DELIVERING β- GLUCAN VIA SELECTED BAKERY SYSTEMS: CAKE

A thesis submitted for the degree of

MASTER OF SCIENCE

By

DANUSHA NILAKSHI KALINGA
B.Sc. (Agriculture) and M.Sc. (Food Science and Tech.)

School of Biomedical and Health Sciences
Faculty of Health, Engineering and Science
Victoria University
Melbourne
Australia
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Abstract

In the western world intake of dietary fibre is low and fat consumption is high. This leads to many diet related diseases, such as, type 2 diabetes, colorectal cancer and cardiovascular disease. Fibre enrichment and fat replacement are effective ways in developing a health-promoting diet. β-glucan, a soluble dietary fibre present in cereal grains, has many health benefits, which include reduction in blood cholesterol and, improving insulin response. Due to its viscosity enhancing and water binding properties, β-glucan is considered as a potential fat replacer. β-glucan from oat and barley were studied as functional ingredients in bakery systems using cake as a model to deliver health benefits.

β-glucan concentrates (BGC) were prepared from oat and barley and added to cake formulation at different levels as fat replacer or enrichment. The quality of the cake so produced was compared with the control in terms of physical properties (texture, rheology, volume, specific gravity) and sensory characteristics (hardness, colour, appearance, overall acceptability). Cakes containing β-glucan demonstrated increased hardness, reduced volume, and change in colour, thereby reducing the acceptability of enriched cakes. Since, it is important to maintain acceptable quality of products while adding physiologically effective dose of β-glucan into foods, the objectives of this study was to investigate the interaction of β-glucan with key ingredients in the cake formulation by studying the thermal, pasting, gelling and sorption properties responsible for adverse effects on sensory quality.

Addition of BGCs showed changes in thermal, pasting, and gelling behaviour of flour-BG mixtures. Thermal properties were measured using differential scanning calorimeter (gelatinisation temperature profile and enthalpy of gelatinisation), pasting properties were measured using a rheometer and gelling properties were measured using a texture analyser. Increase in the onset, endset and peak temperatures and decrease in enthalpy values were observed for flour and starch mixtures containing BG. This suggested retention of the integrity of the starch granules and low degree of gelatinization. The level of inclusion of BG in flour-water dispersion had a significant ($p<0.05$) influence on the pasting characteristics. Both type and level of β-glucan concentrates affected pasting properties of flour and starch mixtures. As the level of BG increased from 10 to 30% in the mixtures, peak viscosity, pasting viscosity, holding strength, breakdown viscosity, final viscosity, and setback from trough increased, while peak time, pasting time and peak temperature decreased. These effects were attributed to reduction in starch fractions, increment in water retention capacity and swelling power of BG concentrate, and limited availability of water to complete gelatinisation. Gels produced with different levels of β-glucan concentrates were softer than those of the controls.

Water adsorption characteristics of flour mixtures containing barley β-glucan concentrate (BBGC) were determined at 20, 35, 40 and 50^{o}C. Experimental sorption isotherms of the mixtures were intermediate between those of pure BBGC and cake flour indicating intermediate adsorption capacities for mixtures. Cake flour and flour mixtures containing BBGC showed type II isotherms, while BBGC showed type II at low water activities and type III at higher water activities (> 0.6) typical of hydrocolloids. Sorption data were fitted to GAB model (Toledo, 2007a). The GAB monolayer estimated values decreased for all mixtures except for pure BBGC and mixture containing 20% BBGC. These results suggested the influence of BG in immobilising the water molecules particularly at high water activities.

In order to evaluate the effect of the level of BGC and the method used in preparation of cake, a full factorial design with four factors at two levels of β-glucan, water, mixing time and emulsifier was implemented. Each factor was used at two levels. The factorial design allowed measurement of interactions among the factors. Out of the factors tested, the level of BGC and water were found significant ($p<0.05$) in influencing batter rheological properties, specific gravity, texture of cake, moisture content, water activity and volume of the cake. Addition of BG increased the hardness and on the other hand addition of water decreased the hardness of cake. Emulsifier improved the cake batter, but it did not improve the final cake quality. Increased mixing time deteriorated the quality of cake as it increased the hardness. Sensory evaluation of cakes was conducted to determine the consumer acceptability and there was no difference between the treatments. Appearance of cake produced with 10% BG, 270 ml water, without emulsifier and 12 min mixing time was better compared to all other treatments. Cake with 10% β-glucan, 270 ml water, 0.03% emulsifier and 12 min mixing time was ranked as the lowest for hardness and, the highest for cohesiveness. This cake had the highest overall acceptability which could be due to the perceived softness. Further studies with different levels of water, and different types and concentrations of emulsifiers are suggested to optimise the quality of BG added cake.

Declaration

"I, Danusha Nilakshi Kalinga declare that the Master by Research thesis entitled Delivering β- glucan *via* selected bakery systems: Cake is no more than 60,000 words in length, including quotes and exclusive of tables, figures, appendices, bibliography references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Signature Date: 12 April 2010

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Table of Contents

CHAPTER 1

INTRODUCTION

CHAPTER 2

LITERATURE REVIEW

2. 2 FAT REPLACERS

2. 3 β-GLUCAN AS A FUNCTIONAL INGREDIENT

2.5 EFFECT OF BG ON KEY PHYSICOCHEMICAL EVENTS INFLUENCING QUALITY OF CAKES

CHAPTER 3

GELATINISATION BEHAVIOUR OF CAKE FLOUR MIXTURES CONTAINING β-GLUCAN

3.2 MATERIALS AND METHODS

3. 3 RESULTS AND DISCUSSION

CHAPTER 4

SORPTION BEHAVIOUR OF β-GLUCAN CONTAINING FLOUR MIXTURES

4.3 RESULTS AND DISCUSSION

CHAPTER 5

EFFECT OF CHANGE IN FORMULATION AND BATTER MIXING ON QUALITY OF HIGH RATIO WHITE LAYER CAKE CONTAINING β-GLUCAN

List of Tables

List of Figures

Abbreviations

ANOVA	analysis of variance
a_w	Water activity
BBGC	Barley β-glucan concentrate
BG	β-glucan
BGC	β-glucan concentrate
C	GAB constant
CO_2	Carbon dioxide
DF	Dietary fibre
G’	Storage modulus
G”	Loss modulus
k	GAB constant
K	Consistency index
n	Flow behaviour index
OBGC	Oat β-glucan concentrate
PVP	Pasting viscosity profile
RVA	Rapid Viscoamylograph
T_{end}	Endset temperature
T_{on}	Onset temperature
T_{peak}	Peak temperature
X_m	Monolayer moisture content
WRC	Water retention capacity
ΔH	Enthalpy

CHAPTER 1

INTRODUCTION

In recent years, the diseases related to the diet have gained increased attention worldwide. Obesity, type II diabetes, coronary heart diseases and colon cancers are common health problems that require a lot of resources from public health care system (WHO, 2003), and related to diet and life style. In the developed countries, the major reasons for these diseases are intakes of high amounts of fat and low levels of dietary fibre in the diet. As a consequence, government regulatory bodies have set nutritional goals to limit total fat intake to <30% of the total calories, and saturated fat to <10% of total energy consumption averaged over a period of a week (Anon, 2005). Following these recommendations, consumers are showing a clear preference to healthier foods containing less fat and sugar and more fibre (Sandrou and Arvanitoyannis, 2000).

Dietary fibre (DF) intake is not adequate in many developed countries compared to developing countries (Lyly, 2006; Prosky and Devries, 1992) despite of it being implicated in reducing the risk of colorectal cancer, cardiovascular disease, and type II diabetes (Anderson, 1990; Jenkins *et al*. 2003; Robertson, 1998). Hence, DF is regarded as one of the key components of a health promoting diet. Promotion of an increased fibre from sources of plant cell wall origin can be through supplementation of processed foods (Robertson, 1998). Therefore, replacement of fat with dietary fibre in high fat, highly consumed, ready-to-eat products, such as bakery products continues and will continue to draw industrial and academic interests (Brennan and Cleary, 2007; Kalinga and Mishra, 2009; Knuckles *et al*., 1997; Lee *et al*., 2004; Lee *et al*., 2005a, 2005b, 2005c; Lee and Inglett, 2006) in order to deliver potential health benefits.

It is well known that enrichment of food with β-glucan (BG) or its addition as a fat replacer brings enormous health benefits to the consumers. Oat and barley BG, soluble dietary fibre, have ability to control post-prandial blood glucose and insulin levels (Jenkins *et al*., 2003; Symons and Brennan, 2004b; Toppy *et al*., 1996) and to lower blood cholesterol levels (Anderson *et al*., 1990a, 1990b; Hecker *et al*., 1998; Pins *et al*., 2002). These health benefits have been attributed to high viscosity and water absorption capacities of β-glucan (Wood, 2007).

Cereal foods supply majority of macronutrients in diet worldwide. Bakery products are highly consumed by many consumers, and some of these products such as, cake, biscuits and muffins contain high amount of fat. Therefore, many researchers have attempted to deliver BG using bakery products as pure enrichment and as a potential fat replacer. These cereal products include cakes (Kalinga and Mishra, 2009; Lee *et al*., 2004; Lee *et al*., 2005a, 2005c), biscuits (Brennan and Samyue, 2004; Lee and Inglett, 2006; Sudha et al., 2007), muffins (Hudson *et al*., 1992), noodles (Inglett *et al*., 2005), pasta (Knuckles *et al*., 1997; Tudorica *et al*., 2002) and bread (Andersson *et al*., 2004; Brennan and Creary, 2007; Cavallero *et al*., 2002; Knuckles *et al*., 1997; Symons and Brennan, 2004b; Wang *et al*., 2002). It is now widely accepted that both reduction and replacement in fat results in quality defects, such as, the reduction in volume, impaired colour, and increase in hardness (Kalinga and Mishra, 2009; Lee and Inglett, 2006; Lee *et al*., 2004; Lee *et al*., 2005a, 2005c). In this thesis, cake was selected as the medium to deliver BG and to replace fat as it is a highly consumed bakery product, which contains high amount of fats (up to 17%). Lee and Inglett (2006) replaced fat in cookies with Nutrim oat bran at up to 30% level and observed quality defects in terms of decrease in diameter and an increase in height of cookies as high level of Nutrim contributed more to the elastic properties of the dough. Similarly, fat substitution at >40% by Nutrim oat bran (10% β-glucan) or flaxseed powder in cakes was shown to increase the hardness (Lee *et al*., 2004). In 2005, the same authors reported that Oatrim (5.8% β-glucan) can be used as a fat replacer in cakes up to 20% without any significant change to the hardness of the cake. In both cases, increase in hardness and reduction in volume of the cake were observed when high level of these formulations were used. The levels of BG in these formulations were very low and hence effects could not be entirely attributed to BG. Kalinga and Mishra (2009) used barley β-glucan concentrates (BBGC) and oats β-glucan concentrates (OBGC) up to a level of 40% fat replacement in cakes and reported increased hardness of cakes and decreased volume index as level of fat substitution increased to 40% using BBGC (60% β-glucan) and OBGC (50% β-glucan). However, cake with 20% fat replacement showed similar volume to that of the control containing full fat.

Deterioration in quality of cakes prevents bakery industry to use BG as a functional ingredient. It is important to understand the underlying reasons for these quality defects for a successful enrichment. To overcome these problems, it is necessary to investigate the interactions of BG with other ingredients of the recipe (e.g. starch and protein in the flour, water, emulsifiers, sugar, and lipids) and the changes occurring during preparation of batter and production of cake. This information is lacking in the literature. This project attempts to explore these interactions with a view to increase the delivery of health benefits of BG through bakery products.

1.2 GENERAL AIMS AND OBJECTIVES

The overall aim of this project is to deliver physiological benefits associated with consumption of BG using cake as an example of a bakery system. The specific objectives were:

1. To study the effect of type and the level of β-glucan on the gelatinisation behaviour (thermal, pasting and gelling properties) of a model bakery system (cake)
2. To determine the sorption behaviour of cake flour mixtures containing different levels of β-glucan concentrates at different temperatures
3. To investigate the effect of formulation and processing parameters on quality of cake containing β-glucan

1.3 THESIS OUTLINE

β-Glucans have been scientifically shown to provide a remarkable range of health benefits, including promoting heart health, healthy blood glucose levels, weight loss and enhancing immune system function (Wood, 2007). This study intends to improve nutritional and sensory qualities of cereal foods with enrichment in fibre and replacement of fat. The study will generate intellectual property with commercial potential, which is likely to benefit the bakery industry. As functional food and low calorie foods become popular in human diet, the demand for such food will increase. Thus, the project has potential economic significance to the bakery industry.

Cake was selected in this project to deliver β-glucan as a source of dietary fibre and as a fat replacer. Cake is consumed daily by many people and contains 10-20% fat and 27-42% sugar (FSANZ, 2006). Thus, replacement of fat with β-glucan in cake formulation is expected to deliver health benefits of BG in addition to benefits of reduction in calories due to fat replacement.

In order to improve the consumer acceptability, it is important to understand the underlying reasons for the quality defects, such as, impaired colour, increased hardness and low volume of cake. β-glucan has ability to bind water, which alters important processes such as gelatinization, pasting and gelling and finally influence on starch digestibility. Studying of the influence of different ingredients and processes is important in optimization of overall quality of β-glucan containing cakes

Interactions of β-glucan with water and other components of food system were studied using differential scanning calorimetry, rheology, swelling, water retention capacity and by measuring gel hardness. The ability of β-glucan to bind water in a cake flour was determined using sorption analysis. Influence of different levels of β-glucan, water, time of mixing and level of emulsifier sodium steroyl lactate (SSL) on physical and sensory properties was studied.

CHAPTER 2

LITERATURE REVIEW

2.1 DIETARY FATS AND FIBRE: RELEVANCE TO HEALTH

One of the major nutritional problems today is consumption of high amounts of fats and low amount of fibre, which are associated with an increased incidence of obesity, coronary heart diseases, hypertension, insulin resistance, certain cancers (eg, breast, colon, or prostate), and gallbladder disease (Anon, 1998). This is perceived to be contributing to high cost of medicare in western world. Thus, the demand for low fat/calorie and foods enriched with dietary fibre in the market has been increasing over the years.

People are concerned with high consumption of fat over the carbohydrates and proteins, since fat is the most calorically dense of the three macronutrients, having 9 cal/g, compared to 4 cal/g for protein or carbohydrates (Oreopoulou, 2006). Recommended dietary fibre intake in Australia is 25-30 g/day with an advice to reduce fat intake, from 30% to 15% energy level. Also, it is recommended to reduce saturated fatty acid intake and dietary saturates should be replaced by a mix of complex carbohydrates and other fatty acids (Anon, 2005).

Dietary fibres (DF) promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation (Anon, 2001) and included as carbohydrates in proximate analysis of foods (Asp, 2004). According to the definition given by American Association of Cereal Chemists (AACC), dietary fibre is the edible part of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances (Anon, 2001). The plant cell wall from fruits, vegetables, legume seeds, algae (seaweeds) and cereals currently accounts for most of fibre present in the diet.

Polysaccharide food additives, such as pectin, guar gum, alginates and modified starches, also constitute fibre (Robertson, 1998).

There is no standard classification or terminology system devised for the purpose of characterising various compounds or components of DF in a consistent way. A number of possible schemes could be developed for this purpose. These could be based on the (1) chemical makeup for each of the components that has been completely characterised, for example 1,4-β-glucans (cellulose) or β-1,3-glucans (β-glucans), (2) functions in the plant of origin (cell wall or storage), (3) physiological response in the human body (hypercholesterolemic, laxative) (Prosky, 2001). However none of these systems are completely clear cut. Dietary fibre is divided into two main types, soluble and insoluble dietary fibre based on the solubility in hot water (Prosky, 2001). Examples of insoluble DF's included, cellulose, hemicellulose, lignin, cutin and plant waxes. Soluble DF is soluble in warm or hot water, but is precipitated when that water is mixed with four parts of ethyl alcohol for example gums, BG, and pectin (Prosky, 2001). Physiological effects of these fibres are different. Soluble DF is more effective in reducing hyperlipidemia, while insoluble DF is better for alimentary system dysfunctions such as constipation (Anderson, 1990; Brennan *et al.*, 2002; Prosky, 2001; Schneeman, 1987; Warrand, 2006).

2. 2 FAT REPLACERS

2.2.1. General Aspects

Food manufactures have developed several approaches for fat replacement that provide a variety of options for combining ingredients to yield products with characteristics like their full-fat counterparts. Termed as "fat substitutes" or "analogs", these compounds are designed to replicate the functional and sensory properties of fats, but are not chemically classified as fat and contribute less energy than fats. They may be used to replace all or portion of the fat normally present in the product. A second class of ingredients is referred to as "fat mimetics", which replicate only a subset of the properties of the fats. They are designed typically for partial fat replacement. Fat "barriers", a third type of replacers reduce the absorption of fats during the frying process (Anon, 1998). Fat replacers can also be classified according to the chemical structure and macronutrients base as carbohydrate based, protein based, or fat based. The key fat replacement products, their functions, properties and application are given in the Table 2.1.

Carbohydrate based fat replacers are divided into three main categories based on their beneficial impact on the humans: prebiotics, which play a role on probiotics (related action); dietary fibre with direct physiological properties (direct action); and fat-mimics (indirect action) (Warrand, 2006). BG can be a prebiotic, for DF with direct influence on physiological properties and a fatmimetic. The gelling capacity and ability to increase viscosity of water solutions are the main rheological characteristics of potential fat replacer (Lazaridou and Biliaderis, 2007). High viscosity, water binding, foaming and emulsion stability capacities are the potential determinants of BG’s suitability as fat replacers (Burkus and Temelli, 2000).

Table 2.1 Example of fat replacers, trade names, applications and functions (Anon, 1990, 1998; Oreopoulou, 2006)

Class of fat replacer	Trade name	Application	Functional properties
Carbohydrate based			
Polydextrose	Litessse, Sta-Lite	Dairy products, sauces, frozen desserts, salad dressings, baked goods, confections, gelatines, puddings, meat products, chewing gum, dry cake and cookie mixes, frosting and icings	Moisture retention, bulking agent, texturiser
Starch and Modified food starch	Amalean I & II, CrystaLean, N-Lite, Instant Stellar, Sta-Slim, OptaGrade, Pure-gel, Remyrise, Slenderlean, Tapiocaline, C*delight, Lorelite, Lycadex, Maltrin, Paselli D-LITE, Paselli EXCEL, Paselli SA 2, STAR-DRI	Processed meats, salad dressings, baked goods, fillings and frostings, condiments, frozen desserts, dairy products	Gelling, thickening, stabilizing, texturiser

Maltodextrins	CrystaLean, Maltrin, Lycadex, Star-Dri, Paselli Excell, Rice-Trim	Baked goods, dairy products, salad dressings, spreads, sauces, fillings and frostings, processed meat, frozen desserts, extruded products	Gelling, thickening, stabilizing, texturiser
Grain-based (fibre)	Betatrim, Opta. Oat Fiber, Dairytrim, Snowite, Ultacel, Z-Trim, Oatrim, Nu-Trim, Viscofiber, Glucagel,	Baked goods, meats, extruded products, spreads	Gelling, thickening, stabilizing, texturiser
Dextrins	N-Oil, Stadex, Amylum,	Salad dressings, puddings, spreads, dairy products, frozen desserts, chips, baked goods, meat products, frostings, soups	Gelling, thickening, stabilizing, texturiser
Gums (xanthan, guar, locust been, carrageenan,	Kelcogel, Keltrol, Viscarin, Gelcarin, Fibrex, Novagel, Rohodigel, Jaguar	Salad dressing, processed meats, formulated foods (eg desserts and processed meats)	Water retention, texturiser, thickener, mouthfeel, stabilizer

alginates, Arabic)			
Inulin	Raftiline, Frutafit, Fibruline	Baked goods, Dairy products	Gelling, thickening, mouthfeel
Pectin	Grindsted, Stendid, Splendid	Baked goods, soups, sauces, dressing	Gelling, thickening, mouthfeel
Cellulose (carboxy-methyl cellulose, microcrystalline cellulose)	Avicel, cellulose gel, Methocel, Solka-Floc, Just Fiber	Dairy products, sauces, frozen desserts, salad dressings	Water retention, texturiser, stabilizer, mouthfeel
Fruit based (Fibre)	Prune paste, dried plum paste, Lighter Bake, WonderSlim, fruit powder	Baked goods, candy, dairy products	Moisturizer, mouthfeel
Protein based			
(Microparticulated protein, Modified	Simplesse, K-Blazer, Dairy-lo, Veri-lo, Ultra-Bake, Powerpro,	Cheese, mayonnaise, butter, salad dressing, sour cream, spreads, bakery	Mouthfeel, emulsion stabilising,

whey protein concentrate)	Proplus, Supro	products	
Fat based			
(Emulsifiers, Low-calorie fats, Fat analogs or substitutes)	Caprenin, Olean, Benefat, Dur-Em, Dur-Lo, EC-25, Salatrim, Neobee MLT-B, DDM, EPG, TATCA, Sorbestrin	Chocolate, confections, bakery products, savoury snacks	Mouthfeel
Combinations (of all mentioned above)	Prolestra, Nutrifat, Finesse	Ice cream, salad oils, mayonnaise, spreads, sauces, bakery products	Mouthfeel

2.2.2 Replacement of Fat in Bakery Products

Bakery foods present a great variation in fat content. Some are low in fat (e.g. bread), while others (e.g. soft type cookies and fried doughnuts) are considered fat rich foods. A fat content of different bakery products is shown in Table 2.2 (FSANZ, 2006).

Table 2.2 Fat content of different bakery products (g/100g of food)

Product	Fat content (g/100g)
Cake	5-17
Brownies	25-28
Muffins	5-10
Biscuits	9-32
Bread	1-2.7
Doughnuts	19-24
Croissant	20.7
Scones	8.8

Fats and oils have multiple functions in bakery foods, such as, help in incorporation of air during mixing, contribute to lubricity by preventing sticking of dough and products on surfaces, provide tenderness and brittleness, give buttery flavour, provide creamy, moist, flaky and smooth mouth-feel, and give shiny surface and uniform internal structure (Oreopoulou, 2006).

The current trend in nutrition and health awareness leads consumers to turn towards low-fat or reduced-fat bakery foods. As consumers have obtained better information about the risk and benefits of nutrition to health, they have moved from no additives/no preservatives foods in the 1970s to low calorie/light foods in the 1980s, to low-fat foods in 1990s. The reduction of fat in a food system is a complex problem because fat contributes to major sensory and physiological characteristics. Fat provides flavour, taste and mouthfeel; it also contributes to creaminess, appearance, palatability, texture, and lubricity. Therefore, in most food products, the removal of fat must be accompanied by the addition of other ingredients that can contribute the desired functions of fat to produce an acceptable product. The substances used to achieve these goals are generally called fat replacers or fat substitutes (Oreopoulou, 2006). Selection of a suitable fat replacer in bakery products is crucial. Carbohydrate based replacers act as thickening and moisture retention agents. Also, they increase the batter viscosity, which helps in the retention of air bubbles and in some cases improves the handling properties. The fat replacers used for various types of cake, muffins and cookies are gums, cellulose, modified starches, fibres, non-fat dry milk, egg white, and emulsifiers. Soluble fibres such as β-glucan (Hudson *et al.,* 1992; Kalinga and Mishra, 2009; Lee and Inglett, 2006; Lee *et al.,* 2005a, 2005b, 2005c), inulin (Brennan *et al.,* 2004), polydextrose (Kamel and Rasper, 1988), xanthan and guar gum (Zambrano *et al.,* 2004) were used in bakery products like cake, bread, muffins and biscuits. Some adverse effects, such as increase in hardness, change in colour and decrease in volume were observed depending on the type and level of BG. For example, increase in viscoelastic properties of cake batter, decrease in volume and increase cake hardness were observed when fat in cake was replaced with barley and oat β-glucan concentrates (Kalinga and Mishra, 2009; Lee *et al.,* 2004, 2005a, 2005b).

Because of the differences in properties and functionality between the fat replacer and shortenings, several changes in consistency and processing conditions are necessary to produce acceptable baked goods (Oreopoulou, 2006). For example change in water content, addition of emulsifiers and foam stabilizers can be considered.

