



STRESS RELAXATION TEST AS A PREDICTOR OF BREAD FLOUR QUALITY

BY

Paballo G. Mokoena

Submitted in partial fulfilment of the requirements for the degree

MSc (AGRIC) FOOD SCIENCE AND TECHNOLOGY

In the

Department of Food Science

Faculty of Biological and Agricultural Sciences

University of Pretoria

South Africa

December 2001

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to:

God Almighty for the opportunity and strength to carry out this task.

Prof. J.R.N. Taylor, my promoter, for his guidance, encouragement and endless effort that ensured successful completion of this research work.

Albany Bakeries for funding the research and for the usage of their test bake facilities. I would also like to thank the technical staff in the test bakery for their assistance with the test bakes.

Quest International for funding and for supplying ingredients.

THRIP for funding the research work.

Miss R. Ehlers from the Department of Statistics and Mrs. Mauer from the Department of Information Technology, University of Pretoria, for helping with statistical analyses of my results.

My dearest mother Makgotso Mokoena, who is the reason I undertook these studies, and the rest of my family for their support.

My best friend Tshepo Mosese for his love, support and patience.

DECLARATION

I declare that the dissertation herewith submitted for the degree MSc (Agric) Food Science and Technology at the University of Pretoria, has not previously been submitted by me for a degree at any other university or institution of higher education.

ABSTRACT

STRESS RELAXATION TEST AS A PREDICTOR OF BREAD FLOUR QUALITY

By

Paballo G. Mokoena

Study leader: Prof. J.R.N. Taylor
Department: Food Science
Degree: MSc (Agric) Food Science and Technology

Bread flour quality, which is directly related bread quality, varies from time to time. It is therefore almost impossible to obtain bread with consistent quality without determining the flour's suitability for bread-making and the addition of bread improvers. Rheological tests such as the farinograph and the mixograph which are commonly used by bakeries to predict flour quality are empirical in nature which makes fundamental interpretation of the results difficult.

The stress relaxation test, a more fundamental rheological test, was used in combination with the mixograph to determine if the stress relaxation test can provide additional information to the mixograph on prediction of the effect of ascorbic acid and DATEM on bread-making quality of three different flour samples. In this test, an optimally developed ball of dough was compressed between parallel plates of a TA-XT2 texture analyser. The 20 g dough was compressed to a load of 1.5 N and thereafter allowed to relax at constant deformation. The relaxation time (RT) was recorded as time taken for the compression force to decay to a force of 0.65 N. Longer RT indicated better flour quality. RT was compared with the mixograph peak time and peak height as predictors of the effect of ascorbic acid and DATEM on bread quality.

Test bakes were carried out, and concentrations of ascorbic acid and DATEM were varied as in the stress relaxation test and the mixograph test. At the various stages of the baking process several dough and bread properties were assessed subjectively and scored according to a standardised scoring system.

The mixograph was successful in characterising untreated flours in terms of bread-making quality and the stress relaxation test did not provide additional information in this regard.

The mixograph was better able to predict the effect of improvers on the stronger Lelie while the stress relaxation test was better at predicting improver effect (especially of DATEM) on the weaker flours, Tiger and Silver Queen. The mixograph predicted the improving effect of DATEM on Tiger and Silver Queen up to a peak, followed by no further improvement. The stress relaxation test predicted improvement beyond the peak, and this continued improvement was observed in the test bake and strong correlation ($p < 0.05$) was found between effect of DATEM on RTs and these important test bake parameters: baking height, loaf volume, drop baking height and the bread score. In addition to information on mixing properties provided by the mixograph, RT seemed to be predicting dough's stability, related to its gas-retaining properties. This stability which can be enhanced by DATEM may be related to both the extensibility of dough's gluten matrix and the stability of the liquid film surrounding the gluten matrix.

TABLE OF CONTENTS

LIST OF FIGURES		v
LIST OF TABLES		x
CHAPTER 1	INTRODUCTION	1
1.1	Statement of the Problem	2
1.2	Research Aim and Objectives	3
	1.2.1 Aim	3
	1.2.2 Objectives	3
CHAPTER 2	LITERATURE REVIEW	4
2.1	The Bread-making Process	4
	2.1.1 The Dough Development Process	7
	2.1.2 Functionality of Protein Molecules in Dough Development	9
	2.1.2.1 <i>The Wheat Proteins</i>	9
	2.1.3 Chemical Bonding During Dough-Making	16
	2.1.3.1 <i>Hydrogen Bonding</i>	17
	2.1.3.2 <i>Ionic Bonding</i>	18
	2.1.3.3 <i>Disulphide Bonding</i>	19
	2.1.3.4 <i>Hydrophobic Bonding</i>	19
	2.2.3.5 <i>Tyrosine Cross-Linking</i>	19
2.2	Bread Improvers	21
	2.2.1 Bread Improver Components	21
	2.2.1.1 <i>Gluten Strengthening Agents</i>	22
	2.2.1.2 <i>Dough Strengthening Agents</i>	27
	2.2.1.3 <i>Gluten Softening Agents</i>	29
	2.2.1.4 <i>Enzyme Supplements</i>	30
	2.2.1.5 <i>Crumb Softeners</i>	32

2.2.1.6	<i>Yeast Foods</i>	32
2.2.1.7	<i>Crumb Brighteners</i>	32
2.3	Evaluation of Dough-Making Quality of Bread Flour and Improver Effect on Flour Quality	33
2.3.1	The Brabender Farinograph	34
2.3.2	The Brabender Do-Corder	34
2.3.3	The Brabender Resistograph	36
2.3.4	The National Mixograph	36
2.3.5	The Brabender Extensigraph	37
2.3.6	The Chopin Alveograph	37
2.3.7	The Brabender Amylograph	39
2.3.8	The Hagberg Falling Number Method	39
2.3.9	The Stress Relaxation Method	39
2.3.10	Dynamic Rheological Testing	41
2.4	Summary	43
CHAPTER 3 EXPERIMENTAL		44
3.1	Materials	44
3.1.1	White Bread Flour	44
3.1.2	Bread Improvers	45
3.1.3	Other Bread Ingredients	45
3.2	Methods	45
3.2.1	Baking Test	46
3.2.2	Mixograph Test	48
3.2.3	Stress Relaxation Test	48
3.2.4	Statistical Analyses	50
CHAPTER 4 RESULTS		51
4.1	Effect of Ascorbic Acid on Baking Test Parameters	51
4.1.1	Dough Development	51
4.1.2	Proof Height	51

4.1.3	Baking Height	53
4.1.4	Loaf Volume	53
4.1.5	Drop Baking Height	56
4.1.6	Drop Volume	56
4.1.7	Drop Test Score	56
4.1.8	Symmetry Score	62
4.1.9	Crumb Texture Score	62
4.1.10	Crumb Colour Score	67
4.1.11	Crumb Softness Score	67
4.1.12	Bread Score	67
4.2	Effect of Ascorbic Acid on Mixograph Parameters	71
4.2.1	Mixograph Peak Time	71
4.2.2	Mixograph Peak Height	71
4.3	Effect of Ascorbic Acid on Stress Relaxation Test	74
4.4	Effect of DATEM on Baking Test Parameters	76
4.4.1	Dough Development	76
4.4.2	Proof Height	76
4.4.3	Baking Height	78
4.4.4	Loaf Volume	78
4.4.5	Drop Baking Height	81
4.4.6	Drop Volume	81
4.4.7	Drop Test Score	86
4.4.8	Symmetry Score	86
4.4.9	Crumb Texture Score	86
4.4.10	Crumb Colour Score	92
4.4.11	Crumb Softness Score	92
4.4.12	Bread Score	92
4.5	Effect of DATEM on Mixograph Parameters	97
4.5.1	Mixograph Peak Time	97
4.5.2	Mixograph Peak Height	97
4.6	Effect of DATEM on Relaxation Test	97

4.7 Correlations Between Rheological and Baking Data	101
CHAPTER 5 DISCUSSION	104
CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS	119
CHAPTER 7 REFERENCES	121

LIST OF FIGURES

Figure 1	Longitudinal section of a wheat grain (Hoseney, 1994)	10
Figure 2	Conventional classification of wheat proteins based on solubility (Frazier, 1992)	11
Figure 3	Physical properties of gluten (left) and its components, gliadin (centre) and glutenin (right) (Hoseney, 1994)	12
Figure 4	A gluten spiral caused by the repeating pentapeptide of ω -gliadin (PYPQQ) and stabilised by hydrogen bonds (Frazier, 1992)	13
Figure 5	Structures of dityrosine (left) and isodityrosine (right) (Tilley <i>et al.</i> , 2001)	14
Figure 6	Proposed reactions to explain the improver action of ascorbic acid (Every <i>et al.</i> , 1998; Grosch and Wieser, 1999)	25
Figure 7	Model for the aggregation of gluten molecules, showing changes in solubility brought about by dough strengthening emulsifier (Stauffer, 1996)	28
Figure 8	Model for dough expansion. The starch-protein matrix formed after mixing fails to enclose the gas cell completely at advanced stages of fermentation, leaving areas that contain only a thin liquid lamella. Increases in the rate of expansion during baking demands new surface area generation which the lamella film is eventually incapable of meeting, thus converting the foam structure into an open sponge (Gan <i>et al.</i> , 1995)	30
Figure 9	Farinogram (A), Do-corder curve (B) and mixogram (C) showing some commonly measured indices (Rasper, 1990)	35
Figure 10	Extensigram showing the most commonly measured	

	Indices (A). Alveogram showing the most commonly measured indices where P is overpressure (mm), L is abscise at rapture (mm), G is swelling index (ml), V is volume of air (ml) and W is deformation energy (10^{-4}) J. (B). Amylogram of wheat flour (C) (Rasper, 1990)	38
Figure 11	Typical Stress Relaxation curve showing how RT is measured	40
Figure 12	Dough between oscillating plates. The dough is deformed through rotation of the bottom plate (left). Ratio of elasticity to viscosity of the consistency as a function of work input for small deformations (Morgenstern <i>et al.</i> , 1998)	42
Figure 13	Summary of baking process	47
Figure 14	Compression of a dough ball on the TA-XT2 texture analyser	49
Figure 15	Summary of the Stress Relaxation Test	50
Figure 16	Effect of ascorbic acid concentration on proof heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	52
Figure 17	Effect of ascorbic acid concentration on baking heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	54
Figure 18	Effect of ascorbic acid concentration on loaf volumes of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	55
Figure 19	Effect of ascorbic acid concentration on drop baking heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	57
Figure 20	Effect of ascorbic acid concentration on drop volumes of the three flours, Tiger (◆), Lelie (■) and Silver	

	Queen (▲)	58
Figure 21	Effect of ascorbic acid on drop volumes of Tiger (A), Lelie (B) and Silver Queen (C)	59
Figure 22	Effect of ascorbic acid concentration on drop scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	61
Figure 23	Effect of ascorbic acid concentration on symmetry scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	63
Figure 24	Effect of ascorbic acid on symmetry of Tiger (A), Lelie (B) and Silver Queen (C)	64
Figure 25	Effect of ascorbic acid concentration on crumb texture scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	66
Figure 26	Effect of ascorbic acid concentration on crumb colour scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	68
Figure 27	Effect of ascorbic acid concentration on crumb softness scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	69
Figure 28	Effect of ascorbic acid concentration on bread scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	70
Figure 29	Effect of ascorbic acid on peak times of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	72
Figure 30	Effect of ascorbic acid on peak heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	73
Figure 31	Effect of ascorbic acid on relaxation time of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	75
Figure 32	Effect of DATEM concentration on proof heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	77

Figure 33	Effect of DATEM concentration on baking heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	79
Figure 34	Effect of DATEM concentration on loaf volumes of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	80
Figure 35	Effect of DATEM concentration on drop baking heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	82
Figure 36	Effect of DATEM concentration on drop volumes of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	83
Figure 37	Effect of DATEM on drop volumes of Tiger (A), Lelie (B) and Silver Queen (C)	84
Figure 38	Effect of DATEM concentration on drop test scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	87
Figure 39	Effect of DATEM concentration on symmetry scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	88
Figure 40	Effect of DATEM on symmetry of Tiger (A), Lelie (B) and Silver Queen (C)	89
Figure 41	Effect of DATEM concentration on crumb texture Scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	91
Figure 42	Effect of DATEM concentration on crumb colour scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	94
Figure 43	Effect of DATEM concentration on crumb softness scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	95
Figure 44	Effect of DATEM concentration on bread scores of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	96

Figure 45	Effect of DATEM on peak times of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	98
Figure 46	Effect of DATEM on peak heights of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	99
Figure 47	Effect of DATEM on relaxation time of the three flours, Tiger (◆), Lelie (■) and Silver Queen (▲)	100

LIST OF TABLES

Table 1	Forces participating in the formation of protein structure (Stear, 1990)	18
Table 2	Analytical results of the Tiger, Lelie and Silver Queen white bread flour samples	44
Table 3	Correlation coefficients between baking performance and rheological data of Tiger	101
Table 4	Correlation coefficients between baking performance and rheological data of Silver Queen	102
Table 5	Correlation coefficients between baking performance and rheological data of Lelie	103

CHAPTER 1

INTRODUCTION

Bread in its many forms is one of the major staple foods consumed by humanity. Traditionally bread is based on flour derived from the cereal wheat. Many other types of cereals, pulses and even legumes can be milled to give flour but the ability of the proteins present in wheat to transform a flour and water into an elastic, extensible, gas-retaining dough which becomes bread is essentially limited to wheat. The bread-making process relies upon the leavening of this glutinous material (Cauvain, 1998a).

To make this elastic dough from flour, the wheat gluten proteins have to be hydrated and developed. The dough is said to be optimally developed when the flour proteins are hydrated and the viscoelastic dough is able to retain optimum amount of gas which will later be generated by yeast fermentation. Before modern bread-making methods were invented, doughs were developed very slowly by hand (kneading) and by the gentle action of yeast during a lengthy bulk fermentation. Many modern bread-making processes rely on a short period of intensive mechanical energy input to develop the dough structure (Frazier, 1992). This highly mechanized system requires flours that possess a good deal of “tolerance” to both under- and over-mixing, and the ability to withstand the rather rigorous treatment of doughs on the conveyer belt systems used to deliver loaves to and from the ovens (Graybosch, Peterson, Hareland, Shelton, Olewink, He & Stearns, 1999). It is common practice for bakeries to add improvers, those additives added to yeast-raised doughs to improve handling properties. These improvers enhance dough development as well as improve eating quality and shelf life. Not only is it difficult to obtain bread of high quality without these improvers, but it is also impossible to obtain bread of consistent quality (Flitcroft, 1998) since the quality of flour used is highly variable.

Regrettably, even flour from the same supplier can be variable in quality. It is therefore necessary to ensure its suitability for bread-making prior to the actual commercial baking, to avoid huge wastage as a result of failure of the flour to perform as required. The most certain way to ensure suitability of flour is to actually bake bread with it, which is why test bakes are commonly carried out in pilot bakery plants. However, these test bakes themselves are expensive and time consuming.

Laboratory rheological tests designed for physical testing of wheat flour doughs such as the National Mixograph, Brabender Extensigraph and the Chopin Alveograph, are quicker and less expensive. They are useful in helping us to understand the rheological effects of dough development and can also be used to predict how flour will perform in the bakery. They can also be used to study the response of flours to improvers and to predict how an improver will affect the quality of the final bread

1.1 STATEMENT OF THE PROBLEM

Although these commonly used rheological tests have proven to be useful in practical industrial applications, and continue to be used in research on wheat flour doughs, they are empirical in nature which makes fundamental interpretations of the results difficult. The data obtained cannot be translated into a well defined physical quantity. Furthermore, the applied deformations are large and often poorly defined, which implies that the test procedure may change the material significantly in an uncontrolled way (Janssen, van Vliet & Vereijken, 1996).

One of the ways which have been used to investigate fundamental rheological properties of wheat flour doughs is to subject dough pieces to biaxial extension under well-defined conditions such as in a stress relaxation test (Kenny, Wherle,

Dennehy & Arendt, 1999). The rheological data obtained can be related with deformation around a growing gas bubble during bread-making. Such fundamental rheological tests are not commonly used in bakeries.

1.2 RESEARCH AIM AND OBJECTIVES

1.2.1 Aim

To determine whether the stress relaxation test provides additional information to the mixograph on prediction of bread-making quality of flour.

1.2.2 Objectives

- To determine dough-making quality of the Tiger, Lelie and Silver Queen white bread flour samples using the stress relaxation test after mixing dough with the mixograph. To use relaxation time used as a quality indicator.
- To determine dough-making quality of the Tiger, Lelie and Silver Queen white bread flour samples using the mixograph test. To use mixograph peak time and peak height being used as quality indicators.
- To determine the effects of ascorbic acid and mono- and diacetyl tartaric esters of mono- and diglycerides of fatty acids (DATEM) on the mixograph peak times and peak heights and the relaxation times of the three flours.
- To perform baking tests in order to determine the bread-making quality of the three flours and the effects of ascorbic acid and DATEM on final bread quality.
- To correlate the results of the mixograph test and the stress relaxation test with those of the baking test to determine whether the stress relaxation test provides additional information to the mixograph test on prediction of flour bread-making quality.

CHAPTER 2

LITERATURE REVIEW

Flour of good quality for the baker is that which conforms to the baker's processing requirements to produce bread with the required characteristics. In order to understand flour bread-making quality it is necessary to describe the bread-making process and the chemical as well as physical changes to the flour components brought about the bread-making process. In this review the bread-making process will be discussed. Special emphasis will be placed on the dough development step of the bread-making process. Also to be discussed are bread improvers added to doughs to enhance flour bread-making quality, as well as methods used to determine flour bread-making quality.

2.1. THE BREAD-MAKING PROCESS

Bread is made by baking a dough which has for its main ingredients, wheat flour, water, yeast and salt (Hoseney, 1994). However even “those most skilled in the art of baking would agree that at the very least it would be difficult to make bread of high quality from only these ingredients” (Williams & Pullen, 1998). Other ingredients which may be added include: fat, soya flour, yeast foods, emulsifiers, oxidants, reductants (Hoseney 1994; Kent & Evers, 1994). The bread-making process commences when these ingredients are mixed.

According to Cauvain (1998b) many different bread-making processes exist and each baker uses a bread-making process which is unique, in that the combinations of ingredient qualities, formulations, processing conditions and equipment reflect the qualities of the products s/he is seeking to achieve. All of the processes which have evolved for the manufacture of bread have a common

aim, namely: to mix the ingredients adequately to develop the dough; to divide it; shape it; proof it and then bake it. The processing stages which occur after dividing the bulk of the dough such as shaping, proving and baking are largely common to all bread-making processes. The differences lie in the methods which are used to produce a developed dough ready for dividing and further processing. Common bread-making methods include: the straight-dough system, sponge and dough, the bulk fermentation, short time baking procedures and mechanical development processes.

The following is a summary of reviews by Kent & Evers (1994) and Cauvain (1998b) of the Chorleywood Bread Process (CBP), the most widely used method to achieve dough development in South Africa.

The CBP is a mechanical dough development process whose essential features are: mixing and developing the dough in a single operation lasting between two and five minutes at fixed energy input; the addition of an oxidising improver; the inclusion of a high melting point fat, emulsifier or fat and emulsifier combination; the addition of extra yeast to maintain final proof times comparable with that from bulk fermentation; the addition of extra water to adjust dough consistency to be comparable with that from bulk fermentation; and the control of headspace atmosphere to achieve given bread cell structures.

The main difference between the CBP and the traditional bulk fermentation process lies in the rapid development of the dough in the mixer rather than through a prolonged resting period. In the bulk fermentation process, the ingredients are mixed at low speeds or by hand to form a homogenous dough. The dough is then rested for a period of one to three hours, depending on flour quality, dough temperature and the bread variety being produced. The dough may even be re-mixed part way through the bulk fermentation period. The main advantage of the CBP in contrast with bulk fermentation is therefore a reduction in processing time. The vigorous mixing not only saves time, but also imparts

energy to the dough that can play a role in optimizing bread quality. Increasing levels of energy per kilogram of dough increases loaf volume, reduces the cell size and increases uniformity. An optimum level of energy was standardized as 40 kJ/kg dough for CBP. However optimum input varies according to flour characteristics, with strong flours requiring optimum energy inputs higher than 40 kJ/kg. It is likely that the high energy inputs are capable of mechanically breaking the disulphide bonds holding the original protein configurations together, and as such, increasing the sites available for oxidation and development of the dough. The energy input also causes a considerable rise in temperature which can give a dough which is more relaxed (has less resistance to deformation) during moulding and is less susceptible to moulder damage.

Mixing in the CBP is also responsible for the final cell structure of the bread. The creation of bubble structures in the CBP depends on the incorporation and subdivision of air during mixing. The number, sizes, and regularity of the gas bubbles depend in part on the mixing action, energy inputs and the control of the atmospheric conditions in the mixer headspace. The final bread crumb structure is almost exclusively based on an expanded version of that created during the initial mixing process.

The CBP has been shown to make better use of flour protein, i.e. a given bread volume can be achieved with a lower protein content in the CBP than with bulk fermentation (Cauvain, 1998a). In South Africa the CBP is used and there has been a change in the direction of the wheat programme in the late 1970s to develop new cultivars with shorter development times to suit the then already widely used CBP (Cheetham, 1997). However, such flours may not be able to withstand the rather rough handling of doughs in the bakery, which is why the addition of an oxidizing agent is of such importance in the CBP to assist development and stabilize the developed structure (Graybosch *et al.*, 1999).

The need to add extra water to adjust dough consistency to provide a softer, more machinable dough can lead to increased yields. The process also saves space by eliminating the bowl of dough at different stages of bulk fermentation. It can also lead to more consistent product quality by manipulating dough.

2.1.1 The Dough Development Process

According to Kent & Evers (1994) and Cauvain (1998b) dough development covers a number of complex changes in bread ingredients which are set in motion when the ingredients first become mixed. These changes are brought about in the physical properties of the dough and in particular, the ability to retain CO₂ gas which will later be generated by yeast fermentation is improved. This improvement in gas retention ability is particularly important when the dough pieces reach the oven. In the early stages of baking before the dough has set, yeast activity is at its greatest and large quantities of carbon dioxide gas are being generated and released from solution in the aqueous phase of the dough. If the dough pieces are to continue to expand at this time then the dough must be able to retain a large quantity of that gas being generated, and it can only do this if a gluten structure with the correct physical structure has been created, through different physical and chemical processes.

Formation of this gluten requires both the hydration of the proteins in flour and the application of energy through the process of kneading (mixing). To describe the process leading to the formation of this gluten more easily, these gluten-forming processes are divided into three phases, which are not separate but overlap in time and space. The first phase of dough formation mainly involves the hydration of the flour particles. The dough water becomes dispersed between the flour particles by the movements of the mixer elements and/or bowl (Stear, 1990). Mixing speeds up hydration by removing the hydrated surface as the hydrated particles are rubbed against each other, the mixer bowl or the mixer blades (Hoseney, 1994). Water adsorbs onto the surface of the flour particles,

which results in the shearing elements of the mixer developing a high mechanical moment to the counter forces of adhesion (Stear, 1990).

During the second phase of dough formation the main processes involved are solubilization and swelling. Flour contains protein, starch granules (both damaged and undamaged), and pentosans, all of which absorb water, but to differing degrees. As mixing proceeds, these water-soluble flour components become dissolved. The albumin and globulin proteins, being water-soluble and on account of their swelling power, form a colloidal solution by the spontaneous formation peptides. Also, the soluble carbohydrates and mineral salts become taken up in the water-soluble phase. The starch absorbs water, and the pentosans also swell (Kent & Evers, 1994). The swelling ability of the starch fractions is more rapid than that of the proteins. The dissolution and swelling processes overlap one another in both time and space, having a complex effect on the rheological behaviour of the dough, which manifests itself in the form of a increased turning moment. On reaching this point, the solubility and swelling reactions are complete (Stear, 1990). The proteins and starch are now hydrated and able to interact in a beneficial way (Hoseney, 1994).

The third phase of dough formation is essentially one of restructuring of the gluten proteins, the swollen flour proteins being changed by the energy input of mechanical mixing into polypeptide chains, which are aligned as more linear film-forming molecules. Progressive energy input results in the initiation of chemical reaction, the most important of which is the breaking of disulphide bonds and their reformation, the formation of hydrogen bonds and hydrophobic bonding. As a result of the continuous building of intermolecular disulphide bonds, the gluten structure takes form, and the viscoelastic rheological system emerges (Stear, 1990). The dough is said to be optimally developed and at this stage mixing operations should be stopped. Further mixing at this stage will cause the disruption of disulphide bonds which will cause dough consistency to fall. The

dough will also become sticky, and thus difficult to handle, and result in poor quality bread (Stear, 1990; Hosenev, 1994).

2.1.2 Functionality of Protein Molecules in Dough Development

As reviewed by Frazier (1992) the wheat grain and all other cereals are mainly composed of starch (approximately 70%), followed by protein (5-13%) and lesser amounts of lipids and non-starch polysaccharides. Although starch is the primary macromolecule conferring rigidity to the structure of baked products after gelatinization by heating, the initial creation of a leavened structure especially in bread, is dependent on protein functionality.

2.1.2.1 The Wheat Proteins

According to Frazier (1992) the wheat grain has a range of protein content of about 9-13% under normal cultivation conditions. Most of this protein resides in the endosperm (about 72%), while the aleurone layer accounts for about 15%. During milling, the remaining protein in the embryo and scutellum (the germ) and the pericarp and testa (the bran) is normally separated from the endosperm. However, some aleurone protein may be lost from the flour because of cells adhering to the bran (Fig. 1).

According to (Frazier, 1992) the proteins of wheat have conventionally been classified by solubility into four groups: albumins, soluble in water; globulins, soluble in dilute salt solutions; prolamins, soluble in aqueous ethanol; and glutelins, soluble in dilute acids. The albumins and globulins are often classified together as a salt-soluble or non-gluten fraction and comprise about 15% of the flour protein. The wheat prolamins and glutelins are called gliadins and glutenins, respectively and constitute the gluten fraction. This represents about 85% of the flour protein and is essential for elastic dough formation (Fig. 2).

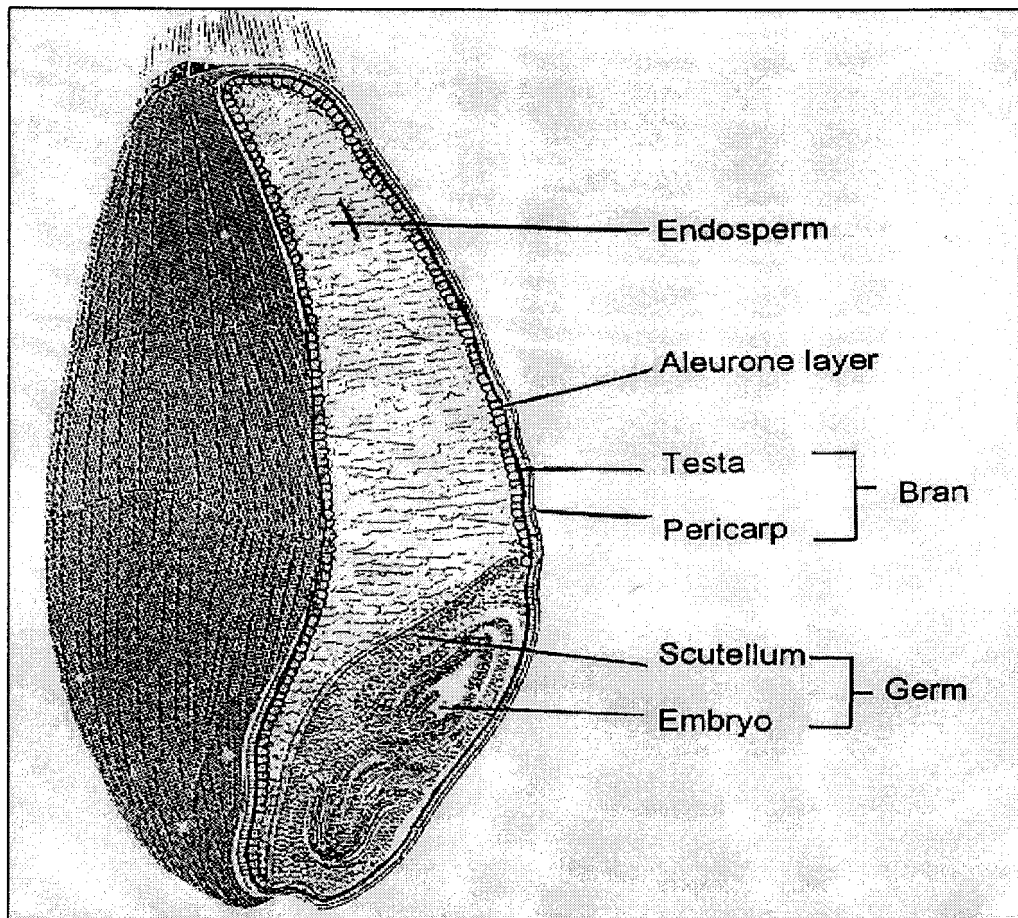


Fig. 1 Longitudinal section of a wheat grain (Hoseney, 1994)

The Gluten Fraction

The gluten proteins, made up of the glutenin and gliadin fractions, are the storage proteins of wheat. They are easily isolated as a result of their insolubility in water. Gently working wheat dough under a small stream of water washes away the water solubles, leaving a rubbery ball of gluten (Hoseney, 1994). Gluten proteins, which make up about 80% of the total protein content of flour (Pomeranz, 1988), are characterised by a high level of glutamine (35%) and low levels of basic amino acids as well as low levels of lysine. There are therefore low levels of potential positive charges and no negative charges, resulting in low charge

density, less repulsion and easy interaction for dough formation (Hoseney, 1994). The suitability of wheat for bread-making is determined to a large extent by the properties of these storage proteins. (Hoseney, 1994).

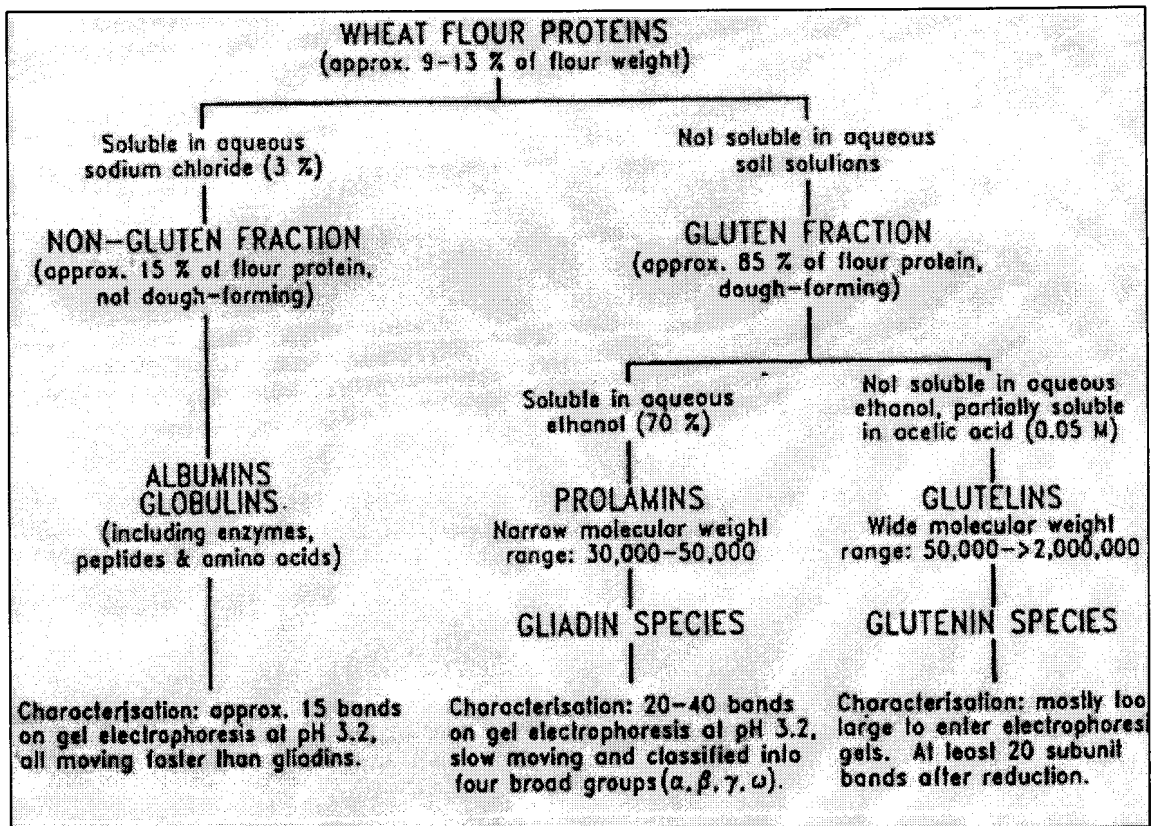


Fig. 2 Conventional classification of wheat proteins based on solubility (Frazier, 1992)

Glutenin proteins

The glutenin proteins are the main proteins involved in determining the functional properties of wheat flour in bread-making. They are resilient and rubbery but prone to rupture. The glutenin gives dough its property of resistance to extension (Fig. 3) (Hoseney, 1994). These multi-chained proteins make up 35-40% of flour protein and consist of subunits that form large polymers stabilised by inter-chain disulphide bonds, having molecular weights above 1×10^6 and possibly exceeding 1×10^7 (Frazier, 1992; Shewry, Halford & Tatham, 1992). The glutenin polymers consist of three, four or five high molecular weight (M_r) (HMW)

glutenin subunits together with an uncertain number of low Mr subunits (LMW) (Shewry *et al.* 1992).

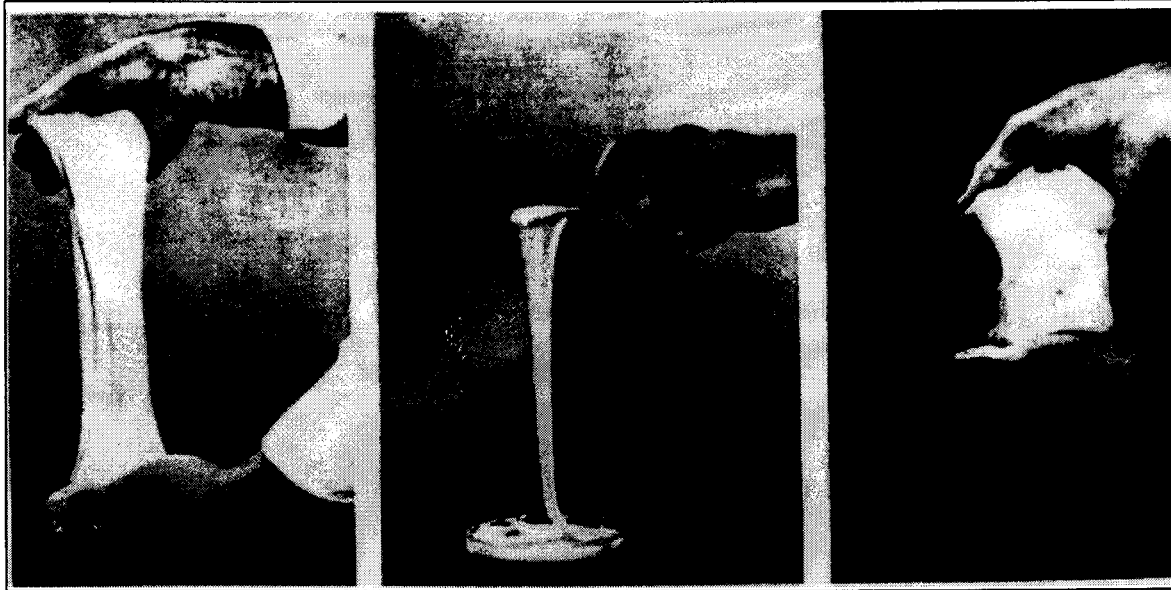


Fig. 3 Physical properties of gluten (left) and its components, gliadin (centre) and glutenin (right) (Hoseney, 1994)

A number of studies have shown that the strength of dough is related to the amount and type of HMW glutenin subunit (Hoseney, 1994). A survey by Payne, Nightingale, Krattinger & Holt (1987) showed that variation in HMW glutenin subunit composition accounted for 60% of the variation in actual bread making quality.

According to Frazier (1992) extensive studies of the molecular structure of HMW glutenin subunits have shown that these subunits contain long repetitive central domains having an unusual sequence which could form regular β -turns. According to Frazier (1992) proline, in sequences such as PYPQQ (P-Proline, Y-Tyrosine, Q-Glutamine), is of key importance in creating a β -spiral conformation, which is stabilised by hydrogen bonds across the helix of the axis rather than along it, as in the case of an α -helix (Fig. 4). This allows a degree of stretch by rotation of the bonds around the two glutamine residues. At the N- and C- termini

short α -helices, each containing a single -SH group, enable polymerization by disulphide bond cross-linking. The overall elastic behaviour of gluten is likely to be influenced considerably by alignment of individual subunits or polymers, such that the β -spirals act co-operatively. This may well be an important role for dough development during mixing and the action of improvers.

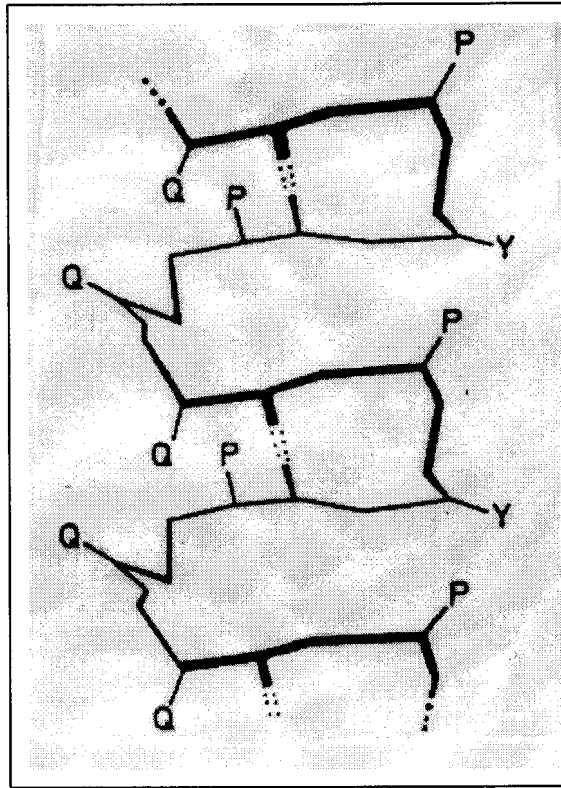


Fig. 4 A gluten spiral caused by the repeating pentapeptide of ω -gliadin (PYPQQ) and stabilised by hydrogen bonds (Frazier, 1992)

Tatham, Drake & Shewry (1990) predicted the Tyrosine-Tyrosine-Proline-Threonine-Serine (YYPTS) to be the site for β -spirals in the glutenin structure. According to Tilley, Benjamin, Bagorogoza, Okot-Kotber, Prakash & Kwen (2001) the double-tyrosine residues (Fig. 5) occurring within the YYPTS repeats occur approximately 11 to 22 times throughout the length of the spiral protein

backbone. The double tyrosine residues are involved in the development of the gluten structure through formation of dityrosine links in these YYPTS repeats.

