CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

It has been documented that diets high in sugar and fat, particularly saturated fat, and low in complex carbohydrates are associated with an increasing incidence of obesity, coronary heart disease and certain cancers, especially in affluent societies where physical activity may be low (English, 1987; Hetzel & McMichael, 1987). In an attempt to improve the health status of Australians, Dietary Targets were developed by the Nutrition Taskforce of the Better Health Commission (English, 1987), to supplement the NH&MRC Dietary Guidelines for Australians (1992). The Nutrition Targets recommended a reduction in the total energy contribution from fat to 33% and from refined sugars to 12% by the year 2000 (English, 1987).

Consumers have been urged to improve their health by following these dietary recommendations and to consume sufficient energy to maintain weight or reduce overweight. Dieting success has generally been poor and consumers have demanded low sugar and low fat alternatives so that they do not have to sacrifice sweet and high fat foods (Altschul, 1989; Barndt and Antenucci, 1993).

In certain developed countries, some biscuits are major sources of dietary fat and sugar and are targeted for fat and energy reduction (Cauvain, 1992a; Drewnowski, 1993). Cauvain (1992a) believed it may have been possible for fat reduction in biscuits to
comply with UK dietary recommendations, but thought it was unlikely that biscuits could meet low fat labelling criteria. The reduction of fat in biscuits has been reported by Kelly (1992) and Yakel and Cox (1992) to be extremely difficult due to the low moisture content and the loss of the tenderising effect of fat. Similar conclusions can be made in relation to the bulking effect of sugar.

This may explain why so few low fat biscuits have been marketed compared with the extensive range of low and reduced fat dairy and processed meat products. With recent advances in ingredient technology however, starch based fat replacers are being specifically designed with the potential for use in baked goods (eg. Oatrim™). As time progresses, ingredient approval of synthetic fat substitutes (eg. Olestra™) may also provide a means of producing low fat or fat free biscuits.

As reported in Hoseney (1994) and Manley (1991), plain sweet biscuit doughs are characterised by a well developed three dimensional gluten network which imparts extensibility and cohesiveness to the dough. During mixing, increased amounts of fat and sugar inhibit gluten formation which in turn reduces dough extensibility. The functional properties of fat and sugar in plain sweet biscuits are predominantly texture (relating to structure formation and eating quality), appearance and flavour development. The prime requirement for plain sweet biscuits is an open texture with a firm to hard bite and a smooth surface with a slight sheen (Manley, 1991).

Lite biscuits have been produced in America and other European countries for some years (Vetter, 1993). The biscuit types in these countries however are quite different to Australian and UK varieties, and use different processing conditions.
Polydextrose (Litesse™), was developed to replace sucrose and a portion of fat, flour and starch (Leibrand, Smiles and Freeman, 1985) in reduced energy products including baked goods. Polydextrose has been used in cakes and muffins, but not extensively in plain sweet biscuits. This thesis investigates the effects of sugar and fat reduction and the functional properties of polydextrose as a sugar and fat replacer in plain sweet biscuits.

1.2 AIMS

The thesis aims were:

i) To develop a procedure for producing consistent and reproducible plain sweet biscuit doughs and biscuits in the Arnott’s laboratory scale test bakery.

ii) To use the optimised procedure to determine the functionality of sugar and fat in a modified plain sweet biscuit formulation (PS Control) using equal weight replacements of wheat starch.

iii) To use a plain sweet biscuit formulation (TB Control) to determine the functional properties of polydextrose (Litesse™) when used as a sugar replacer, fat replacer and sugar and fat replacer.

iv) To make recommendations for producing a plain sweet biscuit containing low levels of sugar and fat.
CHAPTER 2
LITERATURE REVIEW

2.1 AUSTRALIAN DIETARY GUIDELINES

The first edition of the Australian Dietary Guidelines were published in 1982 (English, 1987). The guidelines were revised in the 1990’s based on current scientific knowledge of the association between health and disease, with the second edition published in 1992 (NH&MRC, 1992). The current guidelines are set out in Figure 2.1.

The second edition emphasised a change in the recommendations for sugar and fat which included recommendations to reduce the contribution of energy from fat to 35% and refined sugars to 12% by 1995. For the year 2000, there was a further recommendation to reduce the energy contribution from fat to 33% (English, 1987). The World Health Organisation guidelines recommend a 30% energy contribution from fat with saturated fat not exceeding 10% of the energy contribution (Clydesdale, 1994; Wheelock, 1992).

The primary intention of the Dietary Guidelines was to encourage healthy food choices and eating which contribute to a healthy lifestyle with minimal risk of developing diet related diseases. Other risk factors such as genetics, sex, age and lifestyle are associated with disease prevalence. With the exception of lifestyle, these factors are not
controllable (Hetzel and McMichael, 1987). Changes in diet and lifestyle consistent with the Dietary Guidelines are ultimately required to improve the health status of Australians.

**Figure 2.1** Dietary Guidelines for Australians.
(Revised Edition, 1992)

<table>
<thead>
<tr>
<th>Dietary Guidelines</th>
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<tbody>
<tr>
<td>1. Enjoy a wide variety of nutritious foods.</td>
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<tr>
<td>2. Eat plenty of breads and cereals (preferably wholegrain), vegetables (including legumes) and fruits.</td>
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<tr>
<td>3. Eat a diet low in fat and, in particular, low in saturated fat.</td>
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<tr>
<td>5. If you drink alcohol, limit your intake.</td>
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<td>6. Eat only a moderate amount of sugars and foods containing added sugars.</td>
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<tr>
<td>7. Choose low salt foods and use salt sparingly.</td>
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<td>8. Encourage and support breastfeeding.</td>
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<tr>
<th>Specific Nutrient Guidelines</th>
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<tbody>
<tr>
<td>1. Eat foods containing calcium. This is particularly important for girls and women.</td>
</tr>
<tr>
<td>2. Eat foods containing iron. This applies particularly to girls, women, vegetarians and athletes.</td>
</tr>
</tbody>
</table>

Source: NH&MRC, 1992
2.2 DIETARY MODIFICATION AND THE LITE MARKET

With increased knowledge of the association between health and disease, health authorities urged consumers to follow NH&MRC dietary recommendations and improve their health by reducing their intake of foods high in fat (particularly saturated fat), sugar, salt, cholesterol and energy and increase their intake of complex carbohydrates to consume only enough energy to maintain weight or reduce overweight (Altschul, 1989; Clydesdale, 1994).

