainly to the presence of lipid metabolising enzymes (present in bran and germ fractions), as well as reducing substances such as glutathione.

The physical effects of bran on baking quality have also been studied (Galliard & Gallagher, 1988; Gan et al, 1989; Gan et al, 1992;), but in less detail. It appears that the non-endosperm components, notably the epicarp hairs, play a prominent role in disrupting the gluten protein matrix (Gan et al, 1989).

The situation with brown bread in South Africa is unusual in three ways. Firstly, not all South African wheats have excellent breadmaking qualities (Cheetham, 1988). Secondly, the consumption of brown bread is much higher than in other countries. This makes the production of bread with a good loaf volume and crumb structure all the more important. Thirdly, and perhaps the most important difference is the method of brown bread production. In South Africa brown bread is produced by adding bran back to the white base flour (replacing up to 15% of the flour), in contrast with other countries where brown flour is generally produced during the milling process itself. The manufacture of brown bread by the addition of bran to white flour presents the baker with an opportunity to optimise baking performance and loaf volume, if it could be established in what condition the bran should be added, for example what size or shape the bran should be, or how it should be treated before addition.

At present, the absence of a complete understanding of the effects of bran makes the manufacture of whole wheat bread with the same loaf volume as white bread expensive, since extra flour must be used to compensate for the bran effect (Lai, Davis & Hosney, 1989a). It has recently been suggested that further research is needed to elucidate the interplay of what appears to be numerous chemical and physical effects (Gan, Ellis & Schofield, 1995).

## **1.2 OBJECTIVES**

The main objective of this project was:

*To investigate the chemical and physical effects of different brans on brown bread*

This incorporated investigation of the following:

- The influence of bran origin on loaf volume
- The effect of bran type and bran particle size on loaf volume
- The effect of heat treatment of the bran on loaf volume
- The effect of bran on bubble formation in the dough
- The influence of bran on sensory quality of brown bread



## CHAPTER 2: LITERATURE REVIEW

### 2.1 THE WHEAT KERNEL

#### 2.1.1 Structure

The structure of the wheat kernel has been reviewed by many authors including Evers & Bechtel (1988) and Hosenev (1994). Members of the grass family (Poaceae), which include wheat, produce dry one-seeded fruits. This type of fruit is a caryopsis but is commonly called a kernel or grain. A longitudinal and cross section of a caryopsis or kernel of wheat is shown diagrammatically in Figure 1.

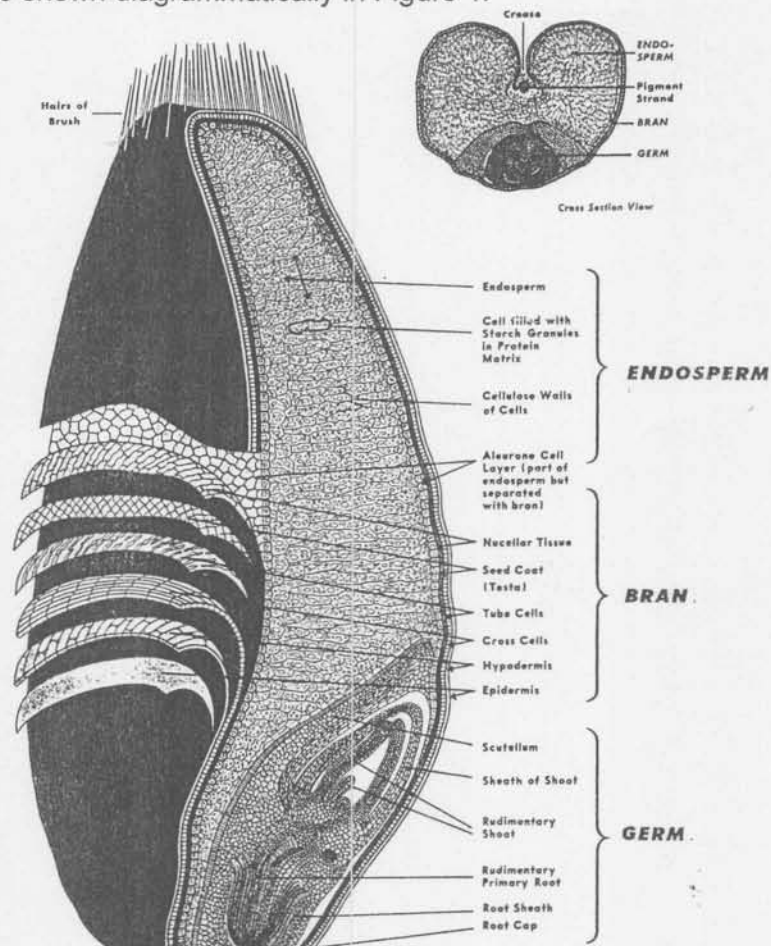


Fig. 1: Longitudinal and cross sections of a wheat kernel (Hosenev, 1994).





The kernels average about 8 mm in length and weigh about 35 mg. Wheat kernels are rounded on the dorsal side and have a longitudinal crease the length of the ventral side (opposite the germ). Wheat grains can be separated into three main parts: the bran, the germ or embryo, and the endosperm. The relationship between grain components and major mill fractions are shown in Table 1.

**Table 1: Ideal relationship between botanical constituents and major mill fractions (Evers & Bechtel, 1988).**

Grain component	Mill fraction
Grain (caryopsis)	
1. Pericarp (fruit coat)	
a. Outer pericarp	
Outer epidermis (epicarp)	
Hypodermis	
Thin-walled cells	
b. Inner pericarp	
Intermediate cells	
Cross cells	
Tube cells	
2. Seed	
a. Seed coat and pigment strand	
b. Nucellar epidermis	
c. Endosperm	
Aleurone layer	
Starchy endosperm	
d. Embryo	
Embryonic axis	
Scutellum	
	Bran
	White flour
	Germ

a) *Bran*

The hairs of brush, or epicarp hairs of the wheat kernel can be seen in Figure 1. During milling, the first (outermost bran) fraction contains the highest concentration of epicarp hairs (Gan et al, 1992). Gan et al (1989) found that these epicarp hairs appear to play a prominent role in disrupting the gluten protein matrix.

The bran consists of the outermost layer of cells of the wheat grain. These cells have thick walls made mainly of cellulose and hemicellulose. The bran layers account for 14-15% of the entire kernel (Wheat Board, s.a.) and consists of the pericarp, the seed coat and nucellar epidermis, as well as the aleurone layer (Hoseney, 1994).

The pericarp surrounds the entire seed and is composed of several layers. The outer pericarp is called the beeswing. The innermost portion of the outer pericarp consists of remnants of thin-walled cells; because of their lack of continuous cellular structure, they form a natural plane of cleavage. When they are disrupted, the beeswing is released (Hoseney, 1994). The inner pericarp is composed of intermediate cells, cross cells and tube cells (Evers & Bechtel, 1988).

The seed coat is firmly joined to the tube cells on the outside and the nucellar epidermis on the inside (Hoseney, 1994). The seed coat does not cover the entire surface of the seed, because it stops short on either side of the crease. However, the space in the crease is occupied by a structure called the pigment strand which runs along the chalazal region just inside the conducting tissue (Evers & Bechtel, 1988). The seed coat consists of three layers: a thick outer cuticle, a layer that contains pigment (for coloured wheats) and a thin inner cuticle. The thickness of the seed coat varies from 5 to 8  $\mu\text{m}$ . The nucellar epidermis, or hyaline layer, is about 7  $\mu\text{m}$  thick and closely united to both the seed coat and the aleurone layer (Hoseney, 1994).

The aleurone layer, which is generally one cell thick, completely surrounds the kernel, covering both the starchy endosperm and the germ. From a botanical point of view, the aleurone layer is the outermost layer of the endosperm. During milling, however, it is removed along with the nucellar epidermis, seed coat and pericarp to form part of the bran. The aleurone cells are heavy-walled, essentially cube-shaped and free of starch. The average thickness of the cells is about 50  $\mu\text{m}$ . The cell walls are 3-4  $\mu\text{m}$  thick, and

have been reported to be largely cellulosic in composition (Hoseney, 1994). The cell walls of the aleurone layer are somewhat thicker than those of the starchy endosperm. They consist of two distinct layers: an inner, relatively thin layer (0.3-0.6  $\mu\text{m}$ ) that remains essentially intact during germination, and an outer layer that has a striated or lamellated appearance and is degraded during germination (Fincher & Stone, 1986).

#### *b) Germ*

The germ of wheat comprises 2.5-3.5% of the kernel. The germ is composed of two major parts, the embryonic axis (rudimentary root and shoot) and the scutellum, which functions as the storage organ (Hoseney, 1994). A layer of crushed cells (fibrous region) separates the scutellar epithelium from the starchy endosperm. These crushed cells are extremely important, for it is at this junction that the embryo is separated from the rest of the grain during milling. Crushed cells are formed from starchy endosperm cells that fail to develop normally (Evers & Bechtel, 1988).

#### *c) Endosperm*

The starchy endosperm consists of three types of cells: peripheral, prismatic and central. The cells vary in size, shape and location within the kernel. The peripheral cells are the first row of cells inside the aleurone layer and are usually small, equal in diameter in all direction or slightly elongated toward the center of the kernel. Several rows of elongated prismatic cells are found inside the peripheral cells. They extend inward to about the center of the cheeks. The central cells are inside the prismatic cells. They are more irregular in size and shape than the other cells (Hoseney, 1994).

The contents and cell walls of the endosperm make up flour. The cells are packed with starch granules embedded in a protein matrix. The protein is mostly gluten, the storage proteins of wheat. In maturing wheat, the gluten is synthesised in protein bodies. However, as the grain matures, the protein bodies are compressed together into a matrix that appears claylike, and the protein bodies are no longer discernible. The starch granules occur as large, lenticular granules of up to 40  $\mu\text{m}$  across the flattened side and as small spherical granules (2-8  $\mu\text{m}$  in diameter) (Hoseney, 1994).

### 2.1.2 Chemical composition

The chemical composition of whole grain, endosperm, bran and germ, as reviewed by Bushuk and Scanlon (1993), is given in Table 2.

**Table 2: Composition of whole grain, endosperm, bran and germ (Bushuk & Scanlon, 1993)**

Constituent	Grain (%)	Endosperm (%)	Bran (%)	Germ (%)
Dry matter	100	(82) <sup>a</sup>	(15)	(3)
Carbohydrate	82.7	86.4(85)	70.0(13)	50.6(2)
Protein (N×5.7)	12.8	11.2(72)	16.7(20)	32.4(8)
Fat	2.5	1.6(52)	5.4(32)	11.9(16)
Minerals	2.0	0.8(34)	7.4(58)	5.1(8)

<sup>a</sup>Figures in parentheses are expressed as percent of whole grain

#### a) Bran

Much of the available information concerning the composition of the bran layers refers to them only as a whole. The reported composition depends on the type of wheat milled, the way in which the bran was separated, the mill stream from which the bran has been taken, as well as the method used to determine the composition (Oakenfull & Topping, 1987; Pomeranz, 1988). To emphasise this point, it is of interest that a procedure described for separating the aleurone and pericarp-seed coat of wheat bran produced fractions that have widely different effects in dietary trials with animals (Cheng, Trimble, Illman, Stone & Topping, 1987). The proportion of fat, starch and protein present depends to a large degree on the amount of germ and endosperm extracted with the bran. Bran is therefore a variable commodity (Oakenfull & Topping, 1987).

Commercial bran has a very low gluten protein content. When bran replaces flour in a brown bread formulation, it dilutes the functional gluten protein (Pomeranz et al, 1977). Czuchajowska and Pomeranz (1993) found that when high protein flour was replaced by dietary fibre (10%), dough rise was impaired as a result of dilution of functional protein.

It was possible to compensate, to various degrees, for the volume decrease when the dough was supplemented with high-quality gluten.

The mineral content of bran is between 4.8 and 6.7%, the biggest contributors being potassium (1.2-1.9%) and phosphorus (0.9-1.55%). Lipid constituents (determined by ether extraction) of mill bran make up 3.1-4.8% of the total composition. Niacin is present in the range of 140-214 ppm, while tocopherols range from 25-87 ppm, pantothenic acid 39.9 ppm, riboflavin 1.5-4.8 ppm and thiamin 4.5-6.4 ppm (Pomeranz, 1988).

Bran is a good source of dietary fibre (Theander, Westerlund & Åman, 1993). As reviewed by Delcour and Eerlingen (1996), there are a number of definitions of dietary fibre: 1) the sum of plant polysaccharides and lignin that are resistant to hydrolysis by the digestive enzymes of man; 2) the sum of non-starch polysaccharides (NSPS) and lignin; and 3) non-starch polysaccharides. Furthermore, resistant starch can also be classified as dietary fibre. Lee and Prosky (1996) proposed the expansion of the definition of dietary fibre to include resistant oligosaccharides (oligosaccharides that are resistant to hydrolysis by human alimentary enzymes), in addition to currently included non-starch polysaccharides, resistant starch and lignin. The dietary fibre content and composition of wheat bran is given in Table 3.

**Table 3: Dietary fibre content and composition of wheat bran (Theander et al, 1993)**

	%
Total dietary fibre <sup>a</sup>	37-42
Lignin <sup>a</sup>	4-5
NSPS <sup>a</sup>	32-37
Relative composition of NSPS	
Glucose	26-31
Galactose	2-4
Mannose	1
Xylose	36-45
Arabinose	22-30
Rhamnose	Trace
Fucose	Trace
Uronic acids	2-5

<sup>a</sup>Calculated as percentage of dry product

A number of enzymes are present in the bran, including phosphomonoesterase, diamine oxidase, lipoxidase, dehydrogenases, hypertensinase, glycosidases, catalase and peroxidase. Catalase activity is four to eight times higher in bran than in flour and peroxidase five to 13 times higher in bran (Pomeranz, 1988). O'Connor, Perry and Harwood (1992) studied the location and source of wheat lipase using an adapted copper soap method and a radioactive assay. The majority of wheat lipase activity was located in the bran component of the grain (75-80%). Lipase catalyses hydrolysis of triglycerides to produce diglycerides and free fatty acids; and monoglycerides to give glycerol and free fatty acids (Kent & Evers, 1994). Tait and Galliard (1988) investigated the effect of changes in lipid composition during storage on the baking quality. There appeared to be a close association between lipase activity and loss of baking performance during storage of wholemeal, with high lipase activity being associated with poor baking performance.

**b) Germ**

The protein content of mill germ has been reviewed by Pomeranz (1988) and is reported to be in the range of 17.7-35%. Germ protein types, as percentages of the total, are albumin, 30.2%; globulin, 18.9%; prolamin, 14%; glutelin, 0.3-0.37%; and insoluble types, 30.2%.

The lipid content of mill germ, as reviewed by Pomeranz (1988) is given in Table 4. The influence of the method of extraction on the results has been demonstrated.

**Table 4: Lipid content of wheat mill germ (Pomeranz, 1988)**

Lipid	Value <sup>a</sup> (%)
Ether extract	5.05-18.8 (9.45)
Alcohol extract	7.7-14.14 (10.75)
Acid hydrolysis	8.27
Phospholipid	0.65-4.17 (1.55)
Unsaponifiable	0.32-0.81 (0.49)

<sup>a</sup>Mean values in parentheses

Vitamin E is one of the major vitamins present in wheat germ (Pomeranz, 1988). Values (as total tocopherol) range from 256-500 ppm, averaging 332 ppm. Of the total 49-59% is  $\alpha$ -tocopherol, 28-29%  $\beta$ -tocopherol, and 1.5-9%  $\epsilon$ -tocopherol. Other vitamins present include thiamine, niacin, riboflavin, folic acid and biotin. Germ contains approximately 17% sugars. Other carbohydrates, e.g. starch, come from contaminating endosperm and cellulose and hemicellulose from contaminating bran.

As would be expected from its embryonic nature, the germ contains innumerable enzymes, including lipoxygenase (Pomeranz, 1988). Lipoxygenase catalyses the peroxidation of polyunsaturated free fatty acids to form free radicals and peroxides, which in turn, oxidise glutathione (Lai, Hosney and Davis, 1989c). Lipoxygenase has a number of effects on wheat flour doughs. It is an effective bleaching agent; a coupled oxidation destroys the yellow pigments in wheat flour. The enzyme also increases the

mixing stability of wheat flour doughs and has been reported to alter rheology to produce a strong dough (Hoseney, 1994). Frazier, Brimblecombe, Daniels and Eggit (1977) investigated the improving effect of lipoxygenase on bread doughs and found that the presence of fat was necessary for the improvement.

*c) Endosperm*

The starchy endosperm varies in composition from its outer portion, just beneath the aleurone layer, to its centre: There is a decrease in both protein and ash content from the outer portion to near the central portion of the endosperm (Pomeranz, 1988). The aleurone cells have 2% of cellulose, 2% glucomannan, 60% arabinoxylan and 30%  $\beta$ -glucan (Bacic & Stone, 1981ab).

Carbohydrates of the rest of the endosperm consist of starch, sugars, oligosaccharides and hemicellulose. Starch, the principle constituent of the endosperm, has been estimated to constitute 64-74% (14% mb) of milled endosperm with a protein content of 8,3-13% (Pomeranz, 1988).

Among the cereal flours, only wheat flour has the ability to form a strong, cohesive dough that retains gas and produces a light baked product. Wheat proteins, and more specifically the gluten proteins, are believed to be primarily responsible for that uniqueness of wheat. As reviewed by Hoseney (1994), the gluten complex is composed of two main groups of proteins: gliadin (a prolamin) which is responsible for the dough's cohesiveness, and glutenin (a glutelin) which gives dough its property of resistance to extension. Gliadins have an average molecular weight of about 40 000, while the glutenin proteins vary in molecular weight from about 100 000 to several million, averaging about 3 million. The molecular weights of the glutenin subunits vary from less than 16 000 to about 133 000. The HMW subunits of glutenin are important in dough formation. If they are absent, a very weak dough is formed. As reviewed by Schofield & Chen (1995), the HMW subunits cross-link the individual polypeptide chains by the disulphide bonds of the amino acid cysteine. These disulphide bonds play an important role in the formation of a stable dough. In addition, about 35% of the total amino acids of gluten proteins have hydrophobic side chains. It is believed that hydrophobic interactions between gluten proteins also have an influence in stabilising the gluten structure and in the rheological and baking properties of flour (Hoseney, 1994).



The protein content of wheat flour depends greatly on the cultivar type, but Pomeranz (1988) reported it to range from 10.8- 16.6%. The total lipid content of milled endosperm is in the range of 0.75-2.16%, averaging 1.08%.

Some of the enzymes found in the starchy endosperm of wheat have been reviewed by Pomeranz (1988) and Hosney (1994). They include esterase, lipase,  $\alpha$ -amylase,  $\beta$ -amylase, protease (proteinase and peptidase) and phytase. The  $\alpha$ -1,4 glucosidic bonds are broken on a nearly random basis by  $\alpha$ -amylase.  $\beta$ -amylase attacks every second  $\alpha$ -1,4 glucosidic bond from the non-reducing ends of the polymers. The amylase activity of wheat, barley and rye appears to be much higher than that found for the other cereal grains. Both proteinases and peptidases are found in mature, sound cereals; however, their levels of activity are relatively low. They hydrolyse internal peptide bonds and peptide chains from the end respectively. Phytase is an esterase that hydrolyses phytic acid. Phytic acid is inositol hexaphosphoric acid, and the enzyme converts it to inositol and free orthophosphate (Kent & Evers, 1994). According to Hosney (1994), about 70-75% of the phosphorus in cereals occurs as phytic acid, which is thought to chelate divalent ions and keep them from being absorbed in the intestinal tract. Thus, the enzyme's activity appears to be important, as it converts a detrimental entity into inositol (a vitamin) and nutrients. Studies have shown that at least part of the phytic acid in wheat flour is hydrolysed during fermentation. The limiting factor appears to be the solubility of the substrate.

## **2.2 MILLING AND BREADBAKING PRACTICES**

### **2.2.1 Milling practices**

The objective of milling is to make cereals more palatable and thus more desirable as food. Milling generally involves the removal of bran (i.e. the pericarp, seed coat, nucellar epidermis and aleurone layer). The germ, which has relatively high oil content, is also removed in order to prevent rancidity during storage. In addition to making the product more palatable and increasing its ability to store longer, milling often involves some type of constraint with regard to particle size. Cereals can be dry- or wet milled. Dry milling,

which is employed to make flour for breadmaking, attempts to separate the anatomical parts of the grain as cleanly as possible (Hoseney, 1994).

The flour milling process as applied to wheat can be divided into six main parts: 1) Receiving and storing wheat, 2) Cleaning the grain, 3) Tempering or conditioning, 4) Production of flour and by-products, 5) Treatment of flour with additives (not the case in South Africa), and 6) Packaging, storing and shipping the products (Matz, 1989).

Wheat is received and stored in silos. Silos consist of unloading facilities, scales, storage bins, conveying systems, preliminary wheat cleaning equipment, and associated equipment such as exhaust systems, wheat dryers and wheat turning and blending facilities. Incoming wheat is weighed, sampled and immediately analysed for foreign material (such as other seeds, sand, straw, stones, insects and damaged kernels), moisture and protein content, as well as  $\alpha$ -amylase activity. The wheat is weighed as received, dumped through a grate to remove coarse foreign material, passed over a magnet, and passed through a preliminary cleaner ("receiving separator") on its way to the storage bin where it is stored according to class, grade and protein content (Bass, 1988), or some "in house" segregation criteria.

Although large variations are found in the type and number of cleaning steps that different mills employ, certain basic steps are necessary. Early in the system, a magnetic separator removes any tramp metal that would be undesirable in the product and to protect machines from damage and reduce sparks that might trigger an explosion. Also early in the cleaning system, a milling separator removes foreign material (e.g. maize, soybeans, mustard seed, rapeseed) that differ in size from the grain being cleaned. Aspiration cleaning is used to remove chaff, dust and shrivelled kernels (Bass, 1988).

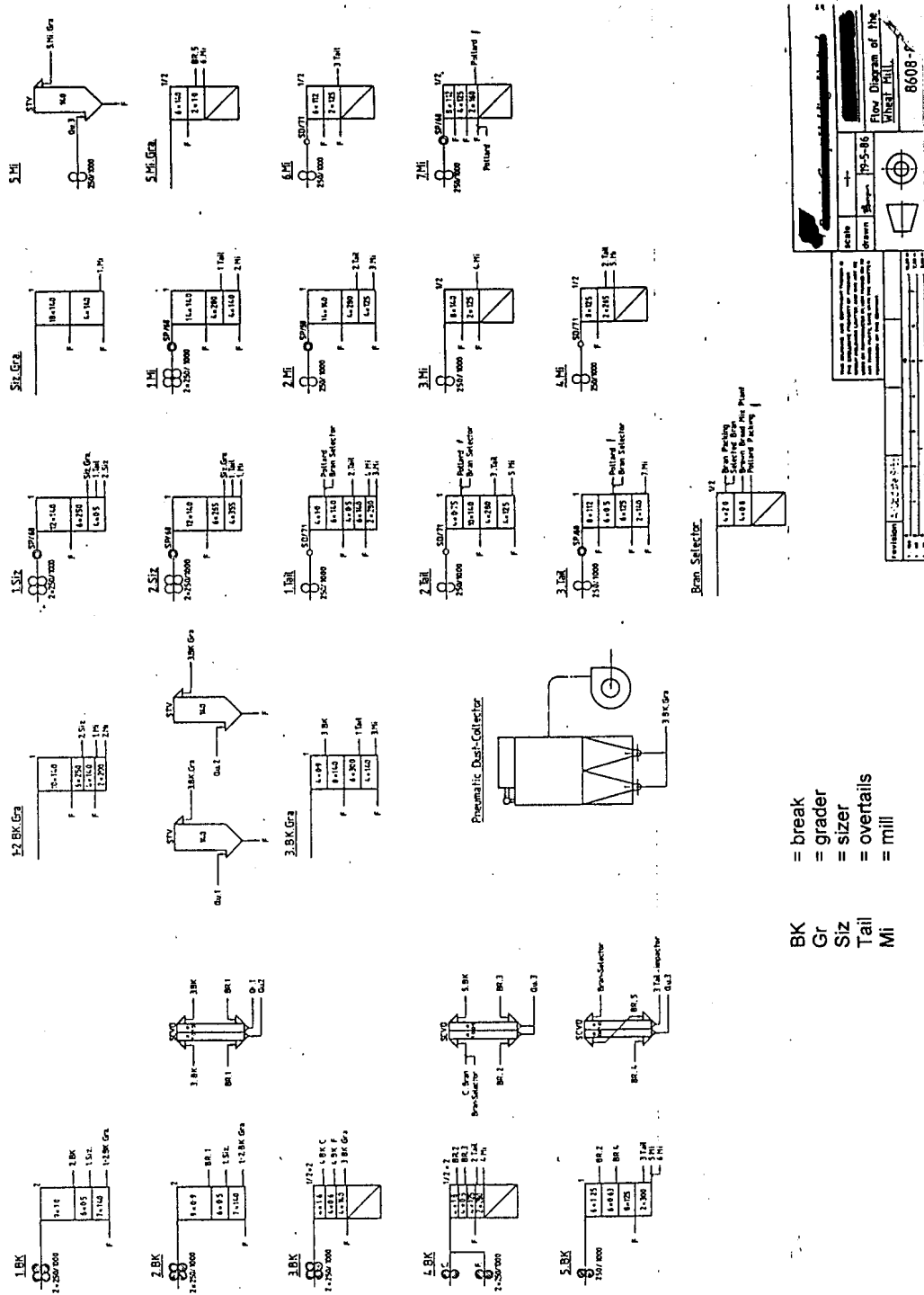
From the milling separator, the wheat passes through a destoner which removes materials similar to wheat in shape and size but differ in specific gravity (e.g. mudballs, small stones, glass and nonferrous material). The wheat from the destoner may still contain impurities either slightly longer or shorter than the wheat grains but of similar cross section (e.g. oats, barley, wild buckwheat seeds). Either disc separators or cylinder separators are used to remove these type of impurities (Bass, 1988). Another

important piece of cleaning equipment is the scourer. The grain is scoured against itself or a perforated metal screen to remove adhering dirt. The adhering material loosened by this treatment is removed by aspiration. This machine is useful to remove not only mud, but also smut or rust (Hoseney, 1994).

After cleaning, the wheat is conditioned before milling. Conditioning (or tempering) is the addition of water to wheat through spray nozzles (Bass, 1988) up to a maximum moisture content of 17% (Bushuk & Scanlon, 1993). Soft wheat is usually tempered to 15.0-15.5% moisture, while hard winter or spring wheats are conditioned to 16.5% and durum wheat to even higher moisture levels (Hoseney, 1994). The time given for the water to penetrate the grain also varies with the grain hardness. Soft wheat requires a much shorter temper time than does hard wheat: 4-6 hours as opposed to 10-36 hours. Correct tempering of wheat is essential to ensure maximum milling efficiency and optimum performance in the final product (Bass, 1988). Wheat is tempered to achieve the following objectives: 1) to toughen the bran and thus make it resist being broken into small pieces during milling; 2) to soften the endosperm and make it easier to grind (Hoseney, 1994); 3) to facilitate the physical separation of endosperm from bran; 4) to ensure that all materials leaving the grinding rolls are in optimum condition for sifting; and 5) to ensure that grinding produces the optimum level of damaged starch consistent with the hardness of the wheat and the end use of the flour (Bass, 1988).

The cleaned, conditioned wheat can now be milled. The objective of milling is to break open the grain, scrape off as much endosperm from the bran skin as possible, and gradually grind (reduce) the practically pure endosperm into flour (Bass, 1988). The number of parts of flour by weight produced per 100 parts of wheat milled is known as the flour yield, or percentage extraction rate (Kent & Evers, 1994). The wheat grain contains about 82% of white starchy endosperm which is required for white flour, but it is never possible to separate it exactly from the 18% bran, aleurone and germ. The extraction rate for bread flour in typical South African mills is 76% (Mr. N. Dumas, Mill Manager, Ruto Mills – Personal communication). Colour and ash curves are used to determine the maximum extraction rate that can be used. This is based on the principle that bran has a darker colour and higher mineral content than starchy endosperm. Milling of wheat is carried out on a large number of size reduction (grinding) and separation machines (Bushuk & Scanlon, 1993). For simplification the milling machines

can be divided into three systems: the break rolls and their associated sifters, the scratch system, and the reduction rolls and their sifters (Kent & Evers, 1994). A flow diagram of wheat milling in a typical South African mill is illustrated in Figure 2.



**Fig. 2: Flow diagram of wheat milling in a typical South African mill**

### *Break system*

The objectives of the break system are to break open the wheat grain and remove starchy endosperm from the grain in pieces as large as possible. The break system consists of four or five breaks. Each break consists of a pair of corrugated rolls rotating in opposite directions. At the nip, where the two rolls approach each other, the two surfaces are going in the same direction. The rolls are generally run at different speeds, with the fast roll going about two and a half times the speed of the slow roll. Thus, in addition to the crushing action as a large particle passes the narrow gap between the two rolls, there is a shearing action because of the speed differential (Hoseney, 1994).

A thin curtain of particles is fed into the nip between the rolls. In the first break the particles are whole grains. The flutes shear open the grain, often along the crease, and unroll the bran coats so that each consists of an irregular, relatively thick layer of endosperm closely pressed to a thin sheet of bran. A small amount of endosperm is detached from the bran coats, mostly in the form of chunks (semolina); small fragments of bran are also broken off, but little flour is made. The first break grind thus consists of a mixture of particles. The largest are the bran coats, still thickly coated with endosperm; the intermediate-sized particles are either semolina, middlings and dust, or bran snaps; the smallest are flour (break flour). The types of particles are separated from one another according to size by scalping, dusting and grading. The overtails of the wire scalping sieves become the feedstock to the second break. The finer stocks are graded and conveyed to be purified in preparation for the appropriate further treatment on reduction mills, except for the flour, which is a finished product and is retained for blending with other machine flours (Kent & Evers, 1994).

In each grinding (break) stage the bran becomes progressively cleaner until, following the last grind, it can yield no more endosperm through further grinding (Kent & Evers, 1994). It may become a finished by-product, or it may be subjected to treatment in bran finishers to remove final traces of endosperm. For reducing the size of bran flakes, cutting rolls, grinders or bran cutters may be used.

Part of the roller floor and plansifters of a South African mill are shown in Figures 3 and 4 respectively.





Fig. 3: Part of a roller floor in a South African mill

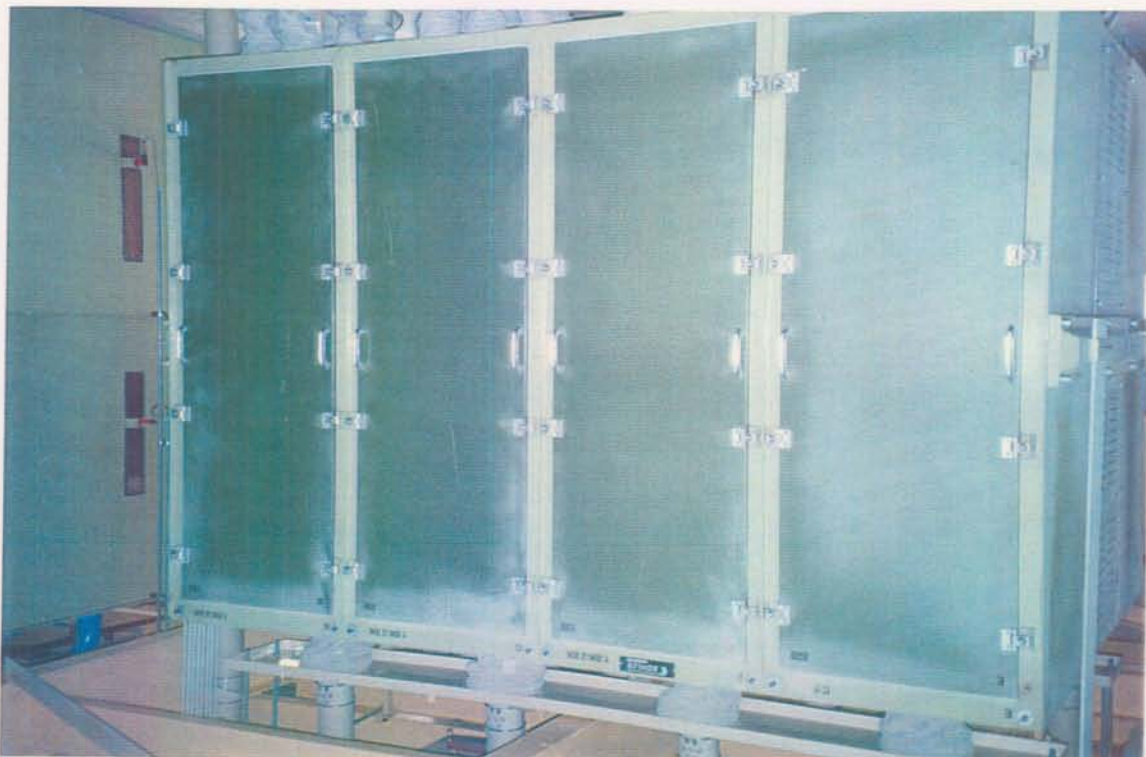


Fig. 4: Plansifters in a South African mill

### *Scratch system*

The scratch system separates particles of bran and endosperm which are still stuck together after passing through the break system. These particles are too small to have overtailed to the next break, but are not clean enough to go to the reduction system. The scratch system consists of two to four grinding stages. The feed to the scratch system contains large particles of semolina and pieces of bran with attached endosperm, but particles are much smaller and cubical than break feeds. The objective are to scrape endosperm from the bran without undue production of fine stock, and to reduce oversize semolina. The grind from the scratch rolls is scalped, dressed, graded and purified in much the same way as that from the breaks, and fractions dispatched respectively to subsequent grinding stages, to offals, to flour (as end product) or to the reduction system (Kent & Evers, 1994).

### *Reduction system*

The reduction system 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). It consists of 8-16 grinding stages, interspersed with siftings for removal of the reduction flour made by each preceding grind, and a coarse (tailings) fraction made from some grinds. The feeds to the first two rolls, inevitable contain a few particles of bran. The feeds also contain particles of germ. By carefully controlling the roll pressure, these can be flattened without fragmentation, and subsequently sifted off as coarse "cuts" from the grinds (Kent & Evers, 1994).

In South African mills, all the bran fractions collected from the different mill streams are collected in one stream and then sieved to produce three sizes: Digestive bran (largest), Select bran, and Pollard (smallest) (N. Dumas – Personal communication). The epicarp hairs are also collected in a separate mill stream. Pollard is regarded as an offal product and is not analysed routinely for quality. The properties of the Digestive and Select bran are given in Table 5.

**Table 5: Properties of Digestive and Select Bran produced at Ruto Mills, Pretoria, South Africa**

Property	Digestive bran		Select bran	
	Minimum	Maximum	Minimum	Maximum
Moisture (%) (Brabender)	11.28	13.28	11.82	13.82
Ash (%)	4.93	6.93	4.40	6.40
Protein (%) (12% mb)	13.45	15.45	15.24	17.24
Fat (%) (soxhlet)	3.06	5.06	3.37	5.37
Particle size distribution				
>2360 $\mu\text{m}$	12.88	32.88	-	-
>2000 $\mu\text{m}$	32.70	52.70	-	-
>1400 $\mu\text{m}$	12.53	32.53	-	-
<1400 $\mu\text{m}$	1.72	52.70	-	-
>1000 $\mu\text{m}$	-	-	20.45	40.45
>850 $\mu\text{m}$	-	-	10.93	30.93
>710 $\mu\text{m}$	-	-	11.32	31.32
<710 $\mu\text{m}$	-	-	17.23	37.23

In South Africa, brown flours are produced by adding Select bran (12%) back to white flour (N. Dumas – Personal communication). In other countries, bran is not separated from the white flour, and different terms are used to describe different flours (Kent & Evers, 1994). In the U.K., wholemeal flour, by definition, must contain all the products of milling of cleaned wheat, i.e. 100% extraction rate. In the U.S.A. the 100% product is known as wholewheat flour. Brown flours can be of extraction rates between 85% and 98%. For milling brown flour, the white flour process may be modified in various ways:

Releases are increased throughout the break system, by narrowing the roll gap, and by using scalping covers of slightly more open mesh.

Operation of the purifiers is altered by adjusting the air valves, altering the sieve clothing and reflowing the cut-offs so that less stock is rejected to wheatfeed, and more goes to the scratch and reduction systems.





The scratch system is extended by the use of additional grinding stages.

The extraction of flour from the reduction system is increased by more selective grinding, by changing some of the smooth grinding rolls to fluted rolls, and by employing additional grinding stages to regrind offally stock that would be rejected as unremunerative in white flour milling.

Additional flour may be obtained, at the sacrifice of good colour, by bringing the wheat onto the first break rolls at 1-1.5% lower moisture content than the optimum for white flour milling.

### **2.2.2 Breadbaking practices**

Bread can be made by many different procedures. All of these processes have a single, common aim, namely to convert wheat flour into a palatable and aerated food product. In achieving this conversion there are a number of common steps which are used.

The mixing of flour, water, yeast, salt and other specified ingredients.

The development of a gluten structure in the dough through the application of energy during mixing.

The incorporation of air bubbles within the dough during mixing.

"Ripening" or "maturing" of the dough where the gluten structure is further developed.

The creation or modification of particular flavour compounds in the dough.

The subdivision of the dough into unit pieces

A preliminary modification of the shape of the divided dough pieces.

A short delay in processing to further modify the physical and rheological properties of the dough pieces.

The shaping of the dough pieces to achieve their required configurations.

The fermentation and expansion of the shaped dough pieces during "proof".

Further expansion of the dough pieces and fixation of the final bread structure during baking (Cauvain, 1998b).

**a) Ingredients**

Although the word "bread" covers a considerable variety of products, they share the same four basic ingredients:

1. *Wheat flour*, which contains unique proteins which, when hydrated with water, form a viscoelastic protein structure called gluten. Under the influence of mixing and further processing, gluten is capable of forming a bubble structure in the dough which can be inflated by carbon dioxide gas produced by fermentation. 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). Bran, which is added back to white flour to produce brown bread, causes the dough to absorb more water and depresses the loaf volume of the final baked product (Pomeranz, 1977).
2. *Water*, to hydrate the flour proteins, to be partially absorbed by the flour starch and to form a water phase in the dough in which soluble solids such as sugars, salt and soluble proteins are dissolved and in which the yeast cells are dispersed (Brown, 1993). In South African bakeries, water addition for white bread averages 61% (based on flour weight) and for brown bread 64% (Mr. D.G. Carroll, Technical Services Manager, Albany Bakery – Personal communication).
3. *Yeast*, to aerate the dough by the production of carbon dioxide gas by fermentation. The carbon dioxide goes into solution in the dough/water phase, which, when saturated with carbon dioxide, releases it into gas cells in the dough, which have been formed by mixing and processing. Yeast fermentation also contributes greatly to the flavour of bread. In addition it produces reducing sugars which react with the dough proteins to produce the characteristic brown colour during the baking process (Brown, 1993). In South Africa yeast is added at 1.5-3.0% (based on flour) levels (D.G. Carroll – Personal communication).
4. *Salt*, to flavour the bread, both by its own characteristic flavour and by highlighting other flavour products in the bread. Salt also has a retarding effect on fermentation (Brown, 1993), and strengthens the dough, presumably by shielding charges on the dough proteins (Hoseney, 1994). Levels of salt used in South African bakeries range from 1.8-2.2% (based on flour), averaging 2.0% (D.G. Carroll – Personal communication).

While these are the only four essential ingredients required, other optional ingredients may be added to improve loaf quality or to change specific bread characteristics (Brown, 1993):

1. *Fats (shortening)* change the eating characteristics of bread, giving it a shorter, softer bite and at the same time a modest enhancement of the soft-eating shelf life (Williams & Pullen, 1998). Fats also gives bread with increased loaf volume compared to bread made without shortening (Hoseney, 1994). Hydrogenated palm oil with a slip point between 40 and 45°C, is the fat most commonly used in South African bakeries. Levels used range bewteen 0 and 1% (based on flour) (D.G. Carroll – Personal communication).
2. *Sugar* is added to bread formulas for two reasons. It is a source of fermentable carbohydrate for the yeast, and it provides a sweet taste to the bread (Hoseney, 1994). South African bakeries use brown sugar at 0.5-1% (based on flour) level of addition (D.G. Carroll – Personal communication).
3. *Soya flour* has two beneficial functions, both being due to a particular enzyme system present in the uncooked bean. This enzyme system, lipoxygenase, catalyses the oxidation of unsaturated fats by atmospheric oxygen to lipid peroxidases via a number of intermediate oxidation compounds. Some of these intermediate compounds transfer oxygen from the atmosphere surrounding the dough to the yellow-coloured carotinoid pigment of flour. The oxidised products derived from these pigments are colourless and therefore the first functional effect of soya flour is as a bleaching agent. The second effect, as a mild oxidising agent, improves bubble formation and dough structure (Williams & Pullen, 1998). The average usage of soya flour in South Africa is 0.75% (based on flour) (D.G Carroll – Personal communication).
4. *Milk or milk solids* can be added to improve both nutritional value and crust colour (Brown, 1993).
5. *Oxidants* such as ascorbic acid improve dough strength and result in bread with better loaf volume and texture (Hoseney, 1994). The role of the oxidant is to first oxidise the water-soluble protein -S-H groups in the system. This would benefit the dough structure by preventing them from preferentially reacting with the -S-H groups of the glutenin molecules exposed during the development period. The removal of the water-soluble protein -S-H group from the system causes a shift of the balance of the reactions of glutenin molecules towards the formation of interglutenin -S-S-

bonds rather than glutenin-soluble protein -S-S- bonds, thus producing a more elastic structure (Williams & Pullen, 1998). Ascorbic acid is the most commonly used oxidant in South African bakeries. It is used at levels of 70-80 ppm for white bread and 100 ppm for brown bread. The use of azodicarbonamide is also possible, but because this is a fast acting oxidant, which could damage the dough during any delay that might be experienced on the production floor, it is not a popular choice (D.G. Carroll – Personal communication).

6. *Emulsifiers*, e.g. monoglycerides are added to increase the softness shelf life of bread. Other surfactants, e.g. sodium stearoyl lactylate (SSL), are used as dough strengtheners to allow the dough to withstand the mechanical abuse of processing lines (Hoseney, 1994). When, for example, diacetylated tartaric acid esters of mono- and diglycerides of fatty acids (DATA esters) are incorporated into bread doughs, they bond rapidly and totally to the hydrated gluten strands. The resultant gluten network is not only stronger, but is more extensible and has a more resilient character. This produces a dough which has a gas bubble network with small-sized, strong and extensible gas cell walls, and a baked bread with higher volume and whiter crumb (Williams & Pullen, 1998). The most effective emulsifiers are DATA esters, and in South Africa, they are used at 0.1-0.2% (based on flour) levels. The most commonly used emulsifier in South Africa is SSL, which is used at a 0.5% level of addition. Glycerol monostearate (GMS) (0.1-0.5%) is also used (D.G. Carroll – Personal communication).
7.  *$\alpha$ -Amylases* catalyse the breaking of hydrated starch molecules, both amylose and amylopectin, into short-chain unbranched molecules known as dextrins. In combination with  $\beta$ -amylase, an enzyme which attacks the ends of the amylose and amylopectin chains breaking off individual maltose sugar molecules, and given sufficient time and the right conditions, they are capable of converting starch almost totally to maltose. It is the level of  $\alpha$ -amylase which is the rate-determining enzyme in the system. Most wheat flours contain adequate levels of  $\beta$ -amylase, but usually only a low level of natural  $\alpha$ -amylase and therefore it has become common practice to make adjustments to the amylase levels through the addition of suitable materials. These include  $\alpha$ -amylase from fungal, cereal or bacterial sources. The use of fungal  $\alpha$ -amylase reduces the risk of the formation of an excessive level of dextrins in the bread during the later stages of the baking process as compared to

cereal  $\alpha$ -amylase because of its lower heat inactivation temperature. Bacterial  $\alpha$ -amylases are very heat stable and will continue to produce dextrans throughout the entire baking cycle and even during cooling. The resulting bread is very sticky and it may even become impossible to slice the loaf (Williams and Pullen, 1998). The South African baking industry make use of so called enzyme “cocktails” which is a preparation of different enzymes. It may include  $\alpha$ -amylase, pentosanases, xylanase and hemicellulase. Depending on the activity of the enzymes, these cocktails are used at levels between 50 and 200 ppm (D.G. Carroll – Personal communication). Pentosanases have been reported to increase gluten coagulation, and xylanase have been shown to increase gluten strength (Qi Si, 1997). Lipase can also be used to increase loaf volume, crumb structure and crumb softness.