2. 3 β-GLUCAN AS A FUNCTIONAL INGREDIENT

2.3.1 Physical and Chemical Characteristics of Cereal β-glucans

β-Glucan is a trivial name for the glucose polymer found in the endosperm cell walls of barley and oats, usually at a level of 3-7% of grain weight (Burkus and Temelli, 2005; Wood, 2007, 1993). The chemical structure of BG is given in Figure 2.1. It is a linear homopolysaccharides composed of D-glucopyranosyl residues linked via a mixture of β-(1→3) and β-(1→4) linkages (Lazaridou *et al.,* 2007; Skendi *et al.,* 2003; Wood, 2007; Wood *et al.*, 1994). Structurally, it is (1→3) (1→4)-β-D-glucan with cellulose-like portions linked through (1→3) glycosidic bonds, which makes it more soluble. The β bond is not digestible by enzymes in human gastrointestinal tract, resulting in the classification of BG as a soluble dietary fibre (Burkus and Temelli, 2005). In barley and oat β-glucan, 90% cellotriosyl and cellotetraosyl units can be found making them structurally similar. However, oat β-glucan usually exhibits somewhat higher viscosity due to its longer molecular chains (Beer *et al.,* 1997).

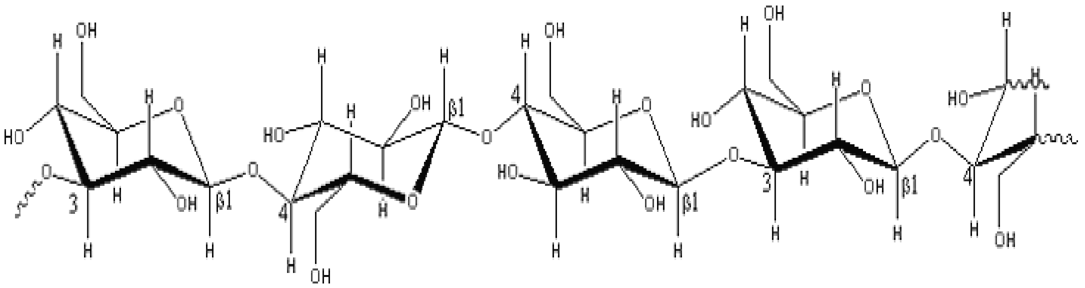

Figure 2.1 Chemical structure of β-glucan from barley and oat

The physiological functions in the gastrointestinal tract and physical properties of BG are mainly determined by molecular structure. The physical properties, such as water solubility, dispersibility, viscosity and gelation properties are important when they are used as ingredients in cereal-based foods and other formulated products (Lazaridou *et al.,* 2007). Even at low concentrations, BG produces viscous, shear thinning solutions making it suitable to use as thickening, stabilizing and a fat replacing agent (Burkus and Temelli, 1999, 2005). For example, at > 0.5% concentration, barley β-glucan produces a higher viscosity than pectin at the same concentration (Temelli *et al.,* 2004). Viscosity is controlled by molecular weight of BG. Increase in viscosity is the most important physical characteristic of BG which is linked to many physiological benefits such as controlling of glycemic and insulin response, plasma glucose and cholesterol level (Wood, 2007).

There are many commercial products available in the market that varies in the method of β-glucan isolation, concentration of β-glucan, molecular weight, water holding capacity and viscosity. Some of the marketed products are given in Table 2.3 (Inglett *et al.,* 2008) along with their composition. Technical and physiological functionalities of these vary with their composition, molecular weights, methods of isolation, ratio of β-(1-3) and β-(1-4) linkages.

2.3.2 Physiological Benefits of β-glucan

In the past 30 years, numerous studies on oat and barley BG have documented their beneficial role in controlling blood pressure, arterial health and insulin level (Warrand, 2006; Wood, 2007). Number of studies conducted with barley is much smaller than with oat products (Lyly, 2006). These physiological benefits are associated with a capacity of BG to produce high viscosity in solution at low concentration, a property of soluble high molecular weight polysaccharide (Wood, 2007).

β-Glucans have the ability to modify the structure of foods in a similar way to other soluble dietary fibre by affecting food degradation and the susceptibility of the starch components to amylolysis during digestion (Brennan *et al.,* 2002; Tudorica *et al.,* 2002). The combined effects of change in viscosity and structure modifying properties are involved in the nutraceuticals effect of BG rich foods (Brennan and Cleary, 2005) particularly reduction of serum cholesterol levels (total LDL-cholesterol), reduction in the postprandial glycemic response. When β-glucan concentrate was added to bread at 1.5 and 5% levels significant reduction in starch digestion was observed (Symons and Brennan, 2004b) and this reduction in starch digestibility leads to low glycemic response and low energy intake beneficial to obesity and diabetes management (Hecker *et al.,* 1998). In addition to this, BG can act as a powerful antioxidant. When participants were fed with one-half cup of Oatrim (a β-glucan containing commercial product) mixed with food; subsequent tests revealed fat oxidation reduction by 80% (Inglett, 2001).

Table 2.3 Composition of commercial barley and oat product

Product	% β-glucan	% Carbohydrate	% Protein	% Fat	% Dietary fibre
Cerogen™	70-90	93	4	0	77-90
C-trim20	21	63	27	7	21
C-trim30	32	79	14	2	32
C-trim50	48	80	18	10	48
Glucagel®	75-80	94	2	0	91
Natureal®	20	34	25	10	37
Nature®	15	61	28	3	30
Nutrim-OB	11	69	10	1	11
Oat β-glucan (Ceapro)	94	94	1	0	94
Oat bran concentrate (Quaker)	9	54	18	7	12
Oatrim	5	73	10	4	10
OatsCreme™	1	30	3	2	1
OatVantage™	54	84	11	2	54
Oatwell® 14%	14	64	20	5	30
Oatwell® 16%	16	64	20	5	34
Oatwell® 22%	22	64	20	5	44
Viscofiber®	50	86	4	5	82
Z-Trim™	0	86	1	0	86

2.3.2.1 Blood Sugar Control by β-glucan

The ability of BG to attenuate postprandial blood glucose and insulin response was evaluated by many scientists (Jenkins *et al.,* 2003; Symons and Brennan, 2004b; Toppy *et al.,* 1996). These studies showed significant correlation between dose of BG and glycemic response. Toppy *et al.,* (1996) incorporated highly enriched oat bran which had ~15% of BG (dwb) into an extruded breakfast cereal at 4, 6 and 8.6 g levels, and found significant decrease in the peak and average increase in glucose compared to control in subjects with non-insulin-dependent diabetes mellitus. The use of BG in bread reduces starch degradation and sugar release and the effects were observed to be proportional to the amount of β-glucan incorporated (Cavallero *et al.,* 2002). Reduction in glycemic index by 4 units for every gram of β-glucans was reported by Jenkins *et al.,* (2003).

β -Glucan enhances control of blood glucose by moderating the rate at which the body absorbs glucose from food. β -Glucan forms a highly viscous solution in the stomach and small intestine. This viscous solution has ability to entrap glucose molecules from dietary sugars and slows down their absorption at the intestinal surface. As a consequence, it reduces the release of glucose into the blood after meals resulting in a lowered insulin response (Cavallero *et al.,* 2002; Knuckles *et al.,* 1997).

2.3.2.2 Potential Prebiotic

As a potential prebiotic, β-glucan acts by stimulating and activating useful micro-organisms and improve quality of intestinal microflora. The experiments conducted on rats' revealed the ability of using purified BG products as dietary supplements for human consumption (Snart *et al.,* 2006). In this study they found that lactobacilli formed a greater proportion of the cecal microbiota in high viscous BG fed rats. *In-vitro* experiments confirmed that some Lactobacilli can utilize oligosaccharides (degree of polymerization, 3 or 4) present in BG hydrolysates. *In-vitro* studies with oat flour BG proved that BG is a good substrate for fermentation (Sayar *et al.,* 2007). These researches reported drop in pH due to fermentation, which provided favourable conditions for absorption of minerals and prevented overgrowth of pH sensitive pathogenic bacteria. Production of propionate and butyrate, the short chain fatty acids have greater potential in reducing the risk of tumorogenesis and hypercholesterolemia. Moreover, soluble dietary fibre has better impact on colon health as an anti-constipating agent, binding excess bile acids and salts, and interacting with mutagens and carcinogens in the gut (Warrand, 2006).

The effect of adding barley and oat BG on growth and metabolic activity of *Bifidobacterium animalis* ssp. *lactis* (Bb-12™) in yogurt during prolonged cold storage was determined by Vasiljevic *et al.,* (2007). Improved probiotic viability and stability in yoghurt was confirmed as an increase in acetic acid concentration due to enhanced metabolic activity of Bb-12™. Also, oat β-glucan increased propionic acid production during storage. Effect of barley BG on *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* was investigated in model yoghurt systems (Gee *et al.,* 2007). They found that BG did not affect the fermentation efficacy of starter cultures, but BG appears to have been broken down and utilized by the starter cultures when lactose became a limiting nutrient during the fermentation process. These findings show the potential prebiotic ability of BG.

2.3.2.3 Control of Serum Cholesterol and Hypertension

Consumption of BG reduces total serum cholesterol in hypercholesterolemic subjects by as much as 23% with no change in high density lipoprotein (HDL) cholesterol (Anderson *et al.,* 1990a, 1990b; Hecker *et al.,* 1998; Pins *et al.,* 2002). Consumption of β-glucan has been associated with significant reduction in antihypertensive medication needed and improved blood pressure control (Pins *et al.,* 2002). Hence, it greatly reduced the risk for cardiovascular diseases for hypertensive patients (Pins *et al.,* 2002). Soluble fibre-rich oat cereals may affect blood pressure by modulating changes in insulin metabolism. The mechanism of action is thought to slowing the absorption of macronutrients from the gut, resulting in a flattening of the postprandial glycemic curve. Moreover, plasma cholesterol reductions are associated with improvements in endothelium-mediated vasodilation (Anderson *et al.,* 1990a, 1990b; Marlett, 2005). Rats fed with BG tortillas had higher ($p<0.05$) faecal fat excretion, suggesting impairment of intestinal fat absorption (Hecker, 1998).

2.3.3 Health Claims

Considering all the health benefits of consumption of β-glucan from oat (Anon, 1997) and barley (WNBFC, 2006), the U.S. Food and Drug Administration (FDA) granted a health claim for BG. The use of oat-based foods for lowering the risk of heart disease passed a unique ruling that allowed oat bran to be registered as the first cholesterol-reducing food. The recommended dosage is 3 g of β-glucan per day (Anon, 1997). Similar claim has been allowed for oatrim (Anon, 2002) and Foods containing β-glucan can be labelled as functional foods (Anon, 2002) due to their ability to provide non-nutritive physiological benefits.

2.3.4 BG as a Fat Replacer

β-Glucan is classified as a soluble DF and carbohydrate based fat replacer (Temelli, 1997; Temelli *et al.,* 2004; Warrand, 2006; Wood, 2007). The pseudoplasticity of BG gums is a well established fact with high viscosity gums having a high consistency coefficient and low (<1) flow behaviour index (Bhatty, 1995). Burkus and Temelli found that high viscosity laboratory extracted β-glucan gum at low concentrations, such as 1% (w/w), was highly pseudoplastic but with a relatively high flow behaviour index of >0.8 above 15°C, which led them to suggest that high viscosity β-glucan gum could be a good fat replacer (Burkus and Temelli, 2005). The development of a weak gel network by cereal β-glucans with certain structural characteristics (molecular weight, distribution of cellulose oligomers, and ratio of tri- to tetramers and of β-(1→4) to β-(1→3) linkages in the polysaccharide chain) under certain conditions (above 0°C) is a desirable attribute in water-continuous and low fat spread (Lazaridou and Biliaderis, 2007; Lazaridou *et al.,* 2003; Lazaridou *et al.,* 2004; Skendi *et al.,* 2003; Vaikousi *et al.,* 2004). Cereal β-glucans show potential as a fat replacer due to their highly viscous nature and water binding, foaming, and emulsion-stabilizing capabilities (Burkus and Temelli, 2000). BG forms weak gel structure at temperatures above 0°C depending on the concentration. For example, Burkus and Temelli (1999) observed gel formation by low viscous barley β-glucans at concentrations ≥5%. Additionally, it has capability to bind water and stabilise emulsions and foams. The use of fibre in the technology of low calorie foods can be attributed to the enhancement of consistency and the texture of the water phase in food systems and to the restoration of mouthfeel that is lost when fat was removed. Fibre aims at compensation of fat functionality, water control and development of the desired bulk. The properties of fat mimetics results from association of water with the structure of carbohydrate particles, which should bind and orientate water in such way to provide in the oral cavity a sensation similar to that of fat with a desired cohesiveness, viscosity, juiciness and a certain moisture of the end-product that mimic fat (Sandrou and Arvanitoyannis, 2000).

2.4 TECHNOLOGICAL CHALLANGES IN DEVELOPING BAKERY FOOD CONTAINING β-GLUCAN

The basic ingredients in cake are flour, fat, egg, milk, sugar and salt. Flour, egg white, milk solids and salt are used to toughen the cake, while sugar, fat and egg yolk are used to tenderize the cake (Sahin, 2008). Cake batter can be considered as a complex oil-in-water emulsion with a continuous aqueous phase containing dissolved or suspended dry ingredients such as sugars, flour, salt and baking powder. The oil phase remains dispersed in clumps throughout the continuous or liquid phase and does not become part of the liquid phase (Painter, 1981).

Cake has a foam structure (Pyler, 1988) due to the presence of entrapped air. The interaction of ingredients developed during the mixing and baking stages are responsible for structure development (Sahin, 2008). The incorporation of bubbles in the system during mixing give rise to foam and it is important to obtain large amount of air pockets to provide higher cake volume (Handleman *et al.,* 1961). Baking converts aerated emulsion of cake batter to semisolid porous and soft structure through starch gelatinization, protein coagulation, production of CO_2 gas from chemicals dissolved in the batter, air inclusion during mixing, and the interaction among the ingredients (Sahin, 2008). Interactions of ingredients in batter influence the rheological and physical properties of batter. Therefore when changing the recipe of cake it is important to study their interactions as they can finally influence the cake quality. At the same time processes has to be modified in order to compensate any quality loss or improvement happened due to change in ingredients.

β-Glucan has been used in number of bakery products, such as, bread (Brennan and Creary, 2007; Cleary *et al.,* 2007; Knuckles *et al.*, 1997; Niba, 2003; Symons and Brennan, 2004b), cookies (Brennan and Samyue, 2004; Lee and Inglett, 2006) and cakes (Kalinga and Mishra, 2009; Lee *et al.*, 2004, 2005a, 2005c). Significant changes were observed in physical, sensory and physiological properties due to addition of BG by all these researchers. The type and level of BG used in various bakery products are summarised in Table 2.4. The adverse effects limiting their use are due to flow properties (consistency), water binding capacity, colour, flavour etc. The typical slimy texture of BG in the mouth may be unacceptable in some products. Due to high fat content in oat formulations, it can easily develop rancid off-flavour which can be imparted into the finished product along with masking of sweetness (Lyly, 2006). Increased hardness and decrease in volume of bread and cake (Brennan and Creary, 2007; Cleary *et al.,* 2007; Kalinga and Mishra, 2009; Lee *et al.,* 2004; Lee *et al.,* 2005a, 2005c), reduction of the diameter of biscuits (Lee and Inglette, 2006), and colour impairment have been reported in all those products (Kalinga and Mishra, 2009). In all the above studies, the adverse effects were accentuated at high level of fat replacement. Therefore, when developing food with BG as an ingredient, maintaining of satisfactory balance between sensory properties and health effects is important (Brennan and Cleary, 2005). If we go for very low levels of BG then it is difficult to achieve desired health benefits. Therefore it is important to overcome quality defects of BG added bakery products by changing the recipe and/or the process.

The quality of cake is affected by the amount, size and the distribution of air bubbles (Sahin, 2008). Addition of emulsifiers and increasing mixing time can be adapted to incorporate air bubbles (Sahin, 2008). Once the amount of air bubbles incorporated was high, improvement in cake quality such as softness and volume could be expected due to positive relationship. Increasing the level of water is another important step. It is assumed that due to hygroscopic nature of BG, it reduces the water availability in the system required for pasting and gelatinisation of starch.

Table 2.4 Type and level of BG used in different bakery products

Product name	Type of β-glucan	Level of BG	Reference
Cake	High viscous oat (50% BG) and barley (60% BG)	20 -40% (fat replacemet)	Kalinga and Mishra, 2009)
Cake	Nutrim OB (10% BG)	Up to 40% fat replacement	Lee *et al.,* 2004
Cake	Oatrim (5.8% BG)	Up to 60% fat replacement	Lee *et al.,* 2005a
Cake	C-trim20 (20% BG)	1g BG per serving	Lee *et al.,* 2005b
Biscuits	Nutrim OB (10% BG)	Up to 30% fat replacement	Lee and Inglett, 2006
Biscuits	BGC	2.5–10% enrichment	Brennan and Samyue, 2004
Bread	Glucagel® (83% BG)	2.5-5% enrichment	Brennan and Creary, 2007
Bread	High molecular weight and low molecular weight BG extract from Megazyme™ (95% BG)	4.5g/100g bread enrichment	Cleary *et al.,* 2007
Bread	Sunrise (5.77% BG)	2.5-5% enrichment	Symons and Brennan, 2004b

2.5 EFFECT OF BG ON KEY PHYSICOCHEMICAL EVENTS INFLUENCING QUALITY OF CAKES

2.5.1 Starch gelatinization

The major ingredient in cake is wheat flour, which contains on an average 72% of starch. Starch undergoes series of physicochemical changes during baking and provides the required quality attribute in cakes. Gelatinisation of starch is a nonreversible change occurring when starch-water mixture is heated above a certain temperature. The critical temperature of gelatinisation varies depending upon the source of starch. For native wheat starch, the critical temperature is just above 50^{o}C. Once this temperature exceeded, a number of changes occur and the first change is known as gelatinisation (Whistler and Paschall, 1965), which can be measured microscopically by the loss of birefringence or by the melting of crystals by differential scanning calorimetry (Hoseney, 1998).

As a result of heating of starch with water, swelling and solubilisation of starch granules can be seen and this leads to rapid increase in the consistency of the mixture. Upon reaching the maximum temperature, almost about 100^{o}C, maximum granule remnants and soluble starch are suspended in water. The consistency of this mixture is higher than that of totally solubilized starch-water mixture. This phenomenon is called pasting. If the starch water mixture is heated to 95^{o}C and held at that temperature with continuous stirring, the consistency will decrease. This is referred as shear thinning which is caused by the alignment of long molecules and the effect of shear on the swollen starch granules. The more the starch solubilises or swollen, the greater is the degree of shear thinning. Cooling this mixture (paste) will results in an increase in consistency and is called set-back (Hoseney, 1998). Cooling converts starch paste at sufficiently high starch concentrations (>6%, w/w) to form an opaque elastic gel (Morris, 1990).

The change in viscosity during pasting can be measured by Brabender Viscoamylograph and Rapid Viscoamylograph (RVA). Pasting properties of starch vary due to addition of different food ingredients and these changes finally influence the quality of the product. A typical RVA profile is presented in the Appendix 1. Influence of addition of different gums, fibres, salts and sugars to different types of starches and flour has been extensively studied using viscosity profiling. Pasting properties of wheat flour with different levels of sucrose, glucose, glycerol and hydroxypropyl β-cyclodextrin were studied using RVA and increase in viscosities were observed due to increased concentrations of these ingredients (Gunaratne *et al.,* 2007). Different fibres (celite, Arabic gum, locust bean gum and guar gum) were mixed with wheat starch and wheat flour, and increase in viscosities was observed (Brennan *et al.,* 2008) to different extent. Food gums decreased the viscosities of starch suspension due to their negatively charged characteristics (Shi and BeMiller, 2002). Interestingly, decrease in viscosities was also observed when β-glucan (uncharged) was mixed at different concentrations with wheat starch (Symons and Brennan, 2004a). It has been observed that pasting characteristics of the starch are dependent on type and level of hydrocolloids, electrical charges available, starch source and the method of measurement used.

2.5.2 Rheological Properties of cake batter

Non-Newtonian shear thinning (pseudoplastic) behaviour is observed in cake batter. Power Low (equation 2.1) and Herschel-Bulkley (equation 2.2) models are used to characterise cake batter (Sahin, 2008; Steffe, 1996; Toledo, 2007b).

$$\tau = K (\gamma)^{n} \quad \text{equation 2.1}$$

$$\tau = \tau_0 + K (\gamma)^{n} \quad \text{equation 2.2}$$

where, τ - shear stress, K – consistency index, γ- shear rate, n – flow behaviour index and τ_0 - yield stress

Rheological properties of cake batter can be correlated to the quality attributes of cakes such as volume and texture (Sahin, 2008). Volume of the cake is the most important factor with regard to the consumer acceptability and is controlled by batter viscosity (Sahin, 2008) with an optimum viscosity of batter required to achieve high volume. If the viscosity of batter is very low, batter cannot hold the air bubbles inside and cake collapse in the oven. On the other hand, high viscous batters hold the air bubbles inside but prevent expansion of bubbles (Sahin and Alava, 2003) and may reduce volume. This may not be true when BG is present (Kalinga and Mishra, 2009).

There are few studies conducted on rheological properties of cake batter containing different levels of BG (Kalinga and Mishra, 2009; Lee *et al.,* 2004, 2005a). Both storage (G') and loss (G") moduli and consistency indices (Power Law Model) increased upon fat replacement with different levels of barley and oat β-glucan concentrates (Kalinga and Mishra, 2009; Lee *et al.,* 2004, 2005a). With increasing concentration of β-glucan up to a certain level, increases in volume and viscosities were investigated. However, when BG concentration was further increased, viscosity increased but volume decreased. This could be due to poor expansion of air bubbles with higher viscosities (Kalinga and Mishra, 2009; Lee *et al.,* 2004; Lee *et al.,* 2005a). Lee *et al.,* (2004) observed when fat was replaced by 20% NutrimOB volume index increased but at 40% level volume index decreased. Fat replacement by using 20% BBGC level was statistically not significant ($p>0.05$) from the full fat containing control cake. However, volume index decreased when fat was replaced further (30 and 40%). These researchers found increased cake hardness with increased consistency of batter. For example, consistency index of full fat control cake was 19.9 Pas^n and in 40% BBGC level (fat replacement) was 338.1 $Pa.s^n$. The corresponding hardness values were 1.32 kg and 4.75 kg (Kalinga and Mishra, 2009).

The dynamic oscillatory shear viscoelastic properties (G' and G") of cake batters were investigated as a function of frequency in fat replaced cakes by Lee *et al.,* (2004) and Kalinga and Mishra (2009). Increase in both G' and G" was observed due to addition of BG and the batter showed more elastic properties than viscous properties which was evident by higher G' than G"(Kalinga and Mishra, 2009).

2.6 REVIEW SUMMERY

Cereal β-glucan is a soluble dietary fibre sourced from mainly oat and barley with several health benefits and can be considered as carbohydrate based fat replacer. Health benefits of consumption of BG are reduction of blood cholesterol levels and management of blood sugar levels in diabetics. Besides providing health benefits, BG offers reduction in calories through fat replacement.

Cake is an important cereal food consumed widely. It may contain 5-17% fat and can be considered as an ideal candidate for delivering BG both as enrichment and/or as fat replacer. The level of BG used for enrichment of cake is limited due to its impact on quality of the cake through reduction of volume and increasing hardness. At high levels of use, cakes show decrease in volume and increase in hardness, reducing their sensory acceptance. This requires attention for further investigation to ensure the use of this important functional ingredient in foods.

Commercial sources of BG vary enormously in composition and in particular the level of BG. The level of BG varies from 1 to 90% in the available formulations, which also contain various other components which may influence the end product quality. Further, the physical properties of BG are dependent on type of BG.

Rheological properties of cake batter can be used to predict the quality of cakes containing BG. Addition of BG increases the consistency of the batter in proportion to the level of its use. Batter containing BG retains its non-Newtonian characteristics with higher values of elastic and viscous moduli. This may have important implications in deciding the final cake quality parameters, such as, hardness and volume.

Additions of hydrocolloids in flour used for making bakery products influence the pasting and gelatinisation properties of starch. The effect depends on the type of hydrocolloids and their concentrations. There is considerable evidence that suggests BG interferes with the gelatinisation and pasting properties of the starch present in flour. Higher water retention and swelling of BG suggests its effect in making water unavailable for gelatinisation of starch and may be for coagulation of proteins.