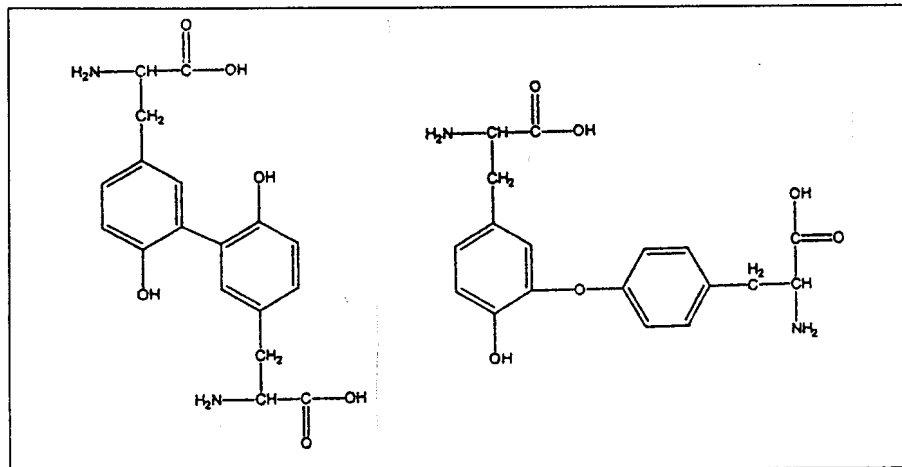


Fig. 5 Structures of dityrosine (left) and isodityrosine (right) (Tilley *et al.*, 2001)

Gliadin proteins

The gliadin fraction constitutes 35-50% of flour proteins and is soluble in alcohol (Frazier, 1992). Gliadins are a large group of proteins with similar properties. They are single-chained and are extremely sticky when hydrated. They have little or no resistance to extension, and are responsible for cohesiveness and extensibility (Fig. 3) (Hoseney, 1994). They form four broad groups namely α -, β -, γ - and ω -gliadins. The ω -gliadins are characterised by the absence of cysteine residues (and therefore not very effective at increasing extensibility) and a very high content of glutamine, proline and phenylalanine. Molecular weights range between 30 000 and 75 000. The α -, β -, γ -gliadins are similar to one another, with the former being the best characterised. It was shown to contain eight repeats of PQPWPF and PWWPY (P-proline, Q-glutamine, F-phenylalanine, Y-tyrosine, W-tryptophan) in the first 99 residues, located in the N-terminal end (Frazier, 1992). It also contains six cysteine residues, four located centrally and two at the C-terminal end (Schofield, 1986). Disulphide bridges are all intra-chain as a result of cysteine residues (Frazier, 1992). The gliadins do not appear to become

covalently linked into large elastic networks and their functional role in dough structure appears to be that of a plasticizer, promoting viscous flow and extensibility which are also important rheological characteristics of dough. Extensive non-covalent interactions may be involved here, notably hydrophobic interactions and hydrogen bonds (Frazier, 1992).

The Non-Gluten Fraction

This fraction of soluble proteins is mainly composed of albumins and globulins (Pomeranz, 1988). Molecular weights of this fraction range from above 100 000 down to small peptides (Frazier, 1992). Many of the proteins have enzyme activity. The proteins are not in themselves dough-forming but a number are believed to play important roles in mechanical dough development and bread improver interaction since it can be shown that gluten alone does not develop in the same way without the presence of the non-gluten fraction (Frazier, 1992). SH-interchange reactions may be important here and may involve small molecules such as glutathione (GS), a tripeptide of glutamic acid, cysteine and glycine (γ -L-glutamyl-L-cysteinylglycine) (Grosch, 1986). Another important functional component of the non-gluten fraction is the enzyme, ascorbic acid oxidase (AAO). L-ascorbic acid (LAA) (Vitamin C), widely used to improve the rheological properties of dough is in fact a reducing agent, and its action is dependent on pre-oxidation by AAO to dehydroascorbic acid (DHA) (Pollit, 1991). Other wheat enzymes such as DHA reductase are also believed to be involved in the process (Grosch, 1986). According Fitchett & Frazier (1986) these enzyme systems have become particularly important for the CBP.

Lipid binding proteins

Lipid interactions are becoming increasingly important in dough structure, especially in relation to the commercial use of emulsifying agents and the quality of wholemeal and high volume bread products. Ligolin has been shown to

complex with lipids during the dough-making process, in addition to being associated with wheat polar lipids (Frazier & Daniels, 1986). It has been proposed as a key functional element in the formation of glutenin structure, involving both disulphide and hydrophobic interactions, and forming nucleus for further hydrophobic binding of lipids (Frazier & Daniels, 1986). A protein called S-protein appears similar in amino acid composition and size to ligolin and is probably closely related or identical (Frazier, 1992). Puroindoline which is an amphiphilic protein in wheat flour may have strong polar lipid binding properties and may be surface active, thus also helping to stabilise foams in bread dough and gas retention (Gan, Ellis & Schofield, 1995).

2.1.3 Chemical Bonding During Dough-Making

According to Stear (1990) "rheological properties are the summation of the interactions of all the reactive functional groups, and the effect of superimposed dough additives such as reducing and oxidising agents". The relatively small, uniform, compact gliadin molecules do not offer much surface for contact with other molecules. On the other hand, glutenin consists of many large molecules, arranged in random coils, offering numerous opportunities for molecular associations. Such glutenin associations give rise to cohesion and elasticity. These two proteins blend on hydration to give properties intermediate between the separate proteins. This interaction is further modified by the presence of starch and lipids.

According to Ornerbro, Nylander & Eliasson (2000) intermolecular interactions involve chemical changes such as the formation of disulphide bonds between proteins, hydrogen bonds between and among proteins and other molecules, ionic bonding, and non-covalent aggregation of proteins and lipids. These chemical interactions generally, but not necessarily, lead to stabilisation of the foam structure of bread dough. The number of attractive interactions is expected

to increase as the temperature is increased during the baking process, due to e.g. exposure of hydrophobic and free thiol groups in the proteins.

2.1.3.1 Hydrogen bonding

According to Stear (1990) hydrogen bonding arises because of the tendency of hydrogen, when attached to oxygen or nitrogen, to share electrons with a neighbouring oxygen. The oxygen or nitrogen draws electrons away from the hydrogen, leaving it with a positive bias. Hydrogen bonding is a relatively weak electrostatic linkage compared to electrostatic bonds. However, their occurrence is frequent and their total effect is highly significant. They occur between amide and carbonyl groups, tyrosine and carbonyls (Table 1).

The important role of hydrogen bonds in dough formation and for ensuring suitable rheological characteristics for subsequent processing has been demonstrated by adding chemicals which liberate or decompose hydrogen bonds. Hydrogen decomposing chemicals (e.g. urea) result in a decrease in dough formation time and decreased stability (Hoseney, 1994). These chemicals may split the hydrogen bonds within the molecule, thus influencing the conformation of the polypeptide chains, or decomposition of bonds of larger units of the molecules. During the initial period of dough formation, these chemicals accelerate gluten swelling by loosening the structure. Disaggregation of the swollen, formed dough due to the hydrogen bond decomposing chemicals then proceeds at a rapid rate. Doughs with poor quality gluten are less sensitive to such chemicals, since they contain a reduced number of hydrogen bonds, and have a looser gluten structure (Stear, 1990). Mixing flour with Deuterium oxide (D_2O) instead of water has the opposite effect. D_2O has stronger hydrogen bonding, producing stronger doughs (Hoseney, 1994).

Table 1
Forces participating in the formation of protein structure (Stear, 1990)

Type of bond	Interacting groups	Examples
Covalent	C-C, C-N, C=O, C-H, C-N-C, S-S	Internal amino acid, peptide, disulphide bonds, dityrosine links
Ionic	-NH ₃ ⁺ -NH ₃ ⁺ -COO ⁻	Lysine, glutamic acid, histidine, arginine
Hydrogen	-N-H...O=C-	Amide-carbonyl tyrosine-carbonyl carbonyl-carbonyl
Hydrophobic interaction		Alanine, valine, proline, etc.
Non-polar	Polar	Polar groups in the side-chain
Repulsive forces	All groups	All groups

2.1.3.2 Ionic bonding

Ionic bonding is due to electrostatic attractions between different charges. It occurs when pH conditions are favourable between neighbouring ionized amino and carboxylate groups, present either as end-groups of peptide chains or in the side groups of diamino, e.g. lysine, and dicarboxylic, e.g. glutamic acids (Table 1) (Stear, 1990). This type of bonding is not as strong as a covalent bond, and can be broken by a change in pH of the surrounding medium. Changes in pH are therefore of importance in dough behaviour. Hosney & Brown (1983) found that decreasing dough pH from a native flour value of 6.2 decreased mixing stability whereas increasing pH increased both mixing time and stability (i.e. strengthened the dough) as a result of enhanced ionic bonding.

2.1.3.3 Disulphide bonding

These covalent bonds form between neighbouring cysteine units due to electron distribution. Electrostatic repulsion between particles of the same charge gives rise to polar groups of amino acid chains, which means the sulphur-containing amino acid cysteine can cross-link with its two sulphur atoms, forming the disulphide linkage (Table 1) (Stear, 1990). These bonds play a very important part in protein structure, giving it strength and rigidity (Fitchett & Frazier, 1986; Grosch, 1986). As is the case with hydrogen bonding, disulphide bonding can occur between groups in the same chain (intramolecular) or between groups on different chains (intermolecular), thus contributing to the formation of both helical and pleated sheet structures (Fig. 4) (Stear, 1990). Oxidation of the reactive sulphhydryl groups of the cysteine within the protein molecule (e.g. through the addition of an oxidising improver) results in a firm bonding, which can easily be split with reducing agents (Fitchett & Frazier, 1986).

2.1.3.4 Hydrophobic bonding

These involve non-polar group interaction e.g. between alanine, valine and proline (Table 1) (Stear, 1990); 35% of the total amino acids have hydrophobic side chains (Hoseney, 1994). In addition, repulsion due to van der Waals forces, between non-polar groups in close proximity is widespread amongst all groups (Stear, 1990). It is believed that hydrophobic interactions between gluten proteins play an important role in stabilising gluten structures and in the rheological and baking properties of flour, and may be responsible for the mechanism of the dough improving action of emulsifiers (Hoseney, 1994).

2.1.3.5 Tyrosine cross-linking

According to Tilley *et al.* (2001) these covalent bonds form between the aromatic tyrosine rings and occur in the form of isodityrosine and dityrosine (Fig. 5). They

are common in glutenin subunits which contain from three to five % tyrosine within their structures. These cross-links are reported by Tilley *et al.* (2001) to occur during dough formation and bread-making processes, and to be responsible for the mechanism through which oxidants improve dough and bread-making quality.

2.2 BREAD IMPROVERS

The term bread improvers, was defined by Williams & Pullen (1998) as “any material or combination of materials which are added to yeast-raised doughs to enhance and control gas production or gas retention or both. Bread improvers are needed here in South Africa because flour used for bread-making can be of inappropriate quality (Cheetham, 1997), thus unable to withstand mechanical abuse occurring in the bakery. With flour quality being inconsistent, bread improvers are also necessary to maintain consistent bread quality

According to Flitcroft (1998) the use of bread improvers maximises the inherent flour quality and improves the dough development. This occurs through the rapid modification of the gluten structure in dough to produce a gluten matrix so that the maximum amount of gas released (by the yeast during fermentation) is retained in the dough. They also impart greater tolerance to processing at all stages of manufacture in commercial baking operations. This results in a more uniform and consistent dough throughout the batch and from batch to batch. As the various complex functions of a bread improver contribute to improved dough characteristics, this results in enhanced overall eating qualities of the bread produced.

2.2.1 Bread Improver Components

As discussed by Flitcroft (1998), there are various types of bread improvers and also a range of ingredients that may be incorporated into a bread improver. The list of ingredients which are generally used can be categorised according to their particular functionality. The list of ingredients includes: gluten strengthening agents, gluten softening agents; dough strengtheners; enzyme supplements; crumb softeners; yeast foods; and crumb brighteners. The choice of which bread improvers to include and the ratio of those ingredients varies, and will depend on

the bread-making process used, the type of equipment used, and on whether the ingredient is permitted by legislation to be used in bread.

2.2.1.1 Gluten strengthening agents

Gluten strengthening agents are oxidising agents which stabilise and strengthen the gluten matrix by converting sulphhydryl groups on gluten protein molecules into disulphide groups, thus connecting adjacent chains (Flitcroft, 1998). Oxidising agents which have this effect on bread doughs include: ascorbic acid, potassium bromate, potassium iodate, calcium peroxide, azodicarbonamide, potassium persulphate, and oxidative enzymes such as hexose oxidases (Fitchett & Frazier, 1986). Of these, only ascorbic acid is used to any significant extent in South Africa and other countries such as Australia and New Zealand. The other oxidising agents have been banned in most countries because of evidence that they may be carcinogenic (Dirndorfer, 1992). Enzymes such as hexose oxidases are of natural origin and may have future potential use as bakers look for alternatives with a "green" image (Dirndorfer, 1992).

Ascorbic acid (AA) is actually a reducing agent as noted by Pollit (1991), but in the presence of atmospheric oxygen and ascorbic acid oxidase (which is active in flour) it is converted to dehydroascorbic acid (DHA) which is an oxidising agent, but which cannot itself be added as it is somewhat unstable. Its functioning is therefore dependent upon the adequate availability of oxygen within the dough. This is important to note especially in the CBP where dough is often mixed under vacuum in closed containers to achieve optimal throughput, best crumb texture, good volume and thus an acceptable, palatable loaf (Pollit, 1991; Cauvain 1998c). The solution to this is to add oxygen as well as using another fast acting oxidant such as azodicarbonamide (ADA) (Pollit, 1991). ADA is not a viable option since it may be banned in some countries (Dirndorfer, 1992). AA has the advantage that the amounts needed are not too critical; improvement will occur with as little as 15 ppm or as much as 200 (Fitchett & Frazier, 1986; Pollit, 1991;

Yamada & Preston, 1992). The optimum amount will depend on the bread-making process and whether the AA is used on its own or in combination with other improvers. The optimum level of addition according to Fitchett & Frazier (1986) is 75 ppm for the CBP, the advantage being that it is virtually impossible to over-treat bread doughs, unlike the situation with other oxidants (e.g. ADA, potassium bromate). Effects of AA include improved loaf volume and crumb texture and increased tolerance to over-mixing (Yamada & Preston, 1994).

Due to the demand for more natural products in the baking industry oxidising enzymes such as hexose oxidases have gained importance (Si, 1997). Glucose oxidase is an enzyme derived from a fungal source (Vermulapalli, Miller, & Hosney, 1998). This enzyme reacts with β -D-glucose in the presence of oxygen to form gluconic acid and hydrogen peroxide. The hydrogen peroxide is the molecule that produces the strengthening effect similar to other oxidants, resulting in improved loaf volume (Vermulapalli *et al.*, 1998). Hexose oxidase catalyses the conversion of a number of mono- and oligosaccharides into corresponding lactones and hydrogen peroxide, and works in a similar manner to glucose oxidase. Its advantage is that it can convert more than one type of substrate (Poulsen & Hostrup, 1998). The lipoxygenase enzyme, as discussed by Frazier (1979), is found naturally in wheat and wheat flour although to a much smaller extent than in soya flour. Enzyme-active soya is routinely added here in South Africa to bread doughs to promote bleaching of the carotenoid pigments. However, an oxidative improvement of the dough is also obtained. Work by Frazier, Leigh-Dugmore, Daniels, Russell Eggitt & Coppock (1973) showed that the lipoxygenase enzyme in soya flour exerts a considerable effect on the rheological properties of mechanically developed dough. They postulated the mechanism to be that of coupled oxidation of the protein involving transient lipid oxidation intermediates.

Mechanism for oxidative dough improving effect

The mechanism for the improving effect of oxidising agents on bread dough may be similar for most oxidising agents. However, the most studied one is that of AA, which will be the focus of this section, especially because it is the one accepted in most countries and here in South Africa. The mechanism proposed for the improver action of LAA is based on the assumption that the DHA formed inhibits the cleavage of the intermolecular disulphide bonds of gluten proteins by thiol-disulphide interchange reactions with GS (Pollit, 1991; Xuizhen-Lu & Seib, 1998; Grosch & Wieser, 1999). The most reactive group in GS is the sulphhydryl of the cysteine side chain (Dong & Hoseneey, 1995) which is why GS reacts almost exclusively with intermolecular SS-bonds which are responsible for the aggregation properties of LMW subunits of gluten.

During kneading of dough, L-AA is oxidised by gaseous oxygen and ascorbic acid oxidase (AAO) to DHA (Fig. 6, reaction (1)) which in turn withdraws endogenous reduced glutathione (GSH), forming oxidised glutathione (GSSG) with the enzyme glutathione dehydrogenase (GSH-DH) as a catalyst (Fig. 6 reaction (2)) (Grosch & Wieser, 1999). The specificity of this enzyme is the reason why the improver action of L-threo-AA (LAA) differs from that of D-threo-AA (DAA). GSSG undergoes a thiol/disulphide (SH/SS) interchange reaction with protein SH groups to form a mixed disulphide of protein and glutathione (PSSG) and GSH (Fig. 6 reaction 3) (Walther & Grosch, 1987) which then could soften the dough by depolymerization of glutenin molecules (Fig 6, reaction (4)) (Dong & Hoseneey, 1995). However, reaction (4) (non-enzymic) is slow in comparison with (2). Consequently, depolymerization of glutenin molecules decreases but the PSSG formed by (3) increases in the glutenins (Hahn & Grosch, 1998). In the absence of L-AA, reduced cysteine (CSH) increases in dough, probably due to a reaction of GSH with oxidised cysteine (CSSC) (Fig. 6 reaction (5)) (Chen & Schofield, 1996). This increase is inhibited by L-AA with the consequence that CSSC may take part in SS-SH interchange reactions with thiol groups of gluten

proteins leading to an increase in mixed disulphides of proteins and cysteine (PSSC) and CSH (Fig. 6 reaction (6)) (Grosch & Wieser, 1999). In essence, the reduction in the native thiol content of flour accounts for the improving effect of oxidising bread improvers.

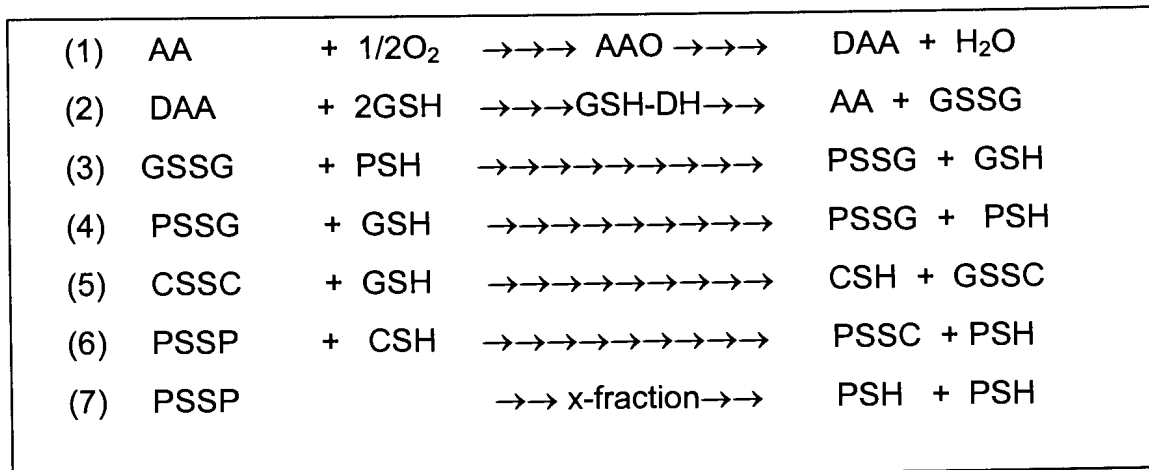


Fig. 6 Proposed reactions to explain the improver action of ascorbic acid (Every *et al.*, 1998; Grosch & Wieser, 1999)

This theory on the mechanism of AA on dough improver response was supported by work done by Every, Simmons & Ross (1998), whereby critical components of flour were isolated to test their role in reconstituted dough and bread system. In their work, Every *et al.*, (1998) reported the presence of an x-fraction in addition to the others, which is possibly enzyme-like and responsible for the weakening of dough through the cleavage of disulphide bonds to form protein thiols (7).

The following conclusions were drawn from this experiment:

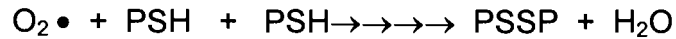
- Enzymes involved in the AA-improver effect: Ascorbic oxidase (AAO), Glutathione dehydrogenase (GSH-DH), and X-fraction (possibly enzyme-like)
- Damaging reactions for dough and bread: reactions (4), (6) and (7)
- AA-improving reactions for dough and bread: reactions (1) and (2)

Nakamura & Kurata (1997) disagreed with this hypothesis and suggested that DAA was not involved in the AA-improver effect. They claim that proteins are cross-linked by oxygen radicals generated during the AA oxidation by free radicals ($O_2\bullet$):

AA oxidation generates oxygen radicals



(1) oxygen radicals oxidise protein thiols (PSH) to disulphide bonds



Kerr, Hosney & Faubion (1993) also reported the involvement of a free radical in SS-SH interchange reactions. Dong & Hosney (1995) stated the free radical to be a glutathione free radical ($GS\bullet$) formed during mixing. According to them, during mixing disulphide are ruptured and create thiol radicals. Reaction of proteins with this free radical causes cleavage of protein disulphides and their depolymerization.

According to Meuser & Suckow (1986) the improvement in the baking performance of wheat flour on the addition of oxidants also depends on changes that take place when water extractable pentosans undergo oxidative gelation. The mechanism through which this happens is uncertain although it is assumed that ferulic acid found in the gel is either linked to the protein of the glycoprotein or serves as a bridge between the pentosan parts and the protein.

According to Tilley *et al.* (2001) oxidising agents strengthen dough by the formation of dityrosine links (Fig. 5) catalysed by an enzyme present in the water soluble extract of flour. They reported that a free radical mechanism was responsible for the cross-link formation and that CYS and GSH, which have been thought to break down the gluten structure through scission of SS bonds (Grosch & Wieser, 1999), instead acted as free radical scavengers preventing tyrosine cross-link formation.

2.2.1.2 Dough strengthening agents

Surfactants (emulsifiers) were first introduced into bread as crumb softeners which acted as anti-staling agents by reducing the degree of retrogradation of starch through complexing with the starch molecules, especially the amylose molecules (Tamstorf, Johnson & Krog 1986). A longer lasting crumb softness is important whenever bread is to be distributed over long distances or a shelf life of several days is expected (Tamstorf *et al.*, 1986). These surfactants also have a strengthening effect on dough, helping it to withstand mechanical abuse during processing (Flitcroft, 1998). They strengthen the dough differently to oxidants in that they do not react with the sulphide bonds on the gluten as oxidants do. Instead, they strengthen the dough by binding to and supporting the starch and the gluten matrix as well as by forming an aqueous film between the gluten and the gas bubbles (Flitcroft, 1998). Surfactants commonly used as dough strengtheners in bread include DATEMs and stearyl lactylates (Tamstorf *et al.*, 1986)

DATEMs are mono- and diacetyl tartaric acid esters of mono- and diglycerides of fatty acids. These surfactants have been found to improve gas retention of dough, thus increasing loaf volume (Armero & Collar, 1996).

Stearyl lactylates are reaction products of lactic acid and stearic acid, partially neutralized in the form of sodium salts (sodium stearyl lactylate (SSL)) or calcium salts (calcium stearyl lactylate (CSL)) (Kamel & Hoover, 1992). Kamel & Hoover (1992) found SSL to result in improved texture, volume and shelf life. Armero & Collar (1996) and Lang, Neises & Walker (1992) also observed improved loaf volume and mixing properties. They also observed that no increase in volume took place in the presence of DATEM. The two emulsifiers should therefore not be used together. Dirndorfer (1992) in his comparison of the effect of the different emulsifiers on loaf volume found SSL to be the best of all at a certain level of addition.

Mechanism for surfactant dough improving effect

The mechanism by which these surfactants strengthen dough is not known in detail but a number of hypotheses exist that try to explain it. One theory suggests that surfactants are bound to the glutenins by hydrophobic bonding between the hydrocarbon chain of the lipid and the hydrophobic regions of the protein (Tamstorf *et al.*, 1986; Stauffer, 1996). According to Armero & Collar (1996) and Stauffer (1996) these hydrophobic interactions incorporate the negative charges into the complex, moving the net charge of the protein closer to zero and promoting protein aggregation in the dough. Aggregation of these gluten molecules then helps to form a continuous layer around gas bubbles and therefore help in stabilising them (Fig. 7).

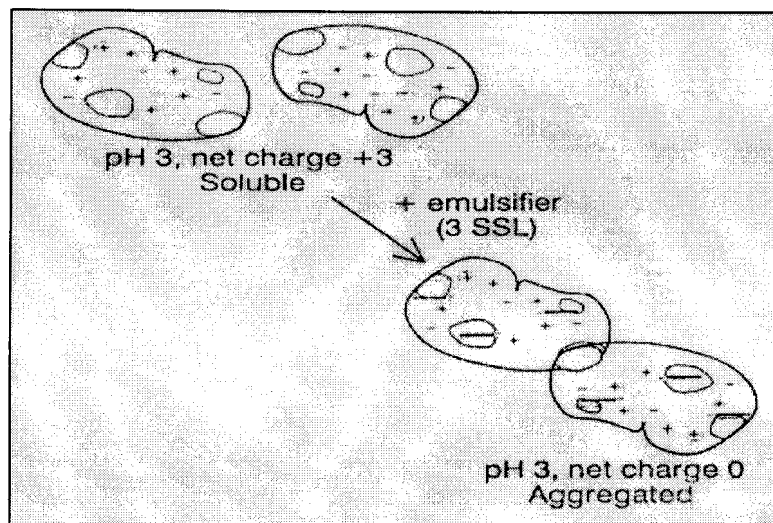


Fig. 7 Model for the aggregation of gluten molecules, showing changes in solubility brought about by dough strengthening emulsifier (Stauffer, 1996).

Another theory suggests that surfactants act by associating with gliadin proteins, together with native polar flour lipids, in liquid-crystalline structures in the aqueous phase surrounding the gas bubbles and starch granules in a dough

(Tamsorf *et al.*, 1986). Surfactants form a lamella liquid-crystalline phase in water, and may therefore combine with native polar lipids in membrane-like structures in the dough, thus enhancing the polar flour lipids in their baking function. This contributes to dough elasticity, allowing gas cells to expand and results in an increased volume of baked goods (Tamstorf *et al.*, 1986; Ornerbro *et al.*, 2000). According to Gan, Angold, Ellis, Vaughan, & Galliard (1990) and Gan *et al.* (1995) a dough consists of discrete gas bubbles lined with liquid films stabilised by surfactants and embedded in a continuous starch-protein matrix soon after mixing. As the volume fraction of the gas increases, the expanding gas cells develops discontinuities in the matrix, leaving areas that contain only a thin, lamella film between neighbouring cells. The degree to which these discontinuities occur depends on the starch-protein matrix, which is largely dependent on the gluten proteins. The surface area of the lamella film increases as discontinuities develop further. Failure of this film to maintain the rate of new surface area generation towards the end of oven spring leads to the rupture of this film and loss of gas (Fig. 8). Surfactants at the gas/liquid interface improve wetting properties and stabilise the dispersed phase to improve gas retention.

2.2.1.3 Gluten softening agents

These are reducing agents that are added to dough to soften it in order to improve handling properties. An example of such an agent is L-cysteine which softens dough by breaking disulphide bonds between gluten protein molecules (Fitchett & Frazier, 1986). These agents are not used in the CBP unless very strong flour is used and will be omitted in this discussion.

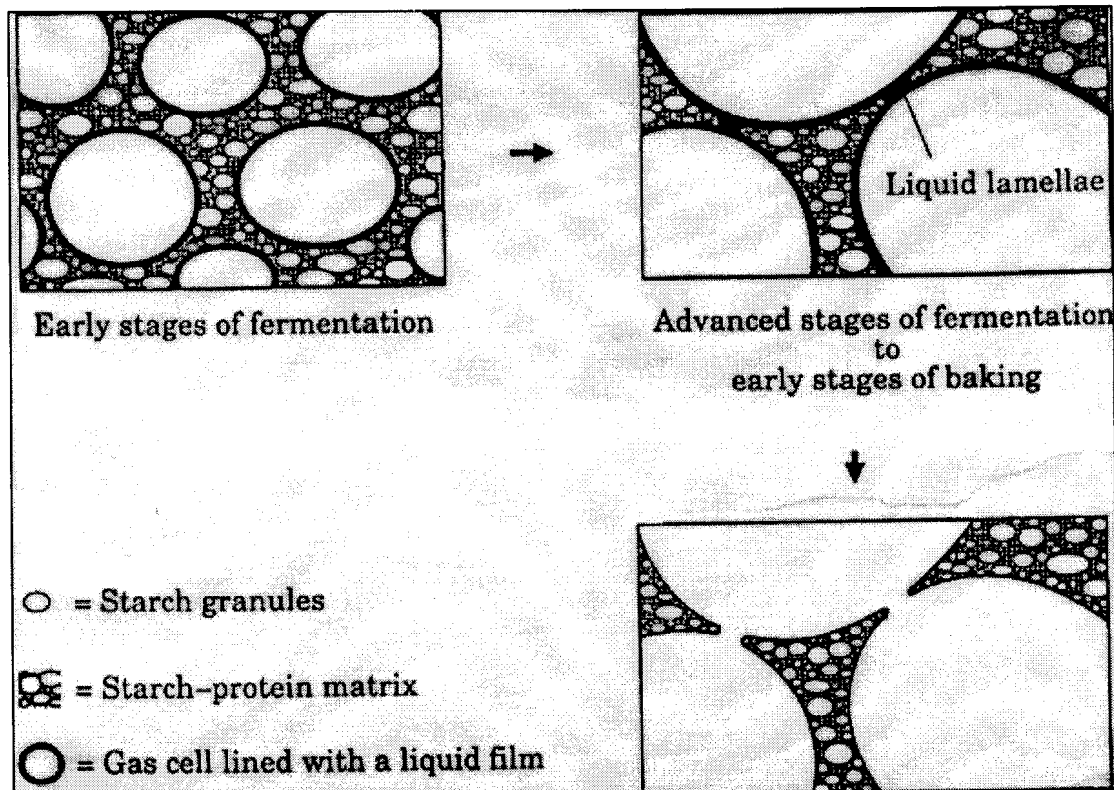


Fig 8 Model for dough expansion. The starch-protein matrix formed after mixing fails to enclose the gas cells completely at advanced stages of fermentation, leaving areas that contain only a thin liquid lamella. Increases in the rate of expansion during baking demands new surface area generation which the lamella film is eventually incapable of meeting, thus converting the foam structure of dough into an open sponge (Gan *et al.*, 1995)

2.2.1.4 Enzyme supplements

Enzymes of significance in the CBP are amylases and pentosanases. Amylases hydrolyse damaged starch to fermentable sugars which then act as food for the yeast. While sound wheat flour normally contains sufficient levels of beta-amylase for bread-making purposes, addition of further alpha-amylase is required to produce good quality bread (Flitcroft 1998), especially since according to Dirndorfer (1992) South African wheat flours are deficient in natural fermentable

sugars. Amylases added are of fungal origin and are heat stable, which means they are still active at dough temperatures of 60-65°C when the starch gelatinises (Kent & Evers, 1994). These enzymes can therefore improve crumb texture, softness and loaf volume through increased CO₂ (Cauvain, 1998b). It has been believed that these enzymes can also slow down the process of realignment of the starch molecules and thus the staling process (Kent & Evers, 1994). However, Si (1997) disagreed, and reported that the enzyme reduced crumb firmness by means of volume or crumb structure improvement, but had no effect on retarding the retrogradation of starch during storage. She also reported that maltogenic (biotechnologically enhanced) bacterial alpha-amylase had a substantially improved anti-staling effect compared to fungal alpha-amylases and also improved elasticity of bread crumb.

Pentosans, the major non-starch polysaccharides of wheat (Meuser & Suckow, 1986) are believed to interfere with gluten coagulation through steric hindrance (Williams & Pullen, 1998). Pentosanases are thus added to the dough to break them down and enhance increased interaction between the protein molecules (Williams & Pullen, 1998). They are believed to have a beneficial effect on dough handling and loaf volume through increased protein coagulation (Hamer, Weegels, Marseille & Kelfkens, 1989). They are also believed to improve crumb softness possibly through the partial breakdown of pentosans and also the subsequent liberation of water, and solubilization of the pentosans which results in increased viscosity within the dough (Flitcroft, 1998). Genetically modified xylanase, a type of pentosanase, has been reported to have far fewer side activities and therefore, a lower dosage is needed to achieve the same effect with less risk of possible interference from side activities (Si, 1997). Enzyme quality is also more consistent (Si, 1997).

2.2.1.5 Crumb softeners

These comprise of emulsifiers that interact with the starch fraction of the flour to form amylose-lipid complexes (Flitcroft, 1998). Amylose is bound and increased interaction with the amylopectin fraction occurs. This then reduces the degree of starch retrogradation and therefore reduces the staling of bread (Kent & Evers, 1994). Such emulsifiers include SSL, CSL, monoglycerides of fatty acids (MGL), and sucrose esters (SE). Unlike the other emulsifiers, MGL exhibits no dough improving effects like those mentioned earlier as emulsifiers acting as dough strengtheners (Tamstorf *et al.*, 1986), possibly because they do not increase protein aggregation. Instead they increase the capacity for intermolecular hydrogen bonding, inducing conformation changes (Armero & Collar, 1996). In fact, Armero & Collar (1996) found that addition of MGL to DATEM and SSL had a detrimental effect on dough strength. He attributed the detrimental effect to excess surfactant that solubilized the gluten proteins by additional adsorption to the surface.

2.2.1.6 Yeast foods

Yeast foods are included in bread improvers to promote vigorous yeast activity and thereby increase the rate of fermentation. These include mineral salts which act directly as a nitrogen source (e.g. ammonium chloride) for the yeast or act indirectly by regulating enzyme activity in the dough (e.g. acid calcium phosphate) (Flitcroft, 1998).

2.2.1.7 Crumb brighteners

Enzyme active soya flour is included in some bread improvers as the lipoxygenase in the soya flour oxidises complex lipids in the wheat flour to form peroxides. The peroxides, in turn, bleach the flour pigments resulting in a whiter, brighter bread crumb (Flitcroft, 1998).

2.3 EVALUATION OF DOUGH-MAKING QUALITY OF BREAD FLOUR AND IMPROVER EFFECT ON BREAD FLOUR QUALITY

The physical condition of dough depends, to a large extent, on the quality of the flour used. Thus, testing doughs for their physical properties has become an essential part of methodology for quality evaluation of wheat flours. Physical properties of dough determine dough properties and thus its performance at the various stages of the bread-making process. According to Larsen (1992) it is becoming increasingly vital to monitor these dough properties as bread-baking processes are increasingly being monitored with feedback via computer control. To monitor dough properties, it is necessary to understand the interactions between dough properties and bakery processes such as mixing, dividing, rounding, proofing, sheeting, cutting, moulding and panning. This means that basic information needs to be collected, using objective methods developed for defining and measuring dough properties.

According to Rasper (1990) the different tests available for this purpose reflect the relevance of the individual physical qualities of dough at the different stages of the bread-making process. A group of tests i.e. the farinograph, mixograph, and resistograph tests are concerned with the behaviour of dough when it is developed from flour and water and subsequently subjected to over-mixing. Recording mixers are used to measure and record the changes in the resistance of dough to mixing with time. The recorded mixing curves are characterised by an ascending part which indicates changes during the dough development process, while the subsequent decline in resistance is taken as a sign of a steady breakdown of the dough structure upon mixing beyond the point of optimum development (Figs. 9 and 10).

2.3.1 The Brabender Farinograph

The Brabender Farinograph (C.W. Brabender Instruments Co., Duisburg, Germany) is one of the most widely used recording mixers. The two z-shaped blades of the farinograph mixer rotate at constant but different speeds and subject the dough to relatively gentle mixing at constant temperature (Rasper, 1990). The farinograph record (the farinogram) (Fig. 9) provides a measure of dough development time (time taken to reach peak) and stability (time taken for consistency to fall below peak) which increase with increasing strength of flour; and mixing tolerance index (5 min. after peak) and degree of softening (12 min. after peak) which decrease with increasing strength of flour. The farinograph also measures water absorption of a flour, with strong flours of a high protein content and better gluten quality being characterised by higher absorption (Tipples, Preston & Kilborn, 1982; Shuey, 1984; Rasper, 1990; Schoggl, 1993).

2.3.2 The Brabender Do-Corder

A variant of the farinograph, the Brabender Do-corder (C.W. Brabender Instruments Co., Duisburg, Germany) mixer simulates conditions of mechanical dough development. It has a nearly closed mixer in which dough can be subjected to mixing at variable speeds and work input levels higher than in an ordinary farinograph mixer (Rasper, 1990; ICC, 1992). The temperature of the mixing bowl can be raised gradually to almost 100°C. By so doing, the rheological properties of the bread dough in the early stages of baking can be reproduced, which is the most important stage from the standpoint of the change in flour components (Nagao, 1985). The Do-Corder can be used with many interchangeable measuring heads, and can thus be very flexible, (Nagao, 1985; ICC, 1992). The Do-Corder curve (Fig. 9) has two peaks in heated doughs. The first peak at 75°C is associated with the protein fraction and the second with the starch fraction (Nagao, 1985).

