# Members Only R&D REPORT NO. 152

Factors affecting the loss of perceived freshness in cakes

2001

# Campden BRI

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Chipping Campden Gloucestershire GL55 6LD, UK

Tel: +44 (0)1386 842000 Fax: +44 (0)1386 842100 www.campden.co.uk

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# Factors affecting the loss of perceived freshness in cakes

J Anstis and T Sharp

2002

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#### **Abstract**

"Freshness", as perceived by the consumer, is usually associated with the softness and moistness of cake. Apart from mould growth, the change in eating quality is the biggest factor in determining customer acceptance of cake products. The aim was to identify the effects of altering ingredient ratios and storage conditions on the perceived fieshness of high-ratio unit and fruit cakes.

Using a statistical design, ingredients were combined in differing amounts and baked into cakes that were assessed for flavour and texture changes during storage by a sensory panel, and for texture changes using instrumental methods.

Results showed that sensory and instrumental texture measurements were highly correlated, and that low volume cakes were initially firmer, becoming increasingly so during storage.

Cakes with higher moisture and lower starch contents lost perceived fieshness most rapidly, whilst ingredients such as fat, egg and fruit had no significant effect on texture. Low levels of egg, however, did increase the incidence of off-flavours in stored cakes. Reducing the storage temperature prolonged the perceived fieshness of cakes.

Although Differential Scanning Calorimetry did not show that starch retrogradation occurred during cake storage, a progressive loss of freezable water was detected and might be used to monitor changes during storage. Improving perceived fieshness will enable industry to improve quality throughout storage, or to extend the period of consumer acceptability of cake products.

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#### 1.0 **Aim**

The aim of this work was to **identify** the effects of altering ingredient ratios and storage conditions on the perceived fieshness of high-ratio unit and **fruit** cakes. The benefits to industry should include: Development of an understanding of how ingredient balance and storage conditions affect the rate of staling and the loss of **perceived** fieshness, and linking objective and subjective texture measurements across a range of cake qualities.

Consequently, it is expected that **this** work will enable the manufacturing industry to optimise eating quality throughout shelf life for new and existing cake products.

### 2.0 Introduction

The definition of loss of fieshness is dependent on what the consumer expects from a freshly baked product. For example, the texture of bread and cakes tends to become firmer and drier over storage, compared to pastry products which are perceived as 'stale' when they become soft and moist over storage.

The word "stale" tends to be classed as a physical or chemical term, and is not associated with microbial spoilage (Guy 1980). On a sensory level, staling is a term which describes the changes to product texture and eating quality, caused by changes in the starch, which adversely affect the perceived fieshness of a product (Cauvain, 1992). It is a major factor affecting the loss of perceived fieshness in soft bakery products.

The majority of work has been completed on the mechanism of staling in bread with very little in the cake area. Zobel and **Kulp** (1996) give a comprehensive review of bread staling. Work, to date, has concluded that there are two basic processes occurring in the **crumb during** chemical staling:

- 1. Intrinsic firming of the crumb cell wall material.
- 2. Macroscopic migration of moisture from the centre of the cake crumb to the drier crust regions, causing the crumb to firm over time.

It has been shown that the extent of crystallisation of wheat starch gels depends on the moisture content (Longton and LeGrys, 1981). Crystallisation did not occur when the total solids content was below 10% or above 80% - implying that a reduction or excess of moisture in the system results in lower levels of chemical staling.

The reduction in water content would, however, reduce the initial softness of the crumb.

The loss of perceived freshness is a widespread problem for manufacturers, distributors and retailers of baked products. Demand for better quality products is increasing constantly, as is the need to extend a product's shelf life beyond mould-free problems.

Previous work (Guy *et* al, 1983) has shown that recipe alterations which reduce the amount of starch in a cake formulation, i.e. increasing **crumb** moistures and altering texture, will affect the rate of staling and perceived loss in crumb freshness.

Data produced by Sych *et al* (1987) indicate that cake moisture loss did not account for all the increases in cake **crumb** firming and that a secondary firming process may intervene. This work also stated that the initial cake crumb **moisture** content might affect the type of firming behaviour during storage. Low moisture cake crumb did not produce the same firming curve as samples of **higher** moisture content. It was speculated that this might be due to incomplete starch gelatinisation at the lower moisture levels.

### 2.1 Staling mechanism

#### **Starch properties**

Starch is a polysaccharidemade up of glucose units, which can exist in two forms:

**Amylose** (20-25%) - a long chain molecule composed of glucose units linked like beads. **A** predoniinantly dominant linear a-(1-4)-glucan, a mobile polymer which is unstable in the hydrated form in water.

**Amylopectin** (75-80%) - glucose units forming a branched structure. Highly branched, high molecular weight, an a-glucan, based on 1-4 glycosidic linkages with a-(1-6) branch points.

Seventy percent of the starch granule is believed to be amorphous, i.e. a solid that is not crystalline, and much of the amylopectiii is in an amorphous state. During baking, the crystalline structure of starch is disrupted as the starch granules swell with moisture uptake and deform. The degree of disruption depends on the availability of the water in the system, which in turn is linked to the level of dissolved solutes in the aqueous part of the system.

During the mixing of a cake batter, the starch in the flour hydrates, and on heating gelatinisation begins. Gelatinisation occurs when starch is heated in the presence of water, which involves several different processes:

- starch granule swelling;
- conformational change of the starch, accompanied by hydration;
- translation and rotational diffusion of portions of starch chains within the granule;
- breaking or disintegration of the starch granule; and
- increased viscosity due to loss of water to the starch granules and from loss of hydrated starch polymer from disrupted granules.

After baking, the starch polymers are hydrated and amorphous for a brief period before complexing. Starch polymers can form double helices with their neighbouring molecules and within molecules. These double helices aggregate to form crystalline junction areas (when two molecules intertwine in a double helix). It is also possible for starch polymers to complex with monoacyl lipids and other molecules in a single helix to form isolated crystalline structures. This mechanism is described as starch retrogradation or starch recrystallisation, and it is this more ordered structure and redistribution of water that changes the eating quality.

### 2.2 Starch retrogradation

A definition of starch retrogradation according to Atwell *et al* (1988) is 'the event which occurs when starch molecules begin to associate into ordered structures. In the initial phase, two or more molecules may form a simple juncture point that can develop into more extensively ordered regions. Ultimately, under favourable conditions, crystalline order appears.'

The crystalline phase is not always obvious, and as in the early stages of retrogradation, this terminology applies to the number of independent double helices present. The basic reactions occurring during the process of starch retrogradation or 'chemical' staling involve:

- the formation of crystals as double helices stacking together;
- the crystal junctions increasing crumb firmness; and
- crystals forming on nuclei (the amylose complexes may act as nuclei for the amylopectin).

# 2.3 Differential Scanning Calorimetry (DSC)

This equipment can be used to track the thermal changes that occur in materials, including bread and cake products, when they are heated under controlled conditions. Using the equipment, the starch crystals within a cake crumb sample are melted and show endothermic peaks at given temperature ranges:

amylose/lipid @ 100-110°C
amylopectin A @ 55-60°C
amylopectin B @ 50-60°C
'freezable' water @ approx. 0°C

The measurement of the heat required to melt the crystals can be monitored to record the growth of crystals, i.e. retrogradation.

#### 'Freezable' water

Vodovotz and Chinachoti (1998) indicated that thermal transitions monitored by DSC go through some changes upon the ageing of a wheat starch gel. The enthalpy of ice melting and the percent 'freezable' water decreased in a parallel fashion with increased storage time. The ice melting peaks can be shown as the major endothermic transition at about 0°C. The peak decreased in magnitude during storage, and the change in enthalpy of the DSC endotherm can be used to calculate the percentage 'freezable' water. With an increase in both the amount of 'unfieezable' water and the degree of amylopectin recrystallisation, there is an increase in the glassy-rubbery transition involving more than just moisture loss. Some amorphous network may also have developed extensively, and during storage the segmental mobility in certain regions may be increasingly restricted due to the additional cross-links.