According to Miller and Frier (1989), Bennett (1992), Barker and Cauvain (1994), consumers demanded a technical solution involving recipe reformulation and dietary modification to produce healthy alternatives to the indulgent foods they were not prepared to sacrifice. Many of these consumers had difficulty maintaining weight reducing diets and were not prepared to compromise on taste. Consumers demanded products low in fat, sugar and energy which tasted as good or better than their traditional counterparts (Calorie Control Council, 1991).

Increased consumer awareness and concerns regarding health and nutrition is evidenced by the size and continued growth of the American lite market (Heasman, 1991; Singhal, Gupta and Kulkarn, 1991). O’Brien Nabors and Gelardi (1991) stated that low calorie and ‘lite’ foods and beverages comprised one of the fastest growing segments of the American food and beverage industries. These consumers used lite products a part of a healthy lifestyle (Lachance, 1989; O’Brien Nabors and Gelardi, 1991) with the primary
market, being greatest in the United States, where in 1991, 84% of the adult population included low-calorie, sugar-free or reduced fat foods and beverages in their diets (Gelardi, 1993).

A similar survey in Australia revealed that 30% of all consumers included sugar free products and 64% indicated low fat products into their diets with the greatest consumption in soft drinks and dairy products (Scriven, 1992). The primary reason for consuming lite products was ‘to stay in better overall health’ which was consistent with other lite consumers around the world (Calorie Control Council, 1991). Results of the Australian Lite Survey indicated that almost 30% of regular lite consumers demanded additional low fat and low sugar baked goods such as biscuits (Scriven, 1992). Barker and Cauvain (1994) also reported a strong demand and opportunity for fat and sugar reduced baked products in the U.K.

As some biscuit varieties contain high proportions of fat, they are a likely target for fat reduction (Nisbet, Rossiter, Miller and Thacker, 1986; Cauvain, 1992a; Drewnowski, 1993). Research using fat and sugar replacing ingredients in biscuits was investigated by Robbins and Rodriguez (1984), Dartey and Biggs (1987), Lim, Setser and Sook Kim (1989), Stanyon and Costello (1990), Vetter (1991) and Armbrister and Setser (1994) with limited sensory success. The main conclusion was that no single ingredient could replace all the functional properties of fat or sugar hence a multiple systems approach was recommended (Kroskey, 1990; Barker and Cauvain, 1994, Abboud, 1995).
Recent research of the American biscuit market revealed that fat-free cookies and crackers were the third most active product category (Sloan and Stiedemann, 1995). Consumer interest in avoiding fat however is beginning to decline as the lite consumers are gaining weight from having consumed low or fat free foods with similar energy values as the traditional products. Sloan and Stiedemann (1995) reported that these consumers were reverting back to counting calories.

Despite the advancements in ingredient technology and availability, Vetter (1991), Cauvain (1992b), Kelly (1992), Abboud (1995) and Shukla (1995) agreed that the creation of low fat and or sugarless baked goods is a technical challenge. The main reason is the difficulty in providing all the functional properties of sugar and fat with ingredients which have completely different chemical structures whilst maintaining the product quality. The low moisture content is a further constraint as most of the starch based sugar and fat replacers require water for optimum functionality.
2.3 SUGARS

2.3.1 Carbohydrate Chemistry

Carbohydrates contain carbon, hydrogen and oxygen atoms assembled into single molecules (monosaccharides), two molecules (disaccharides) or more than 2 molecules (polysaccharides). The di- and polysaccharides can be made of the same or different monosaccharides (Wahlqvist, 1984; Fox and Cameron, 1989). Naturally occurring carbohydrates containing six or multiples of six carbon atoms are of particular importance to food scientists and nutritionists and include glucose, sucrose and starch.

Sucrose, or sugar (C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}) is one of the most common carbohydrates and is used raw or refined in many food products (Fox and Cameron, 1989). In regard to sweetness, sucrose is used as a reference with a sweetness value of 1.0. Sucrose has many unique physical and chemical functional properties in baked goods which many ingredient technologists are trying to duplicate in view of the current lite market.

2.3.2 Carbohydrate Nutrition

Carbohydrates are a nutritionally important source of energy, providing 17kJ/g. During digestion, carbohydrates are hydrolysed by enzymes into their component monosaccharides which pass from the small intestine into the blood stream and are carried to the liver (where fructose and galactose are converted to glucose) and the muscles where glucose is converted into glycogen (Fox and Cameron, 1989). In the body, absorbable carbohydrates provide energy for metabolism and body warmth.
intracellular structure, ribose for synthesis of DNA and RNA and sugar units that may be attached to proteins to modify functionality. Non-absorbed carbohydrates contribute to gut function and affect nutrient absorption (Wahlqvist, 1984).

Despite suspicion, Fox and Cameron (1989) stated that there was no conclusive evidence that excess consumption of sugars is a causative agent in heart disease, diabetes, gall or kidney stones or certain cancers. There is also no simple or direct link between excess consumption of sugars and tooth decay (Drummond, 1995). Black (1993) suggested that these associations were based on misunderstood consumption data. It is known that high blood sugar levels (a condition of diabetes mellitus) are damaging to the body and metabolism and may initiate the development of coronary heart disease (Anon., 1992), and that a relationship exists between sugars and protein tissue damage which may impair metabolism of fat and cholesterol (Grande, 1974; Anon., 1992). In both instances however, diabetes and damaged protein tissue must be pre-existing conditions and are not directly related to excess consumption of dietary sugars.