8. *Preservatives* are added to inhibit the growth of moulds and thermophilic bacteria. Propionates (e.g. calcium- and sodium propionate) provide the most effective protection against mould growth (Williams & Pullen, 1998). In South Africa the most commonly used preservatives are calcium propionate, sodium diacetate and calcium acetate. The legal limit for these preservatives are 0.3% (based on flour) (D.G. Carroll – Personal communication).

#### *b) Breadmaking processes*

The production of bread is a complicated series of operations which must be carried out to produce the particular bread product required. The operations involved can be listed in basic terms as follows:

1. Selection of flour and other ingredients for the product to be produced.
2. Mixing of the ingredients into a dough.
3. Maturing of the dough so that it is capable of producing the bread quality required. Maturing may be achieved during mixing of the dough by mechanical or chemical means, or it may be brought about by the fermentation of the dough in bulk for a set period of time.
4. Dividing the dough into pieces of required size, molding it to the shape required, placing it in pans and transferring it to the final prover.
5. Proving of the dough in a temperature and humidity controlled area until it reaches the proved volume or height required.
6. Baking, depanning and cooling of the loaves (Brown, 1993).

### Dough development

If flour, yeast, water and salt are mixed into a dough and processed immediately, the resultant bread will be of poor volume and with an uneven, dense crumb cell structure. This is because the dough protein has not been developed or matured correctly to allow it to retain the gas produced by the yeast and expand. A dough development process is any method of mixing and handling of the dough which gives it the following properties when it is ready for dividing and processing into the required dough shapes:

1. The protein structure of the dough should be in a condition which will withstand the stresses of dividing and molding and be capable of being formed into the final shape without tearing.
2. The dough after molding should contain a network of gas cells which have been formed during mixing and subsequent processing. These gas cells will be inflated by carbon dioxide gas during final proof and the early stages of baking.
3. The dough protein structure surrounding the gas cells should be capable of retaining the gas produced by the yeast during final proof and the early stages of baking and expand evenly without rupturing.
4. The dough must contain active yeast and sufficient substrate for the yeast to continue producing carbon dioxide during final proof and the early stages of baking (Brown, 1993).

The methods by which dough development is achieved in the bakery have been reviewed by Kulp (1988), Hosney (1994) and Cauvain (1998b). These methods may be fitted into five broad processing groups:

1. Straight dough bulk fermentation
2. Sponge and dough
3. Liquid ferment
4. Rapid processing
5. No-time method (continuous processing or mechanical dough development).

### *Chorleywood Bread Process (CBP)*

The system employed in most South African bakeries is a mechanical dough development system of which the CBP is most commonly used by larger bakeries (Kent & Evers, 1994). In mechanical dough development, there is no fermentation period in bulk, and dough development is largely, if not entirely, achieved in the mixing machine.

The changes brought about by bulk fermentation periods are achieved in the mixer through the addition of improvers, extra water and a significant planned level of mechanical energy. According to Cauvain (1998b), the essential features of the CBP are:

Mixing and dough development in a single operation lasting between 2 and 5 minutes at a fixed energy output.

The addition of an oxidising improver.

The inclusion of a high melting point fat, emulsifier or fat and emulsifier combination.

The addition of extra water to adjust dough consistency to be comparable with those attained in bulk fermentation.

The addition of extra yeast to maintain final proof times comparable with those obtained in bulk fermentation.

Rapid development of the dough occurs in the mixer rather than through a prolonged resting period. The protein structure in the dough is modified to improve its ability to stretch and retain gas from yeast fermentation in the prover. The advantages gained by changing from bulk fermentation to the CBP include:

A reduction in processing time.

Space savings from the elimination of bowl of dough at different stages of bulk fermentation.

Improved process control and reduced wastage in the event of plant breakdowns.

More consistent product quality

Financial savings from higher dough yield through addition of extra water and retention of flour solids which are normally fermented away.

Disadvantages include:

Faster working of the dough is required because of the higher dough temperatures used.



In some views, a reduction of bread crumb flavour because of shorter processing times (Cauvain, 1998b).

As the level of energy per kilogram of dough in the mixer increases, so bread volume increases, and with this comes a reduction in cell size and increased uniformity. Optimum energy levels are 11 Watt-hour/kg dough. This high energy input is capable of mechanically breaking the disulphide bonds holding the original protein configurations together since such processes are known to occur in the mechanical modification of other molecules. The effect of mechanical energy might therefore be likened to the effects of natural or chemical reduction and will increase the sites available for oxidation. The input of energy during mixing causes a considerable temperature rise to occur. Final dough temperatures are higher than those with other breadmaking processes and fall in the region of 27-32°C. This gives a dough which is more "relaxed", in other words has less resistance to deformation during molding (Cauvain, 1998b).

A given bread volume can be achieved with a lower flour protein content in the CBP than with bulk fermentation. A standard sandwich loaf can be made with a flour protein content of about 10.5% (14% moisture base). However, not all bread using the CBP benefits from such a low protein content. The quality characteristics demanded in the bread will largely dictate the flour specification and it is common for higher protein contents (12%) to be used for other bread varieties e.g. brown bread (Cauvain, 1998b). This, however, is not common practice in South African bakeries. Brown bread in South Africa is baked with flour specified to have a protein content of no less than 11% protein. In addition, brown bread recipes are formulated with higher levels of oxidants, enzymes and emulsifiers in order to help the gluten carry the bran (D.G. Carroll – Personal communication).

In contrast to the situation in bulk-fermented doughs the cell structure in the final bread does not become finer as a result of processing CBP doughs. In the case of CBP doughs, the final bread crumb cell structure is almost exclusively based on an expanded version of that created during the initial mixing process. The creation of bubble structures in mechanically developed doughs depends on the occlusion and subdivision of air during mixing. The number, sizes and regularity of the gas bubbles depend in part on the mixing action and energy inputs (Cauvain, 1998b).



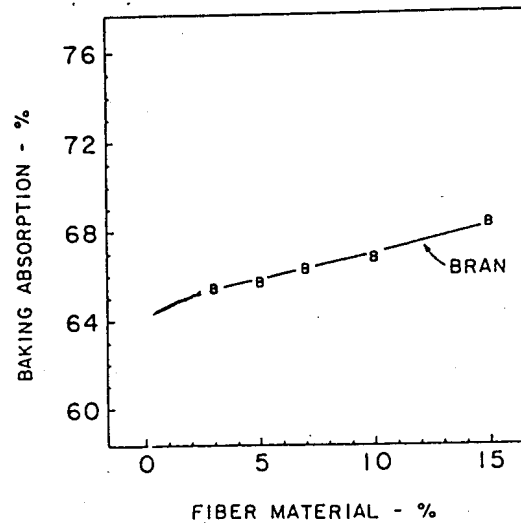
### *No-time doughs with spiral mixers*

In many bakeries, especially the smaller ones, the spiral mixer has taken over as the main type of mixer being used. Spiral mixers have higher work input levels compared with traditional low-speed mixers, with accompanying reductions of mixing times to achieve maximum dough development. Although mainly used for no-time doughs some bakers will use short periods of bulk fermentation (20-30 minutes) to assist with dough development after mixing. Some spiral mixers impart sufficient energy to raise dough temperatures above that expected from the ingredients. Final dough temperatures vary widely and practical examples may be found from 21°C to 27°C. For many bakers the advantage of using lower dough temperatures lies in restricting yeast activity which comes with the usually higher levels of added yeast. A counter to this advantage is the reduction in chemical and enzymic activity which will occur at lower dough temperatures with a subsequent reduction in overall dough development (Cauvain, 1998b).

## **2.3 THE INFLUENCE OF BRAN ON DOUGH AND BREAD BAKING PROPERTIES**

### **2.3.1 *Water absorption***

On average, water absorption increases linearly with the addition of wheat bran. Pomeranz et al (1977) found that water absorption increased linearly from 64.2% in the control to 68.3% in the sample with 15% bran (Fig. 5).



**Fig. 5: Bake water absorption (%) of doughs from wheat flours in which 3, 5, 7, 10 or 15% was replaced by wheat bran (B) (Pomeranz et al, 1977)**

Other work showed similar trends (Pomeranz, Shogen & Finney, 1976; Shogren, Pomeranz & Finney, 1981; Lai et al, 1989a; Lai, Hosney and Davis, 1989b; Young, 1998). The effect of replacing wheat flour with bran on water absorption as found by Pomeranz et al (1976) is shown in Table 6.

**Table 6: Effect on water absorption of replacing wheat flour with bran (Pomeranz et al, 1976)**

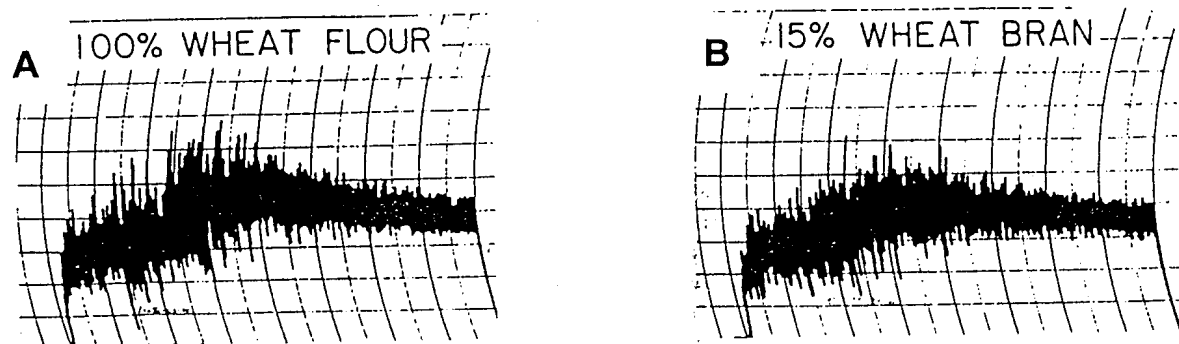
Bran addition (%)	Water absorption (%)
0	64.4
3	64.9
5	65.6
7	66.6
10	68.3
15	70.1

Even higher water absorption levels were reported in this study. When the water absorption of the added fibre were computed, it was found that it generally increased as the level of added bran increased within the range of 3 to 15%. The computed increase was 80 to 102% (Pomeranz, et al, 1976). It is possible that because the bran binds a

relatively large amount of water, the gluten is not properly hydrated and developed at normal absorption levels. The use of an inappropriate absorption level therefore results in a reduction in loaf volume (Lai et al, 1989a)

### 2.3.2 *Mixing properties*

In general, an increase in bran level is accompanied by an increase in mixing time (Pomeranz et al, 1976; Pomeranz et al, 1977; Shogren et al, 1981; Cheetham, 1997; Young, 1998). Cheetham (1997) found that dough development of mature brown meal is about 1.5 minutes longer than for mature white flour. Mixograms and average mixing times of doughs with different brans as found by Pomeranz et al (1977) are given in Figure 6 and Table 7 respectively. Bran did not increase mixing time at 15% replacement level (with the exception of coarse bran-medium). The mixing time of the control flour was 3 7/8 minutes. Replacing wheat flour with 15% bran had no consistent effect on bake mixing time.



**Fig. 6: Mixograms of control flour (A) and control flour in which 15% was replaced by finely ground fine bran (B) (Pomeranz et al, 1977)**

**Table 7: Mixing time of flours with different replacements of bran (Pomeranz et al, 1977)**

Replacement level (%)	Average mixing time (min)
3	3 5/8
5	3 5/8
7	3 1/2
10	3 5/8
15	3 7/8

### 2.3.3 Gassing power

To determine whether loaf volume was depressed more than expected by impaired gas formation or gas retention, Pomeranz et al (1977) determined gassing power at 1 hour intervals for 5 hours on 10 and 8.5 g flour doughs and on a dough prepared with 8.5 g flour plus finely ground fine bran. They detected no significant differences in the gassing power the first three hours, but the recorded pressures after 4 and 5 hours are given in Table 8.

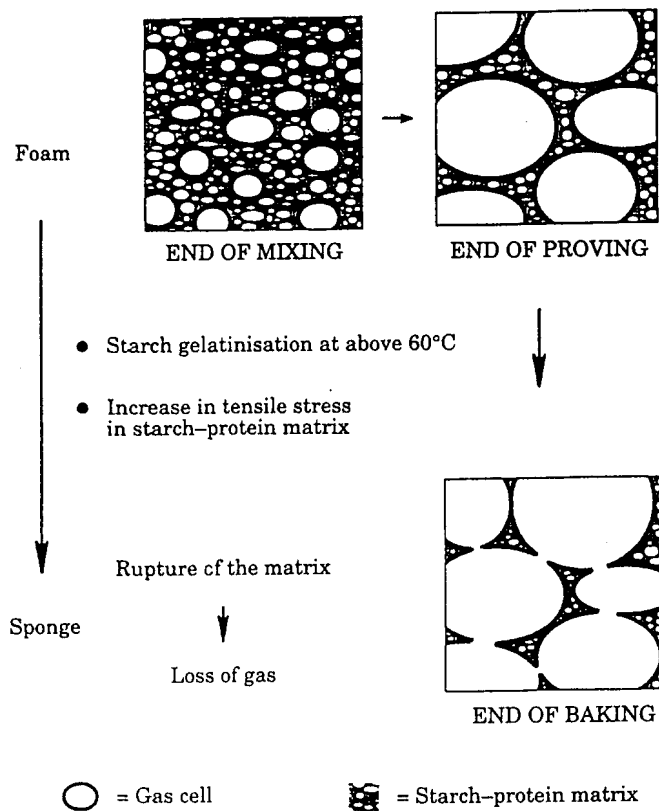
**Table 8: Gas pressure of doughs made with straight flour and with the addition of bran (Pomeranz et al, 1977)**

Dough	Pressure (mm Hg) at the end of	
	4 h	5 h
10 g flour	552	722
8.5 g flour	514	660
8.5 g flour + 1.5 g bran	610	832

Bran did not depress gassing power; on the contrary, it increased it considerably. Consequently, loaf-volume-depressing effects of bran seem to result from reduced gas retention rather than reduced gas formation.

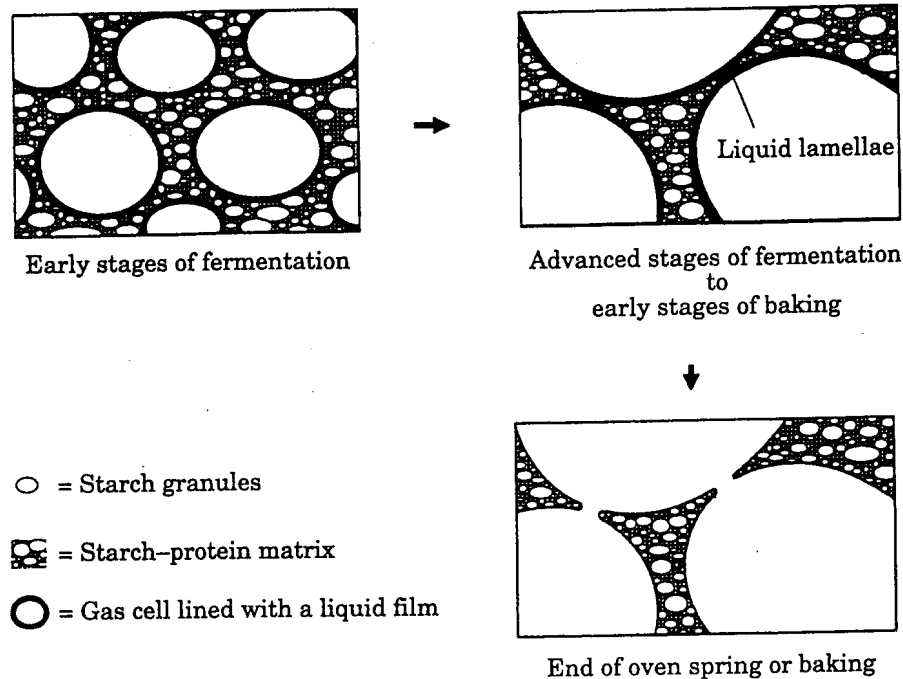
To produce a loaf of bread with a light and even crumb structure, the dough must be able to retain gases produced by yeast fermentation as discrete cells for a sufficiently

long period (Bloksma, 1990). The foam structure of a fermenting dough is a dispersion of discrete gas cells in a continuous starch-protein matrix. A possible explanation for a loss of gas retention is that the matrix ruptures during baking (because of a sharp increase in dough viscosity), resulting in the interconnection of adjacent gas cells, converting the foam structure of dough into an open sponge and enabling direct escape of gas (Fig. 7) (Gan et al, 1995).



**Fig. 7: The structural transformation of dough as explained by the conventional starch-protein matrix hypothesis (Gan et al, 1995)**

The liquid film hypothesis is a revised possible reason for gas loss (Gan et al, 1995). Soon after mixing, the dough consists of discrete gas cells lined with liquid films and embedded in a continuous starch-protein matrix. The matrix fails to enclose the gas cells completely at advanced stages of fermentation, leaving areas that contain only a thin liquid lamella. Baking increases the rate of expansion until the lamellar film is incapable of meeting the demand for new surface area generation, thus converting the foam structure of dough into an open sponge. The loss of gas retention is caused, therefore, by the rupture of the liquid film, not that of the starch-protein matrix (Fig. 8).



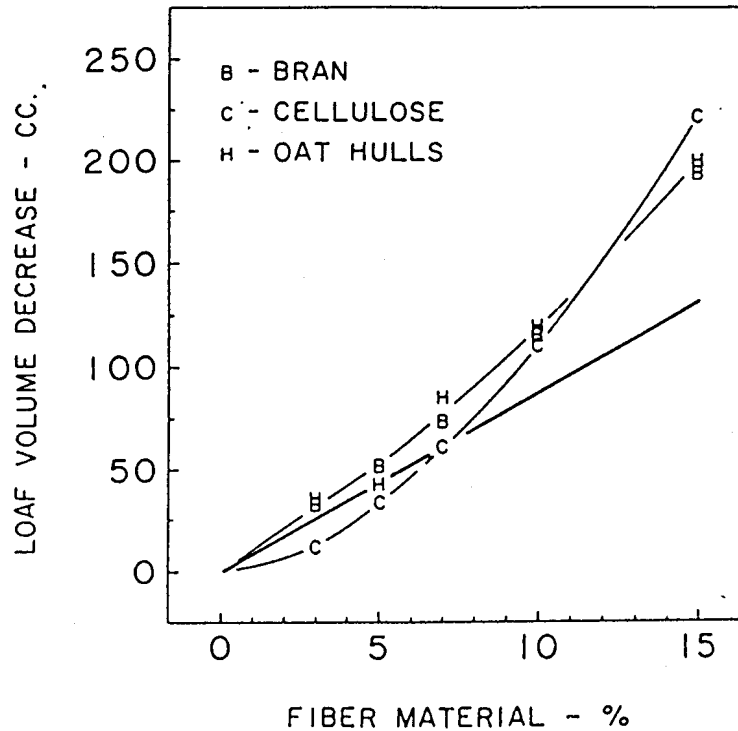
**Fig. 8: A revised model of dough expansion (Gan et al, 1995)**

Czuchajowska and Pomeranz (1993) found that it was possible to compensate, to various degrees, for a volume decrease as a result of poor gas retention, by supplementing dough (both brown and white) with high-quality gluten. Other authors (Gan et al, 1989) also found that the gas-cell walls of gluten-supplemented wholemeal bread appear to be thicker, smoother and more continuous than those from the unfortified flour. They proposed that the gluten supplement may strengthen the gas-cell walls, thereby counteracting the adverse effects of the non-endosperm components.

#### **2.3.4 Loaf volume**

When brown bread is produced, a proportion of the flour is replaced by bran (non-endosperm components). The resulting bread has a dense crumb structure and a low specific volume. This cannot be explained solely in terms of the dilution effect of the non-endosperm components on the gluten-forming proteins (Lai et al, 1989b; Rogers & Hosney, 1982; Pomeranz, 1977). Pomeranz et al (1977) compared the effects of adding bran on loaf volume with the theoretical effect (Fig. 9). The theoretical line was calculated from loaf volume decreases expected from dilution of gluten proteins. Replacing up to 5% of the wheat flour with fibre materials reduced volume by the

expected theoretical amount. At 10% replacements, reductions in loaf volume were greater than expected. The deviation from the theoretical line increased almost exponentially with increase in amount of fibre material.



**Fig. 9: Effects on loaf volume decrease of replacing 3, 5, 7, 10 and 15% wheat flour by celluloses (C), wheat bran (B) or oat hulls (H), compared with the theoretical loaf volume decrease (heavy straight line) (Pomeranz et al, 1977)**

The precise reason for the decrease in loaf volume, caused by the addition of bran, is not known (Bloksma & Bushuk, 1988). Research suggests that the reduction in loaf volume can be attributed to two possible main effects, namely chemical or physical or a combination of the two.

*Chemical effect of bran on loaf volume*

In commercial practice, flour is normally stored for short periods only. Loss of baking performance and consequent reduction in loaf volume would not be expected during this time. When flour is stored for longer periods, however, it shows progressive deterioration in baking performance. The actual mechanism of deterioration in baking quality remains unproven, although it is known that the variation in baking performance



during storage is dependent on such factors as moisture content, storage temperature and storage atmosphere (Warwick et al, 1979).

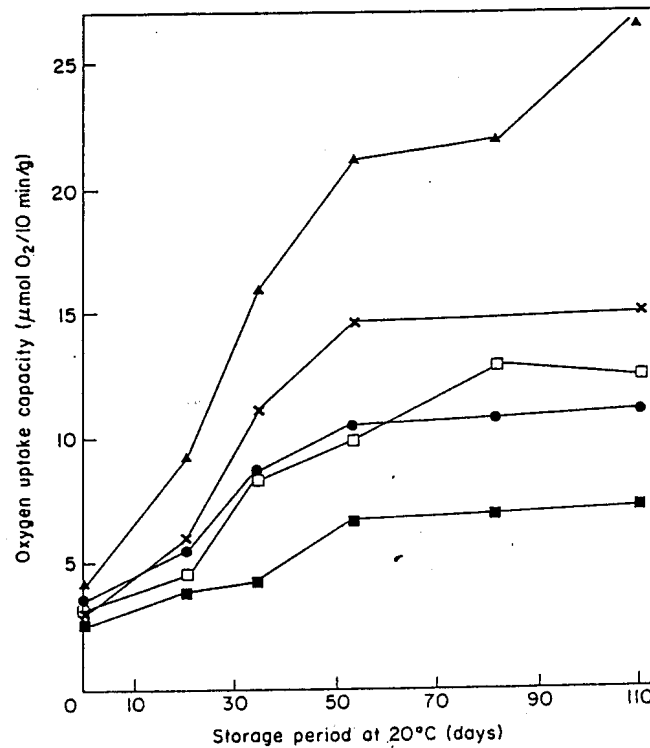
Most of the published information on the effects of storage on the baking properties of wheat concerns white flour, which consists almost entirely of the starchy endosperm. There is little information concerning wholemeal flour although it is widely accepted that wholemeal deteriorates rapidly on storage compared with white flour, and it is considered that this difference is due to the greater amounts of lipid-rich germ and bran tissue in wholemeal (Barnes & Lowy, 1986). Indeed Galliard (1986a) provided evidence that the decreased shelf-life of wholemeal flour, as compared with white flour, is due to the presence of lipid metabolising enzymes present in the bran and germ fractions of the wholemeal. They showed that the oxygen consumption values of aqueous suspensions of wheat wholemeal were substantially higher than those of white flours. The actual values depended upon storage history. The O<sub>2</sub> consumption value of the materials stored for 2-4 weeks at 20°C and 65% R.H., were many-fold higher than those of the same materials from freshly milled grain. The O<sub>2</sub> consumption of mixtures of finely-ground (<0.5 mm) bran and germ increased on storage more rapidly than that of bran or germ stored separately. The O<sub>2</sub> uptake was due primarily to the oxidation of unesterified, polyunsaturated fatty acids, catalysed by lipoxygenase that is concentrated in the germ fraction. The increased O<sub>2</sub> demand of the stored materials was due to higher levels of polyunsaturated fatty acids, released during storage, by hydrolysis of triacylglycerols, catalysed by lipase that is concentrated in the bran fraction. According to O'Connor et al (1992), 75-80% of wheat lipase activity is located in the bran component of the grain. This work was done after these authors had established that very little lipase activity was found in the soluble fraction of the flour, providing evidence that lipase is membrane-bound (O'Connor & Harwood, 1992). Galliard (1986a) proposed that competition for oxygen between lipid oxidation and ascorbic acid oxidation in wholemeal dough might affect the improving action of the ascorbic acid and ultimately influence baking performance and loaf volume.

Further studies by Galliard (1986b) showed that the incipient rancidity of wholemeal flour, measured as the rate of oxygen uptake by aqueous suspensions, increased linearly with storage at 20°C and was correlated closely with increases in unesterified fatty acids. Fine milling of the bran, germ and blends of the two increased the rate of

deterioration and enhanced the synergistic effect between bran and germ on both O<sub>2</sub> uptake and fatty acid increases. Lipid analysis of bran-germ blends supported his conclusions that, during storage, there is a relatively slow (over several weeks) release of fatty acids, catalysed by a lipolytic enzyme in the bran component of wholemeal, but that lipid oxidation occurs rapidly (within minutes) when excess water is added, facilitating lipoxygenase-catalysed peroxidation of polyunsaturated fatty acids.

The theories obtained in the above investigations led to the study of the effect of changes in lipid composition during wholemeal storage on the baking quality (Tait & Galliard, 1988). A simple and relatively rapid method for measuring the lipase activity of wholemeal flour was developed. It involved the measurement of the increase in fatty acid content observed during incubation of unhydrated wholemeal at elevated temperatures. The lipase activities of the different samples of finely-milled wholemeal showed a high correlation with their known rates of deterioration. There appeared to be a close association between lipase activity and loss of baking performance during storage of wholemeal, with high lipase activity being associated with poor baking performance. Storage of wholemeal at 20°C for 23 weeks had a deleterious effect on baking quality (as measured by loaf volume and crumb texture). Interchanging the lipids between freshly-milled and stored wholemeals showed that the extracted lipid fraction from the stored wholemeal could account totally for the decreases in baking quality observed when using stored wholemeal flour. Other authors have also found that wheat fatty acids reduced loaf volumes (Bell et al, 1979). In addition, Warwick and Shearer (1982) found that gluten formation is inhibited by free fatty acids.

Galliard and Gallagher (1988) looked at the effect of bran particle size on deterioration rate (measured as O<sub>2</sub> uptake capacity) baking performance. They found that the rate of deterioration increased as the particle size decreased (Fig. 10).

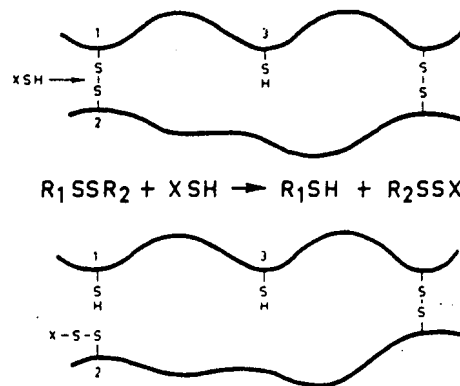


**Fig. 10: The effect of bran particle size on the rate of deterioration (measured as O<sub>2</sub> uptake capacity) of wheat bran during storage at 20°C. □, Bran as received (53% were 1-2 mm); ▲, bran < 0.5 mm; ✕, bran = 0.5-1 mm; ●, bran = 1-2 mm; ■, bran > 2 mm (Galliard & Gallagher, 1988)**

Fine milling of 20 and -20°C-stored bran immediately before blending and baking had no effect on the baking performance when compared with blends containing untreated bran. However, when the bran was finely milled on receipt and then stored at 20 or -20°C for one month before blending with flour, the resultant loaf volumes were lower than the equivalent values with untreated bran or with bran milled immediately before use.

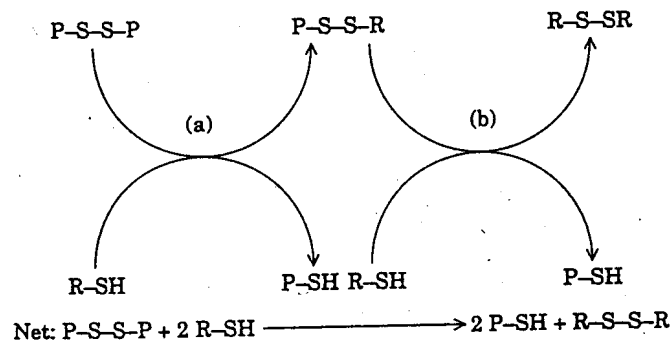
Nelles et al (1998) also found that a wet heat treatment of bran, which practically inactivated lipase and lipoxygenase activities, resulted in higher loaf volumes. From all these studies it can be concluded that the reduction in baking performance may be due mainly to the presence of lipid metabolising enzymes present in bran and germ fractions. Hydrolysis of triacylglycerols, by lipase present in the bran, leads to the accumulation of predominantly polyunsaturated fatty acids which are oxidised by lipoxygenase (present in the germ) when the flour and bran are subsequently hydrated (Tait & Galliard, 1988). This results in a poorer baking quality and a decrease in loaf volume.

Another chemical constituent which may also be responsible for a reduction in loaf volume, is the tripeptide glutathione ( $\gamma$ -glutamylcysteinylglycine; GSH) (Sullivan et al, 1936; Hullet & Stern, 1941; Schofield & Chen, 1995; Chen & Schofield, 1996) which is present in substantial amounts the germ (Bloksma & Bushuk, 1988). The role of protein sulphhydryl (SH) and disulphide (SS) groups in breadmaking is well established. The SS bonds are important because they form cross-links between polypeptide chains and because, by reacting with SH groups, they can interchange (Fig. 11) (Pomeranz, 1988).



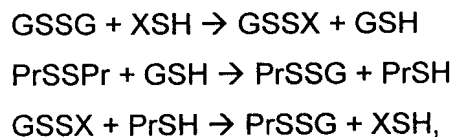
**Fig. 11: Thiol-disulphide interchange reactions in the protein network of dough (Bloksma & Bushuk, 1988)**

Numerous low molecular weight SH compounds are present in flour and they could play important roles in determining dough properties. At high concentration they may cause a net reduction of protein SS bonds through two consecutive SH/SS interchange reactions, themselves becoming oxidised disulphides (Fig. 12). At lower concentrations, a single SH/SS interchange reaction may cleave a protein disulphide bond. The products are a mixed disulphide, comprising the protein and the low molecular weight SH compound, and a free protein SH group (Fig. 12(a)) (Schofield & Chen, 1995).



**Fig. 12: Schematic representation of protein disulphide bond cleavage by two consecutive SH-SS interchange reactions (Schofield & Chen, 1995)**

Of particular interest in the context of the polymeric structure of glutenin and the redox reactions that might affect it, has been the possible role of the GSH (Schofield & Chen, 1995). GSH may cause a reduction in the cohesive molecular forces within the dough by permanent cleavage, or by catalysing disulphide interchange (Ewart, 1985). Oxidised glutathione (GSSG) has been reported to affect dough in the same direction as does the reduced form (GSH), although to a lesser extent. This can be explained by a series of interchange reactions:



Where Pr = protein, GSH = reduced glutathione, GSSG = oxidised glutathione, PrSSG = protein-glutathione mixed disulphides and XSH = an arbitrary thiol compound. In this series of interchange reactions, rheologically ineffective mixed disulphides are formed at the expense of effective cross-links between protein chains (Bloksma & Bushuk, 1988). This may ultimately lead to a reduction in baking performance and loaf volume. Indeed, Chen and Schofield (1996) found that during short-term storage of white wheat flour, GSH levels decreased with a concomitant increase in flour breadmaking performance during the first 10 days of storage. Thereafter, GSH levels remained constant up to 40 days of storage, as did flour breadmaking performance. Nelles et al (1998) also found

that a wet oxidation treatment of bran, which lowered the levels of potentially oxidisable substances such as GSH, resulted in higher loaf volumes.

*Physical effect of bran on loaf volume*

Gan et al (1989) studied the crumb microstructure of wholemeal bread using SEM. This technique revealed that the wholemeal crumb, which contrasts markedly with that of white bread, is coarse and consists of thick gas-cell walls and a discontinuous gluten-protein matrix (Fig. 13). It is characterised by the presence of non-endosperm components of the wheat caryopsis, including bran, epicarp hairs and particles rich in aleurone-pericarp. The non-endosperm components, notably the epicarp hairs, appeared to play a prominent role in disrupting the gluten-protein matrix. Epicarp hairs are seen to be either closely aligned with the surface of the gas-cell wall and or protruding at various angles from the gluten-protein matrix. In some cases, a single hair appears to puncture the surface of the gas-cell wall leaving a small fraction of the protein matrix at the tip of the hair (Fig. 14). Removing the epicarp hairs by pearling significantly improved the baking performance of the resulting flour. The flour from pearled wheat increased loaf volume with 8.5% when compared with wholemeal bread. Pearlings, in which most of the epicarp hairs present, detrimentally affected the baking performance when added back to flour milled from pearled wheat (Gan et al, 1989).



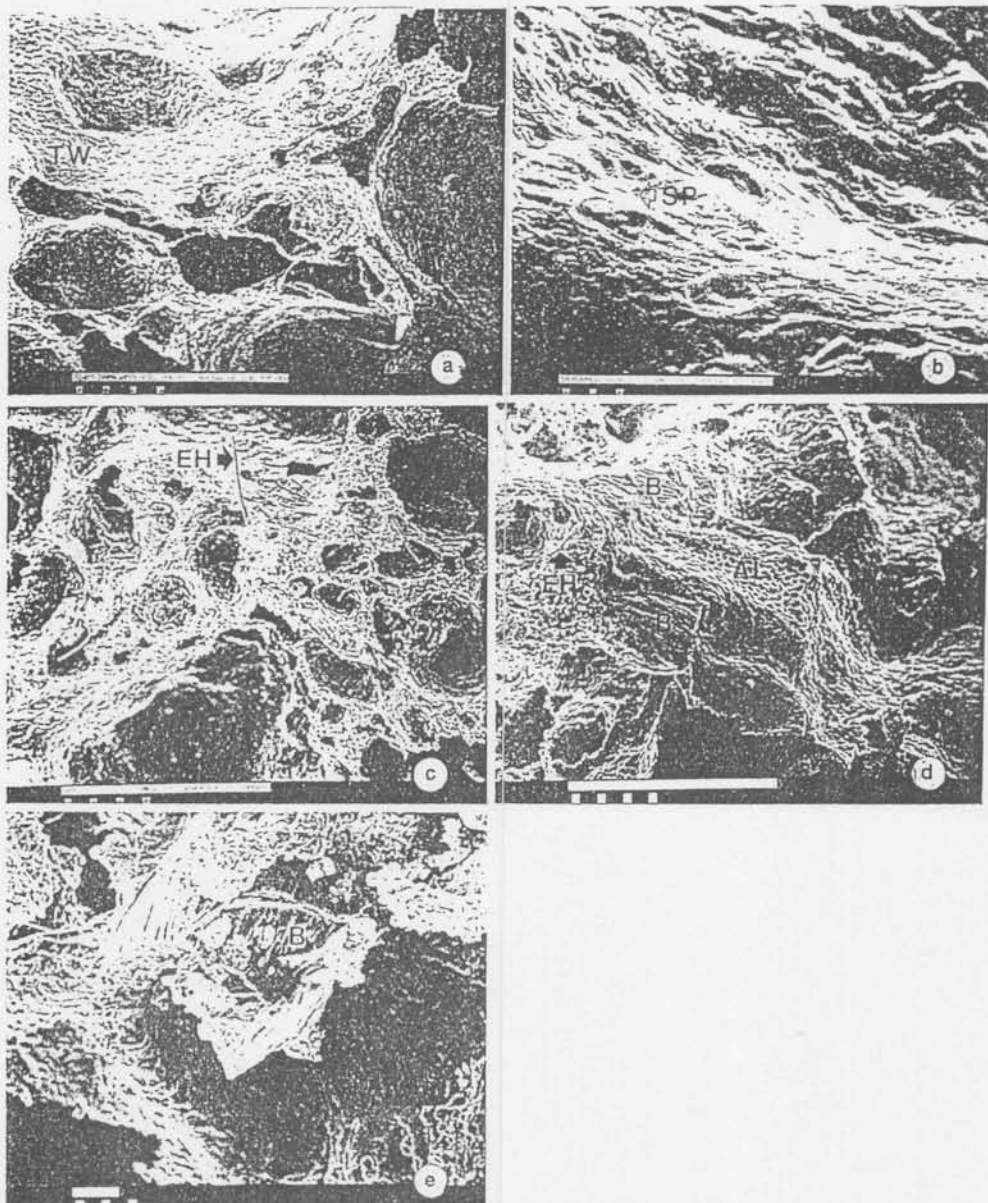
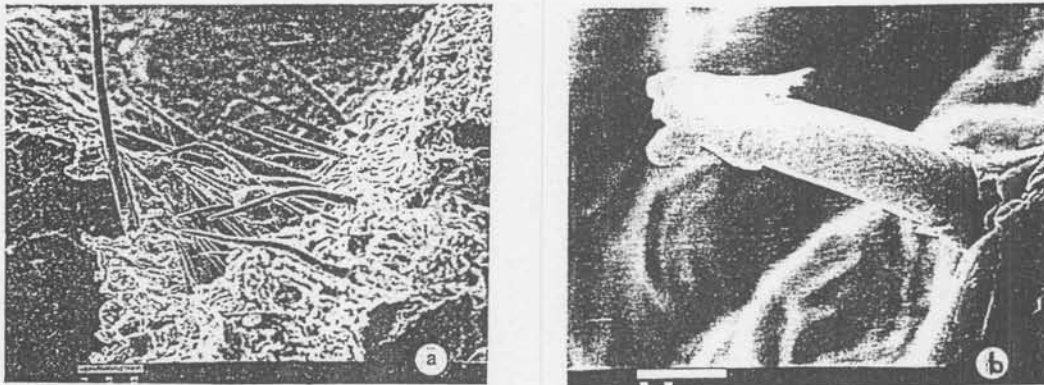


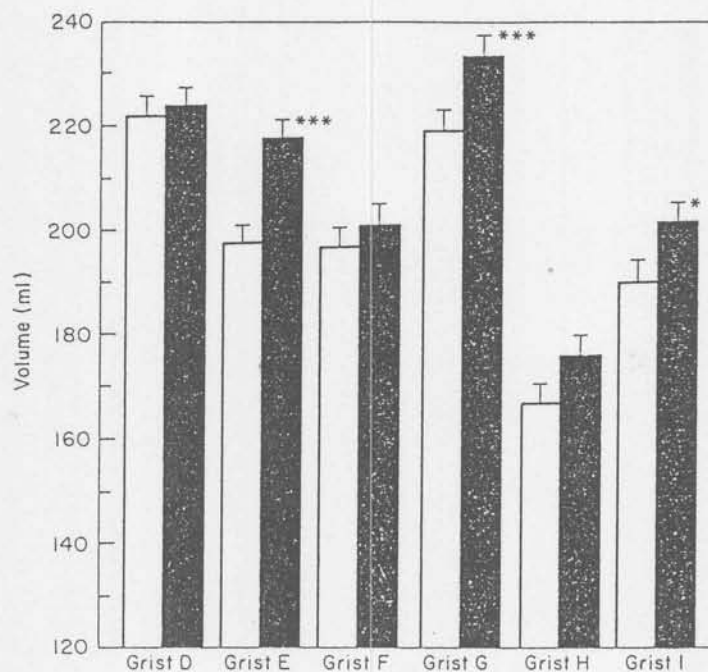
Fig. 13: Scanning electron micrographs of white bread showing (a) thin gas-cell walls; (b) small pores (SP) in the gas-cell wall; and whole meal bread showing (c) epicarp hairs (EH); (d) epicarp hairs (EH), aleurone layer (AL) and bran particle (B); (e) disruption of the gluten-protein matrix by a large particle of bran. Bar = 1000 $\mu$ m (with four squares), =100 $\mu$ m (with three squares) (Gan et al, 1989)





**Fig. 14: Scanning electron micrographs of wholemeal bread showing (a) epicarp hairs and the starch-protein matrix; and (b) a single hair that has punctured the starch-protein matrix and a fraction of protein at the tip of the hair (Gan et al, 1989)**

Gan et al (1992) took this investigation further by studying the effect of the outer bran layers of wheat on the breadmaking quality (loaf volume) of flour by the abrasion (pearling) of wheat grains prior to milling. When the outer layers of six wheat grists were removed by pearling, three of the grists produced loaves with significantly higher volumes than the corresponding controls (Fig. 15). For the three grists giving an improvement in breadmaking quality, the average increase in volume was about 7.4%.



**Fig. 15: Volumes of loaves produced from six wheat grists, pre- and post-pearling.**  
 \*\*\* differences significant at  $P < 0.001$  level; \* difference significant at  $P < 0.05$  level. □ - Controls; ■ - Bread produced from the flours of pearled grists (Gan et al, 1992)

Bran materials collected from a sequential pearling process affected baking performance detrimentally when added to a wholemeal control of a unpearled grist and to a composite flour (white flour plus 12.5% bran). The most marked depression in loaf volume was observed when the outermost bran fraction containing the highest concentration of epicarp hairs was incorporated into the breadmaking recipe. Heat treatment of this fraction did not diminish its adverse effect on loaf volume, suggesting that heat sensitive components (e.g. enzymes) are not implicated. Also the differences in original unesterified free fatty acid levels between the white flour, the wholemeal and the flour from pearled wheat grain were found to be small, and were unlikely to account for the observed differences in baking performance. Microscopical examination of the wholemeal dough suggested that non-endosperm components induce serious structural distortion of gas cells and may contribute to the resultant crumb morphology, which is an important element of crumb texture (Gan et al, 1992).

A few authors have looked at the effect of bran particle size on loaf volume depression. Some found that finely ground bran produced higher loaf volumes than coarse bran (Pomeranz et al, 1977; Moder, Finney, Bruinsma, Ponte & Bolte, 1984; Lai et al, 1989b). Özboy and Köksel (1997), however, found that coarse bran showed unexpected strengthening effects on dough rheology and had a lessened deleterious effect on loaf volume. Brans used in these different studies had different proportions of chemical components such as crude fibre, ash and protein. Factors which could influence bran composition include cultivar (Moder et al, 1984; Pomeranz, 1988; Özboy and Köksel, 1997), the mill steam from which the bran has been taken (N Dumas, Ruto Mills – Personal communication, Pomeranz, 1988; Bass, 1988), as well as the milling regime (Oakenfull & Topping, 1987). Thus bran is not a substance of uniform composition and it is possible that the differences in composition could account for the contradicting data on the effects of particle size on loaf volume.

## **2.4 THE INFLUENCE OF BRAN ON BAKED BREAD QUALITIES**

### **2.4.1 Sensory qualities**

Pomeranz et al (1977) found that untrained taste panels consistently indicated that at all replacement levels a detectable change from added bran was not objectionable. The panels also found that bran darkened the crumb and crust and shifted the red colour component in the crust towards grey-red. Moder et al (1984) found that bread made with finely ground red bran had a darker colour than bread made with a coarse red bran.