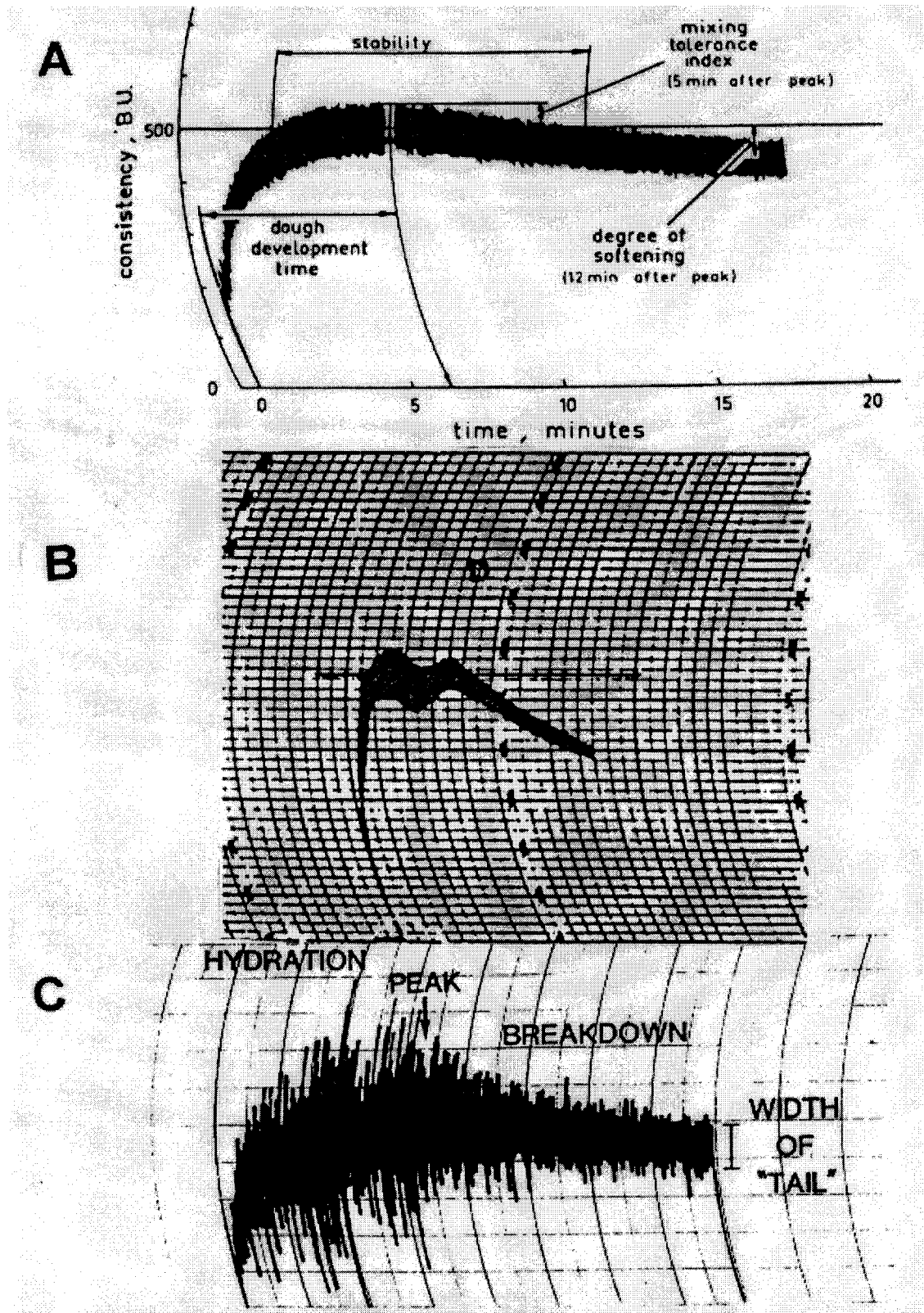


Fig. 9 Farinogram (A), Do-corder curve (B) and mixogram (C) showing some commonly measured indices (Rasper, 1990)

2.3.3 The Brabender Resistograph

The Resistograph, another variant of the farinograph (C.W. Brabender Instruments Co., Duisburg, Germany.) combines mixing with stretching, pressing, and kneading. It therefore imparts high shear and high work input to the dough. The resistograph has two peaks. The first peak is related to binding of water by flour, the second one measures the stickiness of and extensibility at breakdown of the dough (Rasper, 1990).

2.3.4 The National Mixograph

The Mixograph (National Manufacturing Company, Lincoln, NB, USA) mixing action is provided by four planetary pins revolving about three stationary pins on the bottom of the mixing bowl. The mixing can be described as a pull, fold, and repull action, which is more severe than that produced by the farinograph (Rasper, 1990). The mixograph test can therefore be performed at higher speeds. However, according to D'Appolonia & Kunerth (1985), the mixograph is more difficult than the farinograph to standardise between laboratories although a usable level of replication can be obtained in any one laboratory under uniform conditions. It also has a limited applicability for the determination of water absorption of the test flour. The shape of the mixogram (Fig. 9) can be characterised by indices similar to those defined for the farinogram. According to Rasper (1990) peak time is similar to farinogram dough development time. Peak height provides information about flour strength and absorption. Height of curve at 3 min. past the peak is similar to farinogram mixing tolerance (5 min. after peak). Higher values indicate a greater tolerance to over-mixing. A higher tolerance to over-mixing and overall strength of flour can also be judged from the area under the curve. The larger the area the stronger the flour and the greater the tolerance to over-mixing (D'Appolonia & Kunerth, 1985; Rasper, 1990).

2.3.5 The Brabender Extensigraph

Load extension instruments e.g. the extensigraph and the alveograph measure resistance to extension. They provide information on the potential behaviour of the dough during its rise due to the development and expansion of gas at the fermentation and early baking stages (Rasper, 1990).

The Brabender Extensigraph (C.W. Brabender Instruments Co., Duisburg, Germany) stretches a cylindrically shaped dough piece until it ruptures while the resulting force on the test piece is recorded. The dough is prepared in a farinograph mixer at its optimum absorption and development/consistency and fermented for a specified period of time. While the dough piece is stretched, a curve of force versus time, an extensiogram (Fig. 10), is recorded. Extensigraph indices provide a practical guide to general strength of the dough and these include resistance to extension, dough extensibility, energy required to stretch the test piece to its rupture point; the more energy required, the stronger the flour (Tipples *et al.*, 1982; Rasper, 1990; Schoggl, 1993). The stretching characteristics measured by the extensigraph are an important quality parameter due to their close relationship to the baking results (Schoggl, 1993; Stable Micro Systems, 1998).

2.3.6 The Chopin Alveograph

The Chopin Alveograph (Chopin SA, Villeneuve la Garenne, France) subjects dough to extension in all directions by blowing a moulded and rested sheet into a bubble. Air pressure in the bubble is recorded as a function of inflation time. Doughs are prepared with constant water addition to flour irrespective of its true absorption (Rasper, 1990). Interpretation of the alveogram (pressure/time record) (Fig. 10) is similar to that of the extensiogram. Its indices give a measure of resistance to extension, extensibility and deformation energy. (Tipples *et al.*, 1982; Rasper, Hardy & Fulcher, 1985).

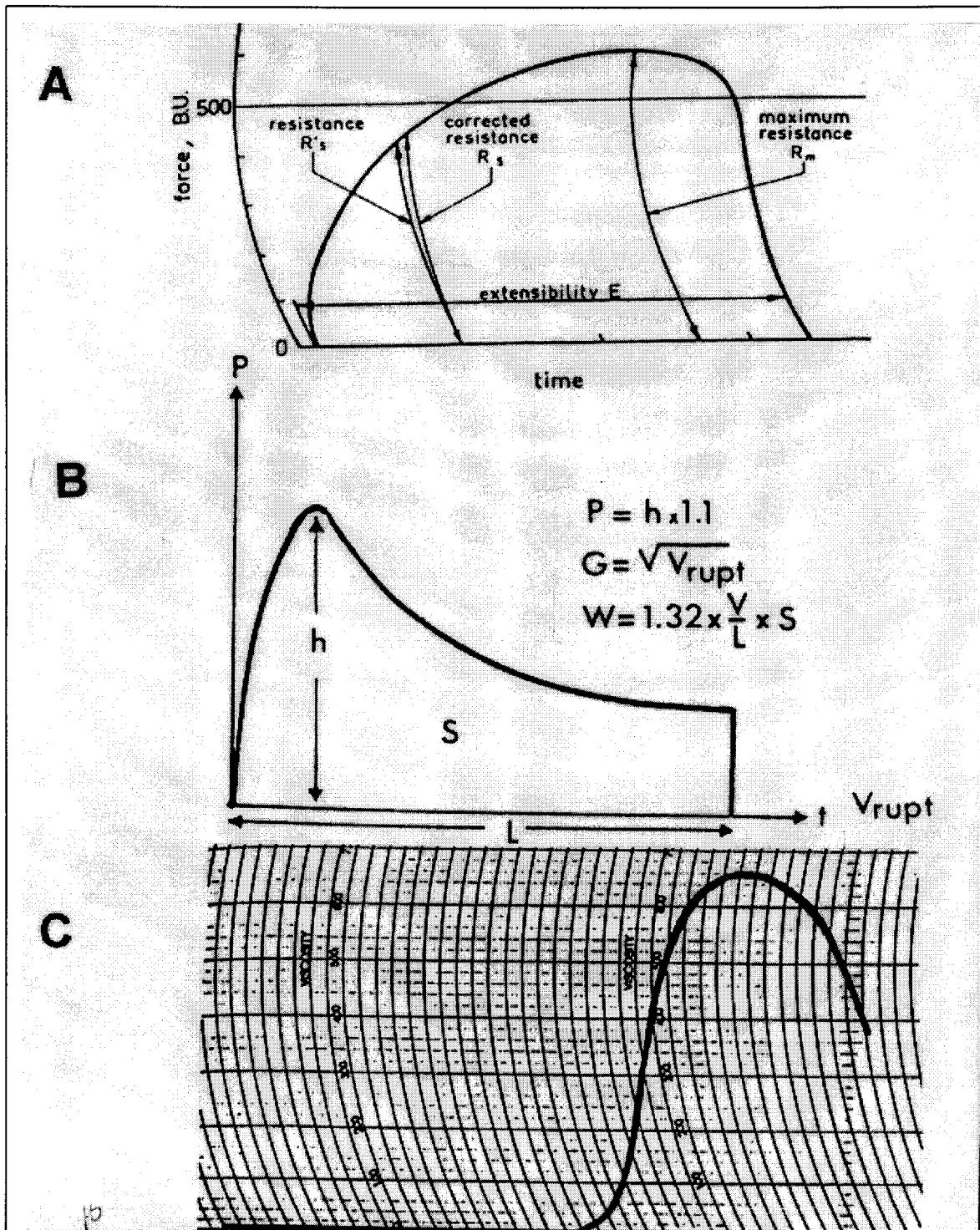


Fig. 10 Extensigram showing the most commonly measured indices (A).

Alveogram showing the most commonly measured indices where P is overpressure (mm), L is abscise at rapture (mm) m G is swelling index (ml), V is volume of air (ml), and W is deformation energy (10^{-4}) J. (B). Amylogram of wheat flour (C) (Rasper, 1990)

2.3.7 Brabender Amylograph

The Brabender Amylograph (C.W. Brabender Instruments Co., Duisburg, Germany) determines viscosity of starch as well as amylase activity. The flour/water suspension is heated under controlled conditions until gelatinization takes place. As viscosity increases the now accessible starch is broken down by amylases. At a certain temperature, the viscosity reaches a maximum and then falls off again. The peak of the amylogram (Fig. 10) and the maximum viscosity are significant characteristics of the baking quality of the flour (Schoggl, 1993).

2.3.8 The Hagberg Falling Number Method

In the Hagberg Falling Number (Falling Number A.B., Stockholm, Sweden) method the water/flour suspension is introduced into boiling water and is thus heated rapidly. The gelatinization temperature is exceeded in less than one minute and gelatinization is therefore rapid. As a function of amylase activity the gel is liquefied more or less rapidly and the time is measured (Schoggl, 1993). Amylase activity has an important effect on bread quality since fermentation of dough, loaf volume, staling rate, crust colour, and crumb characteristics of bread depend largely on this property (Dirndorfer, 1992). Flour with too little amylase activity results in lower sugar content during fermentation, and therefore reduced yeast activity and lower bread volume. Too much amylase activity results in dough that is sticky and difficult to handle.

2.3.9 The Stress Relaxation Test

The method described by Frazier *et al.* (1973) involved mixing doughs to a series of increasing work levels up to 350 kJ/kg using a farinograph bowl attached to a modified Brabender Do-corder, with the rate of work being kept constant at 20 kJ/kg.min by computer feedback control. Replicate dough samples (10 g) were then moulded into spheres, rested for 45 min at 30°C and compressed between

parallel plates at 10 mm/min in an Instron materials testing machine, to a load of 1.8 N. The time for the force to decay by 1.0 N is then recorded as the stress Relaxation Time (RT) (Fig. 11). According to Frazier (1992) this method provides a simple and reproducible test, which is very sensitive to the state of development of the gluten proteins in the dough.

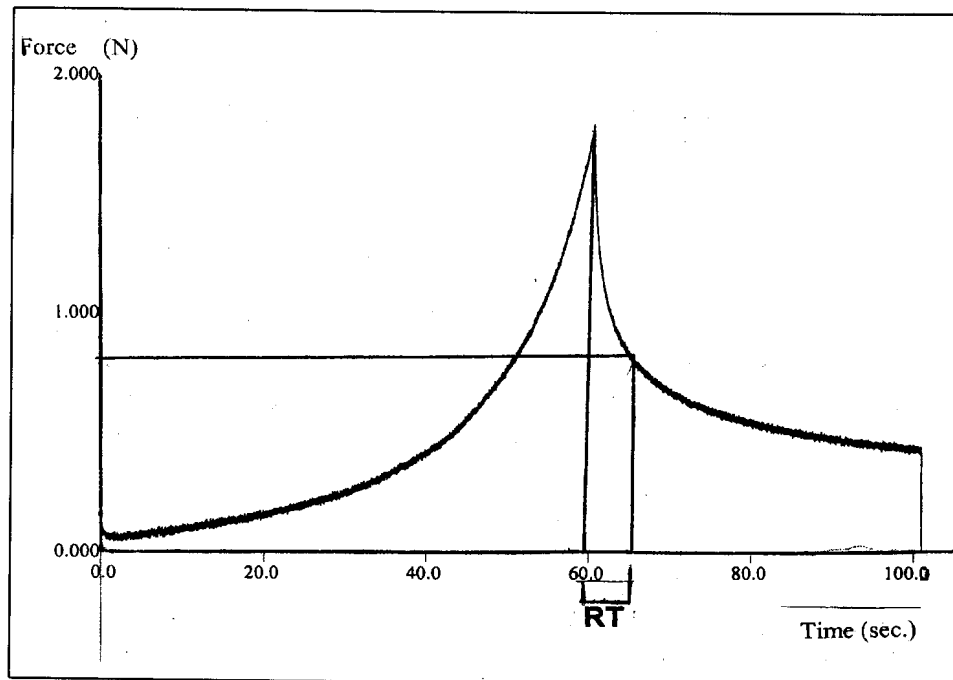


Fig. 11 Typical Stress Relaxation curve showing how RT is measured (Frazier, 1979)

Larsen (1992) of the Grain Processing Laboratory of the New Zealand Institute for Crop and Food Research developed a similar method for the purpose of measuring the surface stickiness of bread and biscuit doughs. In his method, a fresh dough surface was created for each measurement by cutting off a 10 mm slice of dough. A round teflon-coated flat probe (25 mm diameter) was then quickly applied to the upper dough surface. The dough was compressed to a force of 150 ± 2 g. By delaying withdrawal of the probe after compression,

relaxation time was measured. The Instron probe was then withdrawn at maximum speed (500 mm/min) to minimise dough cohesion. From each compression-tension cycle, compression energy, maximum tensile force, tensile energy and relaxation time were measured, all from one test. Tensile energy (TE) is the area under the tension curve and it indicates the surface "stickiness" of dough. Stickiness is important at the mixing, dividing and rounding stages. A dough that is too sticky does not leave the mixer or rounder properly. A dough that is not sticky enough is not formed properly by the rounder and the resulting product does not have the desired crumb structure (Stable Micro Systems, 1998).

2.3.10 Dynamic Rheological Testing

Dynamic rheological testing is performed using a number of different rheometers to impart either small or large deformations to a piece of dough in order to measure the force needed to change the shape of a piece of dough (deformation). This in turn gives the rheological properties of the dough. Dough undergoes large deformations during mixing and moulding, but much smaller deformations during proofing and baking. Therefore it is necessary to test wheat flour dough at both small and large deformations although because of its non-linear nature it is commonly done at low deformations where it approaches linear behavior (Faubion, Dreese & Diehl, 1985). In a small deformations test, e.g. the Bohlin dynamic rheometer, a piece of dough is placed between two flat plates and subjected to a small oscillating deformations (shear) (so small they are hardly visible) by oscillating the lower plate (Fig. 12) (Morgenstern, Companella & Zheng, 1998). This results in a torque on the top plate which is recorded as a function of time. By comparing torque and shear data, information on viscous and elastic behaviour of the sample can be obtained, and a curve can be constructed (Fig. 12). Consistency increases similarly to mixing curves. When testing for large deformations (100-1000 times larger than oscillating techniques), the lower plate is rotated at constant speed so that the dough is continuously deformed (shear). The torque on the upper plate is measured and plotted against deformation until

rupture occurs, which is manifested by a peak on the curve (Fig. 12). Here the curve also follows the mixing curves, peaking at optimum work input (Faubion *et al.*, 1985; Morgenstern *et al.*, 1998).

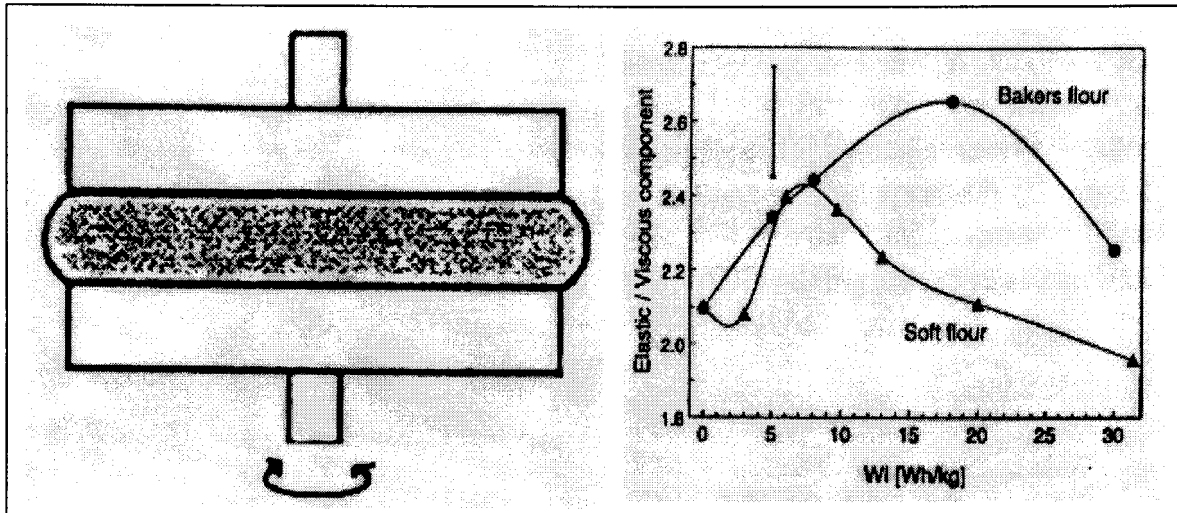


Fig. 12 Dough between oscillating plates. The dough is deformed through rotation of the bottom plate (left). Ratio of elasticity to viscosity of the consistency as a function of work input for small deformations (right) (Morgenstern *et al.*, 1998).

2.4 SUMMARY

Rheological methods are useful in helping us to understand the rheological effects of dough development; and can be used to make flour quality comparisons as well as study the response of flours to improvers. However, owing to the high levels of work required to develop dough methods such as the farinograph are not sensitive enough. They are generally unsuitable for studying flour performance in short-time, high-energy bread-making processes such as the CBP where total energy input to the dough is carefully controlled and the rate of work input is also an important factor (Frazier, Fitchett & Russell Eggitt, 1985). Other methods such as the mixograph and the resistograph apply deformations so large that they may alter the dough's properties in an uncontrolled way. Most of the commonly used rheological methods such as the mixograph, farinograph, alveograph are also empirical in nature, making interpretation of the results difficult. More work needs to be done on more fundamental tests, such as the stress relaxation test if possible, with controlled energy input to find out precisely which property of the dough they measure so that their information can be directly applicable to the baking process.

CHAPTER 3

EXPERIMENTAL

3.1 MATERIALS

3.1.1 White Bread Flour

Three samples of commercially milled, specified unbleached and untreated white bread flour were used in this research. The three flours were chosen to represent a variety of quality of bread flours. The Tiger, an example of a weak flour, was obtained from Tiger Milling in the Western Cape, South Africa. Lelie, an example of strong flour, was obtained from Meneba Miling in the Netherlands. Silver Queen, an example of a poor quality flour, was obtained from Rank Hovis millers in the United Kingdom. The samples were analysed at the respective millers and the analytical results provided are shown in Table 2. The values tabulated for Silver Queen were specifications that were provided with the flour, and not actual analytical results. Samples were available in very limited quantities and as a result some tests were not replicated as many times as required for statistical analyses.

Table 2

Analytical results of the Tiger, Lelie and Silver Queen white bread flour samples

Analysis	Tiger	Lelie	Silver Queen
Moisture (%)	14.0	14.0	14.0
Protein (14 % mb)	11.1	12.3	10.5-11.1
Farinograph absorption (14 % mb)	60.8	61.0	59.0
Falling Number (s)	348	344	172
Mixograph peak time (min)	2.3	3.2	3.2
Mixograph peak height (mm)	89	103	68

3.1.2 Bread Improvers

Ascorbic acid (analytical grade) and ADMUL DATEM 1954 supplied by Quest International (Johannesburg, South Africa) were used.

3.1.3 Other Bread Ingredients

Other bread ingredients used for the baking test included: salt, brown sugar, full fat soya flour, bread fat, compressed yeast and these were supplied by Albany Bakeries, Germiston, South Africa. Quantities of bread ingredients used as per Albany Bakeries standard methods.

3.2 METHODS

3.2.1 Baking Test

The method used was provided by and is used for routine tests by Albany Bakeries, Germiston. All ingredients were placed in the mixing bowl of a 30 kg Esmach spiral mixer (Esmach, Italy), and the mixer started. The ingredients were mixed for four minutes at low speed and six minutes at high speed. A dough temperature of 29°C after mixing was aimed at to achieve good bread quality. To achieve this temperature, the following equation was used to determine what the temperature of the added water should be:

$$\begin{aligned} \text{Water temperature} &= 2 \times (\text{required dough temperature} - \text{temperature rise}) \\ &\quad - \text{flour temperature} \\ &= 2 \times (29 - 3^*) - \text{flour temperature} \\ &= 52 - \text{flour temperature} \end{aligned}$$

*temperature rise = 3° for the Esmach spiral mixer used in this research

After mixing, the dough was divided into dough pieces of 790 g each. Dough pieces (two from each mixing, one for the drop test to be described below) were rounded by hand and placed under a sheet of plastic on a table surface for six minutes to simulate the first prover in the bakery. The rounded pieces were then put through a final moulding process in an in-store bakery bread moulder to form the doughs into sausages. The dough pieces were then placed into baking tins. The tins were placed in the prover where the dough was proved for 60 minutes at 43.5-45.5 °C and 82-86 % relative humidity. The proved doughs were then baked at 250 °C for 25-30 minutes. The breads were then allowed to cool and wrapped in polythene bags.

At the various stages of the baking process several dough and bread properties were assessed subjectively by myself and scored using Albany bakeries standardised scoring system. Higher scores indicated good quality. The properties assessed were: dough stickiness (score 16-20), dough development (8-15), loaf volume measured using a rape seed displacement volumeter (6-12),

crust colour (3-5), symmetry (3-5), drop test (4-8), external faults (-2 per fault), softness (5-10), crumb colour (5-10), crumb texture (7-10), butterability (3-5), internal faults (-2 per fault). An overall bread score was calculated as the sum of the scores for all the variables, the maximum being 100.

A drop test was done on doughs after proofing to test stability of the dough to knocking and banging after proofing. The pans were placed on two sticks, each one cm from the surface. The sticks were quickly removed, dropping the pan onto the table. The dropping was done twice. The doughs were then baked as the other doughs. The baking procedure is summarised in Fig. 13. Test bakes were performed in duplicate for Tiger and Lelie and only once for Silver Queen which was limited in quantity.

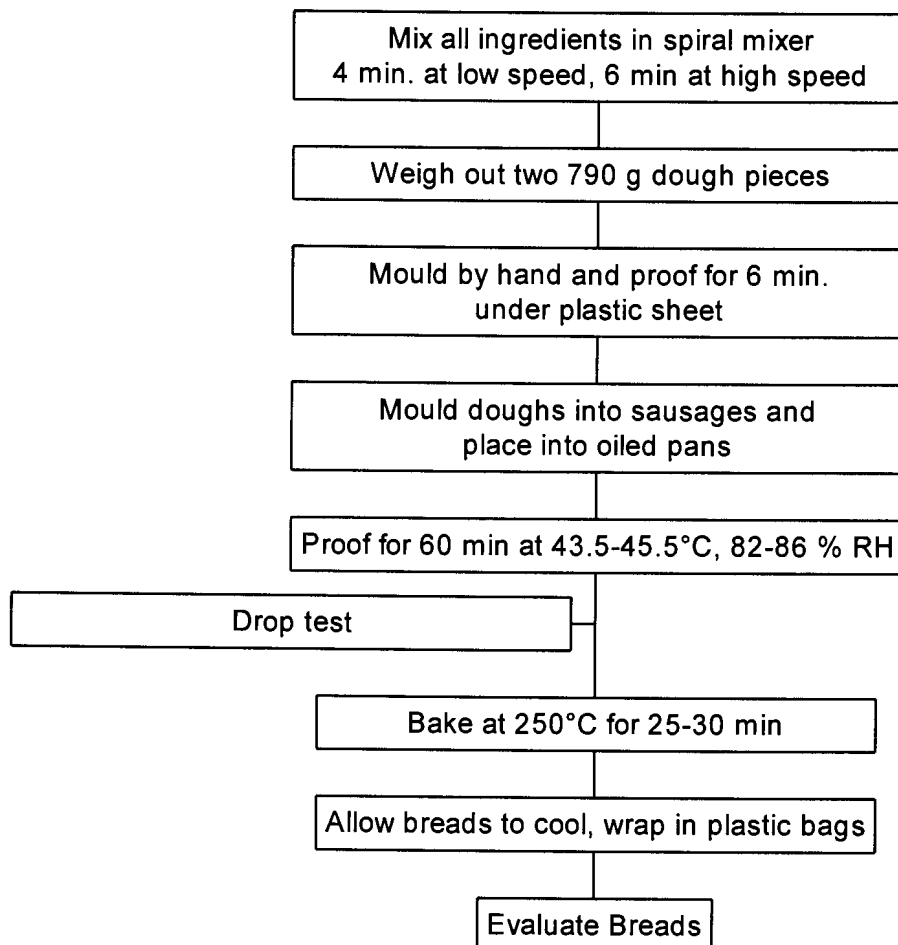


Fig. 13 Summary of the baking test

3.2.2 Mixograph Test

AACC Method 54-40A (American Association of Cereal Chemists, 1983) was used to determine the mixograph peak times and mixograph peak heights of the three flours. Doughs containing distilled water equal to farinograph water absorption (according to optimized absorption farinography (Rasper, 1990)) (Table 2) were mixed for 8 min. in a 35 g mixograph. DATEM was added at levels of 0.2, 0.3, 0.4, and 0.5% of flour weight. Ascorbic acid was added at levels of 50, 100, 150, and 200 ppm of flour weight. Doughs without any improvers were also mixed. Peak time was taken as time in minutes to peak dough resistance and peak height as height of the curve at peak resistance. The mixograph test was performed in duplicate.

3.2.3 Stress Relaxation Test

Stress relaxation tests were carried out on a TA-XT2 (Stable Micro Systems Ltd., London, United Kingdom) texture analyser. The method used was adapted from that described by Frazier *et al.* (1973). Doughs were mixed in a 35 g mixograph to their peak times (as determined in the mixograph test in 3.2.2) at each level of improver addition. The mixograph was used because it is readily available in most bakeries and can be considered as imitating mechanical dough development because of its high shear mixing. Dough pieces, each of 20 g (two balls per mixing) were moulded by hand into balls and proofed in air-tight plastic containers in a water bath at 30°C for 45 min. Each dough ball was then compressed between parallel plates of the TA-XT2 texture analyser (Fig. 14) at a speed of 0.2 mm/s. The texture analyser was programmed to stop movement when a compressive load of 1.50 N was reached, the dough being allowed to relax at constant deformation. The relaxation time was recorded from the stress relaxation curve from forces of 1.50 to 0.65 N. Each test was done in triplicate, each replicate having two dough balls. Mean relaxation times were calculated

from between four and six replicate dough balls at each level of ascorbic acid and DATEM addition.

The TA-XT2 settings for the test were as follows:

Mode:	HLDD (Force Relaxation)
Pre test speed:	10 mm/s
Test speed:	0.2 mm/s
Post test speed:	10mm/s
Force:	1.5 N
Time:	100 sec
Trigger type:	auto-0.2 N
Probe:	50 mm diameter aluminium cylinder
Data acquisition rate:	12.5 pps
Graph type:	force vs time

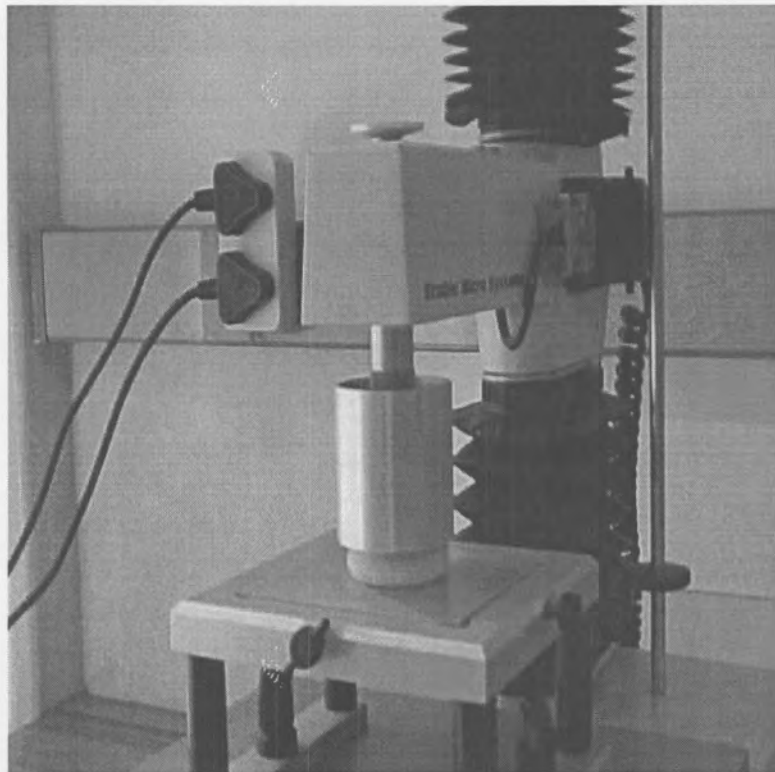


Fig. 14 Compression of a dough ball on the TA-XT2 texture analyser

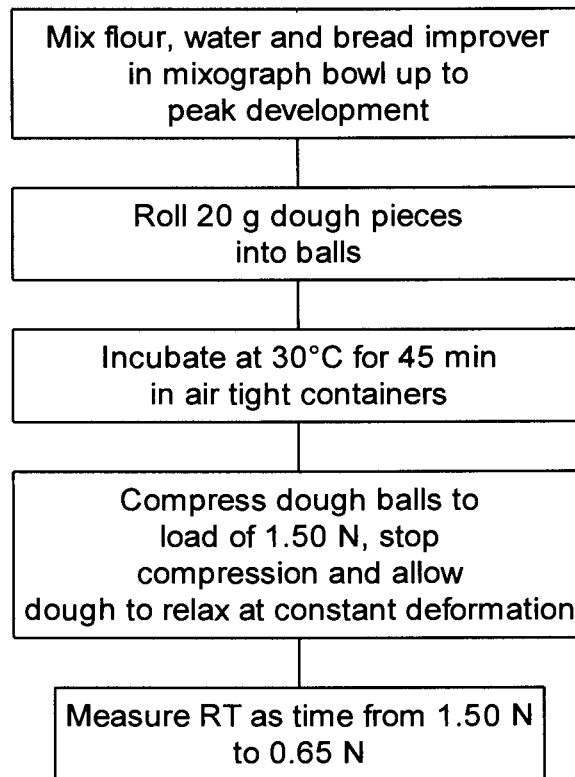


Fig. 15 Summary of the Stress Relaxation test

3.2.4 Statistical Analyses

The least significance difference (LSD) means test was used to determine if there were significant differences in test parameters at different concentrations of improver additions. A p-value smaller than 0.05 was considered to be statistically significant. Pearson correlation coefficients were calculated between means of rheological data and means of test bake data to determine linear correlation.

All analyses of variance (ANOVA) and correlation statistics were performed using Statistic Analysis Software (SAS) methods (SAS Institute, Cary, NC.).

CHAPTER 4

RESULTS

4.1 EFFECT OF ASCORBIC ACID ON BAKING TEST PARAMETERS

4.1.1 Dough Development

After mixing, Tiger was slightly sticky without ascorbic acid and formed a thin film that broke upon stretching. Ascorbic acid did not seem to improve the stickiness but did however improve development in that with ascorbic acid, the dough formed a thin film without breaking upon stretching. Silver Queen was stiff and dry but still manageable and tore without forming a thin film. Ascorbic acid did not improve this condition. With or without ascorbic acid Lelie was not sticky. It was smooth, soft and easy to handle. It formed a very thin film with little or no tearing.

4.1.2 Proof Height

Fig. 16 shows the relationship between ascorbic acid concentration and heights of Tiger, Lelie and Silver Queen after the second proofing stage. Without ascorbic acid, proof heights of Tiger, Lelie and Silver Queen were approximately 146 mm, 177 mm, and 138 mm, respectively. Ascorbic acid had no significant effect on the proof heights of the Lelie. Proof heights for the Tiger increased with increasing ascorbic acid concentrations up to an optimum of approximately 177 mm at an ascorbic acid concentration of 150 ppm, and then remained unchanged. Silver Queen proof heights increased slightly with increasing ascorbic acid concentrations without reaching an optimum over the range of ascorbic acid concentrations investigated.

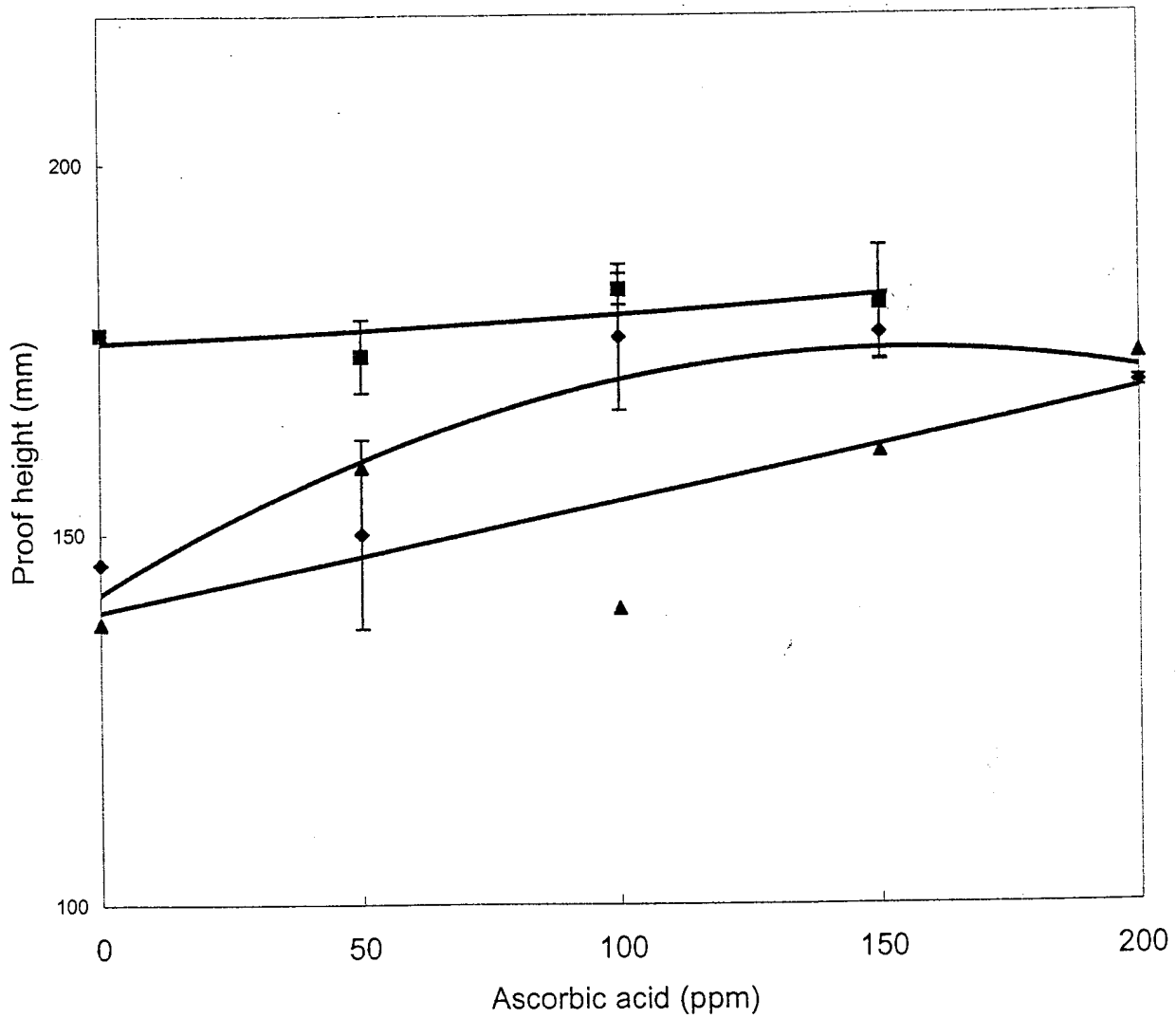


Fig. 16 Effect of ascorbic acid concentration on proof heights of doughs made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.1.3 Baking Height

Fig. 17 shows the relationship between ascorbic acid concentration and bread heights after the baking stage. Without ascorbic acid, baking heights of Tiger, Lelie, and Silver Queen were approximately 135 mm, 189 mm and 125 mm, respectively. Baking heights of Lelie were not affected by increasing concentrations of ascorbic acid to any significant extent. Baking heights of Tiger and Silver Queen increased slightly (although statistically insignificant, $p < 0.05$) and seemed to reach an optimum at approximately 200 ppm. Baking heights of Tiger and Silver Queen were lower than proof heights at most ascorbic acid concentrations tested.

4.1.4 Loaf Volume

Fig. 18 shows the relationship between ascorbic acid concentration and bread loaf volumes. Without ascorbic acid, loaf volumes were approximately 2675 cm³, 3600 cm³, and 2325 cm³ for Tiger, Lelie and Silver Queen, respectively. Tiger and Silver Queen loaf volumes were lower than required to make an acceptable loaf of bread. Lelie loaf volumes were already excessive without ascorbic acid and were not statistically significantly affected by increasing concentrations of ascorbic acid. No baking tests were performed at 200 ppm ascorbic acid for Lelie because the loaves were excessive and touched the oven roof and could not be taken out of the oven without breaking. Both Tiger and Silver Queen showed very slight increases in loaf volumes with increasing ascorbic acid concentrations. Tiger volumes increased up to approximately 2975 cm³ and seem to reach an optimum at about 200 ppm while Silver Queen increased up to approximately 2875 cm³.