Excess consumption of sugars can contribute to overweight and obesity in a diet where the energy balance exceeds energy expenditure. As fats contribute more energy than sugars, it is most likely that a diet high in energy from both sugars and fats are most likely to contribute to a positive energy balance and weight gain where physical activity is low. According to Foreyt and Becker (1991), achieving ideal weight, reduces the health risks associated with obesity and increases longevity by reducing the risk of secondary conditions such as heart disease and certain cancers.
2.3.3 Functional Properties of Sugars in Biscuits

The principle functions of sugars are to sweeten and enhance flavour, provide texture, body and bulk, contribute moistness and participate in colour development (Campbell, Penfield and Griswold, 1984; Shelton and D'Appolonia, 1985; Dziezak, 1986a; Neville and Setser, 1986; Kulp, Lorenz and Stone, 1991; Bornet, 1993; Peklo, 1995). The following table outlines the main functional properties of sugars in biscuits.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk</td>
<td>The solubility of sucrose give a particular mouthfeel which is generally referred to as ‘bulk’.</td>
</tr>
<tr>
<td>Colour Development</td>
<td>During baking, reducing sugars are involved in caramelisation and Maillard reactions which result in crust colour development and production of associated flavours.</td>
</tr>
<tr>
<td>Humectant</td>
<td>The osmotic pressure of sucrose and its ability to bind water and decrease the water activity of the product provide humectancy, moisture retention and product stability.</td>
</tr>
<tr>
<td>Sweetness</td>
<td>Sucrose is sweet, contributing sweetness and flavour. Sucrose has no cooling effect and has a pure, clean taste.</td>
</tr>
<tr>
<td>Tenderisation</td>
<td>Sugars compete with flour proteins for water and slows the development of gluten and swelling of starch and inhibits heat coagulation of gluten protein during baking.</td>
</tr>
<tr>
<td>Volume</td>
<td>The tenderising effect associated with protein during baking allows the leavening gases to expand the structure gradually, thereby improving volume and mouthfeel.</td>
</tr>
</tbody>
</table>

Source: Campbell et al., 1984; Shelton and D'Appolonia, 1985; Dziezak, 1986a; Neville and Setser, 1986; Kulp et al., 1991; Bornet, 1993; Peklo, 1995.
2.3.4 Sugar (Sucrose) Reduction

Sugar consumption began to decline in the late 1970’s with the introduction of artificial sweeteners (Dziezak, 1986a). These sweeteners enabled significant energy reductions but lacked all the functional properties of sucrose. According to Beck (1975), the increase in the development and use of sugar substitutes may have been due to increased consumer demand to control energy intake, promote dental health, facilitate diabetic requirements and reduce the prevalence of obesity.

Sugar reductions were evaluated in cookies whilst investigating its functionality. Finney, Yamazaki and Morris (1950) reported a 35% reduction in sugar in cookies without altering the sensory characteristics by increasing ammonium bicarbonate 0.75%. A 33% reduction in sugar has also been reported without a significant loss in sweetness (Manley, 1991).

As sucrose is removed, sweetness, moistness and volume are reduced (Manley, 1991). As no single ingredient has the same functional properties as sugar, recipe reformulation is required using artificial sweeteners with bulking agents or fibres (Alonso and Setser, 1994). As most artificial sweeteners are temperature sensitive they decompose during baking, resulting in a different sweetness profile and bitter aftertaste. The development of polydextrose as an effective bulking agent has enabled significant reductions in sugar and energy in biscuits (Frye and Setser, 1993). With the recent development of temperature stable sweeteners, the effectiveness and acceptability of producing low sugar baked products can be more thoroughly investigated.
2.3.4.1 Artificial Sweeteners

According to Stamp (1990), Grenby (1991), Gelardi (1987), and Lim et al. (1989), artificial sweeteners should have a similar sweetness onset and flavour profile to sucrose with no unpleasant aftertaste. The sweetener should be colourless, odourless, low calorie, physically inert, environmental and temperature stable, non-carcinogenic, non-toxic and be metabolised normally or excreted unchanged and should also possess similar functional properties of viscosity and surface tension as sugar. The main disadvantages of artificial sweeteners include heat sensitivity, lack of solids, bitter aftertaste, laxative effects and lack of bulk (Jenner and Smithson, 1989).

Artificial sweeteners have been used together with synergistic effects of improved and enhanced sweetness and decreased bitterness (Lindley, 1991). Bakal (1987) and Jenner and Smithson (1989) used a combination of saccharin and cyclamate in sugar reduced baked goods which provided good sweetness and chemical and physical stability. Table 2.2 lists the sweetness comparison of some artificial sweeteners compared to sucrose.

Table 2.2 Comparison of Nutritive and Non Nutritive Artificial Sweeteners with Sucrose.

<table>
<thead>
<tr>
<th>Non-Nutritive Sweeteners, 0 kJ</th>
<th>Nutritive Sweeteners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweetener</td>
<td>Relative Sweetness¹</td>
</tr>
<tr>
<td>Acesulfame K</td>
<td>130 - 200</td>
</tr>
<tr>
<td>Cyclamate</td>
<td>30 - 60</td>
</tr>
<tr>
<td>Saccharin</td>
<td>300 - 400</td>
</tr>
<tr>
<td>Sucralose</td>
<td>400 - 1000</td>
</tr>
</tbody>
</table>

¹ Relative to a 1% sucrose solution with a sweetness value of 1.

2.3.4.1.1 Acesulfame K™ (Hoechst)

Acesulfame K™ is the potassium salt of 6-methyl-1,2,3-oxathiazine-4(3H)-one-2,2-dioxide (Altschul, 1989) and was discovered accidentally by Clauss in 1967 (Grenby, 1991). The sweetness was described as being perceived quickly with no lingering or bitter aftertaste and being similar in intensity to aspartame (Dziezak, 1986a; Altschul, 1989; Stamp, 1990). Later studies by Wiet and Beyts (1992) however, indicated a lingering bitter aftertaste when assessed in aqueous solutions and compared to sucrose.

Acesulfame K™ is able to withstand baking and pasteurisation temperatures (O’Brien Nabors and Gelardi, 1991). Ranhotra (1994) found a 99% recovery of Acesulfame K™ from cakes and cookies when used at a level of 70mg per 100g of product, whilst Peck (1994) found 100% recovery when cookies were baked at 275°C for 5 minutes. Stamp (1990) and Peck (1994) indicated that Acesulfame K™ does not decompose until prolonged exposure above 225°C which verifies the findings of Ranhotra (1994) and Peck (1994).