### **2.4.2 Bread crumb structure**

SEM and light microscopy of white and brown bread done by Pomeranz et al (1977) revealed a major difference between the crumb structure of the control (white) and breads containing fibre (brown). The control bread had a fine crumb structure composed of thin sheets and filaments. Such a structure was essentially absent in the bran-containing breads. To produce a loaf of bread with a light and even crumb texture, the dough must be able to retain the gases produced by yeast fermentation as discrete gas cells for a sufficiently long period (Bloksma, 1990). Gan et al (1995) proposed that loss

of gas retention during baking is caused by the rupture of the liquid lamellar film which lines gas cells in the dough structure.

Moder et al (1984) also found that bread produced from a finely ground bran showed a finer and more uniform crumb grain structure, when compared to bread produced from a coarse bran.

## **2.5 METHODS TO IMPROVE LOAF VOLUME OF BROWN BREAD**

Quite a few methods have been proposed to increase the loaf volume of brown and whole wheat bread. Shogren et al (1981) found that the deleterious effects of up to 15 parts of wheat bran per 85 parts of wheat flour could largely be counteracted with the addition of vital gluten (together with surfactants). Gan et al (1989) also supplemented wholemeal flour with gluten and found an increase in loaf volume. Shogren et al (1981) found that surfactants also improved loaf volume. Similar results were found by Lai et al (1989a).

Lai et al (1989a) also reported that the addition of certain salts (such as phosphates) improved loaf volume. Additionally they found that a reconstituted whole wheat bread with a loaf volume equal to the control was obtained by allowing endogenous lipoxigenase (soaking the non-flour milling fractions) or added lipoxigenase to oxidise the glutathione from the germ and using optimum water absorption.

Moder et al (1984) compared coarse brans and shorts (mixture of germ, aleurone and pericarp layers) in breadmaking to those that were finely ground. Finely ground bran and shorts produced somewhat higher loaf volumes than that for coarse bran and shorts.

Nelles et al (1998) studied three different bran treatments: hydration, wet heat and wet oxidation. They found that all treatments improved brown bread quality significantly, resulting in larger, softer loafs. All treatments resulted in an increase in water absorption of brown bread dough and a decrease in potentially oxidisable substances in bran.



## **2.6 SUMMARY**

In South Africa brown bread is produced by addition of bran to white flour. This causes a reduction in loaf volume and bread quality. Although published information on this subject is limited, there is a clear indication that both chemical and physical factors could be responsible for this phenomenon. The negative effect of bran on bread texture and loaf volume can not be fully accounted for on the basis of dilution of the gluten proteins (Pomeranz et al, 1977). Active constituents of bran and germ interact with gluten proteins and other flour constituents to prevent the development of anticipated rheological properties and bread qualities. The key chemical constituents of bran and germ appear to be the lipid and lipolytic enzymes (Galliard, 1986a). Apart from the chemical constituents, bran also exerts a physical effect which adversely affects bread quality (Gan et al, 1992).

Modification of rheological and subsequent quality properties of doughs can result by several mechanisms: inhibition of gluten formation by free fatty acids (Warwick & Shearer, 1982); lipid hydrolysis, by lipase present in the bran, which produces polyunsaturated fatty acids that are oxidised by lipoxygenase (present in the germ) (Tait & Galliard, 1988); modification of the gluten proteins resulting from the reduction of disulphide bonds by glutathione (Schofield & Chen, 1995; Chen & Schofield, 1996); physical effect of epicarp hairs and bran particles on gluten structure (Gan et al, 1989; Gan et al 1992); as well as the physical effect of different bran types and sizes on loaf volume (Pomeranz, 1977; Moder et al, 1984; Lai et al, 1989b; Özboy & Köksel, 1997).

It is proposed that brown bread quality could be improved if the interplay between numerous chemical and physical effects of bran could be elucidated.

## **CHAPTER 3: MATERIALS AND METHODS**

### **3.1 RAW MATERIALS**

#### **3.1.1 Bran**

To investigate the effect of bran origin, ten samples of wheat (50 kg) of widely different origins were obtained from Ruto Mills (Pretoria, South Africa) and the South African Wheat Board. Their origin and protein content ( $N \times 5.7$ ) on a dry weight basis (in brackets) were as follows: 1-UK (10.9%) (soft winter wheat), 2-Germany (12.7%) (soft winter wheat), 3-Canada (14.7%) (hard spring wheat), 4-USA (15.3%) (hard winter wheat), 5- Western Cape (12.8%) (hard winter wheat), 6-Free State (18.1%) (hard winter wheat), 7-Western Cape (12.6%) (hard winter wheat), 8-Free State (14.8%) (hard winter wheat), 9-Free State (16.9%) (hard winter wheat) and 10-Mpumalanga (13.5%) (hard winter wheat). The wheat samples were milled using a Buhler Miag roller mill and the bran was collected in each case. A bran fraction of  $>0.85$  mm -  $<1.61$  mm (approximately the same as that generally used in the South African baking industry) was obtained by sieving. The bran samples were packed in high density polyethylene bags and stored frozen at  $-20^{\circ}\text{C}$ .

To investigate the effect of bran type, bran particle size and effect of heat treatment, three different bran fractions, defined by the South African milling industry in terms of sieve size, were collected from different mill streams at Ruto Mills, Pretoria:

- Pollard (specified size  $< 0.75$  mm)
- Select (specified size  $> 0.75$  mm,  $< 1.8$  mm)
- Digestive (specified size  $> 1.8$  mm)

The bran was packed in high density polyethylene bags, and stored at  $-20^{\circ}\text{C}$ .

The protein, starch, moisture, ash, fibre and fat contents of the bran were determined.



### 3.1.1.1 Protein

Protein was determined by the Kjeldahl AACC method 46-12 (American Association of Cereal Chemists, 1983a) with slight modification. The method was based on the wet combustion of bran by heating it with concentrated sulphuric acid in the presence of a Kjeltab catalyst (potassium sulphate : copper sulphate : selenium at 100:6:1) to effect the reduction of organic nitrogen in the sample to ammonia, which was retained as ammonium sulphate. The digest, having been made alkaline, was distilled to release the ammonia which was trapped in a 4% boric acid solution, and then titrated with 0.1 M HCL, rather than H<sub>2</sub>SO<sub>4</sub>. The protein content was calculated as follows:

$$\% \text{Protein} = \frac{T \times N \times 1.4007 \times 5.7}{m}$$

Where T = titration figure (ml)

m = mass sample (g)

N = normality of HCl

### 3.1.1.2 Starch

A modification of the Ewers polarimetric method for starch determination was used. It is based on the principle that starch, which is optically active, rotate polarised light to an extent proportional to its concentration (Pomeranz & Meloan, 1994).

#### Reagents

0.3084 M HCl

4% Tungstophosphoric acid (4 g/100 ml)

#### Method

Bran was milled fine enough to go through a 0.8 mm sieve. A 2.5 g sample was weighed into a 100 ml erlenmeyer flask. HCl (50 ml) was added and placed in a boiling water bath for exactly 15 minutes and stirred every 5 minutes. It was then cooled in cold water to approximately 20°C. The mixture was transferred quantitatively to a 100 ml volumetric flask. Tungstophosphoric acid (10 ml) was added and made up to 100 ml with distilled water. A double filtration with Whatman No. 4 filterpaper was done until the



filtrate was more than 60 ml. The rotation angle on the polarimeter was read. The starch content was calculated as follows:

$$\%Starch = \frac{\alpha \times 10.94 \times 100}{100 - moisture\%}$$

Where  $\alpha$  = angle of rotation (degrees)

### 3.1.1.3 Moisture

The moisture was determined in a Brabender moisture oven (Duisburg, Germany). Approximately 10 g of sample was dried at 131°C for 1 hour, after which the weight difference was determined.

### 3.1.1.4 Ash

A magnesium acetate method, described by Pomeranz and Meloan, (1994), was used to determine ash content.

#### Reagents

Magnesium acetate (30 g) was dissolved in 150 ml distilled water and made up to 2 litres with 96% ethanol.

#### Method

Clean silica crucibles were heated in a muffle furnace at 700°C for 30 minutes and allowed to cool in a sealed desiccator containing fresh desiccant. The mass of a crucible was determined to 4 decimal places of a gram. Bran (ca. 5 g) was weighed accurately into the crucible and the mass noted. Magnesium acetate solution (5 ml) was pipetted onto the sample. The sample was ignited and left to burn out. The crucibles were placed in the muffle furnace for 3 hours after the temperature reached 700°C. After removing the crucibles from the oven, they were allowed to cool in a desiccator to room temperature. The mass of each crucible containing ash was determined immediately. A blank sample was also prepared. The % ash was calculated as follows:

$$\%Ash = \frac{(Mass_{ash} - Blank) \times 100 \times 100}{Mass_{sample} \times (100 - moisture\%)}$$

### 3.1.1.5 Fibre (acid detergent)

Fibre was determined with an acid detergent method.

#### Reagents

Acid detergent: N-cetyl-N,N,N-trimethyl ammonium bromide (100 g) was dissolved in ca. 3 litres distilled water in a 5 litre beaker. Concentrated sulphuric acid (204 ml) was added very slowly while stirring. The mixture was left overnight, transferred to a 5 litre volumetric flask and made up to volume with distilled water.

#### Method

Bran (ca. 1 g) was weighed in duplicate into 600 ml beakers. Samples were wetted with decahydronaphthalene (2 ml). Hot acid detergent (200 ml) was added to the sample. It was then boiled under reflux conditions for 1 hour. The crucibles were dried for 1 hour at 105°C, cooled in a desiccator and weighed after 30 minutes. After 1 hour, beakers with samples were removed from hotplates and filtered through crucibles using a water suction pump. The beakers were rinsed three times with ca. 50 ml hot distilled water and filtered through. Fibres were scraped from the sides of the beakers with a spatula, rinsed with acetone and filtered through. The fibre containing crucibles were placed in an oven at 105°C for 1 hour, cooled in a desiccator for 30 minutes and then weighed.

The % fibre was determined as follows:

$$\%Fibre = \frac{(M_{cf} + M_c) \times 10000}{M_s \times (100 - moisture\%)}$$

Where

$M_{cf}$	= mass of crucible and fibre
$M_c$	= mass of crucible
$M_s$	= mass of sample

### 3.1.1.6 Fat

The AACC method 30-25 (American Association of Cereal Chemists, 1983b) was used to determine the crude fat content of the bran. Fat was extracted with petroleum ether in

Soxhlet extractors. After removing the ether from the samples by evaporation, the remaining fat was weighed. The fat content of the bran was determined as follows:

$$\%Fat = \frac{M_f \times 100}{M_s}$$

Where  $M_f$  = mass of fat (g)  
 $M_s$  = mass of sample (g)

### **3.1.2 Base flour**

For investigation into the effect of bran origin, a common base flour of 14.3% protein (N  $\times$  5.7) (dry basis) was used.

For investigation into the effect of bran type, bran particle size and effect of heat treatment, a base flour from the same grist as the bran was collected from Ruto Mills (Pretoria). The protein content (N  $\times$  5.7) of the base flour was 13.6% (dry basis).

The moisture content of the grain and flour was determined the same way as for the bran.

The flour was also stored at -20°C.

## **3.2 METHODS**

### **3.2.1 Heat treatment**

The bran samples were subjected to a heat treatment to eliminate heat-sensitive components that could be responsible for a decrease in loaf volume (e.g. enzymes) (Gan et. al, 1992). Preliminary heat treatments of the brans were carried out by autoclaving them in moisture-tight vessels at 121°C for 20 minutes, 30 minutes and 1hour. The heat-treated brans were compared with the untreated brans with the use of the following tests:

Lipase activity, to determine whether the heat sensitive components had been eliminated ;

Colour (Hunterlab), moisture (oven-method) and size of the bran particles, to determine the effect of the heat treatment on the physical properties of the bran.

The brans used as *heat-treated* brans in further investigations were autoclaved in moisture-tight containers at 121°C for 1.5 hours. The same baking tests were performed using the heat-treated and the untreated brans.

### **3.2.2 Baking tests**

#### **3.2.2.1 Premixes**

##### **Formulation**

The premix formulations for brown and white bread (control) are given in Tables 9 and 10 respectively.

**Table 9: Premix formulation for brown bread**

<b>Ingredients</b>	<b>Percent (% based on flour)</b>	<b>Mass (g) per batch</b>
Salt	2.00	3000
Fat	1.00	1500
Sugar	0.50	750
Soya flour (full fat)	0.50	750
Preservative (Ca-propionate)	0.15	230
Ascorbic acid	0.0075	11.3
Fungal $\alpha$ -amylase (South Bakels, Johannesburg)	0.0080	12.0

**Table 10: Premix formulation for white bread**

<b>Ingredients</b>	<b>Percent (% based on flour)</b>	<b>Mass (g) per batch</b>
Salt	2.00	1000
Fat	1.00	500
Sugar	0.50	250
Soya flour (full fat)	0.50	250
Preservative (Ca-propionate)	0.15	80
Ascorbic acid	0.0075	3.8
Fungal $\alpha$ -amylase (South Bakels, Johannesburg)	0.0050	2.5

#### Preparation

The soya flour, ascorbic acid and amylase were mixed in a Hobart paddle mixer for 10-15 minutes. After addition of the Ca-propionate, it was mixed for another 10 minutes.

The mixture was transferred to a larger paddle mixer. Sugar, salt and fat were added allowing for a 15 minute mixing time between each addition.

The premix was stored in sealed bins at 12°C.

#### 3.2.2.2 Bread formulation

For the investigation into bran type, bran particle size and effect of heat treatment, three levels of bran addition were used (9, 12, and 15% flour weight basis) and for the investigation into the effect of bran origin, a single level (15%) was used. The formulation of the brown and white bread (control) is given in Table 11.

**Table 11: Formulation of white and brown bread with 9, 12, and 15% bran addition**

Ingredient	Control (white bread)		9% bran		12% bran		15% bran	
	% <sup>b</sup>	Mass (g)	% <sup>c</sup>	Mass (g)	% <sup>c</sup>	Mass (g)	% <sup>c</sup>	Mass (g)
Base flour	100	1200	91	1092	88	1056	85	1020
Bran	0	0	9	108	12	144	15	180
Premix <sup>a</sup>	4.2	50	4.2	50	4.2	50	4.2	50
Yeast	2	24	2	24	2	24	2	24
Water	61	732	63	756	63	756	63	756

<sup>a</sup>Salt (2.0%), fat (1.0%), sugar, (0.5%), soya flour (0.5%), preservative (0.15%), ascorbic acid (0.0075%) and fungal  $\alpha$ -amylase (0.005% for white bread and 0.008% for brown bread)

<sup>b</sup>Based on flour

<sup>c</sup>Based on flour and bran mix

### 3.2.2.3 Baking procedure

A mechanical dough development baking process was used. The flour and the bran were first mixed together in a Chopin 10 litre mixer for 5 minutes, and the yeast was dissolved in part of the water ( $\pm 17^\circ\text{C}$ ). The flour plus bran and premix were put into the dough mixer (Morton Machine Coy, Ltd. Wishaw, Scotland, Ref no. 17822/M, Model NO/O.DUP), and then the water and yeast solution were added. The dough was mixed at high speed (11.0 Wh/kg). Two 900 g pieces of dough were allowed to rest for 10 minutes and were then formed in a dough former (Mono Universal No 71/09835 D. Ayres Jones & Co, Ltd. Swansea, Great Britain). The loaves were placed in greased, open pans, before being proved in a proof oven for 70 minutes at  $40^\circ\text{C}$ , 95% RH. The loaves were then baked for 30 minutes at  $230^\circ\text{C}$  in a rotary test baking oven (Simon Rotary Test Baking oven, Henry Simon, Ltd. Stockport, Great Britain No 36265). After cooling, loaf volumes (by rape seed displacement) and heights were measured.



The baking tests were repeated six times for the investigation into bran type, bran particle size and effect of heat treatment, and twice for the investigation into bran origin. A white bread control was baked with every batch.

### **3.2.3 Image analysis**

Brans were subjected to IA using a Tracor Northern 8502 Image Analyzer (Tokyo, Japan). Samples were placed on black cardboard. A video camera, positioned over the samples, was directly connected to the main computer of the image analyzer. It was attempted to put as many particles as possible in a single layer in the visible field of view of the camera. The image analyzer then calculated the following parameters of the bran particles: Number of particles in the field, area, external perimeter, roughness, minimum projection, maximum projection, mean projection, standard deviation projection, width and aspect ratio.

### **3.2.4 Scanning electron microscopy (SEM)**

A stub was fitted with double-sided tape and covered with bran in a single layer. Samples were then gold coated and studied using a Hitachi S-450 electron microscope (20 times magnification).

### **3.2.5 Lipase**

The method of Sullivan and Allison Howe (1933) was used. Lipase present in the bran hydrolysed triacetin (added substrate) under standardised conditions into free fatty acids which were determined titrimetrically with standard alkali.

### **3.2.6 Total reducing substances (TRS)**

The AACC method 10-01 for total reducing substances (American Association of Cereal Chemists, 1983c) was used with slight modification. Bran (5g instead of 2 g) was extracted with 50 ml (instead of 25 ml) 10% (w/v) trichloroacetic acid. After centrifugation, 20 ml clear supernatant and 3 ml standardised 0.005 M iodine solution was titrated against 0.005 M sodium thiosulphate, using 1 ml of a 2% starch solution as



indicator. Iodine that was not reduced by reducing substances present in the bran was determined titrimetrically.

### 3.2.7 CAT scans

To investigate bubble formation during proofing, bread loafs were CAT scanned by a Philips CAT scanner at the Johannesburg General Hospital. A white bread control, together with three brown breads (15% addition of three bran types) were studied. Doughs were developed as described. Four dough pieces (800 g) were placed in open glass loaf pans (235 mm X 130 mm X 70 mm) and taken to Johannesburg General Hospital where they were placed in a proofing oven at 40°C. The relative humidity was regulated by spraying the inside of the oven with water every 5 minutes. The first loaf was scanned after 0 minutes of proofing, the second after 20 minutes, the third after 40 minutes and the last loaf after 60 minutes. At each time interval, four slices were scanned (Fig. 16).

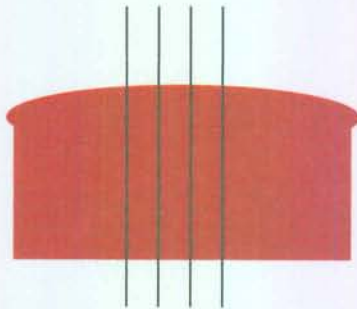


Fig. 16: CAT scan slices of bread

The loafs were scanned with the same settings as a lung:

Scanogram length:	250 mm
Scanogram tube angle:	+180
Tube voltage:	120 kV
Tube current:	100 mA
Field of view:	70
Scan time:	4.0 s
Gantry angulation:	0.0
Convolution filter:	5

Slice thickness: 1.5 mm  
Matrix size: 320

The CAT scans were then image analysed in order to determine bubble area, length, perimeter and roundness.

### **3.2.8 Sensory evaluation**

#### *3.2.8.1 Test objectives*

The test objectives were to compare the acceptability of brown bread baked with different bran types and to determine preference by:

- Evaluation of visual appearance, both internally and externally
- Evaluation of the following sensory quality characteristics on a seven-point scale:  
Texture, moistness, graininess, chewiness, taste and overall acceptability

An example of the score sheet is given in Appendix A.

#### *3.2.8.2 Panel*

Use was made of five panelists who are experts in the field of bread baking. The panelists were familiarised with the score sheet, as well as with the terms used to describe the various characteristics of the product.

#### *3.2.8.3 Test environment*

An air-conditioned panel room with partitioned booths was used. The use of individual booths eliminated any distractions and prevented communication between panelists. The conditions in the testing area were controlled and panelists were supervised throughout the testing period. White light conditions prevailed in order to ensure that the product appearance was not influenced by lighting, as proposed by Larmond (1977).

#### *3.2.8.4 Test material*

Six different types of brown bread were evaluated. The bran types that were used were as follows: pollard, heat-treated pollard, select, heat-treated select, digestive and heat-



treated digestive bran. All the breads were baked with a 12% level of bran addition to simulate bread baked in industry. The breads were cut into cubes and each panelist received a representative sample of each of the six breads.

### **3.2.9 Statistical analysis**

Analysis of variance was carried out using the Statgraphics programme version 5.0 (Statistical Graphics Corporation, Wiley & Sons, New York). The Least Significant Difference test was used at the 95% significance level.

## CHAPTER 4: RESULTS

### 4.1 RAW MATERIALS

#### 4.1.1 Bran

The composition of bran fractions obtained from a standard grist of hard bread wheat is given in Table 12.

**Table 12: Proximate composition (%) of brans**

Bran	Moisture	Protein <sup>a</sup> (N×5.7)	Ash <sup>b</sup>	Fat <sup>b</sup>	Fibre <sup>b</sup> (acid detergent)	Starch <sup>b</sup>
Pollard	10.5	17.3	4.1	6.4	9.5	28.4
Heat-treated pollard	10.0	17.4	4.2	6.4	9.8	28.0
Select	11.3	15.3	5.6	5.8	15.0	20.0
Heat-treated select	11.0	15.3	5.6	5.8	16.4	19.8
Digestive	12.0	15.4	6.3	5.6	18.8	13.5
Heat-treated digestive	11.7	15.4	6.4	5.6	19.4	13.2

<sup>a</sup>12% moisture basis

<sup>b</sup>Dry basis

From this table it is evident the Digestive bran had the highest fibre and ash content, with an accompanying low fat and starch content. Pollard had highest fat and starch content, and roughly only half of the fibre and starch of digestive bran. Select bran had values between Pollard and Digestive bran. Heat treatment did not have any significant effect on bran composition.

#### 4.1.2 Base flour

The properties of the base flour are given in Table 13.

**Table 13: Base flour properties**

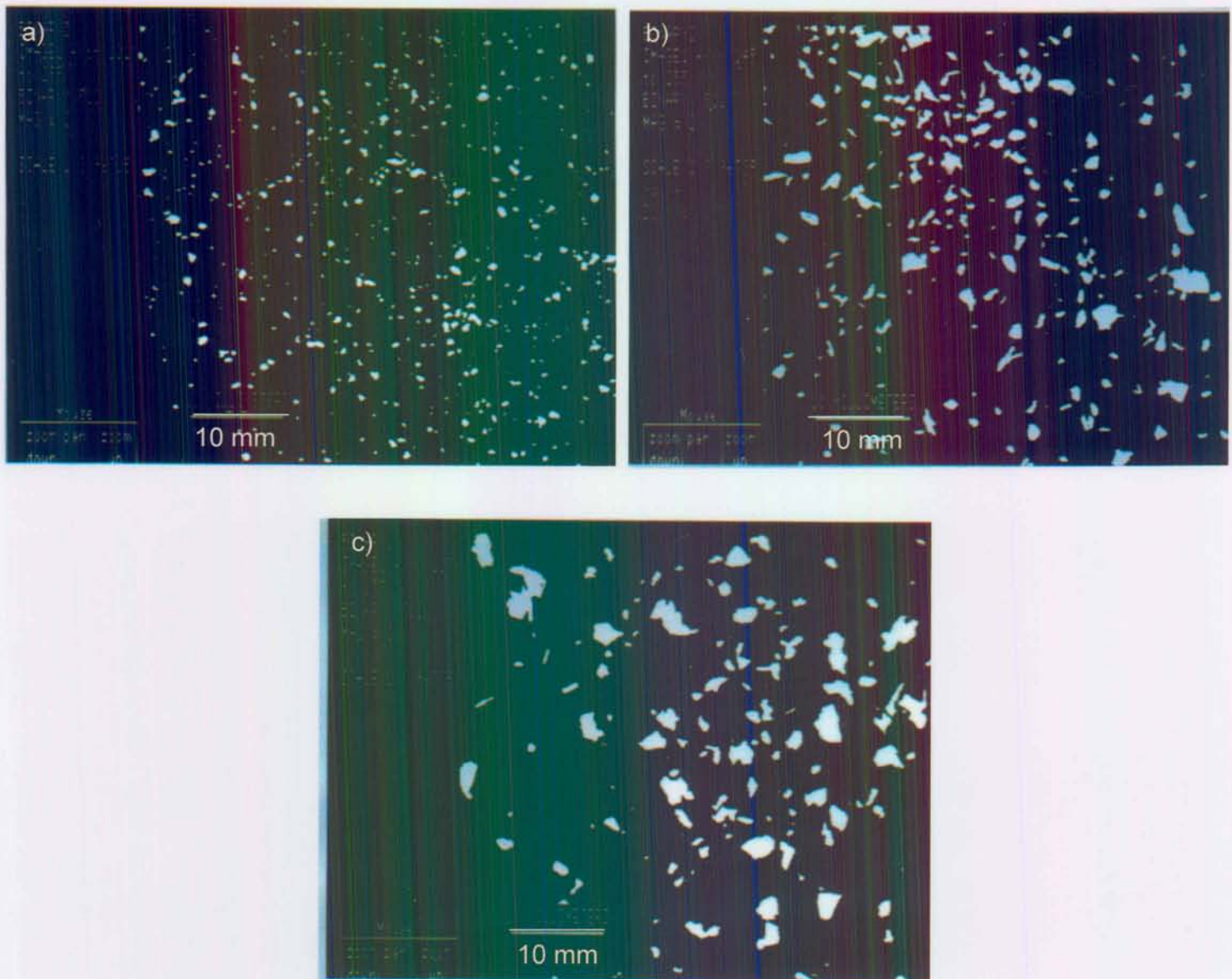
<b>Property</b>	
Moisture (%) (Brabender)	12.2
Ash (%)	0.76
Kent Jones colour units	4.00
Falling number (s)	485
Protein (%) (N $\times$ 5.7 - dry basis)	13.63
Diastatic activity (%)	2.39
Damaged starch (%)	13.61
Wet gluten (%)	31.34
Baking performance	B1 (good commercial quality)
Bread height (cm)	15.3
<b>Chopin alveograph</b>	
Stability P (Height $\times$ 1.1mm)	103.4
Distensibility L (mm)	94
P/L value	1.10
Strength (cm <sup>2</sup> )	28.0
<b>Brabender farinograph (500 BU)</b>	
Water absorption	64.5
Development time (min)	5.4
Stability (min)	12.7
<b>Brabender extensograph</b>	
Strength (cm <sup>2</sup> )	112.0
Extensibility (cm)	21.1

The base flour was a fairly strong flour with a protein content of 13.6%. Water absorption was 64.5%. Dough development time and stability, as shown by the farinograph data, were good, and the extensograph proved that the dough had a fairly high resistance and extensibility.



## 4.2 IMAGE ANALYSIS

A binary image of the different brans is presented in Figure 17.

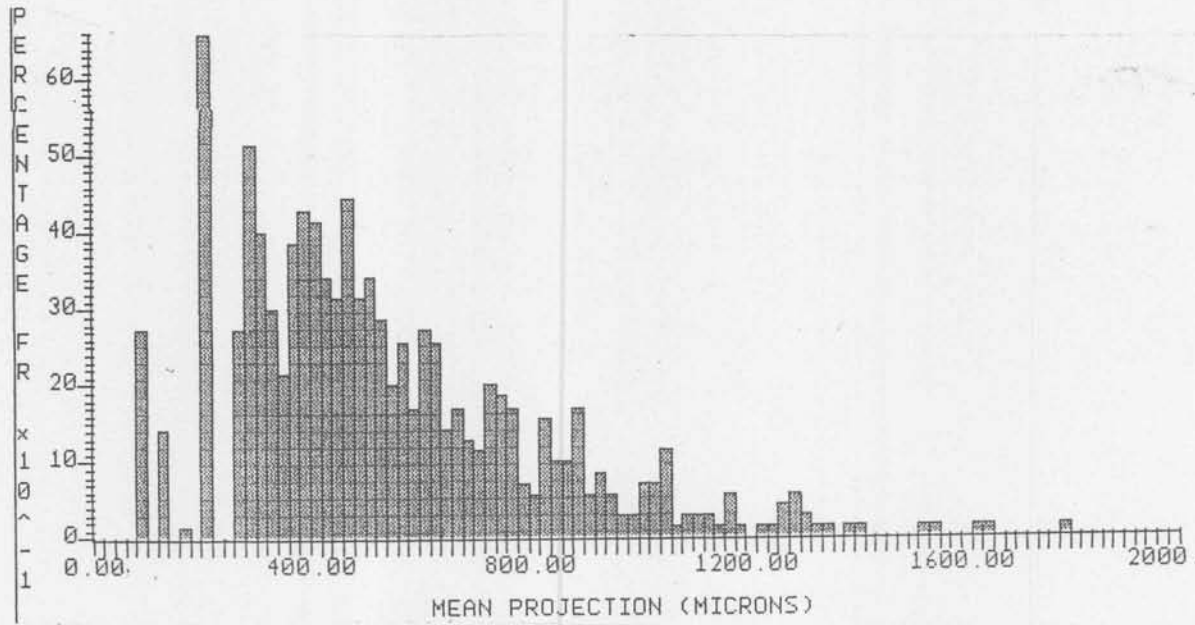


**Fig. 17:** Image analysis of a) Pollard; b) Select bran; and c) Digestive bran

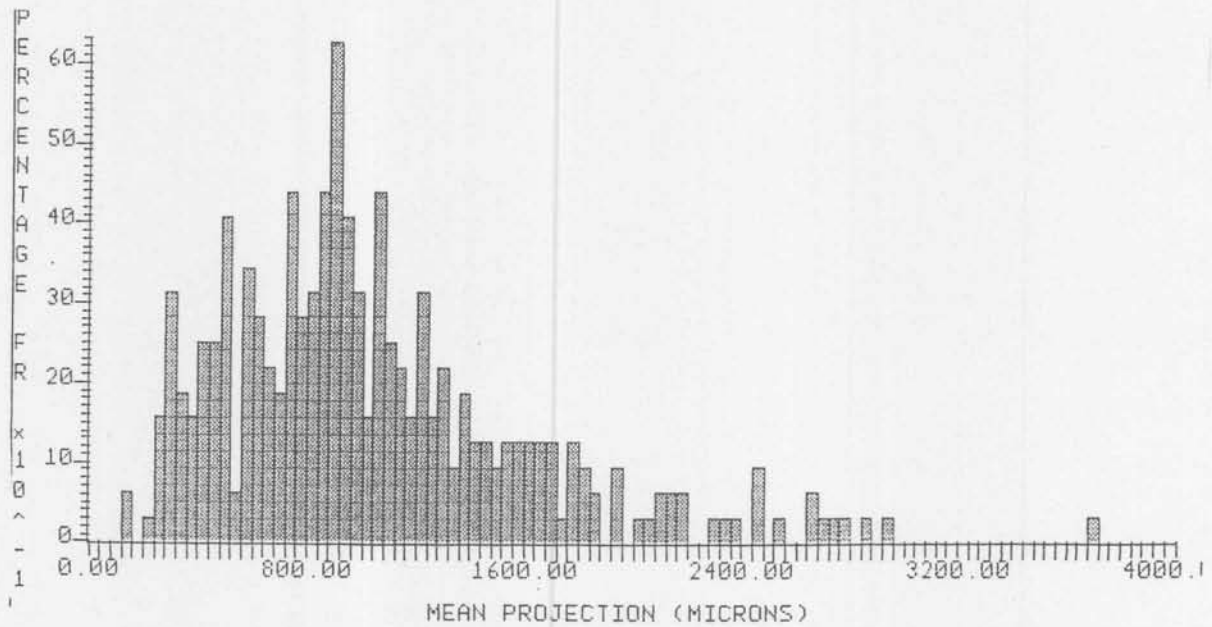


A graphical representation of the mean projection of the different brans in a preliminary trial, as determined by IA, is given in Figure 18.

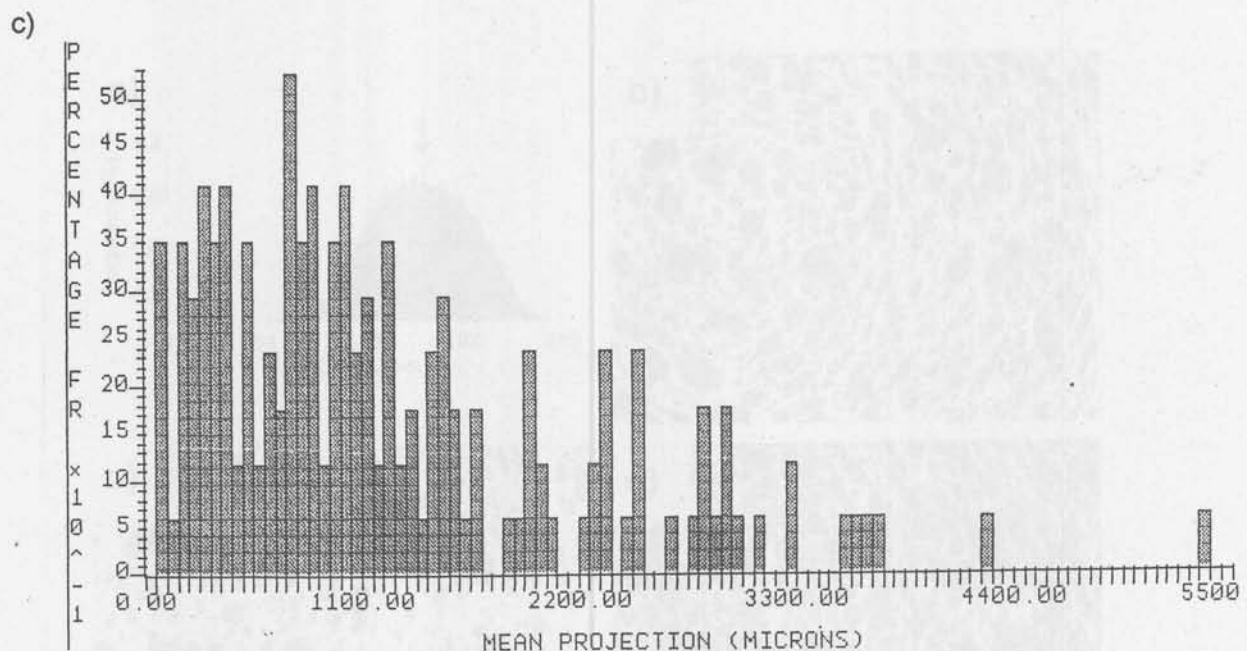
a)



b)







**Fig. 18: Mean projection of a) Pollard; b) Select bran; and c) Digestive bran particles**

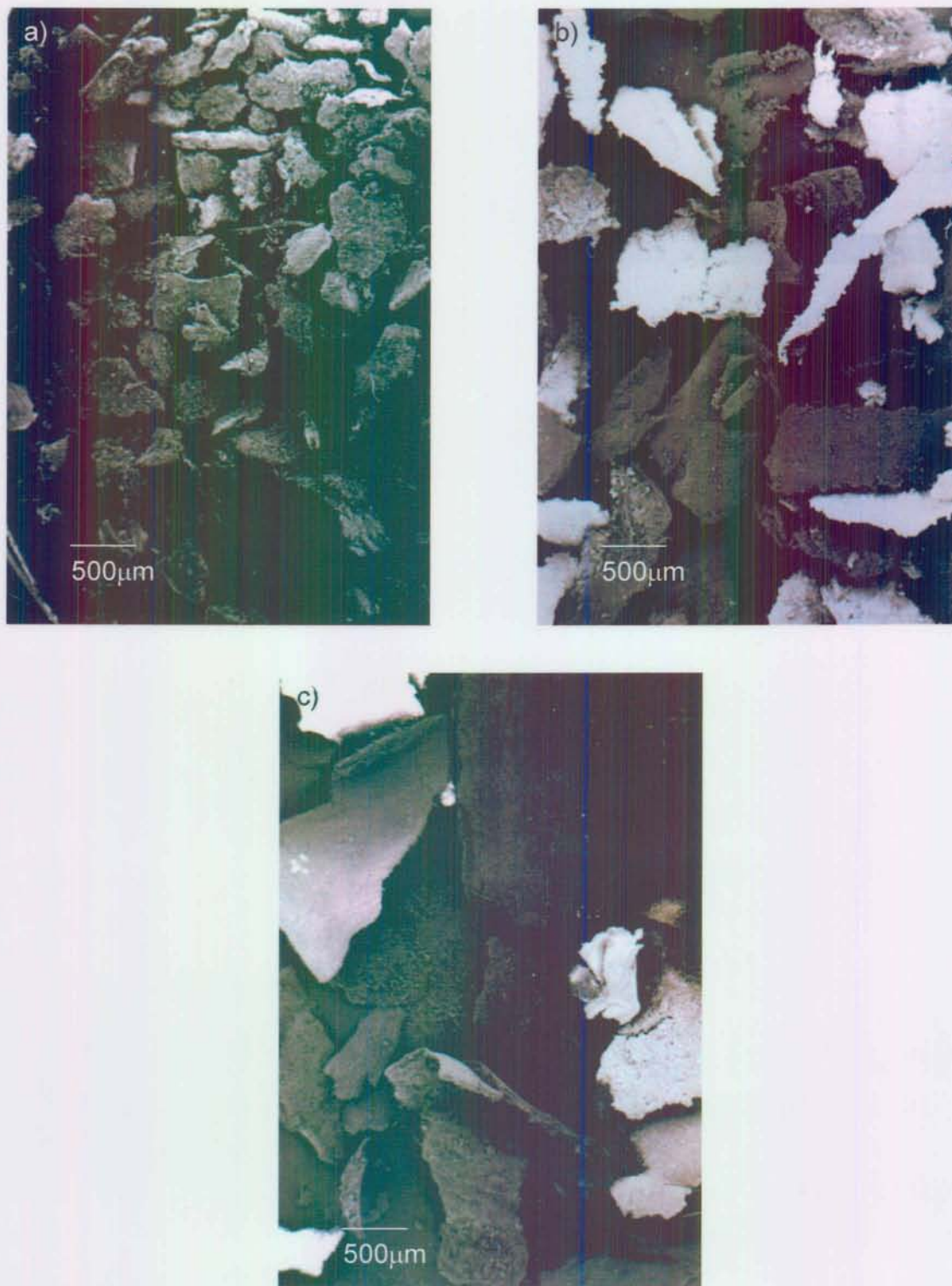
Pollard was the smallest particles (85 % of the Pollard particles was smaller than 800  $\mu\text{m}$ ), followed by Select (73% was smaller than 1200  $\mu\text{m}$ ) and Digestive bran particles (64% was smaller than 1100  $\mu\text{m}$  and 18% was lying between 1100 and 2200  $\mu\text{m}$ ). In a subsequent trial with bigger samples, Pollard was found to have an average mean projection of 0.6 mm, while Select and Digestive brans had average mean projections of 1.4 mm and 3.2 mm respectively. These values were consistent with the sieving range specified for the different brans. Despite the differences in size, the aspect ratios of the particles of the three types of bran were similar: Pollard 1.50, Select 1.60 and Digestive 1.46, showing that the bran types had the same general shape. Table 14 shows the complete results of IA of the different bran types that were used in the rest of this study.

**Table 14: Properties of different bran types as analysed by image analysis**

<b>Bran type</b>	<b>Parameter</b>	<b>Mean value</b>	<b>Standard deviation</b>
Pollard	No. of particles in field	755	
	Area	$2.50 \times 10^5 \mu\text{m}^2$	$2.19 \times 10^5$
	External perimeter	1618 $\mu\text{m}$	898
	Min. projection	467 $\mu\text{m}$	184
	Max. projection	692 $\mu\text{m}$	334
	Mean projection	586 $\mu\text{m}$	250
	Aspect ratio	1.50	0.38
Select	No. of particles in field	253	
	Area	$1.33 \times 10^6 \mu\text{m}^2$	$1.28 \times 10^6$
	External perimeter	4498 $\mu\text{m}$	2651
	Min. projection	1061 $\mu\text{m}$	521
	Max. projection	1720 $\mu\text{m}$	911
	Mean projection	1395 $\mu\text{m}$	705
	Aspect ratio	1.61	0.42
Digestive	No. of particles in field	56	
	Area	$6.65 \times 10^6 \mu\text{m}^2$	$5.67 \times 10^6$
	External perimeter	11651 $\mu\text{m}$	7665
	Min. projection	2550 $\mu\text{m}$	1274
	Max. projection	3848 $\mu\text{m}$	2135
	Mean projection	3231 $\mu\text{m}$	1747
	Aspect ratio	1.46	0.45

### 4.3 SEM

Scanning electron micrographs of the different brans are presented in Figure 19.



**Fig. 19: Scanning electron micrographs of a) Pollard; b) Select bran; and c) Digestive bran**

It can be seen from this figure that the Pollard particles were the smoothest and most uniform, whereas the Digestive bran particles were flaky with jagged edges.

#### **4.4 HEAT TREATMENT**

The lipase activities of different brans that were heat-treated for 30 and 60 minutes, are given in Table 15.

**Table 15: Effect of heat treatment (121°C) for 30 and 60 minutes on lipase activity in different bran types**

<b>Bran sample</b>	<b>Lipase activity (mL 0.1 mol/L NaOH/ 5 g bran)</b>		
	<b>Untreated</b>	<b>Heat-treated (30 minutes)</b>	<b>Heat-treated (60 minutes)</b>
Pollard	307	136	85
Select	320	157	88
Digestive	340	91	71

Heat treatment for 30 minutes only partially inactivated the lipase. Heat treatment for 60 minutes inactivated more of the lipase. In order to ensure that all the lipase was inactivated, samples were heat-treated at 121°C for 1.5 hours.

The effect of heat treatment on the colour properties of Pollard and Digestive bran is given in Table 16.



**Table 16: Effect of a dry heat treatment (121°C, 30 minutes) on colour of Pollard and Digestive bran**

Bran sample	Hunterlab values					
	L		a		b	
	Untreated	Heat-treated	Untreated	Heat-treated	Untreated	Heat-treated
Pollard	66.5	60.0	2.6	3.5	13.2	14.8
Digestive	45.9	40.2	6.6	7.2	14.9	15.1

From this table it is evident that the L-value decreased considerably during heat treatment of both bran types. A L-value of 100 represents a total white colour and a L-value of 0 depicts a black colour. It is therefore clear that during heat treatment the bran becomes darker (more black). Heat treatment did not have a significant effect on a- (green (-) to red (+)) and b- (blue (-) to yellow (+)) values. Breads baked with heat-treated brans also had a darker colour than the breads baked with non-treated bran (Figures 23, 25 and 27).

The effect of heat treatment on moisture content and particle size is shown in Table 17.

**Table 17: Effect of heat treatment on moisture content and particle size of different bran types.**

Bran sample	Moisture content (%)		Perimeter (mm)	
	Untreated	Heat-treated	Untreated	Heat-treated
Pollard	10.48	10.00	1.62	1.62
Select	11.30	10.99	4.50	4.51
Digestive	12.04	11.67	11.65	11.63

Heat treatment lowered moisture content very slightly, but did not have any significant effect on bran particle size.

## 4.5 LIPASE

Table 18 shows the lipase activities of heat-treated and untreated wheat brans of different origin.

**Table 18: Effect of heat treatment (121°C, 1.5 h) on lipase activity in brans from wheat samples of different origin**

Bran sample <sup>a</sup>	Lipase activity <sup>b</sup> (mL 0.1 mol/L NaOH/ 5 g bran)	
	Untreated	Heat-treated
1	315f	7w
2	309f	5yx
3	251d	4zy
4	275e	5yx
5	214a	6xw
6	270e	4zy
7	220a	6xw
8	234b	3z
9	245cd	4z
10	239bc	3z
Mean	257 $\alpha$	5 $\beta$

<sup>a</sup>Origin:

1-UK; 2-Germany; 3-Canada; 4-USA; 5 Western Cape; 6-Free State; 7-Western Cape; 8-Free State; 9-Free State; 10-Mpumalanga

<sup>b</sup>Values with different letters in the same column are significantly different (P<0.05)

There was a significant variation in the level of lipase activity in most of the brans from the different samples. The highest lipase activities were in 1 (UK) and 2 (Germany), and the lowest in 5 (Western Cape) and 7 (Western Cape). Heat-treatment of the brans from different origins practically inactivated the lipase in all cases.