It was suggested by Willhoft (1973) that the starch fraction was more dilute in cakes than in bread and undergoes retrogradation at a reduced rate because of less available moisture in the cake crumb. It is therefore very difficult to obtain a 'staling enthalpy peak' for a high ratio cake sample, particularly over 21 days storage time, due to the low concentration of starch in the formula. With this information in mind, and also work completed by Vodovotz and Chinachoti (1998), it was believed that the first enthalpy peak would occur at about O°C, giving an indication of some starch retrogradation reactions.

# 2.4 The effect of ingredient interactions on the staling reaction

#### **2.4.1** Lipids

The presence of lipids can influence starch granule properties as they lower the granule hydration abilities, swelling power and solubilisation (Morrison, 1995). Long chain lipids are probably capable of forming inclusion complexes with amylose under suitable conditions. Triglyceride binding by chlorinated starch granules under mild conditions is a property of starch surface proteins (Seguchi, 1984). Amylopectin also binds lipid complexes but at a substantially lower level than amylose (Lagendijk & Pennings 1970).

#### **2.4.2 Sugars**

Sucrose, maltose and lactose have been shown to slow the firming rate of starch gel systems in cakes, specifically at high levels. This is due to an interaction with the starch related to their hydrodynamic volume contribution in the gel (Maxwell and Zobel, 1978). There is also a major interaction between the sugars and the temperature of starch gelatinisation; sucrose elevates the starch gelatinisation temperature. Sucrose is effective at reducing the crystallisation of starch during heating (baking) - perhaps due to a steric effect interfering with crystallisation or the quantity of fiee water present in the gel system to reduce the rate of starch crystallisation and/or plasticise the crystalline network (Maxwell and Zobel, 1978). In concentrated sucrose solutions, chlorinated starch granules exuded a significantly higher level of amylose (Telloke, 1986). Again this may affect the subsequent starch retrogradation process.

#### 2.4.3 Moisture

As water content increases in a wheat starch system, crystallisation is inhibited at higher moisture levels. Increasing the available water in a starch gel appears to accelerate the gelling of the amylose, but slows the **complexing** and crystallisation of amylopectin (van Soest *et* al, 1994).

#### **2.4.4 Surfactants (emulsifiers)**

Formation of amyloselsurfactant (monoglyceride) complexes is part of the explanation behind the use of commercial emulsifiers as anti-crumb firming agents. Theory considers that the formation of these types of complexes inhibits staling by either:

- directly preventing amylose or amylopectin retrogradation, or
- indirectly by having fewer B-type nuclei that could promote amylopectin retrogradation and the development of crystalline structures (Zobel, 1973).

Studies using DSC have followed the progressive retrogradation of amylopectin in wheat starch (bread products) over time. The analysis showed that the presence of only 1% monoglyceride in the bread had an effect on the extent of starch retrogradation - indicating the surfactant's reaction with the amylopectin (Krog *et* al, 1989).

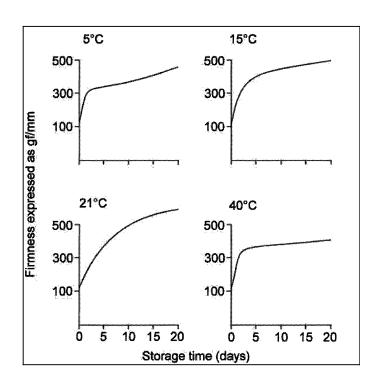
In this project, the use of emulsifiers is limited to the 3% inclusion of glycerol monostearate present in the high ratio shortening.

# 2.5 Effect of cake storage temperature on the loss of perceived freshness

The intrinsic firming of cake crumb is retarded at low temperatures, the maximum rate having been seen at about 15°C for a plain slab cake formulation. As the temperature increases further, the process slows again. Extrinsic firming is slowed with reduced temperature, due to the reduced rate of moisture transfer from the cake crumb to the crust.

A slow firming rate has been reported at storage temperatures of 0-5°C for whole cakes, and above 20-25°C for crustless cakes. The fastest rate of staling was seen at 15-20°C for whole cakes (Guy *et* al, 1983), see Figure 1.

Figure 1



Taken from FMBRA Report No. 107 (1983)

The work described in the current report is based on storage temperatures of 21°C and 8°C, since dairy cream cakes are kept at below 8°C to ensure that the cream does not support microbial growth. The majority of cakes in the ambient sector are held at 20-21°C for storage, so it was sensible to carry out trials at this storage temperature range.

#### 3.0 Materials and Methods

High-ratio unit cakes were produced according to a statistical plan of formulations derived from a mixture model software package. These were further screened through recipe balance software (CCFRA Cake Expert System) to ensure that all recipes were viable (i.e. able to produce a cake suitable for testing).

Using a range of balanced formulations (see Table 1), plain cakes were produced (see Appendix A for method), wrapped in moisture impermeable film and stored at two temperatures; 8°C and 21°C. Table 2 shows the quantity of fruit (sultanas) in the fruited cakes.

Cakes were assessed over 21 days storage for crumb firmness, recovery and cohesiveness using an instrumental texture analyser for Texture Profile Analysis (see Appendix E). Staling was assessed using Differential Scanning Calorimetry, and loss of perceived freshness using a trained sensory panel. Cake specific volume, crumb moisture and equilibrium relative humidity (ERH) assessments were also carried out using standard methods, and photographs were taken as a record. The sensory panel produced 4 attributes to describe the plain and fruited cakes. These were firm, dry, stale, and off-flavours (see Appendix B for assessment methods).

## **Recipes for High Ratio and Fruited Cakes**

# Basic High-Ratio Cake Formulation

# Ingredients

	% Flour weight
High-ratio cake flour	100.0
White high-ratio shortening	60.0
Whole liquid egg	80.0
Baking powder	4.0
Caster sugar	115.0
Water	60.0
Salt	2.5
Skimmed milk powder	7.0

# Basic High-Ratio Fruited Cake Formulation

Ingredients

	% Flour weight
High-ratio cake flour	100.0
White high-ratio shortening	60.0
Whole liquid egg	55.2
Baking powder	4.0
Caster sugar	115.0
Water	88.6
Salt	2.5
Skimmed milk powder	7.0
Tartaric acid	0.1
Sultanas*	136, 92, 48

<sup>\*</sup> High (136), standard (92), low (48) fruit levels

Table 1 - Recipes for plain cakes

Recipe number	% sugar	% added water	% fat	% liquid egg
1	100.0	60.0	80.8	21.2
2	115.8	98.6	24.9	24.4
3	135.2	47.6	80.1	78.2
4	100.0	71.1	25.1	6.5
5	100.0	39.6	48.7	47.7
6	100.0	71.1	25.1	6.5
7	100.0	66.2	79.8	78.1
8	134.7	70.1	49.1	48.4
9	135.4	138.3	50.0	48.7
10	100.0	39.2	80.1	48.1
11	135.1	158.8	80.1	21.2
12	135.3	115.3	80.4	78.1
13	135.1	128.4	50.5	13.4
14	100.0	39.2	80.1	48.1
15	135.2	91.1	79.9	21.4
16	115.8	100.8	24.9	21.5
17	100.0	60.0	80.1	21.2
18	100.0	89.4	50.0	13.2
19	100.0	121.0	24.9	6.7
20	135.2	88.7	25.1	24.5
21	100.0	89.2	49.1	48.1
22	135.0	169.5	25.0	6.8
23	116.1	80.3	50.2	13.5
24	100.0	110.0	80.2	21.1
25	116.9	80.3	50.2	13.5