2.3.4.1.2 Sucralose™ (Tate and Lyle Company)

The chemical name for Sucralose™ is 1,6-dichloro-1,6-dideoxy-β-D-fructofuranosyl-4-chloro-4-deoxy-α-D-galactopyranoside (Jenner and Smithson, 1989). Sucralose was discovered in 1976 by the Tate and Lyle Company and is soluble in water and alcohol (Hood and Campbell, 1990). Sucralose™ is manufactured by replacing some of the hydroxyl groups on the sucrose molecule with chlorine. This
chlorination increases the stability to heat, acid and digestive enzymes. Being a sucrose derivative, Sucralose™ possesses some functional and physiochemical properties of sucrose (Hood and Campbell, 1990; Wiet and Beyts, 1992).

Jenner and Smithson (1989), Barndt and Jackson (1990), Hood and Campbell (1990), Stamp (1990) and Grenby (1991) found no loss of sweetness or the development of other compounds during baking. Ranhotra (1994) however, found 10-15% sweetener decomposition at 50-60mg addition in cookies which may question the degree of temperature stability. The main disadvantage of Sucralose™ is discolouration which Jackson (1986) believes may be overcome by co-crystallisation with a nitrogen base.

2.3.4.1.3 Alitame™ (Pfizer)

Alitame™ is a highly potent dipeptide composed of L-aspartic acid, D-alanine and the amide 2,2,4,4-tetra-methylthienanyl amine (Freeman, 1989; Stamp, 1990; Bullock, Handel, Segall and Wasserman, 1992). The sweetness develops quickly with a slight lingering aftertaste similar to aspartame (Newsome, 1993). Alitame™ has excellent stability and functionality over a wide range of baking conditions (Hendrick, 1991), but produces off flavours when exposed to acidic conditions (Ranhotra, 1994). Freeman (1989) produced cakes and brownies using Alitame™ which had comparable sweetness to sucrose but with one third fewer kilojoules as the aspartic acid portion is partially metabolised, contributing 6 kJ per gram. Levels of 30-300ppm are required to achieve a similar sweetness of sucrose (Bullock et al., 1992). Freeman (1989) calculated this to be equivalent to 0.02% of the energy it replaces on an equal sweetness basis.
2.3.4.1.4 Aspartame (The NutraSweet Company)

Aspartame was accidentally discovered in 1965 by Schlatter when attempting to synthesise a product for ulcer therapy (Giese, 1993). Aspartame is N-L-α-aspartyl-L-phenylalanine-1-methyl ester (Stamp, 1990), a dipeptide of the amino acids L-phenylalanine and L-aspartic acid and is metabolised like a protein (Beck, 1975; Dziezak, 1986b). Aspartame is stable in solid and dry forms and is less stable below pH 4 and above pH 5 (Stamp, 1990; Bell and Labuza, 1991). Within this range, the sweetener best survives baking conditions (Conklin, Gressgott and Wolford, 1987).

According to Conklin et al., (1987), Kroskey (1990), Heasman (1991) and Pong, Johnson, Barbeau and Stewart (1991) and Holmer (1984), aspartame is not recommended in applications requiring prolonged exposure to heat because it breaks down, resulting in a loss of sweetness. Encapsulation with a hydrophobic coating increases the thermal stability by delaying the diffusion of water which slows the hydrolysis of the ester group (Conklin et al., 1987; Ranhotra, 1994).

Research by Pszczola (1988) indicated a significant energy reduction (30-50%) using aspartame. Dartey and Biggs (1987) found that the method of addition did not adversely affect appearance, texture or taste of the baked product and that aspartame could be added dry to a cookie to provide a sugar coating appearance. Although the encapsulated form may withstand baking temperatures, Ranhotra (1994) reported that the higher the temperature, the more rapid the breakdown.
2.3.4.2 Bulking Agents

According to Giese (1993), bulking agents imply the use of an ingredient to fill space. With advancements in technology, bulking agents such as polydextrose, maltodextrins, polyols or cellulose not only provide bulk but may also replace some functional properties of sugar (Giese, 1993). These bulking agents may be soluble, such as polydextrose or insoluble, such as cellulose (Ang, 1993).

In baked goods, insoluble bulking agents such as cellulose and fibres dilute the structure binding components of other ingredients within the dough, hence additional vital wheat gluten or gums may be required. These ingredients also absorb large quantities of water and retain moisture in the product which make them unsuitable for use in low moisture biscuits (Ang, 1993; Barker and Cauvain, 1994). Hence the use of soluble bulking agents or a combination of soluble and insoluble bulking agents may be required for reducing the sugar in baked goods as suggested for fat reduction by Ang (1993).

2.3.4.2.1 Polydextrose (Litesse™, Pfizer Food Science)

Polydextrose was discovered by Rennhard at the Pfizer Central Laboratories whilst exploring polysaccharides for their potential as a reduced or zero energy replacement for sucrose and partial replacement for fat, flour and starch (Leibrand et al., 1985; Bill, 1988). According to Leibrand et al., (1985) and O’Brien Nabors and Gelardi (1991), polydextrose was designed to be the ultimate companion to artificial sweeteners and to provide bulk and mouthfeel in the development of reduced sugar baked goods. Polydextrose is a multi purpose ingredient functioning as a bulking agent, formulation aid, humectant and texturiser (Giese, 1993).
Polydextrose is produced directly from dextrose by a process of anhydrous melt polymerisation using a poliol and acid which act as a plasticiser, catalyst and cross linking agent. The polymer is created from a mixture of dextrose, sorbitol and citric acid at a ratio of 89:10:1 and contains some sorbitol end groups and monoester bonds with citric acid. Sorbitol is added during polymerisation to help control the polymer size and prevent the formation of water insoluble materials. This yields a highly water soluble bulking agent with most polymers weighing less than 5000. Polydextrose is composed almost entirely of randomly cross-linked glucose polymers with all types of glucosidic bonds, the 1-6 predominating (Naef, 1982; Leibrand et al., 1985; Dartey and Biggs, 1987; Bill, 1988, Moppett, 1991).