Table 19 shows the lipase activities of heat-treated and untreated brans of different particle size.

**Table 19: Effect of heat treatment (121 °C, 1.5 h) on lipase activity of different bran types**

Bran type	Lipase activity (mL 0.1 mol/L NaOH/ 5 g bran)	
	Untreated	Heat-treated
Pollard	259c	35b
Select	270d	38b
Digestive	286e	21a

Values with different letters are significantly different ( $P < 0.05$ )

The lipase activities of the untreated brans were all of the same order of magnitude, with the highest in the Digestive bran and the lowest in the Pollard. Heat treatment reduced lipase activity by at least 85% in all cases.

#### 4.6 TOTAL REDUCING SUBSTANCES

Table 20 shows the total reducing substances (TRS) of heat-treated and untreated brans of different origin.

**Table 20: Effect of heat treatment (121°C, 1.5 h) on total reducing substances in brans from wheat samples of different origin**

Bran sample <sup>a</sup>	Total reducing substances <sup>b</sup> (mL 0.005 mol/L S <sub>2</sub> O <sub>3</sub> <sup>2-</sup> / 5 g bran)	
	Untreated	Heat-treated
1	1.91b	0.81t
2	2.09a	1.33z
3	1.33f	0.96y
4	1.43de	1.28zy
5	1.42de	0.71s
6	1.66c	1.17xw
7	1.36ef	1.00vu
8	1.24g	1.22yx
9	1.21g	1.09wv
10	1.45d	1.16xw
Mean	1.51 $\alpha$	1.07 $\beta$

<sup>a</sup>Origin:

1-UK; 2-Germany; 3-Canada; 4-USA; 5 Western Cape; 6-Free State; 7-Western Cape; 8-Free State; 9-Free State; 10-Mpumalanga

<sup>b</sup>Values with different letters in the same column are significantly different (P<0.05)

It is evident that there was a significant variation in the level of TRS in most of the brans from the different wheat samples. The lowest TRS were in samples 8 (Free State) and 9 (Free State), and the highest in sample 2 (Germany). With the exception of sample 8, heat treatment significantly reduced the level of TRS in all the brans. However, there remained significant variation in the levels of TRS in most of the heat-treated brans. The highest TRS was still in sample 2 (Germany) but the lowest in samples 1 (UK) and 5 (Western Cape).

## 4.7 BAKING TESTS

### 4.7.1 Effect of bran origin and heat treatment on loaf volume

The effect of bran origin and heat treatment on loaf volume is shown in Table 21.

**Table 21: Effect of brans from wheat samples of different origin and their heat treatment on loaf volume and loaf height when brans were used to bake brown bread (15% bran) using a common base flour**

Bran sample <sup>a</sup>	Loaf volume <sup>b</sup> (% of white bread control)		Loaf height <sup>b</sup> (% of white bread control)	
	Untreated	Heat-treated	Untreated	Heat-treated
1	86.9a	93.3zy	87.3a	93.3zy
2	90.7bcd	93.3zy	90.7bc	94.5zyx
3	91.9d	93.1zy	91.8bcd	92.9z
4	90.3bcd	92.8z	90.0b	93.7zy
5	90.2bcd	95.2yxw	90.1b	95.8yxw
6	91.5cd	93.6zyx	93.7d	94.4zyx
7	90.1bcd	93.0zy	90.2b	93.9zyx
8	89.9bc	96.0w	92.3cd	97.6w
9	89.5b	92.8z	91.2bc	93.1zy
10	91.5cd	95.7xw	92.2bcd	96.7xw
Mean	90.2 $\alpha$	93.9 $\beta$	91.0 $\alpha$	94.6 $\beta$

<sup>a</sup>Origin:

1-UK; 2-Germany; 3-Canada; 4-USA; 5 Western Cape; 6-Free State; 7-Western Cape; 8-Free State; 9-Free State; 10-Mpumalanga

<sup>b</sup>Values with different letters in the same column are significantly different ( $P < 0.05$ )

There were significant differences in loaf volume and loaf height between breads produced from a common base flour, with brans from different origins. In other words, different brans varied in their effect of depressing loaf size. Highest loaf volumes were

obtained with bran samples 2, 3, 4, 5, 6, 7 and 10 (90.1-91.5% of white bread control), and the highest loaf heights with bran samples 3, 6, 8 and 10 (91.8-93.7% of control). The lowest loaf volume and height were obtained with bran sample 1 (86.9 and 87.3%, respectively of the control).

Heat-treatment of the brans from different origins increased both loaf volume and height. However, heat-treatment did not result in the brans all producing loaves of the same volume and height. There were still some significant differences between the samples. Heat-treated bran samples 5, 8 and 10 gave the highest loaf volumes (95.2-96.0% of control) and heights (95.8-97.6% of the white bread control). Samples 1, 2, 3, 4, 6, 7 and 9 gave the lowest loaf volume (92.8-93.6% of the control) and height (92.9-94.4% of the control).

#### **4.7.2 Effect of bran type, level of addition and heat treatment on loaf volume**

The effect of bran type, level of addition and heat treatment on loaf volume is given in Table 22 and Figures 20 to 29.

**Table 22: Effect of different bran types, heat treatment and level of addition on loaf volume**

Bran type	Level of addition (%)	Loaf volume <sup>a</sup> (% of white bread control)	
		Untreated	Heat-treated
Pollard	9	96.3 de	97.7 efg
	12	93.1 bc	96.9 def
	15	89.7 a	91.6 ab
Select	9	100.2 hij	102.2 ijk
	12	95.9 de	99.7 gh
	15	93.1 bc	95.2 cd
Digestive	9	102.4 jk	102.6 k
	12	97.1 def	98.8 fgh
	15	91.99 b	92.6 b

<sup>a</sup>Values with different letters are significantly different (P<0.05)

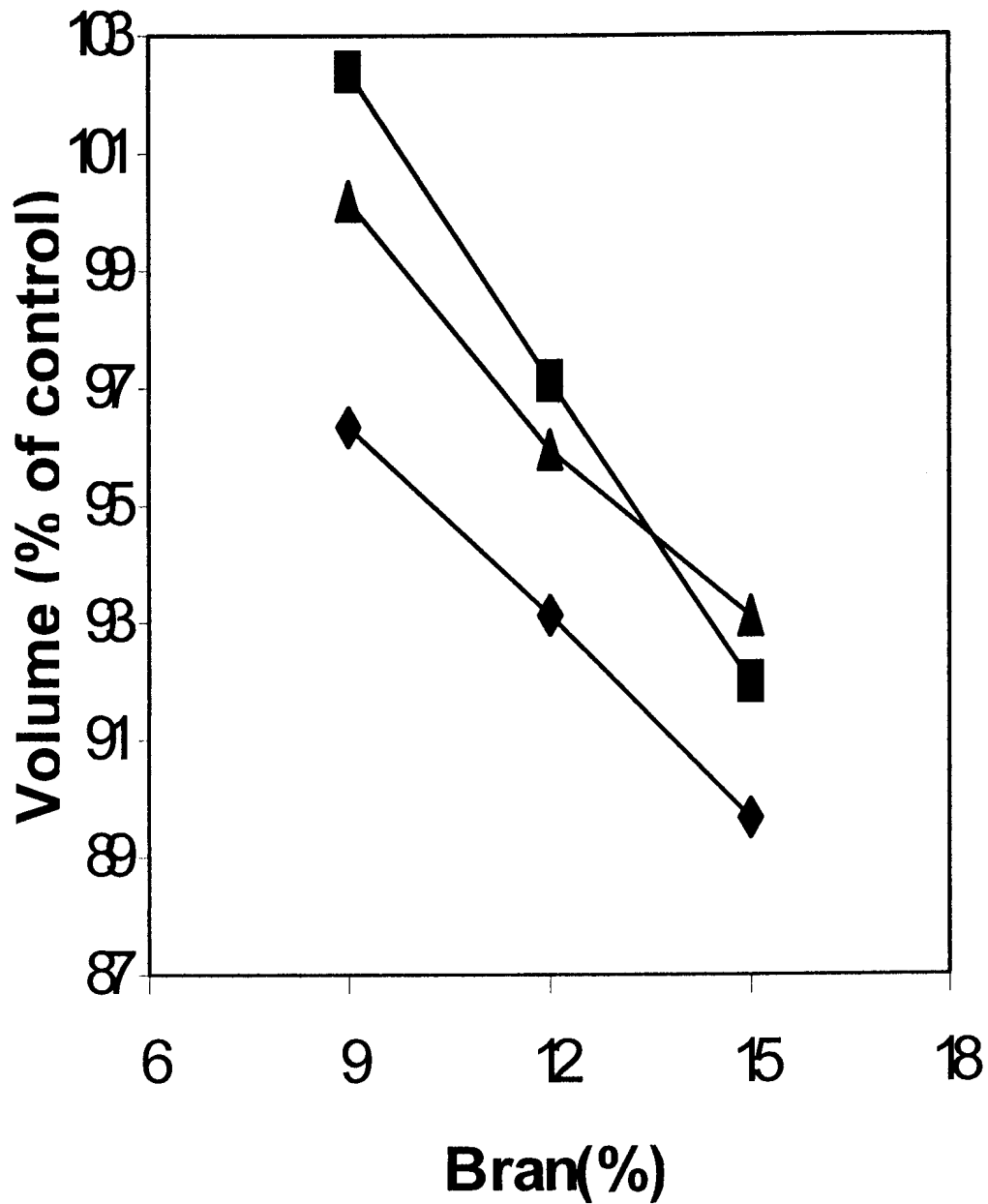
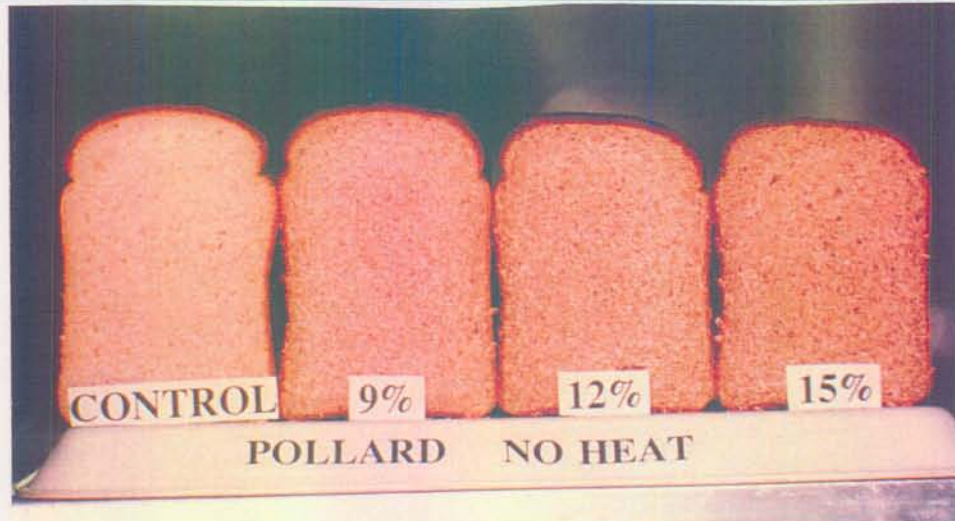
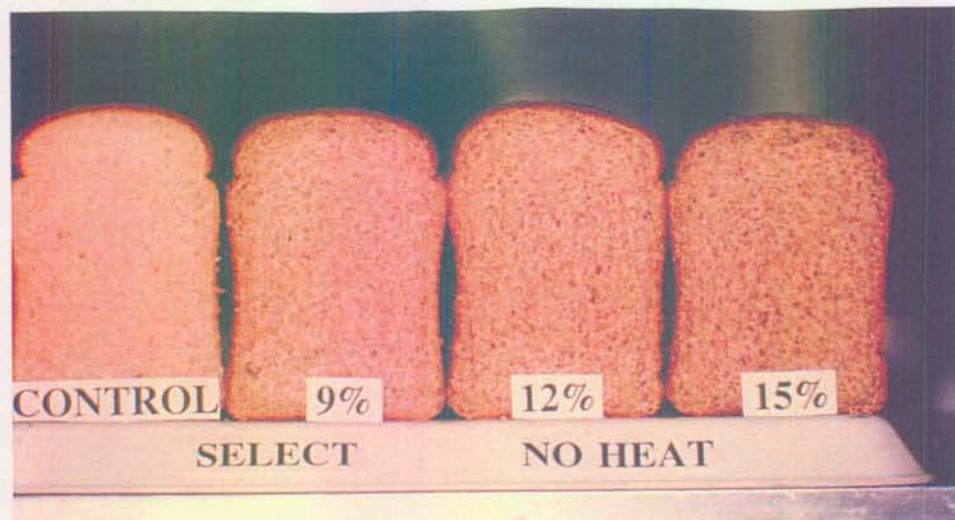


Fig. 20: Effect of bran type and level of addition on loaf volume (results expressed as percent of a white bread control). ◆ - ◆ = Pollard; ▲ - ▲ = Select; ■ - ■ = Digestive

a)



b)



c)

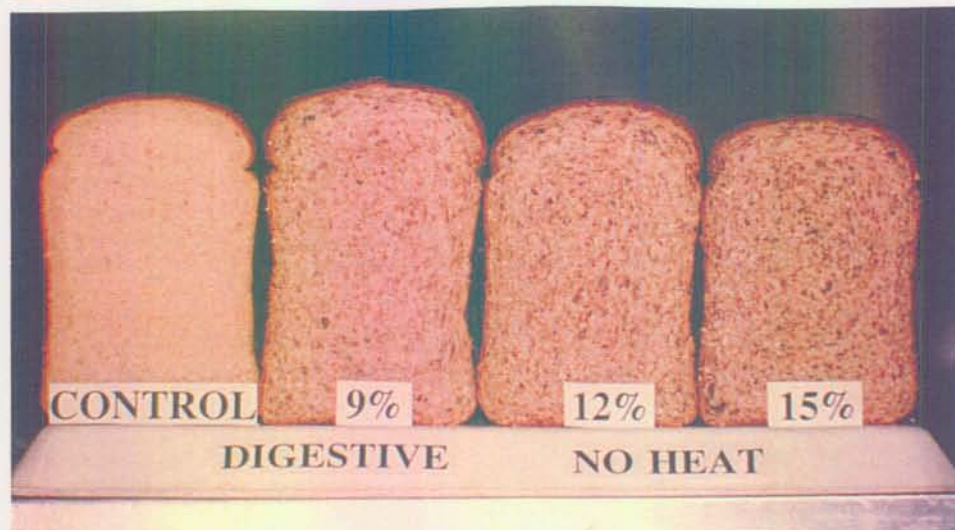


Fig 21: Breads baked with different levels of addition of a) Pollard; b) Select bran; and c) Digestive bran, compared to a white bread control



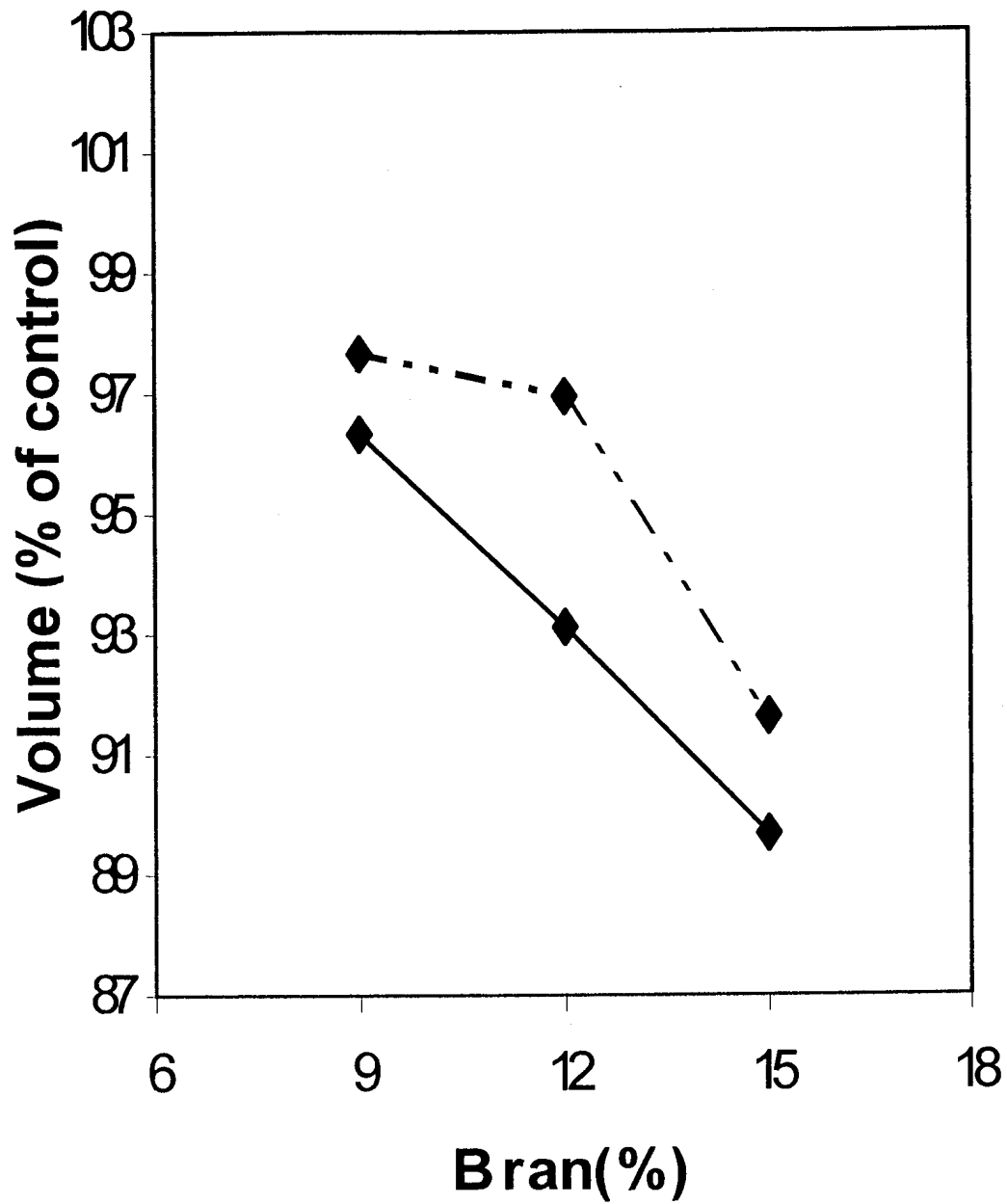
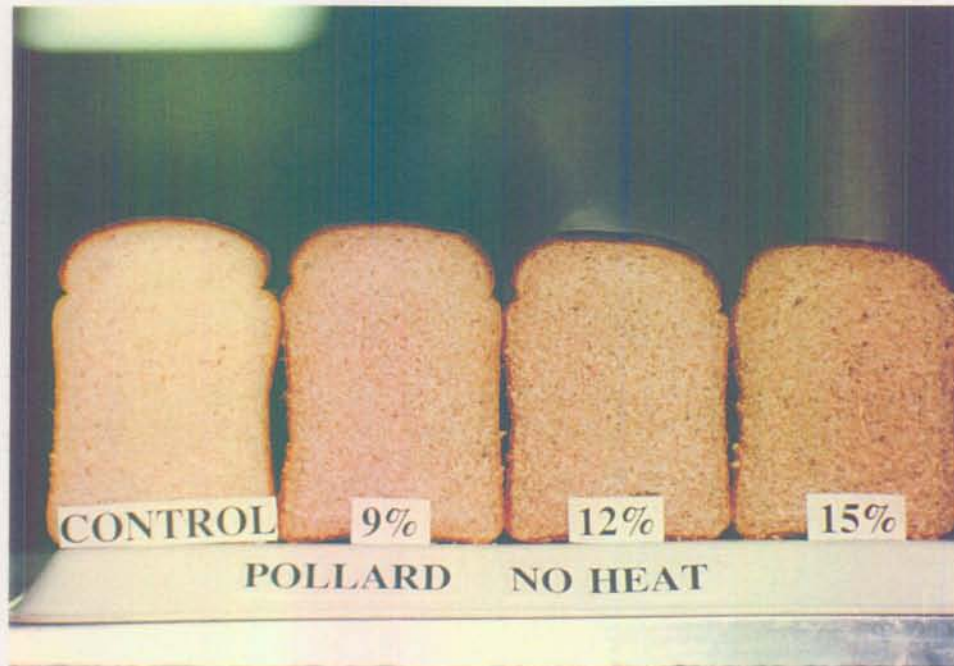


Fig. 22: Effect of heat treatment and level of addition of Pollard on loaf volume (results expressed as percent of a white bread control). ◆ - ◆ = Pollard; ◆ - - - ◆ = heat-treated Pollard



a)



b)

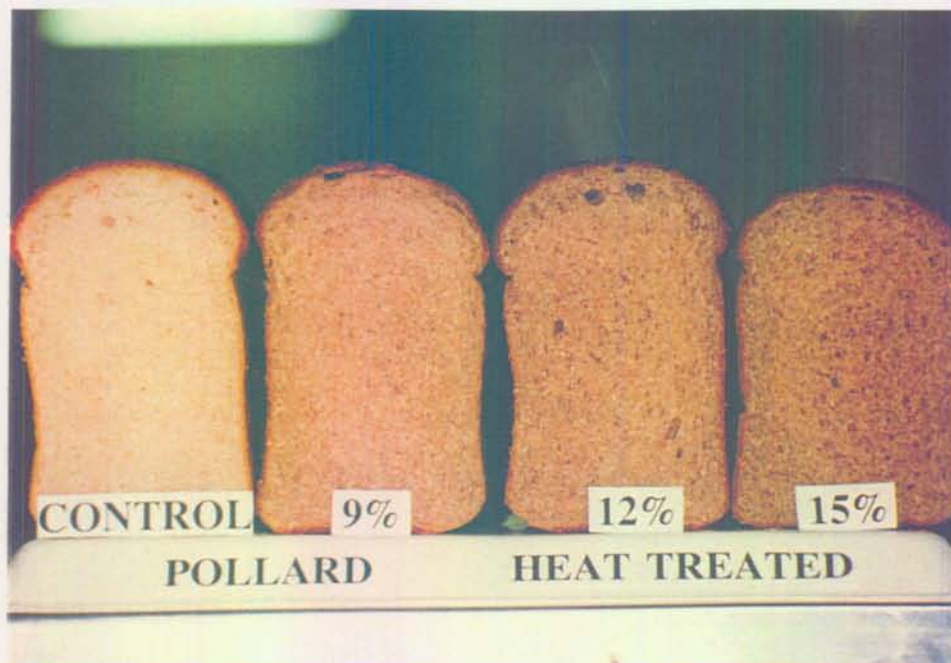


Fig. 23: Breads baked with different levels of addition of a) Pollard and b) Heat-treated Pollard, compared to a white bread control

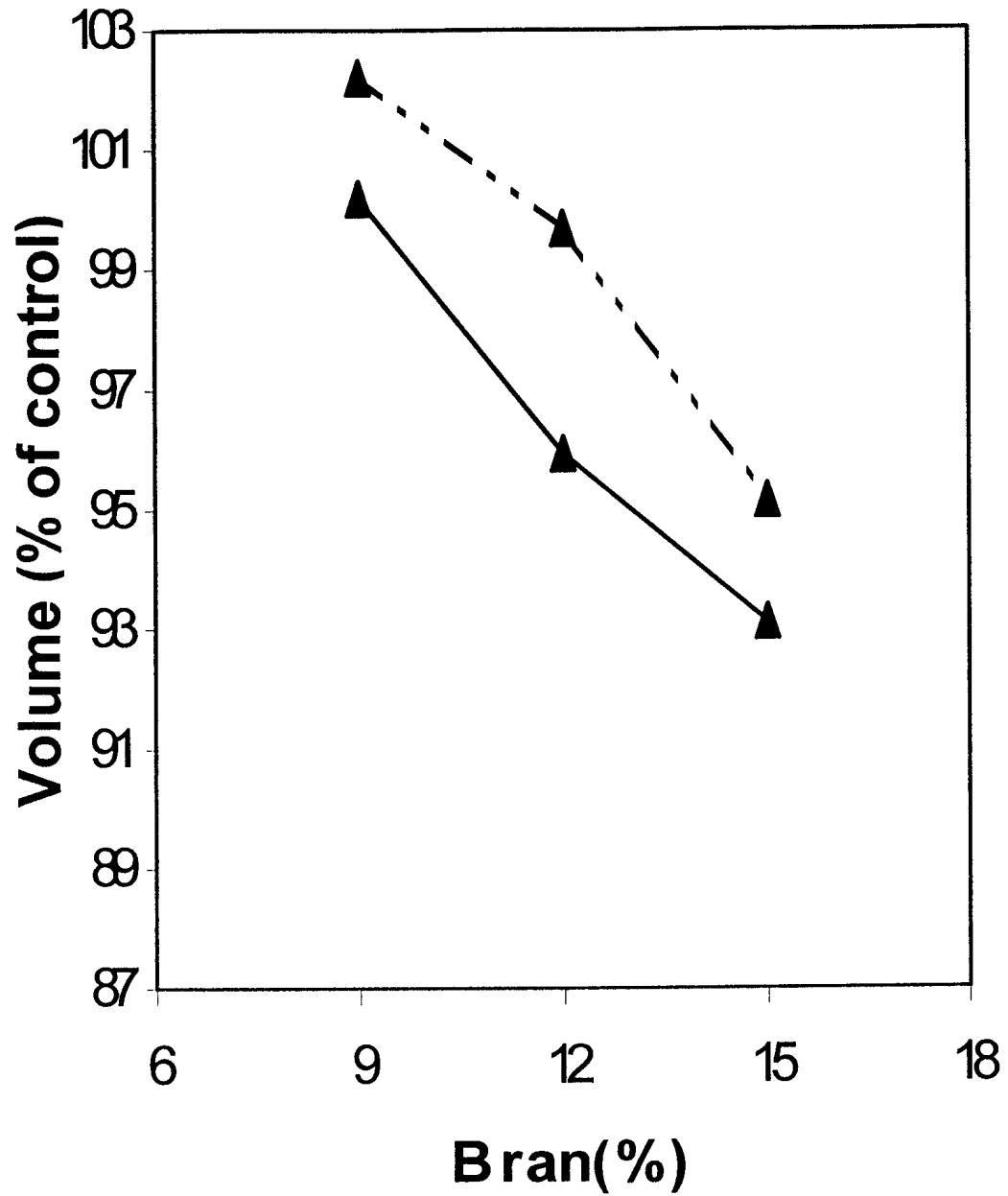
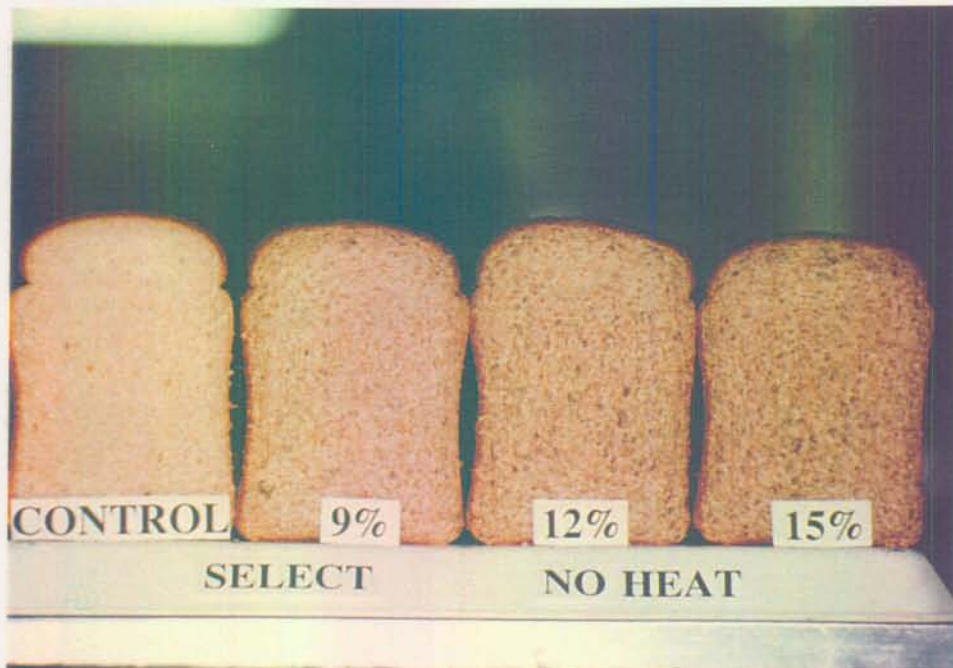


Fig 24: Effect of heat treatment and level of addition of Select bran on loaf volume (results expressed as percent of a white bread control). ▲ - ▲ = Select; ▲ - - -▲ = heat treated Select

a)



b)

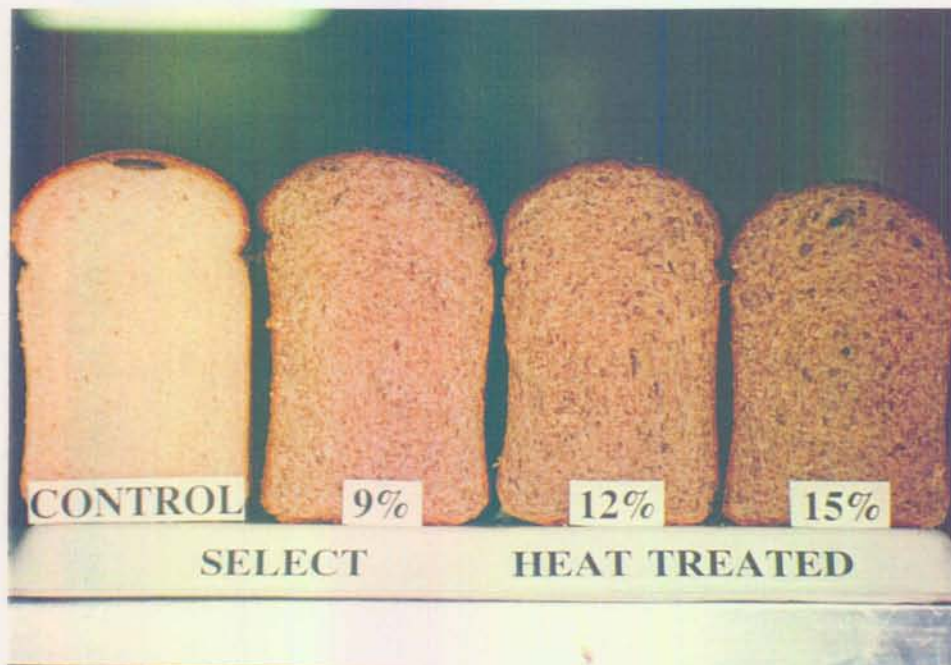


Fig. 25: Breads baked with different levels of addition of a) Select bran and b) Heat-treated Select bran, compared to a white bread control

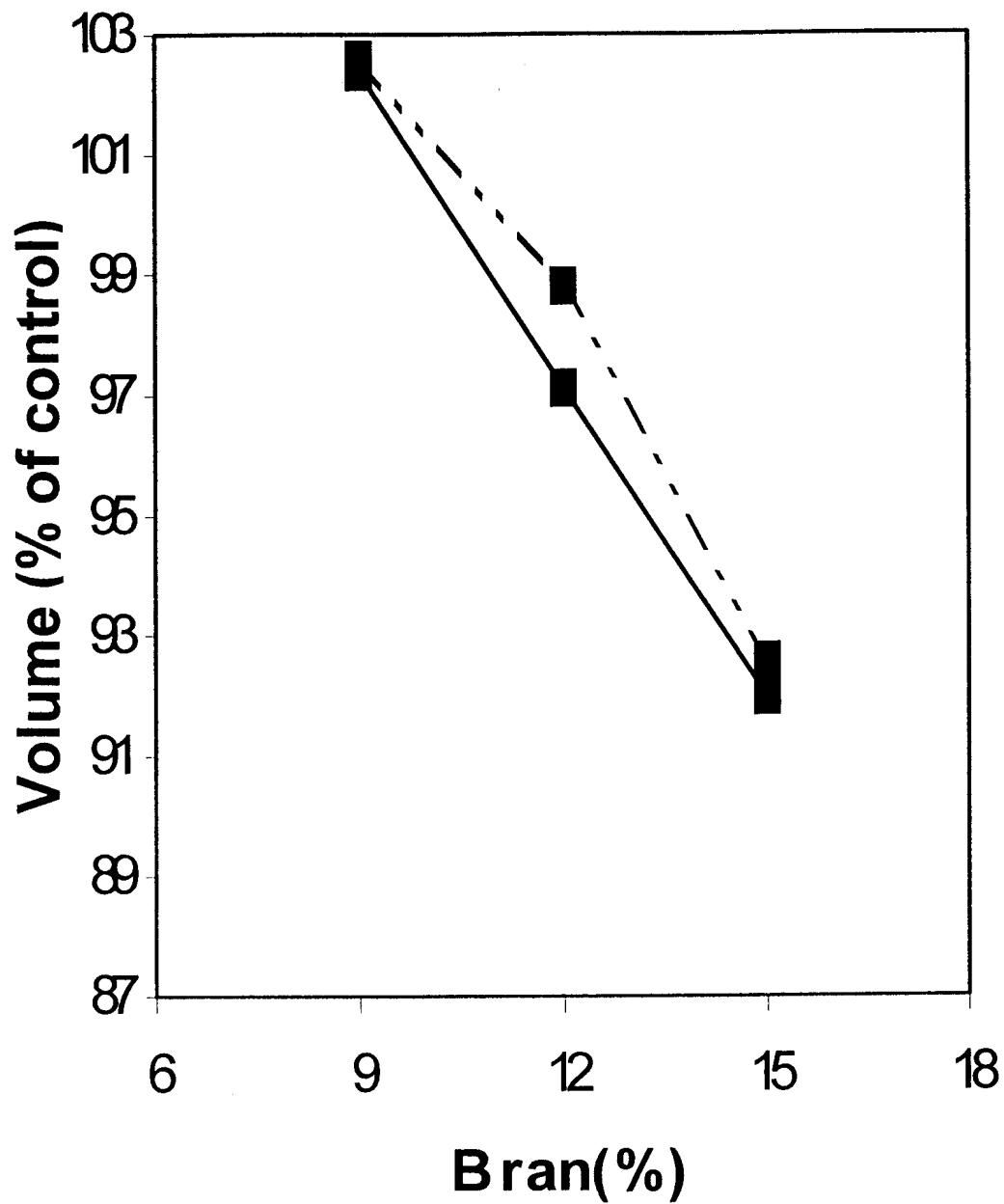
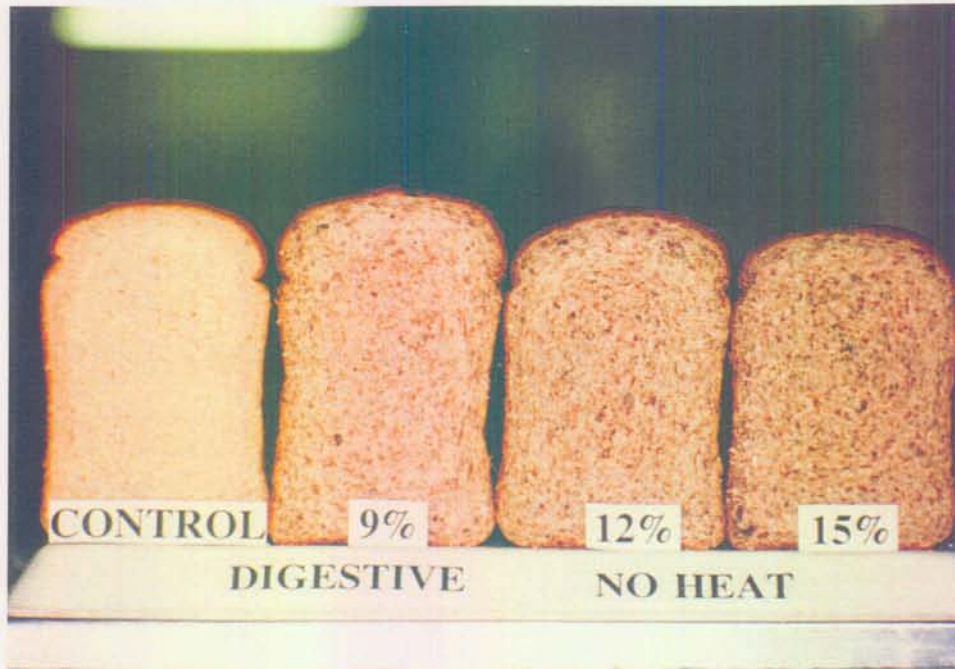


Fig 26: Effect of heat treatment and level of addition of Digestive bran on loaf volume (results expressed as percent of a white bread control). ■ - ■ = Digestive; ■ - - ■ = heat-treated Digestive



a)



b)

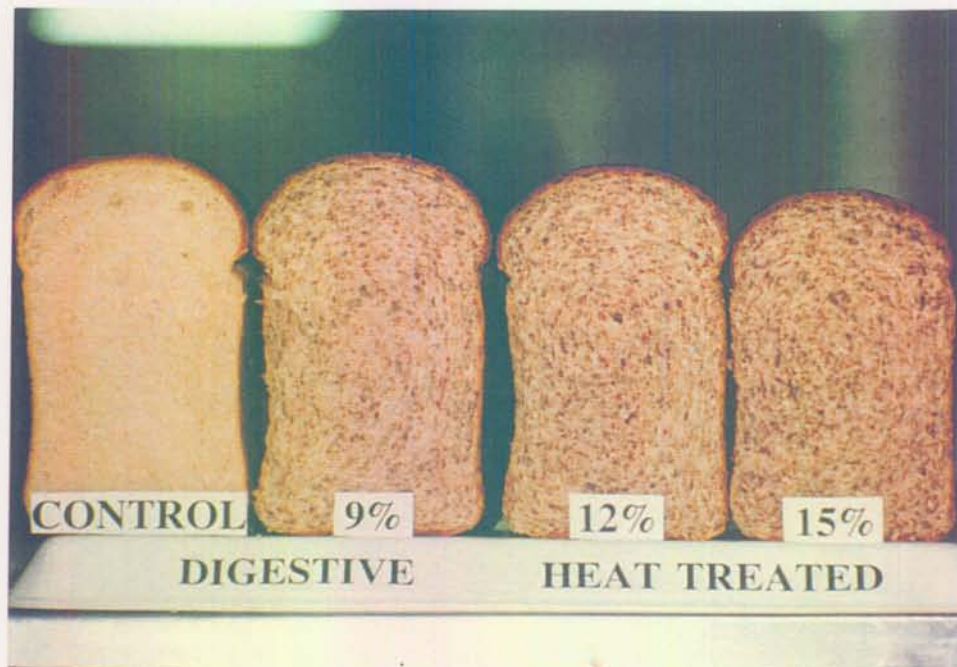


Fig. 27: Breads baked with different levels of addition of a) Digestive bran and b) Heat-treated Digestive bran, compared to a white bread control

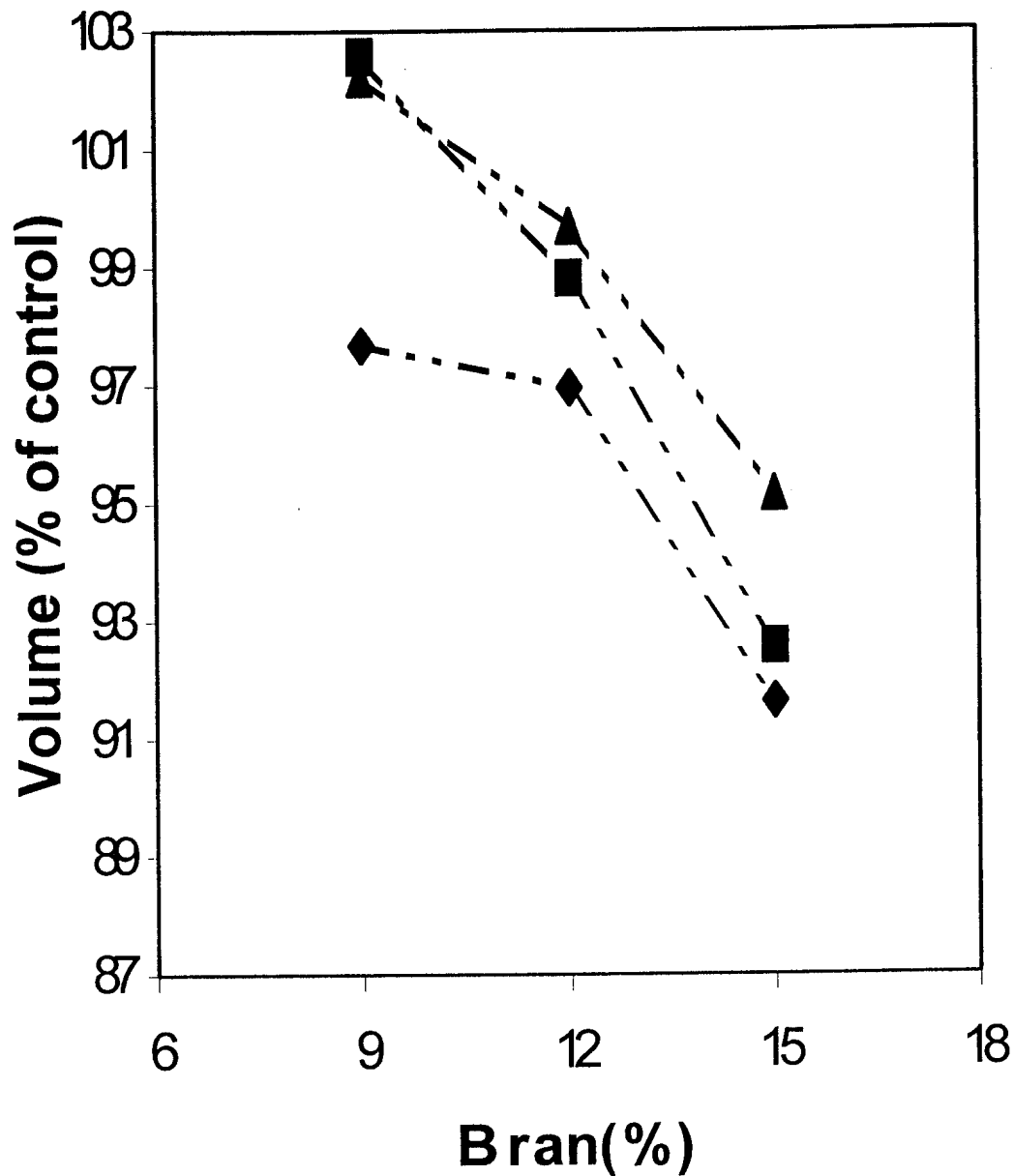


Fig. 28: Effect of heat-treated bran type and level of addition on loaf volume (results expressed as percent of a white bread control).  $\blacklozenge$ - - - $\blacklozenge$  = heat-treated Pollard;  $\blacktriangle$ - - - $\blacktriangle$  = heat treated Select;  $\blacksquare$ - - - $\blacksquare$  = heat-treated Digestive



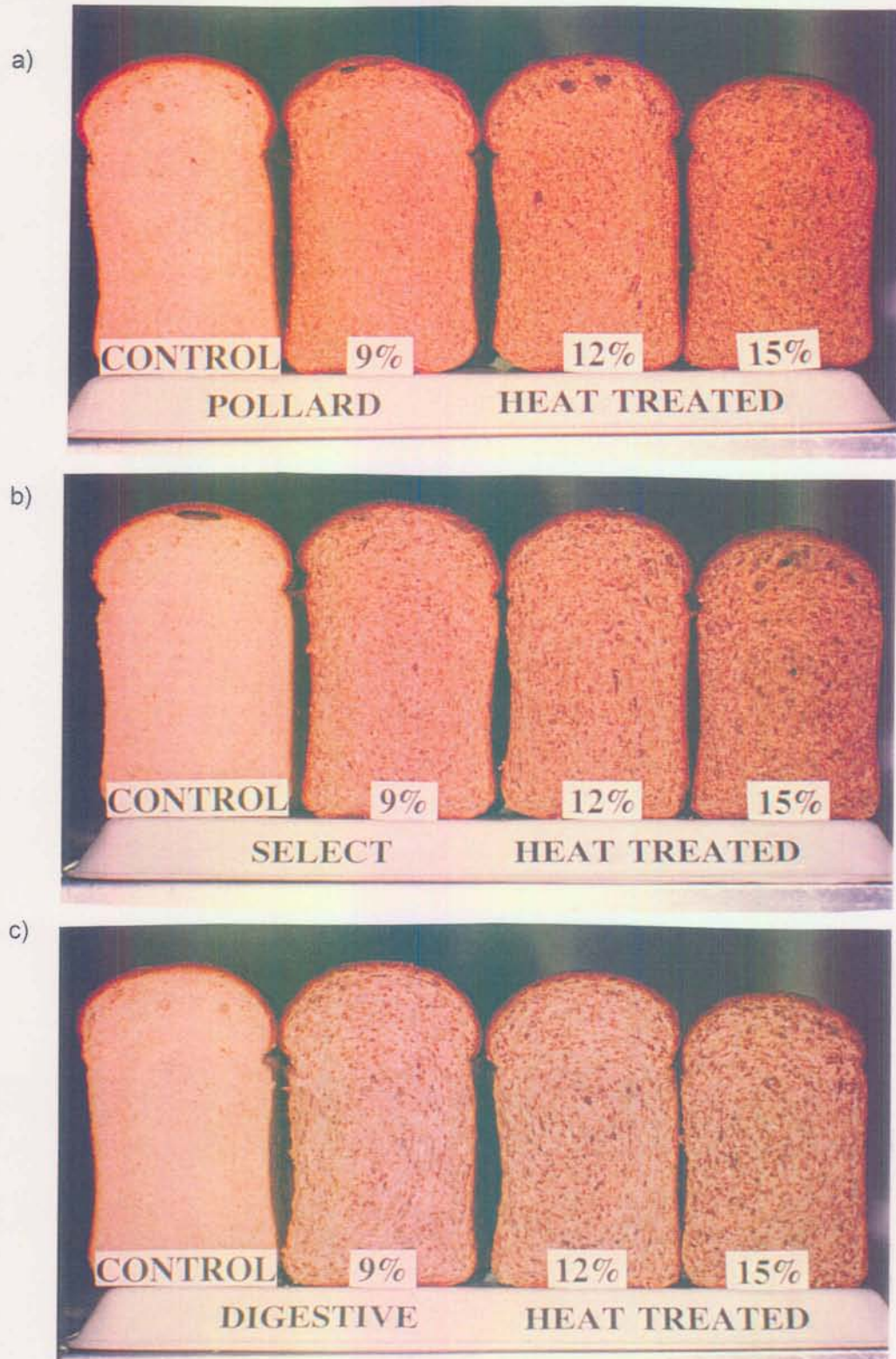
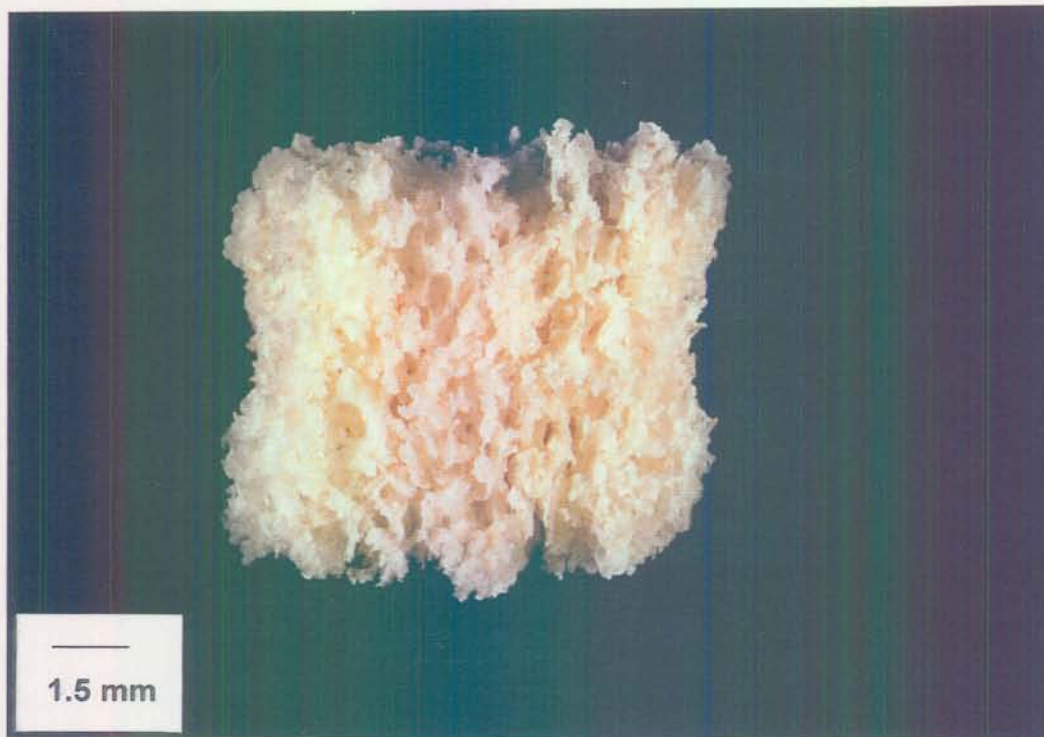


Fig. 29: Breads baked with different levels of addition of a) Heat-treated Pollard; b) Heat-treated Select bran; and c) Heat-treated Digestive bran, compared to a white bread control

Pollard caused the largest depression in loaf volume and Digestive bran the least. Select bran produced intermediate loaf volumes. Increased levels of addition caused loaf volumes to be more depressed. With heat-treated bran there was a clear trend for loaf volumes to be less depressed when compared to the loaves that were baked with the untreated bran. After heat-treatment of the brans, loaves baked with Pollard still gave the smallest volume, whereas the loaves baked with Select bran were at least as large as those baked with Digestive bran. At low levels of addition of Select and Digestive bran, loaf volumes of bread with untreated and heat-treated bran were as big or bigger than the white bread control. It is also evident that heat treatment had the greatest effect on decreasing loaf volume depression in breads baked with Pollard and the least effect on breads baked with Digestive bran.