CHAPTER 3

GELATINISATION BEHAVIOUR OF CAKE FLOUR MIXTURES CONTAINING β-GLUCAN

3.1 INTRODUCTION

β-Glucan (BG) has gained increasing interests as a bioactive ingredient in foods (Brennan and Cleary, 2005; Brennan *et al.*, 2002; Lazaridou and Biliaderis, 2007). Mixed linkage (1→3), (1→4) linear β-D-glucans are major components of endosperm cell walls of cereals, (Lazaridou and Biliaderis, 2007; Vaikousi and Biliaderis, 2005) with barley and oat being the richest sources (Lazaridou and Biliaderis, 2007; Temelli, 1997; Woods, 1993). Cereal BG shows huge variation in properties such as molecular size, ratio of tri- to tetramers, amount of longer cellulosic oligomers, and ratio of β-(1→4) to β-(1→3) linkages (Lazaridou and Biliaderis, 2007; Skendi *et al.*, 2003; Vaikousi and Biliaderis, 2005). These variations influence key functional properties including water solubility, dispensability, viscosity, and gelation properties, as well as of their physiological function in the gastrointestinal tract (Brennan and Cleary, 2005; Cavallero *et al.*, 2002; Lazaridou *et al.*, 2003, 2004a, 2004b; Wood, 1993, 2007).

Due to many well known health benefits, such as reduced energy density, prolonged satiety, effects related to an increase in faecal bulk, flattening of the postprandial serum glucose level (Brennan and Cleary, 2005; Cavallero *et al.*, 2002; Jenkins *et al.*, 2003; Symons and Brennan, 2004b), and reduction in reabsorption of cholesterol (Hecker *et al.*, 1998; Jenkins *et al.*, 2003; Marlett *et al.*, 2005) BG has gained increasing attention by researchers and industries.

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The Food and Drug administration (FDA) has recognised the importance of barley (WNBFC, 2006) and oat (Anon, 2002) bran and allowed making health claims on food labels and suggested a minimum daily intake of BG which is 3g/day (Anon, 2002).

Bakery products are important part of diet worldwide providing bulk of the dietary energy. These products are commonly fortified with BG (Brennan and Cleary, 2005; Oreopoulou, 2006; Warrand, 2006). However, addition of β-glucans into food systems causes changes to chemical, physical, and sensory properties of cake (Kalinga and Mishra, 2009; Lee *et al.*, 2004; Lee *et al.*, 2005a, 2005c), cookies (Lee and Inglett, 2006) and bread (Brennan and Cleary, 2007; Knuckles *et al.*, 1997).

The key food ingredient in bakery products, such as cake, is wheat flour. The quality of cake depends on the type of flour used in the recipe and changes occurring to flour during preparation *via* series of interactions. Flour is one of the most important ingredients affecting the rheological properties of cake batters and, consequently, the quality of cakes. In this experiment soft wheat, high ratio cake flour was used. Soft wheat flour is used in cakes which have low gluten content, low water absorption capacity, and low granular size. This flour is chlorinated and has low pH. Chlorine treatment is functionally beneficial to the production of high-ratio cakes (Sahin, 2008). Starch, protein and water are the key components that control the quality of wheat flour. Starch present in cake flour gelatinises during baking and forms the cake crumb. The protein is important in producing cake fine foam crumb structure during mixing and baking. For the formation of foam structure and starch gelatinisation presence of water is important. All these processes require sufficient amounts of available water (Pyler, 1988).

Acceptance of cake enriched with β-glucan and the consequent health benefits depends on how consumer is provided with cake of acceptable sensory characteristics. Interactions between BG and ingredients used in the recipe are the key to underlying reasons for the quality changes. Addition of BG modifies gelatinisation behaviour which influences the quality of starch containing foods. The rheological properties of starch and hydrocolloid mixtures have been reported previously (Brennan *et al.*, 2008; Cristianson *et al.*, 1981; Shi and BeMiller, 2002; Symons and Brennan, 2004a). When mixtures of starch water and gum were heated, early onset of initial viscosity was observed and that increase in viscosity was attributed to media viscosity rather than an effect on starch granule swelling (Cristianson *et al.*, 1981; Shi and BeMiller, 2002). The solutions obtained after heating of granules displayed stable, synergistic viscosity, suggesting interactions between gum molecules and solubilised amylose and low-molecular-weight amylopectin molecules causing increase in viscosity (Cristianson *et al.*, 1981). There are few studies reported on pasting properties of starch containing cereal BGC. Symons and Brennan (2004a) observed decrease in peak, breakdown, and final viscosities with increasing levels of BBGC. Also, substitution of wheat starch with 5% BBGC fibre fractions resulted in a decrease in enthalpy of gelatinisation compared to the control (Symons and Brennan, 2004a). The objectives of this study were to investigate interactions between cake flour (key ingredient) and BG by measuring thermal, pasting, and gelling properties of cake flour, starch and flour mixtures containing two types of BG concentrates at different levels.

3.2 MATERIALS AND METHODS

3.2.1 Preparation of β-glucan Concentrates

β-Glucans were extracted from barley and oat according to the method given by Vasanthan and Temelli (2002). BG contents of barley β-glucan concentrate (BBGC) and oat β-glucan concentrate (OBGC) analysed using the mixed linkage β-glucan assay kit (Megazyme Pty. Ltd, Wicklow, Ireland), were 60% and 50%, respectively. The moisture contents of BBGC and OBGC were 8.7% as determined by AACC approved methods (AACC, 2000). High ratio cake flour was obtained from Allied Mills (NSW, Australia) containing 10.6% moisture and 7.8% protein as determined by AACC approved methods (AACC, 2000).

3.2.2 Extraction of Starch from Flour

Starch was extracted from the flour using the dough process method (Fellers, 1973). In this process, stiff dough was made with approximately 60% water, and then the dough was allowed to rest and fully hydrated. The dough was then washed continuously while kneading with additional water to remove starch and the water extractable fraction from the gluten. Washed starch was collected by straining and centrifuged at 4000 *x g* for 10min. The water extractable fraction was removed and lighter squeegee starch (Type B starch, damaged starch, water un-extractable non starch polysaccharides, low levels of protein and ash) was separated from the heavier prime starch which was subsequently dried at 40°C for 24hrs in a vacuum oven (Gallenkamp Vacuum Oven, New Jersey, USA). Dried starch granules were ground using a mortar and pestle and sieved with 300µ test strainer (Endecotts Ltd., London, England). The extracted starch contained 10.6% moisture, 0.1% protein, 0.2% ash and 0% fat as analysed following the AACC approved methods (AACC, 2000).

3.2.3 Preparation of Flour β-glucan and Starch β-glucan Mixtures

Flour mixtures were prepared by homogenising BBGC and OBGC with cake flour at 10, 20 and 30% levels (flour basis) in a mixer (Kenwood Ltd, UK) for 10 minutes at speed 1. Samples were stored in airtight bags at room temperature (22°C) until used in further experiments. Similarly, BG and starch mixtures were prepared with BBGC and OBGC at 10, 20 and 30%.

3.2.4 Characterization of Cake Flour, Starch, β-glucan Concentrates and Flour Mixtures

The swelling and water retention capacity (WRC) were determined using the method proposed by Robertson *et al.* (2000). Swelling is expressed as the volume occupied by known weight of sample under the conditions used and reported as settled bed volume. Swelling was determined by hydrating 100mg of dry sample in 10 ml of distilled water containing 0.02% azide as a bacteriostat, in a calibrated cylinder at room temperature (22^{o}C). It was equilibrated for 18 hours and, the bed volume was recorded as volume/g of original sample dry weight (equation 3.1).

Water retention capacity is defined as the amount of water retained by a known weight of fibre under the conditions used and is related to the amount of soluble and insoluble fibre within the gel matrix (Robertson *et al.*, 2000). WRC was determined by adding 1 g of sample into 30 ml of distilled water containing 0.02% azide, in a centrifuge tube at room temperature, equilibrated for 18 hours and centrifuged at 3,000 x *g* for 20 min. The supernatant was removed and sample weight was recorded (residue fresh weight) prior to drying over night at 80^{o}C and the dry weight was recorded (residue dry weight). WRC was calculated as the amount of water retained by the pellet (g/g dry weight) (equation 3.2) (Robertson *et al.*, 2000).

The moisture contents of flour mixtures were determined by oven drying at 105^{o}C until a constant weight was obtained (AACC, 2000). Moisture contents of BBGC containing 10, 20 and 30% flour mixtures were 9.5%, 9.1% and 9.2%, respectively and moisture contents of OBGC containing 10, 20 and 30% flour mixtures were 9.5%, 9.1% and 9.1%, respectively.

Starch weight fractions of flour mixtures were calculated based on the amount of starch present in cake flour which was 72% (Data material sheet, Allied Mills, NSW, Australia).

$$Swelling = \frac{V}{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where, V – volume occupied by sample and W – original sample weight

$$WRC = \frac{W_{fr} - W_{dr}}{W_{dr}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

W_{fr} – residual fresh weight of the sample and W_{dr} – dry weight of the sample

3.2.5 Thermal Analysis of Flour and Starch Mixtures Containing BGC

Differential scanning calorimeter (DSC 7, The Perkin Elmer, Norwalk, Connect int, USA) was used for thermal analysis. Slurry was prepared by mixing flour or starch and water at a ratio of 1:4 (flour: water) on weight basis. 4-6 mg of dry matter of the flour mixture slurry were sealed into aluminium pan and equilibrated at 22°C overnight. The scan rate was 10°C/min over 30°C to 110°C. Empty pan was used as the reference (Symons and Brennan, 2004a). T_{on}, T_{end}, T_{peak} and ΔH of gelatinization were obtained with help of PYRIS 5.0 software, 2002 (PerkinElmer Instruments, LLC, USA).

3.2.6 Pasting Characteristics of Cake Flour and Starch Mixtures Containing BGC

Pasting characteristics of cake flour and starch mixtures with 10, 20 and 30% of BBGC and OBGC were determined using the Starchcell attached to controlled shear, stress rheometer (Physica MCR 301, Anton Paar GmbH, Germany). The instrument was controlled and data was generated using Rheoplus/32 (Physica MCR 301, Anton Paar GmbH, Germany) software. Pasting viscosity profile (PVP), similar to RVA profile in terms of peak viscosity, pasting temperature, pasting viscosity, pasting time, holding strength, break down, final viscosity, and setback from trough was obtained. 20g of 7% dispersion of flour mixtures was held at 50°C for 1 min, and then heated from 50°C to 95°C at a rate of 10°C/min, held at 95°C for 5 min and cooled to 50°C at rate of 30°C/min. Then it was held at 50°C for 1min (Anon, 2004). Starchcell coupled to the rheometer produces a pasting viscosity profile similar to Rapid Visco Analyser in SI units.

3.2.7 Gel Hardness

After the pasting profile analysis, the paste was transferred to a plastic container, covered and stored at 4°C for 7 hours to complete the gel formation. Hardness of these gels was measured using the TA-XT2 Texture Analyzer (stable Micro Systems, Surrey, UK), controlled by Texture Exponent 32 software (stable Micro Systems, Surrey, UK), following the modified method reported by Gunaratne *et al.* (2007). The gel was compressed at a speed of 0.5 mm/s to a distance of 5 mm with a 6 mm diameter stainless steel cylindrical probe.

3. 2.8 Statistical Analysis

The effect of two factors, type of BGC (BBGC and OBGC) and 3 levels of BGC (10, 20 and 30%) on thermal, pasting and gelling properties were studied in this experiments with a cross-balanced design. Two-way analysis of variance (ANOVA) was performed to determine the effect of source, level and the interaction between source and level of BGC. If a significant difference ($p<0.05$) was observed, Tukey's pair wise comparison was performed (Gacula and Singh, 1984). All the values are means of triplicate ($n=3$). Minitab 11 (Minitab Inc., State Collage, Pa., USA) statistical software package was used for analysis of data. All the significant differences are reported at significance level of 0.05.

3. 3 RESULTS AND DISCUSSION

3. 3.1 Characterization of Flour Mixtures

Water retention capacities for BBGC and OBGC containing flour mixtures were shown in Figure 3.1. The highest WRC was observed for BBGC (18.0±0.67 g/g), followed by OBGC (13.0±0.42 g/g). This difference may be due to high level of BG in BBGC (60%) as compared to 50% BG in OBGC. Both concentrates therefore behaved as soluble fibres. As expected, flour mixtures showed significantly ($p<0.05$) high WRC from that of cake flour and starch. WRCs of the mixtures increased in proportion to the levels of BBGC and OBGC used. Similar behaviour was reported by Symons and Brennan (2004a) explaining the ability of BG to retain water.

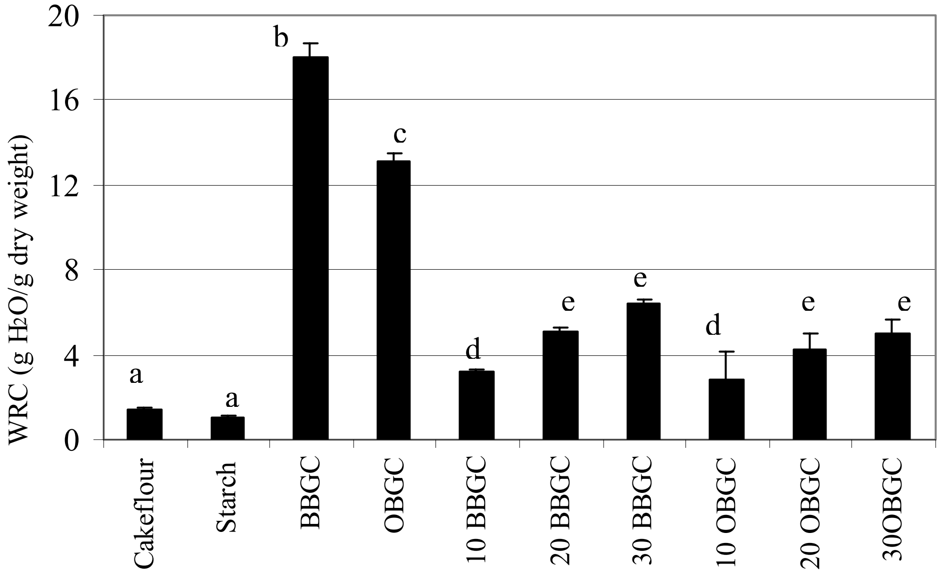


Figure 3.1 Water retention capacities for cake flour, starch and flour mixtures containing BBGC and OBGC

* Different letters indicate significant difference between treatments ($p<0.05$)

The highest value for swelling was observed for BBGC (10.2±0.44 ml/g) and the lowest value (2.2±0.18 ml/g) was for starch (Figure 3.2). As observed for WRC, swelling increased in proportion to the level of BGC in the mixtures. The difference in values was due to the amount of water soluble material present in BBGC and OBGC (Symons and Brennan 2004a). Flour mixtures with BBGC showed higher swelling values compared to flour with OBGC indicating presence of high amount of water soluble materials.

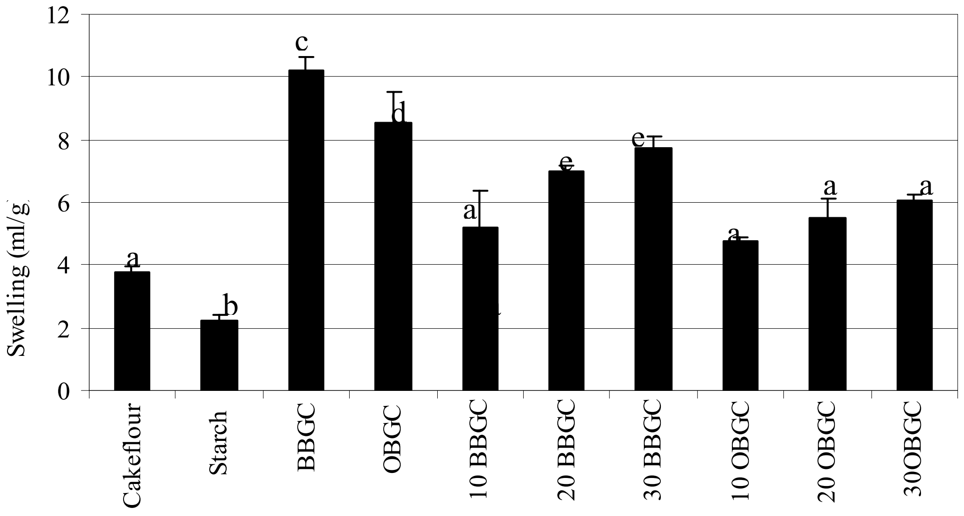


Figure 3.2 Swelling volumes for cake flour, starch and flour mixtures containing BBGC and OBGC

* Different letters indicate significant difference between treatments ($p<0.05$)

The higher WRC and swelling in cake flour than starch can be attributed to the presence of non-starch components (proteins and other carbohydrates) in cake flour. Addition of BGC significantly ($p<0.05$) increased swelling and WRC of flour mixtures. The type of BGC also influenced WRC and swelling. The starch fractions in OBGC and flour mixtures containing OBGC were greater than that of BBGC and flour mixtures with BBGC and hence showed lower WRC and swelling than mixtures containing BBGC. The calculated starch fractions in different sample mixtures are given in Table 3.1. The starch fraction in cake flour was 0.72 and in extracted starch the starch fraction was 0.99. The increase in WRC and swelling is inversely proportional to starch fraction in the mixtures.

Table 3.1 Starch fractions (by weight) of different flour mixtures.

Type of flour	Starch fraction
Starch	0.99
Cake flour	0.72
BBGC	0.02
OBGC	0.04
10% BBGC	0.67
20% BBGC	0.62
30% BBGC	0.57
10% OBGC	0.69
20% OBGC	0.64
30% OBGC	0.59

3.3.2 Thermal Properties of Flour and Starch Mixtures Containing BGC

Change in ΔH, T_{on}, T_{end} and T_{peak} of cake flour mixtures and starch mixtures with 10, 20 and 30% BBGC and OBGC are given in the Tables 3.2 and 3.3. The level of BGC had significant effect ($p<0.05$) on ΔH, T_{on} and T_{peak} in cake flour mixtures and ΔH and Ton in starch mixtures.

Table 3.2 Thermal parameters of cake flour mixtures containing BBGC and OBGC

Level of BGC	Onset Temperature(^{o}C)	Endset Temperature(^{o}C)	Peak Temperature(^{o}C)	Enthalpy (J/g)
Cake flour	49.4 ± 1.0^{a}	70.4 ± 0.8^{a}	62.7 ± 0.2^{a}	9.9 ± 0.6^{a}
10% BBGC	51.4 ± 2.1^{ab}	72.4 ± 0.9^{a}	62.9 ± 0.2^{a}	7.0 ± 0.6^{bc}
20% BBGC	53.4 ± 2.3^{b}	72.9 ± 1.2^{a}	64.0 ± 0.5^{b}	6.3 ± 0.6^{b}
30% BBGC	54.1 ± 1.0^{ab}	73.0 ± 0.7^{a}	63.9 ± 0.5^{b}	5.7 ± 0.9^{b}
10% OBGC	53.0 ± 1.2^{ab}	71.9 ± 1.3^{a}	63.7 ± 0.3^{bc}	7.8 ± 1.2^{c}
20% OBGC	54.0 ± 0.6^{ab}	73.7 ± 1.6^{a}	64.2 ± 0.3^{bc}	6.9 ± 0.7^{bc}
30% OBGC	55.0 ± 2.2^{b}	73.9 ± 1.8^{a}	64.6 ± 0.5^{c}	5.8 ± 0.9^{b}

Means of same column with same letter are not significantly different at $p<0.05$

Table 3.3 Thermal parameters of starch mixtures containing BBGC and OBGC

Level of BGC	Onset Temperature (°C)	Endset Temperature (°C)	Peak Temperature (°C)	Enthalpy (J/g)
Starch	52.0±0.8^{a}	69.6±2.5^{a}	60.6±0.7^{a}	9.2±0.7^{a}
10% BBGC	53.1±0.5^{a}	69.1±0.9^{a}	60.9±0.5^{a}	7.5±0.4^{ab}
20% BBGC	53.2±1.9^{a}	71.1±0.4^{a}	60.4±0.5^{a}	6.3±1.2^{ab}
30% BBGC	57.5±1.0^{b}	69.1±1.6^{a}	61.7±0.4^{a}	5.7±0.5^{b}
10% OBGC	54.6±1.5^{a}	70.7±1.2^{a}	61.9±0.8^{a}	6.8± 0.8^{ab}
20% OBGC	55.2±0.8^{ab}	71.9±1.2^{a}	62.9± 2.0^{a}	6.6± 1.6^{ab}
30% OBGC	55.3±0.9^{ab}	71.3±3.0^{a}	62.8±1.3^{a}	5.6±1.4^{b}

Means of same column with same letter are not significantly different at $p<0.05$

With increasing levels of BBGC and OBGC significant increase ($p<0.05$) in T_{on} was observed in both flour system and starch system (Table 3.2 and 3.3). This indicates delayed gelatinisation of starch. However, T_{end} did not show any significant difference ($p>0.05$) in both systems. T_{peak} significantly ($p<0.05$) increased from 62.7 ±0.2°C in cake flour to 63.9±0.5 and 64.6±0.5°C in 30% BBGC and 30% OBGC respectively (Table 3.2). The effect on T_{peak} was not significant ($p>0.05$) in starch system (Table 3.3). No significant difference ($p>0.05$) in T_{on}, T_{end} and T_{peak} were reported by Symons and Brennan (2004a) for starch containing 1 and 5% BBG and for bread flour supplemented with Glucagel® (Brennan and Cleary, 2007). However in this study BG was added above 10% and significant ($p<0.05$) increase in T_{peak} was observed with increasing concentration of BGC except at 10% BBGC level. The increase in gelatinization temperature can be accounted for, in part, due to competition for available water by BG limiting starch swelling and associated gelatinisation events.

ΔH represents the thermal energy involved in the starch gelatinization process. At molecular level, this may involve cleavage of existing hydrogen bonds between starch molecules and formation of new bonds involving water to give a less-ordered structure with increased entropy, so that the overall process is endothermic (Stevens and Elton, 1971). Clearly the decreasing trend in ΔH with increasing level of BBGC and OBGC was observed in both flour mixtures (Table 3.2) and starch mixtures

(Table 3.3). ΔH for the flour (9.9 J/g) decreased when flour was mixed with different levels of BGC. Significant ($p<0.05$) differences in enthalpy were observed between the enthalpies of flour and starch mixtures containing different levels of BBGC and OBGC. This can be due to interference in starch gelatinization through retention of starch integrity (Brennan and Cleary, 2007) by non-starch components. As similar trends were obtained for both cake flour and starch mixtures in this experiment the limitation of available water for starch gelatinization appears to be the main reason over the interactions of other non-starch components in cake flour system. Brennan and Cleary (2007) reported pronounced difference in the reduction of ΔH upon addition of Glucagel® to the bread wheat flour due to limited water availability to complete gelatinisation. The observed behaviour can be attributed to lowering the available water through binding with BG, and indirectly affecting gelatinisation and stabilisation of amorphous regions of starch, as was previously observed for starch-sugar mixture (Spies and Hoseney, 1982), starch-salt mixtures (Wotton and Bamunuarachchi, 1980), and BG-bread flour mixtures (Brennan and Cleary, 2007). Delayed onset of thermal transition in the presence of BBGC and OBGC further suggests stabilisation of amorphous structure of starch leading to decreased swelling of starch granules, amylose leaching, and granular breakdown. Inability of starch to gelatinise can be the reason for cakes containing BG to be harder (Kalinga and Mishra, 2009) and hence starch would be less digestible. Physiologically less digestible starch is important in reducing the glycemic index of cakes.

3. 3.3 Pasting Viscosity Profile of Flour Mixtures Containing BGC

Pasting is the formation of a more or less thick paste through the combined effects of swollen starch granules and amylose leached from the granule (Batey, 2007). The pasting viscosity profile (PVP) for cake flour and starch fortified with 10%-30% BBGC (A) and OBGC (B) are presented in Figure 3.3 (cake flour) and Figure 3.4 (starch). The viscosities of paste were strongly affected by both types and level of BG and addition of BG increased the viscosities in proportion to the increasing concentrations of BG. The greater water binding capacity of BG may be responsible for a higher synergism with starch (Brennan *et al.*, 2008). Also, viscosities of starch system were greater than that of cake flour system containing same levels of BGC (Figure 3.3 and 3.4).

Pasting properties of flour and starch mixtures containing 10%-30% BGC are shown in Table 3.4 and 3.5, respectively. These properties are predominantly indicative of behaviour of starch upon heating in the presence of water and measured as peak viscosity, pasting temperature, pasting viscosity, pasting time, holding strength, breakdown, final viscosity and setback from trough.