Polydextrose is a large and complex randomly bonded polymer which can not be broken down by digestive enzymes and is highly resistant to microbial degradation in the colon (Moppett, 1991; Singhal et al., 1991; Vetter, 1991). Only 25% of polydextrose is metabolised with 50-60% eliminated in faeces, 30% metabolised into volatile fatty acids and the remainder expelled as carbon dioxide as flatus or exhaled in the lungs. Polydextrose yields 4kJ/g and contributes 25% the energy contribution of sucrose and 11% of fat (Torres and Thomas, 1981; Freeman, 1982; Dziezak, 1986c). Polydextrose contributes to a laxative effect in some individuals when consumed in large quantities as the unabsorbed portion and microbial metabolites can create an increased osmotic load in the lower intestine (Freeman, 1982; Altschul, 1989). Despite this laxative effect, research has shown that utilisation and absorption of essential nutrients is not affected by polydextrose consumption (Jones, 1995).
Polydextrose has a slightly greater viscosity than sucrose, similar melting characteristics and a lower effect on water activity (Leibrand *et al.*, 1985). The primary function is as a humectant which slows undesirable changes in moisture and promotes the shelf life in a manner similar to sucrose (Leibrand *et al.*, 1985). Polydextrose also has phase transitions similar to sucrose (Kim, Hansen and Setser, 1986; Kim and Setser, 1992) and undergoes Maillard browning (Leibrand *et al.*, 1985; Byrne, 1992; Hewitt, 1993). In doughs, the addition of polydextrose reduces the uptake of water by the flour proteins, thereby reducing gluten development which helps to retain the short texture required in many high sugar products (Anon., 1992; Cauvain, 1992b).

The soluble polyglucoses affect rheology and texture of baked goods in a manner analogous to sugar, and enables 20-100% elimination of the normal fat (Dartey and Biggs, 1987). Beereboom (1979), Neville and Setser (1986), Gillatt (1991), Byrne (1992), and Lucca and Tepper (1994) attributed the fat sparing properties to the amorphous structure of polydextrose, its tenderising properties and effect on viscosity.

Extensive research has been conducted in relation to replacing sucrose in cake batters with polydextrose (Neville and Setser, 1986, Pateras, Howells and Rosenthal, 1994; Rosenthal, 1995). Results indicated a maximum replacement of 100% of sucrose with polydextrose. Gumminess was reported in all instances and cakes increased in denseness, hardness and friability. Rosenthal (1995) suggested low internal cohesive strength within the structure which contributed to the hardness and cohesiveness of the cakes. These results were confirmed by texture profile analysis. Rosenthal (1995) also attributed the increase in denseness to the difference in the gelatinisation temperature of
starch and egg protein. Pateras et al., (1994) found that during mixing, cake batters containing polydextrose had reduced air holding capacity which did not affect batter viscosity but reduced baked cake volume, resulting in increased cake density as reported by Rosenthal (1995).

Simic (1992) observed the rheological effects of varying levels of polydextrose in wheat flour doughs. A strong correlation between polydextrose addition and water absorption was evident with absorption decreasing proportionally with polydextrose addition. As polydextrose increased, mixing stability and resistance increased resulting in tougher doughs with reduced water requirements and increased dough stickiness. Simic (1992) thought these effects were due to the potential for polydextrose to interact through hydrogen bonding because of the large number of OH groups, the amorphous structure and low molecular weight.

Simic (1992) hypothesised that one polydextrose molecule could bond to numerous protein sites which would normally bind water thereby reducing gluten development and increasing the moisture content of the dough (in the absence of other ingredients competing for water). Simic (1992) thought that the bonding with protein chains, or complexing with protein and starch could contribute to the increase in dough strength and resistance to extension.

When levels greater than 20% were added to cookie doughs, Dartey and Biggs (1987) reported an increase in dough softness and stickiness. When used as a fat replacer, biscuits increased in hardness and were less cohesive. The cutting of crackers from the
dough sheet was difficult indicating an increase in dough toughness. The baked biscuits also contained raw and floury flavours. Levels greater than 20% also caused flatulence, stool softening and diarrhoea in certain individuals (Dartey and Biggs, 1987).

The addition of polydextrose in the creaming stage of mixing, resulted in lumping and gummy local concentrations in the baked product (Dartey and Biggs, 1987). These authors concluded that lumping and gumminess could be reduced by gradual addition of polydextrose during the dough formation stage, and alkaline conditions with high speed mixing. It was also noted that addition at the dough forming stage increased cookie crispness.

Dartey and Biggs (1987) reported that polydextrose could also replace 20-100% of fat. Studies by Anon. (1989) and Hewitt (1993) reported a 50% reduction of fat in pastry with increased crispness, reduced shrinkage and improved colour. The crispness and shortness were thought to be associated with reduced gluten development (Hewitt, 1993). Armbrister and Setser (1994) suggested that differences in fracturability of cookies were associated with entrapment and mobility of water. As fat replacement increased, dough water increased resulting in a softer and smoother dough.

Polydextrose is one of the most common bulking agents used in modified bakery products (Vetter, 1991). This is due to its sugar replacing and fat sparing properties. Hood and Campbell (1990) replaced up to 60% of the sugar in oatmeal cookies, which resulted in an energy reduction of one-third, without detrimentally affecting the product acceptability. In conjunction with artificial sweeteners, an energy reduction of up to
50% was achieved by Byrne (1992). Polydextrose was found to suitably replace one quarter of the shortening and a portion of the sugar in cookies (Campbell, Ketelsen and Antenucci, 1994).

An improved version of polydextrose was introduced as Litesse with an enhanced flavour profile, followed by Litesse II which was totally bland with virtually no acidity (Kopchik, 1993). These ingredients are currently being used in reduced sugar and reduced energy foods and beverages around the world.
2.4 FATS

2.4.1 Chemistry of Fats

Fats are composed of glycerides which are the products of esterification of glycerol with fatty acids. One ester linkage attached to the glycerol molecule forms a monoglyceride, while two and three ester linkages form di- and triglycerides respectively. The fatty acids can be the same or mixed and can also be saturated, monounsaturated or polyunsaturated. The characteristics of the triglyceride molecule depends on the nature of the fatty acids (Weiss, 1983; Fox and Cameron, 1989; Lorenz, 1994).