Photographs of cubes of the control white bread and breads baked with the different bran types and different levels of addition are shown in Figures 30 to 33.



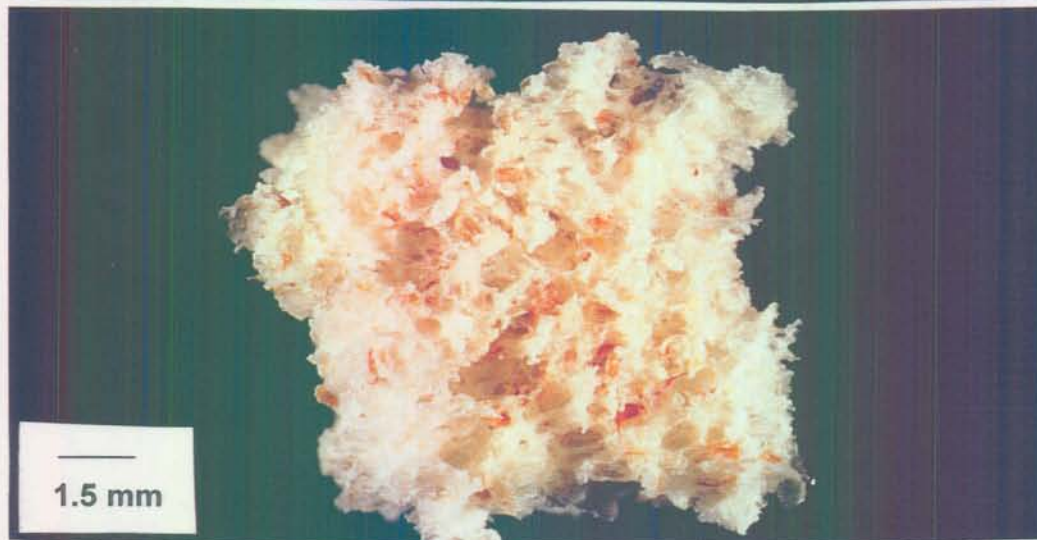
**Fig. 30: Cube of a white bread control**



a)



b)



c)

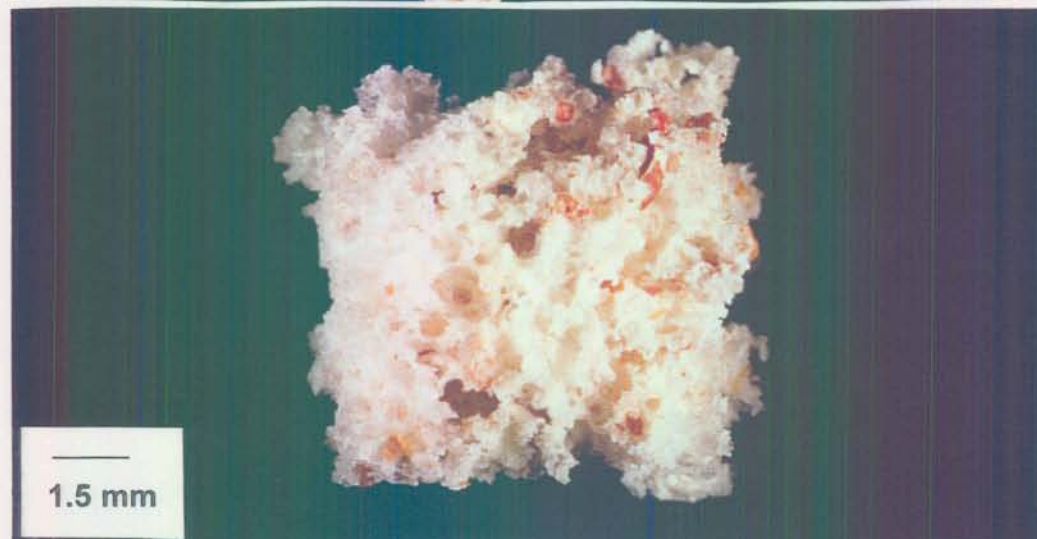
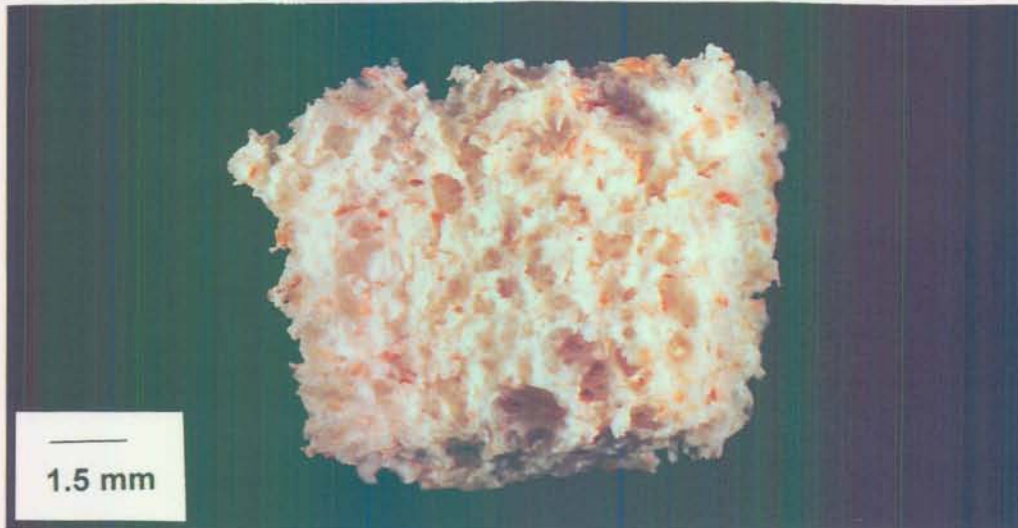
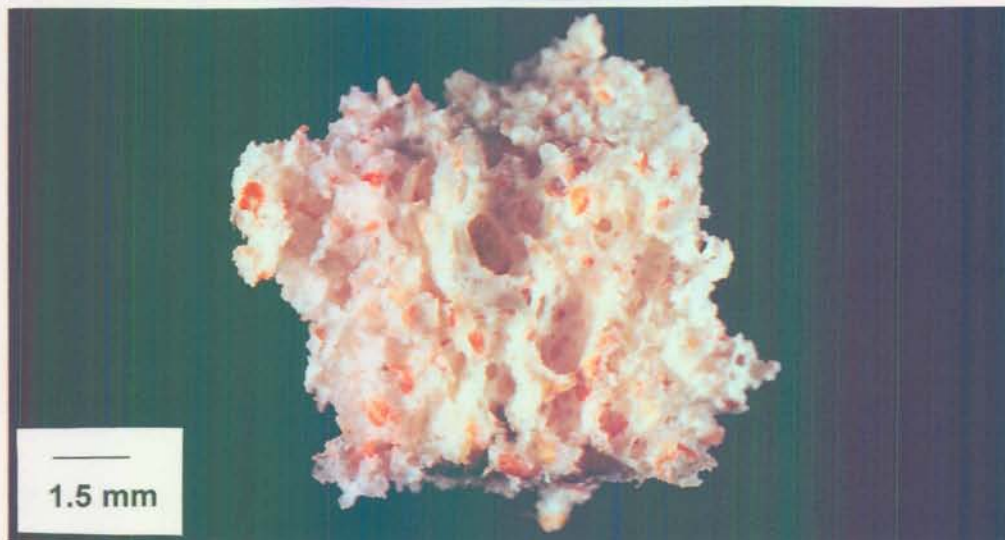


Fig. 31: Cubes of bread baked with a 9% level of addition of a) Pollard; b) Select bran; and c) Digestive bran

a)



b)



c)

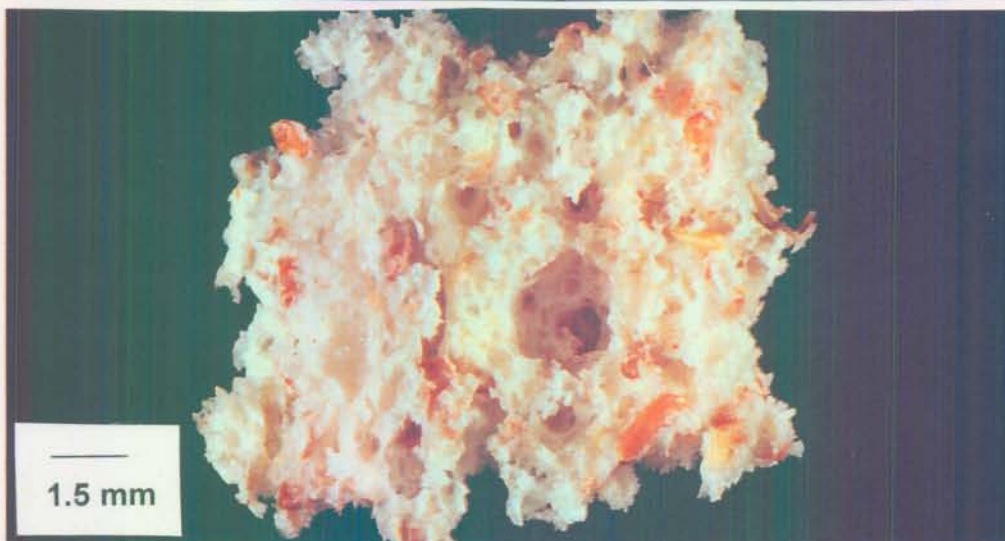
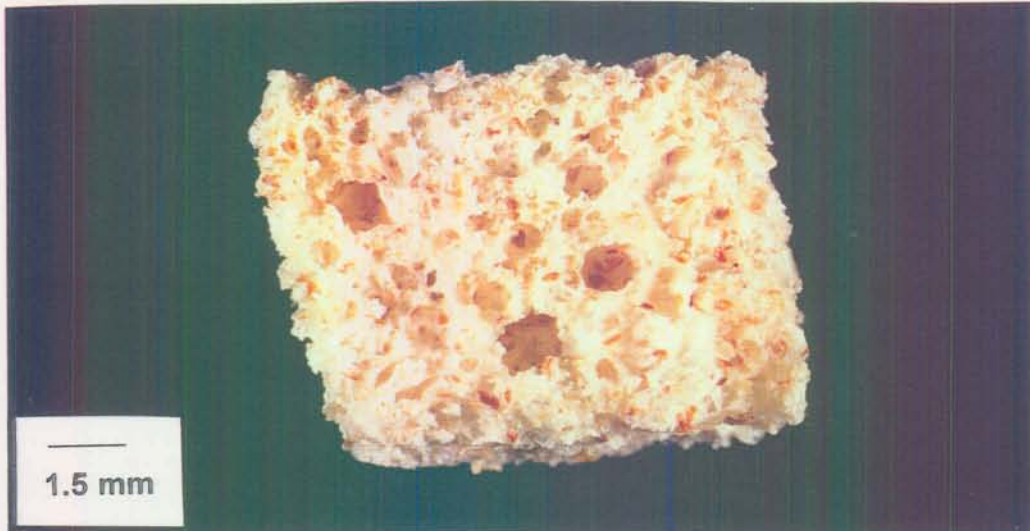


Fig. 32: Cubes of bread baked with a 12% level of addition of a) Pollard; b) Select bran; and c) Digestive bran



a)



b)



c)

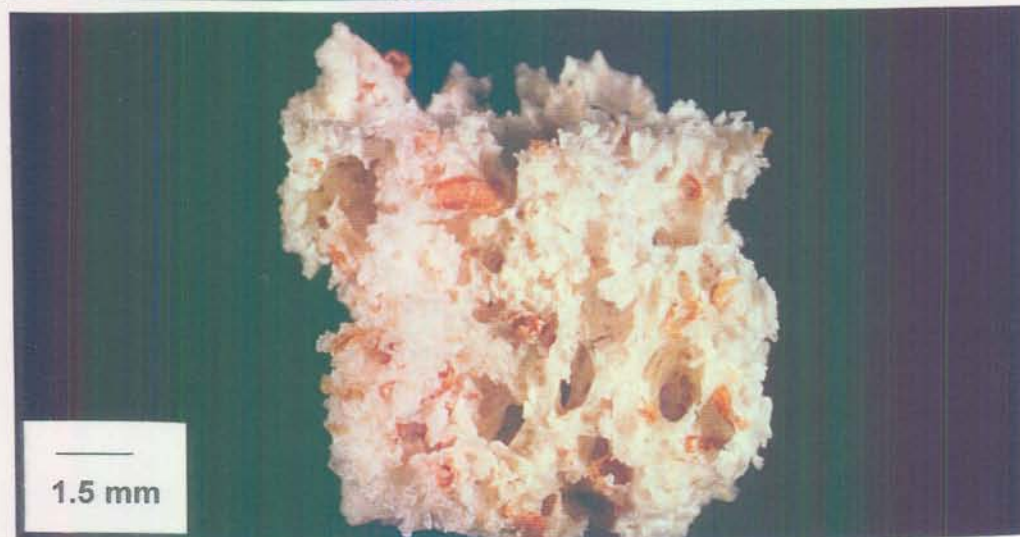


Fig. 33: Cubes of bread baked with a 15% level of addition of a) Pollard; b) Select bran; and c) Digestive bran

It is evident from these figures that the crumb of the bread baked with Digestive bran had a much more open structure than the bread baked with Pollard, which was more dense. Select bran gave an intermediate crumb structure. Increasing the level of addition disrupted the crumb structure.

#### **4.7.3 Effect of size reduction and heat treatment on loaf volume**

Tables 23 and 24 show the effect of bran size, heat treatment and milling on loaf volumes and loaf heights.

**Table 23: Effect of bran size, heat treatment and milling on loaf volume when brans were used to bake brown bread (12% bran) using a common base flour**

<b>Treatment</b>	<b>Pollard<sup>a</sup></b>	<b>Select<sup>a</sup></b>	<b>Digestive<sup>a</sup></b>	<b>Overall mean<sup>a</sup></b>
None	90.8 b	91.7 b	92.6 ab	91.7 b
Milled	85.6 a	86.1 a	90.4 a	87.4 a
Heat-treated	90.7 b	98.1 c	93.0 ab	94.0bc
Heat-treated then milled	93.0 b	94.7 bc	95.6 b	94.4 c
Overall mean <sup>b</sup>	90.0 x	92.7 y	93.0 y	

<sup>a</sup>Values with different letters in the same column are significantly different (P<0.05)

<sup>b</sup>Values with different letters in the same row are significantly different (P<0.05)



**Table 24: Effect of bran size, heat treatment and milling on loaf height when brans were used to bake brown bread (12% bran) using a common base flour**

Treatment	Pollard <sup>a</sup>	Select <sup>a</sup>	Digestive <sup>a</sup>	Overall mean <sup>a</sup>
None	90.9 ab	94.1 b	94.0a	93.0 b
Milled	87.2 a	88.5 a	92.7 a	89.4 a
Heat-treated	94.4 b	98.6 b	94.0 a	95.7 c
Heat-treated then milled	93.3 b	94.8 b	94.0a	94.7 bc
Overall mean <sup>b</sup>	91.5 x	94.0 y	96.0 y	

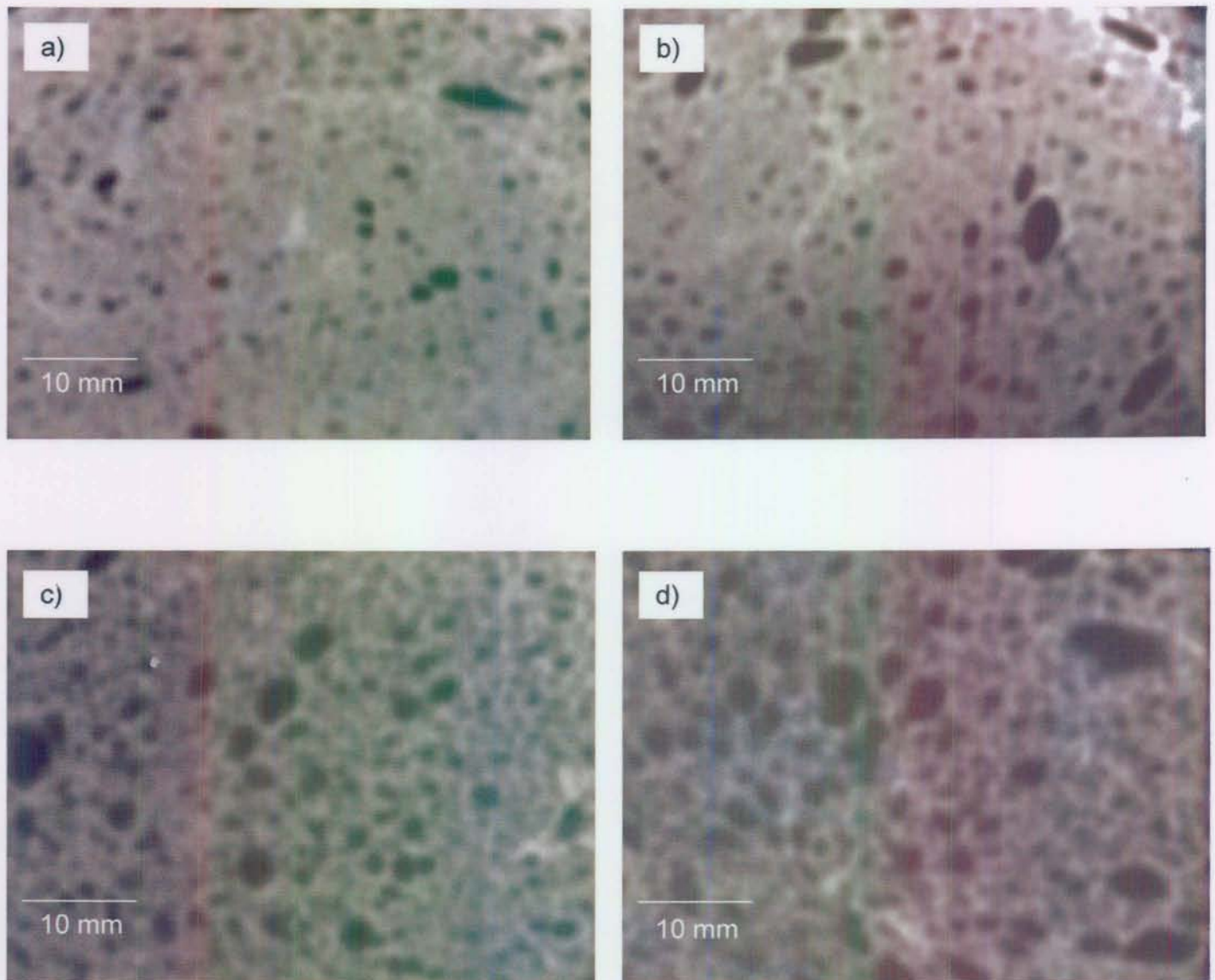
<sup>a</sup>Values with different letters in the same column are significantly different (P<0.05)

<sup>b</sup>Values with different letters in the same row are significantly different (P<0.05)

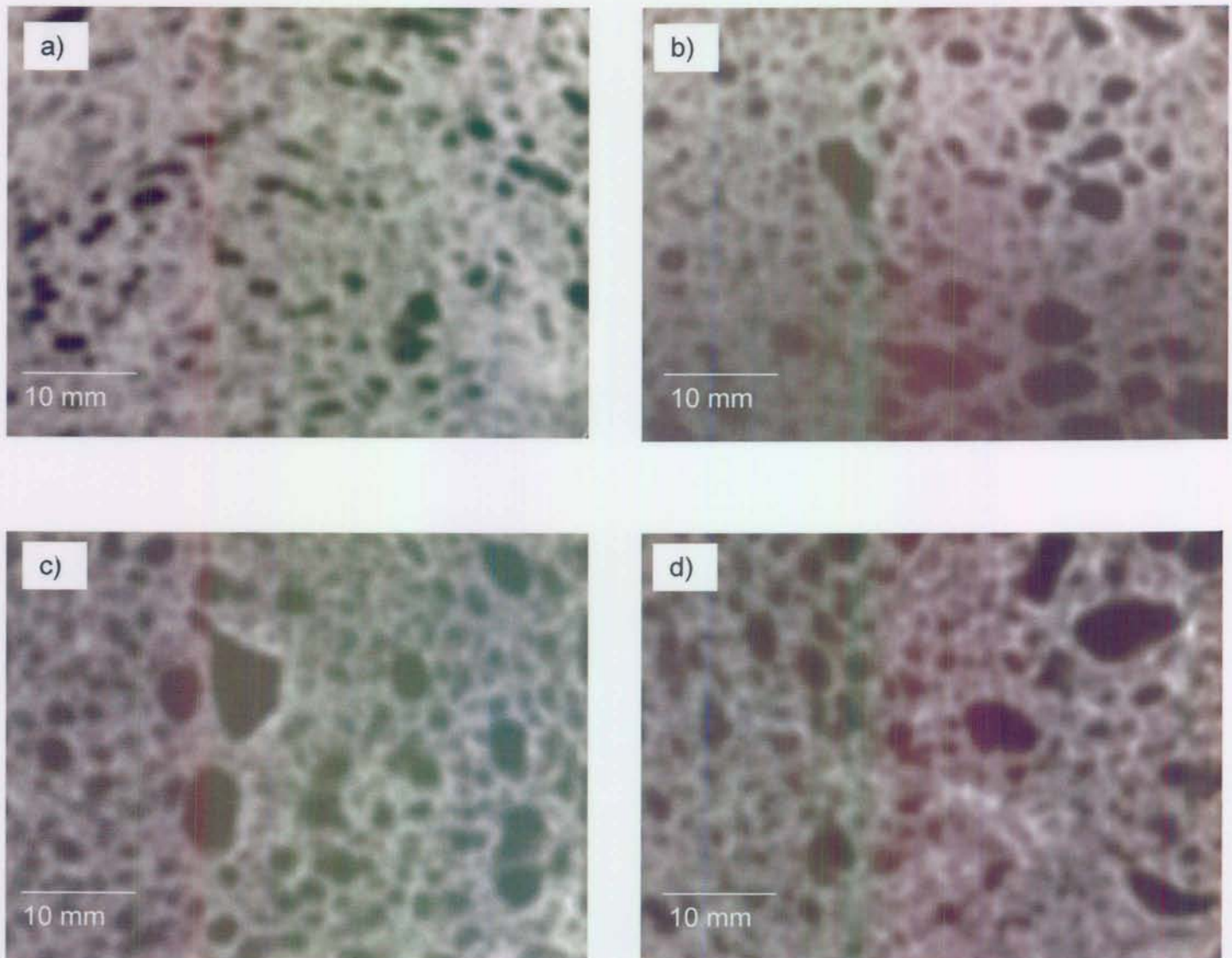
It is evident that, overall, Pollard gave the lowest loaf volumes. It can also be seen that significantly smaller loaf sizes were obtained with the milled bran. Overall, as found previously, heat treatment increased loaf size. Overall, similar loaf volumes and heights were obtained in breads produced with bran which was heat-treated and then milled, and breads produced with bran that had only been heat-treated.

#### **4.8 CAT SCANS**

Figures 34 to 37 represent CAT scans of proofing loaves with different bran types. Figures 38 to 53 show the frequency distribution of bubble size (area, length and perimeter) and shape (roundness or aspect ratio) at different stages of proofing.

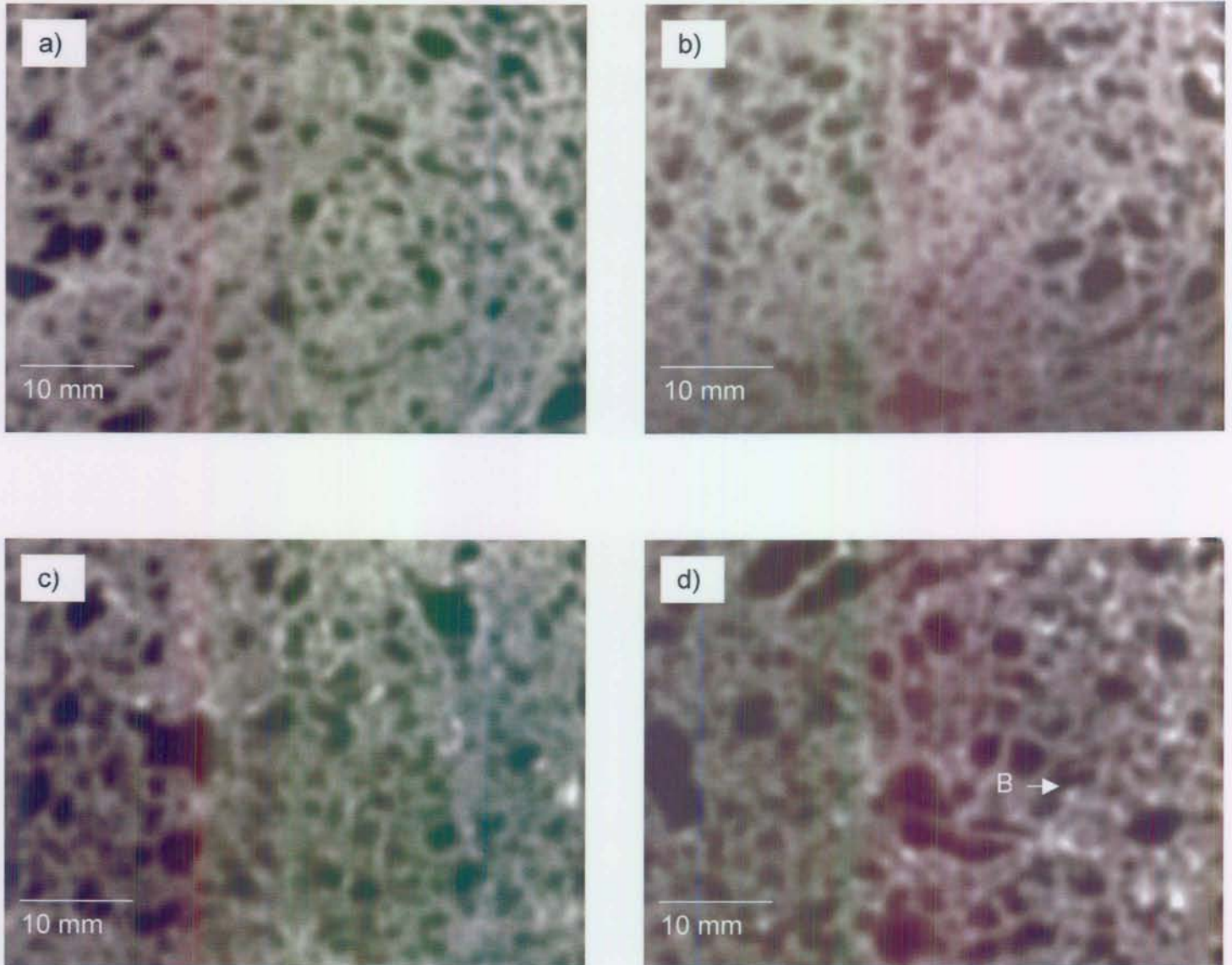


**Fig. 34: CAT scans of a white bread control after a) 0 min.; b) 20 min.; c) 40 min.; and d) 60 min. of proofing at 40°C**

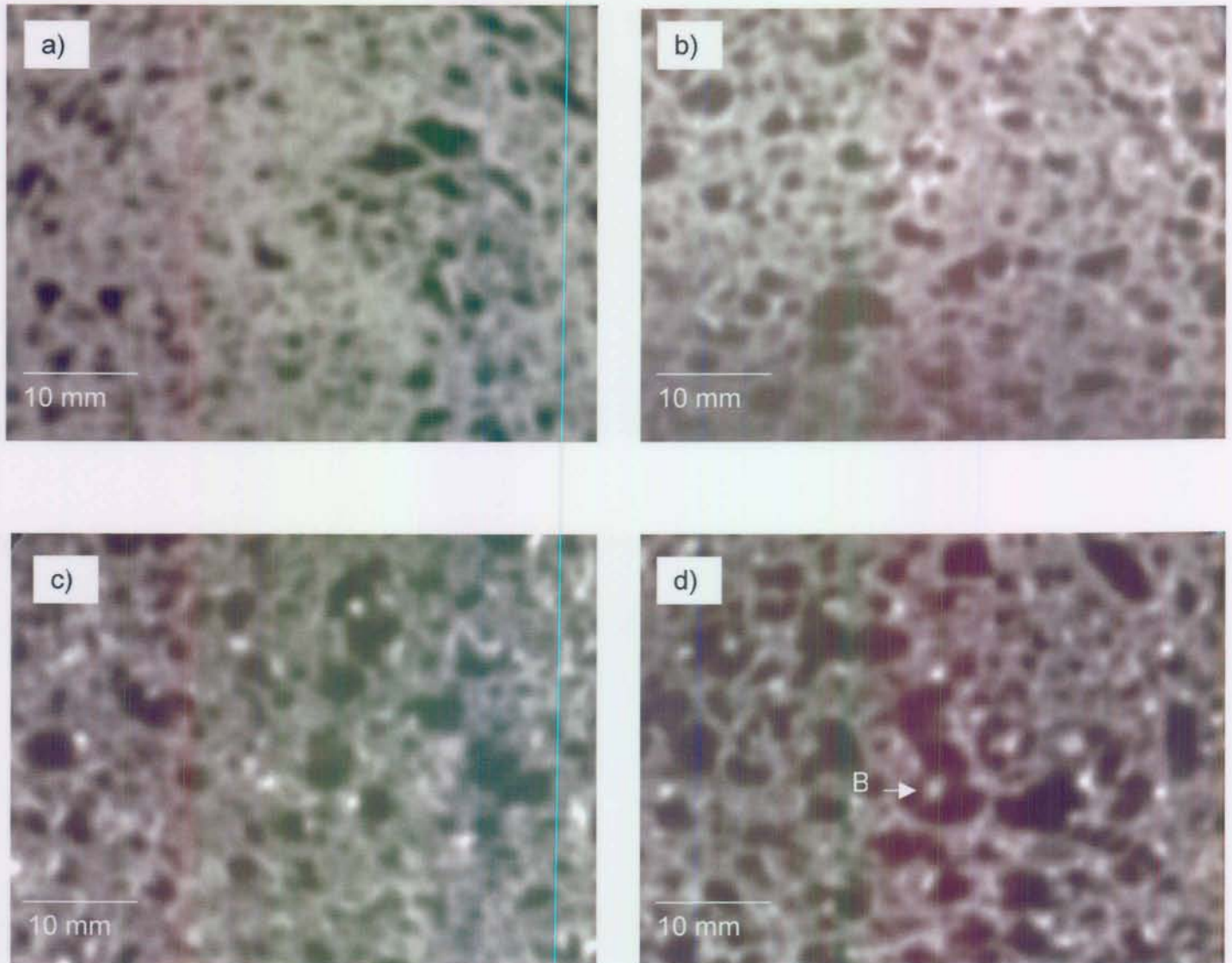


**Fig. 35: CAT scans of loaves with Pollard (15%) after a) 0 min.; b) 20 min.; c) 40 min.; and d) 60 min. of proofing at 40°C**





**Fig. 36: CAT scans of loaves with Select bran (15%) after a) 0 min.; b) 20 min.; c) 40 min.; and d) 60 min. of proofing at 40°C. B = bran particle protruding bubble**



**Fig. 37: CAT scans of loaves with Digestive bran (15%) after a) 0 min.; b) 20 min.; c) 40 min.; and d) 60 min. of proofing at 40°C. B = bran particle protruding bubble**



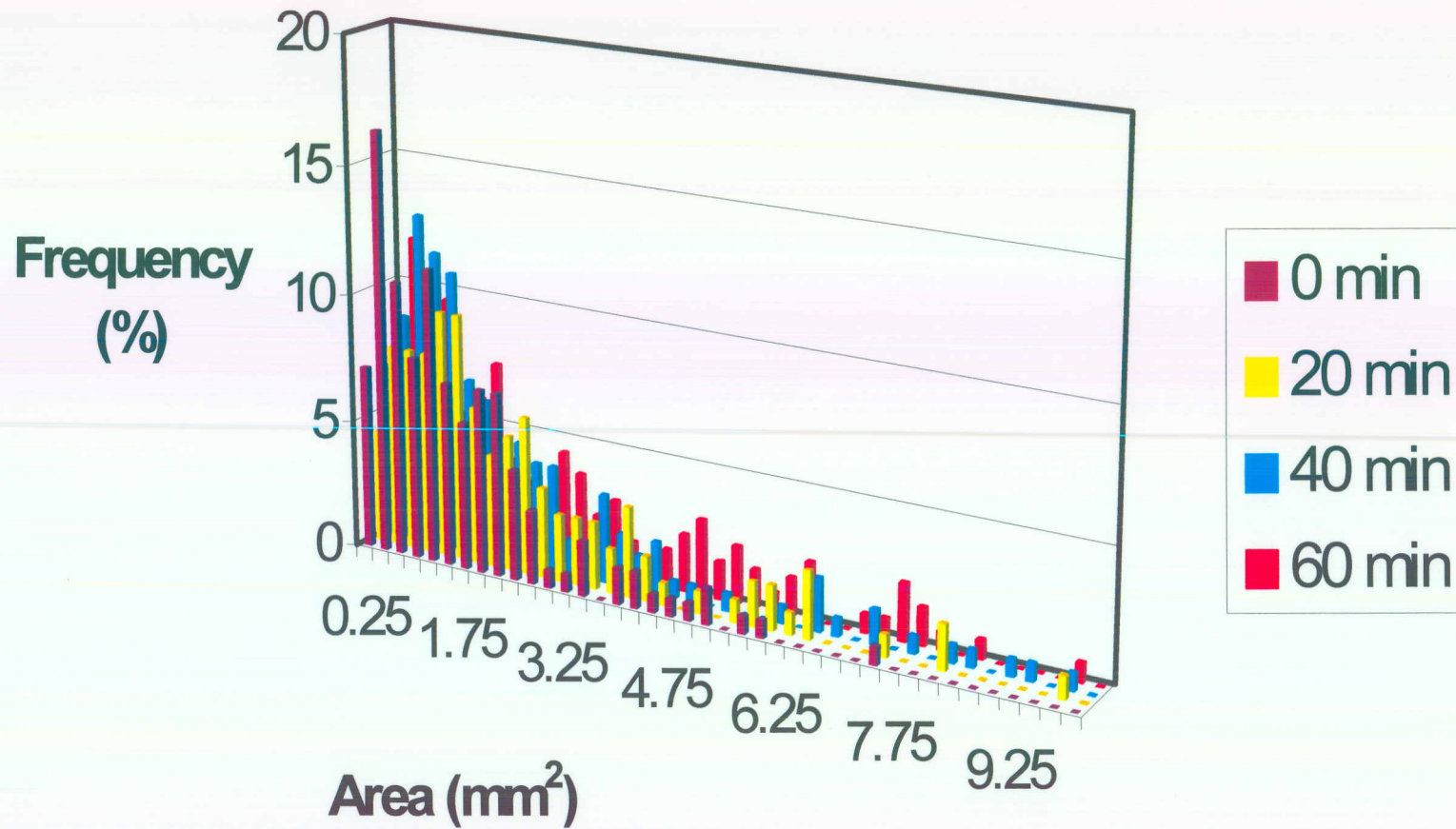


Fig. 38: Frequency distribution of bubble area of a white bread control after 0, 20, 40 and 60 minutes of proofing at 40°C



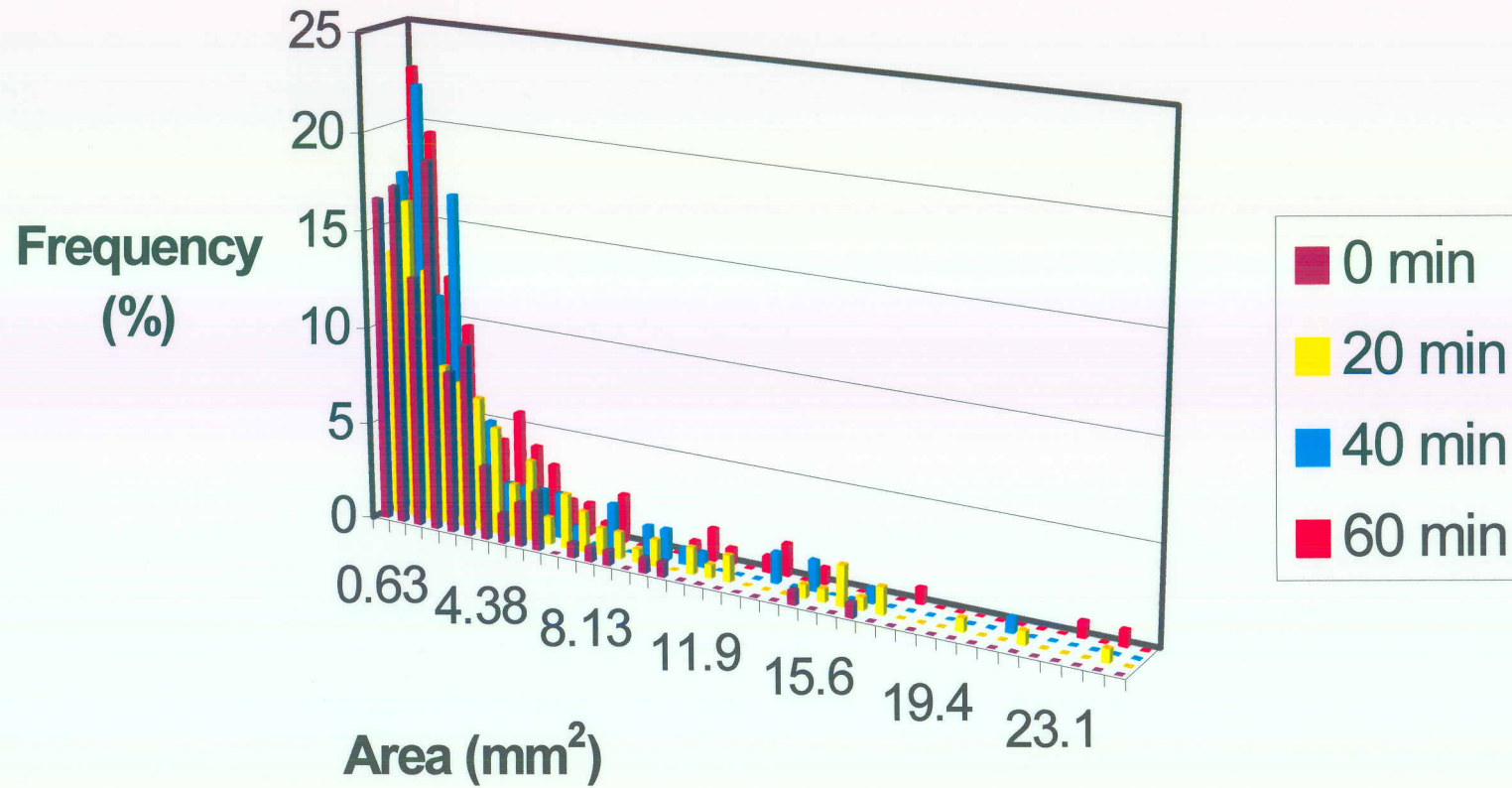


Fig. 39: Frequency distribution of bubble area of loaves with Pollard (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C