Table 2 - Recipes for fruited cakes

Fruit Level	% sultanas in batter	Average % sultanas in final baked product
High fruit	24.0	26.5
Standard fruit	17.5	19.2
Low fruit	10.0	11.1

All values are based on a flour weight of 100%

# 4. Results for High-Ratio Cakes

# **4.1 Sensory Profiling**

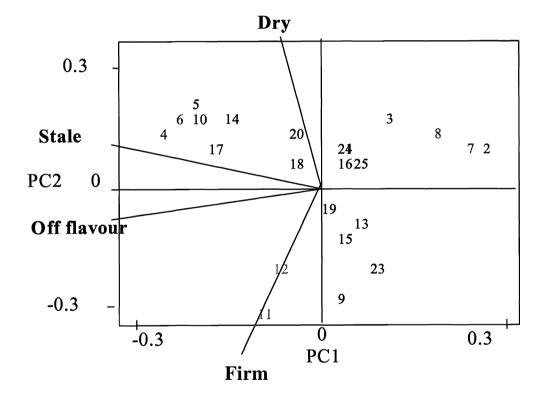
The principle component (PC) analysis for this data set is based on the mean assessments of 4 sensory attributes(firm, dry, stale and off flavours) for 25 recipes, 5 storage times and 2 storage temperatures (See Figure 2 for the PCA plot).

PC1 is weighted for staleness (-ve) and off-flavour (2nd -ve)

PC2 is weighted for dryness (+ve) and firmness (-ve)

NB when a cake is perceived as dry it is not perceived as firm, and *vice* versa. Dryness and staleness attributes are highly correlated in this data set although dryness has a low correlation with off-flavour.

Figure 2 - Principle Component Analysis of all samples



A summary of this PCA plot is as follows:

The recipe cakes perceived as **least stale** had higher levels of liquid, sugar and fat.

(Recipes 2,7 and 8).

The recipe cakes perceived as **most stale** had lower levels of liquid, sugar and fat.

(Recipes 4 and 6).

Cake crumb perceived as the **least dry** came from standard type recipe.

(Recipe 9 and 23)

Crumb perceived as the **most firm** had higher levels of sugar, water and fat.

(recipe 11 and then 12)

Crumb perceived as the **least firm** had high sugar but low water levels.

(recipe 3)

There was a relationship between crumb firmness and specific cake volume, i.e. as specific cake volume falls, crumb firmness increases, see recipes 9, 11 and 12 all of which gave cakes with a very poor crumb structure, and conversely, recipe 3 which had a coarse, open structure.

The same type of information can be plotted to evaluate what happens over a 21-day storage at ambient temperatures (fig 3-7). A very similar trend can be seen with chilled storage (figs 8 – 12). These are summarised in table 3.

#### **Principal component plots**

Figures 3-7 Ambient storage (numbers in **bold** indicate significant effects).

Figure 3 - Day 1

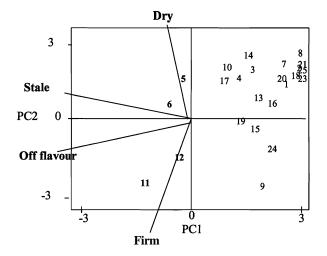


Figure 4 - Day3

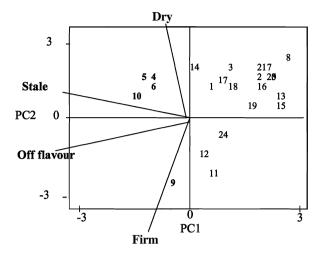


Figure 5 – Day 7

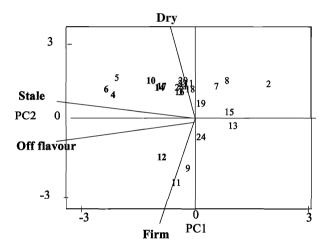


Figure 6 - Day 14

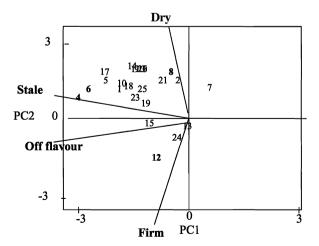
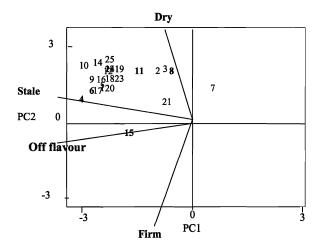


Figure 7 - Day 21



Figures 8 - 12 Chilled storage

Figure 8 - Day 1

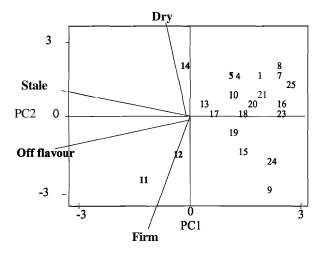


Figure 9 - Day 3

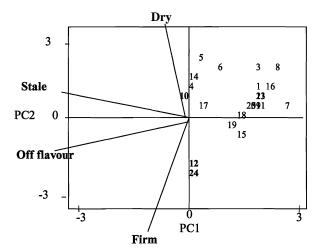


Figure 10 - Day 7

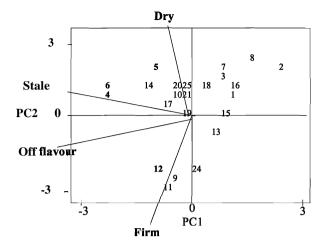


Figure 11 - Day 14

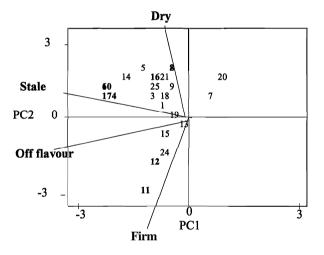


Figure 12 **-** Day 21

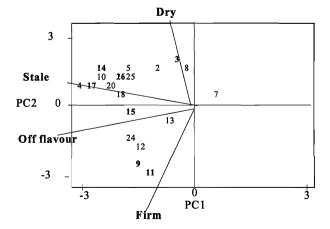


Table 3 Principal Component Analysis: Summary of sensory attributes over storage life (refer to graphs above)

Storage day 1RecipeStorage day 1RecipeFirmest crumb11,12Firmest crumb11,12Most dry5Most dry14	
	•
Most dry 5 Most dry 14	
111000 017	
Most stale 6 Most stale -	
Storage day 3 Recipe Storage day 3 Recip	<u>e</u>
Firmest 9 Firmest crumb 24,12	,
Most dry 4,5,6 Most dry 10	
Most stale 10 Most stale -	
Storage day 7 Recipe Storage day 7 Recip	e
Firmest 12 Firmest 12	_
Most dry 10,14,17 Most dry 5	
Most stale 6,4 Most stale 4,6	
Storage day 14 Recipe Storage day 14 Recip	<u>e</u>
Firmest 12 Firmest 11,12	,
Most dry 8 Most dry 8,16	
Most stale 4,6,1	0,17
Storage day 21 Recipe Storage day 21 Recip	e
Firmest Firmest 9,11	_
Most dry 8 Most dry 3	
Most stale 4,6,11 Most stale 14,17	
Off flavour 15 Off flavour 15	

## Summary over 21 days storage

#### Firmest crumb

Recipes **9**, 11, and 12 all contained high **liquid** levels, 135% sugar and also high levels of fat in the formulations. All of these recipes produced unacceptable cakes with a very solid crumb with little or no crumb structure - similar to a 'marzipan' texture.

#### Most dry crumb

The recipes in this area differed for both chilled and ambient storage temperatures and storage day. Recipes 3 and 8 tended towards dryness at day 21 storage; both recipes contain high levels of liquid and sugar, and different levels of fat.