Peak viscosities for control cake flour and starch were 475.9±25.2 and 535.9±65.6 mPa.s, respectively. Peak viscosities increased with both increasing concentrations of BBGC and OBGC. This increasing trend was observed in cake flour and starch systems. The highest peak viscosities were observed in 30% BBGC mixtures (Table 3.4 and 3.5). Pasting temperature is the temperature at which the viscosity trace first rises above the baseline during the initial heating phase (Batey, 2007). Addition of BGC changed the pasting temperature as the pasting temperature of cake flour and starch was higher than all the other flour mixtures (Table 3.4 and 3.5). The highest pasting temperature of 70.9±6.9 ^{o}C was observed for starch. Lower pasting temperature (66.6±0.6 ^{o}C) was noted for flour due to the effect of non-starch components present. No significant difference ($p>0.05$) was noted for starch mixtures containing various levels of BGCs. The increase in pasting temperature could be due to binding of more water by BGC and achieving a peak viscosity quickly by the slurry, reducing the energy required for this process.

The pasting viscosity is the viscosity when pasting starts. The pasting viscosities for pure wheat flour and starch were 9.8±0.9 mPa.s and 15.1±5.4 mPa.s, respectively. It increased significantly with increasing levels of BGC, irrespective of source of BGC and the highest values were shown by 30% BBGC containing mixture (cake flour and starch) which were 632.1±5.6 mPa.s and 621.8±50.5 mPa.s, respectively (Table 3.4 and 3.5). Pasting viscosity values for different levels of BGC's were significantly different from cake flour and starch ($p<0.05$). Addition of BG at different levels into cake flour and starch decreased the time taken to reach pasting temperature significantly ($p<0.05$). However, different levels of BBGC and OBGC did not show significant difference ($p>0.05$). As BG competes for water with the other components of the bakery system, it binds more water and swells more as well. This ability increased with increasing levels of BG in the mixtures. Thus, the viscosity increased and the time required reaching to this viscosity decreased as the level of BG increased. Similarly, increase in peak and pasting viscosities were observed with increasing contents of BG in oat flour by Colleoni-Sirghie *et al.* (2004) and Zhou *et al.* (2000) due to higher water binding capacity of BG. The trend observed is supported by higher WRC and swelling for BBGC and OBGC (Figure 3.1 and s 3.2).

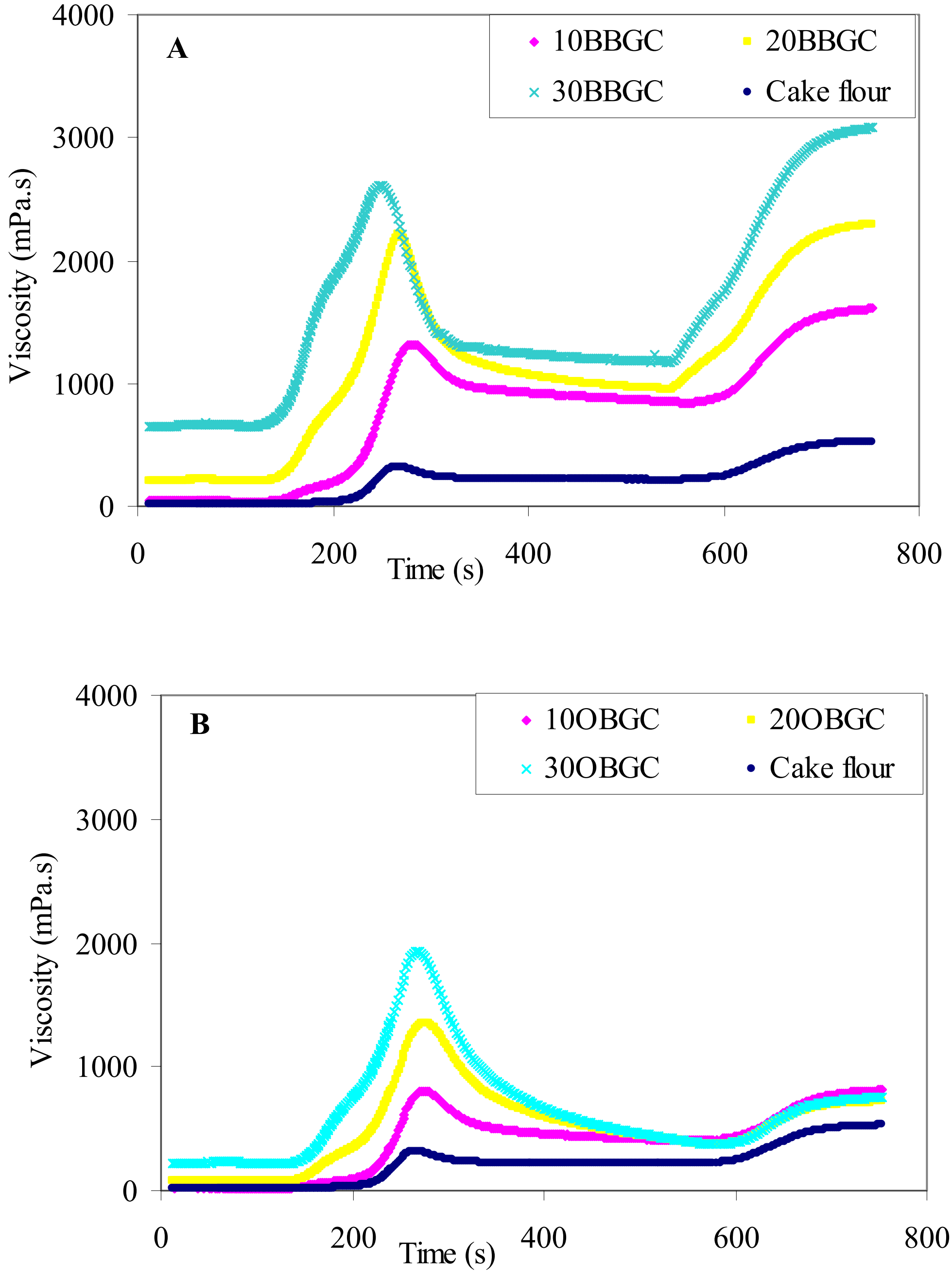


Figure 3.3 Pasting viscosity of cake flour and flour mixtures containing BBGC (A) and OBGC (B)

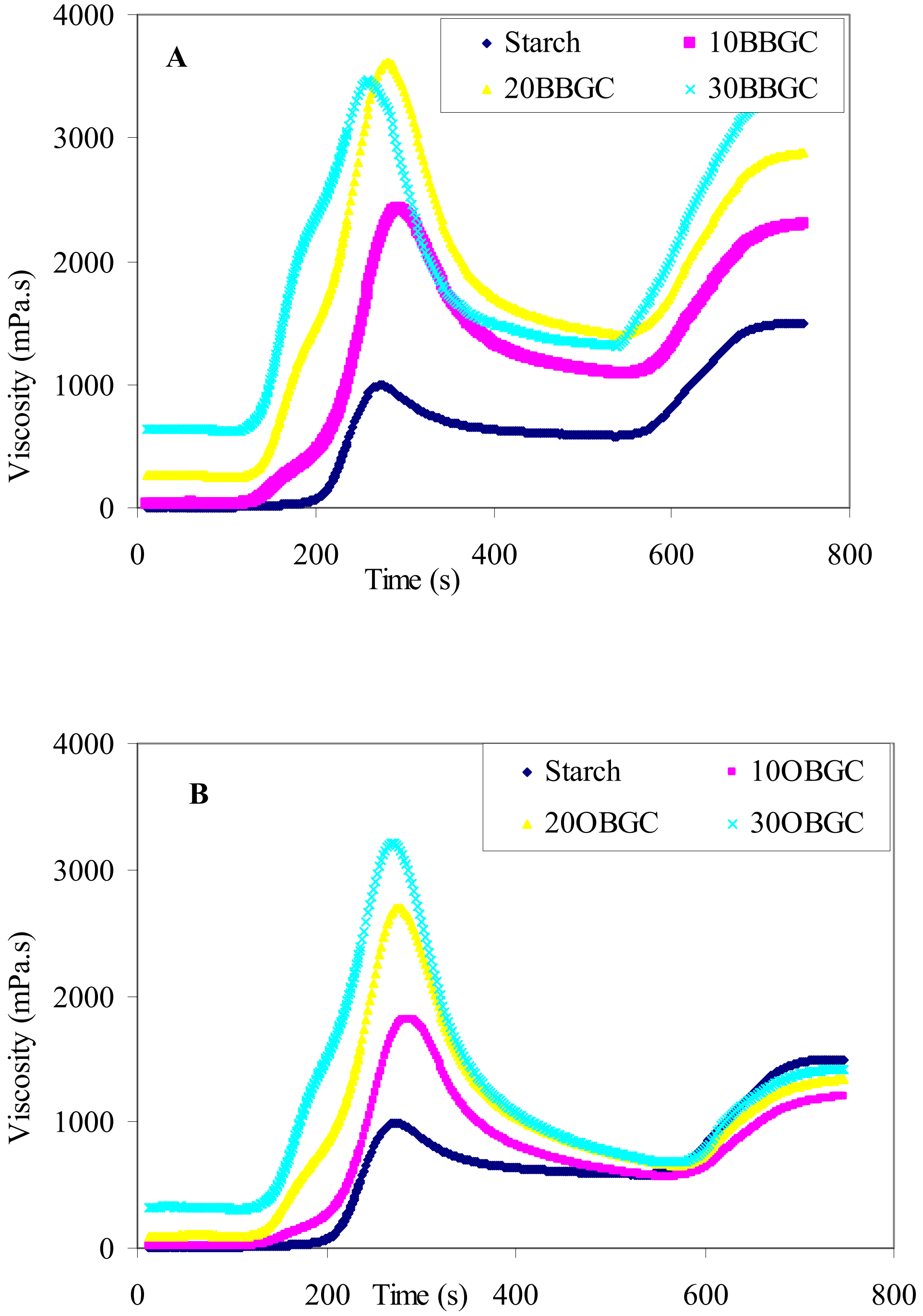


Figure 3.4 Pasting viscosity of starch and starch mixtures containing BBGC (A) and OBGC (B)

Table 3.4 Pasting Viscosity Profile for cake flour and flour mixtures containing BBGC and OBGC

Level of BGC	Peak Viscosity (mPa.s)	Pasting Temperature (°C)	Pasting Viscosity (mPa.s)	Pasting Time (s)	Holding Strength (mPa.s)	Break down (mPa.s)	Final Viscosity (mPa.s)	Setback from trough (mPa.s)
Cake flour	475.9 ± 25.2^{a}	66.6 ± 0.6^{a}	9.8 ± 0.9^{a}	129.7 ± 2.4^{a}	272.7 ± 5.2^{a}	203.3 ± 20.6^{a}	653.0 ± 21.4^{a}	380.4 ± 17.4^{a}
10% BBGC	1319.7 ± 19.7^{b}	65.7 ± 0.1^{b}	37.5 ± 0.2^{b}	126.2 ± 0.1^{b}	843.8 ± 5.2^{b}	476.3 ± 14.9^{b}	1606.0 ± 13.1^{b}	762.4 ± 8.5^{b}
20% BBGC	2218.3 ± 26.1^{c}	65.1 ± 0.1^{c}	199.8 ± 8.7^{c}	123.8 ± 0.2^{c}	951.6 ± 11.6^{c}	1266.0 ± 23.1^{c}	2291.3 ± 7.6^{c}	1340.0 ± 6.9^{c}
30% BBGC	2718.3 ± 127.9^{d}	64.5 ± 0.1^{d}	632.1 ± 5.6^{d}	119.4 ± 2.5^{d}	1178.3 ± 10.5^{d}	1540.0 ± 117.5^{d}	3112.7 ± 38.7^{d}	1934.3 ± 30.7^{d}
10% OBGC	803.5 ± 29.1^{e}	65.9 ± 0.1^{b}	21.7 ± 0.4^{b}	126.7 ± 0.3^{b}	401.7 ± 7.3^{e}	401.9 ± 21.9^{b}	810.1 ± 5.4^{e}	408.5 ± 2.1^{a}
20% OBGC	1353.7 ± 49.1^{b}	65.8 ± 0.01^{b}	73.4 ± 3.5^{e}	126.5 ± 0.1^{b}	374.1 ± 4.0^{e}	979.9 ± 45.0^{e}	715.8 ± 6.1^{e}	341.6 ± 2.3^{a}
30% OBGC	1947.7 ± 44.4^{f}	65.9 ± 0.1^{b}	227.5 ± 22.8^{c}	126.5 ± 0.3^{b}	377.7 ± 4.9^{e}	1569.7 ± 42.7^{d}	750.1 ± 9.1^{e}	371.3 ± 4.7^{a}

Means of same column with same letter are not significantly different at $p<0.05$

Table 3.5 Pasting Viscosity Profile for starch and starch mixtures containing BBGC and OBGC

Level of BGC	Peak Viscosity (mPa.s)	Pasting Temperature (°C)	Pasting Viscosity (mPa.s)	Pasting Time (s)	Holding Strength (mPa.s)	Break down (mPa.s)	Final Viscosity (mPa.s)	Setback from trough (mPa.s)
Starch	535.9± 65.6^{a}	70.9± 6.9^{a}	15.1± 5.4^{a}	141.6±22.1^{a}	582.2±14.7^{a}	46.2±23.5^{a}	1492.0±314.2^{a}	909.8±16.5^{a}
10% BBGC	1001.5±47.3^{b}	64.2±0.06^{b}	36.7±0.9^{b}	112.2±0.2^{b}	1086.7±24.7 ^{b}	84.9±23.2^{a}	2297.3±37.4 ^{b}	1211.0±12.5^{b}
20% BBGC	2339.7±112.3^{c}	63.6±0.1 ^{b}	249.7±37.3^{c}	113.2± 0.1^{b}	1310.7±53.3^{c}	939.1±58.9^{b}	2873.0±14.2 ^{c}	1472.7±65.7^{c}
30% BBGC	3056.0 ±135.9^{d}	63.4±0.1^{b}	621.8±50.5^{d}	115.0± 0.3^{b}	1400.3±77.0 ^{d}	1745.0±88.1^{c}	3404.7±51.7^{d}	2094.0±9.5^{d}
10% OBGC	779.4 ± 22.8^{ab}	64.6±0.1^{b}	19.4±3.2^{a}	114.0±0.1 ^{b}	567.3 ±1.9^{a}	212.0±24.2 ^{a}	1200.0±11.0^{a}	632.5± 9.5 ^{e}
20% OBGC	1594.0±7.5 ^{e}	64.1±0.2^{b}	96.7±10.2^{e}	115.1±0.7 ^{b}	658.5±11.0 ^{a}	935.6± 16.3 ^{b}	1334.0±17.7^{a}	675.6± 6.7^{e}
30% OBGC	2382.7±161.4 ^{c}	63.8±0.1^{b}	312.9±16.4f	116.6±0.3^{b}	678.7±3.3^{a}	1704.3±164.7^{c}	1418.3±13.3^{a}	739.7±11.9 ^{e}

Means of same column with same letter are not significantly different at <0.05

Holding strength is the minimum viscosity after the peak was reached and provides an indication of paste stability (Batey, 2007). Addition of BBGC to flour and starch increased the holding strength significantly ($p<0.05$) while OBGC showed non significant difference ($p>0.05$) (Table 3.4 and 3.5). In mixture containing BBGC, holding strength was dependent on the concentration of BG added. For example, holding strength in cake flour mixtures containing BBGC increased from 843.8±5.2 mPa.s in 10% BBGC to 1178.3±10.5 mPa.s in 30% BBGC (Table 3.4). When BG was mixed with starch at different levels similar pattern was observed as in the cake flour mixture. Holding strength went up from 1086.7±24.7 mPa.s in 10% to 1400.3±77.0 mPa.s in 30% BBGC starch mixtures. However, the effect of OBGC concentration in both flour and starch mixture were insignificant ($p>0.05$). Holding strengths were greater in mixtures containing BBGC than OBGC. For example in cake flour mixture, holding strength of 30% BBGC was 1178.3±10.5 mPa.s and in 30% OBGC it was 377.7±4.9 mPa.s. Hence the pastes produced by BBGC were more stable than those produced by cake flour, starch or mixtures with OBGC.

Breakdown is regarded as the measurement of the degree of disintegration of granules or paste stability (Leon *et al.*, 2006). At breakdown the swollen granules disrupted further, and amylose molecules generally leached out into the solution. The strong swelling volume of starch granule makes it easy to reach maximum viscosity. As temperature increased starch granules break easily due to weak inter molecular forces increasing sensitivity to shear force (Leon *et al.*, 2006). The breakdown viscosity increased with increasing levels of both BGC in similar way as cake flour mixture (Table 3.4) and starch mixture (Table 3.5) irrespective of the type of BGC used.

The starch fractions from the highest to the lowest were starch < cake flour < mixtures with OBGC < mixtures with BBGC. Lowest break down viscosity corresponded to the highest starch fraction. The pastes produced by pure starch showed lowest break down viscosity (46.2±23.5 mPas) indicating weak structure. The break down viscosity of cake flour was 4.4 times greater than that of starch (Table 3.4 and 3.5). Non starchy ingredients, particularly, proteins present in flour provide additional strength. Presence of BGC in mixture formed a stronger structure as more energy would be required to break down these paste. Functionally, the breakdown viscosity is related to the ability of starch to withstand heating at high temperature and shear stress, and is an important factor in many processes (Leon *et al.*, 2006).

The viscosity at the end of the PVP is defined as the final viscosity (Batey, 2007). The added BG bound water and increased the viscosity during heating. The stable paste produced by BG could withstand heat and shear stress increasing the final viscosity. The final viscosity was significantly ($p<0.05$) increased with increasing levels of BGC's and 30% BBGC (3112.7±38.7 mPa.s) was the highest (Table 3.4) in cake flour mixture. Similar behaviour was observed for starch mixture (Table 3.5). A significant ($p<0.05$) increase in final viscosity with increasing levels of BBGC and non significant ($p>0.05$) increase with increasing concentrations of OBGC was observed.

The minimum viscosity value in the constant temperature phase of PVP is setback from trough. The highest drop from peak viscosity to trough viscosity indicates less granule breakdown (Batey, 2007). According to the PVP of different flour mixtures the trough viscosity increased with increasing levels of BGC in cake flour mixtures (Table 3.4) and starch mixtures (Table 3.5), due to the higher resistance of starch granules to breakage during shearing. Highest value in cake flour mixtures was achieved by 30% BBGC (1934.3±30.7 mPa.s) and was 5.1 times higher than the trough viscosity for cake flour. Though the trough viscosity increased with increasing level of OBGC, those levels were not significantly different ($p>0.05$) from cake flour. The effect of OBGC appears to be less than that of BBGC in controlling starch granules breakdown. Similar pattern was observed in starch mixtures containing different levels of BBGC. The highest value was noted for 30% BBGC (2094.0±9.5 mPa.s) in starch BBGC mixture (Table 3.5). The trough viscosities of all the levels of flour mixtures containing OBGC were lower than that of starch due to higher shear resistance of starch after heating.

Higher peak viscosity, breakdown, and swelling power during heating indicate the resistance of starch to heat and shear forces (Leon *et al.*, 2006). Mixtures containing BBGC at 30% level showed highest values for these parameters indicating mixture can withstand more heat and shear stresses in the presence of BGC and consequently, reduced starch gelatinization. Increase in viscosity values are due to lower starch fraction and viscosity enhancing properties of BGC in the mixtures (Cleary *et al.*, 2007). Lower pasting viscosity of the mixture pastes containing BG reported earlier (Symons and Brennan, 2004a; Brennan and Cleary, 2007) were attributed to high starch fraction and low concentrations of low molecular weight BG used in the mixture. Experimental conditions used in this study were different from those of Symons and Brennan (2004a) and Brennan and Cleary (2007) in type of BGC and levels used in the mixtures. BBGC and OBGC were used at high levels i.e. 10- 30% as compared to 1-5%. The increase in viscosity may be attributed to increase in media viscosity by BG as was observed for starch-sucrose system (D'Appolonia, 1972) inhibiting starch granule hydration. When BG was mixed with flour or starch keeping the amount of added water constant, an increase in viscosities was evident in this experiment. When water was bound by BG, water could not act as a plasticiser and then the instrument could easily detect the increase in viscosity. However, in a low concentration of flour slurry the excess water allowed for swelling without a detectable increase in viscosity and so peak, pasting viscosities increased and pasting time and temperature are decreased. These results show the ability of BG to produce stable pastes during heating irrespective of presence of other macromolecules, such as proteins. Even though the effect of protein is evident when comparing starch vs flour, mixture properties were controlled mainly by the BG present. It is postulated that these stable pastes resulting from addition of BG lead to increased hardness when the batter is set under the influence of heat during baking.

3. 3.3 Hardness of Resulted Gels

Figure 3.5 and 3.6 illustrate values for hardness of gels made from wheat flour and wheat starch, respectively, containing 10-30% of BBGC and OBGC. The gel hardness decreased with increasing levels of BGC in cake flour and starch mixtures confirming structure building role of starch. The firmness of the starch gel was 96.8 g (Figure 3.6) as compared to 29.1 g for cake flour (Figure 3.5). This effect was due to the increased levels of non-starch components in the flour control samples interfering with the starch gelatinisation (and hence pasting). Higher starch fraction in samples implies that greater network formation in the starch-rich sample producing firmer gels. Heating of starch suspension results in a fluid, composed of porous, gelatinized and swollen granules with an amylopectin skeleton, suspended in a hot amylose solution.

Solubilisation of sufficient quantity of amylose and a minimum concentration of ~6% w/w starch are necessary for gelation (Morris, 1990). The softening of gels (decreasing hardness) with increasing concentration of BGC's may be attributed to many reasons such as, dilution effect of starch in the suspension, low swelling of starch granules during pasting and low levels of amylose leaching forming very poor gel matrix. Decreased gel hardness at higher concentrations (40%) of sucrose, glucose and hydroxypropyl β-cyclodextrin in wheat starch was observed by Gunaratne *et al.* (2007) and non-starch polysaccharides (guar gum, arabic gum, locust been gum) and celite (1%, 2.5% and 5% w/w) by Brennan *et al.* (2008) due to reduced amylose concentration in the continuous network of the formed gel.

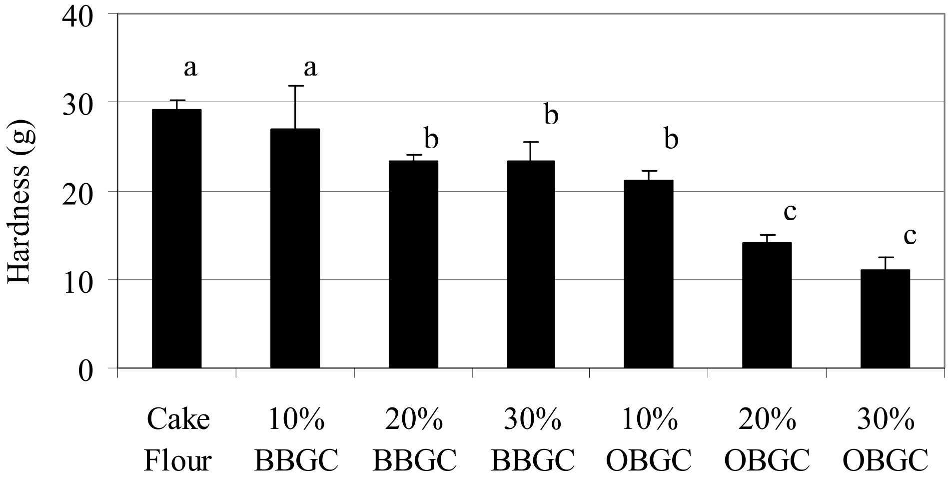


Figure 3.5 Hardness of gels prepared with cake flour and flour mixtures containing BBGC and OBGC

* Different letters indicate significant difference between treatments ($p<0.05$)

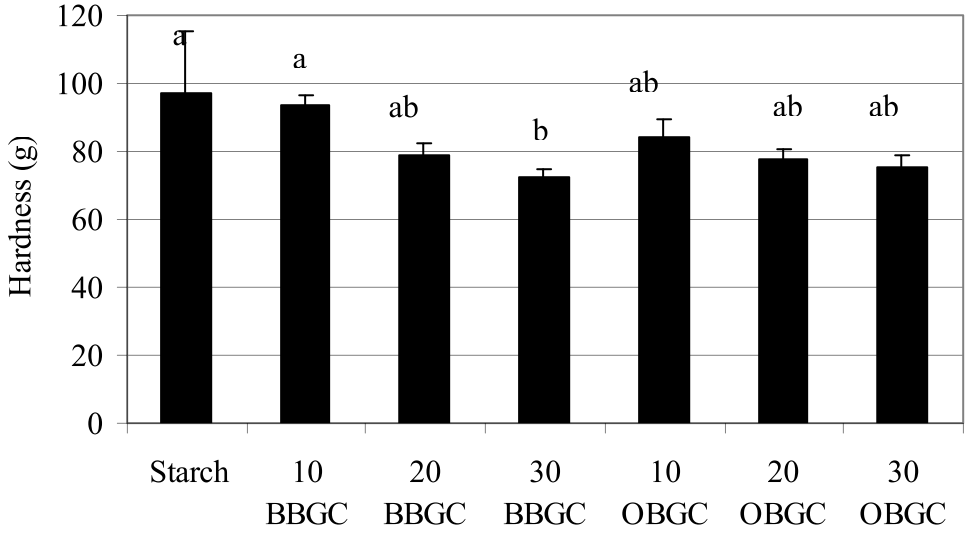


Figure 3.6 Hardness of gels prepared with starch and flour mixtures containing BBGC and OBGC

* Different letters indicate significant difference between treatments ($p<0.05$)

3. 4 CONCLUSIONS

Addition of barley and oats BG had great impact on gelling, pasting and thermal properties of cake flour and starch due to the ability of BG to bind water. The highest water retention capacity and swelling were observed for BBGC and mixtures containing BBGC. The water binding ability of BBGC was greater than that of OBGC. Addition of BG increased the T_{on}, T_{end} and T_{peak} and decreased enthalpy irrespective of type of BG. The type and level of BG significantly influenced pasting characteristics. Peak viscosity, pasting temperature, pasting viscosity, pasting time, holding strength, breakdown viscosity, final viscosity, and setback from trough increased with increasing levels of BGC and the highest viscosities were observed in 30% BBGC level both in cake flour mixture and starch mixture. Pasting time and peak temperature decreased with increasing levels of BGC and the lowest was observed in 30% BBGC. BG swells and increases the viscosity of medium increasing the viscosity during pasting and this paste could withstand high shear during heating.