2.4.2 Nutrition Aspects of Fats

Fats have vital functions in the diet and in the body. In the diet, fats are a concentrated energy source, contributing 37kJ/g; fats provide essential fatty acids and fat soluble vitamins A, D, E and K. In the body, fats form the structure of all cell membranes and body tissues; as adipose tissue, fat protects internal organs from external damage, insulates the body from heat loss, protects bones and nerves, and controls and regulates metabolism by slowing stomach emptying (Fox and Cameron, 1989; Kennedy, 1991; Byrne, 1992). Fats also increase palatability, keeping quality and aesthetics of food.

Excess consumption of fats, particularly saturated fats have been epidemiologically associated with nutritional disease both by the effect of excessive fat consumption and
by such diets generally being low in complex carbohydrates and dietary fibre. These diet related diseases include obesity, a condition in which there is excessive amounts of body fat (Wheelock, 1992); coronary heart disease which is related to a restricted flow of blood to the coronary arteries which supply blood to the heart muscle (Fox and Cameron, 1989); and cancers of the colon, oesophagus, stomach and breast (Hetzel and McMichael, 1987).

Obesity is the most prevalent condition which has been associated with predispositions to diabetes mellitus, a disorder of the body’s regulatory mechanism in which the individual is unable to regulate blood glucose levels effectively (Whitney and Hamilton, 1981), cardiovascular disease and elevated serum cholesterol levels, hypertension, increased respiratory illness, gall bladder disease and some cancers (Beereboom, 1979; Newsome, 1986; Fox and Cameron, 1989; Foreyt and Becker, 1991; Flynn and Herbert, 1993).

O’Brien Nabors (1992) suggested that dietary fats are a major nutrition concern due to the association with risk factors and prevalence of heart and other diet related diseases. The worldwide recommendations for reducing the energy derived from fat to 30% energy contribution is evidence of the increasing prevalence of diet related disease. Despite the increased knowledge of the dietary association with disease, most consumers are still consuming excess fat and demanding reduced fat alternatives so that they do not have to sacrifice the flavour or pleasures of desirable, high fat foods (Shamil, Wyeth and Kilcast, 1991).
2.4.3 Functional Properties of Fats in Biscuits

The functional effects of fat are predominantly textural, relating to structural formation and eating qualities, and colour and flavour changes (Campbell et al., 1984; Cauvain, 1992b; Given, 1994). Fats have a considerable impact on dough consistency and rheology, chemical reactions, microbiological stability, heat transfer and release from equipment (Byrne, 1992; Abboud, 1995; Jones, 1995). The following table summarises the functional properties of fat in biscuits (Anon., 1992; Jones, 1995). Details of fat functionality specific to plain sweet biscuit doughs are included in section 2.5.1.4.

Table 2.3 Functional Properties of Fats in Biscuits.

<table>
<thead>
<tr>
<th>Property</th>
<th>Functional Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Sheen, opacity, oiliness, colour development and stability.</td>
</tr>
<tr>
<td>Texture</td>
<td>Viscosity, tenderness, elasticity, cutability, flakiness, creaminess.</td>
</tr>
<tr>
<td>Flavour</td>
<td>Aroma, flavour masking, flavour release and development.</td>
</tr>
<tr>
<td>Mouthfeel</td>
<td>Cooling, thickness, cohesiveness, adhesiveness, meltability, lubricity.</td>
</tr>
<tr>
<td>Storage Stability</td>
<td>Emulsification, moisture retention, flavour changes, oil migration.</td>
</tr>
</tbody>
</table>

2.4.4 Fat Reduction

Prior to the introduction of fat replacers, fats were reduced in baked goods using low fat alternatives, increasing water or adding emulsifiers or other additives, or by replacing fat with starches (Jones, 1995). Jones (1995) stated that a 50% reduction in fat was achievable using these traditional methods but resulted in detrimental changes to product quality. Reduced fat biscuit doughs are affected by changes in heat stability and distribution, aeration and melting properties. Moisture retention, viscosity and flavour affect appearance and acceptability of the baked biscuit which necessitates reformulation and changes in processing.

When fat is reduced in biscuit doughs, handling is affected due to problems associated with tackiness, dispersion, migration and shear sensitivity in which the doughs become sticky and difficult or impossible to sheet. This makes the products more sensitive to baking temperatures and contributes to uneven leavening, grainy texture, loss of volume and loss in tenderness, resulting in increased hardness (Kelly, 1992). Significant fat reductions in biscuits by Finney et al., (1950) and Abboud, Rubenthaler and Hoseney (1985), also resulted in undesirably hard products.

As fat is reduced, there is generally an increase in water addition and subsequent increase in water activity and moisture content. This alters the microbiological stability of the baked product. In addition, increased biscuit hardness affects acceptability (Jones, 1995). Hence, there is a need for a multiple systems approach to address the diverse functional properties of fat in biscuits (Abboud, 1995; Jones, 1995).
2.4.5 Fat Replacers

According to Singhal et al., (1991) fat replacers were especially designed to overcome the technical difficulty in reducing fat whilst maintaining an acceptable product. Fat replacers include fat substitutes and mimetics. Fat substitutes are synthetic compounds created by obtaining a chemical structure similar to fat but which is partially or completely resistant to hydrolysis by digestive enzymes. Fat mimetics can be carbohydrate or protein based and give the expected mouthfeel of fat but do not replace fat on an equal weight due to their functionality requiring additional water.