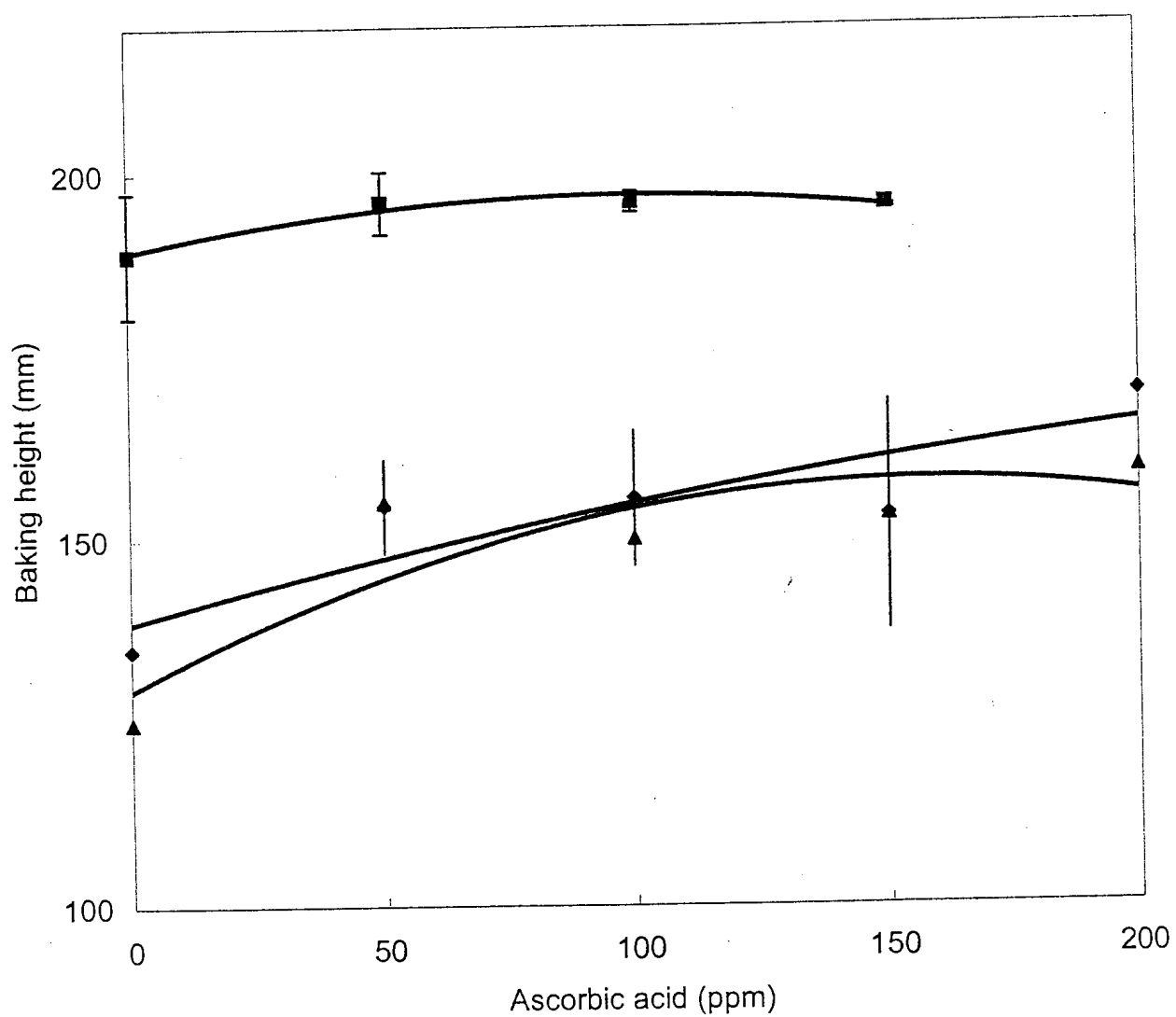


Fig. 17 Effect of ascorbic acid concentration on baking heights of doughs made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

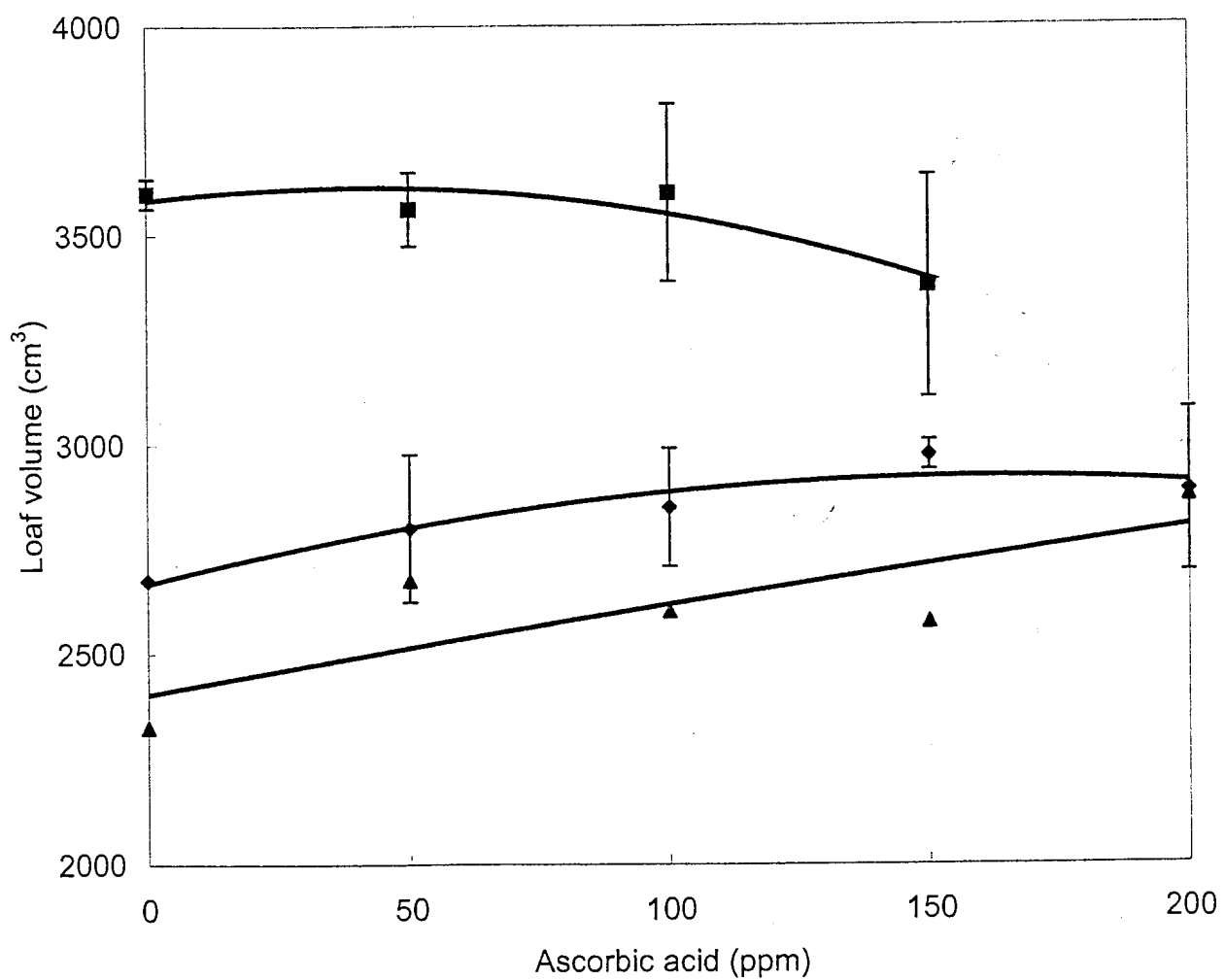


Fig. 18 Effect of ascorbic acid concentration on loaf volumes breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.1.5 Drop Baking Height

Fig. 19 shows the relationship between ascorbic acid concentration and baking heights of bread loaves whose doughs had been subjected to the drop test. Drop heights of Tiger, Lelie and Silver Queen, without ascorbic acid, were approximately 96 mm, 133 mm and 112 mm, respectively. Drop heights of breads made from all three flours were not statistically significantly affected by ascorbic acid.

4.1.6 Drop Volume

Fig. 20 shows the relationship between ascorbic acid concentration and bread loaf volumes of breads whose doughs were subjected to the drop test. Drop volumes, without ascorbic acid were less than 2100 cm³ (the rapeseed volumeter used to measure volume could not measure volumes below 2100 cm³ which is considered by Albany Bakeries as a minimum for the method used) for Tiger and Silver Queen and approximately 2263 cm³ for Lelie. Ascorbic acid had no significant effect on drop volumes of Tiger, Lelie and Silver Queen. Fig. 21 shows bread loaves whose doughs were subjected to the drop test.

4.1.7 Drop Test Score

Fig. 22 shows the relationship between ascorbic acid concentration and the score assigned to the appearance and loaf volume of breads whose doughs were subjected to the drop test. Without ascorbic acid, drop test scores for all three flours were 4. Drop test scores of both the Tiger and Silver Queen remained at a poor score of 4 over the range of ascorbic acid concentrations tested. Lelie drop test score was unaffected by 50 ppm ascorbic acid. One hundred ppm lead to a slight improvement of this score, which then remained the same at an increased ascorbic acid concentration of 150 ppm.

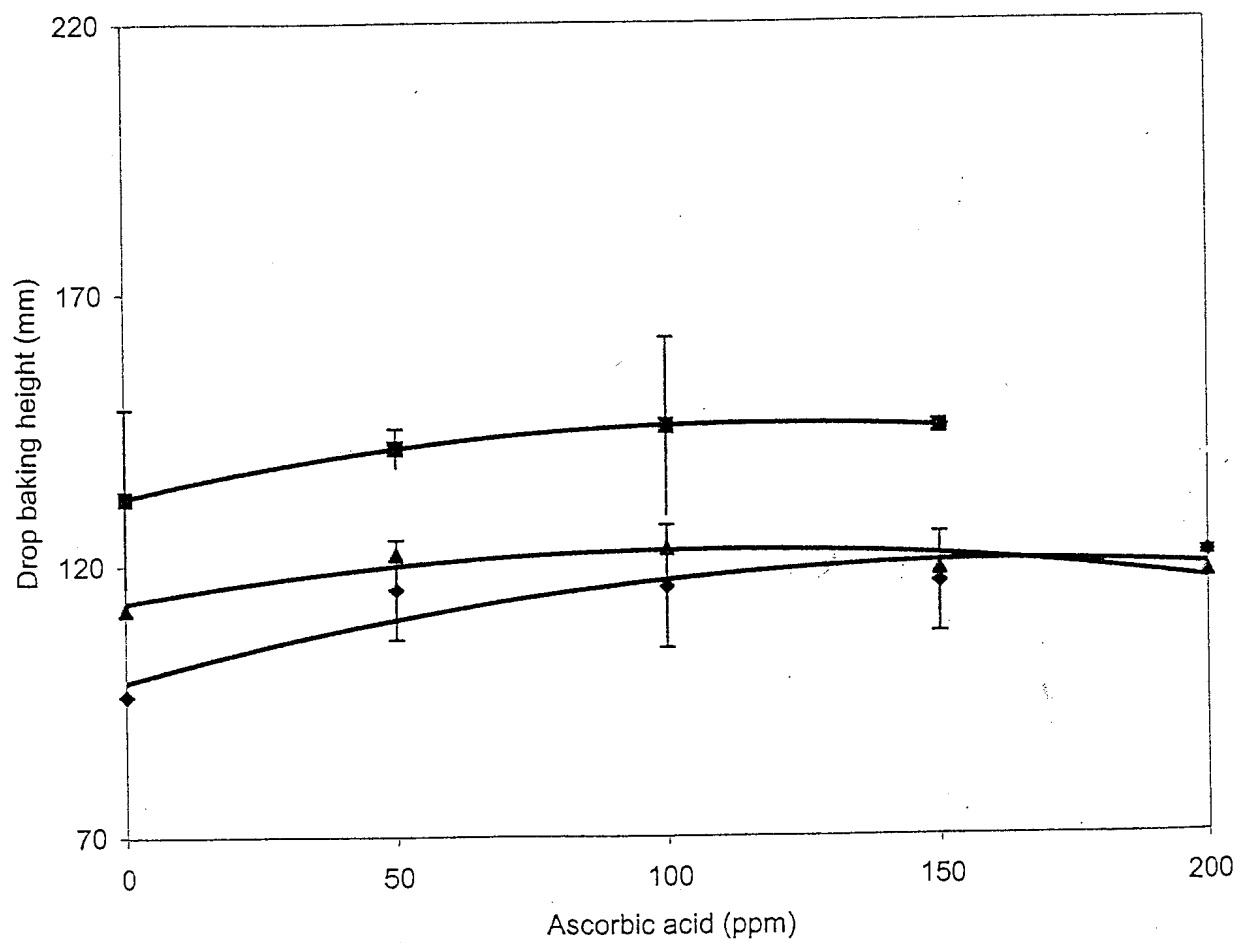


Fig. 19 Effect of ascorbic acid concentration on drop baking heights of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

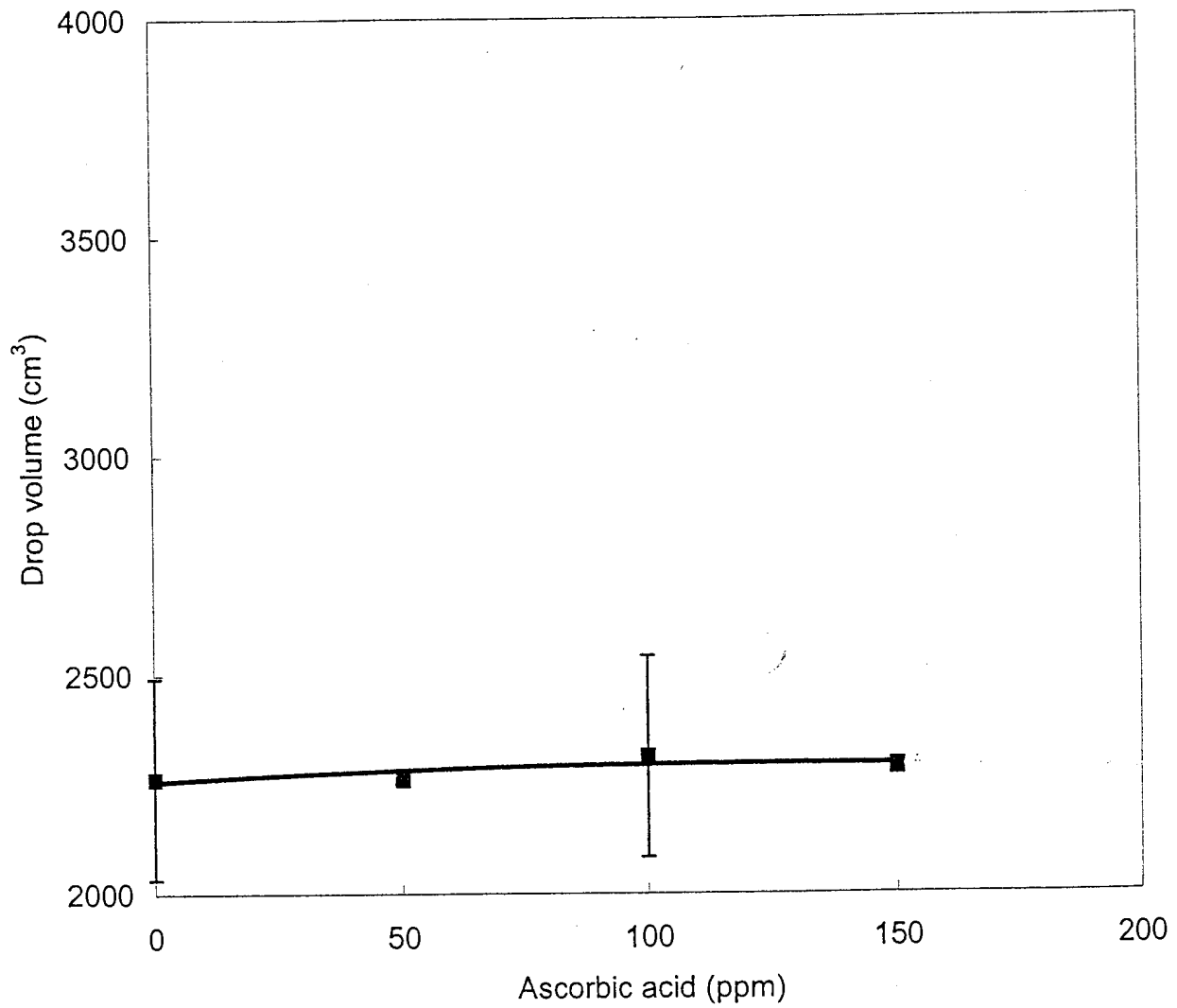
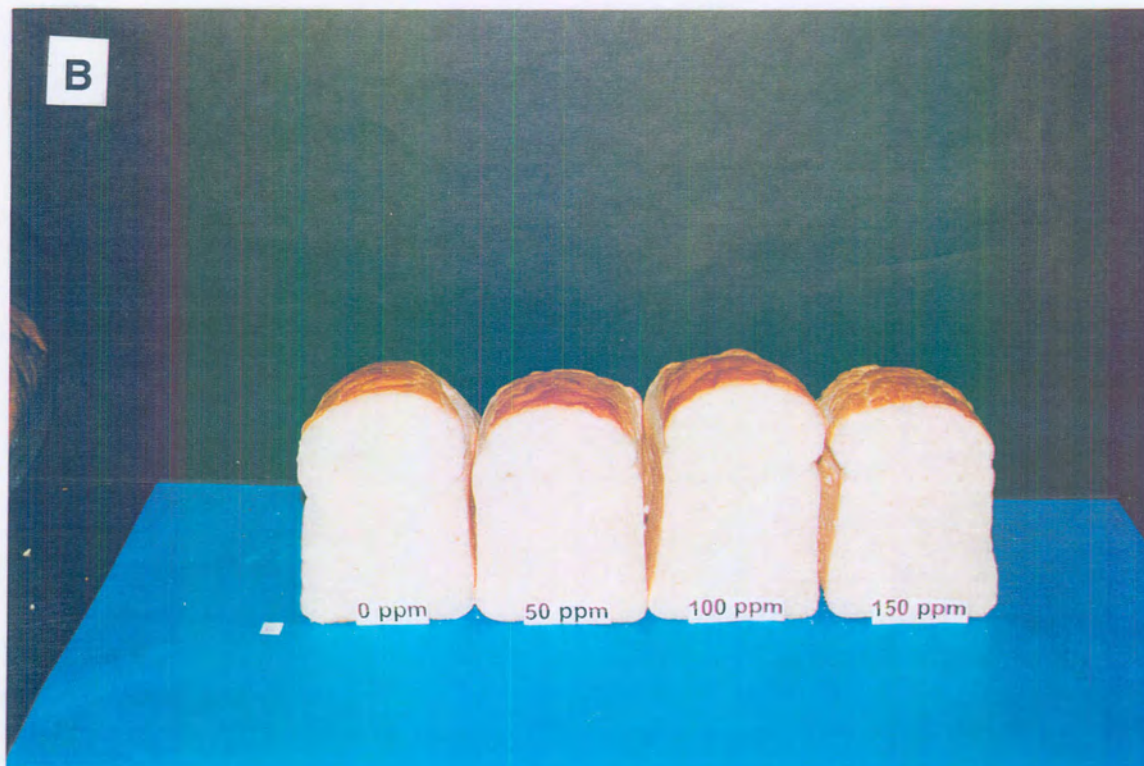
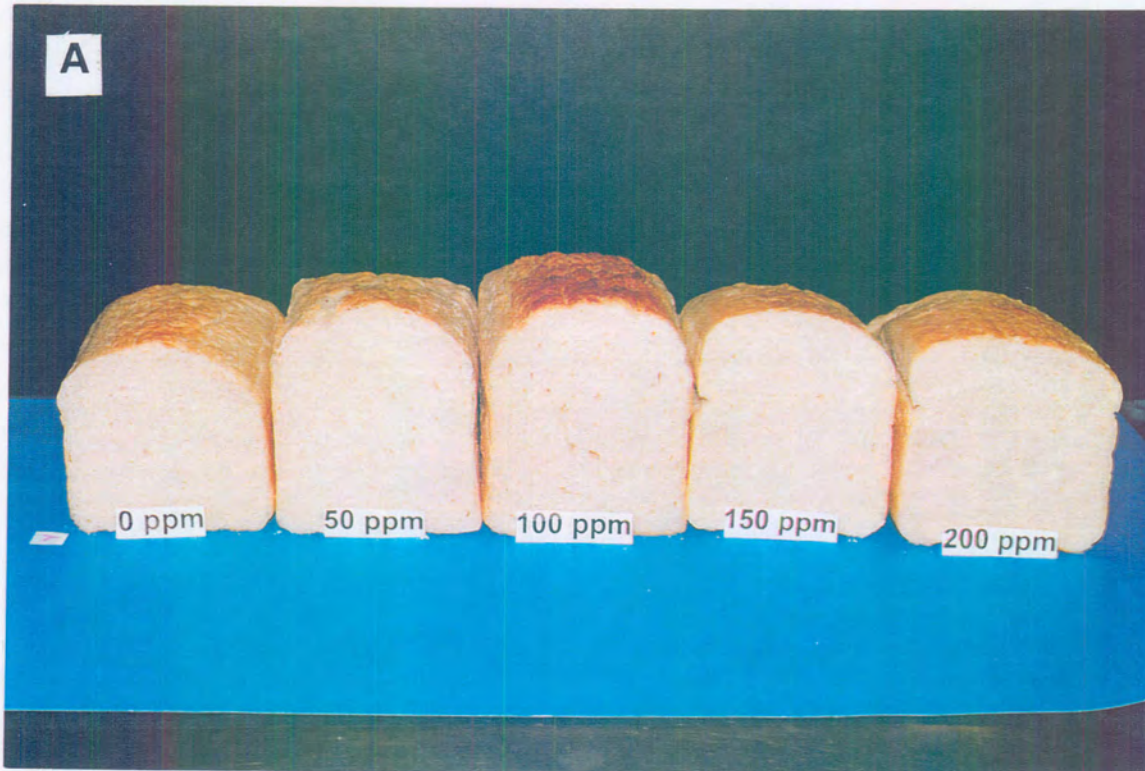


Fig. 20 Effect of ascorbic acid concentration on drop volumes of breads made Lelie (■)



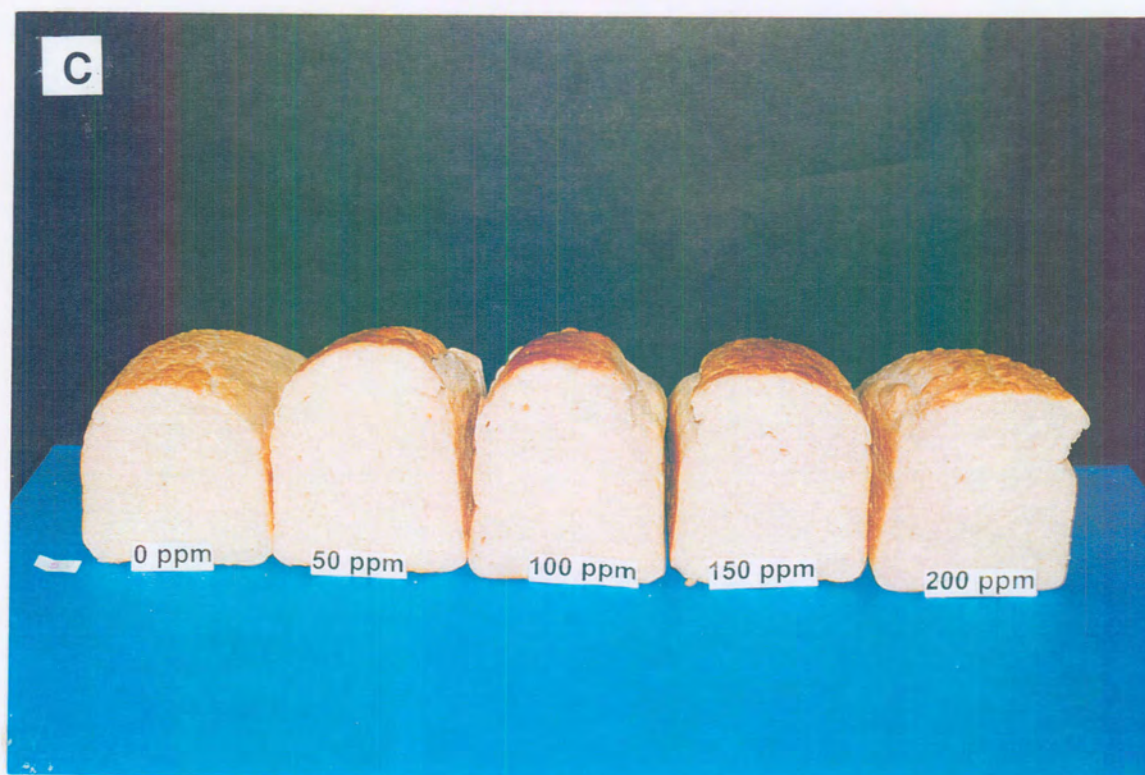


Fig. 21 Effect of ascorbic acid concentration on drop volumes of Tiger (A), Lelie (B) and Silver Queen (C)

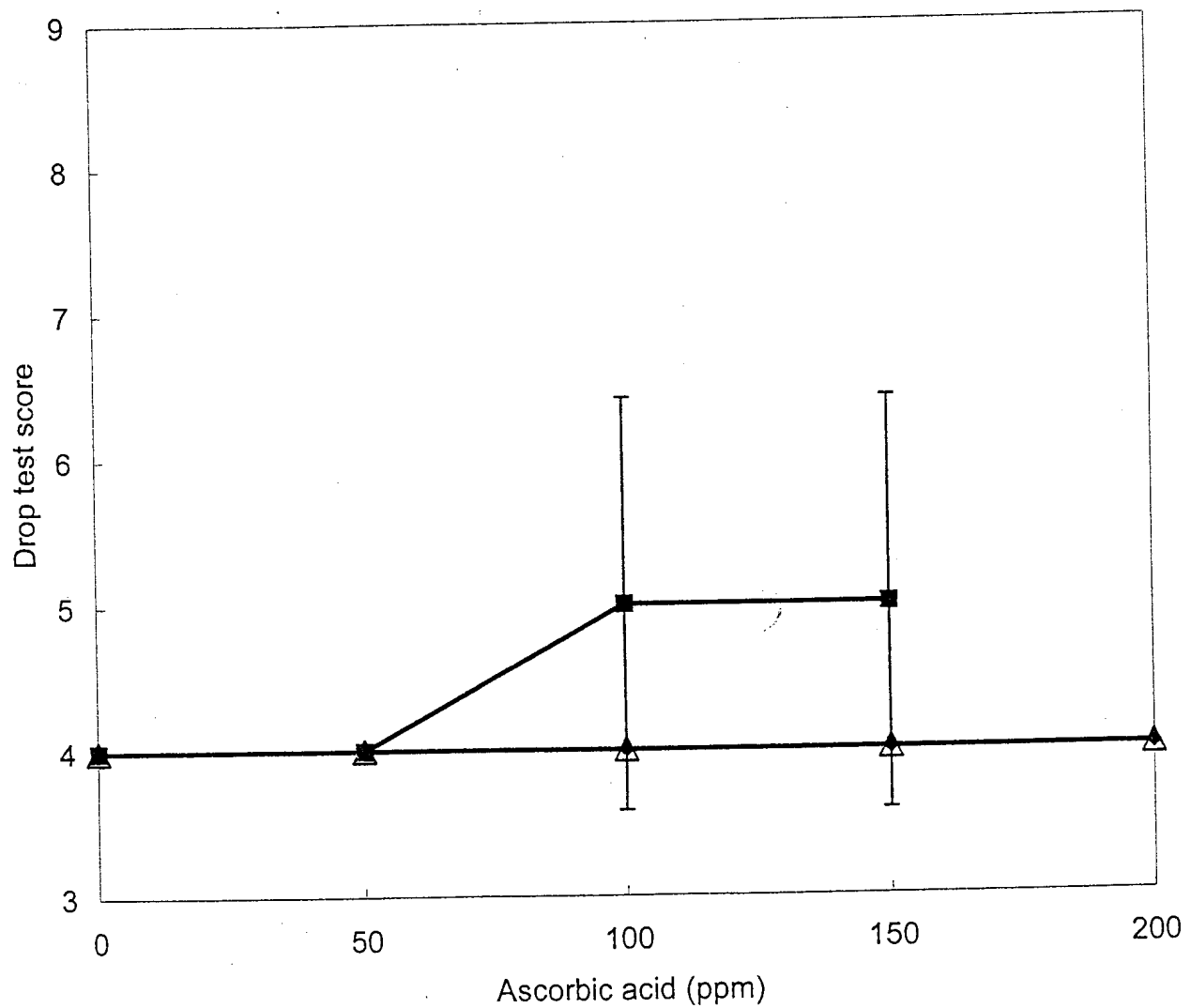


Fig. 22 Effect of ascorbic acid concentration on drop test scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

4.1.8 Symmetry Score

Fig. 23 shows the relationship between ascorbic acid concentration and scores assigned to symmetry of the breads, how well they maintain the required shape. Without ascorbic acid, Loaf surfaces of Tiger without ascorbic acid were uneven and caved in at the centre and were assigned symmetry score 3. Silver Queen loaves without ascorbic acid had sloping corners and were assigned a symmetry score of 4. Additions of ascorbic acid at concentration from 50 to 200 ppm improved the symmetry of Silver Queen and Tiger to a good score of 5. Lelie had the required shape and its score for symmetry remained at a good score of 5 without ascorbic acid and at ascorbic acid concentrations of 50 to 100 ppm. Concentrations of 150 ppm ascorbic acid lowered the score to 4 because the volumes were so large that the bread was distorted and lacked the required shape. Fig. 24 shows the symmetry of the breads.

4.1.9 Crumb Texture Score

Fig. 25 shows the relationship between ascorbic acid concentration and scores assigned to the texture of breads made from the three flours. Without ascorbic acid, crumb texture scores of all three flours were "open" and assigned symmetry scores of 7. Addition of ascorbic acid to Lelie, at concentrations of 50 to 150 ppm improved the crumb texture to a finer although uneven one with a score of 9. Crumb texture scores of Tiger and Silver Queen remained at 7, except for Tiger's crumb texture which only improved at ascorbic acid concentration of 200 ppm.

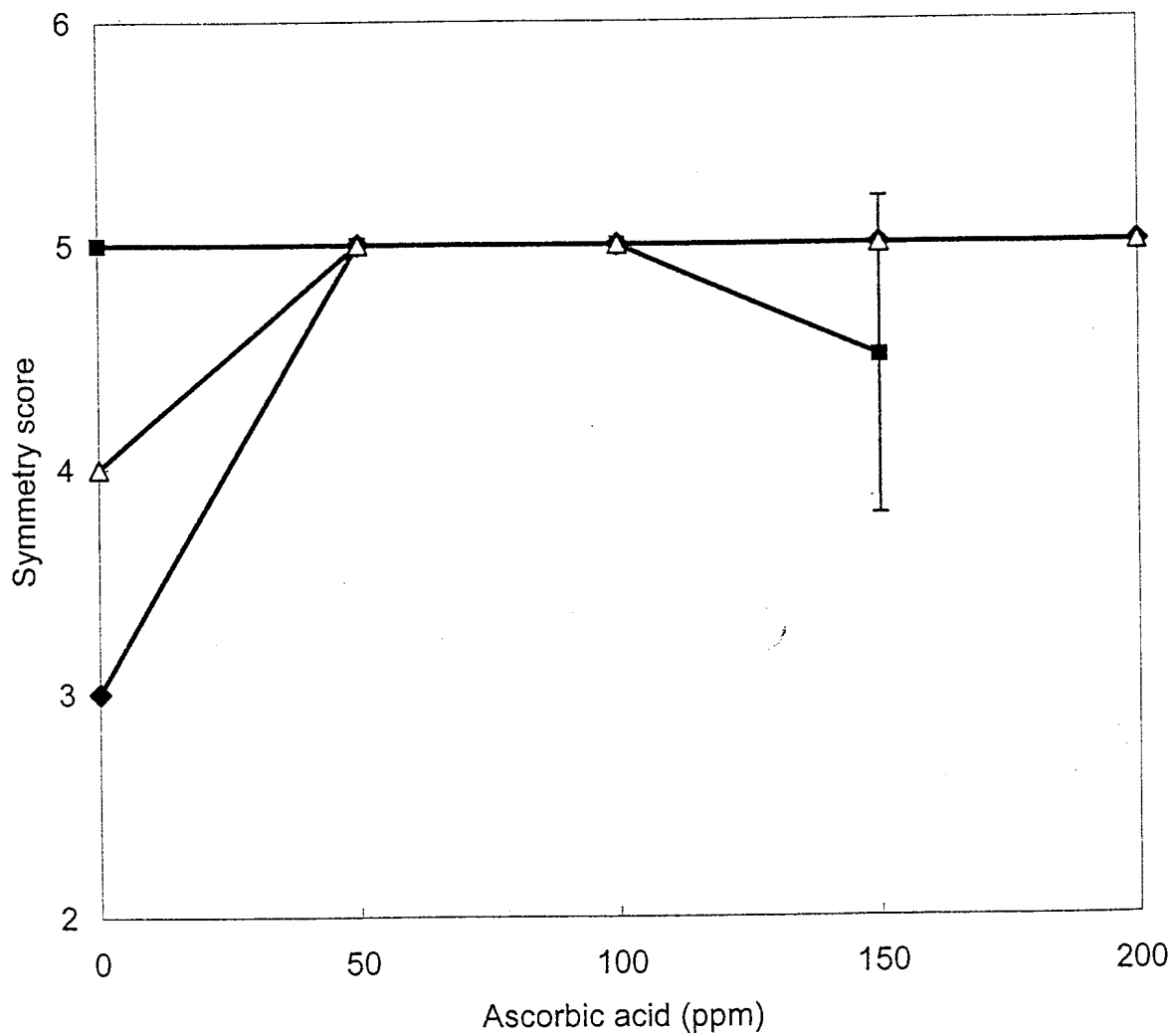
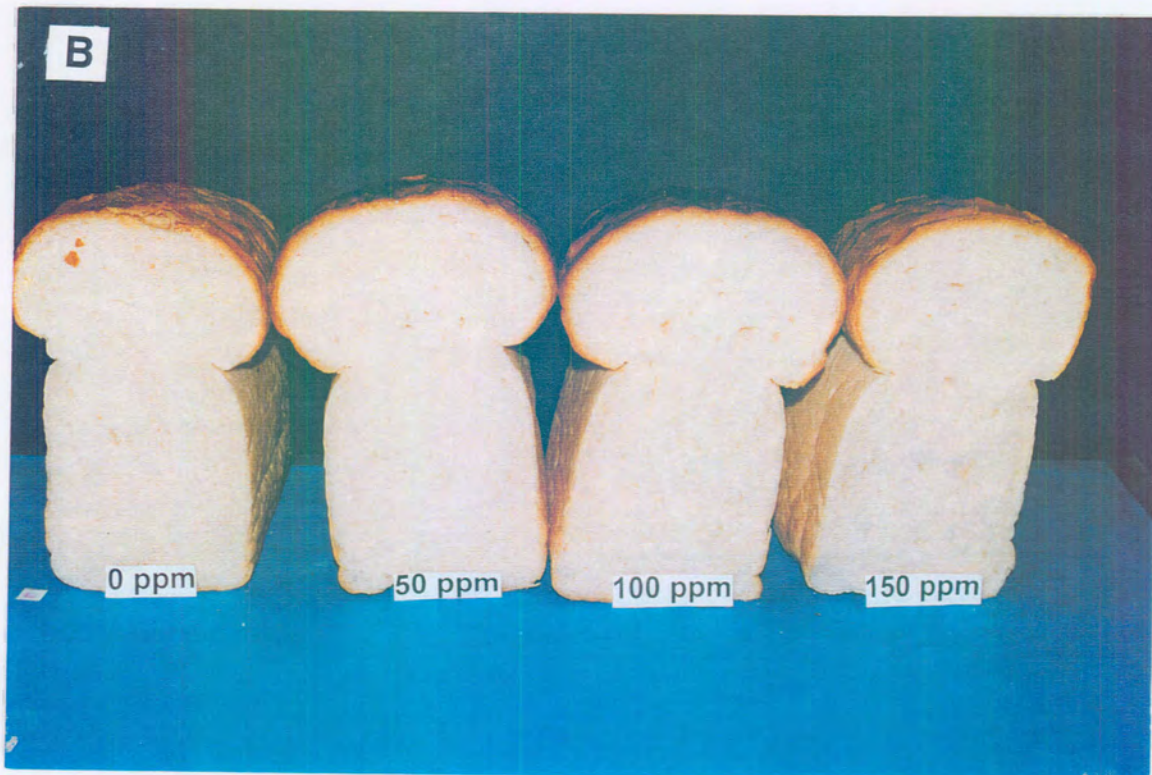
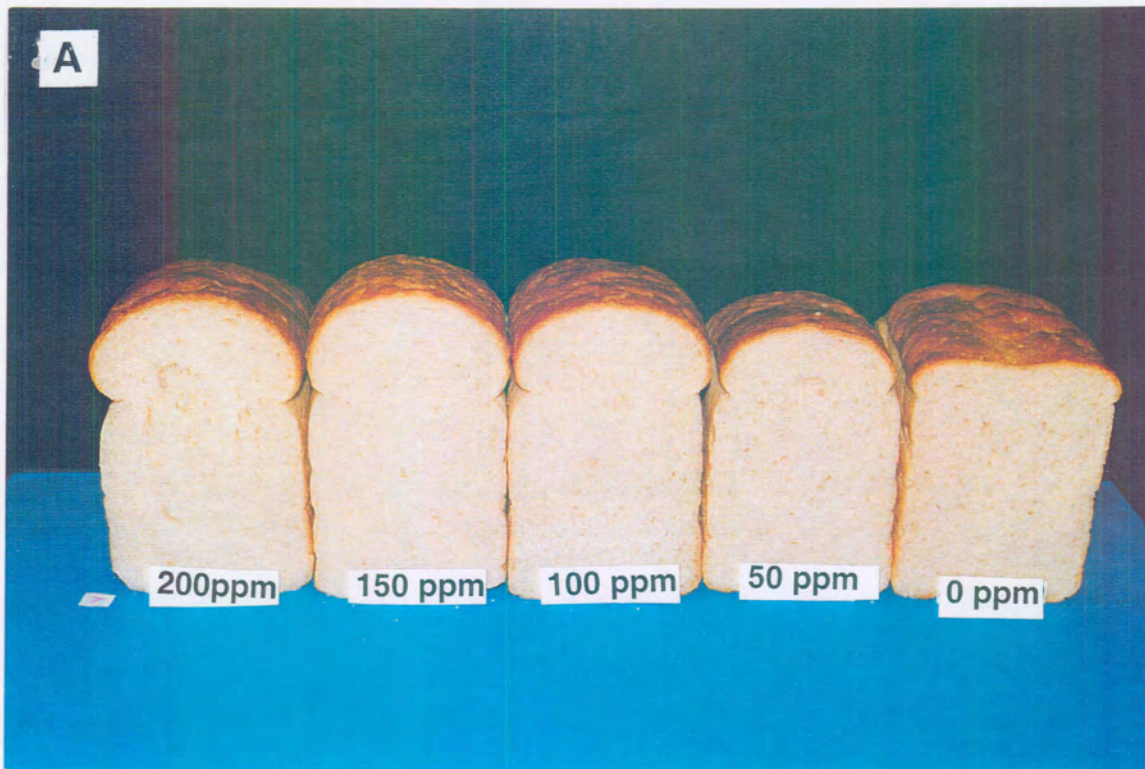