The gel strength was highest for pure starch and decreased upon addition of BG. The gel strength of the mixtures containing BG decreased as the concentration of BG in the mixture increased. The main interaction of BG mixtures studied appears to be between starch-water-BG. At higher levels (up to 30%) of addition, BG restricts the available water and reduces the gelatinization and therefore its digestibility. From the viewpoint of attaining ideal sensory quality in terms of desired hardness, these results suggest to reduce the level of BGC and to add extra water over and above used in the original cake formulation.

CHAPTER 4

SORPTION BEHAVIOUR OF β-GLUCAN CONTAINING FLOUR MIXTURES

4.1 INTRODUCTION

Over the last two decades the acceptance of BG as a functional, bioactive ingredient has increased popularity and consumption (Lazaridou and Biliaderis, 2007). As a water soluble dietary fibre producing high viscosity solution, it improves blood glucose regulations in diabetics and reduces serum cholesterol in hypercholesterolemic subjects (Lazaridou *et al.*, 2007; Wood, 2007). Also, it provides all the health benefits relating to soluble and insoluble dietary fibre (Jenkins *et al.*, 2003). At the same time addition of β-glucan give rise to adverse effect on physical and sensory properties of the product. These adverse changes to the sensory quality of BG enriched products require scientific investigation to understand how BG interacts with flour components and other ingredients in the formulation during manufacture.

Water activity (a_w) in food is defined as the ratio of the partial pressure of water in the headspace of a product to the vapour pressure of pure water at the same temperature. The water and its state in food influence physiochemical properties of foods (Bell and Labuza, 2000; Karel, 1975). Besides affecting microbial spoilage in foods, water activity influences chemical and enzymatic reactivity in foods by acting as a solvent, reactant or by changing the mobility of the reactants by affecting the viscosity of the system (Leung, 1987). The understanding of the physical-chemical relationship between water and the various components in foods enables improvement in foods to maintain desirable textural quality and chemical stability (Bell and Labuza, 2000). The change in mobility of water molecules affects functionality of protein and starch in bakery foods including cakes.

In cereal systems starch gelatinization and retrogradation are affected by the water activity. The effect of a_w on starch gelatinisation has been reported (Hoseney, 1998). Solutes that are known to reduce water activity, such as, sugar and salts, reduce the amount of free water required for gelatinisation of starch and coagulation of proteins responsible for structure formation. This was evidenced by a shift of gelatinisation thermogram to right (increased onset temperature) and appearance of additional peak or peaks on the thermogram (Eliasson, 1991; Spies and Hoseney, 1982), and reduction in amylose leaching (Belia *et al.*, 1996; Tomasik *et al.*, 1995). The shift in gelatinisation temperature profile and higher pasting viscosities were observed in flour and starch mixtures containing different levels of BG (as discussed in Chapter 3). It was assumed that BG had ability to bind water, reduce the water activity of the system, and hence make water less available for these processes.

A number of models have been used in the literature to describe the relationship between the equilibrium moisture content of food and water activity (Bell and Labuza, 2000; Igelias and Cherife, 1982). These models are classified roughly into 5 broad types, kinetic models based on a monolayer, kinetic models based on a multilayer and condensed film, models based on polymer theory, semiempirical and empirical. Out of these models GAB (Guggenheim, Andersen and de Boer) sorption equation (Equation 4.1) has become very popular in the field of food technology and is a kinetic model based on multilayer and condensed film concept. The main reason of its use is that the water activity range covered by this isotherm is much wider ($0.05<a_w<0.08\text{-}0.9$) than that of BET equation (Timmermann, 2003), fits the experimental data reasonable well and its parameters are related to physically meaningful properties, such as heats of sorption of monolayer, multilayer, and condensation of water.

The objectives of this study were to determine the water sorption behaviour of cake flour-BG mixtures at different temperatures as there are no data reported in the literature. The experimental data were used to fit the GAB equation.

4.2 MATERIALS AND METHODS

High ratio cake flour was obtained from Allied mills (Summer Hill, NSW, Australia) containing 10.6% moisture and 7.8% protein as determined by AACC Approved methods (AACC, 2000). β-glucan concentrate (BGC) was prepared from barley in the laboratory (Vasanthan and Temelli, 2002). BGC of extracts was determined using mixed linkage β-glucan assay kit (K-BGLU, Megazyme International Ireland Ltd., Wicklow, Ireland) and was found to be 60%.

4.2.1 Preparation of Flour Mixtures

High ratio cake flour was mixed with different levels (10, 20 and 30%) of barley β-glucan concentrates (BBGC) on flour basis in a mixer (Kenwood Ltd, UK) for 10 minutes at speed 1. The samples were stored in airtight bags at room temperature (20°C) until used in the experiment.

4.2.2 Determination of Water Sorption Isotherms

Sorption isotherms were developed for cake flour, BBGC, and flour mixture by keeping 1-2 g of powders in vacuum desiccators containing saturated aqueous salt solutions which provide defined constant water activity inside the desiccators (Resio *et al.*, 1999; Siripatrawan and Jantawat, 2006). Relative humidity was maintained from 0 to 1.0 by keeping different saturated salt solutions in desiccators (Bell and Labuza, 2000; Rockland, 1960). Samples were allowed to equilibrate at given temperatures 20±0.5, 35±0.5, 40±0.5 and 50±0.5°C, over different saturated salt solutions in vacuum desiccators. To prevent mold growth in samples kept at a_w above 0.5, a vial containing formaldehyde was placed in the desiccators. Samples were allowed to equilibrate with the environment inside the container until there was no discernible weight change, as evidenced by constant (±0.001 g) weight value (Siripatrawan and Jantawat, 2006).

Dry weights of powders were obtained by drying to a constant weight (approximately 24 hrs) in a vacuum oven (Gallenkamp Vacuum Oven, New Jersey, USA) at 80^{o}C. Sorption isotherms were developed by plotting equilibrium moisture content *vs* a_w for different temperatures.

4.2.3 Modelling of Sorption Isotherms

The GAB model is recognized as the most versatile model for sorption of food and bio-based materials (Sundaram and Durance, 2008) and hence experimental data were used to fit the sorption data using a three parameter GAB equation (Equation 4.1), which was rearranged to equation 4.2. Data was fitted to the rearranged equation (4.2) as given by Bizot (1983). The parameters of GAB model (*C*, k and X_m) were estimated using MathCAD 14 (PTC 140 Kendrick St, Needham, Massachusetts 02490, USA). The fit was acceptable if the R^2 value was greater than 0.8.

$$X = \frac{X_m C k a_w}{(1 - ka_w)(1 - ka_w + Cka_w)} \text{ ……………………………….equation 4.1}$$

$$\frac{a_w}{X} = \alpha a_w{}^2 + \beta a_w + \gamma \text{ …………………………………………...equation 4.2}$$

Where, a_w – water activity, C and k are constants, X and – X_m equilibrium and monolayer moisture contents.

Following equations for β, α and γ were used to evaluate *C, k* and *Xm* values

$$\beta = \frac{C - 2}{X_m C}$$

$$\alpha = [\frac{k}{X_m C}][1 - C]$$

$$\gamma = \frac{1}{X_m Ck}$$

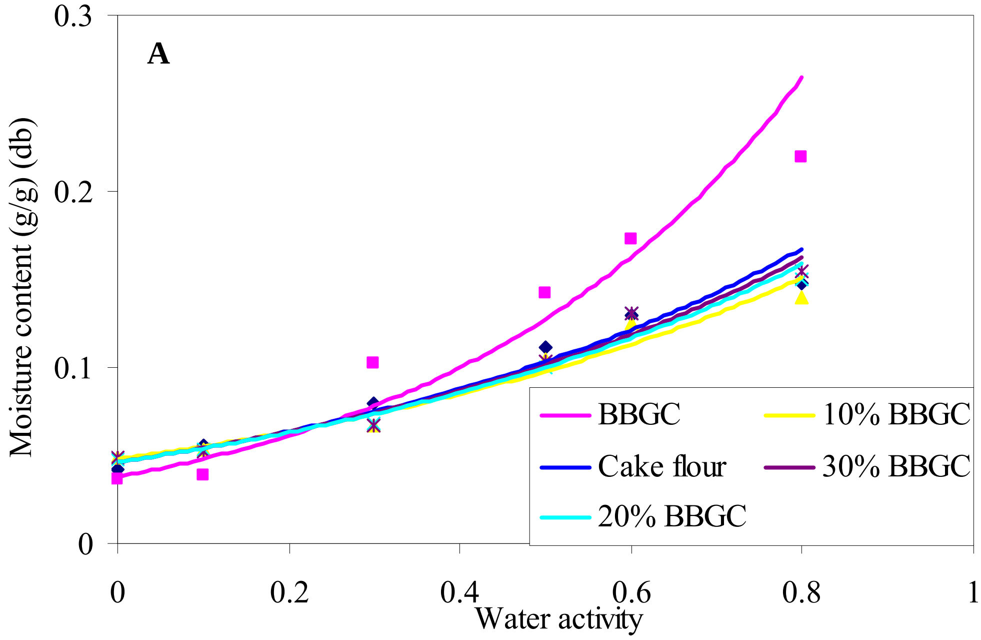
4.3 RESULTS AND DISCUSSION

4.3.1. Sorption Isotherms

The sorption isotherms at 20, 35, 40, and 50°C for cake flour, BBGC and flour mixtures containing 10, 20 and 30% BBGC are shown in Figure 4.1. Sorption data were omitted as there were too much of scatter in the experimental data (BBGC (control) at 20°C, 20% BBGC at 35°C and 30% BBGC at 50°C).

Increase in the equilibrium moisture content with increasing a_w depicted the isotherms are typical Type II (Bell and Labuza, 2000) which is common for starch, (Al-Muhtaseb *et al.*, 2004; Leiras and Iglesias, 1991). Cake flour and all flour mixtures containing BBGC gave Type II behaviour sorption isotherms at all temperatures (Figure 4.1 and 4.2). However BBGC followed Type III sorption isotherm at 35°C and 40°C. At high water activities the equilibrium moisture contents of BG was greater than that of cake flour and flour mixtures (Figure 4.1-B and 4.2-B) typical of being a hydrocolloid and its high water retention properties. Type III sorption isotherms indicate sorption of relatively small amounts of water at low water activity and large amounts at higher water activity. Highly hygroscopic nature of the BBGC control was confirmed similar to other hydrocolloids. Once the bulk moisture point (above a_w = 0.6) was been reached, the product rapidly sorbed large amounts of water, causing it to deliquesce leading to the steep rise in the second portion of the curve corresponding to the formation of hydrate (Sundaram and Durance, 2008). The hygroscopic nature of BG especially at high water activities confirms the water binding ability and its influence on swelling, water retention capacity discussed in Chapter 3 (Figure 3.1 and 3.2 in Chapter 3). High swelling of BG have also exposed more hydrophilic groups increasing the equilibrium moisture content further. Also, differences in the equilibrium moisture contents were much more pronounced at higher water activities (>0.6) due to influence of BG in the mixtures.

The slight sigmoid shape in sorption isotherms of flour mixtures containing 10, 20 and 30% BBGC and cake flour control were due to the presence of starch in cake four (Figure 4.1-A, B and 4.2-A, B). This sigmoid shape in isotherms of different starches was observed by many researches. For example waxy maize, rice, wheat (Enrione *et al.*, 2007), rice flour (Durakova and Menkov, 2004), whole yellow dent corn (Samapundo *et al.*, 2007), cake mixtures (Leiras and Iglesias, 1991), and starch and gluten from wheat (Viollaz and Rovedo, 1999).



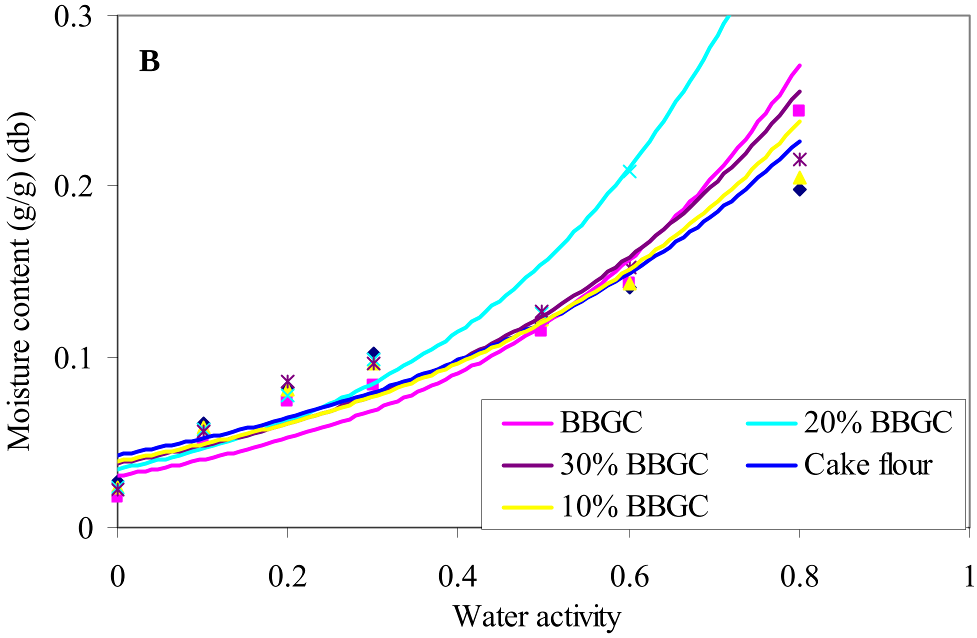
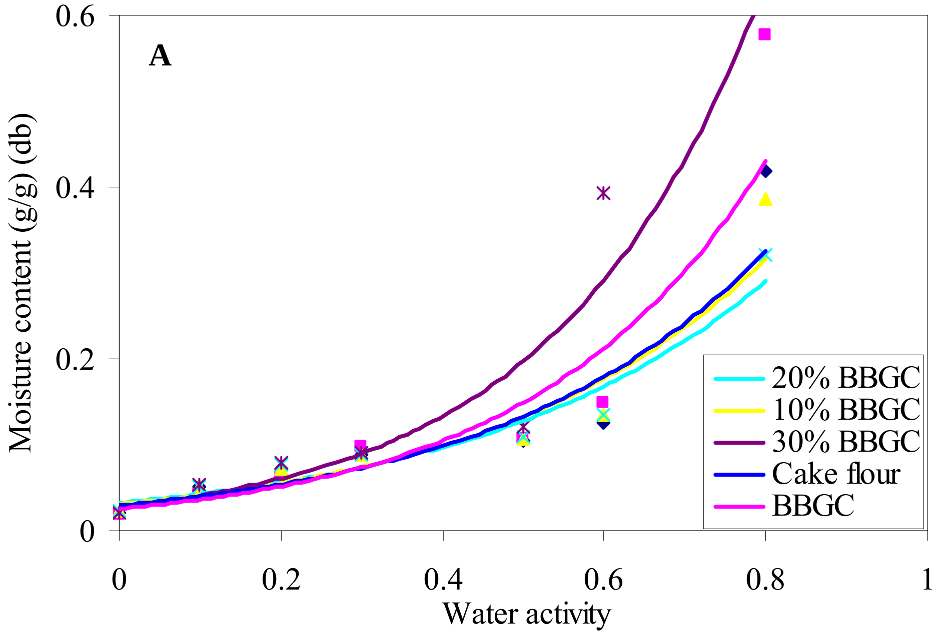


Figure 4.1 Moisture sorption isotherms for cake flour, BBGC and flour containing different levels of BGC at 20 °C (A), 35 °C (B)



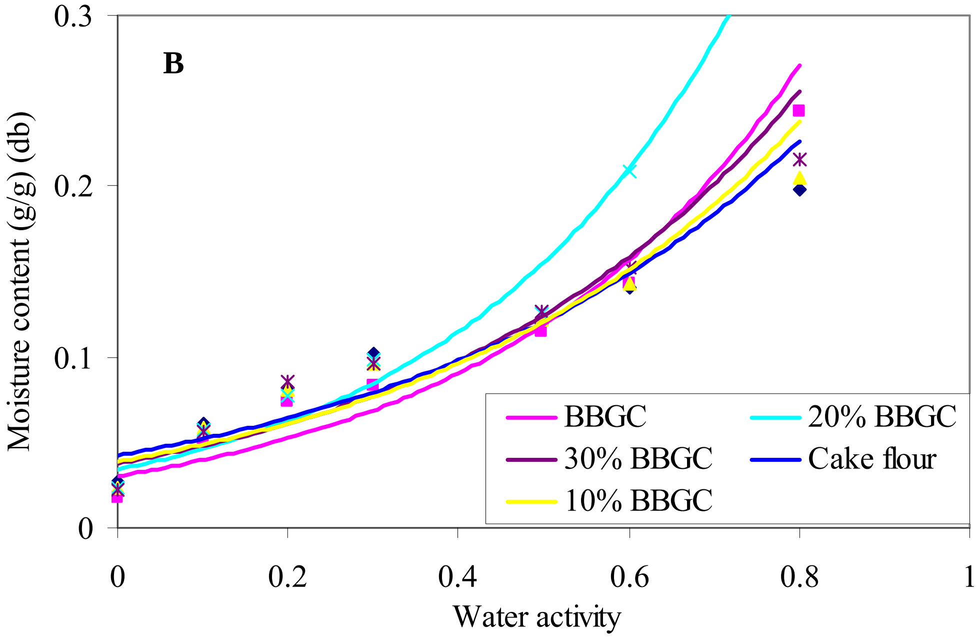


Figure 4.2 Moisture sorption isotherms for cake flour, BBGC and flour containing different levels of BGC at 40 °C (A) and 50°C (B)

The GAB model parameters obtained by fitting experimental sorption data are given in Table 4.1. The monolayer moisture (X_m) indicates that the amount of moisture content is strongly adsorbed by polar specific sites and often considered as the optimum storage value at which the system is most stable. The monolayer moisture of the food materials falls between 4 and 11% on dry basis (Karel, 1975). The monolayer values decreased with increasing temperatures (Table 4.1) in cake flour control, 10% BBGC and in 30% BBGC due to samples becoming less hygroscopic at high temperature. Similar trend was observed for whole dent yellow corn (Samapundo *et al.,* 2007), starch powders (Al-Muhtaseb *et al.,* 2004), potato starches (McLaughlin and Magee, 1998), rice flour (Durakova and Menkov, 2004) and for bean flour (Menkov *et al.,* 2005). This trend can be explained by the variation of excitation states, distance and attraction between molecules as temperature is varied (McLaughlin and Magee, 1998). However, the behaviour of BG was different. At 35°C, X_m was 0.068 g/g H_2O and it slightly decreased to 0.064 g/g H_2O at 40°C. Again X_m increased at 50°C to 0.07 4g/g H_2O. These results confirm the hygroscopic behaviour of BG (explained in Chapter 3), however, the effect of temperature on monolayer values is inconclusive. Normally, at high temperatures adsorption of water is high showing increased the X_m content.

The GAB parameters, *C* and *k* (Table 4.1) provide information related to sorption at low relative humidities and the sorption energies during the sorption process. *C* is defined as the ratio of the partition function of the first molecule sorbed on a site and the partition function of molecules sorbed beyond the first molecule in the multilayer. *C* is almost enthalpic in nature giving a measure of the strength of binding of water to the primary binding sites. The larger the value of *C*, the stronger is the water binding in the monolayer and the larger the difference in enthalpy between the monolayer molecules and multilayer molecules. Since the water molecules are still localised in the multilayer, the entropic contributions to *C* are less in comparison with those of enthalpic in nature (Quirijns *et al.,* 2005). With increasing temperature values of the monolayer moisture contents are lower, and those of GAB constant *C* increased up to 40°C and again decreased at 50°C. This similar pattern was observed in cake flour, BBGC and flour mixtures. These flour samples strongly bound the water in monolayer up to 40°C and at 50°C they can be removed easily.

Table 4.1 GAB Modelling Parameters for Cake flour, BBGC and Flour Mixtures Containing BBGC

	Cake flour	BBGC	10% BBGC	20% BBGC	30% BBGC
20^{o}C					
X_m(g/g H_2O)	0.102	**	0.087	0.085	0.09
C	18.608		15.718	16.871	13.833
k	0.46		0.543	0.569	0.565
R^2	0.979		0.917	0.895	0.894
35^{o}C					
X_m(g/g H_2O)	0.085	0.068	0.082	**	0.087
C	30.057	22.939	25.728		20.224
k	0.72	0.904	0.76		0.762
R^2	0.975	0.985	0.996		0.992
40^{o}C					
X_m(g/g H_2O)	0.08	0.064	0.075	0.074	0.073
C	61.97	50.191	78.342	70.035	73.867
k	0.703	0.896	0.749	0.754	0.781
R^2	0.975	0.943	0.983	0.977	0.981
50^{o}C					
X_m(g/g H_2O)	0.064	0.074	0.07	0.076	**
C	45.621	13.785	25.977	22.605	
k	0.845	0.871	0.818	0.765	
R^2	0.96	0.91	0.98	0.981	

[a] Presented values were obtained from the mean value obtained from three replicates

** Omitted data due to poor R^2 values

k is called a correction factor, since it corrects the properties of the multilayer molecules relative to the bulk liquid. When *k* approaches one, there is almost no distinction between multilayer molecules and liquid molecules. In that case the water molecules beyond the monolayer are not structured in a multilayer, but have the same characteristics as the molecules in the bulk liquid. The more the sorbed molecules are structured in a multilayer, the lower the value for *k* (Quirijns and et al., 2005). In this experiment k values were less than one for cake flour, BBGC and flour mixtures at all the temperature. k approached closer to one when temperature increased suggesting loss of distinction between the multilayer and liquid molecules at high temperature.

The sorption behaviour of BBBG was different compared to the cake flour. Equilibrium moisture contents of BBGC were higher at higher water activities and monolayer moisture contents were higher at high temperatures. Sorption behaviour of cake flour was influenced by addition of BBGC (Table 4.1). For example, at 50°C the lowest X_m was observed in cake flour control which was 0.064 g/g H_2O. This Xm values were increased with increasing levels of BG and the values were 0.07 g/gH_2O in 10% BBGC and 0.076 g/gH_2O in 20% BBGC. At 35°C and 40°C lowest monolayer moisture contents were observed in BBGC and the corresponding values were 0.064 and 0.068 g/gH_2O, respectively. These results show that the sorption behaviour of cake flour was influenced by both the level of BBGC and the temperature of storage. At higher temperatures it binds high amounts of water and this water binding ability increase with increasing concentrations could be the main reason for observed pattern in pasting and gelatinisation properties in Chapter 3.