2.4.5.1 Fat Substitutes

Fat substitutes should be functional analogues to the fats they replace and be free from toxic effects, produce metabolites which are similar to those of natural fats and be excreted from the body completely (Singhal et al., 1991). The most publicised fat substitute to date has been Olestra™ (Procter and Gamble) which contains a mixture of hexa-, hepta- and octaesters from sucrose and long chain fatty acids from edible oils. Olestra™ has similar functionality to natural fats with respect to appearance, flavour, heat stability, flash point and shelf life. This substitute has the potential to reduce plasma cholesterol in hypocaloric diets of hypercholesterolemia patients when consumed in large quantities but has the disadvantage of not being absorbed, resulting in decreased absorption of vitamins A and E and anal leakage. Despite the functional properties the negative health benefits may never see this ingredient approved for use in foods (LaBarge 1988, 1991; Toma, Curtis and Sobotor, 1988; Vetter, 1991; Harrigan and Breene, 1993).
2.4.5.1.1 Emulsifiers

Emulsifiers are categorised as fat substitutes because they are derived from mono- or diglycerides. Emulsifiers are surface acting agents which reduce the surface tension forces at the interface of two normally immiscible substances by dissolving or complexing with both. Hence they promote uniform distribution of the fat into the water system of the dough. The main functions of emulsifiers are aeration and textural modification of fat crystallisation. Emulsifiers change dough consistency, stickiness and starch gelling aspects by complexing with starch, protein and sugars (Rusch, 1981; Dartey and Biggs, 1987; Waring, 1988; Manley, 1991; Flack, 1992).

Table 2.4  Functional Properties of Emulsifiers used in Bakery Products.

<table>
<thead>
<tr>
<th>Aeration</th>
<th>Lubrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylose complexing</td>
<td>Moisture Retention</td>
</tr>
<tr>
<td>Dough softening and conditioning</td>
<td>Plasticity</td>
</tr>
<tr>
<td>Emulsifying</td>
<td>Protein interaction</td>
</tr>
<tr>
<td>Fat sparing and distribution</td>
<td>Reduced Stickiness</td>
</tr>
</tbody>
</table>


Burt and Thacker (1981) assessed the effectiveness of different emulsifiers in reducing fat in biscuits and reported that biscuits were flatter, more spread and retained more moisture than the control. Rusch (1981) also indicated an increase in spread in cookies which he thought was related to a delay in gelatinisation which allows for greater flow. Stevens (1975) also found an increase in dough piece and baked weight which resulted from increased dough density. Dough water requirements also increased.
Dartey and Biggs (1986) found that emulsifier addition up to 10% provided acceptable lubrication and aeration of the dough resulting in a tender baked product. Addition greater than 15% in cookies resulted in an unbalanced product which overexpanded during baking and collapsed. Stevens (1975) and Manley (1991) however reported a 15-20% fat reduction in Marie biscuits using DATEM without detrimental effects.

Flack (1992) stated that emulsifiers were generally not widely used in biscuits due to their low moisture content and suggested that the most effective emulsifier was Panodan (DATEM) whilst Jones (1995) recommended the use of Dur-Lo (vegetable oil monoglyceride) for effective fat replacement. Dartey and Biggs (1986) and Lucca and Teppa (1994) stated that a multicomponent emulsifier system provides greater functionality and stability than single systems. Such blends facilitate the combination of specific emulsifier properties such as crumb softening or dough conditioning.

2.4.5.2 Fat Mimetics

2.4.5.2.1 Carbohydrate Based

Developing starch based fat mimetics involves modifying starch which is hydrophilic by nature to be like fat which is hydrophobic, thus imparting fat like qualities (LaBarge, 1991). Carbohydrate based fat mimetics are usually modified starch hydrolysate products based on the property of the starch forming a gel on hydration. In general they are used to form a gel containing one part starch with three parts water which is substituted for fat on an equal weight basis, with the aqueous gel structure providing mouthfeel properties similar to fat (Stauffer, 1993).
Ideally, carbohydrate based mimetics should possess a structure which strongly binds and orients water to provide a similar rheological oral sensation to fat. The hydrated carbohydrate should coat the mouth like fat and clear the palate in about the same length of time as fat. Functional properties include creamy mouthfeel, body and opacity (Hewitt, 1993). There are several categories of carbohydrate based fat mimetics which include starches, maltodextrins and dextrins, polydextrose, cellulose gel and gums (Yakel and Cox, 1992; Lucca and Tepper, 1994).

Products low in moisture are extremely difficult to replace with carbohydrate based ingredients (Yakel and Cox, 1992; Stauffer, 1993). Attempts to replace the shortening in biscuits with starch gels resulted in a sticky dough which was difficult to process due to the reduced lubricity of the fat (Stauffer, 1993). Insoluble bulking agents also absorb large quantities of water which results in a dry mouthfeel when compared to soluble bulking agents (LaBell, 1992). Ang (1993) found that a combination of soluble and insoluble ingredients were required for effective fat reduction in baked goods.

The most recent development in starch based fat mimetics was the development of Oatrim™ (A.E. Staley Manufacturing Company) by Inglett. Oatrim™ is produced by converting starch in oat flour to maltodextrins using alpha-amylase enzymes for starch liquifaction. The low dextrose equivalent gives the most suitable fat replacing properties whilst the conditions of enzyme treatment liberate and separate the soluble fibre components (Inglett and Grisamore, 1991). Beta-glucan is the major soluble fibre found in oats which has been shown to decrease low density lipoproteins and total blood cholesterol and increase high density lipoproteins (Inglett, 1990; Byrne, 1992;
LaBell, 1992). Oatrim™ is a white, smooth textured product with a bland taste which is suitable for use as a functional ingredient in bakery products (Inglett, 1990).

Inglett, Warner and Newman (1993) described Oatrim™ as an effective fat replacer. In baking, up to 50% of the fat could be replaced with Oatrim™ (LaBell, 1992) whilst Byrne (1992) reported a 50-100% reduction. LaBell (1992), indicated that fat reductions of 50-75% required the addition of gums or emulsifiers to retain moisture. Being predominantly dietary fibre and containing high levels of beta-glucan, this ingredient has the potential to reduce fat in biscuits whilst increasing the soluble dietary fibre content of the diet, thereby reducing blood cholesterol and protecting against heart disease.

2.4.5.2.2 Protein Based

Microparticulation involves the process of blending and agitating heated milk or egg protein which causes them to coagulate into a gel structure, followed by rapid cooling. The proteins are shaped into spherical particles so small that the tongue perceives them as being liquid rather than solid. This produces a creamy sensation similar to natural fats (Singhal et al., 1991). The NutraSweet brand of microparticulated protein is Simplesse™ which has an energy contribution of 6 kJ/g (Calorie Control Council, 1991).