#### Most stale crumb

Recipes **4**, 6 and 10 all produced high correlations with the staleness attribute over 21 days ambient storage. This may be due to each recipe containing low levels of egg the presence of high levels of egg in a plain cake recipe (i.e. without additional flavourings) may mask any **flavour/texture** changes classed as 'staleness' by the sensory panel.

#### Perceived staleness versus ratio of flour: water

The higher the flour:water ratio, the greater the sensory perception of staleness in the plain cakes. Low staleness scores were achieved with recipe 2 that contained a ratio of approximately 1 part flour:1 part water, whereas high staleness scores had a ratio of 1.5 parts flour:1 part water.

#### Perceived firmness versus ratio of flour: water

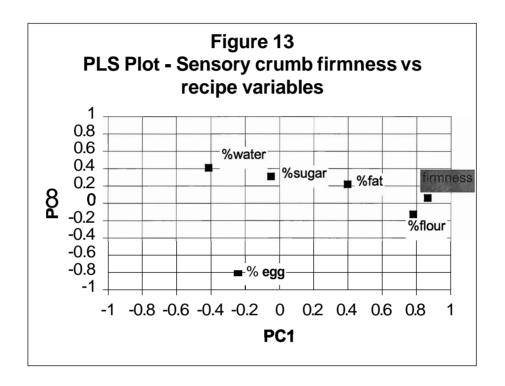
The higher the flour:water ratio, the greater the increase in sensory perception of firmness. Low firmness scores were for recipes 2 and 16, which had 0.75-0.85 parts flour for every 1 part of water. As the level of flour increased above the level of water in the recipe, so the firmness score increased – see recipes 4, 1, and 6.

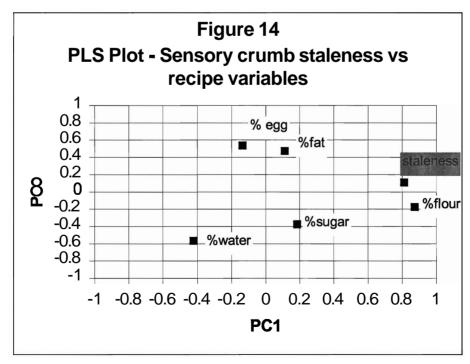
#### Other ingredient influences on sensory profiling of final cakes

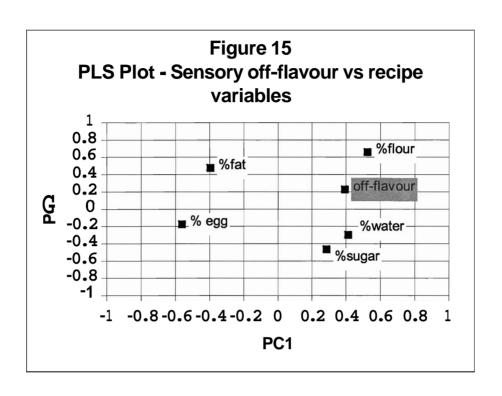
There was no significant effect of fat level on the sensory perception of cake firmness, dryness or staleness within the formulation ranges used for these tests. Low levels of egg may enable the sensory panellist to have a clearer perception of cake 'staleness' but this could not be validated by statistical results since acceptable cakes could not be produced with low egg content.

### Sensory Profiling - Partial Least Squares (PLS) results

As expected there was a high positive relationship between level of flour and crumb **firmness**, and a highly negative relationship between crumb firmness and water level (Figure 13). Staleness was positively associated with flour level, and negatively with water level (Figure 14). Off-flavour had a high negative association with egg and fat levels and a positive relationship with flour level (Figure 15).







# 4.2 Chemical staling – change in DSC first enthalpy peaks over storage

For the work on this study, there were no 'staling' enthalpy peaks detected by **DSC**, but through discussion it was decided that the enthalpy 1 peak would be used as a guide to the predicted reactions occurring within the cake crumb. This enthalpy 1 peak provides information on the 'free water' present within the sample. This water is not expressed by the measurement of **ERH/water** activity and is the 'freezable water' that will reduce as the cake 'ages' as this water becomes bound within the starch matrix.

The overall trend was for a loss in 'fieezable water', with a significant reduction in enthalpy 1 value at days 3/4 or 7 of storage (Table 4).

The most significant loss of 'freezable water' was at ambient storage temperatures; a lower rate was apparent for chilled storage.

Table 4

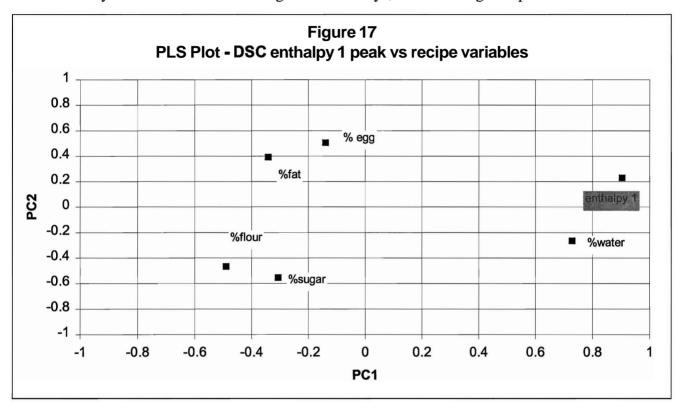
Recipe	Loss of 'freezable water' from different recipes	Ingre	edient le %	vel
	-	Liaui	d Sugar	Fat
4		78	100	25
5	After 4 days storage	87	100	49
6	Their rady storage	78	100	25
14		87	100	80
17		07	100	00
3*	I	126	135	80
1	After 7 days storage	81	100	80
20*	After / days storage	113	135	25
20.		113	133	23
23		94	116	50
25*	After 14 days storage	94	117	50
8*	After 14 days storage	119	135	49
0		119	133	49
2		102	116	01
2		123	116	81
7		144	100	80
13	Limited loss throughout 21 days storage	142	135	50
16	(enthalpy 1 peak 40-25 J/g)	123	115	25
18		102	100	50
19		128	100	25
21		137	100	50

<sup>\*</sup> Reduction in rate of loss of 'freezable water' at chilled storage temperatures.

From Table 4 it can be seen that the loss of 'freezable', (free) water occurred most rapidly from recipes containing the lowest amounts of added water. As levels of added water increased, the loss of 'fieezable' water was delayed. Recipes with the highest added water levels only showed limited loss of 'freezable' water (recipes 2,7,13,16,18,19,21)

There was a highly positive relationship between water level and the Enthalpy 1 values, and a high negative association with flour level (figure 17). This was to be expected as the recipe ingredients involved in the **staling** reaction are water and starch.

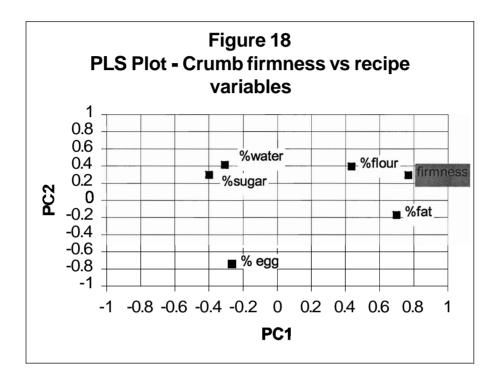
Recipe 13 was different **from** the others due to the reduced loss of 'fkeezable water' over 21 days storage at either storage temperature. The cakes contain high levels of sugar and water. This result is mirrored by the sensory staleness scores, i.e. the sensory score remained low throughout the 21 days, at both storage temperatures



## 4.3 Instrumental texture changes over storage/recipe formulation

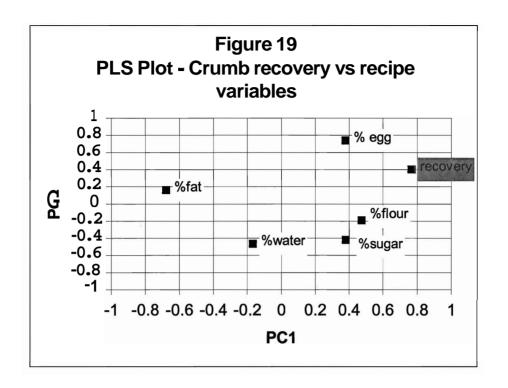
The relationship between various Texture Profile Analysis parameters and that of the recipe formulation ingredients can be explained using PLS plots.