4.4 CONCLUSIONS

Sorption isotherms were experimentally determined and the data were used to estimate GAB parameters at different temperatures. Cake flour and flour mixtures containing BBGC showed type II behaviour and BBGC showed type II at low water activities and type III at high water activities. Hygroscopic nature of BGC as observed in chapter 3 was confirmed. Temperature affected the sorption behaviour of four mixtures and higher equilibrium moisture contents observed when temperature increased. At the same time monolayer moisture contents increased with increasing temperatures. As BG is highly hygroscopic it binds water from cake flour as well as added water. Finally, these interactions of BG with water bring hardness to the cake. Therefore, it may be important to incorporate adequate amount of water when making cake and/or reducing the level of BG added to the cake. The effect of changing the recipe and process on improving the BG added cakes will be discussed in chapter 5.

CHAPTER 5

EFFECT OF CHANGE IN FORMULATION AND BATTER MIXING ON QUALITY OF HIGH RATIO WHITE LAYER CAKE CONTAINING β-GLUCAN

5.1 INTRODUCTION

Addition of dietary fibres including β-glucans into foods causes significant changes to chemical, physical, and sensory properties of cake (Kalinga and Mishra, 2009; Lee *et al.,* 2004; Lee *et al.,* 2005a, 2005c), cookies (Lee and Inglett, 2006) and bread (Brennan and Cleary, 2007; Knuckles *et al.,* 1997) that impact on their sensory acceptance. Fat replacement by BBGC and OBGC resulted in increased hardness and decreased volume, lighter crust colour and darker crumb colour (Kalinga and Mishra, 2009; Lee and Inglett, 2006; Lee *et al.,* 2005a, 2005c). Similarly, addition of BG to bread reduces loaf volume, dough elasticity and height, and leads to darker colour compared to the bread without BG (control) (Cleary *et al.,* 2007; Knuckles *et al.,* 1997). Fat replacement with Nutrim oat bran at up to 30% by weight reduced the diameter and increase in height of cookies (Lee and Inglett, 2006).

As reported earlier in Chapter 3, starch gelatinization and change in pasting properties are linked to sensory quality of cakes containing BG at various levels of fat substitution (Brennan and Cleary, 2007; Symons and Brennan, 2004a) and depend on constituents of the cake formulation, the method of cake batter preparation and baking conditions employed. The effect of formulation on rheological properties of cake batter has been documented (Lee *et al.,* 2004, 2005a, 2005c; Mazukoshi, 1983, 1985a, 1985b, 1986; Ngo *et al.,* 1985, 1986; Sakiyan *et al.,* 2004; Swanson *et al.,* 1999) and recently reviewed by Sahin (2008). Shear thinning and time independent behaviour of batter was reported by Sakiyan *et al.,* (2004). The consistency of batter is known to decrease with an increase in fat content due to lubrication effect of dispersed fat (Sahin, 2008) in the formulation.

Preparation of batter involves addition of air in to the batter. High ratio cakes are aerated during mixing by incorporating air bubbles into the fat phase called “creaming”. During creaming small air cells are formed and then incorporated into the mix. The quality of the cake, particularly the volume and crumb texture, is related to the number of air bubbles that are incorporated into the batter during mixing.

The effect of change in formulation (water content and emulsifiers), batter preparation (mixing) in recipes containing BG as a fat replacer on the cake quality has not been investigated thoroughly except studies reported for cakes containing Nutrim (Lee *et al.,* 2004) and Oatrim (Lee *et al.,* 2005) as fat replacers. It should also be noted that BG formulation used in these two studies, Nutrim and Oatrim, contained 10 and 5.8% BG, respectively, very low amounts of BG compared to concentrates used in this investigation. Water is an essential component in bakery products, including cakes. Adequate amount of water should be available for, foam structure formation, pasting and gelling of starch contributing to soft crumb formation. When BG is added it binds water and the amount of water added in the normal recipe becomes insufficient (refer to Chapters 3 and 4). Also, the mouthfeel similar to fat in cakes can only be assured provided β-glucan is fully hydrated. Therefore, it may be important to study the effect of water content in the recipe on improving the quality of the cake. Thus, the objectives of this study were to study the effect of different factors (water, emulsifier, and mixing time) on rheological, physical and sensory properties of cake produced by replacing fat with β-glucan. The effect of these factors were measured in terms of specific gravity and viscoelastic properties of batter and texture profile analysis, volume, percentage moisture and water activity of the cake.

5.2 MATERIALS AND METHODS

5.2.1 Cake Preparation

Cake samples were prepared with high ratio cake flour (Allied Mills, NSW, Australia), caster sugar (Australian Sugar Co. Pyt, Ltd., NSW, Australia), non-fat dry milk (Home Brand, Woolworths, Bella Vista, NSW, Australia), dried egg white powder (Sanovo

Foods A/S, Victoria, Australia), cooking salt, baking powder (Ward McKenzies Pty Ltd, Altona, VIC, Australia), margarine (Meadowlea Foods, Macquaries Park, NSW, Australia) and distilled water. The barley β-glucan concentrate (Glucagel®), was supplied by CSR Ethanol (Port Melbourne, VIC, Australia). The composition of Glucagel® was 80.8% β-glucan, 3.6% moisture, 4.4% protein, 1.5% lipid, 1.4% ash, and 8.2% non β-glucan carbohydrate (Material data sheet, GraceLine Ltd, Christchurch, New Zealand). The emulsifier, sodium steroyl lactate (SSL) was kindly donated by Asia Pacific Specialty Chemicals (Chaltenham, VIC, Australia). The formulations used to make the cake samples in this study were based on Approved Method 10-90 (AACC, 2000) as shown in Table 5.1.

The shortening and sugar were mixed in a mixer (Kenwood Ltd, UK) for 2min or 4min. Cream was scraped down, 60% of total amount of water was added and mixed for another 2 or 4 min. Cream was scraped down again and all the dry ingredients except flour and baking powder were sifted well, added 50% of remaining water and mixed for 1 min. The cake batter was scraped down and continued mixing for another 2 (at low mixing time) or 10 min (at high mixing time). Batter was scraped down again; well sifted flour and baking powder were added with remaining water and mixed for 1 min. Batter was scraped down and mixed for 4 min. The mixing speed during the whole process was maintained at two for all the samples. 425 g of batter was transferred into a round cake pan (20 cm in diameter) and baked at 170°C in an oven (Rational Combi-Steamers, Rational GmbH, Landsberg a.lech, Germany) for 45 mins. Each treatment was repeated three times.

5.2.2 Rheological Measurement

The rheological properties of cake batter before baking were determined using a controlled stress rheometer (Physica MCR 301, Anton Paar GmbH, Germany), operating with Rheoplus/32 software, V2.81, 2006 (Anton Paar GmbH, Germany). Measurements were taken at 25°C using 25 mm diameter parallel plates. Before testing, the gap between two plates was calibrated to 1 mm; therefore the thickness of the sample was 1 mm. The sample was covered with the hood and water was used to saturate the environment inside the hood. The viscosity of samples was measured as a function of shear rate (10^{-4}-10 sec^{-}

^{1}) under steady shear conditions. At each shear rate, the sample was sheared for 15 sec to reach steady state conditions. The data were fitted to Powel Law model (equation 2.1) and consistency index (K) and flow (n) behaviour index were obtained. Frequency sweep studies were conducted to determine storage (G') and loss moduli (G") as a function of frequency (0.1 – 20 Hz) at 25°C (Kalinga and Mishra, 2009; Lee *et al.,* 2004).

The same rheometer, equipped with a peltier temperature controller was used to evaluate rheological behaviour of cake batter during baking. To minimize the slip of the samples during the experiments, 25 mm serrated probe was utilized and sample was covered with a hood supplied with air to prevent any influence on temperature from outside. G' and G" were monitored from 25 – 170°C at 1 rad/sec and a heating rate of 10°C/min (Lee *et al.,* 2004). Rheological measurements were performed in duplicate for each cake with a total of *n=6 (i.e.3x2).*

Table 5.1 Formulations of cakes prepared with different levels of ingredients and mixing time

	Flour (g)	Sugar (g)	Nonfat dry milk (g)	Dried egg white (g)	NaCl (g)	Baking Powder (g)	Water (ml)	Shortening (g)	Glucagel® (g)	SSL (%)	Time (min)
Original	200	280	24	18	6	11.5	270	100	0	0	12
(-1) BG	200	280	24	18	6	11.5	270	90	10	0	12
(1) BG	200	280	24	18	6	11.5	270	80	20	0	12
(-1) water	200	280	24	18	6	11.5	270	90	10	0	12
(1) water	200	280	24	18	6	11.5	300	80	10	0	12
(-1)time	200	280	24	18	6	11.5	270	90	10	0	12
(1)time	200	280	24	18	6	11.5	270	90	10	0	24
(-1) SSL	200	280	24	18	6	11.5	270	90	10	0	12
(1) SSL	200	280	24	18	6	11.5	270	90	10	0.03	12

(1) high value and (–1) low value

5.2.3 Batter Specific Gravity, and Cake Volume Index, Moisture Content and Water Activity Measurements

Batter specific gravity was determined as soon as batter was prepared, as the ratio of the weight of a measuring cup filled with batter to that filled with water (Lee *et al.,* 2005). Measurements were taken in as two readings from each triplicate sample *(n=6).*

The volume index of cake was obtained using the layer cake measuring template according to the approved method 10-91 (AACC, 2000) after cooling the sample for two hours to room temperature (22^{o}C). Measurements were taken in triplicates *(n=3).*

Percentage moisture content (wet basis) of cake samples was determined following AACC approved method 44-32 (AACC, 2000). Water activity of cake was determined using the water activity meter (Aqua lab, Model CX2, Decagon Devices, Pullman, WA, USA). Measurements were taken in as two readings from each triplicate sample *(n=6).*

5.2.4 Texture Profile Analysis

Texture profile analysis of baked cake was done using Texture analyser (TA.X2, Stable Micro Systems, Surrey, UK) which was controlled by Texture Exponent 32, Version 2.0.20, 2005 (Stable Micro Systems, Surrey, UK). The force *vs* time curves were used to determine the texture profile parameters (hardness, cohesiveness and springiness). Cake samples were cooled to room temperature for two hours and samples were cut into cylindrical shapes (25 mm height *x* 40 mm diameter) and analysed at room temperature (22^{o}C) by placing the sample on a flat stage, and subjected to two successive compressions to 50% of original height using a 75 mm cylindrical probe. The pre-test speed was 1 mm/sec, test speed was 5 mm/sec, time was 60 sec and the contact force was 5 g. Two samples were obtained from each cake and cakes were prepared in triplicates *(n=6).*

5.2.5 Sensory Evaluation

Sensory evaluation of all the cake preparations was conducted by a panel of 25 judges based on their appearance, hardness, moistness, cohesiveness and overall acceptability. A sample of 4 cm x 4 cm x 4 cm was labelled with three digit code were presented to the panellist. The order of sample was changed to prevent sensory bias. The panellists were asked to judge the sensory attributes using nine point hedonic scales, from like extremely (=9) to dislike extremely (=1) (Larmond, 1987). Data were statistically analysed using analysis of variance at α=0.5 and means were separated using Tukey's test (Gacula and Singh, 1984). The questionnaire used for the sensory evaluation is given in the Appendix 2.

5.3 EXPERIMENTAL DESIGN

The full factorial experimental design with four factors and two level (2^k, k=4) was chosen to study the relative contribution of 3 ingredients and mixing time and to determine the most desirable cake formulation. Four factors were the level of fat replacement with β-glucan (X_1), water (X_2), time of mixing (X_3)and level of SSL (X_4) and two levels were designated as high and low (1 being high and -1 low). The design matrix is given in Table 5.2. Margarine was replaced with Glucagel® at 10 and 20% by weight basis. Water content was maintained at 270 and 300 ml. Emulsifier (SSL) was added at 0 and 0.03% (flour basis). Mixing time was 12 min for the low level and 24 min for the high level. To increase the precision, each cake was prepared in triplicate, making it to 48 cakes. Nine dependent variables or responses were measured for each treatment: specific gravity, consistency index, flow behaviour index, volume, hardness, springiness, cohesiveness, moisture and water activity.

The data obtained for batters and the cakes were analysed using one-way ANOVA. MINITAB 11 (Minitab Inc., State Collage, Pa., USA) statistical software package was used for experimental designing and for analysis of data.

Table 5.2 Full Factorial Experimental Design for cakes

Cake Number	β-glucan	Water	Mixing time	SSL
1	-1	-1	-1	-1
2	-1	-1	1	1
3	1	-1	1	-1
4	-1	1	1	1
5	1	1	1	-1
6	1	1	-1	1
7	-1	1	1	-1
8	-1	-1	-1	1
9	1	1	-1	-1
10	1	-1	1	1
11	1	-1	-1	1
12	-1	1	-1	-1
13	1	1	1	1
14	1	-1	-1	-1
15	-1	-1	1	-1
16	-1	1	-1	1

β-glucan: -1 – 10% fat replacement and 1 – 20% fat replacement
Water: -1 – 270ml water and 1- 300ml water
SSL: -1 – 0% and 1 – 0.03% on flour basis
Mixing time: -1 – 12min and 1- 24min

In later parts of this chapter when discussing different batters and cakes they are referred to the cake number given in column 1 in Table 5. 2.

5.4 RESULTS AND DISCUSSION

5.4.1 Rheological and Physical Properties of Cake Batter and Cake

Factorial design enabled to determine effect of different factors and their interactions on quality of batter and cake and therefore in screening of variables that must be considered for assessing their impact on the quality of cake.

Analysis of variances is shown in Table 5.3 for each of the response variables in terms of main effects, 2-Way, 3-Way and 4-Way interactions. Main, 2 and 3 way interactions were significant for K (consistency index), n (flow behaviour index) and specific gravity of batter. Only the main effects were significant ($p<0.05$) for hardness of the cake. None of these independent variables were significant for cohesiveness and springiness as $p>0.05$. Main effects, 2-Way interactions, 3-Way interactions and 4-way interactions were significant ($p<0.05$) on cake volume. Only main effects were significant for moisture content and for water activity, 2-Way interactions and 4-Way interactions were significant. These results show the way these factors control the response variables. These variable affect the amount of air incorporated, the batter properties, hence change in the cake hardness and volume. The amount of water added and level of BG change and their interactions controlled both moisture content and water activity.

The main effects influenced water activity, moisture, K, n, specific gravity, volume, and hardness and therefore, determined the cake quality. These dependent variables need to be suitably varied to achieve desired quality of cake.

Table 5.3 Analysis of Variance for Different Responses

Source	Degreesof Freedom	Adjusted Mean Squares	Probability
K			
Main Effect	4	1189.79	0.000*
2-Way Interactions	6	744.47	0.000*
3-Way Interactions	4	455.99	0.002*
4-Way Interactions	1	28.13	0.590
Residual Error	80	95.87	
Pure Error	80	95.87	
Total	95		
n			
Main Effect	4	0.102	0.000*
2-Way Interactions	6	0.002	0.000*
3-Way Interactions	4	0.002	0.000*
4-Way Interactions	1	0.000	0.889
Residual Error	80	0.000	
Pure Error	80	0.000	
Total	95		
Specific Gravity			
Main Effect	4	0.013	0.000*
2-Way Interactions	6	0.007	0.000*
3-Way Interactions	4	0.005	0.000*
4-Way Interactions	1	0.002	0.082
Residual Error	32	0.001	
Pure Error	32	0.001	
Total	47		
Hardness			
Main Effect	4	576418	0.003*
2-Way Interactions	6	52027	0.845

3-Way Interactions	4	161195	0.267
4-Way Interactions	1	286196	0.129
Residual Error	32	117744	
Pure Error	32	117744	
Total	47		
Springiness			
Main Effect	4	0.0001	0.603
2-Way Interactions	6	0.0002	0.365
3-Way Interactions	4	0.0001	0.533
4-Way Interactions	1	0.0001	0.533
Residual Error	32	0.0017	
Pure Error	32	0.0017	
Total	47		
Cohesiveness			
Main Effect	4	0.0014	0.058
2-Way Interactions	6	0.0002	0.794
3-Way Interactions	4	0.0004	0.586
4-Way Interactions	1	0.0013	0.142
Residual Error	32	0.0006	
Pure Error	32	0.0006	
Total	47		
Volume			
Main Effect	4	5.105	0.000*
2-Way Interactions	6	3.750	0.000*
3-Way Interactions	4	1.920	0.003*
4-Way Interactions	1	3.203	0.006*
Residual Error	32	0.374	
Pure Error	32	0.374	
Total	47		

Moisture			
Main Effect	4	19.37	0.000*
2-Way Interactions	6	2.35	0.258
3-Way Interactions	4	4.53	0.053
4-Way Interactions	1	0.25	0.703
Residual Error	32	1.72	
Pure Error	32	1.72	
Total	47		
Water activity			
Main Effect	4	0.0004	0.000*
2-Way Interactions	6	0.0000	0.017*
3-Way Interactions	4	0.0000	0.688
4-Way Interactions	1	0.0001	0.002*
Residual Error	32	0.0000	
Pure Error	32	0.0000	
Total	47		

* $p<0.05$ are significant terms

Batter properties are correlated with the cake properties. The amount of air bubbles incorporated in the batter can be predicted by specific gravity. The increase in batter density (decrease in air content incorporated in batter) is associated with lower storage (elastic) and loss (viscous) moduli of batter and also the specific volume of cake (Sahin and Alava, 2003). Effect of addition of water, emulsifier and changing mixing time on G' (storage modulii) (A), G" (loss modulii) (B) and G'/G" (damping factor) (C) at 10% Glucagel® and 20% Glucagel® are given in Figure 5.1 and Figure 5.2, respectively. G' and G" increased with increasing frequencies for all treatments.

Figure 5.1 shows how G' (A), G" (B) and damping factor (C) change with level of water, SSL and mixing time at 10% Glucagel® level. The highest G' and G" were observed in 12 (10% BG, 300 ml water, 12 min mixing time and without SSL) and 15 (10% BG, 270 ml water, 24 min mixing time and without SSL). This shows at 10% BG and high levels (300 ml) of water, addition of SSL and increasing mixing time increases the G’ and G”. The lowest specific gravity (0.844) was given by 10% BG and 24 min mixing time without emulsifier (Table 5.4). Thus low specific gravity was obtained at same cake batters, due to increased incorporation of air bubbles to the batter. This change in batter properties was correlated with the cake volume. At this low level of BG the highest cake volume index was observed in cake number 12 which was 12.87 cm.

Change in G’ (A), G” (B) and G”/G’ (C) with water level, mixing time and emulsifier at 20% Glucagel® level are shown in Figure 5.2. G’ was the highest in cake number 11 and 13, and G” was in 9 and 5. The lowest specific gravity at 20% BG level was 0.872 which was cake number 14 (Table 5.4). The water level, mixing time and SSL level were at lower level in this cake. The foaming ability of BG helped in incorporation of more air to cake batter (Burkus and Temelli, 2000). The highest specific gravity was 0.992 which was observed at 20% BG, 270 ml water, 24 min mixing time and 0 levels SSL (Table 5.4) which was the cake number 3. This means that longer mixing time would destroy the foam structure of batter releasing entrapped air bubbles.

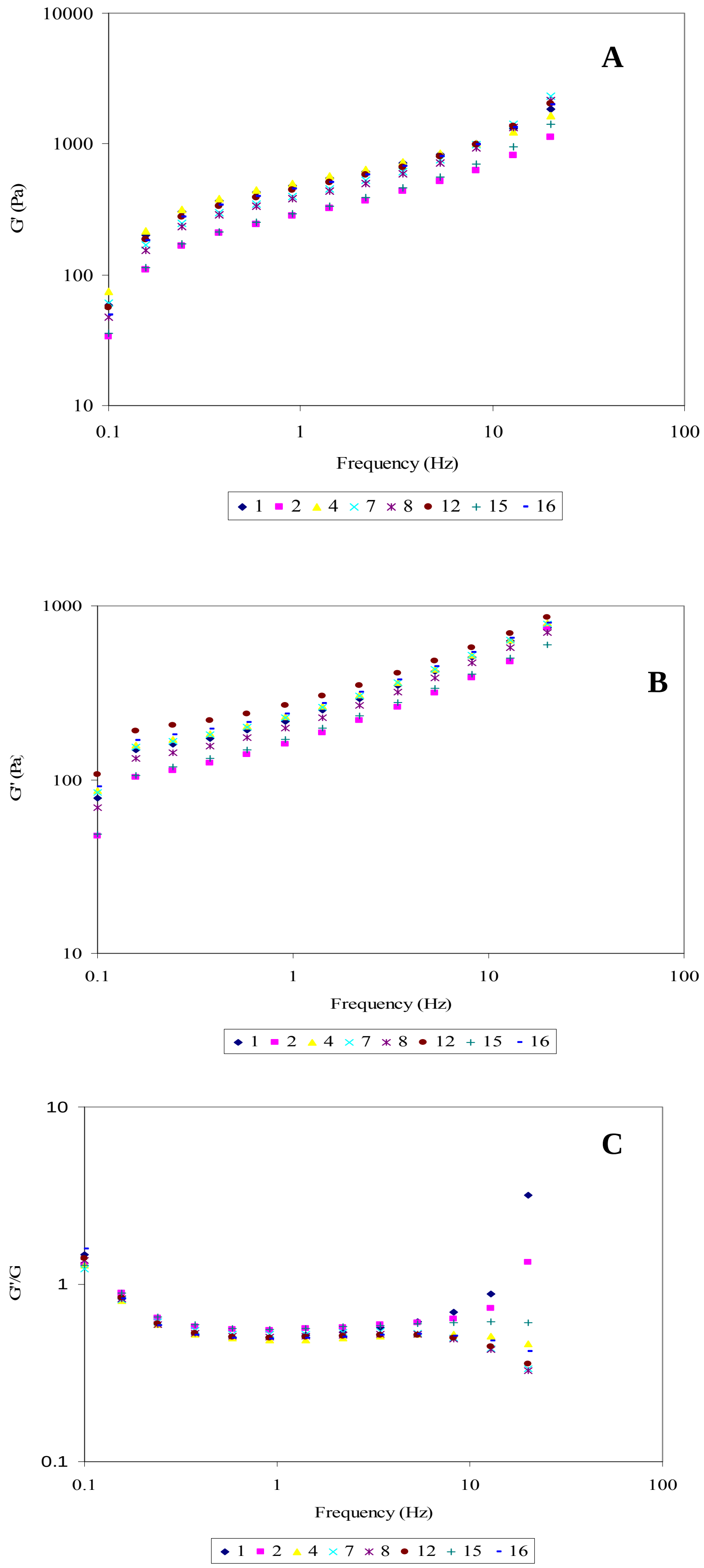


Figure 5.1 Effect of change in water level, mixing time and emulsifier on G’ (A) G” (B) and G”/G’ (C) with 10% Glucagel® at different frequencies

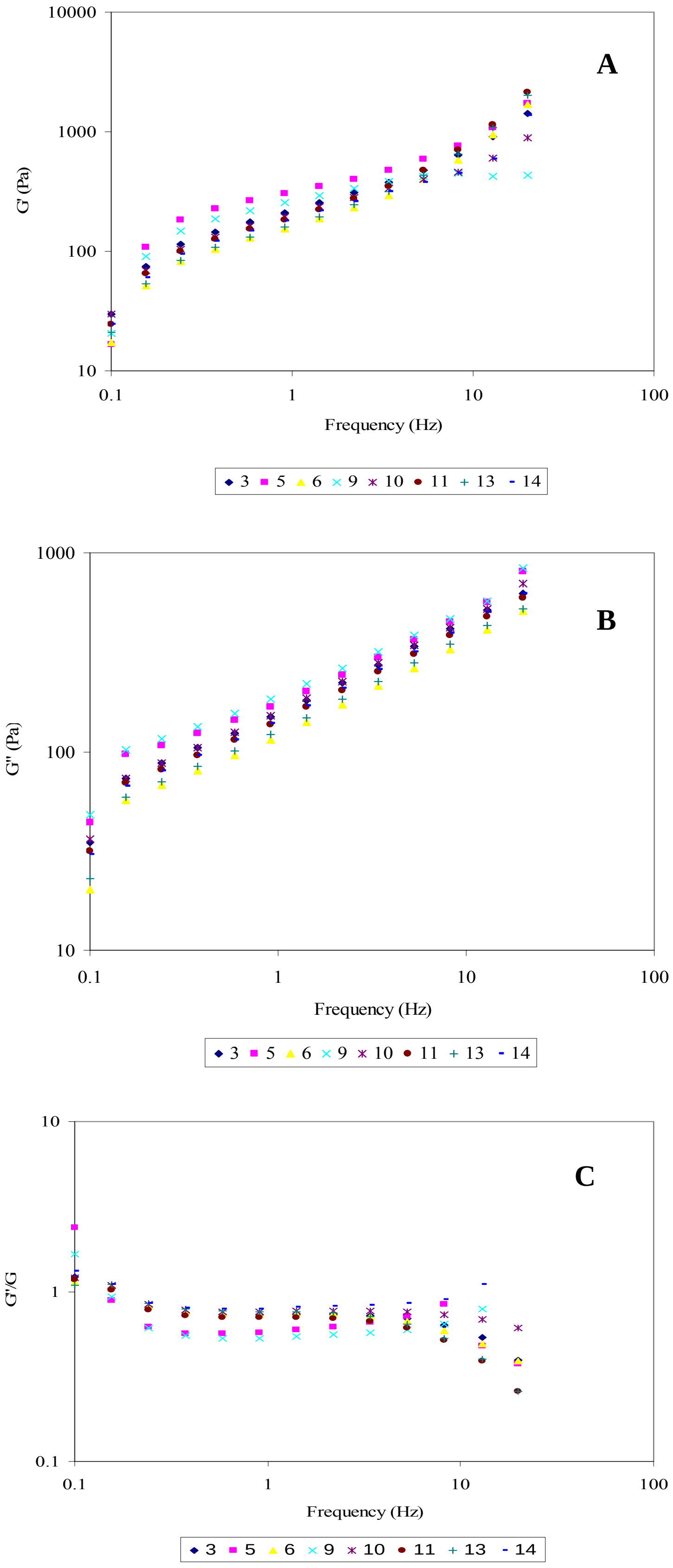


Figure 5.2 Effect of change in water level, mixing time and emulsifier on G’ (A), G” (B) and G”/G’ (C) with 20% Glucagel® at different frequencies

At higher levels of BG, cake volume index was greater than that of 10% BG level (Table 5.4). This is due to the ability of BG to increase viscosity which is evident by increased K value and n at 20% BG level compared to 10% BG (Table 5.4). When viscosities of cake batter increased; the ability of batter to hold air also increased (Lee *et al.,* 2005a; 2005b).