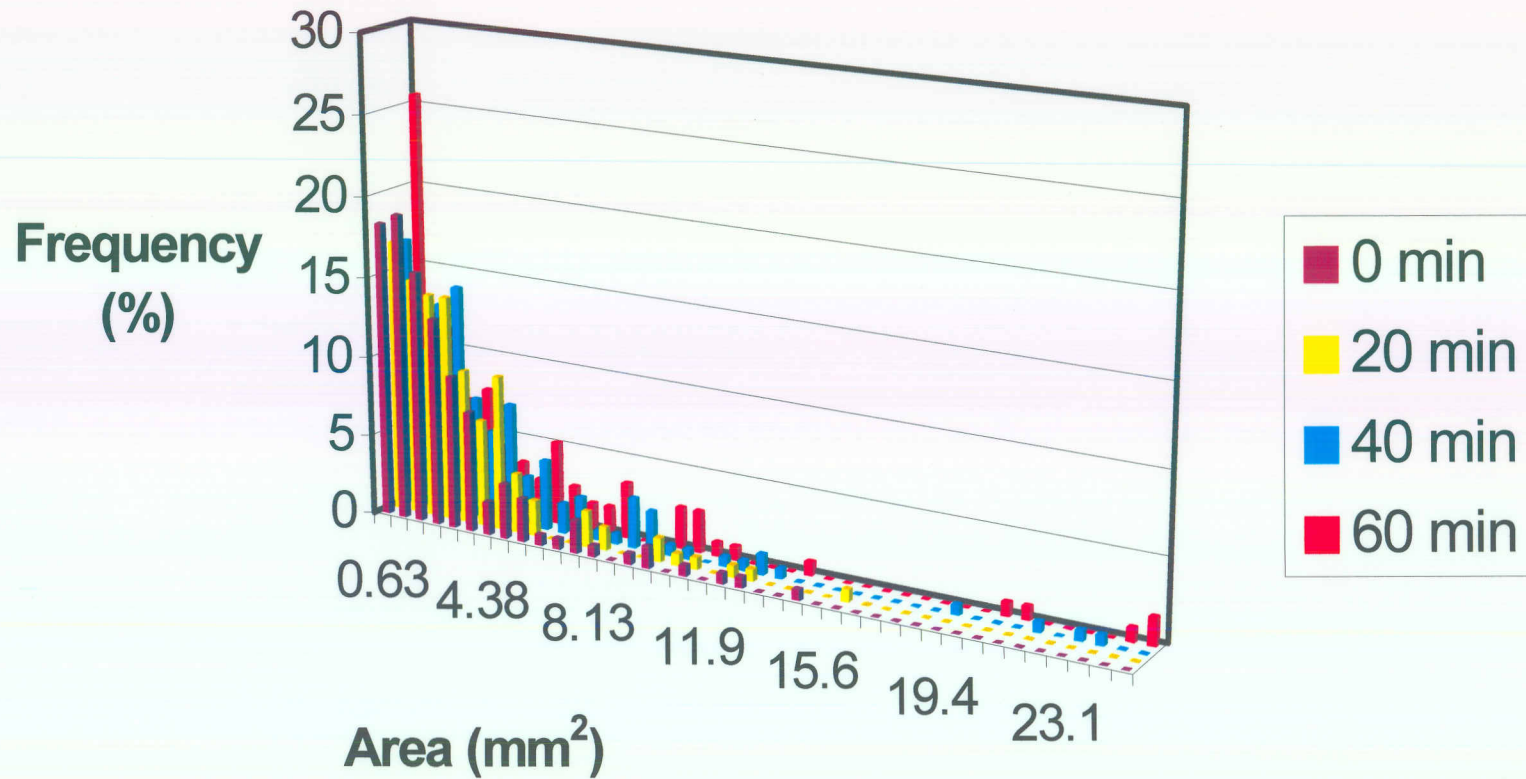


Fig. 40: Frequency distribution of bubble area of loaves with Select bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C

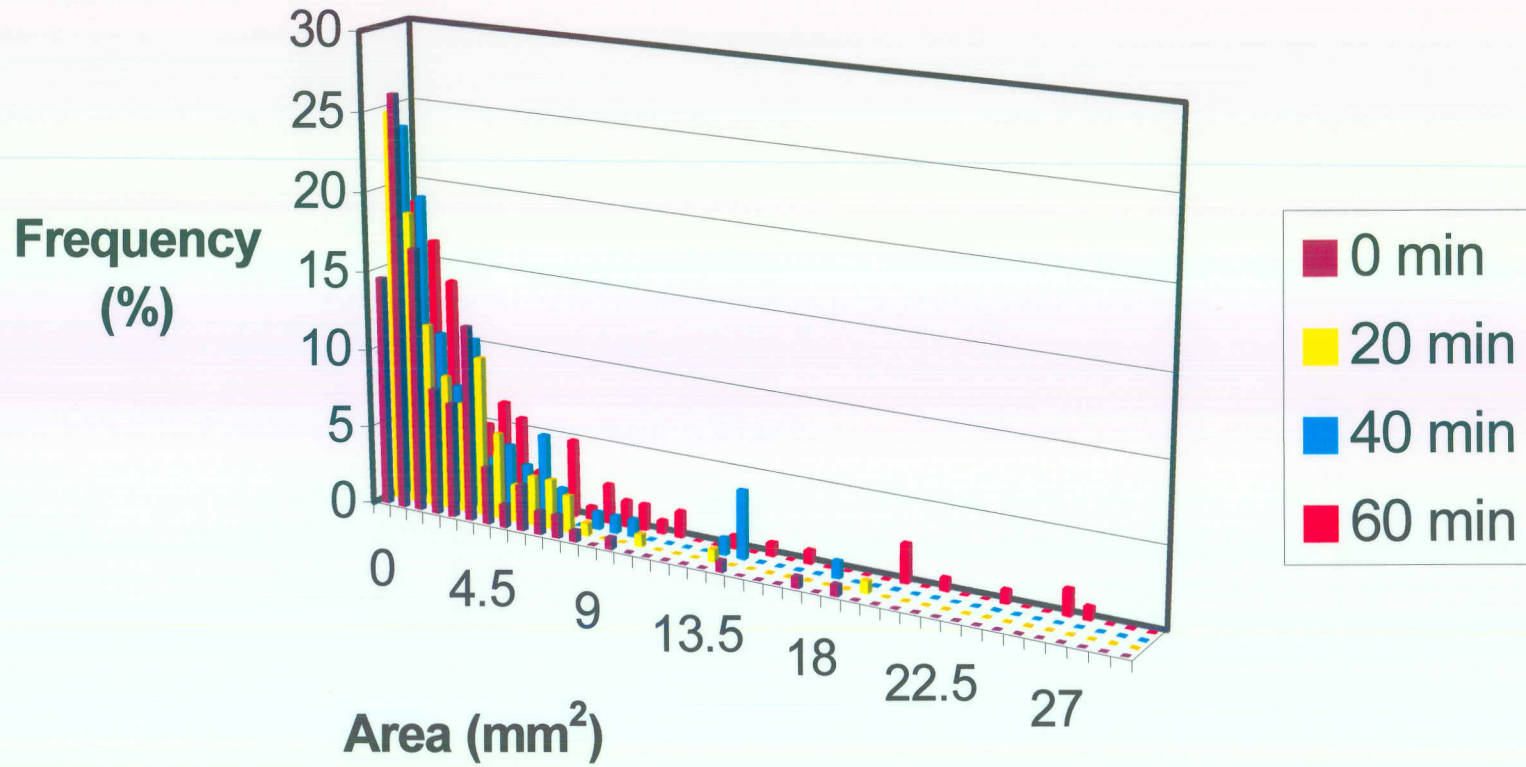


Fig. 41: Frequency distribution of bubble area of loaves with Digestive bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C

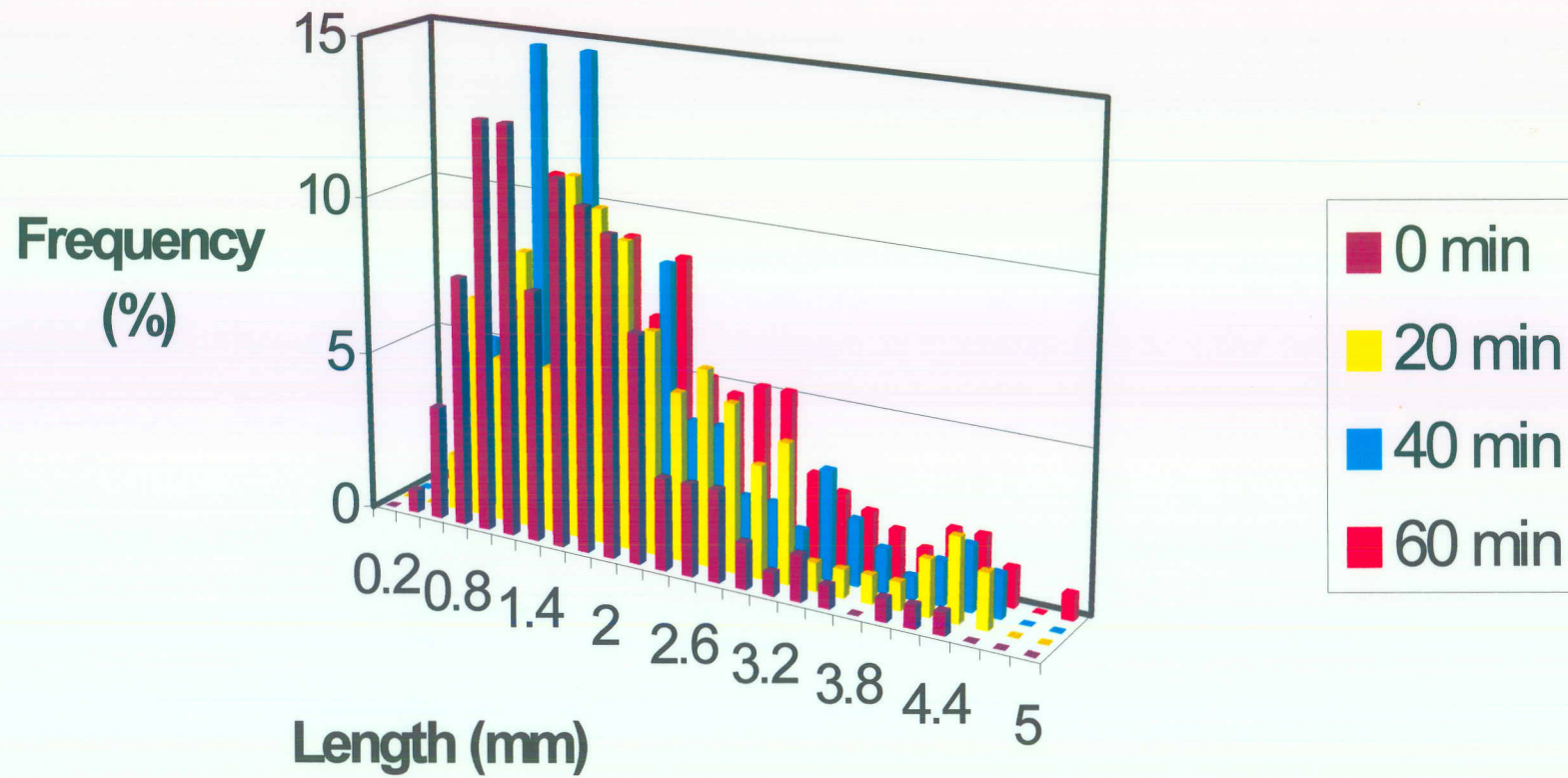


Fig. 42: Frequency distribution of bubble length of a white bread control after 0, 20, 40 and 60 minutes of proofing at 40°C



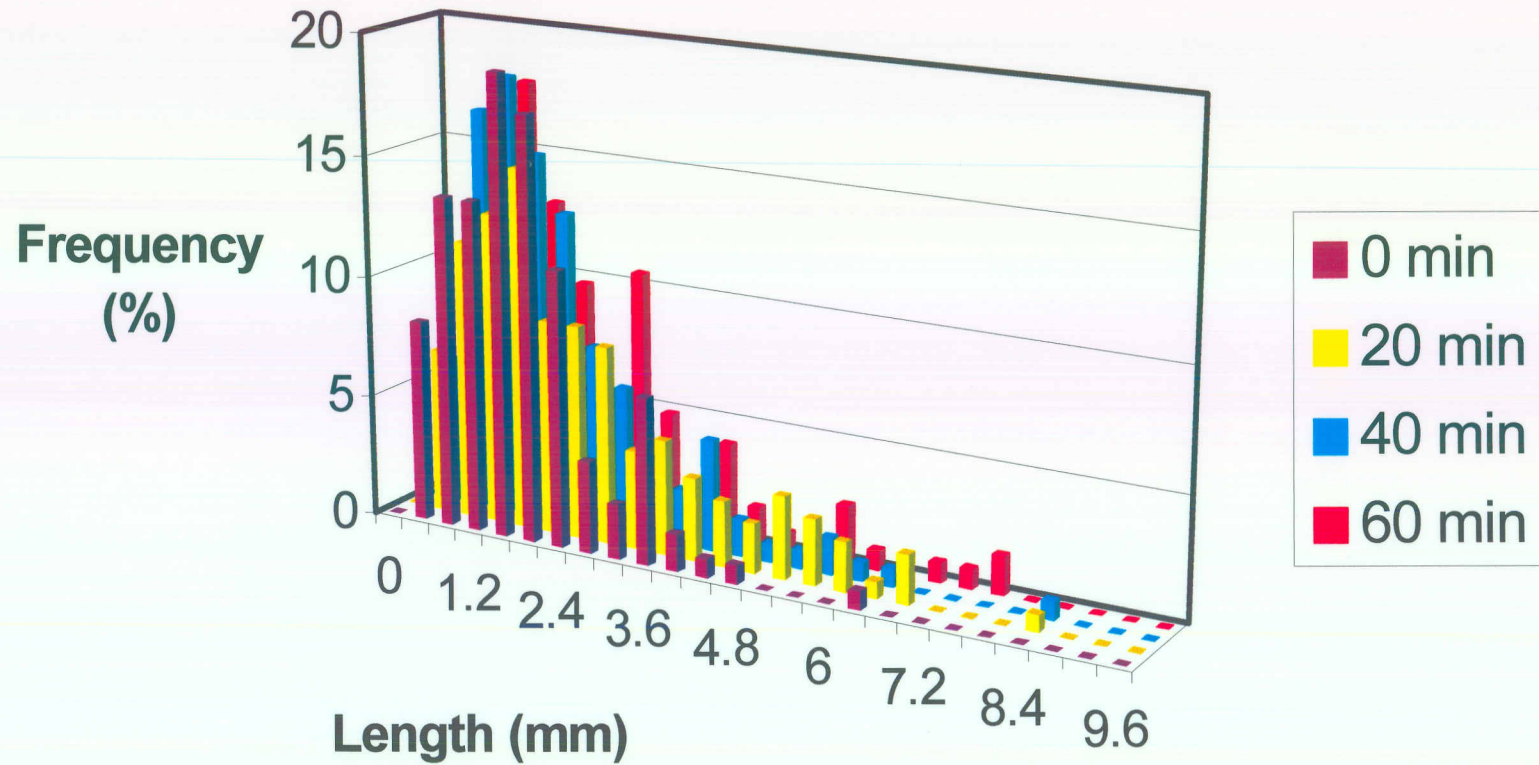


Fig. 43: Frequency distribution of bubble length of loaves with Pollard (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C



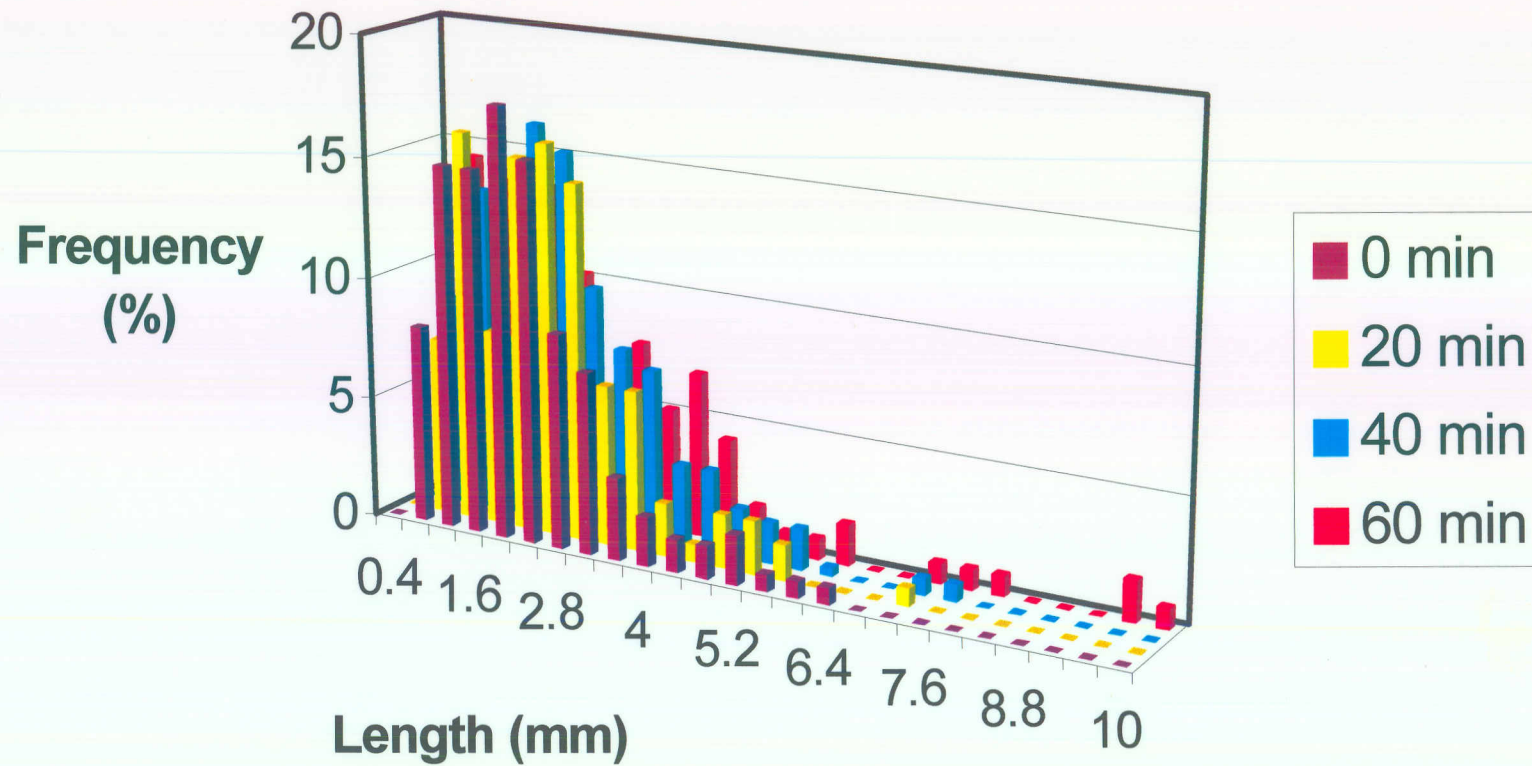


Fig. 44: Frequency distribution of bubble length of loaves with Select bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C

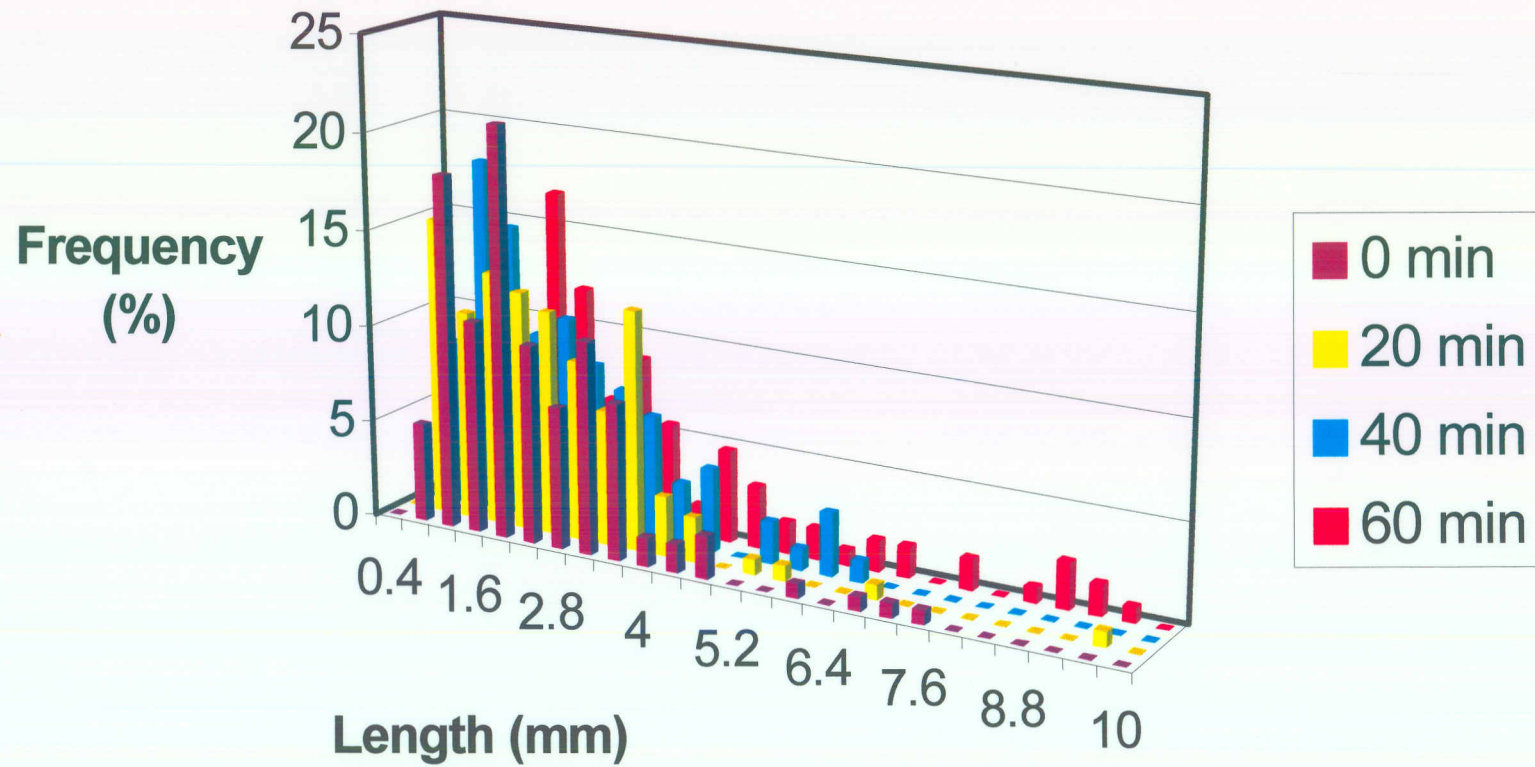


Fig. 45: Frequency distribution of bubble length of loaves with Digestive bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C

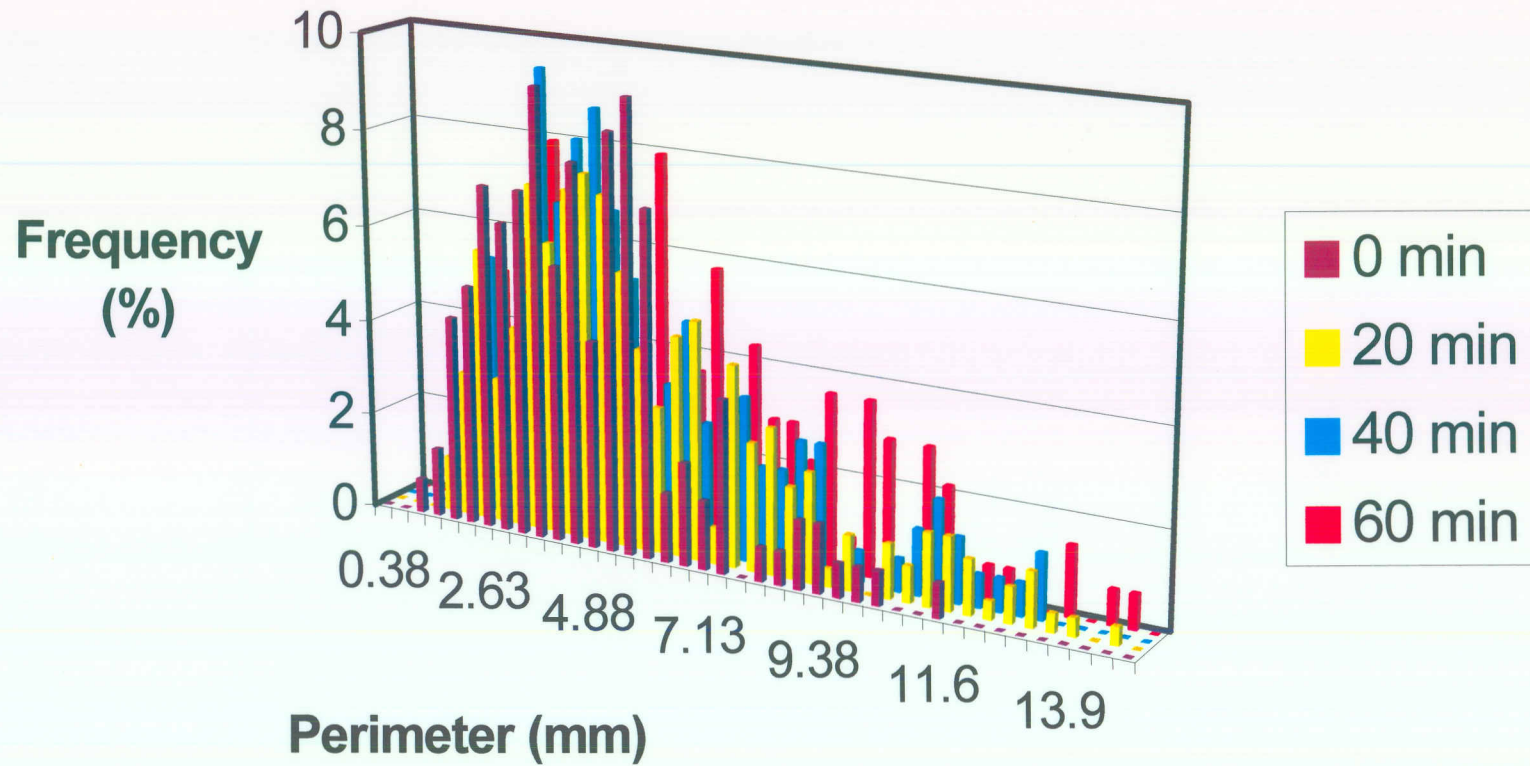


Fig. 46: Frequency distribution of bubble perimeter of a white bread control after 0, 20, 40 and 60 minutes of proofing at 40°C

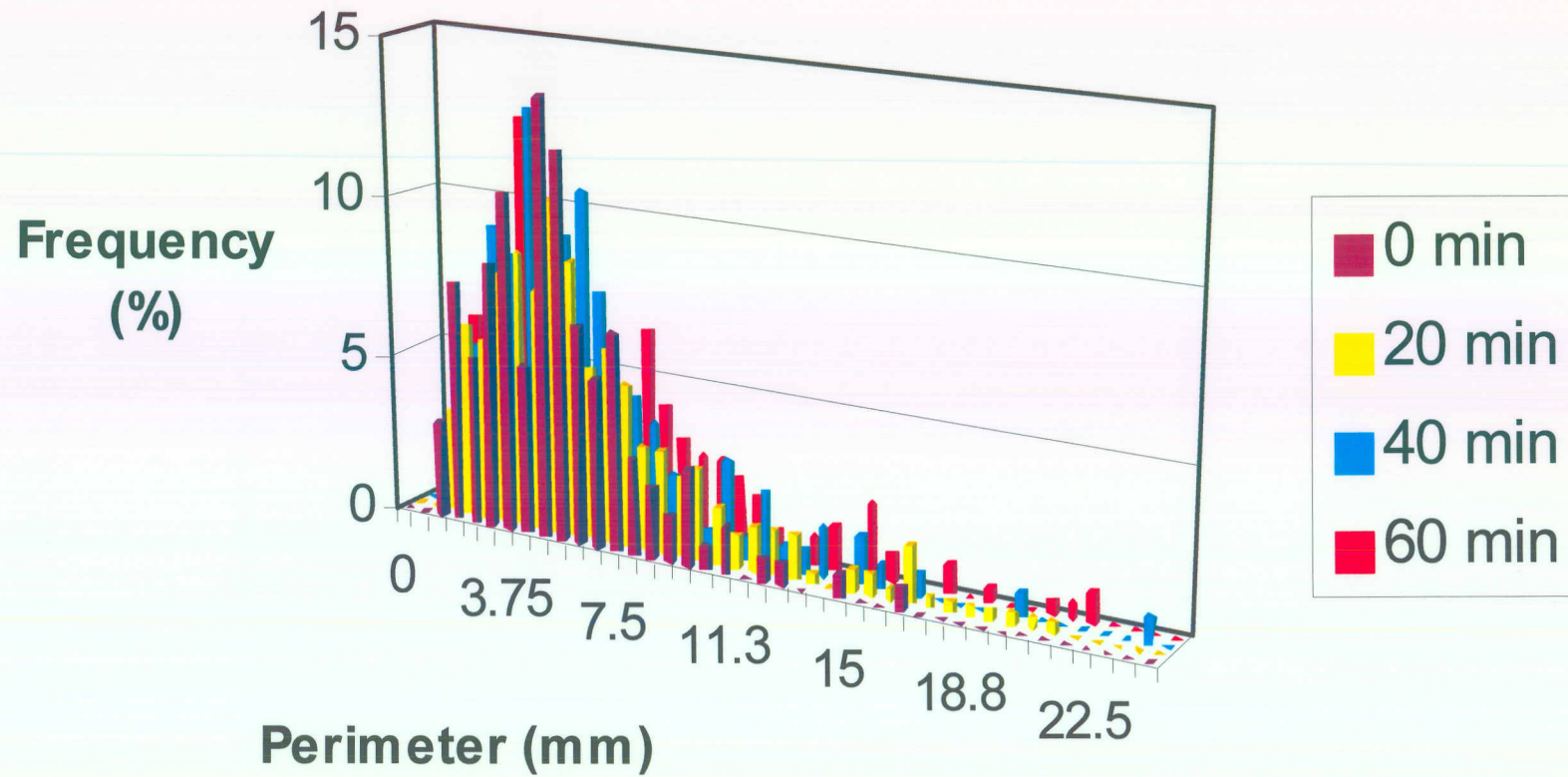


Fig. 47: Frequency distribution of bubble perimeter of loaves with Pollard (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C



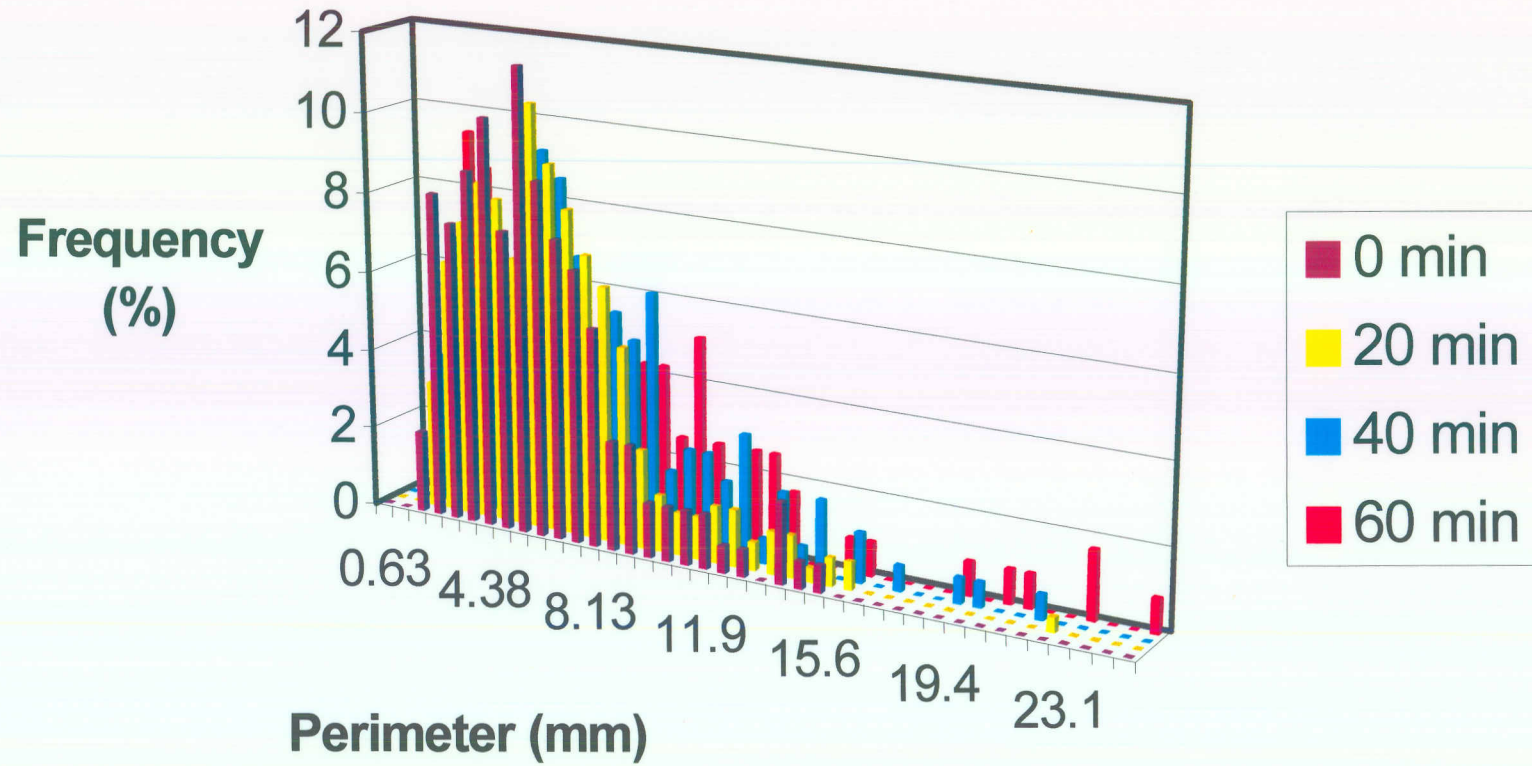


Fig. 48: Frequency distribution of bubble perimeter of loaves with Select bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C



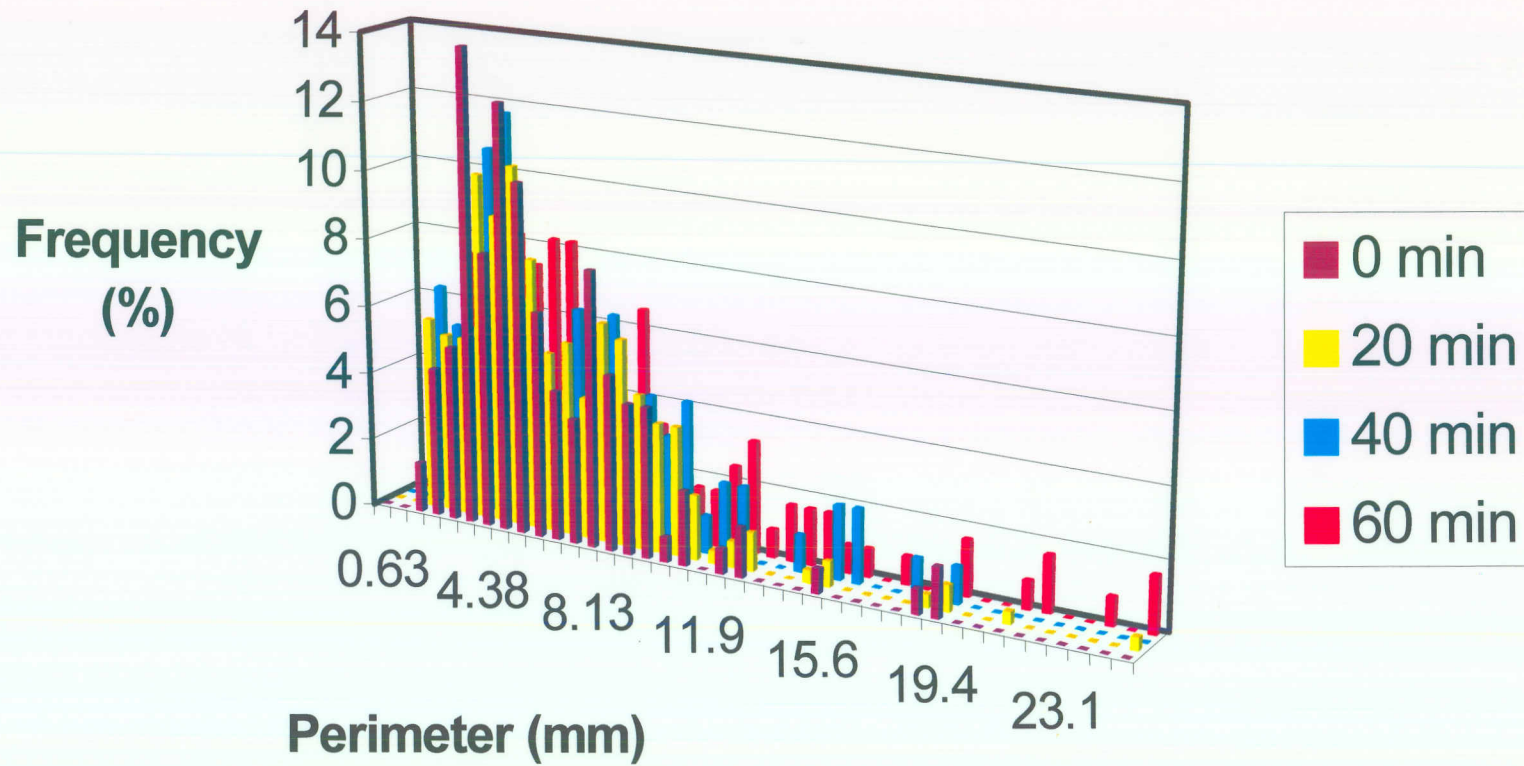


Fig. 49: Frequency distribution of bubble perimeter of loaves with Digestive bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C

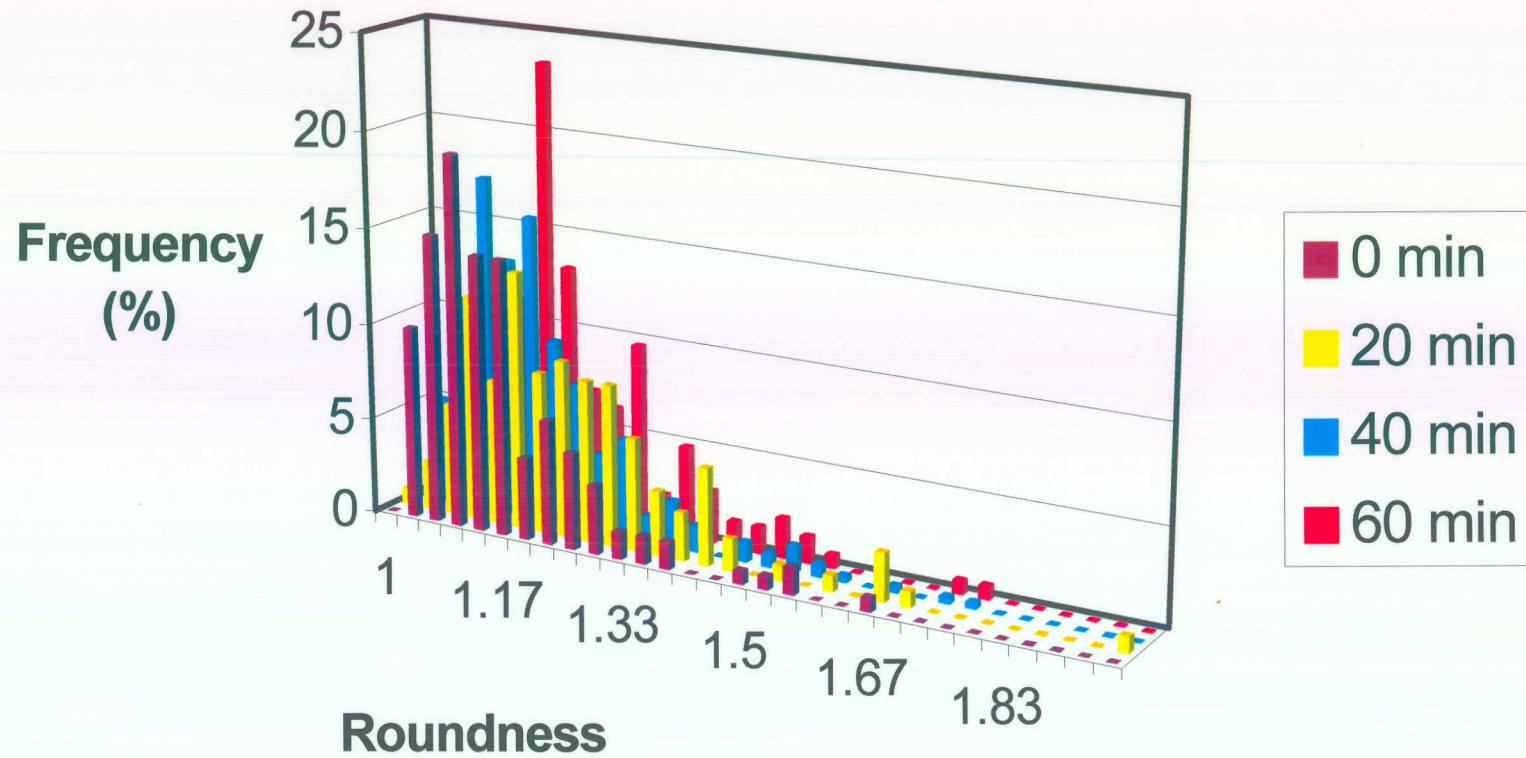


Fig. 50: Frequency distribution of bubble roundness of a white bread control after 0, 20, 40 and 60 minutes of proofing at 40°C. Perfectly round = 1