Fig. 23 Effect of ascorbic acid concentration on symmetry scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)



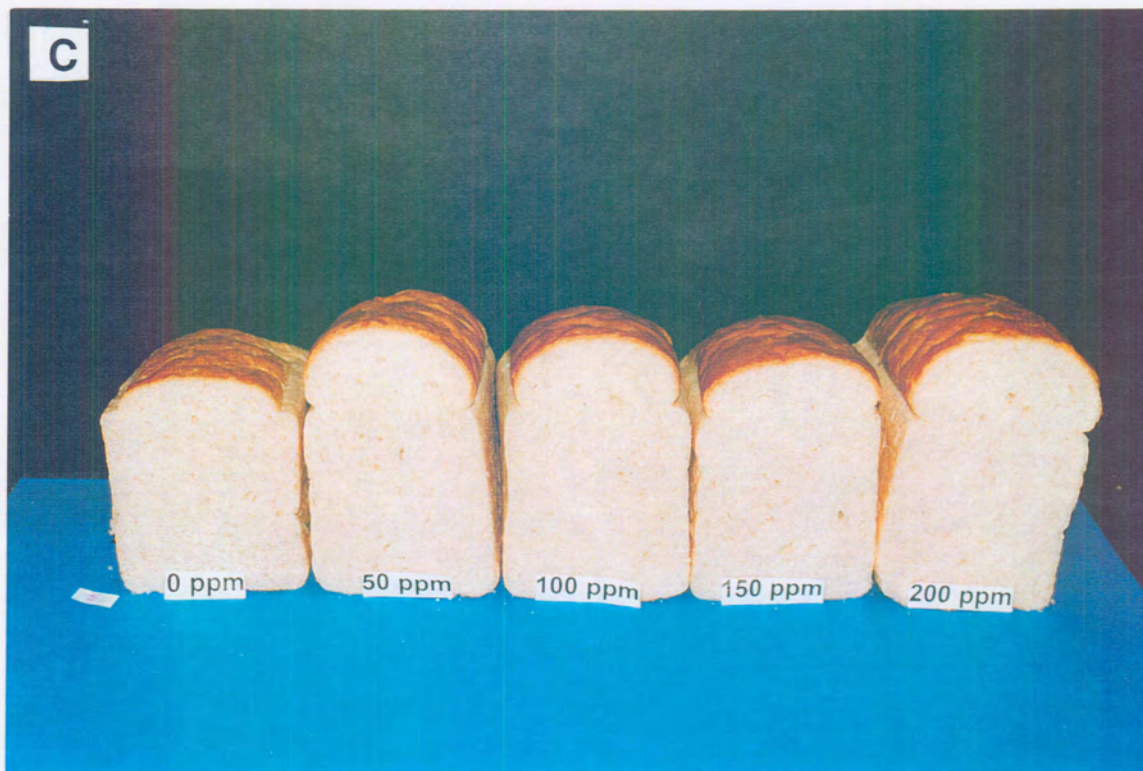


Fig. 24 Effect of ascorbic acid concentration on symmetry of Tiger (A), Lelie (B) and Silver Queen (C)

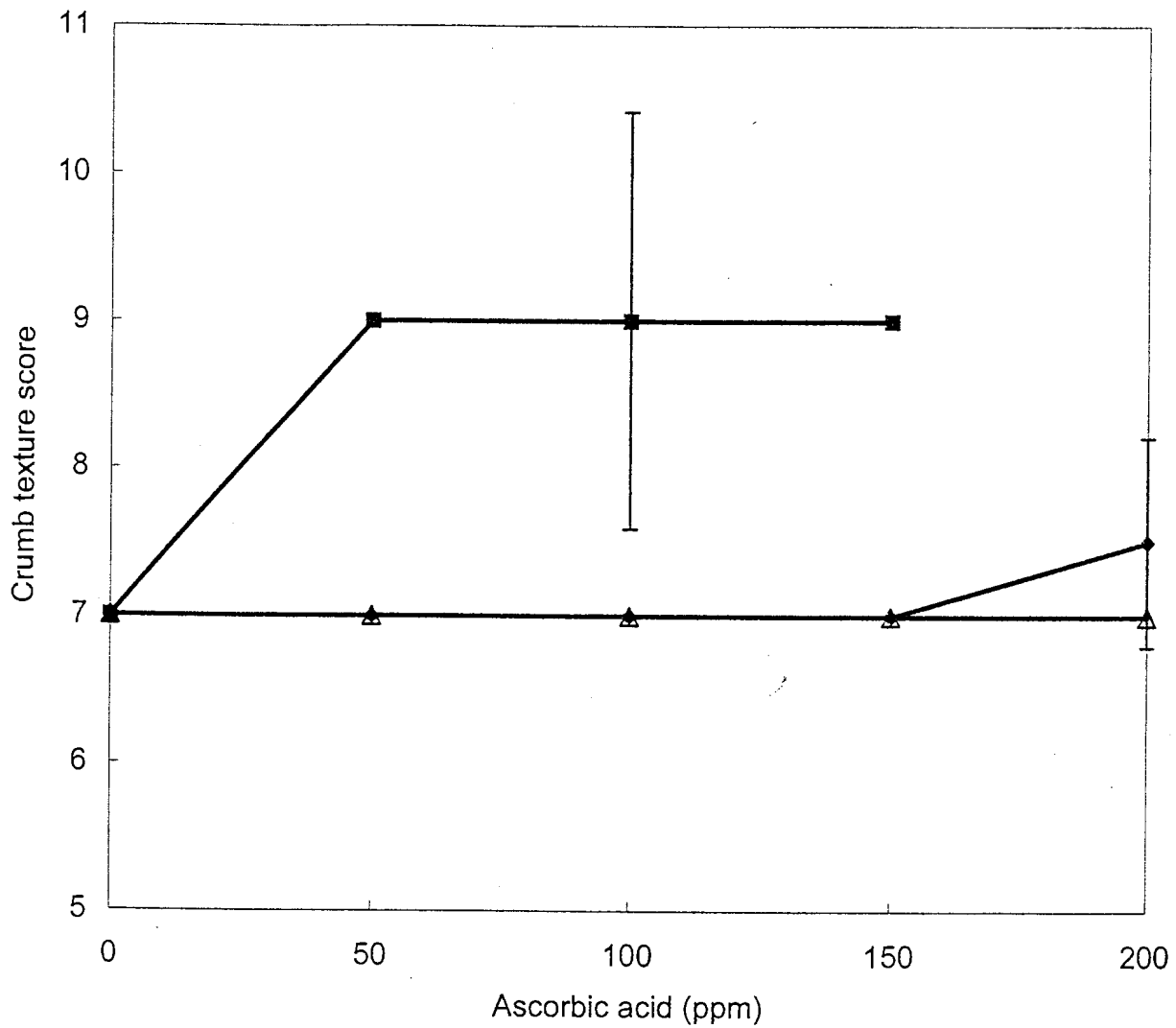


Fig. 25 Effect of ascorbic acid concentration on crumb texture scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

4.1.10 Crumb Colour Score

Fig. 26 shows the relationship between ascorbic acid concentration and crumb colour of breads made from the three flours. Without ascorbic acid, crumb colour scores of Tiger, Lelie and Silver Queen were 5, 10, and 6, respectively. Lelie was not affected by ascorbic acid and its score of 10 was an indication of its excellent crumb colour. Ascorbic acid had no effect on the Silver Queen either and its score remained at a score of 6 (slightly creamy colour). Tiger improved only with addition of 50 ppm ascorbic acid from a greyish colour with a score of 5 to a dull and creamy colour with a score 6 at 50 ppm and then remained at 6.

4.1.11 Crumb Softness Score

Fig. 27 shows the relationship between ascorbic acid concentration and scores assigned to the crumb softness of breads made with the three flours. Without ascorbic acid, softness scores of Tiger, Lelie and Silver Queen were 5, 10, and 5, respectively. Ascorbic acid had no effect on the softness scores of Lelie, which was very soft. Its softness score remained at an excellent value of 10. Silver Queen remained slightly firm (score 5) up to ascorbic acid concentration of 150 ppm beyond which it improved to a slightly soft texture with a score of 8. A stepwise improvement took place at 50 ppm and 150 ppm for Tiger from slightly firm at 0 ppm to very soft at 200 ppm.

4.1.12 Bread Score

Fig. 28 shows the relationship between ascorbic acid concentration and bread scores of breads made with the three flours. Without ascorbic acid bread scores of Tiger, Lelie and Silver Queen were 66, 77 and 63, respectively. Tiger bread score increased linearly with increasing ascorbic acid concentration to approximately 81 at 200 ppm ascorbic acid. The effect of ascorbic acid on Silver Queen was statistically insignificant, with its bread score remaining at approximately 63 over the range of ascorbic acid concentration investigated.

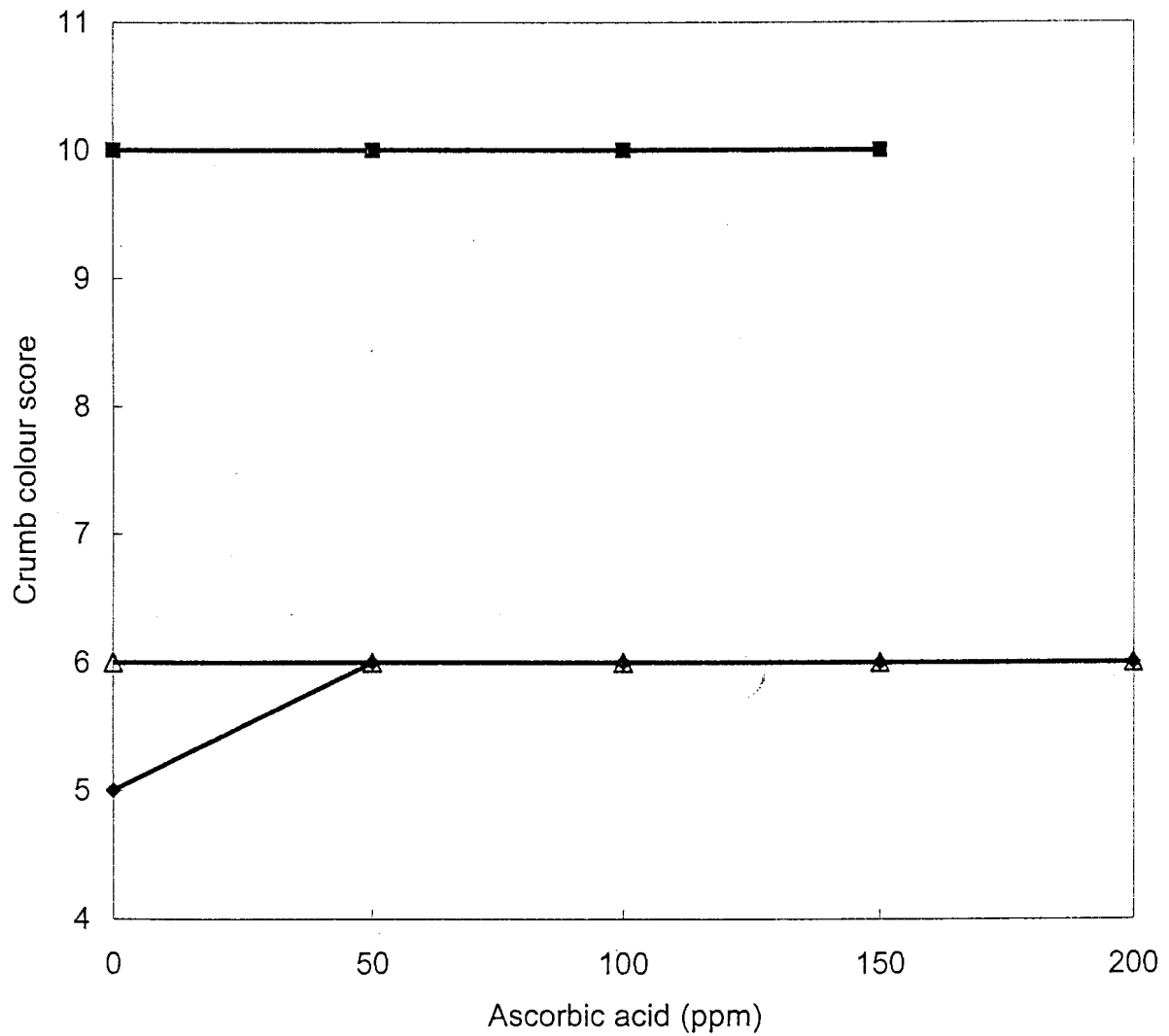


Fig. 26 Effect of ascorbic acid concentration on crumb colour scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

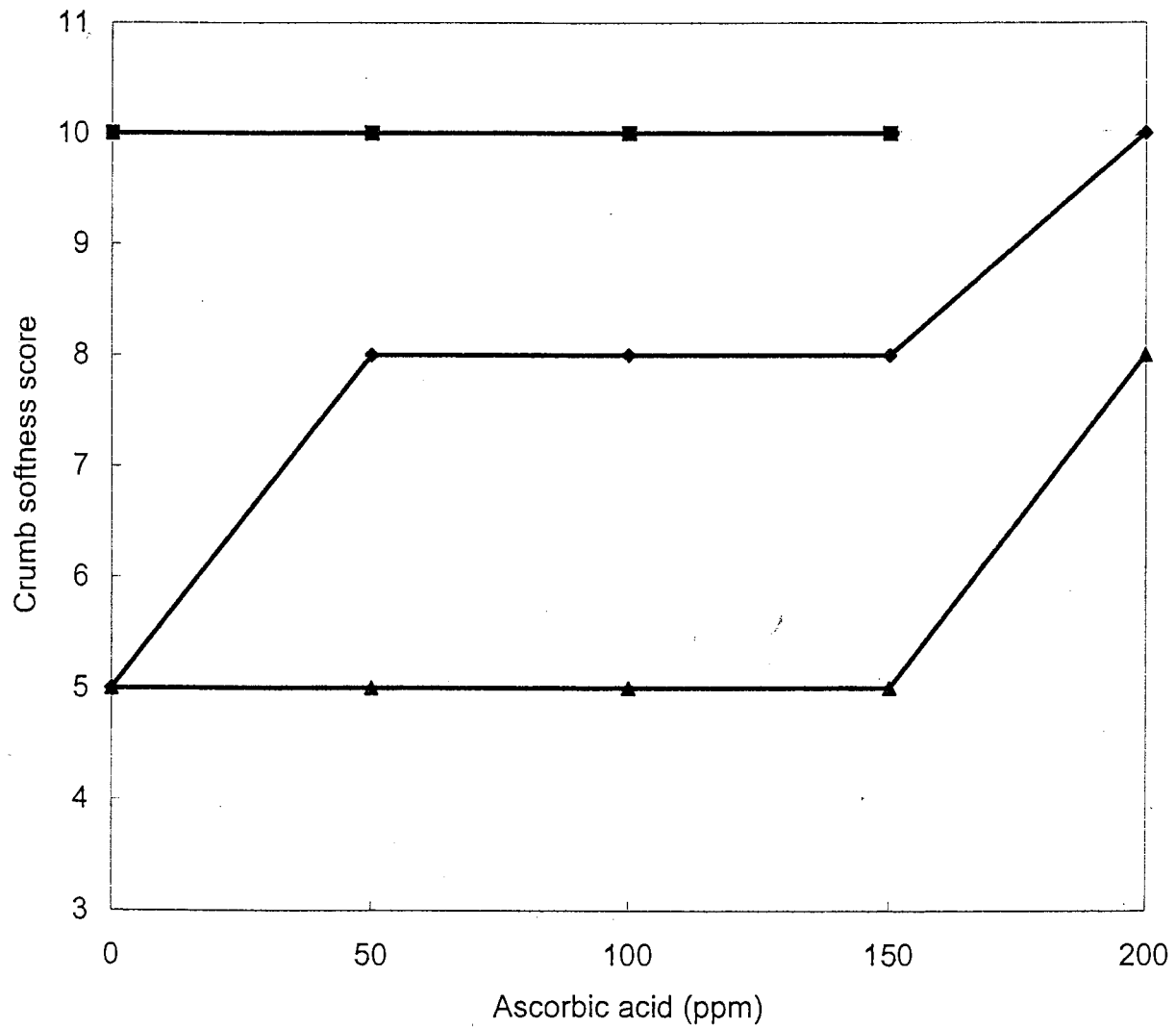


Fig. 27 Effect of ascorbic acid concentration on crumb softness scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

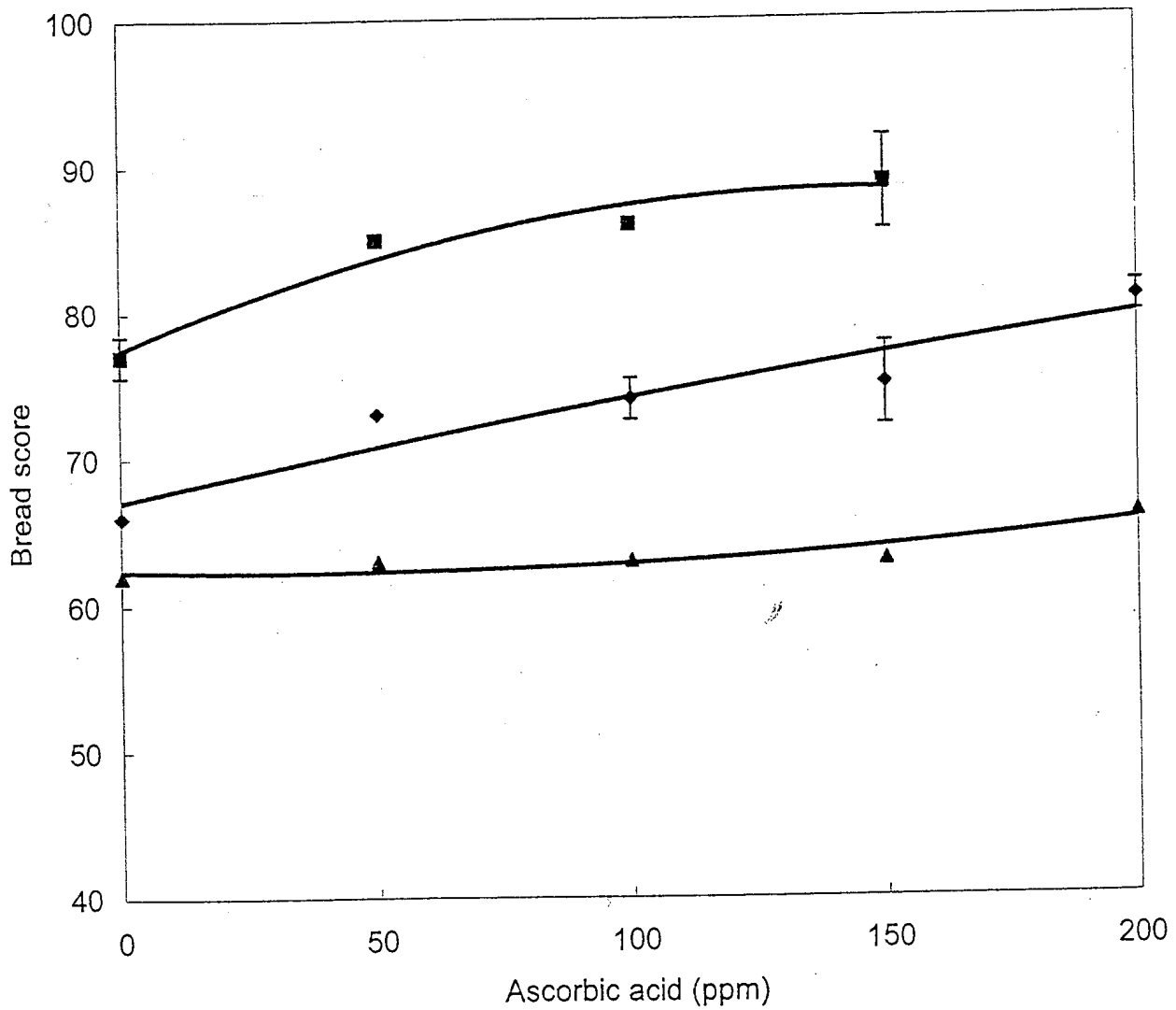


Fig. 28 Effect of ascorbic acid concentration on bread scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

Lelie had a slight increase in bread score with addition of 50 ppm ascorbic acid from approximately 77 to optimum of approximately 85. Higher ascorbic acid concentration lead to no further change.

4.2 EFFECT OF ASCORBIC ACID ON MIXOGRAPH PARAMETERS

4.2.1 Mixograph Peak Time

Fig. 29 shows the relationship between ascorbic acid concentration and mixograph peak time of the three flours: Tiger, Lelie and Silver Queen. Peak times of Tiger, Lelie and Silver Queen without ascorbic acid were 2.3 min., 3.2 min., and 2.3 min., respectively. Addition and stepwise increases in concentrations of ascorbic acid lead to increases in peak times of all three flours up to optimum values. Tiger reached the longest peak time at approximately 100 ppm ascorbic acid, followed by no significant changes in peak times. Silver Queen peak times decreased after the peak at approximately 100 ppm. Lelie had an optimum peak time at approximately 150 ppm ascorbic acid.

4.2.2 Mixograph Peak Height

Fig. 30 shows the relationship between ascorbic acid concentration and mixograph peak heights. Peak heights of Tiger, Lelie and Silver Queen, without ascorbic acid were 89 mm, 103 mm and 68 mm, respectively. Ascorbic acid had no significant effect on peak heights of Tiger and Silver Queen. Lelie showed a decrease in peak heights with increasing concentrations of ascorbic acid up to approximately 100 ppm, followed by no significant change.

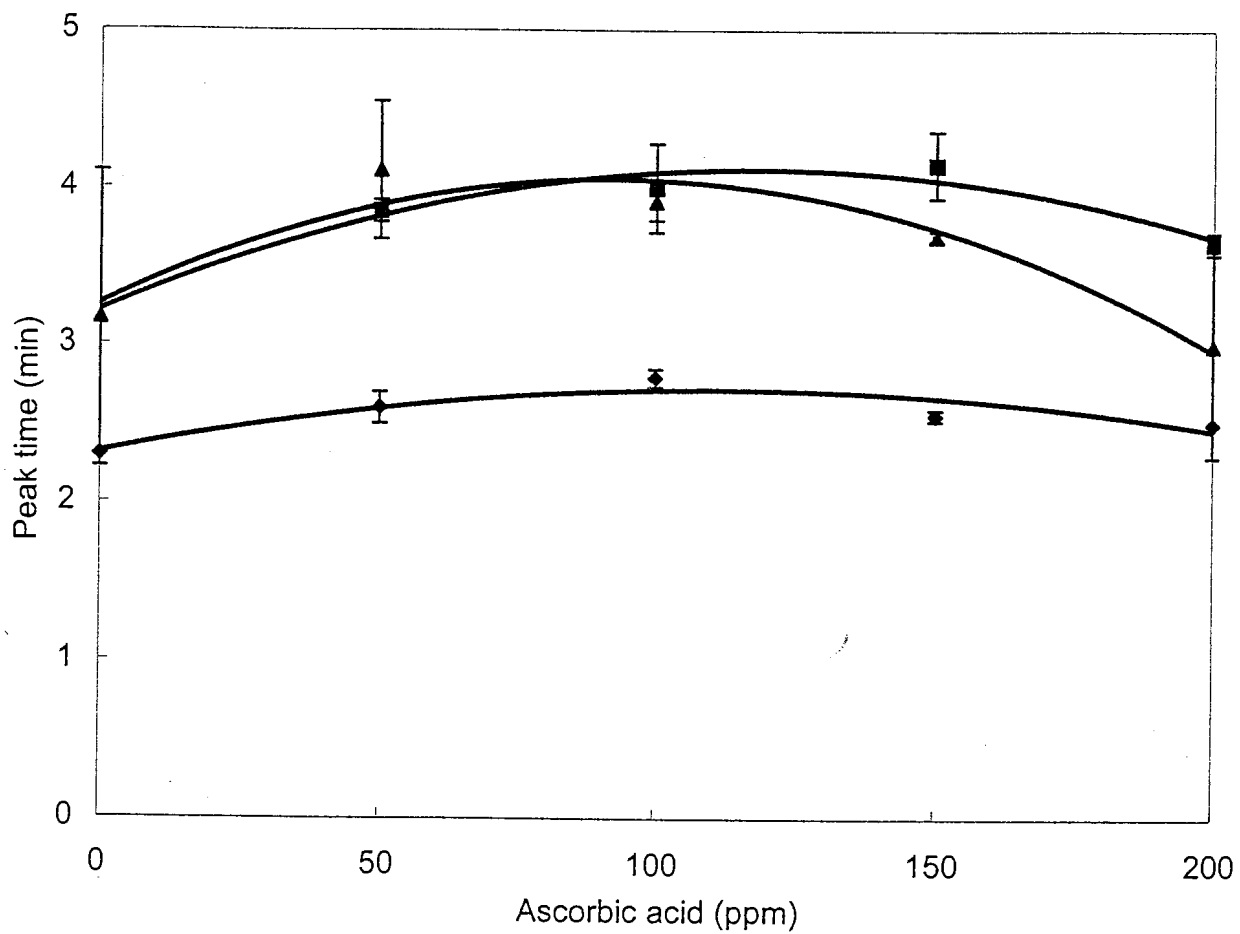


Fig. 29 Effect of ascorbic acid concentration on mixograph peak times of three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

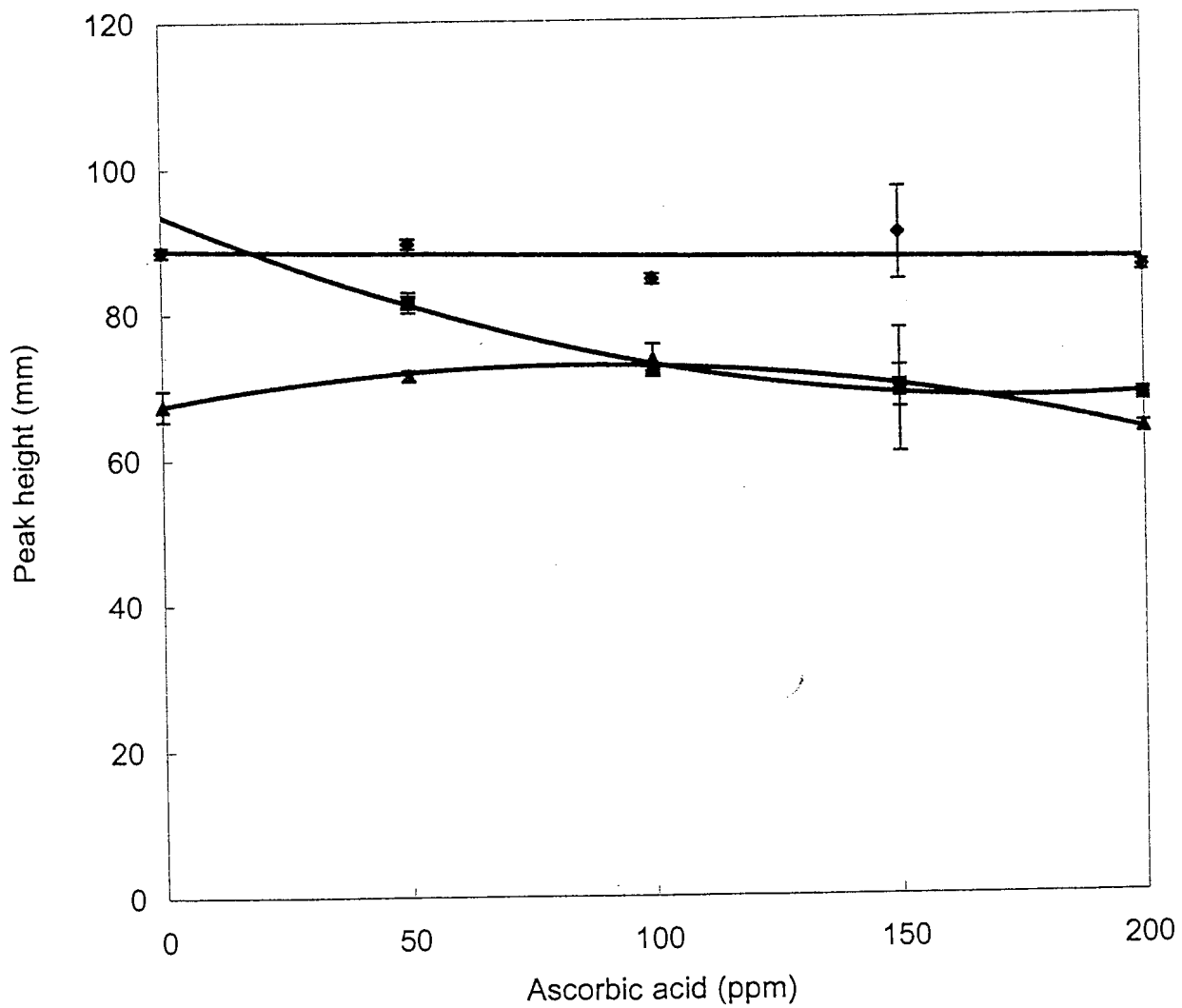


Fig. 30 Effect of ascorbic acid concentration on mixograph peak heights of three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.3 EFFECT OF ASCORBIC ACID ON STRESS RELAXATION TEST

Fig. 31 shows the relationship between ascorbic acid concentration and relaxation times (RT) of the three flours. Without ascorbic acid, the RT of Tiger, Lelie and Silver Queen were 10.5 s, 34.6 s, and 17.6 s, respectively. Addition and stepwise increases in ascorbic acid concentrations caused increases in RT up to an optimum (of approximately 125 ppm for Tiger and approximately 150 for Silver Queen), followed by no significant change. Ascorbic acid had no clear effect on RT of Lelie.

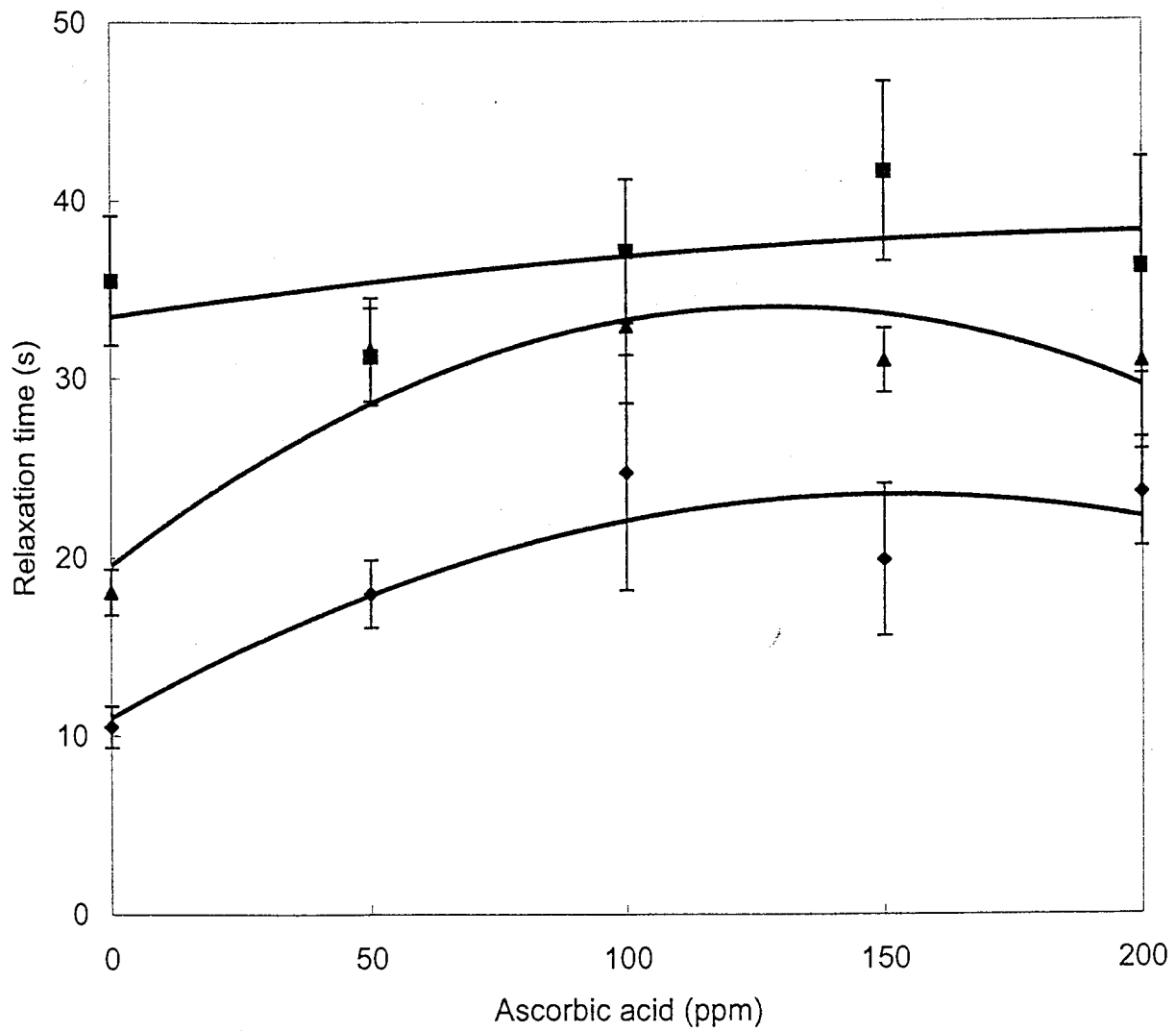


Fig. 31 Effect of ascorbic acid concentration on relaxation times of three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.4 EFFECT OF DATEM ON BAKING TEST PARAMETERS

4.4.1 Dough Development

Without DATEM Tiger was slightly sticky and formed a thin film that tore upon stretching. DATEM did not have improve dough stickiness of Tiger but at 0.3 % and higher concentrations, the dough formed a thin film that did not tear. Silver Queen was stiff and dry and tore without forming a thin film with and without DATEM. Lelie, with or without DATEM, was soft, smooth and easy to handle and formed a very thin film with little or no tearing.

4.4.2 Proof Height

Fig. 32 shows the relationship between DATEM concentration and heights of doughs after the second proofing stage. Without DATEM, proof heights of Tiger, Lelie and Silver Queen were approximately 148 mm, 177 mm, and 153 mm, respectively. There was an almost linear positive relationship between increasing DATEM concentration and proof heights of Tiger. Proof heights increased to approximately 177 mm at 0.5 % DATEM concentration. Proof heights of Lelie increased only to an optimum of approximately 191 mm at 0.3 % DATEM, followed by no statistically significant change. Proof heights of Silver Queen increased up to an optimum of approximately 180 mm at 0.4 % DATEM, followed also by a decrease.

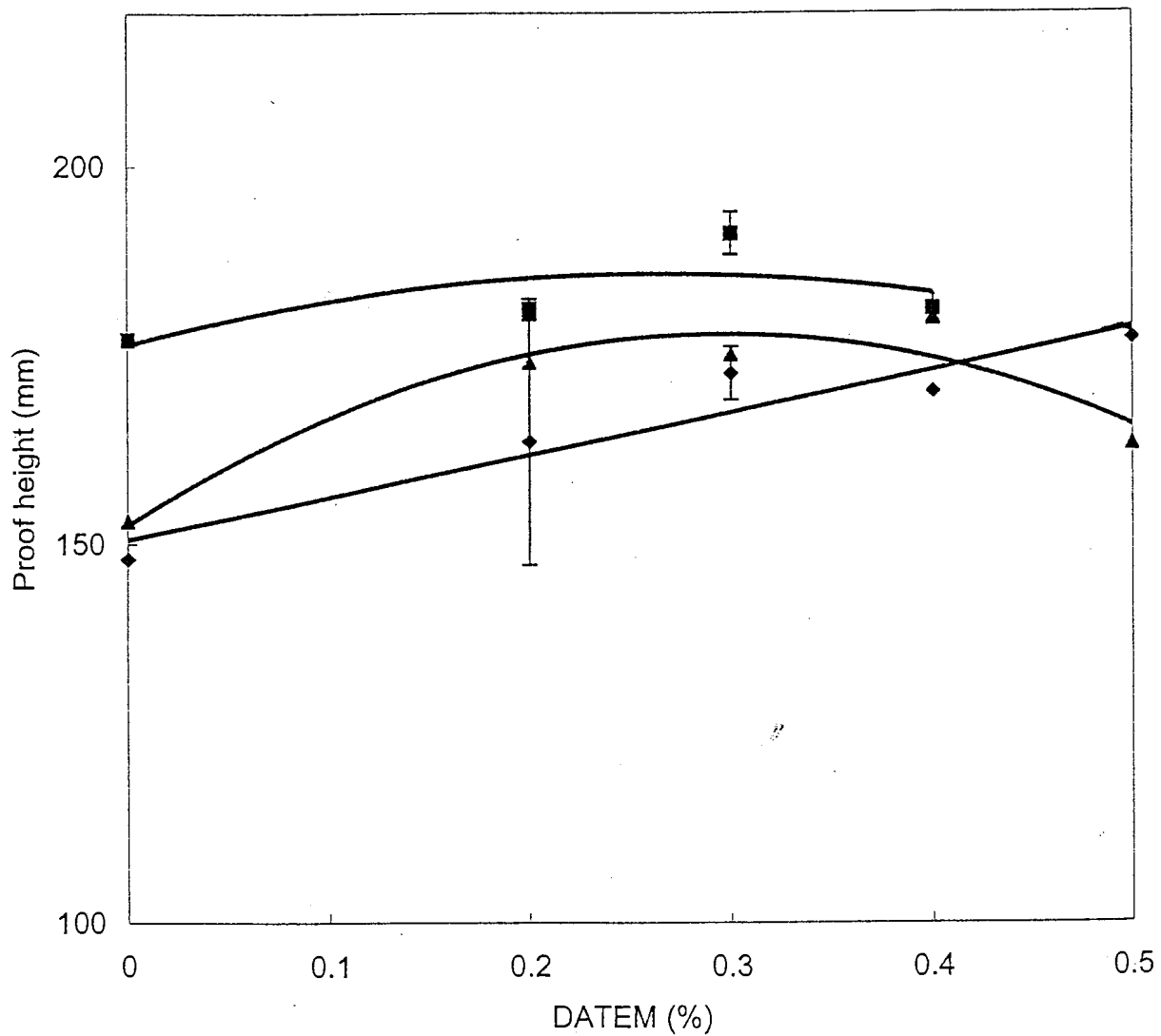


Fig. 32 Effect of DATEM concentration on proof heights of doughs made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.4.3 Baking Height

Fig. 33 shows the relationship between DATEM concentration and bread heights after the baking stage. Baking heights, without ascorbic acid, of Tiger, Lelie and Silver Queen were approximately 152 mm, 196 mm, and 129 mm, respectively. There was an increase in baking heights of all three flours as DATEM concentrations increased. The increase was slight for Lelie whose baking heights only increased to approximately 206 mm at 0.4% DATEM. Tiger baking heights increased to approximately 195 mm at 0.5 % DATEM. Silver Queen baking heights increased to approximately 196 mm at 0.5 % DATEM.