Flow behaviour index of the batter of all treatment combinations was less than 1 suggesting the shear thinning behaviour (Steffe, 1996). Addition of SSL reduced the specific gravity and the K value. In the absence of SSL specific gravity was 0.911 and it was reduced to 0.897 when 0.03% of SSL was added which was due to the increased air entrapment. Similarly consistency (K) reduced from 39.09 $Pa.s^n$ to 31.87 $Pa.s^n$ in the presence of emulsifier. A decrease in viscosity by emulsifier addition was explained by the increase in air entrapment in cake batter, because the emulsifier aids in the incorporation of air and disperses the shortening in smaller particles to give the higher number of available air bubbles (Sahin and Alava, 2003).

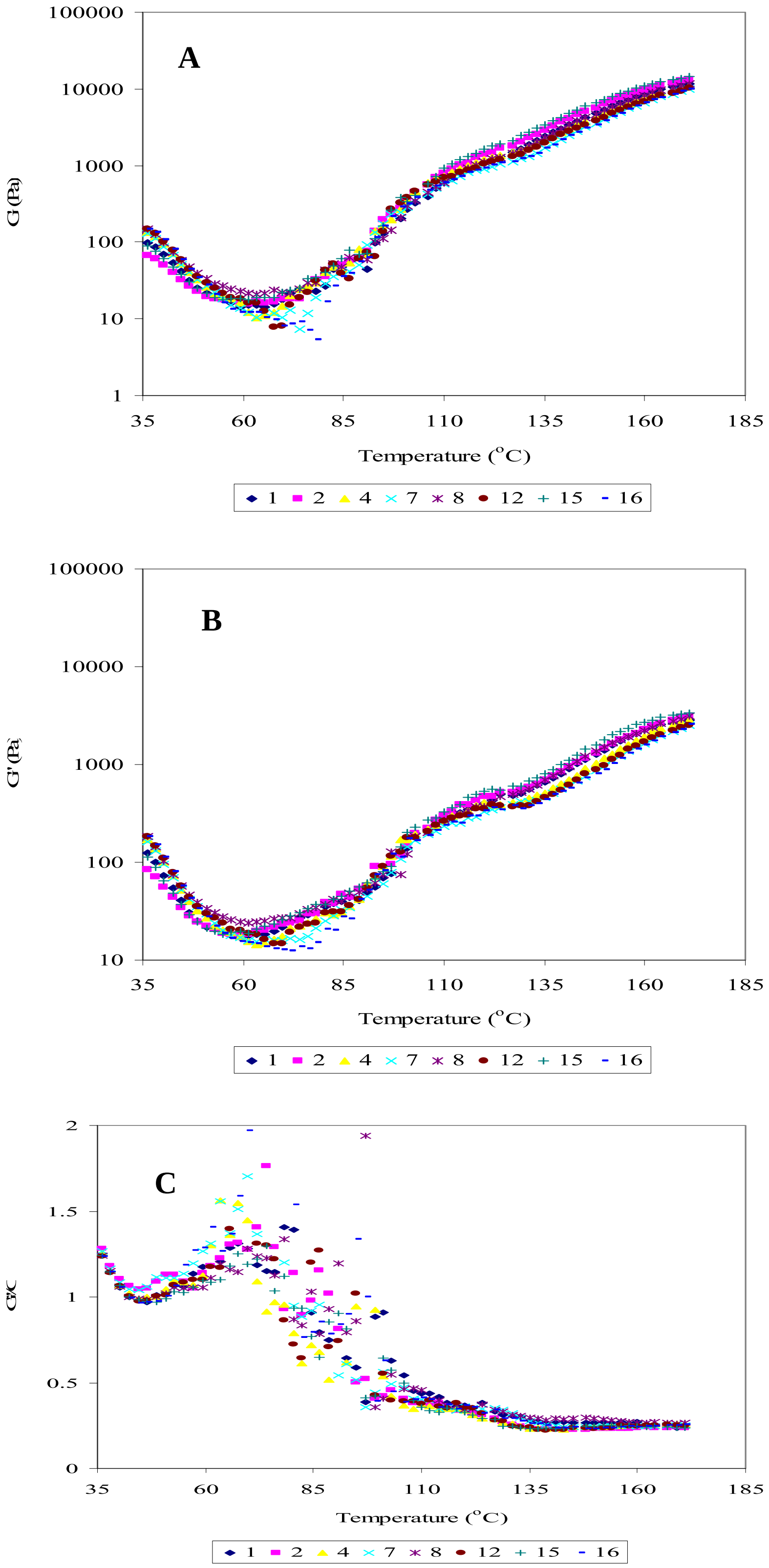


Figure 5.3 Change in Viscoelastic properties of cake produce with 10% fat replacement by Glucagel® different combinations of ingredients and processes during baking, G’ (A), G” (B) and G”/G’ (C)

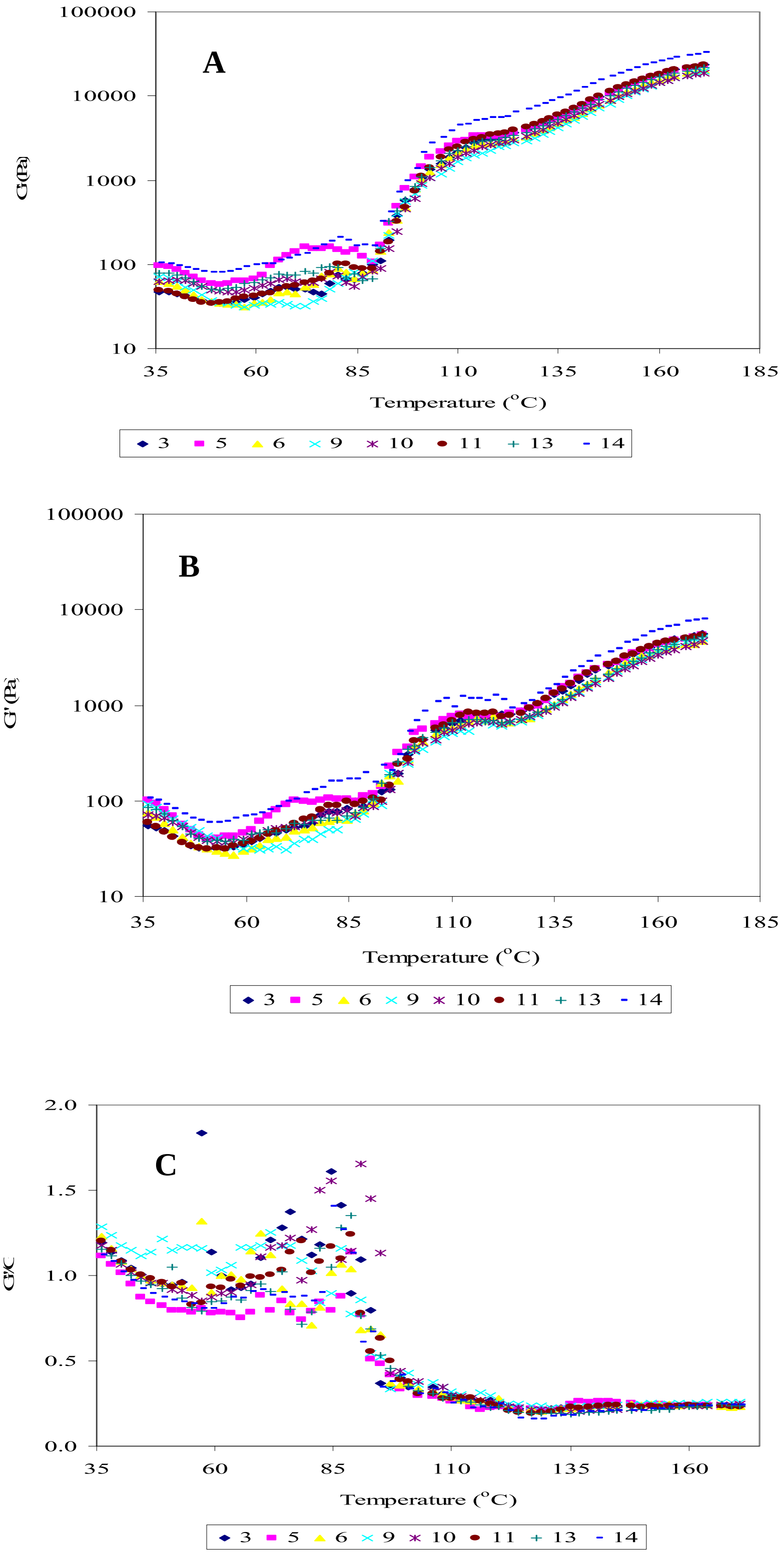


Figure 5.4 Change in Viscoelastic properties of cake produce with 20% fat replacement by Glucagel® different combinations of ingredients and processes during baking, G’ (A), G” (B) and G”/G’ (C)

Change in dynamic rheological properties during baking is presented in Figures 5.3 and 5.4. These figures do not show any clear difference between different treatments. The pattern of change in G’, G” and G’/G” at both 10% and 20% fat replacement levels with temperature were similar. This similar pattern was reportedly observed by many researches (Kalinga and Mishra, 2008; Lee *et al.,* 2004) during fat replacement in cakes by BG. Initially G’ was greater than G” and with increasing temperature G’ decreased and G” increased. This is attributed to melting of shortening, production of carbon dioxide and its diffusion into the air cells increasing the volume. The cake becomes softer and showed more viscous behaviour (Lee *et al.,* 2004). In all the cake batters at 10% BG level this depression in G’ started at temperature between 65 - 85^{o}C. At this range of temperature, rise in G”/G’ can be seen which explains that G” was greater than G’ and the system was more viscous at this stage. The decrease in G’ value started in a later stage when 20% of fat was replaced with BG (in all the cake batters with 20% fat replacement). This depression started approximately around 90^{o}C. At 20% level viscosities were higher and at the same time it delayed the release of air and water, there fore viscous behaviour was observed at a later stage.

In cake mixtures usually delayed gelatinization has been observed due to the presence of sugars and salts (Eliasson, 1991; Spcies and Hoseney, 1982). Both G’ and G” started to increase after 90^{o}C due to starch gelatinization and protein coagulation. After 110^{o}C levelling of curves was due to formation of cake crumb (Ngo and Taranto,1986).

Table 5.4 Mean Values for different responses with respect to their linear and interaction variables

Linear and interaction term	K (Pa s^n)	n	Specific gravity	Hardness (g)	Springiness	Cohesiveness	Volume Index (cm)	Moisture (%)	Water activity
BG									
-1	29.68±1.41	0.374±0.002	0.872±0.005	2027±70.04	0.9728±0.003	0.853±0.005	11.49±0.12	35.69±0.27	0.9031±0.001
1	41.28±1.41	0.502±0.002	0.936±0.005	2283±70.04	0.9768±0.003	0.857±0.005	12.62±0.12	34.58±0.27	0.9006±0.001
Water									
-1	34.17±1.41	0.451±0.002	0.906±0.005	2238±70.04	0.9731±0.003	0.854±0.005	11.77±0.12	34.01±0.27	0.8962±0.001
1	36.79±1.41	0.425±0.002	0.903±0.005	2072±70.04	0.9765±0.003	0.856±0.005	12.34±0.12	36.26±0.27	0.9075±0.001
Time									
-1	34.37±1.41	0.433±0.002	0.901±0.005	2007±70.04	0.9765±0.003	0.860±0.005	11.92±0.12	35.31±0.27	0.9023±0.001
1	36.60±1.41	0.442±0.002	0.908±0.005	2302±70.04	0.9731±0.003	0.850±0.005	12.19±0.12	34.96±0.27	0.9014±0.001
SSL									
-1	39.09±1.41	0.443±0.002	0.911±0.005	2099±70.04	0.9755±0.003	0.8644±0.005	12.13±0.12	35.04±0.27	0.9003±0.001
1	31.87±1.41	0.443±0.002	0.897±0.005	2210±70.04	0.9740±0.003	0.8455±0.005	11.98±0.12	35.24±0.27	0.9035±0.001
BG * Water									
-1 -1	29.82±1.99	0.388±0.003	0.872±0.007	2061±99.06	0.972±0.004	0.851±0.007	11.10±0.18	34.59±0.39	0.895±0.001
1 -1	38.52±1.99	0.515±0.003	0.940±0.007	2414±99.06	0.974±0.004	0.856±0.007	12.44±0.18	33.43±0.39	0.897±0.001
-1 1	29.55±1.99	0.360±0.003	0.873±0.007	1992±99.06	0.973±0.004	0.854±0.007	11.87±0.18	36.79±0.39	0.911±0.001
1 1	44.04±1.99	0.489±0.003	0.933±0.007	2151±99.06	0.979±0.004	0.858±0.007	12.80±0.18	35.74±0.39	0.904±0.001
BG * Time									
-1 -1	32.36±1.99	0.366±0.003	0.895±0.007	1836±99.06	0.974±0.004	0.856±0.007	11.81±0.18	36.08±0.39	0.904±0.001
1 -1	36.37±1.99	0.501±0.003	0.906±0.007	2179±99.06	0.979±0.004	0.864±0.007	12.03±0.18	34.54±0.39	0.901±0.001
-1 1	27.01±1.99	0.383±0.003	0.849±0.007	2217±99.06	0.972±0.004	0.849±0.007	11.17±0.18	35.30±0.39	0.902±0.001
1 1	46.18±1.99	0.503±0.003	0.967±0.007	2387±99.06	0.974±0.004	0.851±0.007	13.21±0.18	34.63±0.39	0.900±0.001
BG * SSL									

-1	-1		29.26±1.99	0.375±0.003	0.886±0.007	1925±99.06	0.972±0.004	0.862±0.007	11.87±0.18	35.76±0.39	0.902±0.001
1	-1		48.92±1.99	0.492±0.003	0.936±0.007	2274±99.06	0.979±0.004	0.867±0.007	12.40±0.18	34.32±0.39	0.899±0.001
-1	1		30.11±1.99	0.374±0.003	0.858±0.007	2129±99.06	0.974±0.004	0.843±0.007	11.11±0.18	35.62±0.39	0.904±0.001
1	1		33.64±1.99	0.511±0.003	0.937±0.007	2291±99.06	0.974±0.004	0.848±0.007	12.84±0.18	34.85±0.39	0.903±0.001
Water * Time											
-1	-1		34.29±1.99	0.442±0.003	0.905±0.007	2091±99.06	0.970±0.004	0.854±0.007	11.33±0.18	34.03±0.39	0.896±0.001
1	-1		34.45±1.99	0.425±0.003	0.897±0.007	1923±99.06	0.983±0.004	0.865±0.007	12.52±0.18	36.59±0.39	0.908±0.001
-1	1		34.06±1.99	0.463±0.003	0.907±0.007	2384±99.06	0.976±0.004	0.853±0.007	12.22±0.18	33.99±0.39	0.896±0.001
1	1		39.14±1.99	0.424±0.003	0.909±0.007	2220±99.06	0.970±0.004	0.847±0.007	12.16±0.18	35.93±0.39	0.906±0.001
Water * SSL											
-1	-1		34.58±1.99	0.453±0.003	0.905±0.007	2174±99.06	0.975±0.004	0.867±0.007	11.77±0.18	34.34±0.39	0.895±0.001
1	-1		43.60±1.99	0.414±0.003	0.918±0.007	2025±99.06	0.976±0.004	0.862±0.007	12.49±0.18	35.73±0.39	0.905±0.001
-1	1		33.77±1.99	0.450±0.003	0.908±0.007	2301±99.06	0.971±0.004	0.841±0.007	11.77±0.18	33.68±0.39	0.897±0.001
1	1		29.98±1.99	0.435±0.003	0.887±0.007	2119±99.06	0.976±0.004	0.850±0.007	12.18±0.18	36.79±0.39	0.910±0.001
Time * SSL											
-1	-1		36.55±1.99	0.433±0.003	0.909±0.007	1946±99.06	0.977±0.004	0.871±0.007	12.24±0.18	35.31±0.39	0.901±0.001
1	-1		41.63±1.99	0.434±0.003	0.913±0.007	2253±99.06	0.974±0.004	0.857±0.007	12.02±0.18	34.76±0.39	0.899±0.001
-1	1		32.18±1.99	0.434±0.003	0.892±0.007	2069±99.06	0.976±0.004	0.848±0.007	11.60±0.18	35.30±0.39	0.903±0.001
1	1		31.57±1.99	0.451±0.003	0.903±0.007	2351±99.06	0.972±0.004	0.842±0.007	12.35±0.18	35.17±0.39	0.904±0.001
BG*Water*Time											
-1	-1	-1	33.78±2.82	0.376±0.005	0.902±0.011	1890±140.09	0.971±0.005	0.849±0.010	11.42±0.25	34.98±0.53	0.896±0.001
1	-1	-1	34.80±2.82	0.508±0.005	0.908±0.011	2293±140.09	0.969±0.005	0.859±0.010	11.23±0.25	33.07±0.53	0.896±0.001
-1	1	-1	30.94±2.82	0.356±0.005	0.889±0.011	1783±140.09	0.977±0.005	0.863±0.010	12.20±0.25	37.18±0.53	0.911±0.001
1	1	-1	37.95±2.82	0.494±0.005	0.904±0.011	2064±140.09	0.988±0.005	0.868±0.010	12.83±0.25	36.00±0.53	0.905±0.001
-1	-1	1	25.87±2.82	0.400±0.005	0.842±0.011	2233±140.09	0.973±0.005	0.853±0.010	10.78±0.25	34.20±0.53	0.895±0.001
1	-1	1	42.24±2.82	0.521±0.005	0.973±0.011	2535±140.09	0.978±0.005	0.853±0.010	13.65±0.25	33.79±0.53	0.897±0.001

-1	1	1	28.15±2.82	0.365±0.005	0.856±0.011	2201±140.09	0.969±0.005	0.845±0.010	11.55±0.25	36.40±0.53	0.910±0.001
1	1	1	50.12±2.82	0.484±0.005	0.961±0.011	2238±140.09	0.970±0.005	0.848±0.010	12.77±0.25	35.47±0.53	0.903±0.001
BG*Water*SSL											
-1	-1	-1	30.18±2.82	0.387±0.005	0.886±0.011	1919±140.09	0.974±0.005	0.869±0.010	11.42±0.25	35.34±0.53	0.894±0.001
1	-1	-1	38.97±2.82	0.518±0.005	0.923±0.011	2429±140.09	0.975±0.005	0.864±0.010	12.13±0.25	33.34±0.53	0.895±0.001
-1	1	-1	28.34±2.82	0.362±0.005	0.886±0.011	1930±140.09	0.970±0.005	0.855±0.010	12.32±0.25	36.17±0.53	0.909±0.001
1	1	-1	58.87±2.82	0.467±0.005	0.949±0.011	2119±140.09	0.982±0.005	0.869±0.010	12.67±0.25	35.30±0.53	0.902±0.001
-1	-1	1	29.47±2.82	0.388±0.005	0.857±0.011	2203±140.09	0.971±0.005	0.833±0.010	10.78±0.25	33.84±0.53	0.896±0.001
1	-1	1	38.07±2.82	0.512±0.005	0.958±0.011	2399±140.09	0.973±0.005	0.849±0.010	12.75±0.25	33.52±0.53	0.898±0.001
-1	1	1	30.76±2.82	0.359±0.005	0.859±0.011	2054±140.09	0.976±0.005	0.853±0.010	11.43±0.25	37.41±0.53	0.912±0.001
1	1	1	29.20±2.82	0.510±0.005	0.916±0.011	2183±140.09	0.976±0.005	0.847±0.010	12.93±0.25	36.17±0.53	0.907±0.001
BG*Time*SSL											
-1	-1	-1	32.10±2.82	0.363±0.005	0.929±0.011	1780±140.09	0.975±0.005	0.870±0.010	12.68±0.25	36.56±0.53	0.904±0.001
1	-1	-1	41.01±2.82	0.502±0.005	0.890±0.011	2112±140.09	0.979±0.005	0.873±0.010	11.80±0.25	34.06±0.53	0.899±0.001
-1	1	-1	26.42±2.82	0.386±0.005	0.844±0.011	2069±140.09	0.969±0.005	0.855±0.010	11.05±0.25	34.95±0.53	0.900±0.001
1	1	-1	56.83±2.82	0.483±0.005	0.983±0.011	2437±140.09	0.979±0.005	0.860±0.010	13.00±0.25	34.58±0.53	0.898±0.001
-1	-1	1	32.62±2.82	0.368±0.005	0.862±0.011	1893±140.09	0.973±0.005	0.843±0.010	10.93±0.25	35.59±0.53	0.904±0.001
1	-1	1	31.74±2.82	0.450±0.005	0.922±0.011	2245±140.09	0.979±0.005	0.854±0.010	12.27±0.25	35.01±0.53	0.903±0.001
-1	1	1	27.60±2.82	0.379±0.005	0.854±0.011	2364±140.09	0.974±0.005	0.844±0.010	11.28±0.25	35.65±0.53	0.905±0.001
1	1	1	35.53±2.82	0.522±0.005	0.951±0.011	2337±140.09	0.970±0.005	0.841±0.010	13.42±0.25	34.68±0.53	0.902±0.001
Water*Time*SSL											
-1	-1	-1	34.03±2.82	0.444±0.005	0.910±0.011	1925±140.09	0.970±0.005	0.870±0.010	11.58±0.25	34.89±0.53	0.895±0.001
1	-1	-1	39.07±2.82	0.421±0.005	0.909±0.011	1967±140.09	0.984±0.005	0.872±0.010	12.90±0.25	35.73±0.53	0.907±0.001
-1	1	-1	35.12±2.82	0.460±0.005	0.899±0.011	2424±140.09	0.979±0.005	0.863±0.010	11.97±0.25	33.79±0.53	0.894±0.001
1	1	-1	48.13±2.82	0.408±0.005	0.927±0.011	2082±140.09	0.969±0.005	0.852±0.010	12.08±0.25	35.74±0.53	0.904±0.001
-1	-1	1	34.54±2.82	0.439±0.005	0.899±0.011	2258±140.09	0.969±0.005	0.839±0.010	11.07±0.25	33.16±0.53	0.897±0.001