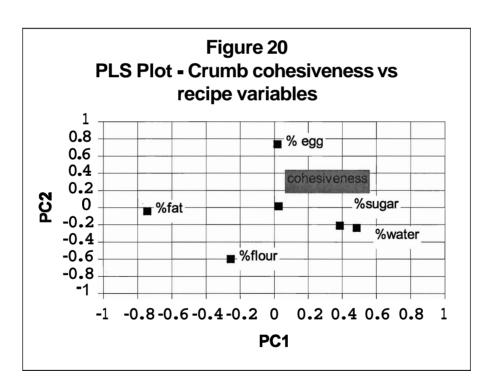
There was a high positive association between crumb firmness and the flour and fat level and a negative relationship with egg, sugar and water levels (Figure 18).



There was also a positive link between the egg level and **crumb** recovery parameter, and a negative link with water and fat levels (Figure 19).

The cohesiveness of the crumb was not significally related to any of the recipe variables by PLS analysis (Figure 20).



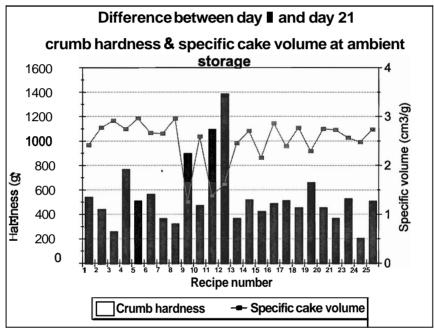


### 4.4 Relationship between crumb firmness and cake specific volume

There was a relationship between **instrumentally** measured crumb firmness and specific cake volume (Figure 21). Lower specific cake volumes were associated with increasing crumb firmness (i.e. recipes 9, 11 and 12, which have very poor crumb structure).

Guy et *al* (1983) found that cakes made with the largest volumes had the lowest firming rates; cakes with low volumes were much **firmer** initially and also firmed more rapidly than the high volume products.

Figure 21



# 4.5 Relationship between perceived crumb dryness (sensory score) and crumb moisture/ERH measurements

Data were averaged for the 17 recipes which produced 'acceptable cakes', at both storage temperatures over the storage period. As expected there was a high correlation between sensory perception of crumb 'dryness' and actual crumb moisture measurements (See Table 5). A similar correlation was observed with ERH and sensory perception of crumb 'dryness'.

Table 5 – Correlation values for sensory perceived crumb 'dryness' and actual crumb moisture/ERH.

	Sensory crumb 'dryness <sup>s</sup>
Crumb moisture content (actual)	-0.772
Crumb ERH	-0.792

# 4.6 Instrumental texture measurement of fwmness and sensory firmness perception

There was a high positive correlation (see Table 6), between instrumental texture measurement firmness and sensory firmness, based on the 17 'acceptable' cake recipes. Guy et al (1983) also previously saw this type of relationship.

Other sensory tests evaluated the effects of staling on bread crumb texture, firmness, mouthfeel, taste and flavour changes. Studies confirmed a correlation between sensory ratings and changes in crumb firmness measured instrumentally (Waldt 1968). Agreement between sensory and instrumental testing is often difficult to obtain as small changes in the crumb may have a large effect on the consumer judgement (Bechtel and Meisner 1954)

Table 6 – Correlation coefficient for instrumental crumb firmness and sensory perception of crumb 'firmness' and 'staleness'.

	Instrumental crumb firmness
Sensory perceived crumb 'firmness'	0.784
Sensory perceived crumb 'staleness'	0.613

# 4.7 Correlation between instrumental texture measurement of firmness and sensory staleness perception

There was a lower correlation between these parameters compared with the relationship between instrumental texture measurement of firmness and the sensory perception of 'firmness' (Table 6). There was a slight increase in measured crumb firmness as the crumb was perceived as more stale by sensory profiling (the staleness score increased). These correlation figures were based on the 17 'acceptable' cake recipes.

# 4.8 Correlation between instrumental texture measurement of firmness and DSC first enthalpy peak

There was a low negative correlation between these parameters (Table 7), with a slight increase in crumb firmness as the **DSC** first enthalpy peak reduced. The amount of 'freezable water' is reduced as the **crumb** firms; it **may** be that this water bound in another chemical reaction (possibly staling).

Table 7 – Correlation coefficient relating Instrumental measurement of crumb firmness and the DSC first enthalpy peak.

	DSC first enthalpy peak
Instrumental crumb firmness	<b>-</b> 0.47

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# 4.9 Effects of storage temperature on loss of perceived freshness

## 4.9.1 Changes in sensory perception of cake crumb with storage temperature.

The reduction in storage temperature created a slight reduction in the loss of crumb freshness, i.e. fewer recipes had moved into the top-left sector on the PCA plot after 21 days stage (Figures 22 and 23). It was observed that during chilled storage more of the cake recipes were described as firm, whereas the majority of ambient stored cakes were positioned in the stale/dry sector on day 21 of storage.

Figure 22 – Day 21 ambient

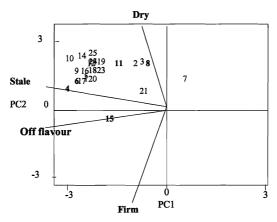
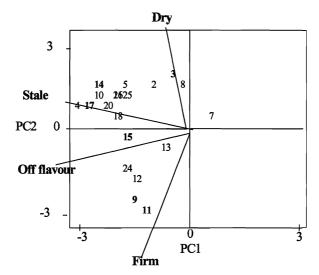
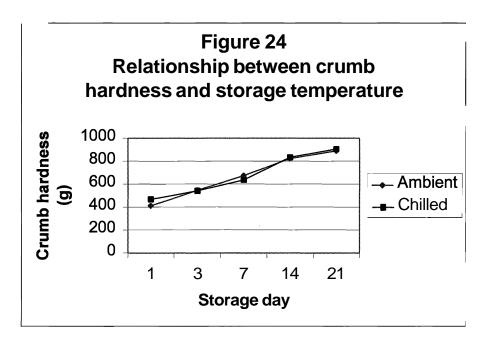


Figure 23 – day 21 chilled

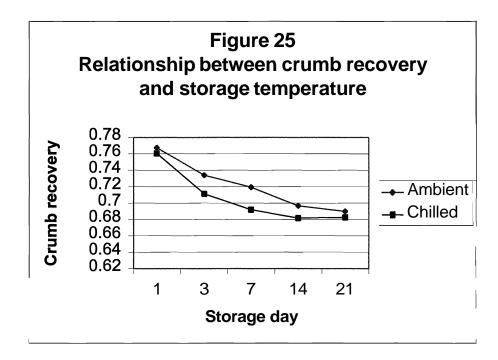


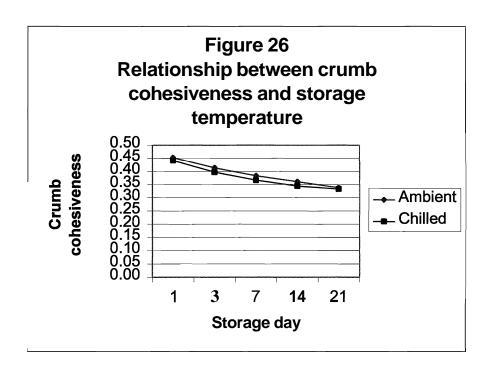
#### 4.9.2 Changes in instrumental texture measurements with storage temperature

Crumb firmness (Figure 24) was not significantly influenced by storage temperature (r = 0.718, p > 0.05).