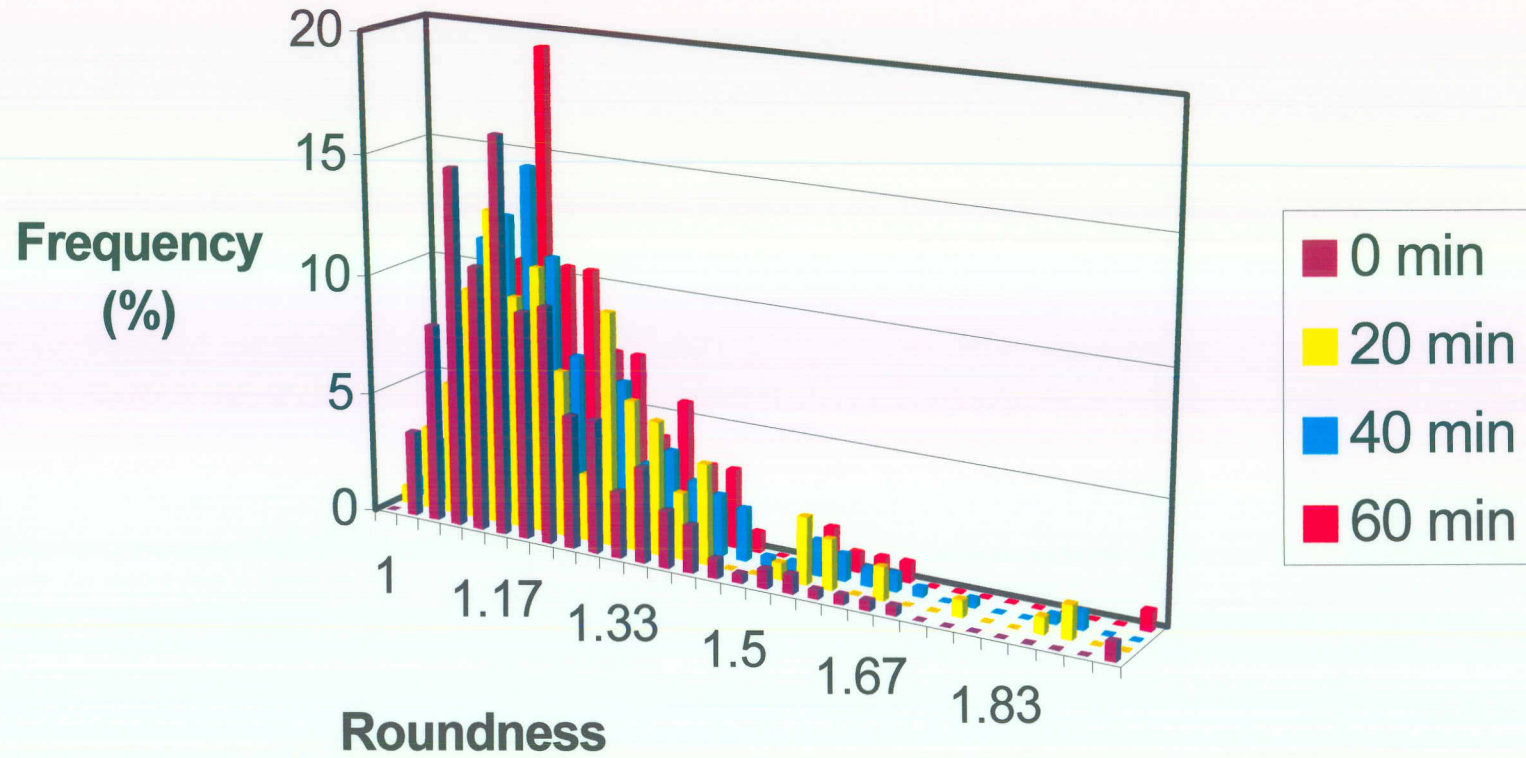


Fig. 51: Frequency distribution of bubble roundness of loaves with Pollard (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C. Perfectly round = 1

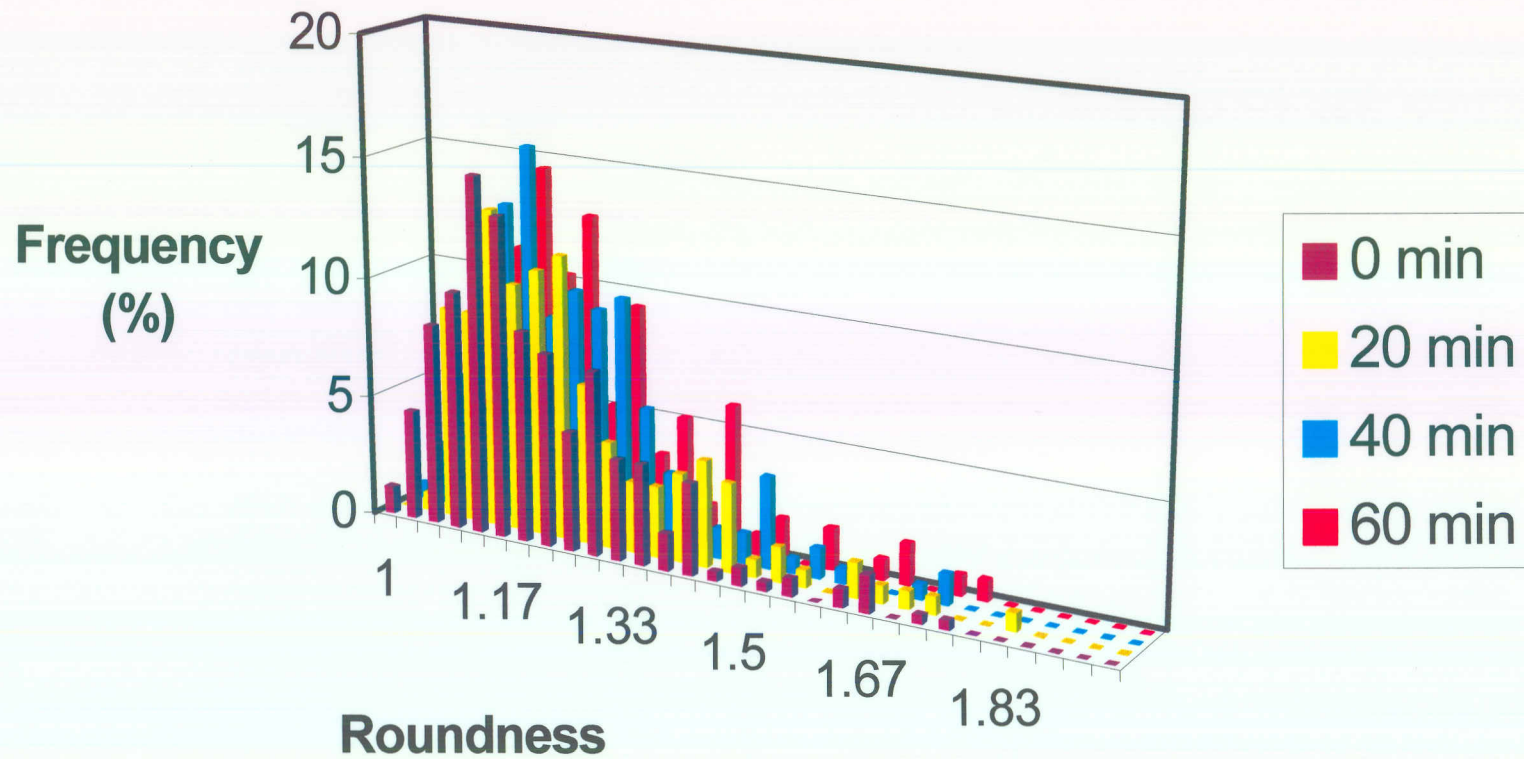


Fig. 52: Frequency distribution of bubble roundness of loaves with Select bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C. Perfectly round = 1



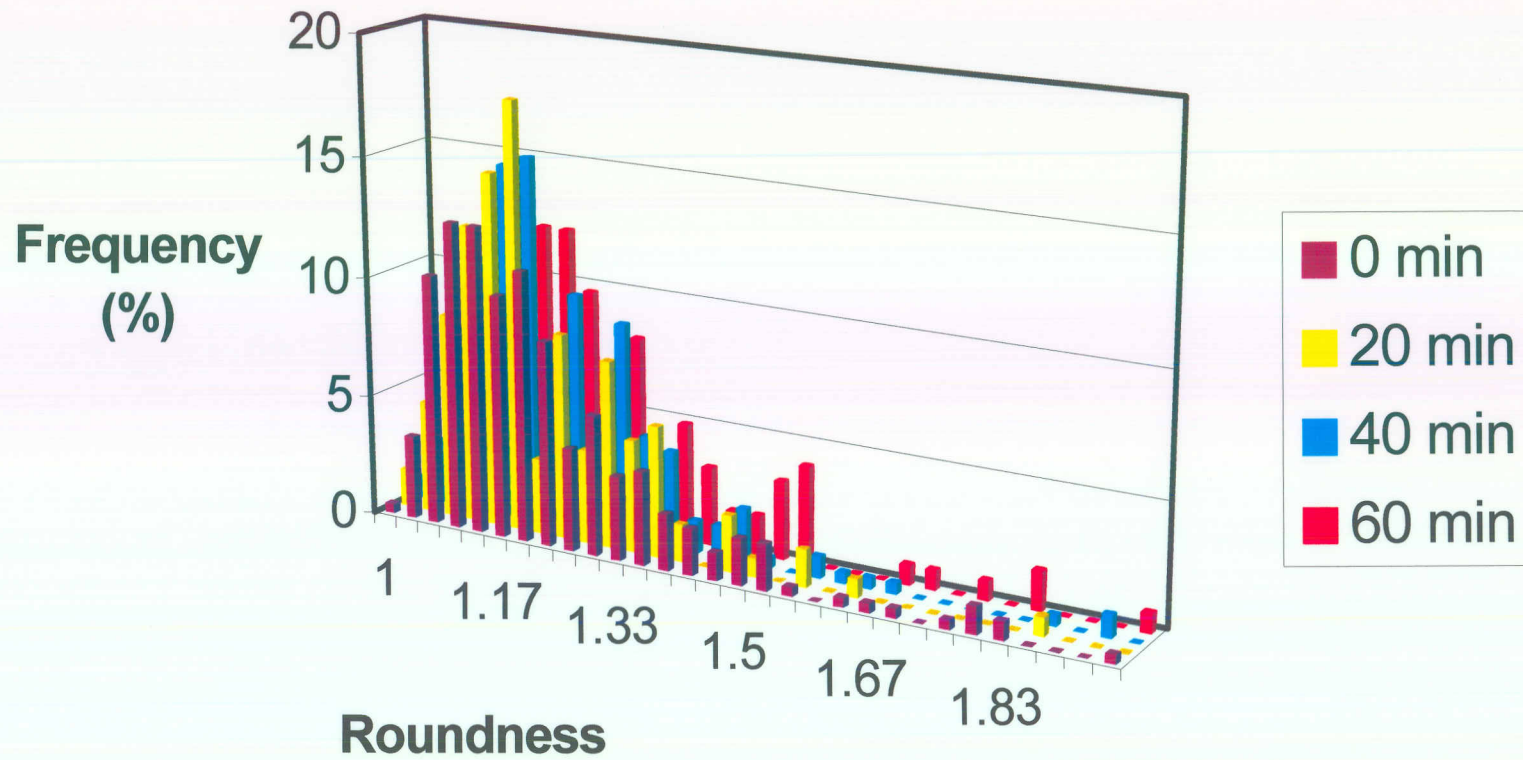


Fig. 53: Frequency distribution of bubble roundness of loaves with Digestive bran (15%) after 0, 20, 40 and 60 minutes of proofing at 40°C. Perfectly round = 1



From these figures it is evident that bubble size (measured as bubble area, length and perimeter) increased during proofing. Bubble size in the white bread was the smallest and the largest in the bread with Digestive bran. The white bread also had bubbles which were uniform and round, which was in sharp contrast with the irregularly shaped bubbles in the bread with Select and Digestive bran. Bubble shape and size in the bread with Pollard were more like that of the white bread. It could also be seen that bubble roundness decreased with proofing time in all cases (Fig. 50 to 53). Bran particles protruding through bubbles could be observed in the breads made with Select and Digestive bran (Fig. 36d and 37d)

#### 4.9 SENSORY EVALUATION

Some sensory qualities of bread baked with different bran types are given in Table 25.

**Table 25: Sensory qualities of bread baked with different bran types (12% level of addition)**

Attribute	Bran type	Mean score <sup>a,b</sup>
Texture	Pollard	6.2 a
	Heat-treated Pollard	4.8 b
	Heat-treated Digestive	2.4 c
	Select	2.2 c
	Digestive	2.0 c
	Heat-treated Select	1.8 c
Moistness	Heat-treated Pollard	3.2 a
	Pollard	2.6 a
	Select	2.6 a
	Heat-treated Digestive	2.2 a
	Digestive	1.8 a
	Heat-treated Select	1.6 a

**Table 25 (cont.)**

<b>Attribute</b>	<b>Bran type</b>	<b>Mean score</b>
Graininess	Pollard	5.2 a
	Heat-treated Pollard	5.2 a
	Heat-treated Digestive	3.6 ab
	Select	2.4 bc
	Heat-treated Select	2.0 bc
	Digestive	1.3 c
Chewiness	Pollard	6.0 a
	Heat-treated Pollard	5.8 a
	Select	4.0 b
	Heat-treated Digestive	3.4 bc
	Heat-treated Select	2.2 cd
	Digestive	1.5 d
Taste	Pollard	5.8 a
	Heat-treated pollard	5.4 ab
	Select	3.6 bc
	Heat-treated Digestive	3.2 cd
	Heat-treated Select	3.0 cd
	Digestive	1.5 d
Overall acceptability	Pollard	6.4 a
	Heat-treated Pollard	5.6 a
	Select	3.4 b
	Heat-treated Digestive	3.4 b
	Heat-treated Select	2.2 bc
	Digestive	1.5 c

<sup>a</sup>1 = Do not differ at all from “ideal brown bread”; 7 = Differ very much from “ideal brown bread”

<sup>b</sup>Values with different letters in the same cell are significantly different ( $P < 0.05$ )



From this table it is evident that bread baked with Digestive bran and heat-treated Select bran were the closest to the panelists' idea of an "ideal brown bread". The bread baked with Pollard was found to differ most from an "ideal brown bread" and was not acceptable.

## CHAPTER 5: DISCUSSION

Traditionally, brown bread is perceived to be of poorer quality than white bread. The two main contributors to bread quality are volume and crumb structure (Stauffer, 1998). Most consumers want a bread with a high loaf volume and a crumb structure which is uniform and fine (Van Vliet, 1999). These two quality parameters differ significantly between white and brown breads. Research has shown, that brown and wholemeal breads, containing non-endosperm components such as bran and/or germ, have significant lower loaf volumes when compared to white bread (Pomeranz et al, 1976; Pomeranz, 1977; Rogers & Hosney, 1982; Moder et al, 1984; Barnes & Lowy, 1986; Bloksma & Bushuk, 1988; Galliard & Gallagher, 1988; Tait & Galliard, 1988; Lai et al, 1989a, 1989b, 1989c; Gan et al, 1989; Gan et al, 1992; and Nelles et al, 1998). In most countries, bran is not separated from the white flour, and brown or wholemeal breads are baked from flours of different extraction rates (Kent & Evers, 1994). Wholemeal flour in the U.K, for example, contains all the products of milled wheat, including bran and germ (100% extraction rate). Brown flours can be of extraction rates between 85% and 98%. In South Africa, brown bread is manufactured by adding bran components back to white flour, after which the dough is mechanically developed through high energy mixing. Despite these differences in processing, similar results were found in this study as were found before. The addition of bran to white flour, caused volumes of loaves baked from the resulting flour to be depressed, when compared to a white bread control (Tables 21 and 22; Fig. 20). A higher level of addition caused lower loaf volumes. This depression in loaf volume can not be explained solely in terms of the bran diluting the gluten proteins (Pomeranz, 1977).

In addition, added bran caused crumb structure to be coarse and open. This contrasted markedly with the uniform crumb of white bread, as was evident in the crumb structures during proofing (Fig. 34 to 37), as well as after baking (Fig. 30 to 33). Pomeranz (1977) and Gan et al (1989) found similar results. It therefore appears that bread quality, as measured by loaf volume and crumb structure, is seriously impaired by addition of bran. Ultimate bread quality depends on optimum properties in the dough matrix. Stauffer (1998) defined two characteristics of a "good" dough:

1. The ability to retain gas generated during fermentation in the form of numerous small gas cells;
2. A proper balance of viscous flow and elastic strength so that the loaf can expand adequately during proofing and the early stages of baking, yet retain its rounded form.

Gluten is the main component of dough that determines how well these requirements are met. Bran components appear to affect gluten functionality by changing its physicochemical characteristics. This hampers proper gluten formation, influences gas retention and eventually causes lower loaf volumes and poor crumb structures. The mechanism by which bran affects gluten functionality and influences bread quality can be explained by a subtle interplay of chemical and physical effects.

### **5.1 CHEMICAL EFFECTS OF BRAN ON BREAD QUALITY**

Bran was subjected to a heat treatment in order to inactivate heat-sensitive components which could have had a detrimental effect on loaf volume. In previous studies (Galliard, 1986b; Nelles et al, 1998), this inactivation was brought about by a wet heat treatment. In this study, however, it was decided to use a dry heat treatment, the brans being autoclaved in air-tight containers. This particular treatment was chosen to ensure that the alteration in size and other physical properties of the bran particles would be minimised, as could not have been the case with a wet heat treatment. It was important not to change the physical properties of the brans, since it was attempted to separate chemical and physical effects. This part of the study concentrated on chemical effects, therefore all other parameters, including physical effects had to be kept constant. Results proved that apart from the colour, physical properties were not significantly altered (Tables 16 and 17). Moisture content was lowered only slightly, and particle size was not changed. Any changes in baking performance of the heat-treated brans could therefore only be attributed to chemical changes.

Dry heat treatment of different brans had at least two effects on chemical substances: It practically inactivated lipase activity in all bran types and brans from different sources (Tables 18 and 19) and significantly reduced TRS (Table 20), such as glutathione, possibly by oxidation. Nelles et al (1998) found similar effects on lipase and



lipoxygenase with a wet heat treatment, and on TRS with a wet oxidation method. Breads baked with heat-treated bran produced higher loaf volumes when compared to bread baked with the untreated bran (Tables 21 and 22; Fig. 22-29). This led to the conclusion that lipase and glutathione could at least in part be responsible for the reduction in loaf volume caused by bran addition. To develop a hypothesis concerning the mechanisms by which these substances cause loaf volume depression, it is necessary to look at what happens during dough formation.

The first basic step in breadmaking is combining water with wheat flour and imparting mechanical energy to the mixture to form an elastic dough. Wheat storage protein (gluten) possesses the unique ability to form a viscoelastic dough when wetted and kneaded. The strong, cohesive dough that is formed, is able to retain gas and a light, baked product is produced (Hoseney, 1994). Gluten is composed of two main groups of proteins: glutenin and gliadin. Glutenin consists of high molecular weight proteins in which individual polypeptide chains are cross-linked by the disulphide bonds of the amino acid cysteine. Gliadins are composed of lower molecular weight proteins in which the cysteine crosslinks are intra- rather than intermolecular, as shown in Figure 54 (Williams & Pullen, 1998). Although this is a very simplistic model for glutenin and gliadin structure, it serves to illustrate the point.

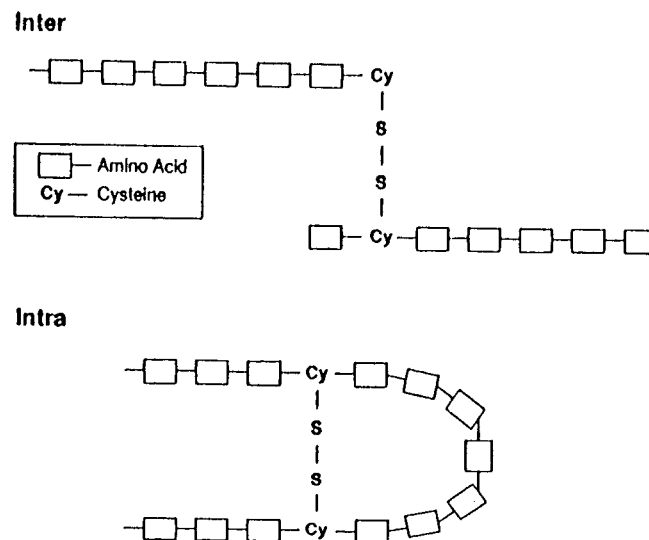
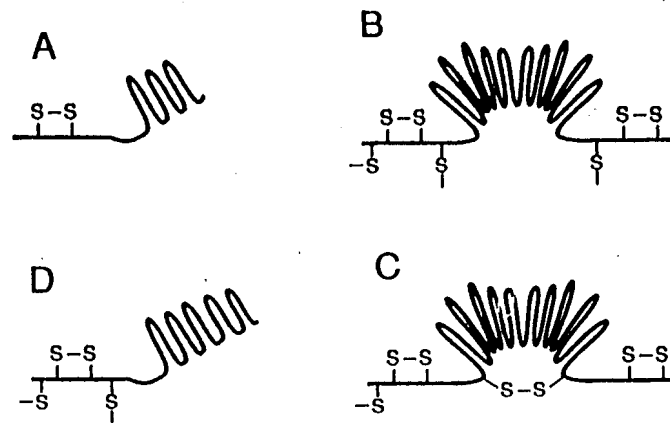


Fig. 54: Representation of cysteine crosslinks in gluten (Williams & Pullen, 1998)

Two groups of glutenin subunits have been identified: High molecular weight glutenin subunits (HMW-GS) and low molecular weight glutenin subunits (LMW-GS) (Stauffer, 1998). The molar ratio of LMW-GS to HMW-GS is 2:1 or higher; the amounts of the two kinds of subunits are roughly equal on a weight basis. One possible model explaining the elasticity of glutenin is shown in Figure 55.

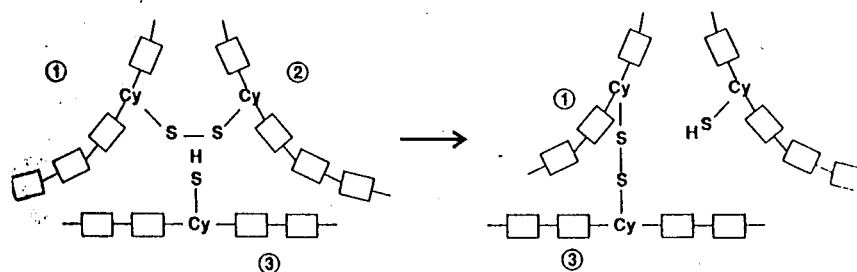


**Fig. 55: Schematic depiction of gluten proteins. A) Gliadin, B) HMW-GS, showing possible action of molecular spring, C) HMW-GS, showing SS bond preventing extension of the spirals, D) LMW -GS (Stauffer, 1998)**

The molecular architecture of glutenin subunits is unusual, as reviewed by Stauffer (1998). In HMW-GS, cysteine is concentrated in the regions near each end of the chain, with a long stretch of other amino acids between these two ends. LMW-GS have a similar concentration of cysteine residue, but at only one end of the chain (Fig. 55D). Thus, both ends of the HMW protein can enter into polymerisation reactions, while only one end of the LMW protein can react this way. The interior regions of both species, but the HMW-GS in particular, are postulated to form  $\beta$ -turn spirals, which in turn can fold into a helical sheet structure that can possibly be linked to a coil spring (Fig. 55B) and account for the elastic nature of glutenin. An intramolecular disulphide bond can retain this spring (Fig. 55C); this bond can be broken during mixing to develop the gluten structure. In fact, it seems clear that mixing breaks the HMW-GS into smaller units, which then reform to some extent. Graveland, Bosveld & Lichtendonk (1985) found that during short high-energy mixing the amount of LMW glutenin increased sharply, but decreased again when the dough was allowed to rest. The points of scission are

thought to be at the disulphide bonds, forming radicals ( $SS \rightarrow 2S^*$ ). As disulphide bonds are broken, they reform between adjacent molecules that have been aligned along the lines of stress in the dough ( $2S^* \rightarrow SS$ ) (Stauffer, 1998).

In addition to the crosslinked cysteine present in wheat protein, numerous low molecular weight SH compounds (reduced form) are present in flour which can cause SS/SH interchanges (Schofield & Chen, 1995). This exchange (Fig. 56) occurs at a rapid rate during mechanical dough development and subsequent resting, and is generally considered to influence dough rheological properties and breadmaking performance (Williams & Pullen, 1998). The radicals, can also react with these SH compounds in the following way:  $S^* + SH \rightarrow SS + H^*$  (Stauffer, 1998).



**Fig. 56: Representation of SS/SH interchange (Williams & Pullen, 1998)**

One of the substances present in flour, which could affect these redox reactions in glutenin, is glutathione (GSH) (Schofield and Chen, 1995). Substantial amounts of glutathione are present in the germ fraction of the wheat kernel (Bloksma & Bushuk, 1988). Even oxidised glutathione has been reported to affect dough in the same way as does the reduced form, although to a lesser extent (Ziegler, 1940). In the series of interchange reactions, rheologically ineffective mixed disulphides are formed at the expense of effective cross-links between protein chains. This could lead to a weak dough and poor baking quality. This is consistent with the work of Nelles et al (1998) whose results showed that a wet oxidation treatment of bran significantly reduced TRS, indicating oxidation of glutathione, and resulted in increased loaf volumes. Lai et al (1989a) also found that oxidising glutathione in whole wheat bread produced loaf volumes equal to that of a white control.

The presence (or absence) of oxygen in a dough system greatly influences SS/S<sub>H</sub> interchanges and dough development. The CBP is the breadmaking system with the greatest need for oxidation (Williams & Pullen, 1998), since dough development occurs mainly during the mixing process and the rest stage thereafter. Oxidising agents, which are added to improve baking properties, are essential in the CBP. Even more so with the production of brown bread, where oxidants are added to help the gluten carry the bran (D.G. Carroll – Personal communication). The positive effects of, for example, ascorbic acid in mechanically developed doughs were described by Williams & Pullen (1998):

Oxidation of S<sub>H</sub> groups to remove them from the system. This would benefit the dough structure by preventing them from preferentially reacting with the S<sub>H</sub> group of the glutenin molecules exposed during the development period.

Causing a SS bond to be formed between two of the glutenin S<sub>H</sub> groups exposed during the developing period. This would increase the elasticity of the dough structure.

Chemically, ascorbic acid is a reducing agent and can only function as an oxidising agent in a dough after it has been itself oxidised to dehydroascorbic acid, and to function efficiently requires the availability of atmospheric oxygen (Kent & Evers, 1994). The presence of oxygen in a developing dough, therefore, plays an important role in determining baking performance and ultimately loaf volume, because of its influence on ascorbic acid and gluten development.

It was found that at low levels of addition, Select and Digestive bran behaved the complete opposite to what was expected. At a 9% level of addition neither of the two brans depressed loaf volume. In fact, Digestive bran produced loaf volumes that were even somewhat larger than the white bread controls (Table 22; Fig. 20). This phenomenon could probably be explained by the large flaky shapes of the Digestive bran particles as could be observed by scanning electron microscopy (Fig. 19). It is possible that the flaky shapes of the bran particles were responsible for trapping or encapsulating air and oxygen and therefore providing extra gas cell nuclei in addition to

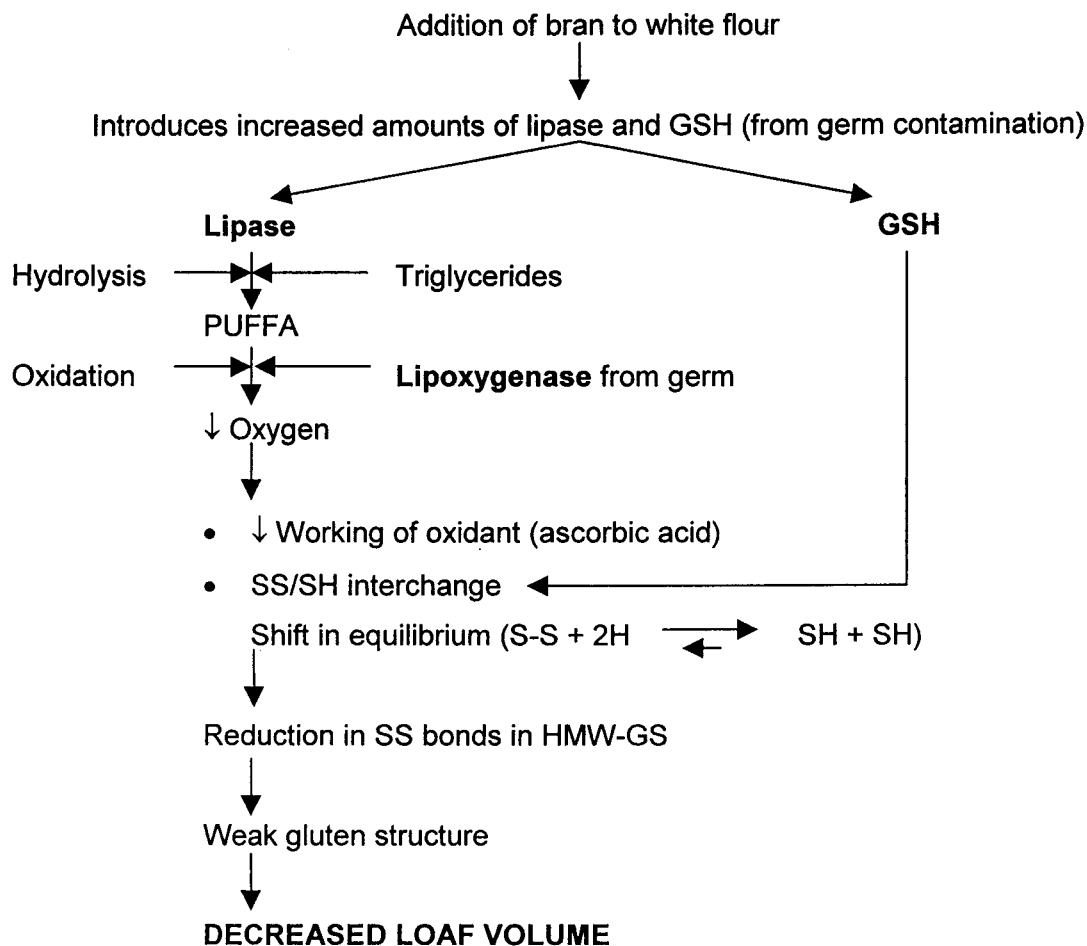
those formed during the mixing process. These nuclei would eventually expand because of CO<sub>2</sub> being produced by yeast cells during fermentation, leading to higher loaf volumes. The extra oxygen trapped by the Digestive bran could also have resulted in increasing the effective operation of the ascorbic acid and increasing gluten development by oxidation, which led to increased loaf volume.

It has been shown that wholemeal flour deteriorates rapidly on storage compared with white flour (Barnes & Lowy, 1986). Galliard (1986a) found that oxygen consumption values of aqueous suspensions of wheat wholemeal were substantially higher than those of white flours. The oxygen uptake was due primarily to the oxidation of unesterified, polyunsaturated fatty acids. In a subsequent study, Galliard (1986b) showed that the rate of oxygen uptake by aqueous suspensions of wholemeal flour increased linearly with increases in unesterified fatty acids. Warwick et al (1979) also found an increase in free fatty acids during storage of flour, with an accompanying loss in baking performance. Bell et al (1979) in addition showed that wheat fatty acids reduced loaf volumes. Galliard (1986a) provided evidence that the increase in unesterified fatty acids and oxygen consumption in wholemeal flour, as compared with white flour, is due to the presence of lipid metabolising enzymes present in the germ and bran fractions. The increased oxygen demand of wholemeal flour is due to higher levels of polyunsaturated free fatty acids (PUFFA) released by hydrolysis of triglycerides, catalysed by lipase. Lipase is a membrane-bound enzyme (O'Connor & Harwood, 1992) and 75-80% of its activity is located in the bran fraction (O'Connor et al, 1992). The polyunsaturated fatty acids are subsequently oxidised, catalysed by lipoxygenase that is concentrated in the germ fraction (Galliard 1986a). Proof of the lipase/lipoxygenase system being responsible for higher oxygen demands and accompanying poor baking quality of wholemeal flour was strengthened when Galliard (1986a) found that oxygen consumption of mixtures of bran and germ increased on storage more rapidly than that of bran or germ stored separately. Similar results were found by Barnes and Lowy (1986).

The principles of all of these findings were confirmed by this study. Brown bread was produced by addition of bran to white flour. This introduced a significant amount of lipase to the dough. Although the germ was removed during the milling process, it is possible that the flour, or even the bran could have been contaminated with germ



fractions, which in turn was responsible for the presence of lipoxygenase. Heat treatment of the bran practically inactivated lipase activity (and probably lipoxygenase as well) (Table 19). The breads baked with heat-treated brans, had higher loaf volumes than those baked with the untreated brans (Fig. 25 to 27) showing that the lipase/lipoxygenase system was partly responsible for the reduction in loaf volumes. This is consistent with work of Nelles et al (1998) who found that a wet heat treatment inactivated lipase and lipoxygenase and resulted in production of higher loaf volumes. Tait & Galliard (1988) also found that high lipase activity in wholemeal flour was associated with poor baking performance, while Lai et al (1989a) showed that lipoxygenase had a detrimental effect on loaf volume. The dry heat treatment used in this study also significantly reduced the level of oxidising activity (TRS) in the brans (Table 20), which produced higher loaf volumes, indicating that glutathione was probably another chemical constituent responsible for loaf volume depression brought about by bran addition. A summary of the proposed chemical reactions involved in loaf volume depression brought about by bran addition is shown in Figure 57.



**Fig. 57: Summary of proposed chemical effects of bran on loaf volume**

Not all bran types depressed loaf volumes equally. Pollard produced smallest loaf volumes and Digestive bran the highest. During the milling process, Pollard is finely ground and contaminated by endosperm and germ (N. Dumas – Personal communication). Apart from having a smaller particle size (Fig. 17; Table 14), Pollard therefore also had a higher relative lipid content than the other brans (Table 12), with a consequently higher lipoxygenase concentration (Tait & Galliard, 1988). It is possible that the milling process was responsible for giving a higher *in vivo* lipase activity, because of more lipid substrate being made available, which caused more chemical deterioration in the resulting Pollard dough and lower loaf volumes. This explanation is consistent with work of Galliard (1986b) and Galliard & Gallagher (1988) who showed

that fine milling of bran and germ mixtures increased rate of deterioration (increased fatty acids and oxygen consumption) and baking performance. It seems that chemical composition of the bran play an important role in determining to which extent loaf volumes will be depressed by their addition. Digestive bran, for example, had the lowest fat content of all the brans (Table 12) and was the least contaminated with germ. Digestive bran, which constitutes the outer most layers of the bran, had the highest lipase activity before heat treatment (Table 19), which is in agreement with O'Connor et al (1992) who found that 75-80% of the lipase activity is located in the bran component of the kernel. However, because the Digestive bran had the lowest fat content and therefore lower lipoxigenase concentrations than Pollard, it is possible that the *in vivo* lipase/lipoxigenase system operated at a lower rate than in the Pollard, partly explaining the higher loaf volumes of breads with Digestive bran. These higher loaf volumes could however also be explained by the air/oxygen trapping mechanism described earlier. Pollard did not have the large, flaky shapes of the Digestive bran particles (Fig. 19) and therefore could not trap oxygen which could have improved baking performance, as could have been the case with Select and Digestive bran.

A difference in chemical composition could also be the reason why brans from different origins caused different loaf volume depressions, and why heat treatment affected loaf volume improvement differently (Table 21). Finney, Henry & Jeffers (1985) also reported that the effect of bran on loaf volume varies with the source of the bran. According to Oakenfull & Topping (1987), chemical composition of the bran could depend on the type of wheat milled, the mill stream from which the bran has been taken, as well as milling practices. Since all the wheat samples from different sources were milled on the same mill, and the bran was separated similarly, the only variable in this instance was the lipase activity of the different brans (Table 18), causing variations in loaf volume depression.

Heat treatment had the greatest effect on decreasing loaf volume depression in breads baked with Pollard and the least effect on breads baked with Digestive bran (Fig. 22 to 27). This indicated that the difference between loaf volumes of bread baked with heat-treated and untreated brans gets smaller as the bran particle size gets bigger, suggesting a greater chemical effect in brans with smaller particle size. These findings led to the investigation of the effect of bran size reduction and heat treatment on loaf

volume. When Pollard, Select and Digestive bran were milled, significant smaller loaf sizes were obtained (Tables 23 and 24). Overall, similar loaf sizes were obtained in breads produced with bran which was heat-treated and then milled, and breads produced with bran that had only be heat-treated. Therefore, it appears that thermal treatment of the bran counteracts its adverse chemical effect.

It can be concluded that the heat treatment probably inactivated all heat-sensitive components that might have had a chemical effect on baking performance. The improvement in loaf volume brought about by heat-treatment of the brans shows clearly that the heat-labile chemical substances in the brans were in part responsible for the depression in loaf volume. However, heat-treatment did not result in all the brans producing loaves of the same volume and height (Fig. 28). There were still some significant differences in loaf volumes between the different bran types after heat treatment, indicating that the depression in loaf volume brought about by bran is due to a physical effect of the bran as well as a chemical effect. This is in agreement with the work of Galliard & Gallagher (1988) who found that bran physically influenced dough properties and consequently caused a reduction in loaf volume.

## **5.2 PHYSICAL EFFECTS OF BRAN ON BREAD QUALITY**

The first physical effect that bran has on dough properties, is increased water absorption. Pomeranz et al (1976), Pomeranz et al (1977) and Lai et al (1989b) showed that water absorption values increased in doughs with bran, as compared to a white dough, accompanied by increased mixing times (Pomeranz et al, 1976; Pomeranz et al, 1977; Cheetham, 1997). Optimum water absorption is important since it could determine dough handling, proofing and baking properties (loaf volume) and finished product characteristics (appearance and eating quality) (Stauffer, 1998). Nelles et al (1998), for example, found that hydrating bran before mixing and baking increased water absorption and loaf volumes significantly.

Four flour components absorb water: Protein, native starch, damaged starch and pentosans (Stauffer, 1998). The relative absorptions are given in Table 26.

**Table 26: Influence of flour components on water absorption (Stauffer, 1998)**

Component	Water per g component (g)	Amount per 100 g flour (g)	Absorption per 100 g flour
Protein	1.3	12	15.6
Intact starch	0.4	57	22.8
Damaged starch	2.0	8	16.0
Pentosans	7.0	2	14.0

Although pentosans are present at levels of only 2-3% in white flour, they can absorb seven times their own weight in water and therefore make a significant contribution to overall water absorption in the dough (Stauffer, 1998). About 65% of wheat flour pentosans are water-insoluble; these are almost exclusively xylans (Michniewicz, Biliaderis & Bushuk, 1990). The water-soluble pentosans are approximately half arabinoxylans and half arabinogalactans. The water-soluble pentosans have been shown to be important in producing optimum loaf volume (Hoseney, 1994). Bran contains 32-37% non-starch polysaccharides (NSPS) (Theander et al, 1993). Approximately 80% of the sugars present in NSPS are the pentoses xylose and arabinose (Stauffer, 1998). Addition of bran to white flour therefore substantially increases the water absorption of the resulting flour. According to Catteral (1998), the pentosan content in wholemeal flour can be up to 10% and can account for absorbing up to one-third of the water in the dough. This additional weight of the absorbed water could have been physically too great for the dough to handle, causing the observed lower loaf volumes and denser crumb structures obtained in breads with added bran. The effect of bran absorbing more water, is similar to the effect caused by flour containing high levels of damaged starch (Collins, 1971).

Lai et al (1989b), however, found that at normal absorption levels, the gluten in brown bread was not properly hydrated, because of the bran competing for and binding a relatively large amount of water. The use of inappropriate absorption levels therefore resulted in a reduction in loaf volume. Therefore, a 63% water absorption was used in this study in breads that were baked with bran, as compared to the 61% in the white bread controls. This higher water absorption resulted in a dough with optimum consistency as determined by dough handling (Ms. C. Hendriks, Wheat Board –



Personal communication), but could have been responsible for producing a heavy loaf with reduced loaf volume. Gan et al (1995) reviewed studies on the influence of pentosans on loaf volume and found them to be contradictory. Andersson, Hamalainen & Aman (1994) did predictive modelling studies of the baking properties of wheat, showing that inclusion of NSPS variables helped to explain some of the variation in dough rheological properties and contributed significantly to variation in flour water absorption, but did not explain variation in loaf volume. Therefore, it is possible that bran could also have been responsible for physically disrupting dough formation which caused ultimate depression in loaf volumes.

Research by Gan et al (1989, 1992) showed that the outer layers of the bran, especially the epicarp hairs, were responsible for loaf volume depression. The epicarp hairs appeared to play a prominent role in disrupting the gluten-protein matrix (Gan et al, 1989). It was shown that removing the epicarp hairs by pearling significantly improved the baking performance of the resulting flour, producing bread with 8.5% higher loaf volumes when compared to wholemeal bread. Incorporating the outermost bran fraction, containing the highest concentration of epicarp hairs into the breadmaking recipe, caused the most marked depression in loaf volume (Gan et al, 1992). Heat treatment of this fraction did not diminish its adverse effect on loaf volume, suggesting that heat sensitive components are not implicated. In addition, other work (Pomeranz et al, 1977; Moder et al, 1984; Lai et al, 1989b) showed that finely ground bran produced a higher loaf volume than coarse bran. It was therefore expected that the larger Digestive bran would cause the greatest depression in loaf volume, and Pollard the least. The opposite was found (Fig. 20, 21). Breads baked with Digestive bran had the highest loaf volumes and those baked with Pollard, the lowest. This is in agreement with the work of Özboy and Köksel (1997) who found that coarse bran showed unexpected strengthening effects on dough rheology and had a lessened deleterious effect on loaf volume. Furthermore, it is pertinent that none of the bran fractions used in this study were found to contain epicarp hairs (Fig. 19). In fact, the milling process used has been observed to separate the epicarp hairs in a different stream from the bran (N. Dumas – Personal communication). Thus the findings of this study cannot be compared directly with those of Gan et al (1989, 1992).

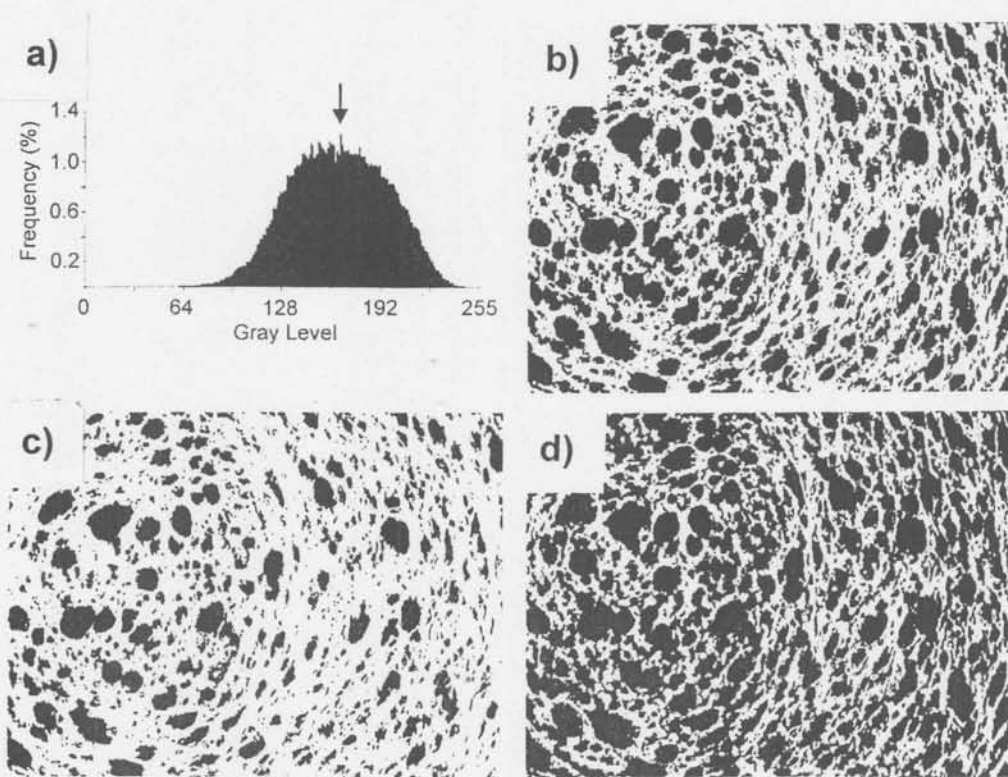
The possibility that larger bran particles (Digestive bran) had less of a detrimental chemical effect on loaf volume when compared to finely milled bran (Pollard), because of a difference in chemical composition and available substrate, has been described earlier. It has also been mentioned that the large, flaky shapes of the Digestive bran particles, could have been responsible for encapsulating air during the mixing process, providing oxygen for dough strengthening and nucleation sites for dough gas cell formation. It is here where the subtle interplay between chemical and physical effects become clear. Physically, because of its shape, Digestive and to a lesser extent Select bran trap air bubbles within the dough structure. Physically, these air bubbles provide gas cell nucleation sites, but chemically they also provide oxygen for effective gluten formation and functioning of the ascorbic acid.