4.4.4 Loaf Volume

Fig. 34 shows the relationship between DATEM concentration and loaf volumes of breads made from the three flours. In preliminary work, it was found that even at high DATEM concentrations, loaf volumes were so low that they would have been difficult to compare because the rapeseed displacement volumeter used could not measure loaf volumes below 2100 cm³. Therefore 50 ppm ascorbic acid was added in formulations where DATEM was a variable. Without DATEM loaf volumes of Tiger, Lelie and Silver Queen were approximately 2700 cm³, 3575 cm³ and 2425 cm³, respectively. Tiger and Silver Queen loaf volumes increased linearly with increasing DATEM concentrations to excessive volumes of approximately 3700 cm³ and 3300 cm³, respectively. Effect of DATEM on Lelie loaf volumes, which were already excessive without DATEM, was not statistically significant. No baking test were performed at 0.5 % DATEM due to excessive volumes.

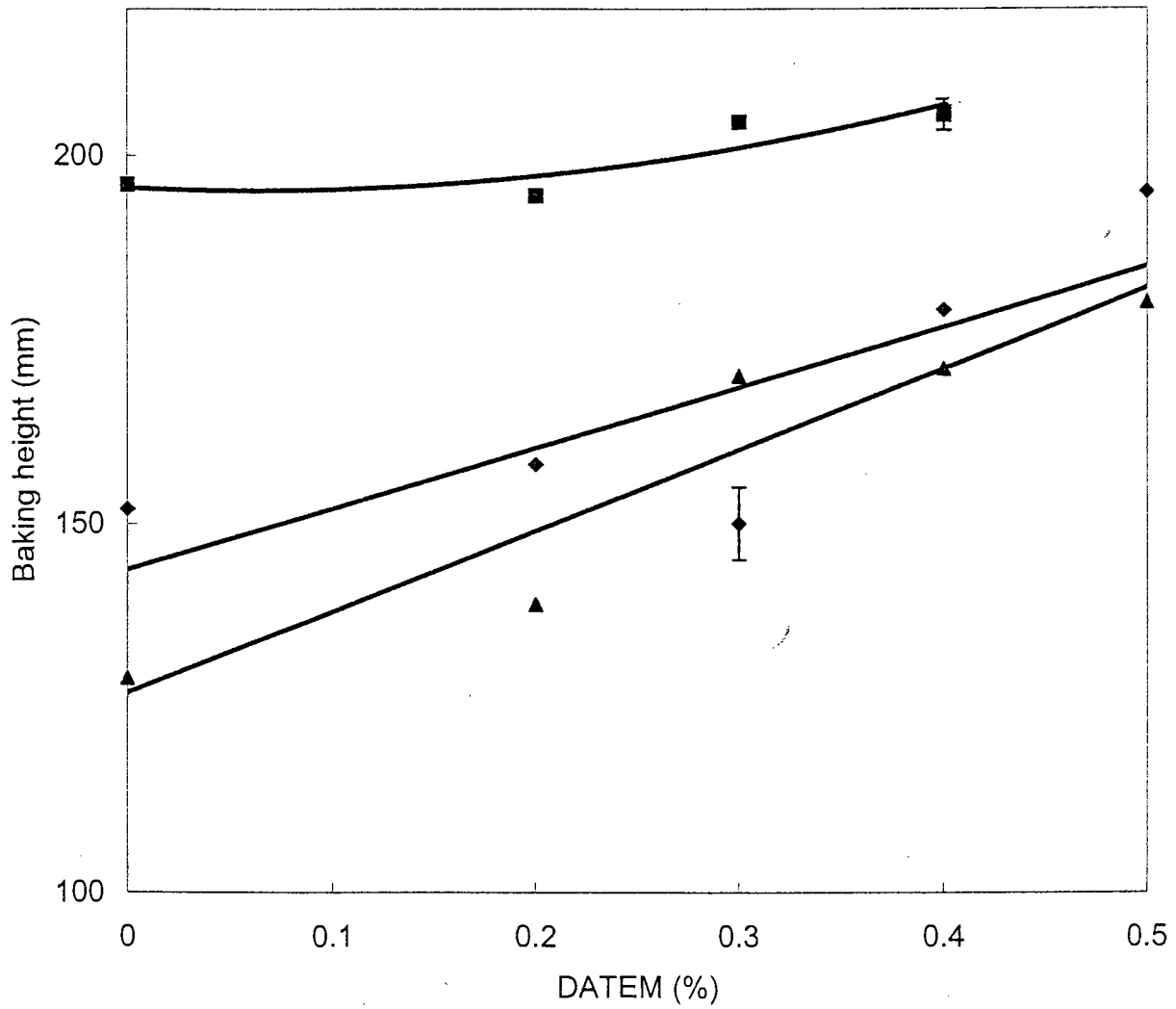


Fig. 33 Effect of DATEM concentration on baking heights of doughs made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

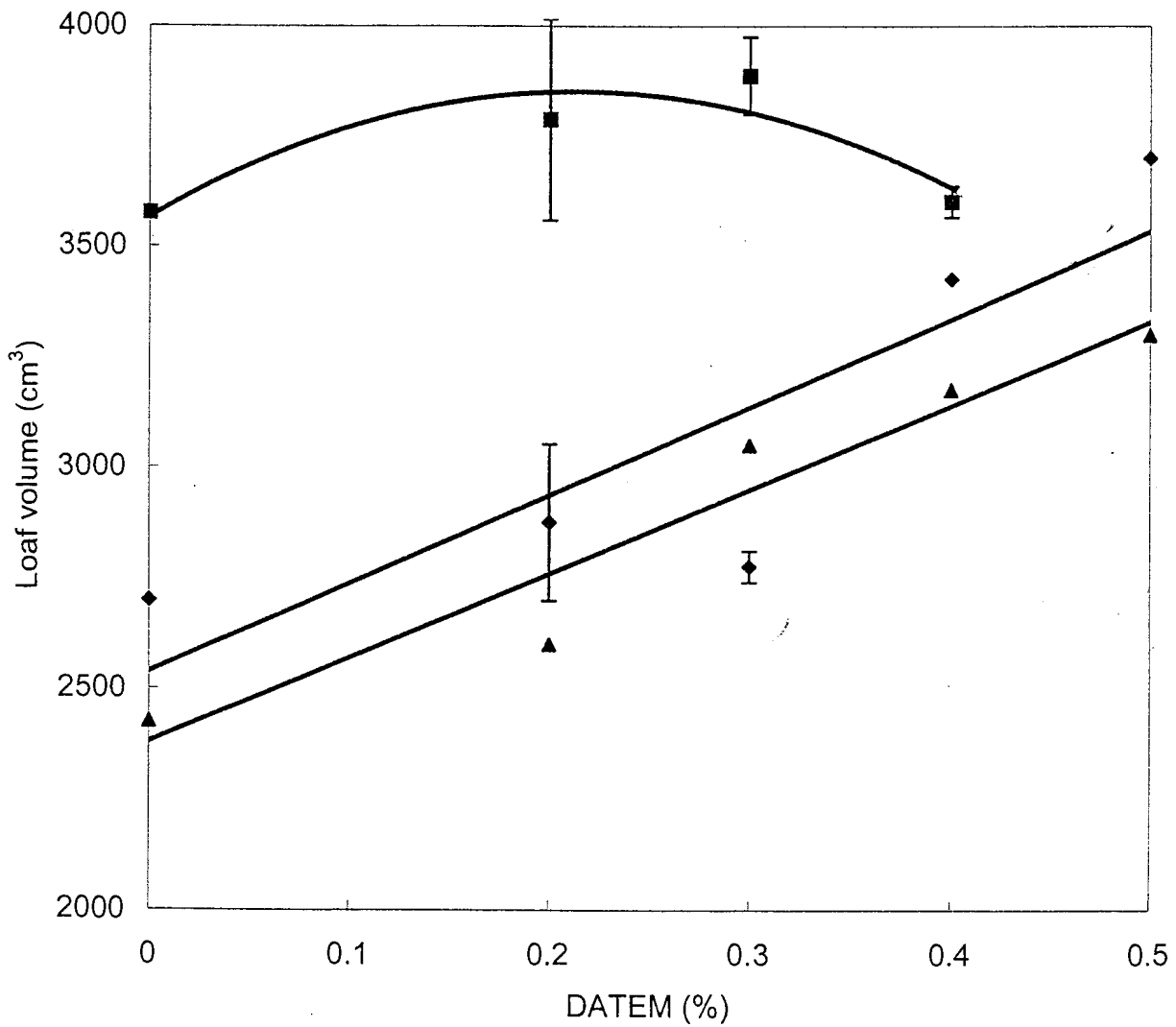


Fig. 34 Effect of DATEM concentration on loaf volumes of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.4.5 Drop Baking Height

Fig. 35 shows the relationship between DATEM concentration and heights of breads whose dough were subjected to the drop test. Drop heights of Tiger, Lelie and Silver Queen without DATEM were approximately 113 mm, 139 mm and 110 mm, respectively. Drop heights of all three flours increased with increasing DATEM concentration. This effect was most pronounced for Lelie, whose drop heights increased to approximately 204 mm. Drop heights of Tiger increased to approximately 158 mm at 0.5 % DATEM and those of Silver Queen increased to approximately 156 mm.

4.4.6 Drop Volume

Fig. 36 shows the relationship between DATEM concentration and loaf volumes of breads whose doughs were subjected to the drop test. Without DATEM drop volumes of Tiger and Silver Queen were below 2100 cm³, while drop volumes of Lelie were approximately 2325 cm³. Drop volumes of Lelie increased with increasing DATEM to approximately 2800 cm³ at 0.4 % DATEM. DATEM had no effect on Silver Queen drop volumes from 0 to 0.4 % DATEM and drop volumes only increased at DATEM concentration of 0.5 % to a volume of approximately 2650 cm³. The increase to drop volumes of approximately 2900 cm³ was observed at 0.4 % DATEM for Tiger, followed by no further significant increase. Fig. 37 shows bread loaves whose doughs were subjected to the drop test.

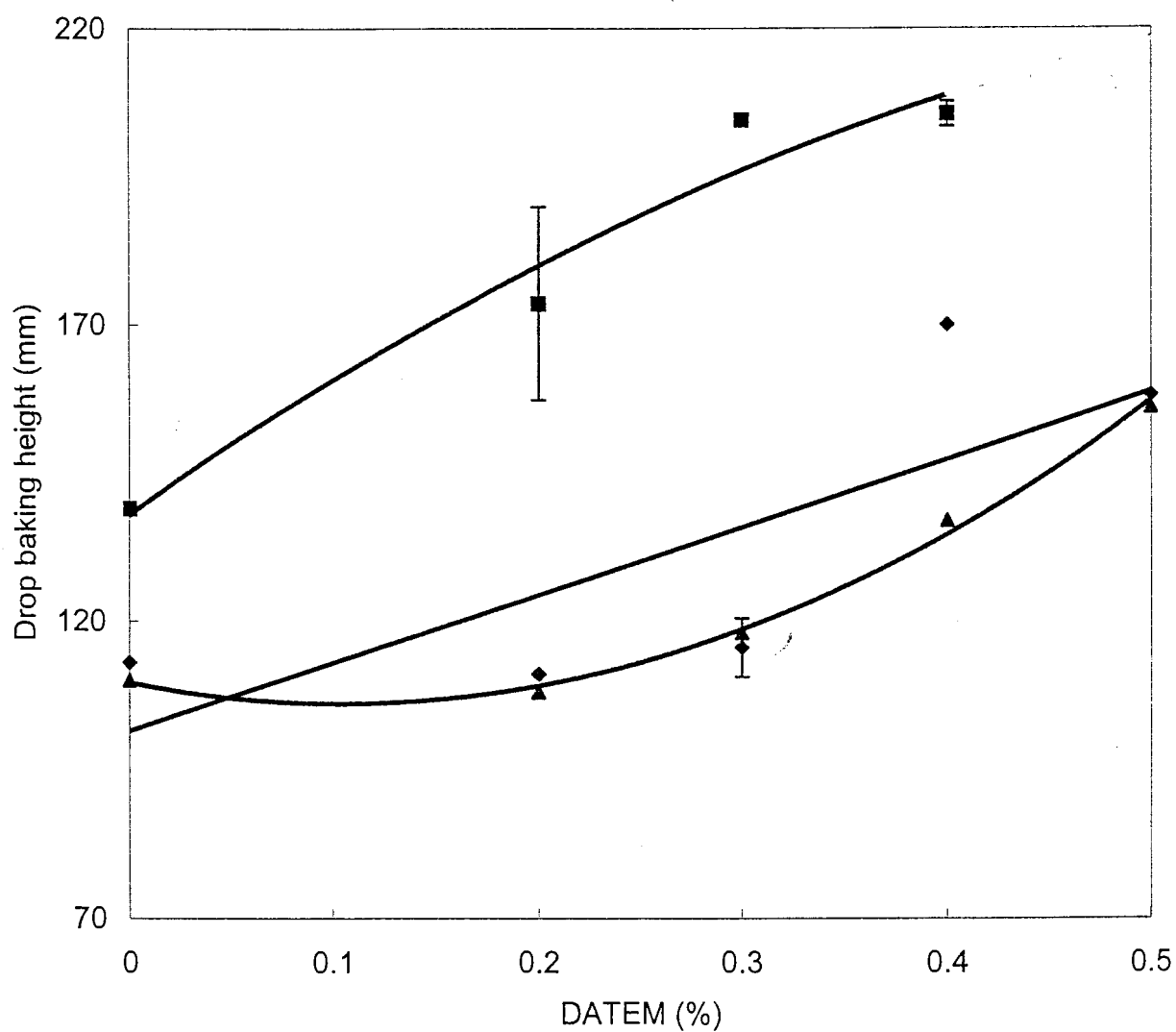


Fig. 35 Effect of DATEM concentration on drop baking heights of doughs made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

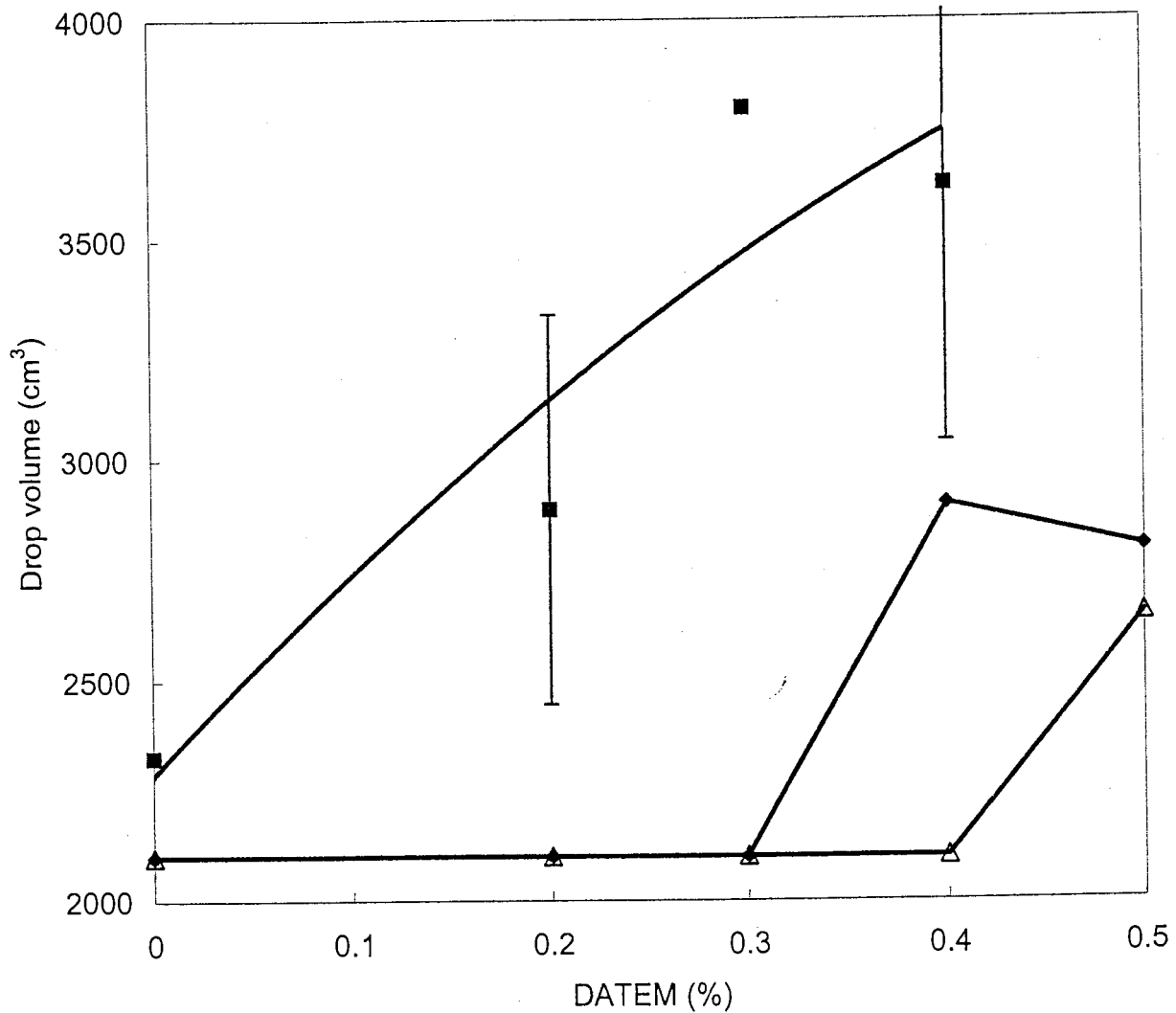
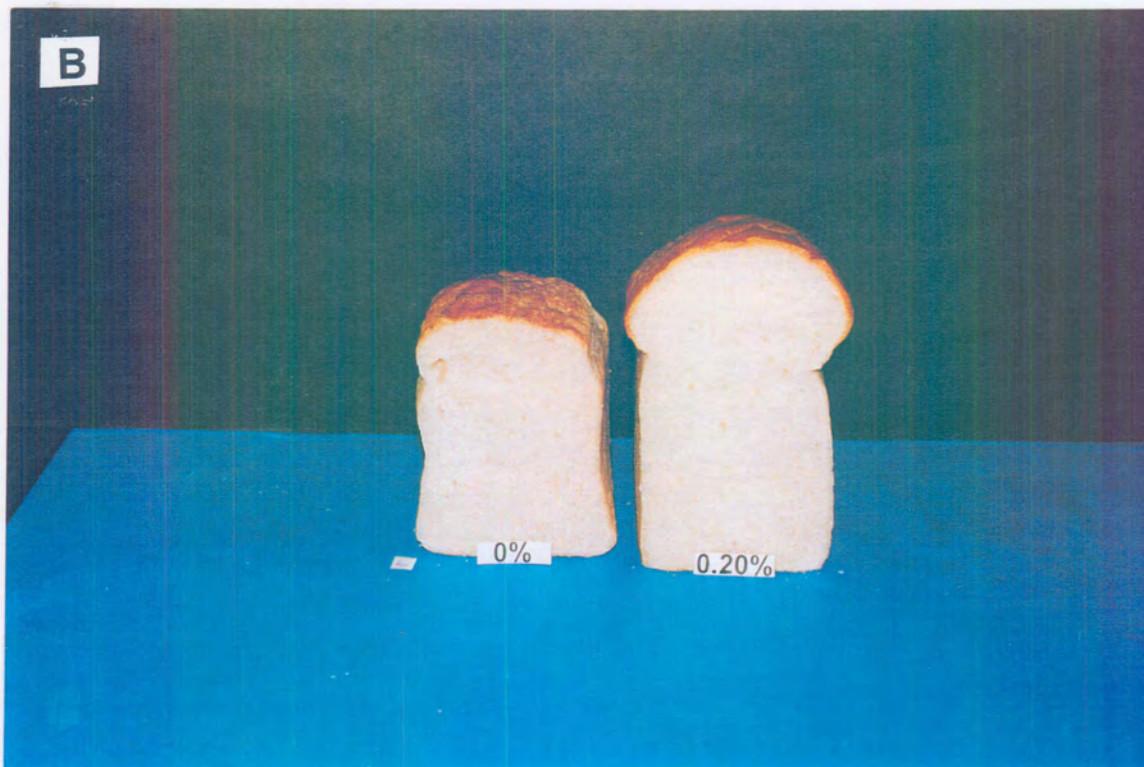
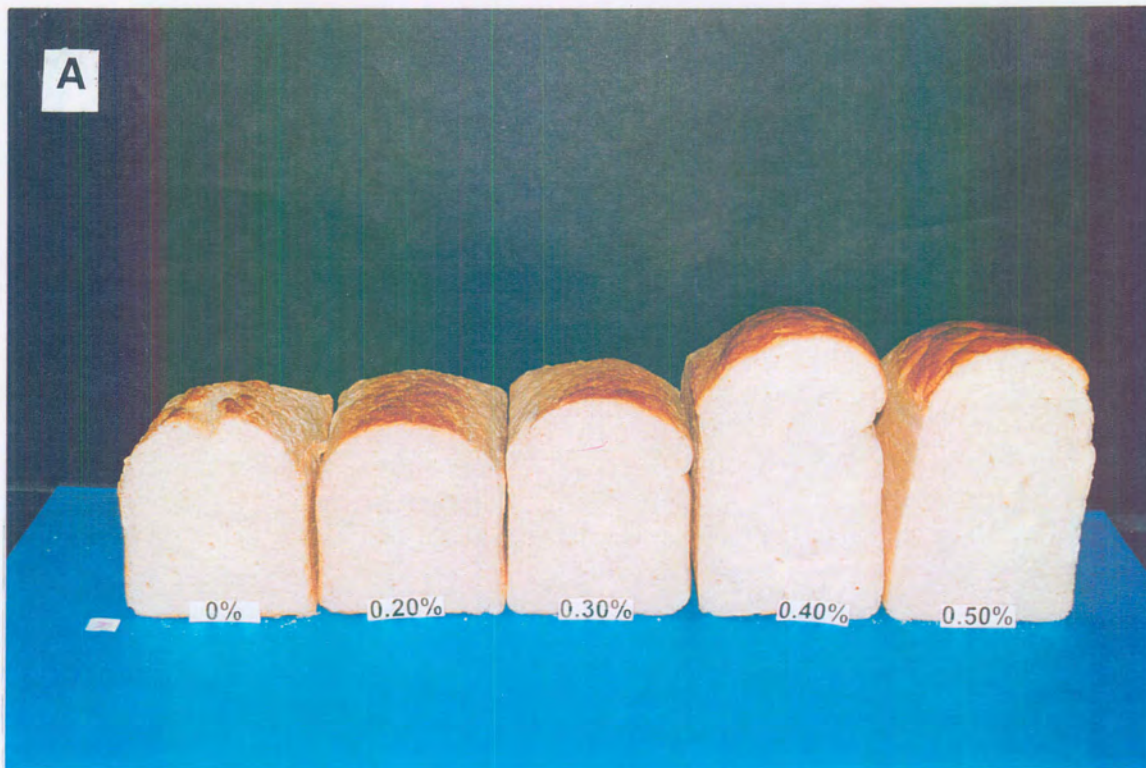


Fig. 36 Effect of DATEM concentration on drop volumes breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (△)



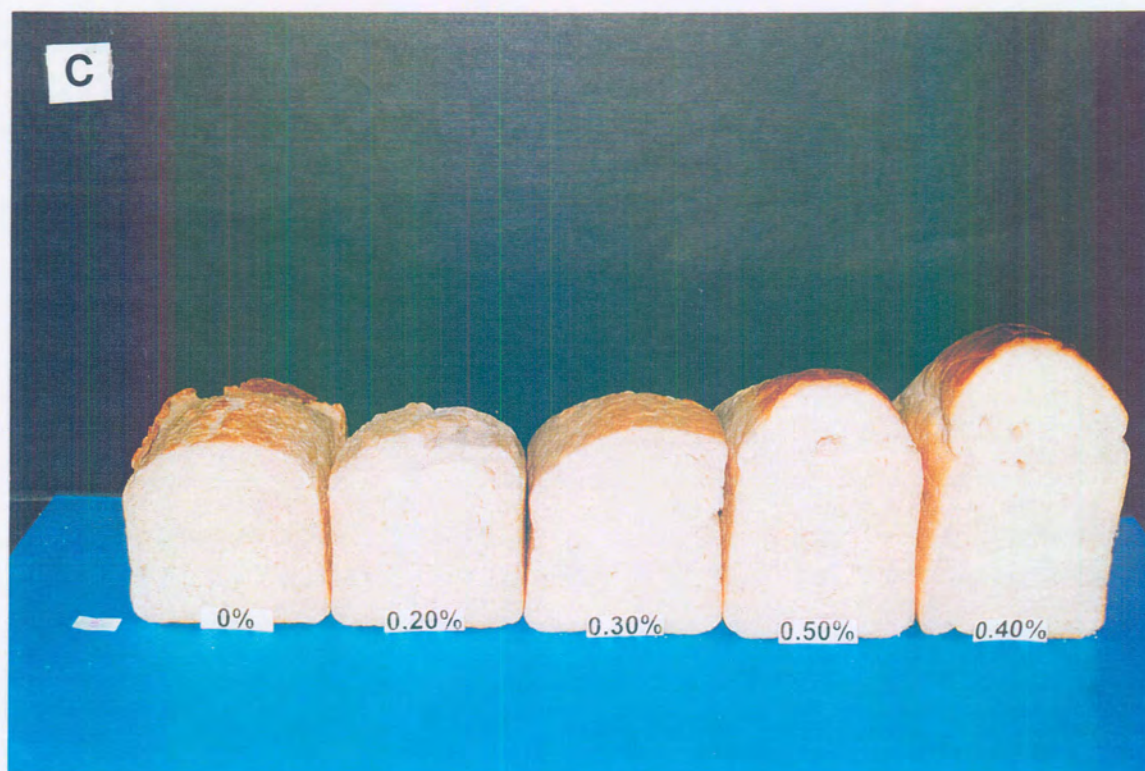


Fig. 37 Effect of DATEM concentration of drop volumes of Tiger (A), Lelie (B) and Silver Queen (C)

4.4.7 Drop Test Score

Fig. 38 shows the relationship between DATEM concentration and the score assigned to the appearance and loaf volume of breads whose doughs were subjected to the drop test. Drop test scores without DATEM were 4 for all three flours. Drop test score of Lelie increased with increases in DATEM concentrations. DATEM only improved the drop test score of Tiger and Silver Queen at 0.5 % DATEM from a score of 4 to 8.

4.4.8 Symmetry Score

Fig 39 shows the relationship between DATEM concentration and symmetry score. Without DATEM, Tiger had sloping corners and was assigned symmetry scores of 4. Silver Queen and Lelie surface were uneven as a result of bubbles on the bread surface and were assigned symmetry scores of 3. Addition of 0.2 % DATEM improved the symmetry of Lelie breads to symmetry scores of 5, but concentrations in excess of 0.2 % caused a decline in the symmetry score which declined back to 3 as a result of excessive volumes. The symmetry score of Tiger breads seemed to increase from a score of 4 with increasing DATEM concentrations up to 0.4 % DATEM, after which the score remained at 5. Fig. 40 shows the symmetry of the breads.

4.4.9 Crumb Texture Score

Fig. 41 shows the relationship between DATEM concentration and bread crumb texture score. Without DATEM, crumb texture scores of Tiger and Silver Queen were "open" and assigned scores of 7. The texture of Lelie was finer although uneven, and was assigned a score of 9. The crumb texture score of Tiger and Silver Queen breads only increased to a finer although uneven texture at 0.5% DATEM. DATEM had no clear effect on Lelie crumb texture scores.

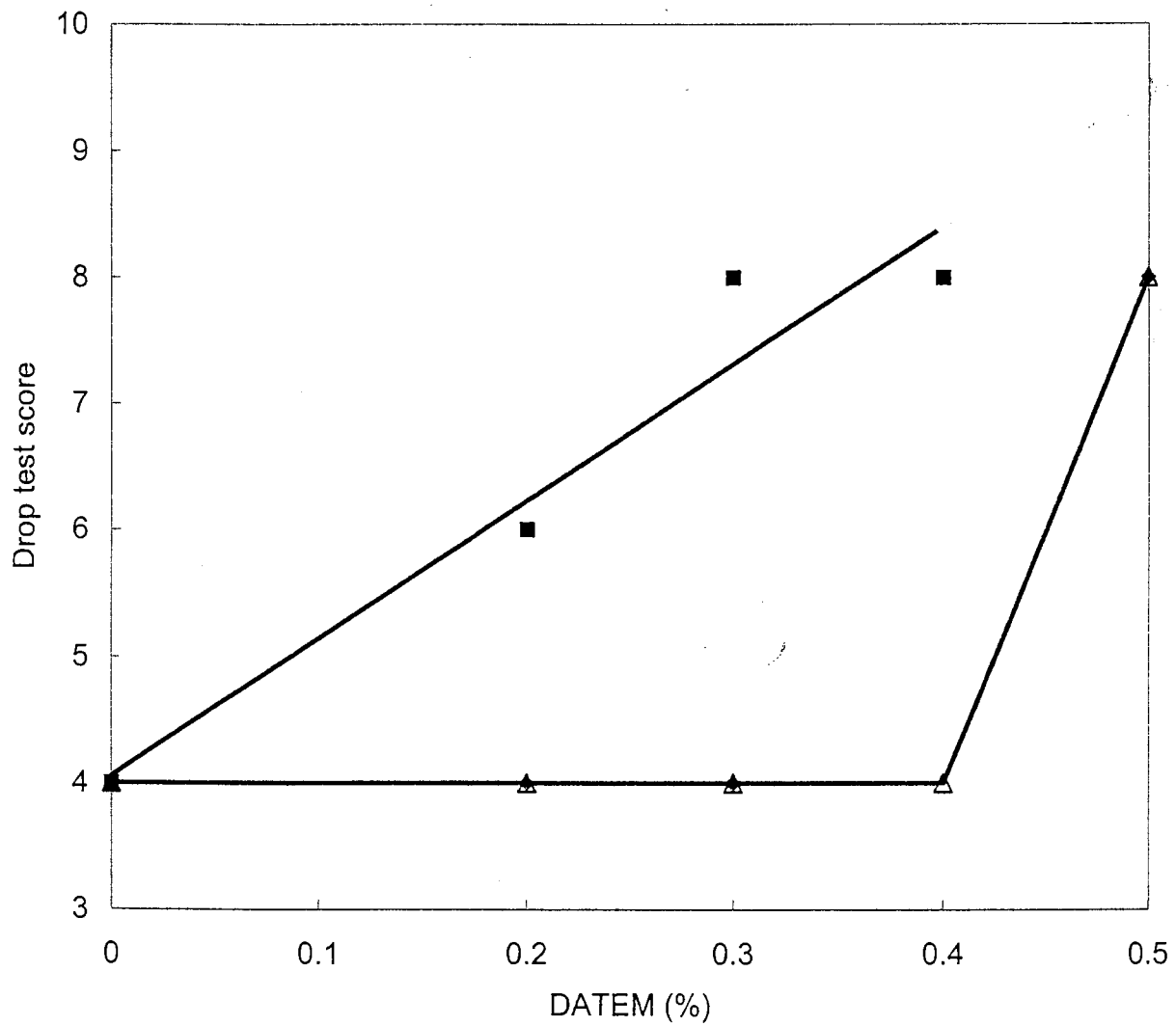


Fig. 38 Effect of DATEM concentration on drop test scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

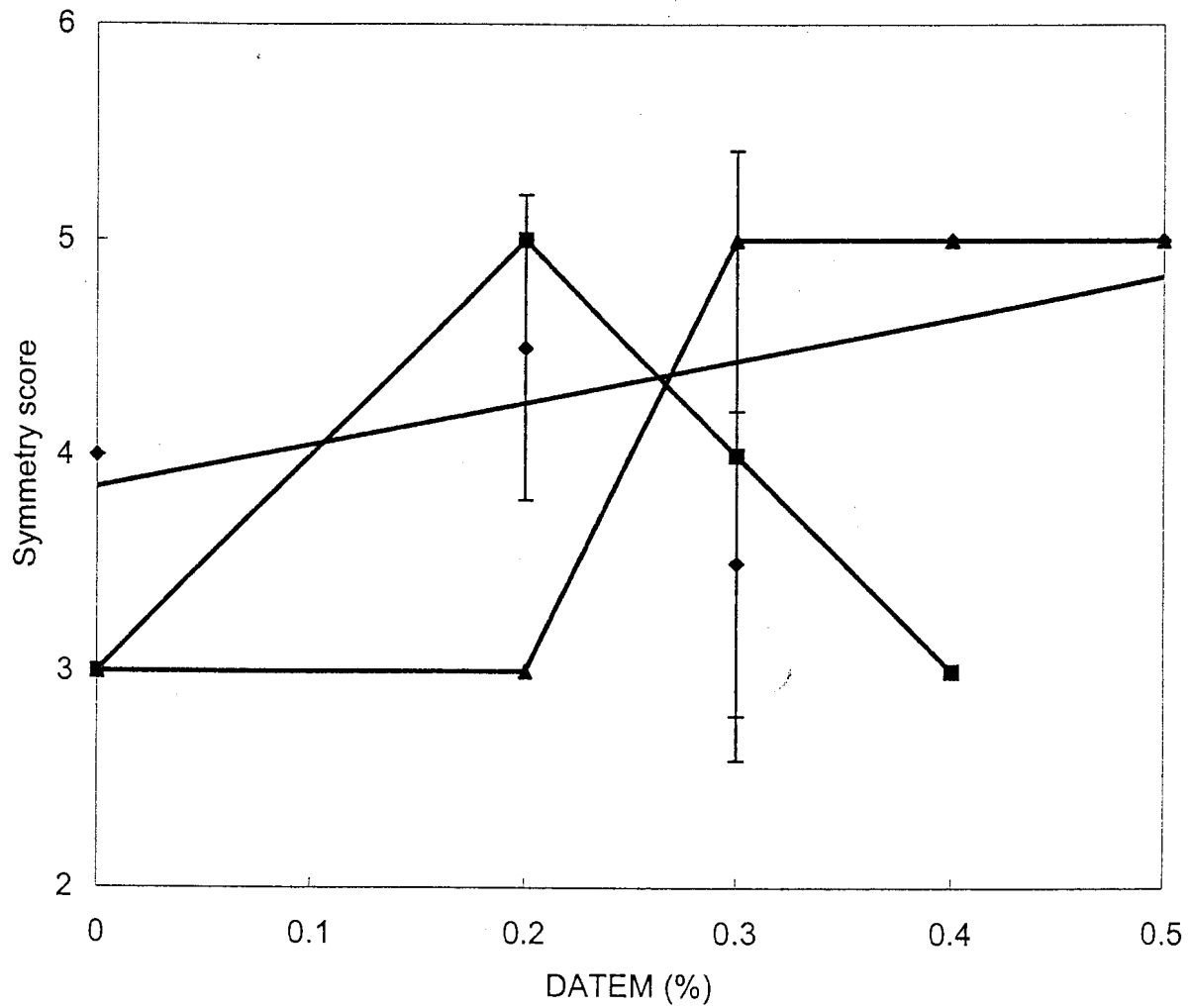
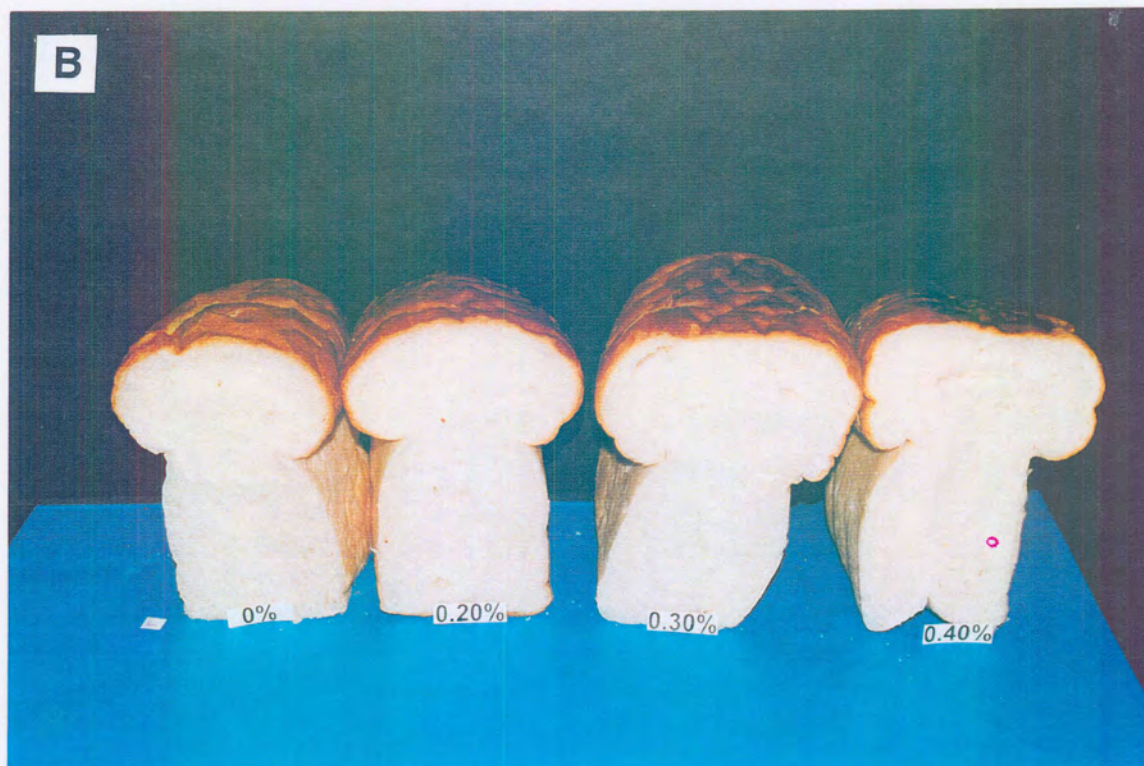
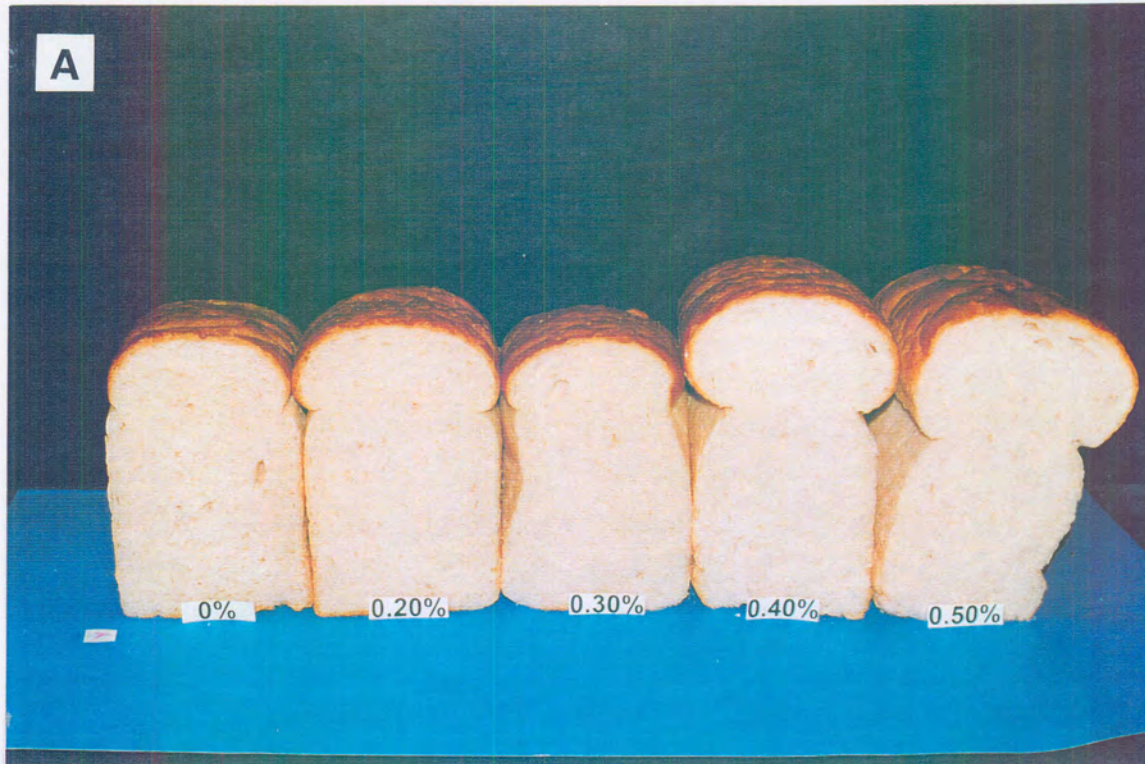