Crumb recovery (Figure 25) and crumb cohesiveness (Figure 26) were both significantly affected by storage temperature. The effect on recovery was significant at the p < 0.05 level and crumb cohesiveness at the p < 0.01 level.



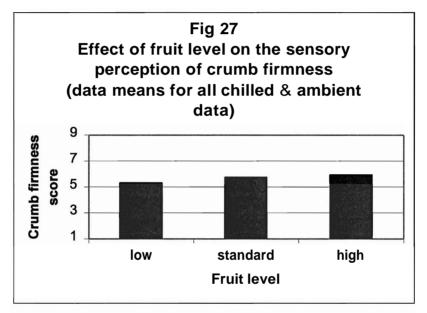


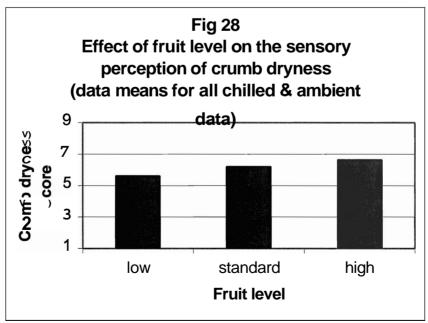
There was an overall highly significant effect of storage time (days) with all the instrumental texture measurement parameters. Cake crumb became firmer, less cohesive and lost its recovery over the 21 days storage trial.

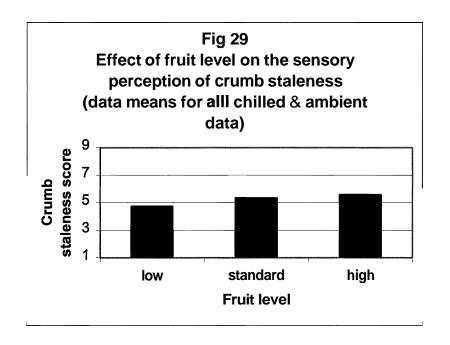
#### 5. Results for Fruited Cakes

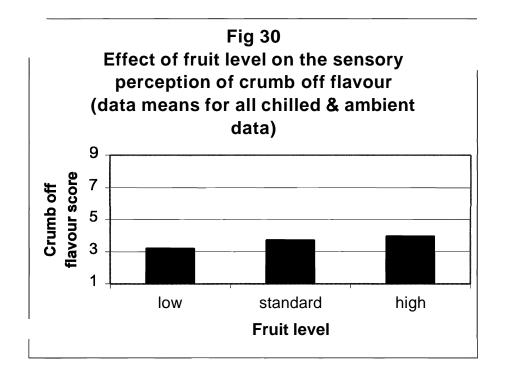
#### 5.1 Influence of fruit level on sensory perception of crumb freshness

The results of ANOVA statistical analysis of the effects of the experimental variables on the loss of cake freshness of **fruited** cakes are shown in Table 8. Storage over 21 days (at both storage temperatures) produced a similar trend for firmness, dryness, staleness and off-flavour • with the high fruit level exhibiting the greatest rate of increase in crumb firming, dryness and staleness, and off-flavour (Figures 27-30). There was a significant influence of storage temperature on these sensory parameters (except for crumb firmness); sensory scores were slightly higher at ambient storage.









As with the plain cakes, storage time had **a** highly significant effect on all sensory attributes. There was an **increase** in firmness, staleness, dryness and off-flavour.

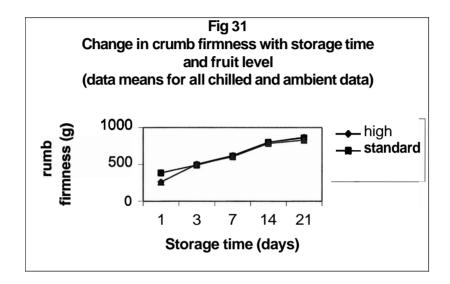
Table 8 - ANOVA results for fruited cakes

Effect	Fruit level	Storage time	Storage temperature	Fruit level * storage time	Fruit level * storage temperature	Storage time * storage temperature
Instrumental texture						
Coremoisture	***	NS	NS	**	NS	NS
Core ERH	***	*** ***	NS	**	NS	NS
Crumb firmness	NS	***	NS	NS	NS	NS
Crumb cohesiveness	NS ***		***	NS	NS	NS
Crumb recovery	***	***	NS	NS	NS	**
Sensory perception						
Firmness	***	***	NS	NS	NS	*
Dryness	***	***	***	NS	NS	***
Moistness	***	***	**	NS	NS	NS
Stale	***	***	***	NS	NS	*
Off flavour	***	***	***	NS	NS	*
DSC						
Enthalpy l	***	***	***	*	NS	**

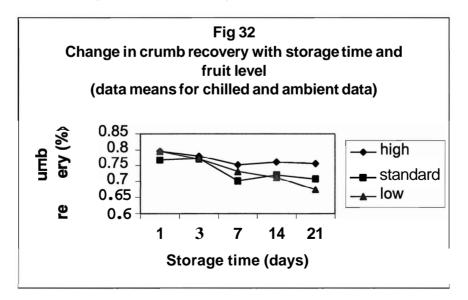
KEY	
***	Significant at the 0.1% significance level
**	Significant at the 1% significance level
*	Significant at the 5% significance level
NS	Not significant at the 5% significance level.

## **5.2** Influence of fruit level on instrumental texture measurements

Instrumental **firmness** data exhibited the trends recognised by the sensory assessment score for the dryness and firmness attributes, although **ANOVA** data showed that there was no significant effect of **fruit** level on crumb firmness and cohesiveness. The level of fruit present in the cake crumb stored at ambient or chilled temperatures had very little effect on the crumb firmness. Generally there was an increase in the overall crumb firmness over 21 days storage (Figure 31).

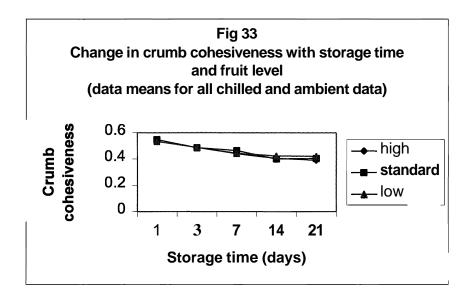


Crumb recovery reduced at a consistent rate for the high **fruit** level cakes during storage. The **standard fruit** level cakes had a substantial drop in crumb recovery at day 7, whereas the low fruit level cakes steadily decreased in crumb recovery up to day 21 (Figure 32). This effect was not significantly affected by storage temperature, regardless of fruit level (see **ANOVA** results).



Crumb cohesion, or strength, was lost over 21 days storage, regardless of the level of fruit present, and this was the only textural parameter that was significantly affected by storage time (Figure 33).

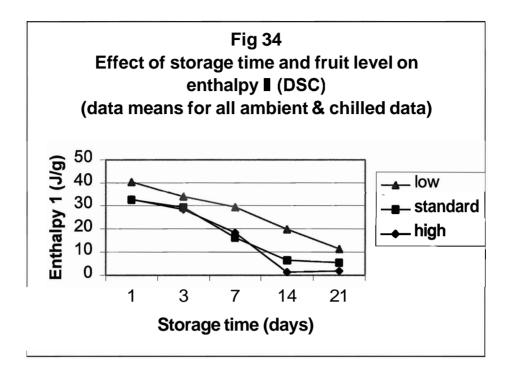
Increasing the fruit content of the formulation can help to reduce the loss of perceived crumb freshness over 21 days storage. Soaking the fruit prior to incorporation into the batter could also produce a similar effect but may affect product moisture and ERH. Fruit level had a limited effect on crumb firming rate in both ambient or chilled storage conditions.