1	-1	1		29.82±2.82	0.429±0.005	0.884±0.011	1880±140.09	0.982±0.005	0.858±0.010	12.13±0.25	37.45±0.53	0.909±0.001
-1	1	1		33.00±2.82	0.461±0.005	0.915±0.011	2344±140.09	0.973±0.005	0.844±0.010	12.47±0.25	34.20±0.53	0.898±0.001
1	1	1		30.14±2.82	0.441±0.005	0.890±0.011	2357±140.09	0.971±0.005	0.841±0.010	12.23±0.25	36.13±0.53	0.910±0.001
BG*Water*Time*SSL												
-1	-1	-1	-1	34.52±3.99	0.370±0.008	0.947±0.015	1773±198.11	0.974±0.008	0.867±0.012	12.50±0.35	36.51±0.76	0.898±0.002
1	-1	-1	-1	33.55±3.99	0.519±0.008	0.872±0.015	2076±198.11	0.966±0.008	0.873±0.012	10.67±0.35	33.28±0.76	0.893±0.002
-1	1	-1	-1	29.67±3.99	0.357±0.008	0.911±0.015	1786±198.11	0.975±0.008	0.872±0.012	12.87±0.35	36.62±0.76	0.909±0.002
1	1	-1	-1	48.47±3.99	0.485±0.008	0.907±0.015	2148±198.11	0.992±0.008	0.872±0.012	12.93±0.35	34.85±0.76	0.905±0.002
-1	-1	1	-1	25.84±3.99	0.405±0.008	0.825±0.015	2065±198.11	0.973±0.008	0.871±0.012	10.33±0.35	34.17±0.76	0.891±0.002
1	-1	1	-1	44.39±3.99	0.516±0.008	0.974±0.015	2783±198.11	0.984±0.008	0.855±0.012	13.60±0.35	33.41±0.76	0.898±0.002
-1	1	1	-1	27.00±3.99	0.366±0.008	0.862±0.015	2074±198.11	0.965±0.008	0.838±0.012	11.77±0.35	35.72±0.76	0.909±0.002
1	1	1	-1	69.27±3.99	0.450±0.008	0.992±0.015	2090±198.11	0.973±0.008	0.866±0.012	12.40±0.35	35.75±0.76	0.899±0.002
-1	-1	-1	1	33.03±3.99	0.381±0.008	0.856±0.015	2006±198.11	0.967±0.008	0.831±0.012	10.33±0.35	33.45±0.76	0.894±0.002
1	-1	-1	1	36.05±3.99	0.496±0.008	0.943±0.015	2510±198.11	0.972±0.008	0.846±0.012	11.80±0.35	32.87±0.76	0.900±0.002
-1	1	-1	1	32.21±3.99	0.355±0.008	0.867±0.015	1779±198.11	0.978±0.008	0.854±0.012	11.53±0.35	37.74±0.76	0.913±0.002
1	1	-1	1	27.43±3.99	0.503±0.008	0.901±0.015	1981±198.11	0.985±0.008	0.863±0.012	12.73±0.35	37.16±0.76	0.906±0.002
-1	-1	1	1	25.90±3.99	0.395±0.008	0.858±0.015	2401±198.11	0.974±0.008	0.835±0.012	11.23±0.35	34.23±0.76	0.898±0.002
1	-1	1	1	40.09±3.99	0.527±0.008	0.972±0.015	2288±198.11	0.972±0.008	0.852±0.012	13.70±0.35	34.17±0.76	0.897±0.002
-1	1	1	1	29.30±3.99	0.363±0.008	0.850±0.015	2328±198.11	0.975±0.008	0.852±0.012	11.33±0.35	37.08±0.76	0.911±0.002
1	1	1	1	30.98±3.99	0.518±0.008	0.930±0.015	2386±198.11	0.967±0.008	0.830±0.012	13.13±0.35	35.19±0.76	0.908±0.002

Addition of BG increased the hardness from 2027 g to 2283 g when the level of BGC increased from 10% to 20%. Water had the softening effect on cake, when it was increased from 270 ml to 300 ml as hardness decreased from 2238 g to 2072 g. A 2-way interaction of BG*Water influenced hardness due to the physical affinity of water to BG decreasing the hardness (Table 5.4). Even at 10% level with addition of 300 ml of water hardness decreased from 2061 g to 1942 g. When excess amount of water is present, more water is available for foam structure formation and starch gelatinization making the final cake softer. However, addition of SSL and higher duration of mixing resulted in increased hardness though it was expected to decrease the hardness. Thus the individual effects of increasing mixing time and addition of emulsifiers were not effective in softening the cake. Hardness of full fat cake (control) was determined by Kalinga and Mishra (2009) and it was 1320 g. All the cakes prepared by adding BG in this experiment were significantly harder than the cake containing full amount of fat. Springiness and cohesiveness were not influenced by any of these independent variables (Table 5.3).

Volume is one of the most important physical properties of cake. A higher volume implies a less compact cake structure; therefore lower cake hardness can be expected (Arozarena *et al.,* 2001). The results show that volume index increased with the level of BG (Table 5.4) in the recipe. The highest volume index observed was 13.68 cm at 20% BG, 270 ml water, 24 min mixing time without emulsifier and lowest was 10.33 cm which was in 10% BG, 270 ml water 24 min mixing time and 0% emulsifier. At high viscosities of cake batter, ability of batter to retain air bubbles is high there by volume index was high (Lee *et al.,* 2004, 2005a, 2005c).

Increased percent moisture of final cake was observed when water content was increased in batter. Moisture content increased from 34.0% to 36.3% upon addition of extra 30 ml of water in the batter (Table 5.4) due to the retention of more water during and after baking. At 20% BG level moisture content was lower than that of 10%; the respective values were 34.6% and 35.7%. High level of mixing time also decreased the moisture content from 35.31 to 34.24%. Higher the mixing time, higher the amount of air bubbles were formed and more water can be evaporated reducing the moisture content in final cake (Arozarena *et al.,* 2001). Elevation of water level is important for final cake quality. It makes water available for starch gelatinization after binding by

BG. This can be a reason for softer cake at 300 ml water content. Addition of SSL slightly increased the moisture content in cake which may be due to the water binding ability of emulsifiers (Sahin and Alava, 2003).

Water activity (a_w) is used to indicate preservation and sensory quality of foods. Depending on the type of cake, it varies from 0.72-0.94. The water activity varied between 0.8-0.9 for all the cakes (Table 5.4) in this study. Main effects, 2-Way interactions and 4-Way interactions were significant ($p<0.05$) on $a_{w.}$ The ability of BG to bind water and make water less available is evident by lower a_w (0.903) at 10% BG vs higher a_w (0.900) at 20% BG cake. Addition of extra 30 ml water increased a_w from 0.896 to 0.907. Increasing mixing time decreased the a_w due to the formation of more air bubbles and more water evaporation during baking.

Emulsifiers are added in baking industry due to their ability to provide the necessary aeration and gas bubble stability during the process (Sahin, 2008). The effect of batter density on bubble behaviour was seen to be dependent on the type of emulsifier and its concentration (Sahin and Alava, 2003). In this experiment SSL was used as the emulsifier. However, it was not effective in either lowering the hardness or increasing the volume of the cake due to perhaps inappropriate choice of emulsifier or the concentration of SSL was inadequate. SSL was found effective in increasing the batter viscosity in formulations where 25% fat was replaced with moltodextrin but failed to improve cake volume or texture (Lakshminarayan *et al.,* 2006).

5.4.2 Sensory Evaluation

The consumer acceptability of cake produced with different combinations of ingredients and mixing time was evaluated sensorily and the results are presented in Table 5.5. The appearance, cohesiveness and overall acceptability were not significantly different ($P>0.05$) for different cakes. The highest score (7.4) for appearance was given to the cake number 2 which had 10% BG, 270 ml water, 24 min mixing time and 0.03% SSL. Significant difference in hardness was detected by panellists for the treatments. The highest score for hardness was given to cake 15. It had low level of BG, low level of water, 24 min mixing time without emulsifiers. The lowest hardness was observed in cake number 8 which corresponded to low level of BG, 270 ml water, 0.03% SSL and 12 min mixing time. These results confirm that increasing the mixing time increases hardness as observed by hardness measurement instrumentally. In addition to cake hardness, batter viscosity increased (K and n) and specific gravity increased (Table 5.4). This may be attributed to removal of air bubbles during over mixing. The highest moistness was detected in cake 7 with low level of BG, high level of water, high mixing time, without emulsifier which can be due to the fact that at low level of BG sufficient water was available for the panellists to detect it. Cohesiveness of cake 7 and 8 were highest. The highest score for overall acceptability was given to the cake 8 which was corresponding to 10% BG, 270 ml water, 12 min mixing time and 0.03% SSL. Panellist may have perceived it as more acceptable due to its softness. It had 10% BG, 270 ml water, 0.03% SSL and 12 min mixing time. Batter properties such as K, n and specific gravity of this cake were 33.03 Pas^n, 0.381, and 0.850 respectively. The cake with lowest overall acceptability (5.5) was 5 which had 20% BG, 300 ml water, 24 min mixing time without emulsifier. The batter properties were K= 69.27 $Pa.s^n$, n=0.450 and specific gravity was 0.992. These values show increase in viscosity and specific gravity in the cake with lowest overall acceptability compared to the most acceptable cake. Even though the viscosity was high it didn’t trap high amount of air (high specific gravity) which may have led to compact structure and poor acceptability.

Table 5.5 Sensory evaluations for different cakes

Cake number	Appearance	Hardness	Moistness	Cohesiveness	Overall acceptability
1	7.2 ± 1.43^{a}	6.0 ± 1.85^{a}	5.0 ± 1.79^{a}	5.9 ± 1.60^{a}	6.2 ± 1.55^{a}
2	7.4 ± 1.25^{a**}	4.9 ± 2.13^{ab}	5.7 ± 1.57^{a}	6.3 ± 1.37^{a}	6.6 ± 1.63^{a}
3	6.5 ± 1.56^{a}	6.4 ±1.56^{a}	4.9 ± 1.72^{a}	5.9 ± 1.89^{a}	5.9 ± 1.32^{a}
4	6.7 ± 1.31^{a}	5.5 ± 1.81^{ab}	5.8 ± 1.69^{a}	6.5 ± 1.87^{a}	6.8 ± 1.49^{a}
5	6.0 ± 1.71^{a}	6.5 ± 1.69^{a}	4.4 ± 1.63^{a*}	5.2 ± 1.37^{a*}	5.5 ± 1.56^{a*}
6	6.5 ± 1.33^{a}	5.8 ± 1.92^{a}	5.4 ± 1.71^{a}	6.0 ± 1.61^{a}	6.3 ± 1.60^{a}
7	6.6 ± 1.60^{a}	5.4 ± 1.96^{ab}	6.2 ± 1.35^{a**}	6.4 ± 1.15^{a**}	6.7 ± 1.28^{a}
8	7.0 ± 1.31^{a}	4.4 ± 2.02^{b*}	5.9 ± 1.49^{a}	6.4 ± 1.36^{a**}	7.1 ± 1.19^{a**}
9	6.8 ±1.48^{a}	5.8 ±1.85^{ab}	5.6 ± 1.61^{a}	5.8 ± 1.80^{a}	6.1 ± 1.48^{a}
10	6.6 ± 1.87^{a}	6.2 ± 1.57 ^{a}	4.8 ± 1.53^{a}	6.3 ± 1.43^{a}	6.1 ±1.35^{a}
11	6.9 ± 1.83^{a}	5.8 ± 2.23^{a}	6.1 ± 1.56^{a}	6.2 ± 1.73^{a}	6.6 ± 1.73^{a}
12	6.9 ± 1.67^{a}	5.2 ± 2.30^{ab}	6.0 ± 1.67^{a}	6.0 ± 1.48^{a}	6.5 ± 1.67^{a}
13	5.8 ± 1.75^{a*}	5.2 ± 1.96^{ab}	5.8 ± 1.76^{a}	6.2 ± 1.42^{a}	6.2 ± 1.56^{a}
14	7.0 ± 1.38^{a}	5.8 ± 2.01^{a}	5.3 ± 1.79^{a}	6.0 ± 1.68^{a}	6.3 ± 1.93^{a}
15	6.6 ± 1.41^{a}	6.6 ± 1.17^{a**}	5.1 ± 1.72^{a}	5.7 ± 1.24^{a}	5.6 ± 1.25^{a}
16	6.4 ± 1.53^{a}	4.7 ± 1.81^{ab}	6.1 ± 1.47^{a}	6.0 ± 1.27^{a}	6.8 ± 1.42^{a}

Means of same column with same letter are not significantly different at $p<0.05$

cake number correspond to the number in Table 5.1

*- lowest score

** - highest score

5.5 CONCLUSIONS

Replacement of fat with BG influenced both batter and cake properties. Sensory results show that acceptability of cake produced with low level of BG was higher in terms of appearance, softness, moistness, cohesiveness and overall acceptability. When the influence of different ingredients and mixing time on different physical and rheological properties were studied, influence of main effects and their interactions were observed. Increased concentration of BG and mixing time increased the hardness of the cake. Increased water content decreased the hardness. Addition of SSL improved the batter properties but didn’t improve the final cake quality. Based on the results acceptable cakes containing BG can be made using 10% BG, lower mixing speed and higher than specified amount of water. Further work needs to be done to optimise the level of BG and water.

CHAPTER 6

GENERAL CONCLUSION

β-glucan has been known to provide health benefits in managing several diet related diseases. It has also been mooted as an ingredient, which can be used for replacement of fats in foods. Several changes in sensory properties, particularly unacceptably high hardness in cereal foods have been widely noticed and perceived to be preventing the use of β-glucan in foods. Arguably health benefits of this important functional ingredient can not be fully realised. The adverse impact on quality upon enrichment resulted from interactions between and within components in the presence of β-glucan. An understanding of these interactions is fundamental to improving the quality of enriched products. In this thesis, how presence of β-glucan influences the interactions responsible for change in the quality of bakery foods was investigated using cake as an example of bakery foods. The study was divided into three parts presented as chapters. Chapter 3 included results on physical properties of BGCs (water holding capacity, swelling), and the effect of addition of different level of BG on pasting, gelling and thermal properties of flour, a key ingredient of cake recipe. In chapter 4 sorption properties of BG and flour mixtures containing different levels of BG were studied. In chapter 5 the effect of changes in formulation and mixing on batter properties and cake quality were discussed.

Both, barley and oat BGCs demonstrated high water holding and swelling capacities confirming their classification as soluble dietary fibre. These polymers are known to provide highly viscous solution in water. The influence of BG on pasting and gelatinisation behaviour of starch in the presence of water and under the influence of heat was studied by thermal analysis and pasting properties. Increment in peak, pasting, breakdown, setback and final viscosities were observed with increasing concentration of BBGC and OBGC. These properties are indicative of starch-water interaction under the influence of heat. During thermal analysis, increase in onset, endset and peak temperatures were observed and enthalpy decreased with increasing concentrations of BG. The effects similar to reduction of water activity by sugars and salt on starch gelatinisation were noted. The type and level of BG influenced pasting, gelling and thermal properties of cake flour and starch were extracted thereof. The gels produced from these pastes were softer compared to the gels of wheat flour and/or starch indicating effects of reduction in starch fraction as pasting temperature decreased with increasing levels of BBGC and OBGC. These trends were similar for both flour and starch mixtures and suggested that BG competed with starch for water making water unavailable for processes such as gelatinisation of starch. The plasticising effect of BG could not be ruled out either.

The hygroscopic nature of BG was further examined by determining its water sorption properties over range of temperatures. Sorption isotherms were constructed using equilibrium moisture of BG, cake flour and their mixtures used in enrichment. Experimental sorption data were used to derive the parameters of GAB equation, which is most accepted model, used for describing sorption isotherms in food science. Hygroscopic nature of BG was confirmed on sorption analysis as higher amount of water was sorbed at higher range of water activities. The isotherms for the mixtures were intermediate between that of flour and BG and roughly proportional to the level of BG in the flour mixtures. Sorption behaviour demonstrated effects of BG in flour mixtures similar to hydrocolloids having high WRC, swelling, and pasting viscosities.

Finally, variations in the recipe and mixing conditions of batter on batter physical and rheological properties, physical properties of cake and sensory properties of cake, were studied using full factorial experimental design. The results as reported in chapter 5 confirmed the role of water in deciding the cake hardness. Increasing the amount of water in the cake recipe by 30 ml decreased the hardness of cake by 166 g. It also reduced batter viscosity and specific gravity. Addition of high levels of BG increased the volume, at the same time increased the hardness. Increasing of mixing time and addition of SSL were not effective in improving the final cake quality. A general conclusion of this screening test was the “cake containing 10% BG, 270 ml water, 0.03% SSL and 12 min mixing time had lowest hardness and highest overall acceptability”. Restricted water availability was proposed as a possible mechanism for hardness of BG enriched cakes. Reducing the level of BG added or increasing the amount of water added may therefore be the key to achieve good quality of cake.

Cake is complex food system. The overall quality of the cake depends on host of factors such as composition of the recipe used, the method of preparation of cake batter and baking conditions. Addition of BG influenced significantly the batter properties and the sensory quality of cake. Volume and hardness of the cake containing BG depended on component interactions, starch-water, protein-water, lipids-emulsifier/foaming agent to name a few. Since starch is the key component of flour, it was expected to control the functionality more than the rest of the components. Due to high hygroscopicity of BG, water was not freely available for completion of gelatinisation of starch. Due to the nature of the experiment it was difficult to find out an optimum level of water required for desired hardness. The study did not attempt to investigate events during baking that may have been responsible for hardness. To what extent proteins-BG, lipid-BG affected the hardness in the BG enriched cake remains to be investigated. The effect of BG addition on the digestibility of starch should be followed in future to ascertain the effect of BG on the glycemic index of cakes.

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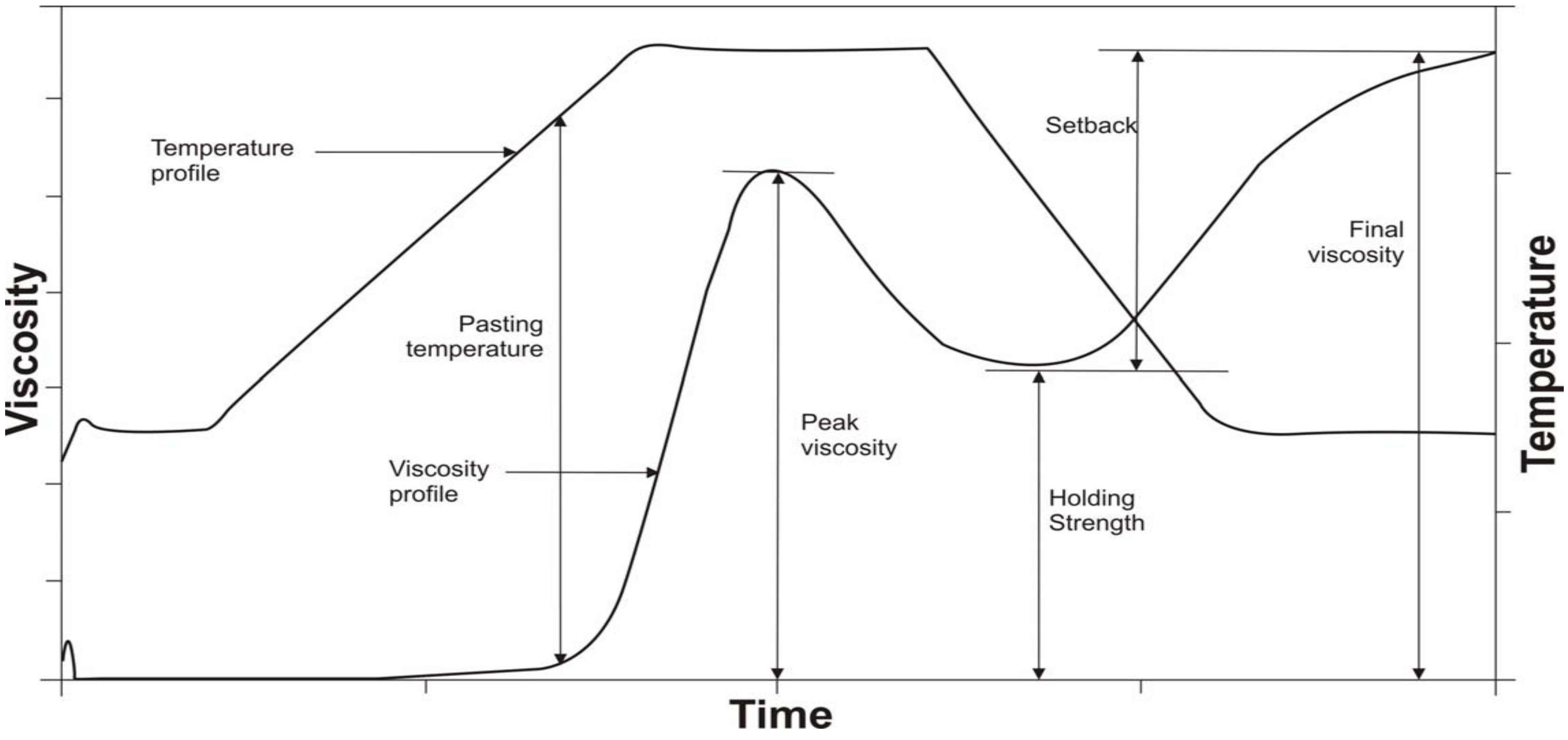
APPENDIX 1



Typical complete RVA curve, showing main parameters used to describe (Batey, 2007)

APPENDIX 2 – Questionnaire for Sensory Evaluation of Cakes

SENSORY EVALUATION QUESTIONNAIRE – CAKE

Date:

Read and follow the instruction carefully. Judge the product one by one focusing on the characteristics underlined below. In giving assessment, please do not remember the proceeding samples. Give assessment base on your acknowledge only. And please wash your mouth with the drinking water provided.

1. Appearance
   This part doesn't required consuming the product. Observe the product carefully and give your assessment based on the colour, size and distribution of cells and heaviness.
2. Hardness
   Place sample in the mouth and press against the upper palate. Judge firmness as the amount of force required by your tongue to flatten the cake. Food that is soft provides very little resistance to flattening whereas firm cake requires considerable force to flatten.
3. Moistness
   Place the sample in the mouth and judge based on the amount of wetness perceived within the mouth.
4. Cohesiveness
   Place the sample in the mouth and gently chew the sample. Judge the cohesiveness based on the extent to which the cake remains intact during handling and chewing. Cake with high cohesiveness remains intact while handling and chewing.
5. Overall acceptance
   Give your judgment upon all the factors observed above and give overall likeness of the product

Please do not swallow the samples. You should spit them in a container provided and clean your palate with drinking water.

Product code: ________

APPEARANCE	HARDNESS	MOISTNESS	COHESIVENESS	OVERALL ACCEPTANCE
___ like extremely	___ Firm extremely	___ Moist extremely	___ Cohesive extremely	___ like extremely
___ like very much	___ Firm very much	___ Moist very much	___ Cohesive very much	___ like very much
___ like moderately	___ firm moderately	___ Moist moderately	___ Cohesive moderately	___ like moderately
___ like slightly	___ firm slightly	___ Moist lightly	___ Cohesive slightly	___ like slightly
___ neither like nor dislike	___ neither firm or soft	___ neither moist or dry	___ Neither cohesive nor crumble	___ neither like nor dislike
___ dislike slightly	___ soft slightly	___ dry slightly	___ crumble slightly	___ dislike slightly
___ dislike moderately	___ soft moderately	___ dry moderately	___ crumble moderately	___ dislike moderately
___ dislike very much	___ soft very much	___ dry very much	___ crumble very much	___ dislike very much
___ dislike extremely	___ soft extremely	___ dry extremely	___ crumble extremely	___ dislike extremely

Product code: ________

APPEARANCE	HARDNESS	MOISTNESS	COHESIVENESS	OVERALL ACCEPTANCE
___ like extremely	___ Firm extremely	___ Moist extremely	___ Cohesive extremely	___ like extremely
___ like very much	___ Firm very much	___ Moist very much	___ Cohesive very much	___ like very much
___ like moderately	___ firm moderately	___ Moist moderately	___ Cohesive moderately	___ like moderately
___ like slightly	___ firm slightly	___ Moist lightly	___ Cohesive slightly	___ like slightly
___ neither like nor dislike	___ neither firm or soft	___ Neither moist nor dry	___ neither cohesive nor crumble	___ neither like nor dislike
___ dislike slightly	___ soft slightly	___ Dry lightly	___ Crumble lightly	___ dislike slightly
___ dislike moderately	___ soft moderately	___ Dry moderately	___ Crumble moderately	___ dislike moderately
___ dislike very much	___ soft very much	___ Dry very much	___ Crumble very much	___ dislike very much
___ dislike extremely	___ soft extremely	___ Dry extremely	___ Crumble extremely	___ dislike extremely