Fig. 39 Effect of DATEM concentration on symmetry scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)



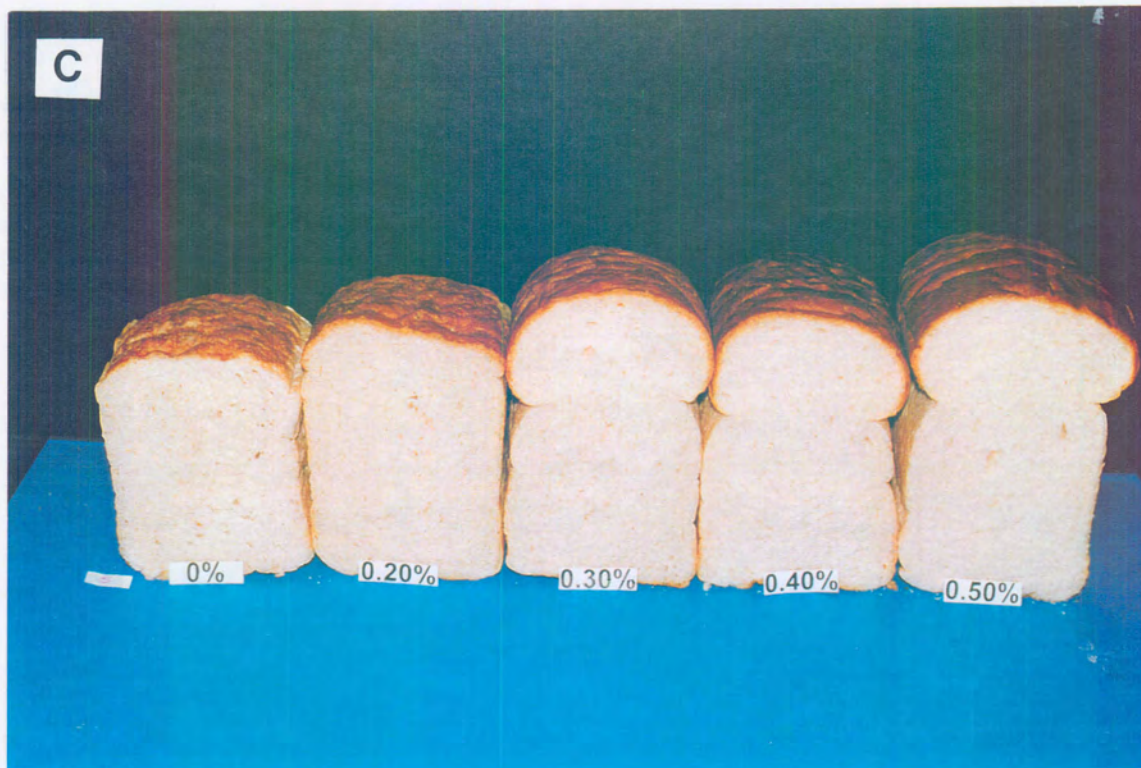


Fig. 40 Effect of DATEM concentration on symmetry of Tiger (A), Lelie (B) and Silver Queen (C)

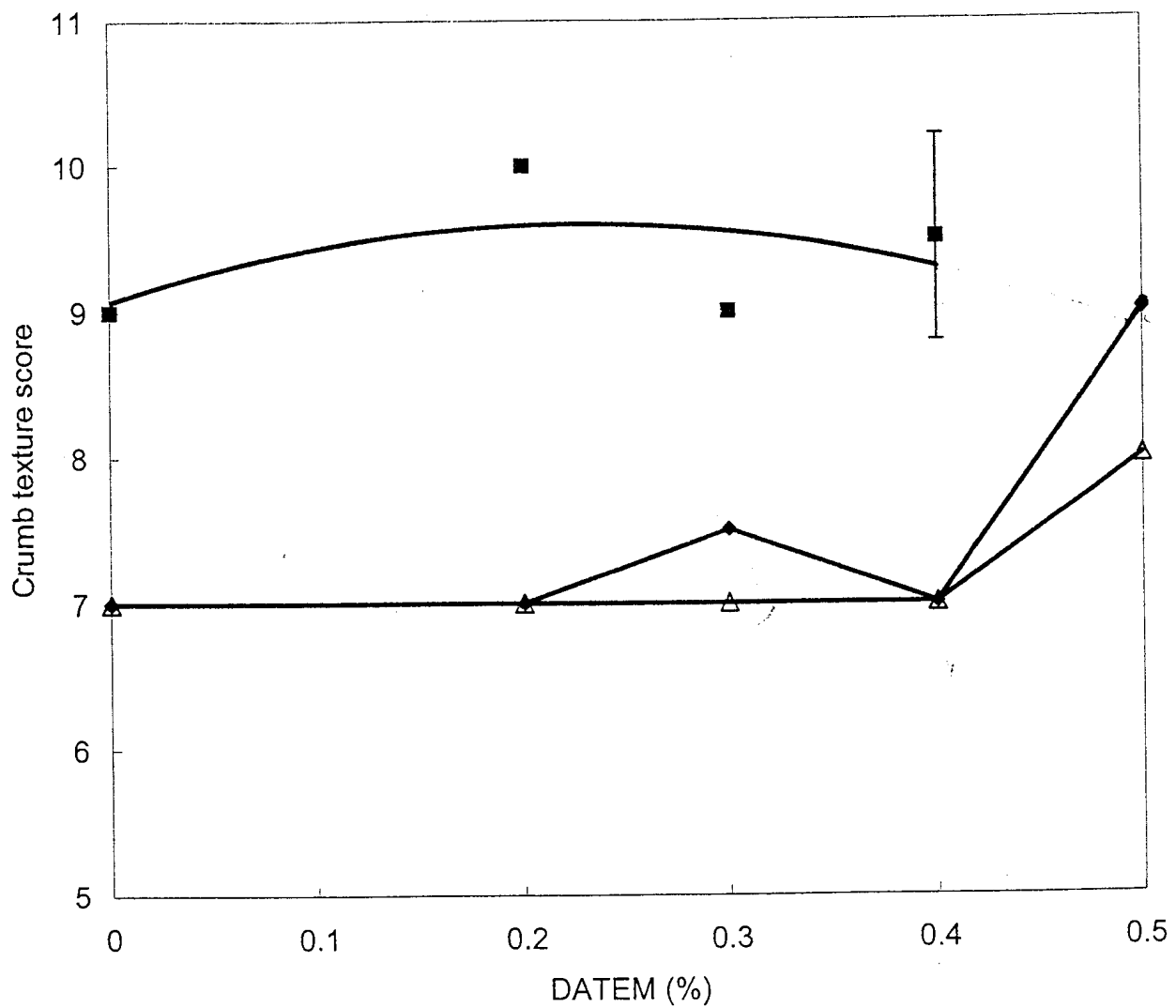


Fig. 41 Effect of DATEM concentration on crumb texture scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

4.4.10 Crumb Colour Score

Fig. 42 shows the relationship between DATEM concentration and crumb colour score. Without DATEM, crumb colour scores of Tiger, Lelie and Silver Queen were 6 (dull and creamy), 10 (white) and 5 (greyish), respectively. Crumb colour scores of Lelie breads were not affected by DATEM. It remained at an excellent score of 10. There was a slight increase in the crumb colour score of both the Tiger and Silver Queen with increasing DATEM concentrations from a dull/grey colour (score 5) to a slightly creamy one (score 8), although the relationship was not linear.

4.4.11 Crumb Softness Score

Fig. 43 shows the relationship between DATEM concentration and softness scores for breads. Without DATEM softness scores of Tiger and Silver Queen were 5 (firm) while those of Lelie were 10 (very soft). DATEM had no effect on softness of Lelie. There was an increase in bread crumb softness scores of Tiger with increasing DATEM concentrations to a score 10 although the relationship was not linear. Silver Queen softness scores were improved at 0.3 % DATEM to a score of 10. Silver Queen improved from a firm texture (score 5) to a soft texture at 0.5% DATEM (score 10).

4.4.12 Bread Score

Fig. 44 shows the relationship between DATEM concentration and bread scores of the breads made from the three flours. Without DATEM, bread scores of Tiger, Lelie and Silver Queen were approximately 70, 83, and 63, respectively. There was an almost linear increase in bread score with increases in DATEM concentrations for Tiger and Silver Queen. Tiger bread scores increased to approximately 83 at 0.5 % DATEM. Silver Queen bread scores increased to

approximately 81 at 0.5 % DATEM. DATEM concentration of 0.2 % caused a very slight increase in bread scores of Lelie, followed by no further change.

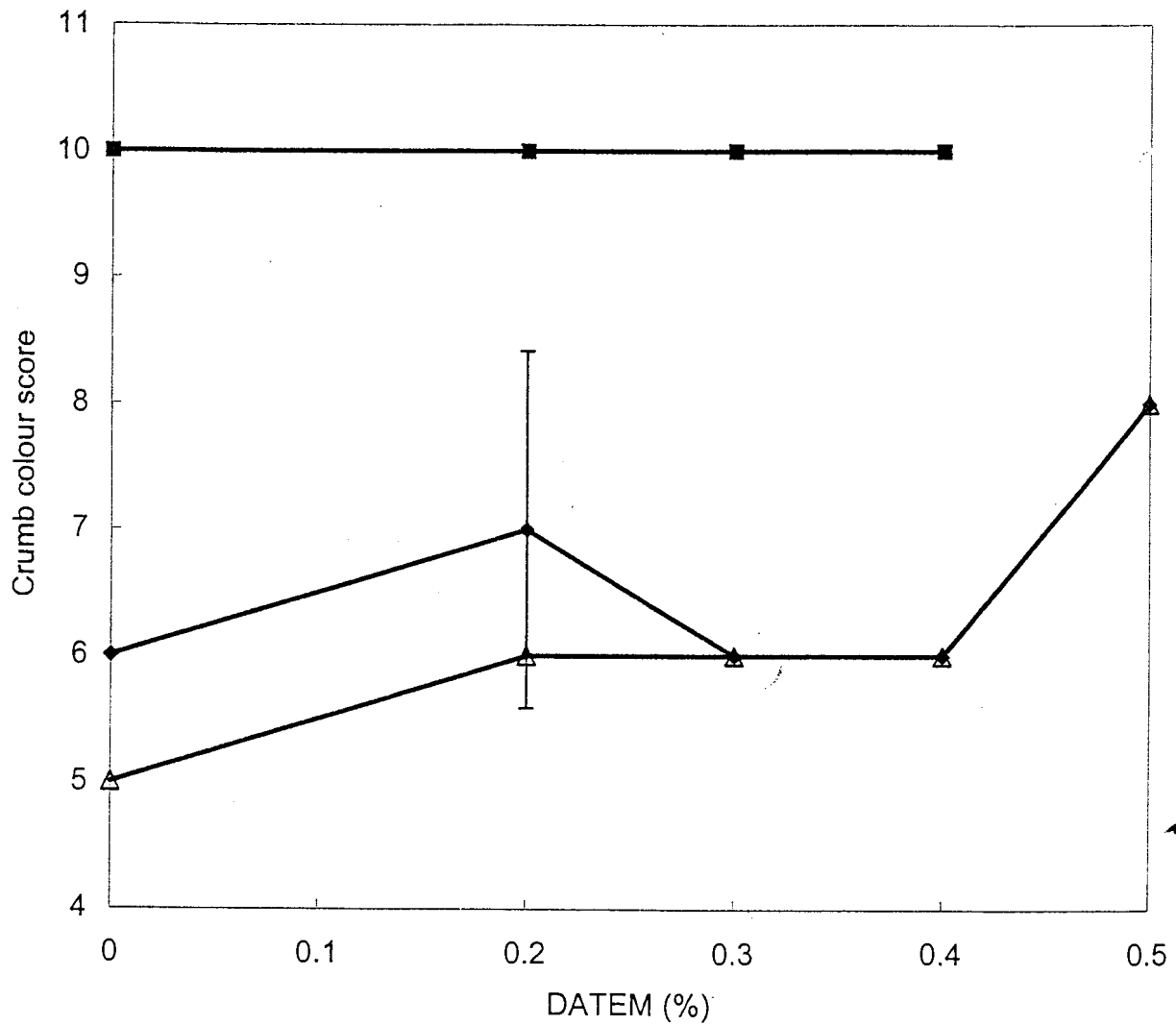


Fig. 42 Effect of DATEM concentration on crumb colour scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

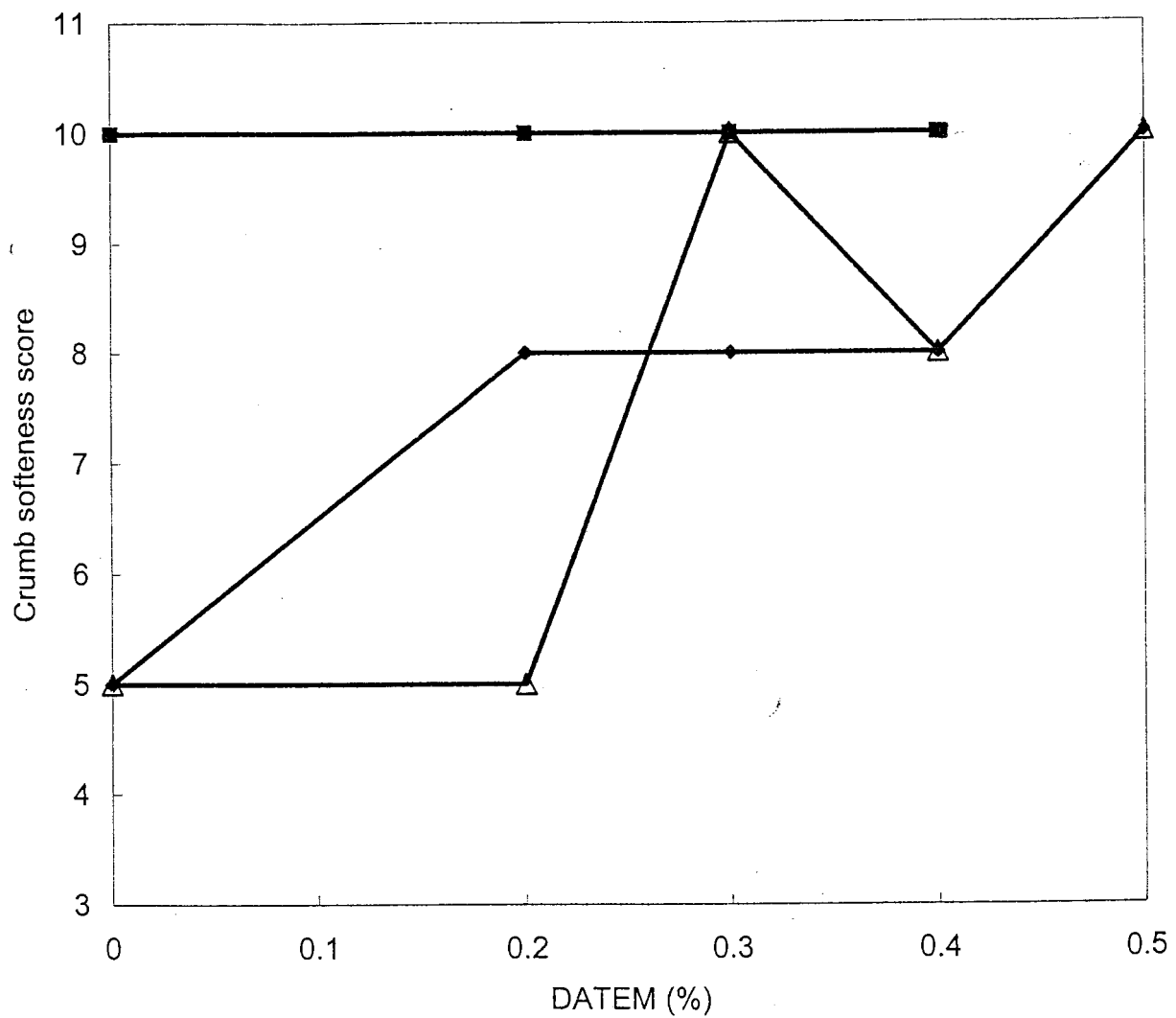


Fig. 43 Effect of DATEM concentration on crumb softness scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (Δ)

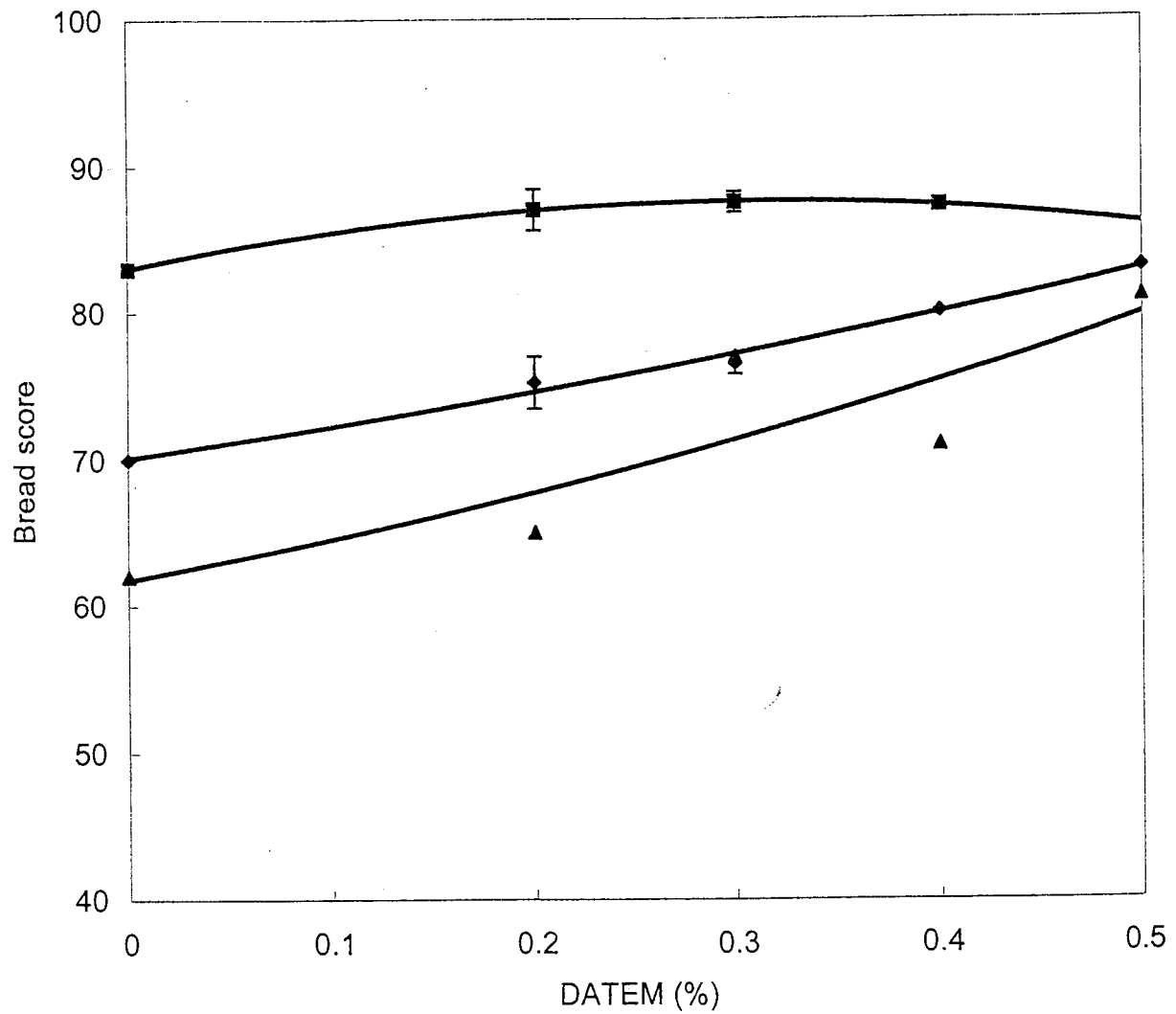


Fig. 44 Effect of DATEM concentration on bread scores of breads made from three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.5 EFFECT OF DATEM THE MIXOGRAPH PARAMETERS

4.5.1 Mixograph Peak Time

Fig. 45 shows the relationship between DATEM concentration and mixograph peak time of the three flours. Peak times of Tiger, Lelie and Silver Queen without DATEM were 2.3 min., 3.2 min., and 2.3 min., respectively. A slight increase in mixograph peak time occurred with increasing concentrations of DATEM Lelie. Peak times of Lelie increased from 3.2 to 3.9 min. DATEM had no clear effect on mixograph peak times of Silver Queen. Peak times of Tiger increased very slightly up to an optimum at about 0.4 % DATEM, followed by no significant change.

4.5.2 Mixograph Peak Height

Fig. 46 shows the relationship between DATEM concentration and mixograph peak heights. Without DATEM, mixograph peak heights of Tiger, Lelie and Silver Queen were 89 mm, 103 mm and 68 mm, respectively. Increasing DATEM concentrations caused a very slight but statistically significant reduction in the peak heights of Silver Queen and Lelie. Peak heights of Silver Queen decreased from to approximately 64 mm and those of Lelie, to approximately 91 mm. DATEM had no statistically significant effect on Tiger peak heights.

4.6 EFFECT OF DATEM ON THE RELAXATION TEST

Fig. 47 shows the relationship between DATEM concentration and RTs of the three flours. RTs of Tiger, Lelie and Silver Queen without DATEM were approximately 10.5 s, 34.6 s and 17.6 s, respectively. DATEM had no statistically significant effect on RT of Lelie. There was a slight (although statistically insignificant) increase in RT of Tiger and Silver Queen with increasing DATEM concentrations.

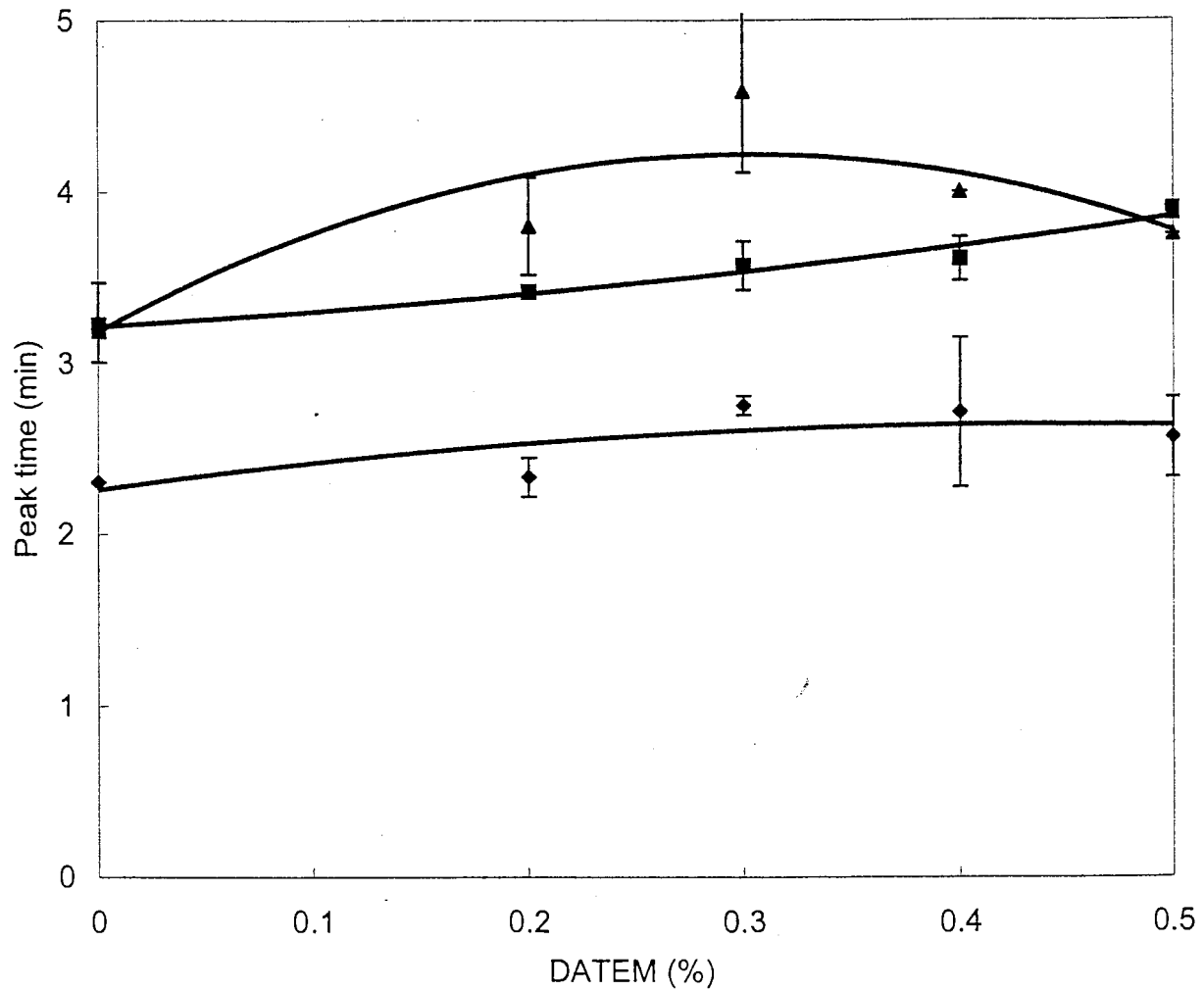


Fig. 45 Effect of DATEM concentration on mixograph peak times of three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

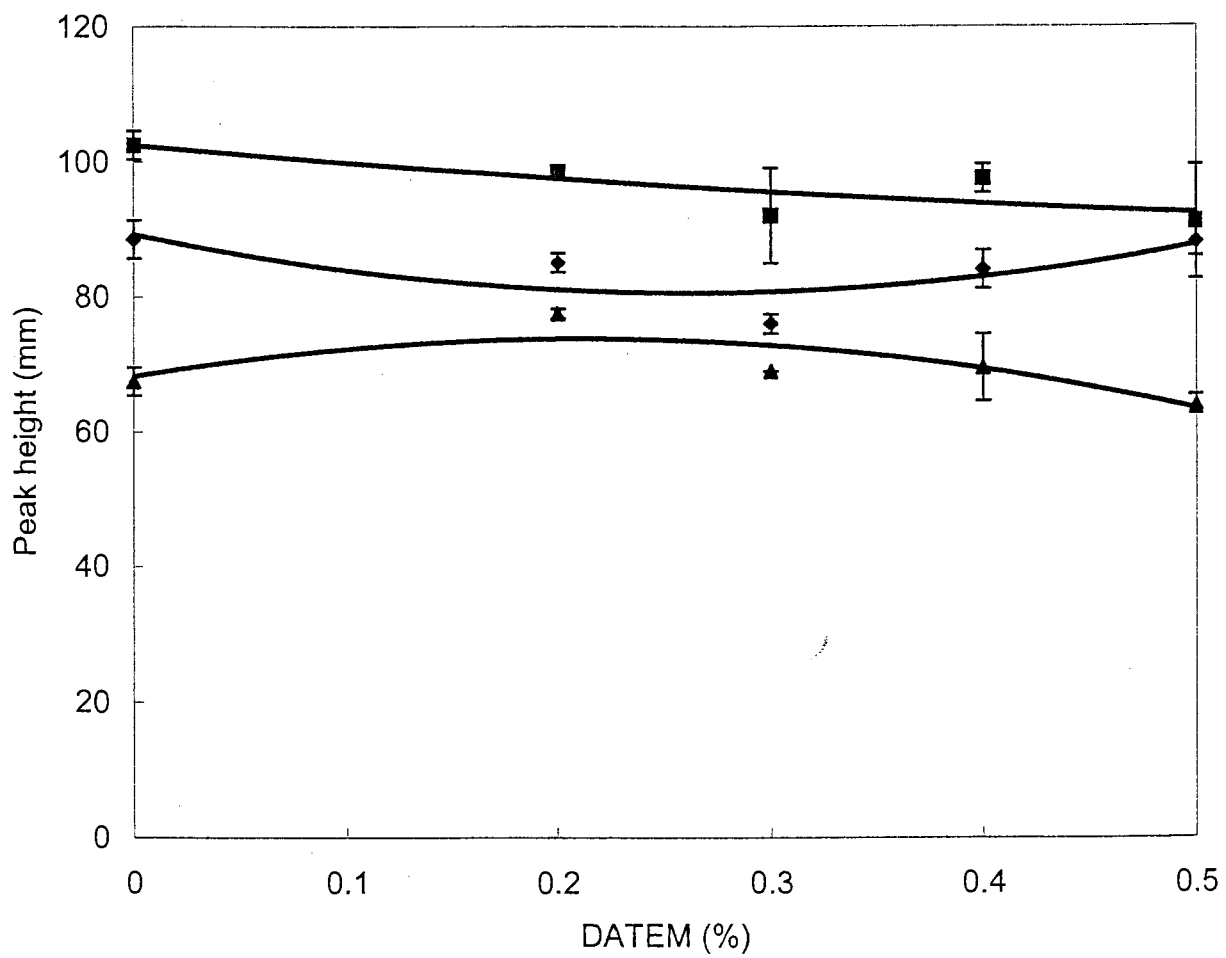


Fig. 46 Effect of DATEM concentration on mixograph peak heights of three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

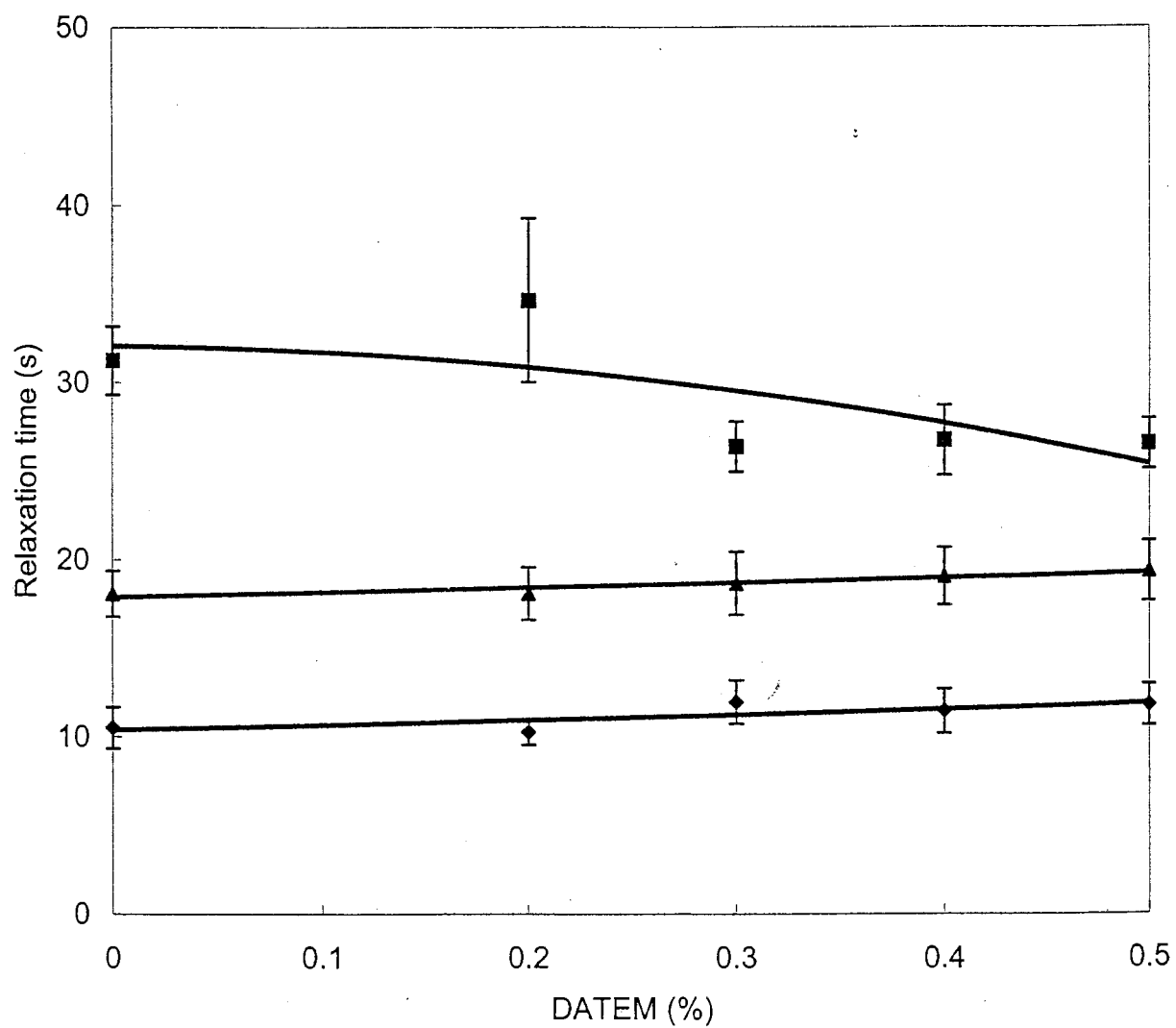


Fig. 47 Effect of DATEM concentration on relaxation times of three flours, Tiger (◆) Lelie (■) and Silver Queen (▲)

4.7 CORRELATIONS BETWEEN RHEOLOGICAL AND BAKING DATA

Tables 3, 4 and 5 shows the relation (as indicated by the Pearson correlation coefficients) between the rheological tests (mixograph and stress relaxation tests) and the baking parameters. To determine correlations for Tiger and Silver Queen loaf volumes below 2100 cm³, a constant value of 2100 cm³ was used.

Table 3
Correlation coefficients between baking performance and rheological data of Tiger

Baking parameter	Relaxation time	Peak time	Peak height
<i>Ascorbic acid</i>			
Proof height	0.679	0.340	-0.775
Baking height	0.868	0.501	-0.440
Drop baking height	*0.903	0.672	-0.270
Loaf volume	0.732	0.508	0.033
Bread score	0.850	0.433	-0.371
<i>DATEM</i>			
Proof height	0.758	0.755	-0.405
Baking height	0.290	0.277	0.439
Drop baking height	0.399	0.533	0.225
Loaf volume	0.370	0.384	0.336
Drop volume	0.365	0.477	0.287
Bread score	0.603	0.624	-0.052

* statistically significant correlations at a 95 % level of significance

Table 4
Correlation coefficients between baking performance and rheological data
of Silver Queen

Baking parameter	Relaxation time	Peak time	Peak height
<i>Ascorbic acid</i>			
Proof height	0.497	-0.213	-0.584
Baking height	*0.936	0.315	0.002
Drop baking height	*0.953	0.709	0.545
Loaf volume	0.760	-0.022	-0.300
Bread score	0.453	-0.455	-0.644
<i>DATEM</i>			
Proof height	0.311	0.581	0.472
Baking height	*0.970	0.453	-0.498
Drop baking height	*0.933	-0.108	-0.674
Loaf volume	*0.983	0.372	-0.496
Drop volume	0.657	-0.317	-0.620
Bread score	*0.894	0.453	-0.498

* statistically significant correlations at a 95 % level of significance

Table 5
Correlation coefficients between baking performance and rheological data
of Lelie

Baking parameter	Relaxation time	Peak time	Peak height
<i>Ascorbic acid</i>			
Proof height	-0.686	0.486	-0.574
Baking height	-0.633	0.935	-0.921
Drop baking height	-0.720	*0.983	*-0.994
Loaf volume	-0.206	-0.594	0.548
Drop volume	-0.903	0.625	-0.711
Bread score	-0.511	*0.997	*-0.981
<i>DATEM</i>			
Proof height	-0.145	0.582	*-0.969
Baking height	-0.150	0.812	-0.683
Drop baking height	-0.613	*0.990	-0.848
Loaf volume	-0.308	0.370	-0.807
Drop volume	-0.394	0.848	*-0.989
Bread score	-0.824	0.918	-0.806

* statistically significant correlations at a 95 % level of significance

CHAPTER 5

DISCUSSION

Bread-making quality of flour can be described in terms of the following functional properties: dough-mixing requirement and tolerance, dough handling properties, water and oxidation requirements of flour, loaf volume potential and crumb grain texture and crumb colour of the bread (Finney, Yamazaki, Young & Rubenthaler, 1987). A flour of good quality for bread-making should have a high water absorption, a short mixing requirement for the CBP, satisfactory mixing tolerance and dough handling properties as well as good loaf potential. It should also yield a loaf that has good internal crumb grain and colour. Each of these properties is a function of both the quality and quantity of flour proteins (Finney *et al.*, 1987).

The stickiness of Tiger after mixing in the test bake may have been a result of over-mixing. The mixing regime designed for flours typically used by Albany Bakeries (Germiston, South Africa) may have been too much for a flour of Tiger's quality. In the dough development test, Tiger (without ascorbic acid) showed satisfactory, although not the best state of development, implying that Tiger was a weak flour. With added ascorbic acid however, good dough development was observed, probably as a result of increased disulphide bonding that strengthens the gluten network (Nakamura & Kurata, 1997). The fact that DATEM improved dough development may have been because DATEM encouraged enhanced interaction of protein molecules due to reduction in charge (Armero & Collar, 1996), as well as the stabilisation of the liquid film surrounding gas cells, thus improving elasticity (Gan *et al.*, 1990).

Lack of stickiness of Lelie and its ability to form a very thin film without tearing was an indication of very good dough development. Lelie exhibited these properties with or without any of the two bread improvers, implying that Lelie was a very strong flour.