# 5.3 The influence of fruit level on DSC enthalpy 1

Fruit level, storage time and storage temperature all had highly significant effects on the DSC enthalpy 1 values (Figure 34).

Storage temperature had a significant effect on the rate of loss of 'freezable water'. The presence of higher levels of fruit within the cake crumb seems to increase the loss of 'freezable water' within the product over storage, especially at ambient temperatures. The low fruit level exhibited a much lower rate of loss of 'freezable water'. It can be concluded that the fruit present in the cake crumb may be encouraging the movement of 'free water' into the starch recrystallisation reaction and that may lead to increased chemical staling.



# 6.0 Discussion

# 6.1 Influence of ingredients on loss of crumb freshness

### • Fat/shortening level

Pelshenke and Hampel (1962) reported on the influence of storage time and the incorporation of extreme levels of fat (0-20%) on bread staling. Using a starch swelling method of determining starch retrogradation, it was shown that the fat-fi-ee formulation was equivalent in the degree of staling to the product containing 20% fat. Elton (1969) provided data supporting the observation that fat decreases initial crumb firmness (in bread) and maintains this decrease throughout storage. In this project there was no statistical evidence to show that fat level had a significant effect on the loss of perceived **freshness** of the cake crumb, or texture measurements.

#### Moisture level

All previous work has pointed to the direct link between crumb moisture and the perception of **freshness**. Bechtel and Meisner (1954) concluded that bread with a higher crumb moisture content was significantly fi-esher than that with a lower moisture content. Pyler (1973) concluded that the higher the initial fi-esh product moisture level the more pronounced staling would be. **Willhoft** (1973) noted that the crumb moisture content could affect the ability of the starch molecules to **reorient** and recrystallise. It was also suggested that the starch fi-action, more dilute in cakes than in bread, undergoes retrogradation at a reduced rate due to less available moisture in the cake crumb. This would explain why sensory perception

of loss in perceived crumb freshness and staleness is observed in the cakes stored over 21 days, although the **DSC** analysis produced no indication of starch retrogradation (with the exception of the change in the 'freezable water level').

#### • Milk solids

Previous work has shown there to be a slight effect on initial crumb firmness with increasing addition of powdered skimmed milk (0-8%) in bread formulations (Platt and Powers, 1940).

## Egg solids

Pelshenke and Hampel (1962) evaluated the effect of egg white and yolk on bread firming properties; there was the same degree of staling with 2% egg white as with the no-egg control, although the bread with 2% egg yolk did not stale as rapidly as the control sample. Off-flavour was negatively correlated to egg level in the cake formulations used for this project.

#### Fruit level

Adding fruit to the cake recipe appeared to have little effect on the rate of crumb firming, but higher levels do reduce the loss of recovery, which is usually another marker for loss of cake freshness. The picture is, however, further complicated by the progressive loss of freezable water with increased fruit addition. This suggests that although the effect of added fruit is likely to increase the rate of water transfer to the starch, and its subsequent retrogradation, the presence of fruit in the cake crumb does alter tasters' perception so that high levels of inclusion give the impression of a "fresher" product.

It has been shown by Giovanelli *et al* (1997) that the baking temperature greatly influences the staling rate of bread. The lower the baking temperature the lower the staling rate, both in terms of crumb firming and starch recrystallisation over storage time. It was also noted that crumb firming and starch retrogradation are only directly related at the beginning of staling, and after that time starch retrogradation halts while crumb firming continues. This paper made further statements concerning the **protein**-starch interactions, which are stronger in bread cooked at higher temperatures, possibly due to altered behaviour of crumb during staling. Protein denaturation may cause a reduction in water affinity due to the protein compacting and loss of hydrophilic sites. Water lost from the protein fraction would promote starch mobility and crystallisation.

# 6.2 Changes in loss of 'freezable water' with storage temperature

There was a significant loss of 'freezable' water over storage of all cakes in the investigation, although at ambient storage the rate of 'freezable' water loss (reduction in enthalpy 1 peak) was greater than that for cakes in chilled storage. There was, however, no indication that the DSC plot displayed the typical endothermic peak due

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to retrograded starch formation, as seen for example when testing bread products. It was thought that the high fat and particularly high sugar levels restrict or mask the actual staling 'peak'.

Vodovotz and Chinachoti (1998) indicated that thermal transitions monitored by DSC go through some changes upon the ageing of a wheat starch gel. The enthalpy of ice melting and the percent 'freezable' water decreased in a parallel fashion with increased storage time.

The ice melting peaks can be shown as the major endothermic transition at about 12°C. The peak decreased in magnitude during storage, and the change in enthalpy of the DSC endotherm was used to calculate the percentage 'freezable' water. With an increase in the amount of 'unfreezable' water, the degree of amylopectin recrystallisation showed that an increase in the glassy-rubbery transition involved more than just moisture loss, possibly due to some amorphous network that may have progressed extensively. During storage the segmental mobility in certain regions may be increasingly restricted due to the additional cross-links.

### 7.0 Conclusions

The following conclusions can be determined from the experimental work:

- 1. Cakes made with a large volume had the lowest firming rates. Low volume cakes not only have an initially firmer **crumb**, but also firmed more rapidly over storage.
- 2. Instrumental texture and sensory perception measurements of crumb firmness were highly correlated, and relate to the loss of perceived crumb freshness. However, a sensory perception of the staleness attribute could not be directly related to instrumental measurement of crumb firmness.
- 3. Cake crumb moisture content was related to the loss in perceived crumb freshness; i.e. a moist crumb became 'stale' more slowly. There was a high correlation between water and sensory perception of staleness.
- 4. Cakes containing high flour (starch) levels were perceived as more stale (less fresh) than those with lower flour (starch) levels. This suggests that a high-ratio cake formulation (low starch content) will firm at a lower rate than a low-ratio formulation (high starch content).
- 5. Chilling cakes slightly reduces the loss of perceived crumb freshness. Chilled cakes on storage day 21 were described as 'firm' whereas the majority of ambient cakes were described as 'stale' or 'dry'.
- 6. Instrumental texture analysis and sensory profiling are recommended as methods most suitable for monitoring the loss of perceived freshness during cake storage. The DSC method of measuring actual starch retrogradation was unsuitable for the cake formulations in this project. However, monitoring the amount of 'freezable'

	water in the cake crumb gave an indication of the crumb firming changes during storage.		
7.	The addition of fruit to a plain cake formulation had a limited effect on the loss of perceived crumb freshness during storage.		

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# **APPENDIX A** Methods for cake production

### Methods for cake production

**An** all-in mixing method was used with a Tonelli pressurised high-speed planetary mixer (Except for the sultanas in fruited cakes).

Basic mixing instructions: -

- Initially blend ingredients for 30 seconds on speed 1, and clear the beater and scraper.
- Mix for a further 2 minutes on speed 4.
- Measure the batter relative density and continue to mix on speed 4, until a batter relative density of 0.80 50.3 gcm<sup>-3</sup> is obtained.
- Fruit is added once the batter relative density has been achieved and blended on speed 1 for 10sec.

## Baking, wrapping and storage: -

- Batter was deposited at 300g into labelled, greaseproof paper lined tins and baked for exactly 50 minutes (55 minutes Phase 2 cakes) in a Bone Reel Oven at a set oven temperature of 220°C.
- Baked cakes were left to cool in the tins for about 5 minutes, then carefully removed by hand, and left to cool on wire racks for at least 2 hours (but no more than 3 hours).
- Cakes were wrapped individually in moisture impermeable film (365 XS), then labelled and stored at either 8 or 21°C until required for testing.