The crumb structure of breads baked with all bran types was more open and irregular when compared to the uniform crumb structure of white bread, with Digestive bran having the most irregular structure (Fig. 30 to 33). These findings are consistent with work of Moder et al (1984) who showed that finely ground bran gave a finer and more uniform crumb grain structure, when compared to bread produced from a coarse bran. It was attempted to find the reason why coarse bran produced an open and unattractive crumb structure by looking at what happens during bubble formation in the proofing stage. CAT scanning (computer aided tomography scanning) of the proofing loaves provided a way to observe bubbles within the dough structure, without changing their sizes or shapes, which would not have been the case if the dough had to be sliced. This procedure preserved the essential nature of the dough and facilitated the detection of cells and computation of a number of bubble parameters that are directly interpretable and technologically relevant. It also provided a means to observe how bubble size and shape changed with proofing time. It was therefore possible to follow the progress of bubble formation and growth throughout the proofing period, which would eventually form the final product crumb structure. The influence of the different brans on bubble formation could also be monitored.

CAT scanning of proofing dough is quite a novel technique in evaluating baking quality, and therefore a few problems were encountered. One of them was logistical issues encountered at the hospital, which sometimes hindered scanning to be done at the precise times. Another was the time lapse that occurred during transport of the panned

loaves to the hospital. A more serious problem, however, came in the image analysis of the scans. The first scans were done before any proofing. The loaf, at this stage, only had a few bubbles and therefore had a very dense texture. To achieve the optimum image on the scan, gray level (GL) settings were adjusted so that a maximum contrast between dough and bubble could be observed. In theory, it was the plan to keep the same settings throughout for all the scans done at the four time intervals, in order to have the same GLs to work with during image analysis. This could, however, not be the case, since proofing changed the densities of the loaves. As proofing times increased, loaves became less dense and therefore the GL settings had to be altered in order to observe an image in which bubble still contrasted with dough (cell constituents). Furthermore, within the same loaf, different densities led to formation of a gray gradient (darker at the bottom of the loaf) (Fig. 34b, 35b and 36b) which complicated things even further. The end result was that GLs during binary imaging had to be chosen subjectively from a personal perspective. This might have led to some bubbles not being detected and therefore not being included in the bubble size and shape calculations, or that some cell constituents were mistakenly included in bubble calculations. For the same reason, the number of bubbles per unit area, which would have been of great interest, could not be determined accurately.

Sapirstein (1999) described the importance of generating a binary image by selecting a single appropriate GL threshold for image segmentation. Any pixels with GLs lower than threshold were deemed to be constituents of cells. The optimum GL threshold can be determined by the  $\kappa$ -means algorithm. Figure 58 shows the influence of choosing the correct GL threshold on imaging properties.



**Fig. 58:** a) Gray level histogram of bread crumb, arrow indicates optimum GL threshold = 172 determined by the  $\kappa$ -means algorithm; b) Binary image of bread crumb segmented at GL = 172; c) Binary image of bread crumb segmented at GL = 155; d) Binary image of bread crumb segmented at GL = 189 (Sapirstein, 1999)

Figure 58b corresponded to a segmented binary image based on the optimum GL level of 172. This binary image corresponded closely with that of the original. This is in contrast to the binary image results shown in Figures 58c and 58d where segmentation was based on GL thresholds selected at 10% below and above 172 respectively. The latter two binary images under- and over-estimated, respectively, the cellular composition of the bread slices. In the case of Figure 58c, the erosion of pixels which occurred in this image had a considerable effect on reducing cell sizes, altering shapes, along with increasing inter-cell distances. As cell wall thickness is a function of these distances, higher values than anticipated would be determined under these conditions. Similarly, Figure 58d considerably overestimated the cellular composition of the bread slice.



Whitworth & Alava (1999) also did CAT scanning on proofing loaves. They proofed the loaves inside the scanner which eliminated any problems that could have been encountered during transport. The authors imaged the internal structure of the proofing loaves and observed changes during proofing, but did not give any bubble measurement of the CAT scans by image analysis. It is suspected, however, that they would have experienced similar problems with GLs since gray gradients in their CAT scans were also observed. The size distribution of bubbles in their doughs was measured by image analysis of thin dough sections (frozen by immersion in liquid nitrogen) imaged with a microscope.

However, even with all the problems experienced during CAT scanning, valuable information was obtained from the CAT scans and image analysis thereof. The CAT scans showed an even and uniform crumb structure in white bread dough (Fig. 34). SEM and light microscopy of white and brown bread done by Pomeranz et al (1977) also revealed a major difference between the two crumb structures. The white bread had a fine crumb structure composed of thin sheets and filaments. Such a structure was essentially absent in brown bread. My work was novel in the sense that the structure of dough was examined, differing from other studies where the crumb structure of the baked bread was studied. It was shown that the structure of doughs made with Pollard closely resembled that of the white bread dough (Fig. 35). Bubbles in the breads made with Select and Digestive bran, however, were large, irregularly shaped and ununiformly distributed (Fig. 36, 37). It also seemed that more bubbles per unit area were present in the white bread than the breads with bran at any given time, with bread made with Digestive bran showing the least amount of bubbles. Image analysis of the CAT scans and consequent calculation of bubble parameters revealed a definite trend for bubble size (measured as bubble area, length and perimeter) to increase during the proofing period (Fig. 38-49). Furthermore, it seemed that bubbles became more elongated as proofing progressed (Fig. 50-53). Although this phenomenon was observed in all the breads, it was more pronounced in the breads made with Select and Digestive bran. The CAT scans also showed bran particles protruding through the bubbles, especially in the breads made with Digestive bran (Fig. 37d) and to a lesser extent in breads with Select bran (Fig. 36d). In order to explain how this phenomenon could physically affect



loaf volume, it is necessary to look at some physical aspects of bubble formation in foods.

Bread dough is a multiphase and multicomponent system composed of proteins, lipids, polysaccharides, water, gas and other minor nutrients and additives. It has a foam structure, with continuously growing gas bubbles dispersed in a semi-solid hydrated dough phase. As the volume fraction of the gas increases during fermentation, foam structure becomes increasingly fragile and unstable. To obtain a loaf of bread with a good loaf volume and a fine even crumb structure, it is crucial to promote the stability of the foam during the bread dough processing (Gan, van der Graaf, Leonard, Brooker, Parker & Schofield, 1999).

Cheftel, Cuq & Lorient (1985) gave an overview of food foams in general. Food foams are usually dispersions of gas bubbles in a continuous liquid or semi-solid phase that contains a soluble surfactant. In foams, a continuous phase of thin liquid layers, called lamellae, separates the gas bubbles. Mechanical energy is required for the creation of this interface. Maintaining the interface against coalescence of gas bubbles usually necessitates the presence of surface-active agents. These agents lower the interfacial tension and form a protective barrier between entrapped gas bubbles. Some proteins, e.g. gluten, are able to form a protective film by adsorbing at the gas/liquid interface. In this case the lamellae between two adjacent bubbles consist of two adsorbed protein films separated by a thin liquid layer. Because many foams have large interfacial areas, they are often unstable. According to Cheftel et al (1985), there are three main destabilising mechanisms.

- a) Drainage of lamella liquid due to gravity, pressure differences, and/or evaporation. The internal pressure  $P$  within bubbles is given by Laplace's capillary pressure equation:

$$P = P_{atm} + \frac{2\gamma}{R}$$

where  $P_{atm}$  is the atmospheric pressure (Pa),  $\gamma$  is the interfacial tension (N/m) and  $R$  is the bubble radius of curvature (m). Drainage is lessened when the bulk liquid

phase is viscous and the surface viscosity of the adsorbed protein film is great. The surface viscosity depends on the strength of protein-protein and protein-water interactions.

- b) Gas diffusion from small to larger bubbles. Such disproportionation results from solubility of the gas in the aqueous phase.
- c) Rupture of the liquid lamellae separating gas bubbles. Such ruptures result in an increase in bubble size through coalescence, and ultimately lead to a collapse of the foam.

The three most important attributes that serve to stabilise foams are low interfacial tension, high viscosity of the bulk liquid phase and strong, elastic films of adsorbed proteins.

During mixing of bread dough a small amount of air is entrapped, in the form of small spherical cells. A large number of these gas cells disappear during proofing and baking, because they are physically unstable or do not grow. According to Van Vliet (1999), of the three main destabilising mechanisms in food foams described by Cheftel et al (1985), two of them apply directly to bread, namely disproportionation, also known as Ostwald ripening, as well as coalescence. Van Vliet (1999) described Ostwald ripening as the growth of large gas bubbles at the expense of smaller ones due to the higher overpressure (Laplace pressure) of the gas in the small gas cells resulting in higher gas concentration in the vicinity of these cells. It causes diffusion of gas towards larger cells. Coalescence of gas cells is due to rupture of the dough film between them. Coalescence results in an irregular and coarse crumb structure.

According to Sapirstein (1999), the integrity of gas cells in weaker (unoxidised) dough compared to those in stronger (optimally oxidised) dough, cannot be maintained throughout the course of dough development, proofing and baking. As a consequence, small gas cells coalesce into larger ones. The greater the degree of gas cell coalescence during dough fermentation, the coarser will be the resulting bread crumb structure.

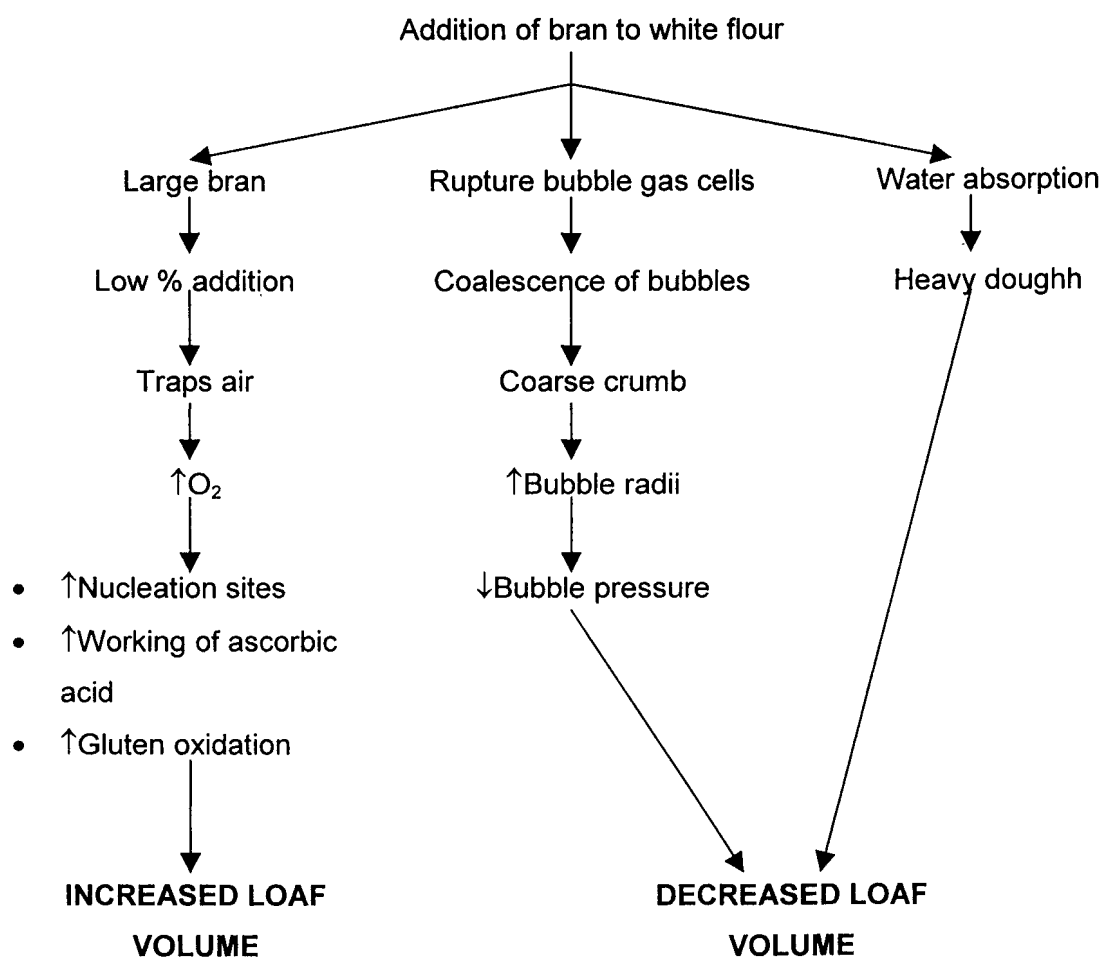
It seems that during the proofing of brown bread, the added bran physically ruptured gas cell walls of the foam structure leading to coalescence of the bubbles. This greater

degree of coalescence resulted in a coarser bread crumb structure, i.e. fewer and larger bubbles, compared to the smaller and greater quantity of bubbles observed in white bread. Coalescence caused bubbles with larger radii. Laplace's pressure equation states that pressure within the bubble is inversely proportional to its radius. The result is that the larger bubbles, formed by coalescence, had a lower internal pressure, possibly leading to the lower loaf volumes obtained in bread baked with bran. The large Digestive bran, with its jagged edges, had the worst effect, leading to large, irregular bubbles (Fig. 37). This is consistent with work of Moder et al (1984) who showed that finely ground bran had a uniform and fine crumb structure compared to the coarse structure of larger bran particles. Panelists in my study did not find the crumb structure of breads with Digestive bran to be objectionable, and indicated that it resembled the structure of an ideal brown bread (Table 25). This anomaly showed that a fine crumb structure in brown bread was not preferred. Breads with Digestive bran produced the highest loaf volumes when compared to Pollard and Select bran, in spite of the high degree of coalescence, which again supports the theory of oxygen being trapped and probably counteracting some of the negative effects of coalescence.

Baking of bread transforms the structure from a foam (containing discrete gas cells) into a sponge (containing a network of interconnected gas cells and a porous structure with a continuous gas phase), and sets the sponge structure (Cilliers & Sadr-kazemi, 1999). To produce a loaf of bread with a light and even crumb structure, the dough must be able to retain gases produced by yeast fermentation as discrete cells for a sufficiently long period (Bloksma, 1990). Gan et al (1995) proposed that soon after mixing, the dough consists of discrete gas cells lined with liquid films and embedded in a continuous starch-protein matrix. The matrix fails to enclose the gas cells completely at advanced stages of fermentation, leaving areas that contain only a thin liquid lamella. Baking increases the rate of expansion until the lamellar film is incapable of meeting the demand for new surface area generation, thus converting the foam structure of dough into an open sponge. The rupture of the liquid film is accompanied by a loss in gas retention. It is probable that the bran physically ruptured the liquid film surrounding the gas cells, causing reduced gas retention and lower loaf volumes. Pomeranz et al (1977) also found that loaf-volume-depressing effects of bran seemed to result from reduced gas retention.

The theory that higher gas retention causes higher loaf volumes, was supported further by Czuchajowska & Pomeranz (1993) who found that it was possible to compensate for a volume decrease as a result of poor gas retention by supplementing dough with high-quality gluten. Gas cell walls of gluten supplemented wholemeal bread appeared to be thicker, smoother and more continuous than those from unfortified flour (Gan et al, 1989).

A summary of the proposed physical effects of bran on loaf volume is shown in Figure 59.



**Fig. 59: Proposed physical effects of bran on loaf volume**

## **CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS**

Bread quality, as measured by loaf volume and crumb structure, is seriously impaired by addition of bran. Crumb structures of brown bread are coarse and open, and loaf volumes are depressed, more than would be expected from the diluting effect of the bran on the gluten proteins. Higher levels of bran addition cause lower loaf volumes. Bran components appear to affect gluten functionality by changing its physicochemical characteristics through a subtle interplay of chemical and physical effects.

In contrast to many other studies, this study showed that Pollard (smallest bran) depresses loaf volumes the most, and Digestive bran (largest bran) depresses loaf volumes the least. The chemical composition of brans, seem to play an important role in determining the extent of loaf volume depression. Pollard has a higher fat content suggesting more available lipid substrate than the other brans. Increased amounts of fat also indicate increased amounts of lipoxygenase. Lipase, present in the bran, catalyses hydrolysis of triglycerides in the fat, leading to the formation of predominantly polyunsaturated free fatty acids. Lipoxygenase catalyses the oxidation of these fatty acids, lowering the amount of available oxygen for gluten formation and functioning of ascorbic acid. This probably leads to the poor loaf volumes obtained in breads baked with Pollard compared to those baked with Digestive bran. Heat treatment of the brans practically inactivates lipase activity and probably lipoxygenase activity as well. Loaves baked with heat-treated Pollard, show significant increases in loaf volumes. A reduction in bran particle size in general decreases loaf volumes, but heat treatment of the smaller bran restore the original loaf volume, indicating that a chemical effect of the bran is at least in part responsible for depressing loaf volumes. Heat treatment of Select and Digestive bran also lessens loaf volume depressions, but to a lesser extent than in the Pollard. The improving effect of heat treatment on loaf volume, is the least in the Digestive bran, suggesting a smaller chemical effect in brans with larger particle sizes.

The difference in loaf volumes obtained with breads baked with brans, of the same nominal particle size range from different sources, also indicate that differences in chemical composition could account for differences in loaf volume depression brought about by bran addition.



In addition to the difference in chemical compositions of the different brans, the higher loaf volumes of breads with Digestive bran, compared to those with Pollard, could also possibly be explained by the large, flaky Digestive bran particles trapping air bubbles in the dough during the mixing stage. This is a perfect example of the interplay between the physical and chemical effects of bran on loaf volume. The trapped air bubbles probably fulfill two main functions which could lead to higher loaf volumes. They could:

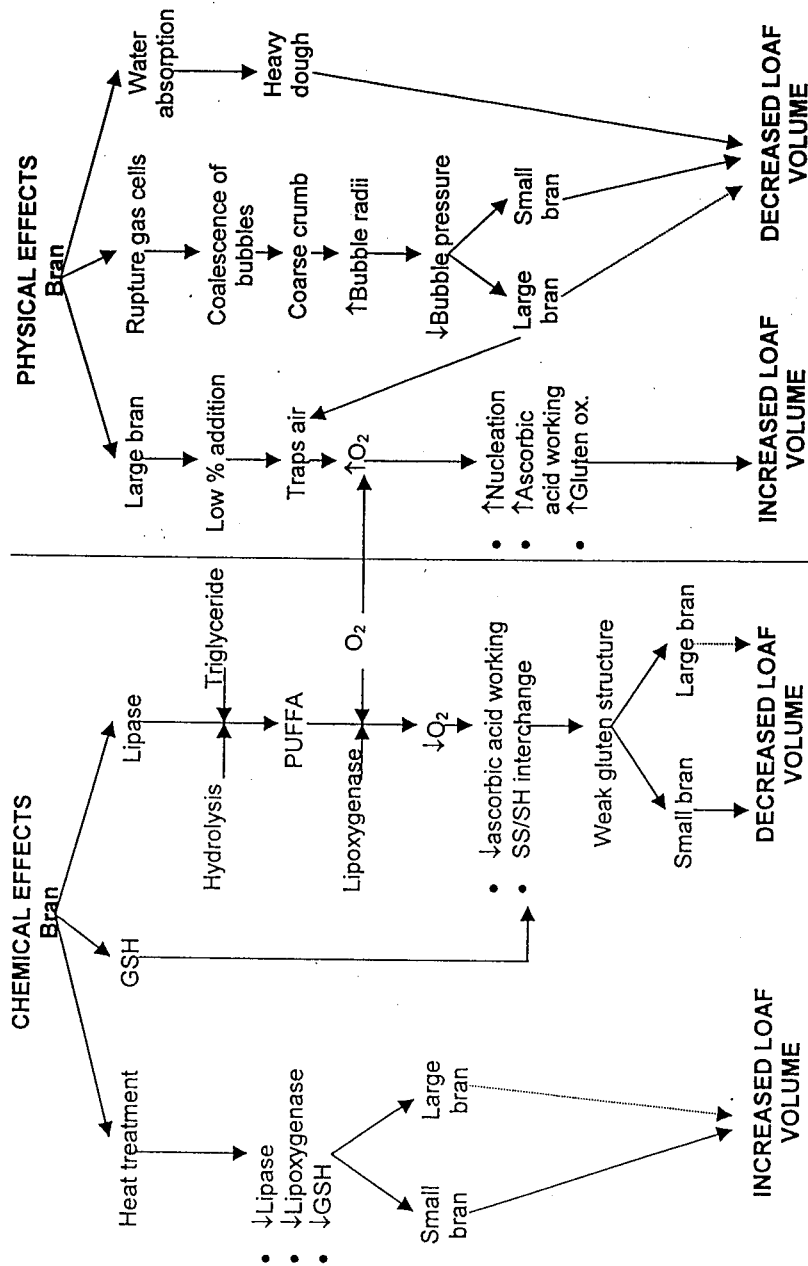
1. Provide extra nucleation sites for gas cells which would later expand with the CO<sub>2</sub> produced by the yeast cells, causing increased loaf volumes;
2. Provide oxygen for the effective functioning of the oxidising agent ascorbic acid and for oxidation of the gluten to form disulphide links within the dough, causing a stronger dough and higher loaf volumes.

The theory that Digestive bran particles trap oxygen, could also explain why at low levels of addition, breads baked with Digestive bran have higher loaf volumes than white bread. However, for large bran particles to be able to increase loaf volume, they have to be free of epicarp hairs.

Another chemical constituent which is probably responsible for decreasing loaf volumes, is glutathione. Bran contains a considerable concentration of glutathione, coming from germ contamination. Addition of bran to white flour, possibly results in SS/SH interchange in the gluten, because of a shift in equilibrium towards the reduced form. This could lead to a weak gluten structure and decreased loaf volumes. Heat treatment significantly lowers TRS, of which glutathione is a part. The resultant increased loaf volumes in breads baked with heat-treated brans, indicate that glutathione also play a role in loaf volume depression.

Heat treatment does not result in all the brans producing loaves of the same volume and height, suggesting that the influence on loaf volume brought about by bran addition is due to a physical as well as a chemical effect. It is possible that bran physically disrupts the gluten-protein matrix by rupturing the gas cell walls of the foam structure, leading to coalescence of the bubbles. Coalescence causes larger and irregular bubbles, the effect becoming more pronounced during the later stages of proofing. Gas retention in these loaves is lowered, and internal pressure within the bubbles becomes less, possibly leading to lower loaf volumes in bread baked with bran. The bubbles in breads with

Digestive bran are the largest and the most irregular, indicating the severe effect of the large, flaky particles, causing coalescence. The negative effects of coalescence are, however, possibly counteracted to some extent by the trapped oxygen. A summary of the proposed interplay between chemical and physical effects is shown in Figure 60.



**Fig. 60: Proposed interplay between chemical and physical effects of bran on loaf volume.**

— Major effect; ..... Minor effect

It is concluded that there is a subtle interplay between the chemical and physical effects of bran brown bread, which determines the extent of loaf volume depression. From a practical perspective, the addition of either large, epicarp hair free bran particles, or heat-treated smaller bran particles to white base flour, appear to have potential as methods of optimising brown bread loaf volume.

Further research is needed to test the suggested hypotheses. To show that the lipase/lipoxygenase system is in part responsible for loaf volume depression, free fatty acids could be added to the dough, and the resultant loaf volumes could be compared with controls which did not contain added free fatty acids. In addition, these loaf volumes could also be compared with breads in which heat-treated brans were used. If loaf volumes were lower in the breads with added fatty acids, and if loaf volumes increased with heat treatment, it could be concluded that the lipase/lipoxygenase system caused a depression in loaf volumes. To show that glutathione was also responsible for loaf volume depression, bran could be oxidised and loaf volumes of breads baked with unoxidised and oxidised brans could be compared. If oxidation caused a significant decrease in glutathione and higher loaf volumes were obtained with the oxidised bran, the adverse effect of glutathione on loaf volume would have been proven. To prove that the large Digestive bran encapsulated air and that the oxygen trapped with the air led to higher loaf volumes, bran could be treated with an inert gas such as nitrogen. If the breads which were baked with the inert gas treated bran had lower loaf volumes than the controls, it could be concluded that trapped oxygen was responsible for increased loaf volumes.

## CHAPTER 7: REFERENCES

**AMERICAN ASSOCIATION OF CEREAL CHEMISTS, 1983a.** AACC method 46-12. Crude protein – Kjeldahl method, boric acid modification. In: Approved methods of the American Association of Cereal Chemists, 8<sup>th</sup> ed., American Association of Cereal Chemists, St. Paul.

**AMERICAN ASSOCIATION OF CEREAL CHEMISTS, 1983b.** AACC method 30-25. Crude fat in wheat, corn and soy flour, feeds and cooked feeds. In: Approved methods of the American Association of Cereal Chemists, 8<sup>th</sup> ed., American Association of Cereal Chemists, St. Paul.

**AMERICAN ASSOCIATION OF CEREAL CHEMISTS, 1983c.** AACC method 10-01. Total reducing substances. In: Approved methods of the American Association of Cereal Chemists, 8<sup>th</sup> ed., American Association of Cereal Chemists, St. Paul.

**ANDERSSON, R., HAMALAINEN, M AND AMAN, P., 1994.** Predictive modelling of the breadmaking performance and dough properties of wheat. Journal of Cereal Science **20**, 129-138.

**BACIC, A. AND STONE, B.A., 1981a.** Isolation and ultrastructure of aleurone cell walls from wheat and barley. Australian Journal of Plant Physiology **8**, 453-474.

**BACIC, A. AND STONE, B.A., 1981b.** Chemistry and organization of aleurone cell wall components of wheat and barley. Australian Journal of Plant Physiology **8**, 475-495.

**BARNES, P.J. AND LOWY, G.D.A., 1986.** The effect on baking quality of interaction between milling fractions during the storage of wholemeal flour. Journal of Cereal Science **4**, 225-232.

**BASS, E..J., 1988.** Wheat flour milling. In: Pomeranz, Y (Ed.), Wheat: Chemistry and Technology, Volume II. American Association of Cereal Chemists, St. Paul, pp. 1-68.

**BELL, B.M., DANIELS, G.H. AND FISHER, N., 1979.** The effects of pure saturated and unsaturated fatty acids on breadmaking and on lipid binding, using Chorleywood bread process doughs containing a "model fat". Journal of the Science of Food and Agriculture **30**, 1123-1130.

**BLOKSMA, A.H., 1990.** Rheology of the breadmaking process. Cereal Foods World **35**, 228-236.

**BLOKSMA, A.H. AND BUSHUK, W., 1988.** Rheology and chemistry of dough. In: Pomeranz, Y (Ed.), *Wheat: Chemistry and Technology, Volume II*. American Association of Cereal Chemists, St. Paul, pp. 198-200.

**BROWN, J., 1993.** Advances in breadmaking technology. In: Kamel, B.S. and Stauffer, C.E. (Eds.), *Advances in Baking Technology*. Blackie Academic and Professional, New York, pp. 38-87.

**BUSHUK, W. AND SCANLON, M.G., 1993.** Wheat and wheat flours. In: Kamel, B.S. and Stauffer, C.E. (Eds.), *Advances in Baking Technology*. Blackie Academic and Professional, New York, pp. 1-19.

**CATTERALL, P., 1998.** Flour milling. In: Cauvain, S.P and Young, L.S. (Eds.), *Technology of Breadmaking*. Blackie Academic and Professional, New York, pp. 296-329.

**CAUVAIN, S.P., 1998a.** Bread – the product. In: Cauvain, S.P and Young, L.S. (Eds.), *Technology of Breadmaking*. Blackie Academic and Professional, New York, pp. 1-17.

**CAUVAIN, S.P., 1998b.** Breadmaking processes. In: Cauvain, S.P and Young, L.S. (Eds.), *Technology of Breadmaking*. Blackie Academic and Professional, New York, pp. 18-44.

**CHEETHAM, G.R., 1988.** The problems of making good quality brown bread. South African Food Review **14(5)**, 30-35.



**CHEETHAM, G.R., 1997.** The influence of dough development on South African breadmaking. In: *Harnessing Cereal Science and Technology for Sustainable Development*. ICC-SA, Pretoria, South Africa, pp. 53-59.

**CHEFTEL, J., CUQ, J. AND LORIENT, D., 1985.** Amino acids, peptides and proteins. In: Fennema, O.R. (Ed.), *Food Chemistry* (2<sup>nd</sup> ed.). Marcel Dekker Inc., New York, pp. 245-369.

**CHEN, X. AND SCHOFIELD, J.D., 1996.** Changes in the glutathione content and breadmaking performance of white wheat flour during short-term storage. *Cereal Chemistry* **73**, 1-4.

**CHENG, B.Q., TRIMBLE, R.P., ILLMAN, R.J., STONE, B.A. AND TOPPING, D.L., 1987.** Comparative effects of dietary wheat bran and its morphological components (aleurone and pericarp-seed coat) on volatile fatty acid concentrations in the rat. *British Journal of Nutrition* **57**, 69-76.

**CILLIERS, J.J.L. AND SADR-KAZEMI, N., 1999.** Image analysis of food foams. In: Campbell, G.M., Webb, C., Pandiella, S.S. and Niranjan, K (Eds.), *Bubbles in Food*. American Association of Cereal Chemists, St. Paul, pp. 245-251.

**COLLINS, T.H., 1971.** The importance of damaged starch. *Milling* **153(5)**, 17-20.

**CZUCHAJOWSKA, Z. AND POMERANZ, Y., 1993.** Gas formation and gas retention. II. Role of vital gluten during baking of bread from low-protein or fibre-enriched flour. *Cereal Foods World* **38**, 504-511.

**DELCOUR, J.A. AND EERLINGEN, R.C., 1996.** Analytical implications of the classification of resistant starch as dietary fiber. *Cereal Foods World* **41**, 85-86.

**EVERS, A.D. AND BECHTEL, D.B., 1988.** Microscopic Structure of the wheat grain. In: Pomeranz Y (Ed.), *Wheat: Chemistry and Technology*, Volume I. American Association of Cereal Chemists, St. Paul, pp. 47-95.

**EWART, J.A.D., 1985.** Blocked thiols in glutenin and protein quality. Journal of the Science of Food and Agriculture **36**, 101-112.

**FINCHER, G.B. AND STONE, B.A., 1986.** Cell walls and their components in cereal grain technology. In: Pomeranz Y (Ed.), *Advances in Cereal Science and Technology*, Volume VIII. American Association of Cereal Chemists, St. Paul, pp. 207-295.

**FINNEY, P.L., HENRY, S. AND JEFFERS, H., 1985.** Effect of wheat variety, flour grinding, and egg yolk on whole wheat bread quality. Cereal Chemistry **62**, 170-176.

**FRAZIER, P.J., BRIMBLECOMBE, F.A., DANIELS, N.W.R. AND EGGIT, P.W.R., 1977.** The effect of lipoxygenase action on the mechanical development of doughs from fat-extracted and reconstituted flours. Journal of the Science of Food and Agriculture **28**, 247-254.

**GALLIARD, T., 1986a.** Oxygen consumption of aqueous suspensions of wheat wholemeal, bran and germ: Involvement of lipase and lipoxygenase. Journal of Cereal Science **4**, 33-50.

**GALLIARD, T. 1986b.** Hydrolytic and oxidative degradation of lipids during storage of wholemeal flour: Effects of bran and germ compounds. Journal of Cereal Science **4**, 179-192.

**GALLIARD, T. AND GALLAGHER, D.M., 1988.** The effects of wheat bran particle size and storage period on bran flavour and baking quality of bran/flour blends. Journal of Cereal Science **8**, 147-154.

**GAN, Z., ELLIS, P.R. AND SCHOFIELD, J.D., 1995.** Mini review: Gas cell stabilisation and gas retention in wheat bread dough. Journal of Cereal Science **21**, 215-230.

**GAN, Z., ELLIS, P.R., VAUGHAN, J.G. AND GALLIARD, T., 1989.** Some effects of non-endosperm components of wheat and of added gluten on wholemeal bread microstructure. Journal of Cereal Science **10**, 81-9.

**GAN, Z., GALLIARD, T., ELLIS, P.R., ANGOLD, R.E. AND VAUGHAN, J.G., 1992.** Effect of outer bran layers on the loaf volume of wheat bread. Journal of Cereal Science **15**, 151-163.

**GAN, Z., VAN DER GRAAF, J., LEONARD, S.A., BROOKER, B.E., PARKER, M.L. AND SCHOFIELD, J.D., 1999.** The role of wheat proteins and polar lipids in the stabilisation of the foam structure of dough. In: Campbell, G.M., Webb, C., Pandiella, S.S. and Niranjana, K (Eds.), *Bubbles in Food*. American Association of Cereal Chemists, St. Paul, pp. 89-93.

**GRAVELAND, A., BOSVELD, P. AND LICHTENDONK, W.J., 1985.** A model for the molecular structure of the glutenin of wheat flour. Journal of Cereal Science **3**, 1-16.

**HOSENEY, R.C., 1994.** Principles of Cereal Science and Technology, American Association of Cereal Chemists, St. Paul, pp. 1-28, 125-145, 197-211, 229-273.

**HULLETT, R.W. AND STERN, R., 1941.** Biological elimination of glutathione from wheat germ and flours used in breadmaking. Cereal Chemistry **18**, 561-572.

**JOHNSON, I.T. AND SOUTHGATE, D.A.T., 1994.** Dietary Fibre and Related Substances. Chapman & Hall, London, p132.

**KENT, N.L. AND EVERS, A.D., 1994.** Kent's Technology of Cereals. An Introduction for Students of Food Science and Agriculture (4<sup>th</sup> ed.). Elsevier Science, Oxford, p197.

**KULP, K., 1988.** Bread industry and processes. In: Pomeranz, Y (Ed.), *Wheat: Chemistry and Technology*, Volume II. American Association of Cereal Chemists, St. Paul, pp. 371-406.

**LAI, C.S., DAVIS, A.B. AND HOSENEY, R.C., 1989a.** Production of whole wheat bread with good loaf volume. Cereal Chemistry **66**, 224-227.

**LAI, C.S., HOSENEY, R.C. AND DAVIS, A.B., 1989b.** Effects of wheat bran in breadmaking. Cereal Chemistry **66**, 217-219.

**LAI, C.S., HOSENEY, R.C. AND DAVIS, A.B., 1989c.** Functional effects of shorts in breadmaking. Cereal Chemistry **66**, 220-223.

**LARMOND, E., 1977.** Laboratory Methods for Sensory Evaluation of Food. Ottawa, Canada, Canadian Department of Agriculture.

**LEE, S.C. AND PROSKY, L., 1996.** Perspectives on complex carbohydrate definition. Cereal Foods World **41**, 88-89.

**MATZ, S.A., 1989.** Technology of the Materials of Baking, Elsevier Science Publishers, LTD., New York, pp. 1-24.

**MICHNIEWICZ, J., BILIADERIS, C.G. AND BUSHUK, W., 1990.** Water-insoluble pentosans of wheat: composition and some physical properties. Cereal Chemistry **67**, 434-439.

**MODER, G.J., FINNEY, K.F., BRUINSMA, B.L., PONTE, J.G. AND BOLTE, L.C., 1984.** Breadmaking potential of straight-grade and whole wheat flours of Triumph and Eagle-plainsman V hard red winter wheats. Cereal Chemistry **61**, 269-273.

**NELLES, E.M., RANDALL, P. G. AND TAYLOR, J. R. N., 1998.** Improvement of brown bread quality by prehydration treatment and cultivar selection of bran. Cereal Chemistry **75**, 536-540.

**OAKENFULL, D.G. AND TOPPING, D.L., 1987.** The nutritional value of wheat bran. Food Technology in Australia **39**, 288-292.

**O'CONNOR, J. AND HARWOOD, J.L., 1992.** Solubilisation and purification of membrane-bound lipases from wheat flour. Journal of Cereal Science **16**, 141-152.

**O'CONNOR, J., PERRY, H.J. AND HARWOOD, J.L., 1992.** A comparison of lipase activity in various cereal grains. Journal of Cereal Science **16**, 153-163.

**ÖZBOY, O. AND KÖKSEL, H., 1997.** Unexpected strengthening effects of a coarse wheat bran on dough rheological properties and baking quality. Journal of Cereal Science **25**, 77-82.

**POMERANZ, Y., 1977.** Fiber in breadmaking. The Bakers Digest **51**, 94-96, 142.

**POMERANZ, Y., 1988.** Composition and functionality of wheat flour components. In: Pomeranz, Y (Ed.), *Wheat: Chemistry and Technology, Volume II*. American Association of Cereal Chemists, St. Paul, pp. 219-370.

**POMERANZ, Y. AND MELOAN C.E., 1994.** *Food Analysis – Theory and Practice*. Chapman & Hall, New York, pp. 438-445.

**POMERANZ, Y., SHOGREN, M.D. AND FINNEY, K.F., 1976.** White wheat bran and Brewer's spent grains in high-fiber bread. The Bakers Digest **50**, 35-39.

**POMERANZ, Y., SHOGREN, M.D. , FINNEY, K.F. AND BECHTEL, D.B., 1977.** Fiber in breadmaking - Effects on functional properties. Cereal Chemistry **54**, 25-41.

**QI SI, J., 1997.** Synergistic effect of enzymes for breadmaking. Cereal Foods World **42**, 802-807.

**RANDALL, P.G., WESSELS, A. AND TRAUT, H.W., 1995.** Wheat usage in southern and central Africa. In: Faradi, H. and Faubion, J.M. (Eds.), *Wheat End Uses Around the World*. American Association of Cereal Chemists, St. Paul, pp. 251-266.

**ROGERS, D.E. AND HOSENEY, R.C., 1982.** Problems associated with producing whole wheat bread. Cereal Foods World **27**, 451-452.

**SAPIRSTEIN. H.D., 1999.** Imaging and measurement of bubbles in bread. In: Campbell, G.M., Webb, C., Pandiella, S.S. and Niranjan, K. (Eds.), *Bubbles in Food*. American Association of Cereal Chemists, St. Paul, pp. 233-243.



**SCHOFIELD, J.D. AND CHEN, X., 1995.** Analysis of free reduced and free oxidised glutathione in wheat flour. Journal of Cereal Science **21**, 127-136.

**SHOGREN, M.D., POMERANZ, Y. AND FINNEY, K.F., 1981.** Counteracting the deleterious effects of fiber in breadmaking. Cereal Chemistry **58**, 142-144.

**STAUFFER, C.E., 1998.** Principles of dough formation. In: Cauvain, S.P and Young, L.S. (Eds.), Technology of Breadmaking. Blackie Academic and Professional, New York, pp. 262-295.

**STEAR, C.A., 1990.** Handbook of Breadmaking Technology, Applied Science Publishers, London, pp. 35-37.

**SULLIVAN, B. AND ALLISON HOWE, M., 1933.** Lipases of wheat. Journal of the American Chemical Society **55**, 320-324.

**SULLIVAN, B., HOWE, M AND SCHMALZ, F.D., 1936.** On the presence of glutathione in wheat germ. Cereal Chemistry **13**, 665-668.

**TAIT, S.P.C. AND GALLIARD, T., 1988.** Effect on baking quality of changes in lipid composition during wholemeal storage. Journal of Cereal Science **8**, 125-137.

**THEANDER, O., WESTERLUND, E. AND ÅMAN, P., 1993.** Structure and components of dietary fiber. Cereal Foods World **38**, 135-141.

**VAN VLIET, T., 1999.** Physical factors determining gas cell stability in a dough during breadmaking. In: Campbell, G.M., Webb, C., Pandiella, S.S. and Niranjana, K (Eds.), Bubbles in Food. American Association of Cereal Chemists, St. Paul, pp. 121-127.

**WARWICK M.J. AND SHEARER, G., 1982.** The association of saturated and unsaturated triglycerides and oleic acid with wheat flour components during dough making. Journal of the Science of Food and Agriculture **33**, 918-924.

**WARWICK, M.J., FARRINGTON, W.H.H. AND SHEARER, G., 1979.** Changes in total fatty acids and individual lipid classes on prolonged storage of wheat flour. Journal of the Science of Food and Agriculture **30**, 1131-1138.

**WHEAT BOARD, s.a.** The Story of Wheat in South Africa. Wheat Board, Pretoria, 24p.

**WHITWORTH, M.B. AND ALAVA, J.M., 1999.** Imaging and measurement of bubbles in bread doughs. In: Campbell, G.M., Webb, C., Pandiella, S.S. and Niranjan, K (Eds.), Bubbles in Food. American Association of Cereal Chemists, St. Paul, pp. 221-231.

**WILLIAMS, T. AND PULLEN, G., 1998.** Functional Ingredients. In: Cauvain, S.P and Young, L.S. (Eds.), Technology of Breadmaking. Blackie Academic and Professional, New York, pp. 45-80.

**YOUNG, H.K., 1998.** Rheological properties of dough added with wheat bran. Journal of the Korean Society of Food Science and Nutrition **27**, 1125-1131.

**ZIEGLER, E., 1940.** Dough improvement studies. II. The effect of adding oxidised glutathione to wheat-flour doughs. Cereal Chemistry **17**, 551-555.



## APPENDIX A: SCORE SHEET USED IN THE SENSORY EVALUATION OF BROWN BREAD

### SENSORY QUALITY:

State for the following attributes how much each sample differs from the scores of an ideal brown bread (1 = not at all; 7 = very much so).

1. Texture

--	--	--	--	--	--	--	--

not at all very much so

2. Moistness

--	--	--	--	--	--	--	--

not at all very much so

3. Graininess

--	--	--	--	--	--	--	--

not at all very much so

4. Chewiness

--	--	--	--	--	--	--	--

not at all very much so

5. Taste

--	--	--	--	--	--	--	--

not at all very much so

6. Overall acceptability

--	--	--	--	--	--	--	--

not at all very much so

## **APPENDIX B: LIST OF PUBLICATIONS AND PRESENTATIONS**

### **PUBLICATIONS:**

**DE KOCK, S., TAYLOR, J. AND TAYLOR, J.R.N., 1999.** Effect of heat treatment and particle size of different brans on loaf volume of brown bread. Lebensmittel Wissenschaft und Technologie **32**, 349-356.

### **PAPER PRESENTATIONS:**

**DE KOCK, S. AND TAYLOR, J.R.N., 1995.** The influence of bran on loaf volume and bread quality. 13<sup>th</sup> Biennial Congress of the South African Association of Food Science and Technology, Durban, South Africa, September, 1995.

**DE KOCK, S. AND TAYLOR, J.R.N., 1999.** The influence of bran on bubble formation and loaf volume of brown bread. 15<sup>th</sup> Biennial Congress of the South African Association of Food Science and Technology, Cape Town, South Africa, September, 1999.

### **POSTER PRESENTATIONS:**

**DE KOCK, S AND TAYLOR, J.R.N., 1998.** The influence of bran on bread loaf volume. 10<sup>th</sup> ICC Cereal and Bread Congress, Porto Carras, Greece.

**“Go thy way, eat thy bread with joy, and drink thy wine with a merry heart; for God now accepteth thy works...”**

**Ecclesiastes 9:7**