Silver Queen's dry and stiff dough after mixing may have been a result of insufficient water added. The information that was supplied with Silver Queen (Table 1) was the specifications for the flour and not the actual analysis. It is possible, then, that the actual water absorption for this flour was higher than the 59 % used. This was not apparent when the rheological tests were performed (before the test bake). For direct comparison, the same water absorption as in the rheological tests was used. Tearing of the dough without forming a thin film, indicated insufficient dough development also possibly as a result of insufficient water.

Without ascorbic acid, proof heights and baking heights of Tiger were lower than required to make a good loaf of bread. The increase in Tiger proof heights, baking heights and loaf volumes with increasing ascorbic acid concentration, up to a peak, with neither further improvement nor detriment, was in agreement with a statement by Fitchett & Frazier (1986) who reported that it was "virtually impossible to over-treat bread doughs". My results were also in agreement with work by Yamada & Preston (1994) who reported that increasing ascorbic acid caused an increase in loaf volumes until peak levels and further increases caused no further changes. They concluded that a wide range of ascorbic acid could be used in doughs without adversely affecting bread quality. The reason is that the mechanism of ascorbic improvement is limited by factors such as available oxygen, concentration of reactants necessary for the reactions, and competition for oxygen from other oxidation reactions (Fitchett & Frazier, 1986; Stear, 1990; Cauvain, 1998c). According to Fitchett & Frazier (1986) this self-limiting effect is of considerable benefit to the baker since it confers the high tolerance to over-treatment. Loaf volumes did not reach figures regarded as excellent (3200-3400 cm³) or good (3000-3200 cm³) as described in Albany Bakeries standards even at 200 ppm ascorbic acid, suggesting that for a flour with Tiger's characteristics, ascorbic acid on its own was not sufficient to strengthen dough so that it produces desirable or even acceptable volumes. The reason could be that ascorbic acid's strengthening effect is exerted mainly during

the mixing stage and during proofing (Cauvain, 1998c), and therefore doughs as weak as Tiger seemed to be, would be unstable and drop in height during transfer from prover to ovens, yielding low volumes.

Contrary to ascorbic acid, DATEM caused linear increases in the proof heights, baking heights and loaf volumes of Tiger with increasing DATEM concentrations, without reaching a peak over the range of DATEM concentrations tested. DATEM concentration of 0.3 % was sufficient to produce loaf volumes scored as excellent. This may have been influenced by the fact that 50 ppm ascorbic acid was added to all formulations where DATEM concentrations were varied. In preliminary work, it was found that even at high DATEM concentrations, loaf volumes were so low that they would have been difficult to compare because the rapeseed displacement volumeter used could not measure loaf volumes below 2100 cm³. Therefore 50 ppm ascorbic acid was added in formulations where DATEM was a variable. Therefore DATEM was not acting alone in improving flour quality.

Except at 200 ppm ascorbic acid, the proof heights of Tiger were higher than the baking heights at each ascorbic acid concentration. This means that the doughs were unstable and the height dropped during transfer from prover to oven and had negative oven spring. Ascorbic acid concentrations below 200 ppm did not prevent this perhaps because ascorbic acid is not a long acting oxidising agent, and it imparts its strengthening effect mainly during mixing (Cauvain, 1998c). Also, perhaps at 200 ppm there was excess ascorbic acid, which was able to react and stabilise dough at later stages of the baking process when conditions were more suitable. DATEM concentrations of 0.4 % and 0.5 % did prevent the drop in height by stabilising the doughs against mechanical abuse, as stated by Kent & Evers (1994) and the doughs experienced oven spring (rise). According to Yamada & Preston (1992) oven rise during the early stages of baking is a primary factor in determining loaf volume and other bread characteristics. At

these DATEM concentrations bread characteristics were, in fact significantly improved.

The baking results were obtained under laboratory conditions that involve closely controlled conditions and gentle handling of doughs. Under commercial processing conditions, the relative effectiveness of these improvers may vary due to their response to harsher dough handling conditions (dough stability) (Kenny *et al.*, 1999), which is why the drop test was included as part of our test.

Subjecting Tiger to the drop test to test its stability showed it to be very unstable. Increasing ascorbic acid improved drop baking heights very slightly but not enough to make acceptable bread loaves. Therefore, ascorbic acid, even at high concentrations, did not help to stabilise doughs against rough handling, because as already mentioned, its strengthening effect is imparted earlier on during mixing and proofing. Unlike ascorbic acid DATEM did stabilise doughs. Drop heights increased with increasing DATEM concentrations. DATEM has been reported by Gan *et al.* (1990) and Kenny *et al.* (1991) to stabilise dough, not only against over-mixing, but also during transfer from prover to oven and in the early stages of baking by stabilising the liquid film surrounding gas cells. Doughs only reached desirable drop baking heights at 0.5 % DATEM. At this concentration the loaves had good appearance. This agrees with statement in Kent & Evers (1994) that DATEM enhances resistance to mechanical abuse during processing and that it is normally used at 0.5 % concentration.

Unlike Tiger, proof heights and loaf volumes of Silver Queen increased with increasing ascorbic acid without reaching a peak over the range of ascorbic acid concentrations tested. It only experienced oven rise at 0.5 % DATEM. The poor effect may have been a result of lower water addition than required for Silver Queen, causing it to need more bread improvers than Tiger to achieve a similar effect. Silver Queen may have reached peak values at higher concentrations. Silver Queen had similar reactions to the drop test as Tiger.

Lelie had the highest proof heights and baking heights of all three flours at all concentrations of improvers. Its loaf volumes, without ascorbic acid, were excessive. The reason for this is that Lelie, which is a strong flour, was used under conditions designed for weaker flours such as used by Albany Bakeries. For example the proofing time used in the test bake may have been too long for Lelie, resulting in excessive proof heights, baking heights and loaf volumes. Neither its proof heights, baking heights nor its loaf volumes were statistically significantly affected by addition and increasing concentrations of ascorbic acid or DATEM.

Lelie doughs were very stable to transfer from prover to oven and all its baking heights were higher than proof heights, indicating that oven spring had occurred. Drop baking heights of Lelie were higher than those of the other two flours, but still lower than required to make an acceptable loaf of bread. Ascorbic acid did not improve drop baking heights of Lelie, possibly because ascorbic acid did not do much to stabilise doughs. With increasing DATEM concentrations Lelie drop baking heights and drop volumes so increased that they were even excessive. At 0.3 and 0.4 % DATEM drop heights and drop volumes were approximately the same as those that had not been subjected to the drop test, indicating that these doughs were extremely stable at these DATEM concentrations.

Without ascorbic acid, Tiger loaves were caved in at the centre, an indication that the doughs were very unstable. Addition of ascorbic acid even as low as 50 ppm improved the symmetry and the loaves had the required shape. Tiger breads without DATEM did not have as bad a shape as without ascorbic acid (breads without DATEM did have 50 ppm ascorbic acid) but had sloping corners resulting from bubbles at the dough surface caused by its instability. It is therefore possible to make decent-looking bread without DATEM but not without ascorbic acid for Tiger. The reason for this may be that without ascorbic acid, Tiger would be prone to over-mixing and breakdown of the gluten structure, resulting in bad quality bread. Although DATEM also protects dough against over-mixing, its

stabilising effect is mainly exerted during the early stages of baking. In the presence of 50 ppm ascorbic acid, DATEM improved stability of the dough and improved bread symmetry.

Tiger's "open" crumb structure was not significantly improved by ascorbic acid. This is contrary to results by (Yamada & Preston, 1994) who reported improvement in crumb texture caused by ascorbic acid. The reason for the different results may be that different bread-making methods were used in the separate research works. I used the CBP while Yamada & Preston (1994) used the sponge-and-dough method which has lower oxidation requirements (Preston & Kilborn, 1982). DATEM caused an improvement in crumb texture only at 0.5 % DATEM to a good texture with smaller holes. Junge, Hosney & Varriano-Marston (1981) attributed texture improvement to more air being occluded during mixing of dough containing the surfactant or smaller cell formed during mixing. According to Cauvain (1998c), improved cell structure leads to improved colour, softness and perceived freshness.

Crumb colour improvement of Tiger at 50 ppm from a greyish colour to a dull creamy one was most probably a result of improved loaf volume. Larger volumes have more occluded air, and thus more reflectance and therefore appear lighter in colour (Stear, 1990). Loaves with DATEM had lighter crumb colours, also perhaps due to larger volumes.

Tiger crumb was firm without ascorbic acid, and addition and increases in ascorbic acid and DATEM improved crumb softness in a non-linear manner. Even though no crumb texture improvement was observed as a result of ascorbic acid, my other results on ascorbic acid effect on other characteristics of bread are in agreement with those of Yamada & Preston (1992) and Yamada & Preston (1994) who reported improvements in loaf appearance, crumb texture, crumb colour, and bread score as a result of ascorbic acid. The improvements were related to increased volumes. According to Yamada & Preston (1992) increased

oven-spring, which leads to increased volumes, as a result of ascorbic acid addition lead to improved crumb texture, crumb colour and crumb softness.

Silver Queen loaves had sloping corners without ascorbic, indicating that the dough collapsed slightly during transfer from prover to oven, because it was unstable. The uneven bread surface (as a result of bubbles) of Silver Queen loaves without DATEM was also a sign of the dough's instability. As with Tiger, ascorbic acid improved the unevenness and shape of the loaves. DATEM caused an improvement at 0.3 % concentration by increasing stability of doughs.

Unlike Tiger, whose crumb texture was not improved by ascorbic acid, crumb texture of Silver Queen improved at 200 ppm. Every *et al* (1998) also reported a minor effect of ascorbic acid on crumb texture. The reason why the different flours reacted differently is unknown. As with Tiger, DATEM caused improvement in crumb texture only at 0.5 %.

Even at larger volumes, the crumb colour of Silver Queen did not seem to be affected by ascorbic acid, perhaps because Silver Queen was initially the darkest flour of the three and required larger volumes to show lighter colours. In fact, DATEM, which caused larger bread volumes than ascorbic acid at concentrations tested, seemed to cause a slight improvement in Silver Queen crumb colour. This agrees with the suggestion of Yamada & Preston (1992) that improvement in crumb colour and some other bread characteristics are related to increased loaf volumes.

Silver Queen's crumb softness only improved from firm to slightly firm at an ascorbic acid concentration of 200 ppm, also associated with increased volumes. Increasing DATEM also caused a stepwise improvement in softness. The bread improved from a firm to a soft texture. Loaves with larger volumes have more air in them at the same mass, thus appearing softer (Cauvain, 1998c).

Contrary to the general trend that ascorbic acid concentration higher than the peak causes no change in bread quality, at 150 ppm, the volumes were so large that the breads were distorted and lacked the required shape. Even though bread shape was good without DATEM, the bread surface was uneven as a result of over-proofing, which caused bubbles at the surface. This was improved by 0.2 % DATEM. As with ascorbic acid, higher DATEM concentrations caused the loaves to be excessive and distorted.

With or without ascorbic acid or DATEM the crumb texture, crumb softness and crumb colour of Lelie were always good, a possible indication that a good flour of Lelie's calibre is possibly of lower extraction rate than typical South African flours.

Concentrations of ascorbic acid required to attain peak bread-making quality were generally higher than those reported in a previous study (Yamada & Preston, 1994). The probable reason for this is that Yamada & Preston (1994) tested flours of higher protein content than those tested in my research. Also, Yamada & Preston (1994) used the sponge-and-dough baking method which has lower oxidation requirements (Preston & Kilborn, 1982) while I used the CBP. It is therefore not feasible to make general recommendations for additives since their effects are dependent on specific flour type and working conditions.

Adding all the scores of the dough behaviour during bread making and the appearance of the bread loaves after processing gives the bread score. The bread score is an indication of the suitability of flours for bread-making when all the functional properties and appearance of the resulting bread have been taken into consideration. Lelie had the highest bread scores, followed by Tiger with Silver Queen having the lowest bread scores. Lelie therefore appeared to be the flour with the best bread-making quality, followed by Tiger, and then Silver Queen.

Bread score values indicated that ascorbic acid did not significantly ($p < 0.05$) improve bread-making quality of Silver Queen. The reason for this is that while ascorbic acid did cause improvements to some of the bread quality parameters, the improvements were not large enough to significantly influence the bread score. Furthermore, dough-handling characteristics that make up a large fraction of the bread score, such as dough development and stickiness, were not improved by ascorbic acid because the flour was used under sub-optimal conditions (less water). The effects of bread improvers on bread-making quality are therefore affected by other factors that affect bread-making quality such as water addition. DATEM caused greater improvement in Silver Queen bread-making quality than the other two flours at all concentrations perhaps because it had lower water addition than required, needing more improvement. Tiger bread-making quality was improved by both ascorbic acid and DATEM. Lelie, which already had superior bread-making quality without any bread improvers was improved only at low concentrations of improvers. Higher concentrations did not cause any further improvements in the bread-making quality of Lelie but in fact caused loaf volumes to be excessive.

Considering the results from the mixograph data with respect to estimating flour quality, Tiger was estimated to be of low quality for bread-making. Tiger controls had short mixing time, the shortest mixing time of the three flours. RT supported findings from mixograph data, indicating Tiger not only to have little elasticity, but also having the shortest RT of the three flours. These findings were supported by the results of the test bake. Tiger, as already discussed, displayed characteristics of a weak flour. The mixograph test was therefore successful in characterising Tiger in terms of flour quality. The stress relaxation test supported the finding and did not really provide additional information in this regard.

With regard to the mixograph as a predictor of bread improver effect, increasing concentrations of ascorbic acid slightly increased peak times of Tiger (improved flour strength) up to maximum peak times, followed by no further changes. A

similar trend was also observed in RT. Both tests seemed to indicate that bread-making quality of Tiger would increase with increasing ascorbic acid up to 100 ppm, beyond which neither further improvement nor detriment would take place. Lang *et al.* (1992) also reported increases in mixograph peak times with increasing ascorbic acid concentrations, with higher concentrations causing no further changes. This trend was in agreement with the review by Fitchett & Frazier (1986) on effect of oxidants on bread flour. However, according to Fitchett & Frazier (1986) the peak RT was reached at lower ascorbic acid concentrations (44 ppm), possibly because flours used in my research were weaker in comparison. Nevertheless, the trend indicated by the mixograph and supported by the stress relaxation test, of the effect of ascorbic acid on the Tiger was not observed in these important bread parameters: baking height, loaf volume and bread score. Contrary to the mixograph peak times and RTs, the baking heights, loaf volumes and bread scores increased with increasing ascorbic acid without reaching peak values. Only proof heights showed trends predicted by both tests.

None of the Tiger mixograph data correlated significantly with any of the baking variables. In contrast, Graybosch *et al.* (1999), using the sponge-and-dough method and no improvers, found significant correlation between mixograph peak times and test bake proof times. Their results did not agree with mine on correlations found between mixograph variables and test bake variables. The difference may be a result of different baking methods, as Graybosch *et al.* (1999) used the sponge-and-dough method. Notwithstanding the fact that there was no statistically significant change ($p < 0.05$) in drop baking heights of Tiger with increasing ascorbic acid concentrations, when the mean values were taken Tiger RTs were highly significantly correlated ($p < 0.05$) with effects of ascorbic acid on drop baking heights.

DATEM increased mixograph peak times of Tiger with increasing concentrations to peak values at 0.3 % DATEM, followed by no further change. Contrary to this

trend, RTs of Tiger increased very slightly (although statistically insignificant) without reaching maximum values at DATEM concentrations tested. To support findings from the stress relaxation test, proof heights, baking heights, drop baking heights, loaf volumes and bread scores of Tiger did not reach peak values over the range of DATEM concentrations tested but instead continued to increase with increasing DATEM concentration. Therefore, the mixograph was also able to predict the improving effect of DATEM on Tiger only up to a point (0.3 % DATEM). RT was more sensitive in being able to predict the improving effect even at higher DATEM concentration, showing trends evident in the baking test. The stress relaxation therefore, provided additional information that was not provided by the mixograph on its own.

Effects of DATEM did not correlate with any of the baking variables as a result of variability in test bake data.

Mixograph peak times for control doughs seemed to indicate that Lelie and Silver Queen were of similar bread-making quality. However, the mixograph peak heights indicated Lelie to be stronger than Silver Queen. Higher peak heights of Lelie indicated that Lelie required more energy to mix to peak development and was therefore a stronger flour. RT supported the finding and Silver Queen had shorter RTs than Lelie and longer than Tiger. Test bake results also supported this. The stress relaxation test, as in the case of Tiger confirmed what was predicted by the mixograph test without providing additional information.

Similar to Tiger, increasing concentrations of ascorbic acid slightly increased peak times of Silver Queen up to a peak at approximately 100 ppm ascorbic acid. However, contrary to Tiger, Silver Queen peak times seemed to decrease beyond the peak, a trend which was not observed in any of the baking variables. Most baking variables either remained unchanged or continued to improve beyond 100 ppm ascorbic acid. RTs increased with increasing ascorbic acid also up to approximately 100 ppm, but followed by no further change. The RT trend

was only observed with baking height, and not in proof heights and loaf volumes which actually increased with increasing ascorbic acid concentration. Neither test was extremely successful in predicting ascorbic acid effect but the stress relaxation test was slightly more successful than the mixograph and strong correlation ($p < 0.05$) was found between RTs of Silver Queen and baking heights and drop baking heights.

Increasing concentrations of DATEM also increased mixograph peak times of Silver Queen up to a peak, followed by a decrease. Contrary to mixograph peak times, baking heights and loaf volumes of Silver Queen increased without reaching peak values over the range of DATEM concentrations tested. RTs increased very slightly (although statistically insignificant) without reaching a peak over the range of DATEM concentrations tested. Notwithstanding the fact that this improving effect was less pronounced in the stress relaxation test than in the test bake, the improving effect of DATEM was observed in the baking heights, loaf volumes and drop baking heights. This implies that the stress relaxation test was more successful in predicting the effect of DATEM on flour quality of Silver Queen. Correlations were found between the effect of DATEM on RTs and baking heights, drop baking heights, loaf volumes and bread scores. The mixograph was able to predict the improving effect of DATEM on Silver Queen only up to a certain concentration. The stress relaxation test predicted the continuing improving effect beyond what was predicted by the mixograph.

In agreement with Lang *et al.* (1992) Lelie peak times increased with increasing ascorbic acid concentration up to a peak, followed by no further change while peak heights decreased with increasing ascorbic acid concentration. RT on the other hand was found not to have a clear effect on Lelie peak times. The mixograph trend was observed in the effect of ascorbic acid on baking heights, drop baking heights and bread scores (notwithstanding the fact that the effect on the former two were found to be statistically insignificant, $p < 0.05$). Strong positive correlation ($p < 0.05$) was found between peak times of Lelie and drop baking

heights as well as bread scores. Negative correlation ($p < 0.05$) was found between peak heights and the same baking parameters. No correlation was found between RT and any of the baking parameters. In the case of Lelie not only did RT not provide additional information but no agreement was found between results of the two tests.

The mixograph peak times predicted that bread-making quality of Lelie would increase with increasing DATEM concentration without reaching a peak at concentrations tested. No clear effect could be deduced from RT. Contrary to the mixograph results, the test bake did not show Lelie baking parameters to experience continuous improvement with increasing DATEM concentrations without reaching peak values. Only drop baking height and drop volume displayed this trend. Correlation ($p < 0.05$) was found only between peak times and drop baking heights while no correlation was found between RT and any of the baking parameters. The mixograph was less successful in predicting the effect of DATEM on Lelie than that of ascorbic acid. RT provided no additional information towards a clearer picture of the effect of the improvers on bread-making quality of Lelie.

The mixograph was better able to predict the effect of improvers on Lelie while the stress relaxation test was better at predicting effect (especially of DATEM) on the weaker flours. The reason for this is unknown. It could be that empirical rheological tests such as the mixograph, use relatively large forces to cause large deformations (Janssen *et al.*, 1996) while more fundamental rheological tests, such as a controlled stress rheometer and the stress relaxation test use small forces to cause small deformations (Kenny *et al.*, 1999).

For Silver Queen, the stress relaxation test was able to predict the effect of ascorbic acid on baking height and drop height. It was also able to predict the effect of DATEM on baking height, drop baking height, loaf volume and bread score. These variables are important indicators of flour quality and the quality of

the final bread. It would seem then that, contrary to Tiger, the stress relaxation test was more useful in predicting effects of DATEM on Silver Queen flour quality.

RT seemed to be related to dough stability. It was strongly correlated ($p < 0.05$) with drop heights of both Tiger and Silver Queen. In the case of Silver Queen it was also correlated with effects of DATEM on baking height and loaf volume, variables which are related to dough stability. As was seen in the baking test, DATEM did impart more stability to doughs compared to ascorbic acid. Better sensitivity to DATEM may be related to the mechanism by which it strengthens dough, thus improving bread-making quality. DATEM may have enhanced dough stability by enhancing protein interaction leading to a more continuous gluten matrix (Armero & Collar, 1996) and by stabilising the liquid matrix surrounding gas bubbles (Gan *et al.*, 1990).

RT may be predicting the dough's gas-retaining properties after proofing, which will be critical during oven spring. This property relates to the dough's ability to expand around growing gas bubbles during the first stages of baking, its extensibility and stability of the liquid film.

Although the mixograph has been proven to be useful in practical industrial applications, its disadvantage is that it is empirical in nature. This means that data obtained cannot be translated into well-defined physical quantity, which makes fundamental interpretation of result extremely difficult (Janssen *et al.*, 1996). The applied deformations are large and often poorly defined, which implies that the test procedure may change the material properties significantly in an uncontrolled way. Moreover, the time scales of the deformations applied differ considerably from those occurring in a fermenting dough, which may strongly affect correlation between the test results and bread-making performance (Janssen *et al.*, 1996). The mixograph test is therefore suitable for describing mixing properties of a material (Kenny *et al.*, 1999), especially for weaker flours.

The stress relaxation, which uses small deformations, do not change properties of the material like the mixograph does, and are suitable describe physical or rheological properties of a material such as its extensibility and state of development (Kenny *et al.*, 1999). The stress relaxation test provided additional information to the mixograph results in some cases and not in others. Because the stress relaxation test is sensitive to the state of development of dough, having prepared doughs using the mixograph rendered the test less sensitive than it would have if the energy imparted to the dough had been strictly controlled by using a Do-corder for example.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Bread-making characteristics demonstrated by Lelie indicated that it was a very strong flour and that it was used under conditions designed for weaker flours. Tiger was a weak flour, needing much improvement to produce good bread. Silver Queen also exhibited weak bread-making characteristics, probably as a result of lower water addition than required for it.

Bread flours with different characteristics react differently to ascorbic acid and DATEM, and it is therefore not feasible to make general recommendations on concentrations of additives to be used for optimum bread-making.

Ascorbic acid did not stabilise bread doughs sufficiently against shock during processing probably due to its improving effect being exerted mainly in the early stages of the bread-making process (mixing and proofing). DATEM better stabilised dough against shock during processing, probably being able to stabilise both the gluten structure and the liquid film surrounding the growing gas bubbles during oven spring.

The mixograph was successful in characterising untreated flours in terms of bread-making quality. Lelie was predicted to be the strongest flour, followed by Silver Queen, with Tiger being the weakest. The stress relaxation test supported these findings, which were proven in the test bake, without providing additional information.

Both the mixograph and the stress relaxation test were unsuccessful in predicting the effect of ascorbic acid on Tiger and Silver Queen. The stress relaxation test however was successful in predicting the effect of ascorbic acid on baking

heights and drop baking heights of Silver Queen, therefore providing information not provided by the mixograph test. In the case of Lelie, the stress relaxation test results contradicted those of the mixograph test, which were correlated with test bake results.

The mixograph predicted the improving effect of DATEM on Tiger and Silver Queen only up to a point followed by no further change. The stress relaxation test predicted improvement even beyond the peak predicted by the mixograph. The continued improvement predicted by the stress relaxation test was observed in the test bake results. The stress relaxation test was therefore more sensitive than the mixograph test in predicting the effect of DATEM on Tiger and Silver Queen and provided additional information. The stress relaxation test provided no additional information on the effect of DATEM on Lelie.

Therefore the mixograph was less suitable in predicting improver effect on the two weaker flours (typically used by a major plant bakery in South Africa) than on stronger Lelie. Possibly the mixograph's large deformations changed the material properties of the weaker flours too much. It is therefore more suitable for predicting dough mixing properties and not bread improver effect.

The stress relaxation test gave more information on improver effect, especially of DATEM. It is recommended that, for better sensitivity of the stress relaxation test, the energy used to develop the dough be regulated more exactly by using e.g., the Do-Corder. The mixograph is less suitable for preparation of doughs to be tested using the stress relaxation test as the energy imparted to the dough cannot be accurately controlled.

CHAPTER 7

REFERENCES

AACC, 1983. Mixograph (Method 54-40A). *Approved Methods of the American Association of Cereal Chemists 8th edition*. St Paul, Minnesota: The American Association of Cereal Chemists.

ARMERO, E. & COLLAR, C., 1996. Antistaling additives, flour type and soughdough process: Effects on functionality of wheat doughs. *Journal of Food Science* **61**, 299-303.

CAUVAIN, S.P., 1998a. Bread- The Product. In: CAUVAIN, S.P. & YOUNG, L.S. (Eds.). *Technology of breadmaking*. London: Blackie Academic and Professional, 1-17.

CAUVAIN, S.P., 1998b. Breadmaking process. In: CAUVAIN, S.P. & YOUNG, L.S. (Eds.). *Technology of breadmaking*. London: Blackie Academic and Professional, 18-44.

CAUVAIN, S.P., 1998c. The Implication of pressure-vacuum mixing for ingredient quantities and improver formulations. *Proceedings of the First New Zealand Mechanical Dough Development Process*. Auckland: The New Zealand Institute for Crop & Food Research Limited.

CHEETHAM, G.R., 1997. The influence of dough development on South African breadmaking. *Harnessing Cereal Science and Technology for Sustainable Development*. Pretoria, South Africa: International Association for Cereal Science and Technology.

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

D'APPOLONÍA, B.L. & KUNERTH, W.H., 1985. Use of the mixograph and farinograph in wheat quality evaluation. In: FARIDI, H. (Ed.). *Rheology of Wheat Products*. St. Paul, Minnesota: American Association of Cereal Chemists, 27-49.

DIRNDORFER, M., 1992. Replacing potassium bromate. *Food Review* **27**, 29.

DONG, W. & HOSENEY, R.C., 1995. Effects of certain breadmaking oxidants and reducing agents on dough rheological properties. *Cereal Chemistry* **72**, 58-64.

EVERY, D., SIMMONS, L.D. & ROSS, M., 1998. How ascorbic acid works in MDD baking. *Proceedings of the First New Zealand Mechanical Dough Development Process*. Auckland: The New Zealand Institute for Crop & Food Research Limited.

FAUBION, J.M., DREESE, P.C. & DIEHL, K.C., 1985. Dynamic rheological testing of wheat flour doughs. In: FARIDI, H. (Ed.). *Rheology of Wheat Products*. St Paul, Minnesota: American Association of Cereal Chemists, 91-116.

FINNEY, K.F., YAMAZAKI, W.T., YOUNG, V.L. & RUBENTHALER, G.L., 1987. Quality of hard, soft and durum wheats. In: QUISENBERRY, K.S. & REITZ, L.P. (Eds.). *Wheat and Wheat Improvement 2nd ed.* USA: American Society of Agronomy, 677-748.

FITCHETT, C. S., & FRAZIER, P. J., 1986. Action of oxidants and other improvers. In: BLANSHARD, J. M. V., FRAZIER, P. J. & GALLIARD, T. (Eds.). *Chemistry and Physics of Baking*. London: Royal Society of Chemistry, 179-198.

FLITCROFT, A. L., 1998. The technology of bread improvers. *Proceedings of the First New Zealand Mechanical Dough Development Conference*. Auckland: The New Zealand Institute for Crop & Food Research Limited.

FRAZIER, P. J., 1979. Lipoxygenase action and lipid binding in breadmaking. *Bakers Digest* **53**, 8-20.

FRAZIER, P. J., 1992. Functionality of cereal macromolecules. *Food Science and Technology Today* **6**, 225-233.

FRAZIER, P.J. & DANIELS, N.W.R., 1986. Protein-lipid interactions in bread dough. In: BIRCH, G.G. & LINDLEY, M.G. (Eds.). *Interactions of Food Components*. London: Elsevier Applied Science Publishers, 299-326.

FRAZIER, P.J., FITCHETT, C. S. & RUSSELL EGGITT P.W., 1985. Laboratory measurement of dough development. *Journal of the Science of Food and Agriculture* **32**, 877-897.

FRAZIER, P.J., LEIGH-DUGMORE, F.A., DANIELS, N. W.R., RUSSELL-EGGIT, P.W. & COPPOCK, B.M., 1973. The effect of lipoxygenase action of the mechanical development of wheat flour doughs. *Journal of the Science of Food and Agriculture* **24**, 421-436.

GAN, Z., ANGOLD, R.E., WILLIAMS, M.R., ELLIS, P.R., VAUGHAN, J.G. & GALLIARD, T., 1990. The microstructure and gas retention of bread dough. *Journal of Cereal Science* **12**, 15-24.

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

- GRAYBOSCH, R.A., PETERSON, C. J., HARELAND, G. A., SHELTON, D. R., OLEWINK, M.C., HE, H. & STEARNS, M.M., 1999.** Relationships between small-scale wheat quality assays and commercial test bakes. *Cereal Chemistry* **76**, 428-433.
- GROSCHE, W., 1986.** Redox systems in dough. In: BLANSHARD, J.M.V., FRAZIER, P.J. & GALLIARD, T. (Eds.). *Chemistry and Physics of Baking*. London: The Royal Society of Chemistry, 155-169.
- GROSCHE, W. & WIESER, H., 1999.** Redox reactions in wheat dough as affected by ascorbic acid. *Journal of Cereal Science* **29**, 1-16.
- HAHN, B. & GROSCHE, W., 1998.** Distribution of glutathione in Osborne fractions as affected by additions of ascorbic acid, reduced and oxidised glutathione. *Journal of Cereal Science* **27**, 117-125.
- HAMER, R.J., WEEGELS, P.L., MARSEILLE, J.P., & KELFKENS, M., 1989.** In: POMERANZ, Y. (Ed.). *Wheat is Unique*. St. Paul, Minnesota: American Association of Cereal Chemists, 467-477.
- HOSENEY, R.C. & BROWN, R.A., 1983.** Mixograph studies V. Effect of pH. *Cereal Chemistry* **60**, 124-126.
- HOSENEY, R.C., 1994.** *Principles of Cereal Science and Technology* (2nd ed.). St Paul, Minnesota: American Association of Cereal Chemists, 197-211.
- ICC, 1992.** Method for using the Brabender farinograph, ICC Standard No. 115. Schwechat, Austria: Standard Methods of the International Association for Cereal Science and Technology.

- JANSSEN, A.M. VAN VLIET, J.M. & VEREIJKEN, J.M., 1996.** Fundamental and empirical rheological behaviour of wheat flour doughs and comparison with bread Making performance. *Journal of Cereal Science* **23**, 43-54.
- JUNGE, R.C., HOSENEY, R.C. & VARRIANO-MARSTON, E., 1981.** Effect of surfactants on air incorporation in dough and the crumb grain of bread. *Cereal Chemistry* **58**, 338-342.
- KAMEL, B.S. & HOOVER, R., 1992.** Production of bread using sodium stearoyl lactylate as replacement for shortening. *Food Research International* **25**, 285-288.
- KENNY, S., WHERLE, K., DENNEHY, T. & ARENDT, E.K., 1999.** Correlations between empirical and fundamental rheology measurements and baking performance of frozen dough. *Cereal Chemistry* **76**, 421-425.
- KENT, N.L., & EVERS, A.D., 1994.** *Kent's Technology of Cereals (4th ed.)*. Oxford, USA: Elsevier, Science Inc., 191-217.
- KERR, C., HOSENEY, R.C. & FAUBION, J.M., 1993.** Mixograph studies. VI. combined effects of charge (pH), activated double-bond compounds and oxidants on dough mixing properties. *Cereal Chemistry* **70**, 633-636.
- LANG, C.E., NEISES, E.K. & WALKER, C.E., 1992.** Effects of additives on flour-water dough mixograms. *Cereal Chemistry* **69**, 587-591.
- LARSEN, N.G., 1992.** Stickiness of bread and biscuit doughs. *Proceedings of the 42nd RACI Cereal Chemistry Conference*. Royal Australian Chemical Institute.

MEUSER, F. & SUCKOW, P., 1986. Non-starch polysaccharides. In: BLANSHARD, J. M. V., FRAZIER, P. J. & GALLIARD, T. (Eds.). *Chemistry and Physics of Baking*. London: Royal Society of Chemistry, 42-61.

MORGENSTERN, M.P., COMPANELLA, O.H. & ZHENG, H., 1998. Dough Development and Rheology. *Proceedings of the First New Zealand Mechanical Dough Development Conference*. Auckland: The New Zealand Institute for Crop & Food Research Limited.

NAGAO, S., 1985. Do-corder and its application in dough rheology. In: FARIDI, H. (Ed.). *Rheology of Wheat Products*. St. Paul, Minnesota: American Association of Cereal Chemists, 75-90.

NAGAO, S., ENDO, S. & TANAKA, K.J., 1981. Scanning electron microscopy studies of wheat protein fractions from doughs mixed with oxidants at high temperature. *Journal of the Science of Food and Agriculture* **32**, 235-242.

NAKAMURA, M. & KURATA, T., 1997. Effect of L-ascorbic acid on the rheological properties of wheat flour dough. *Cereal Chemistry* **74**, 647-650.

ORNERBRO, J., NYLANDER, T. & ELIASSON, A.C., 2000. Interfacial behaviour of wheat proteins. *Journal of Cereal Science* **31**, 195-221.

PAYNE, P.I., NIGHTINGALE, M.A., KRATTINGER, A.F. & HOLT, L.M., 1987. The relationship between HMW glutenin subunit composition and the breadmaking quality of British-grown wheat varieties. *Journal of the Science of Food and Agriculture* **40**, 51-65.

POLLIT, N., 1991. Bread additives: The facts. *Nutrition and Food Science* **133**, 16-17.

- POMERANZ, Y., 1988.** Composition and functionality of wheat flour components. In: POMERANZ, Y. (Ed.). *Wheat Chemistry and Technology (3rd ed.) Vol.2*. St Paul, Minnesota: American Association of Cereal Chemists, 219.
- POULSEN, C. & HOSTRUP, P.B., 1998.** Purification and characterisation of a hexose oxidase with excellent strengthening effects in bread. *Cereal Chemistry* **75**, 51-57.
- PRESTON, K.R. & KILBORN, R.H., 1982.** Sponge-and-dough bread: effects of fermentation time, bromate and sponge salt upon the baking and physical dough properties of a Canadian red spring wheat. *Journal of Food Science* **47**, 1143.
- RASPER, V.F., 1990.** Quality evaluation of cereals and cereal products. In: LORENZ, K.J. & KULP, K. *Handbook of Cereal Science and Technology*. New York: Marcel Dekker, 595-638.
- RASPER, V.F., HARDY, K.M., & FULCHER, G.R., 1985.** Constant water content vs constant consistency techniques in alveography of soft wheat flours. In: FARIDI, H. (Ed.). *Rheology of Wheat Products*. St. Paul, Minnesota: American Association of Cereal Chemists, 51-73.
- SCHOFIELD, J.D., 1986.** Flour Proteins: Structure and Functionality in Baked Products. In: BLANSHARD, J.M.V., FRAZIER, P.J. & GALLIARD, T. (Eds.). *Chemistry and Physics of Baking*. London: Royal Society of Chemistry, 14-29.
- SCHOGL, G., 1993.** Trends in quality control for wheat and wheat flours. In: TAYLOR, J.R.N., RANDALL, P.G. & VILJOEN, J.H. (Eds.). *Cereal Science and Technology Impact on a Changing Africa*. Pretoria, South Africa: The CSIR, 705-714.

- SHEWRY, P.R., HALFORD, N.G. & TATHAM, A.S., 1992.** High molecular weight subunits of glutenin. *Journal of Cereal Science* **15**, 105-120.
- SHUEY, W.C., 1984.** Interpretation of the farinogram. In: D'APPOLONÍA, B.L. & KUNERTH, W.H. (Eds.). *The Farinograph Handbook*. St. Paul, Minnesota: The American Association of Cereal Chemist, 31-32.
- SI, J.Q., 1997.** Synergistic effect of enzymes for breadmaking. *Cereal Foods World* **42**, 802-807.
- STABLE MICRO SYSTEMS, 1998.** From dough to bread. <http://www.stablemicrosystems.com/apmnov98.htm>
- STAUFFER, C.E., 1996.** *Fats and Oils*. St Paul, Minnesota: Eagan Press, 21-43.
- STEAR, C. A., 1990.** *Handbook of Breadmaking Technology*. Barking, England: Elsevier Applied Science, 60-85
- TATHAM, A.S., DRAKE, A.F. & SHEWRY, P.R., 1990.** Conformational studies of synthetic peptides corresponding to the repetitive regions of the high molecular weight (HMW) subunits of glutenin. *Journal of Cereal Science* **11**, 189-200.
- TAMSTORF, S., JOHNNSON, T. & KROG, N., 1986.** The role of fats and emulsifiers in baked products. In: BLANSHARD, J.M.V., FRAZIER, P.J. & GALLIARD, T. (Eds.). *Chemistry and Physics of Baking*. London: The Royal Society of Chemistry, 75-88.
- TILLEY, M.K.A., BENJAMIN, R.E., BAGOROZA, K.E., OKOT-KOTBER, B.M., PRAKASH, O. & KWEN, H., 2001.** Tyrosine cross-links: molecular basis of gluten structure and function. *Journal of Agricultural and Food Chemistry* **49**, 2627-2632.

- TIPPLES, K.H., PRESTON, K.R., & KILBORN, R.H., 1982.** Implications of the term "strength" as related to wheat flour quality. *Bakers Digest* **56**, 16-20.
- VERMULAPALLI, V., MILLER, K.A. & HOSENEY, R.C., 1998.** Glucose oxidase in breadmaking systems. *Cereal Chemistry* **75**, 439-442.
- WALTHER, C. & GROSCH, W., 1987.** Substrate specificity of the glutathione dehydrogenase (dehydroascorbate reductase) from wheat flour. *Journal of Cereal Science* **5**, 299-305.
- WILLIAMS, T. & PULLEN, G., 1998.** Functional ingredients. In: CAUVAIN, S.P. & YOUNG, L.S. (Eds.). *Technology of Breadmaking*. London: Blackie Academic and Professional, 45-80.
- XUIZHEN-LU & SIEB, P.A., 1998.** Assay of dehydroascorbic acid in bread and dough added as a crystalline dimer. *Cereal Chemistry* **75**, 200-206.
- YAMADA, Y. & PRESTON, K.R., 1992.** Effects of individual oxidants on oven rise and bread properties of Canadian short process bread. *Journal of Cereal Science* **15**, 237-251.
- YAMADA, Y. & PRESTON, K.R., 1994.** Sponge-and-dough bread: effects of oxidants on bread and oven rise properties of a Canadian red spring wheat patent flour. *Cereal Chemistry* **71**, 297-300.