## **APPENDIX B** Assessment methods

### **Batter relative density determination**

CCFRA Standard method TES-BCP-203

#### Cake volume determination

CCFRA Standard method TES-BCP-202

#### Moisture determination

CCFRA Standard method TES-BCP-200

#### **Equilibrium Relative Humidity (ERH) determination**

CCFRA Standard method WI-BCP-252 using Aqualab Dewpoint meter (CX-2)

## **Texture Profile Analysis Procedure**

CCFRA Standard method TES-BCP-204

## Equipment

- Stable Microsystems TA-XT2.
- Flat, compression probe, 45mm diameter.
- Metal cutting rig.
- Sharp knife.
- Core sampling rig.
- Core borer.

#### Method

Using a metal cutting rig cut each cake into 6 slices, discarding the end slices. To make a core for TPA, use the core-sampling rig to guide the core borer into the centre of each individual slice of cake. Slowly twist and press down the corer into the centre of the cake to remove a crumb core, with the minimum amount of structural damage to the crumb.

Place the core on the TPA test platform, and subject each of the 4 cores to a compression test (See TPA conditions below). Once the test is completed and a stylised force-distance curve obtained the standard Texture Expert TPA macro is run, which calculates the parameters described below.

#### **TPA Conditions**

**Test Option** 

test option = TPA Compression

Settings

Force units – grams

Distance format = millimetres

**Parameters** 

Pre-test speed=2.0 mm/sTest speed=2.0 mm/sPost test speed=10.0 mm/sDistance=7.0 mm/sTime=5.0 s

Trigger Type

Trigger type = Auto
Trigger force - 5 g

#### **Firmness**

The maximum peak force experienced during the first compression (P1)

#### **Cohesiveness**

The ratio of the positive force area, during the second compression circle, to that during first conipression circle (A2/A1).

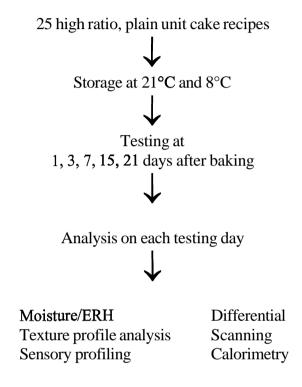
## Recovery

This is the proportion of height that the sample recovers during the elapsed time between the end of the first compression and the start of the second.

# **Appendix C** Test plan and statistical analysis

### Test plan

Cake staling and loss of perceived freshness were monitored using a testing plan shown below.



Sensory profiling was carried out by a trained sensory panel who measured four attributes - *dry*, **off-flavour**, firmness **and** stale (which is described as a taste-texture combination). Each attribute was measured on the same scale of 0 (nil or very slight) to **9** (extreme).

#### Statistical analysis

Three methods of statistical analysis were implemented to analyse the large amounts of data produced from the sensory, instrumental and DSC assessments, being: Principal Component Analysis (PCA) and Partial Least Squares (PLS). Correlations were also used to compare relationships between sensory profiling, instrumental texture measurements, and DSC first enthalpy figures.

#### Principal Component Analysis (PCA)

PCA is used in statistics to reduce the number of variables within a data set to a smaller, more manageable number of data. It can be used to reduce the dimensionality of the data thus simplifying it. PCA gives a 'feel' for a set of data and provides a quick way of assessing the effective **dimensionality** of that set of data by transforming

the original data set of variables to a new set of uncorrelated variables, i.e. the principal components.

#### **Pearson** correlations

Also expressed as the **Pearson** product moment correlation coefficient, it is used to measure the degree of linear relationship between two variables. The correlation coefficient assumes a value between –1 and +1. If one variable increases as the other decreases then the correlation coefficient is negative. Conversely, if the two variables increase together the correlation coefficient is positive.

### Partial Least Squares (PLS)

The purpose of multivariate regression is to find a link between two groups of variables, and express this link quantitatively. The regression method used here is Partial Least Squares or PLS, which models the X- and Y-matrices simultaneously to find the latent variables in X that will best predict the latent variables in Y. In simpler terms, the X-variables (ingredients) that lie closest to the Y-variable (texture or sensory parameters) in the PLS1 plots are associated.

PLS is able to dispose of irrelevant variation in X, and focuses on the variation that has a predictive power. As a consequence, PLS models are often more economical than PCR models, i.e. they predict as well with fewer components. PLS scores have the same interpretation as PCA scores; PLS1 deals with only one response variable at a time.

# **APPENDIX D** Raw Materials Specifications

# **High-Ratio Flour**

**A** white soft flour produced by the roller milling of a blend of EU wheat followed by treatment with chlorine gas.

Chemical and physical data:

Moisture (%)	12.8-15.2
Protein (%)	6.4-8.9
Chlorine (ppm)	1030-1650
Flour colour grade	- 0.1
Alpha-amylase (FU)	26.0
Sieving analysis (%)	
>106microns	2.5
>75 and <106	3.3
>45 and <75	41.1
<45 microns	53.1

## **High-Ratio Shortening**

An aerated, emulsified shortening, designed primarily for the manufacture of high-ratio cakes.

Chemical and physical data:

Slip point - typically 34°C

Ingredients:

Vegetable fat (including hydrogenated oil)

Emulsifier E471

## Skimmed milk powder

**A** white to yellowish colour powder, with no scorched particles and lumps.

Chemical and physical data:

4.0 max
1.25 max
1.25 max
0.15 max

# **Bicarbonate of Soda**

A white powder with no odour.

Chemical and physical data:

Moisture (%)	0.25
Sodium bicarbonate NaHCO <sub>3</sub> (%)	99.2 min
Sodium carbonate (%)	0.8 min
Sodium chloride (%)	0.2 min
Ferrous oxide (%)	0.001 min

# Cream powder

A pale creamy-white powder with no noticeable odour.

Chemical and physical data:

Disodium dihydrogen diphosphate  $64.0 \, (\% \, P_2 O_5)$ 

Other ingredients Calcium sulphate dihydrate

Wheat flour Sodium chloride

#### Salt

A white, free-flowing crystalline powder.

Chemical and physical data:

Moisture (%)	0.10
Sodium sulphate (%)	0.10
Sodium carbonate (%)	0.005
Anti-caking agent (mg/kg)	15.0
Assay (% dry basis)	99.9 min
Bulk density (g/cm <sup>-3</sup> )	1.22-1.32

Sieve analysis (%)

through 1400 micron retained on 850 micron 8.0 max retained on 300 micron 91.0 max

### Caster sugar

A White free-flowing crystalline product sourced from sugar beet.

Chemical and physical data:

Loss on drying (%)

Ash (%)

Solution colour (ICUMSA units)

Reducing sugars (%)

Sulphur dioxide (mg/kg)

Insoluble matter (mg/kg)

0.04 max

0.04 max

12.0 max

12.0 max

5-10 typical

Particle size (%)

above 425 microns 10 below 212 microns 22

### **Sultanas**

Oval berries that range in colour from brown to golden, depending on the treatment, and coated in vegetable oil.

Bright and clean in appearance, uniform in size and free flowing.

Origin - Turkey

Grade ready to use - specially cleaned and **3xhand** picked, washed, left to stand for 72 hours washed again, hand picked and then laser scanned.

Oil content 0.5%max Moisture 18% max

Sulphur dioxide nil

# **APPENDIX E** Texture Profile Analysis Method for Cake

The samples were tested using a Stable Micro Systems TA-XT2 texture analyser.

A slice 2cm thick was cut from the cake with the aid of cutting guides, and a cylindrical core of 4cm diameter was cut from this slice using a cork borer. The core was weighed and then submitted to a compression test. The instrument settings were as follows:

Attachment: Flat plate, 45mm diameter.

Test option: Texture profile analysis (two bite test, compression)

Pre-test speed: 2.0 mm/s
Test speed: 2.0 mm/s
Post-test speed: 2.0 mm/s
Distance: 7.0 mm
Time: 5.0s

Trigger type: Auto Trigger force: 5 g