The application for protein based fat mimetics in bakery goods is limited, especially at elevated temperatures as high heat causes denaturation and coagulation of the proteins which results in the loss of the creamy, fat like mouthfeel (Vetter, 1991; Lucca and
Tepper, 1994). According to Drewnowski (1993), Simplesse™ cannot replace fat in products which are baked.

Research by Vetter (1991) indicated that when Simplesse™ was used in a cream biscuit sandwich, water migrated from the cream to the base, producing a softening effect in the biscuit base. He postulated that this was due to the protein being hydrated in the ratio of one part protein with two parts water during the microparticulation process.

As Simplesse™ cannot be used at elevated temperatures and has a high water activity, it is functionally unsuitable to replace fat in baked products.
2.5 PLAIN SWEET BISCUITS

2.5.1 Dough Ingredients

Plain sweet biscuit doughs are characterised by a developed three-dimensional gluten network which imparts extensibility and cohesiveness to the dough. Doughs are subject to considerable deformation during mixing, sheeting and baking (Wade, Dale and Bold, 1969; Tschoegl, Rinde, and Smith, 1970). The dough structure is based on a continuous protein network in which starch granules and fat globules are embedded (Wade, 1971a; Manley, 1991). Interactions of flour, water, sugar, fat and sodium metabisulphite significantly affect the rheological properties of the dough and the resulting baked biscuit texture (Manley, 1991). The prime requirement for plain sweet biscuits is an open texture with a firm to hard bite and a smooth surface with a slight sheen (Thacker, 1993).

2.5.1.1 Flour

Flour is a major source of product variability and is an important factor determining dough consistency (Fearn, Miller and Thacker, 1983). The flour should be milled from a low protein variety wheat for limited gluten development. A soft endosperm structure is also required which results in a fine particle size, low starch damage, and a high extraction rate. The flour should have a low water absorption and be extensible to produce a cohesive, viscoelastic dough and a light, aerated product upon baking (Bushuk and Scanlon 1993; Hoseney, 1994; McKendry, Henke and Finney, 1995). Protein quality is important for the functional use of flour in baked goods.
According to Hoseney (1994), proteins have been traditionally classified according to solubility. Albumins are soluble in water, globulins, in dilute salt solutions (and insoluble in water), prolamins are soluble in 70% ethyl alcohol and glutelins are soluble in dilute acids or bases. The albumins and globulins are the most physiologically active proteins, whilst the prolamins and glutelins are storage proteins. The proteins only have their functional role when hydrated and mixed to form a dough. Protein content varies from 6-27%, with low protein flours for biscuits typically ranging from 7-9% protein.

In baking, gluten is developed from the hydration and interaction of gliadins and glutenins (Hoseney, 1994). Gliadins consist of single chain molecules which form disulphide bonds intramolecularly, and form a highly viscous mass when hydrated (Bushuk, 1985). Glutenins consist of polypeptide subunits which are linked intermolecularly by disulphide bonds into unbranched or linear chain molecules (Bloksma, 1990) and form a highly elastic mass when hydrated (Bushuk, 1985). The ratio of gliadin to glutenin proteins is an important determinant of dough properties, with glutenin protein determining the resistance to extension and gliadin protein contributing to the plastic and cohesive nature of the dough (Wrigley, 1994).

2.5.1.2 Water

Water is a unique ingredient (Webb, Heaps, Russell Eggitt and Coppock, 1970; Manley, 1991), believed to be the second most critical factor in plain sweet doughs due to its softening effect (Atkins, 1971; Slade and Levine, 1994) and involvement in creating a viscoelastic dough (Faubion, Dreese and Diehl, 1985). The structural role of
water may be due to its involvement in the cross-linkages between protein molecules (Webb et al., 1970). Water hydrates flour proteins and starch, sugar, salt and chemicals, and aids in the dispersion of other ingredients throughout the dough.

In dough, water can be lightly or firmly bound, or free, and is responsible for dough softness and mobility (Webb et al., 1970). When added to dry ingredients to form a dough, the surface of the flour particles come in contact with the water, resulting in hydration of the starch, fibre and protein components. As the dough is kneaded, flour particles rub together and against the bowl, blades and mixer sprags, thereby removing the outer layers and allowing absorption at the exposed, inner layer until hydration is complete (Manley, 1991). Optimum dough water refers to the level of water required to achieve a dough of arbitrary fixed consistency (Fearn et al., 1983).

2.5.1.3 Sugar

The principle functions of sugar are to sweeten, contribute texture and surface colour (Godshall, 1990; Kulp, et al., 1991). Sugar modifies the rheological properties of the gluten network by competing with the flour protein for water, thereby reducing the formation of a three dimensional network and producing a more tender product (Baxter and Hester, 1958; Wade, 1971b). It has also been proposed (Baxter and Hester, 1958; Dubois, 1984; Hood and Campbell, 1990) that sucrose inhibits the heat coagulation of gluten protein during baking.
2.5.1.4 Fat

The functional effects of fat are predominantly textural, although some colour and
flavour changes also occur. The functional roles in processing include structural
formation, lubrication and transferring of heat during mixing. Properly plasticised
shortenings with small β-prime crystals can entrap large quantities of air in mixing.
These small crystals become uniformly dispersed within the dough mass and entrap air,
leavening gasses and water vapour. Expansion during baking results in desirable
textural attributes of a light and fine crumb structure with tenderness, moistness and
shortness (Merritt and Bailey, 1948; Vetter, 1993; Given, 1994; Lorenz, 1994).

During mixing, there is competition at the flour surface between fat and the aqueous
phase (Manley, 1991). Fat disperses throughout the dough in streaks and films,
coating and preventing the starch and protein surfaces from hydrating and forming a
cohesive and extensible gluten network (Pyler, 1988; Cauvain, 1992a). Merritt and
Bailey (1948) reported that hydrogenated vegetable shortenings added to low protein
extensograph doughs had little effect on resistance to extension, but cottonseed oil and
lard increased the resistance to extension. This is related to the ability to effectively
coat the flour particles and the subsequent degree of gluten formation.

2.5.1.5 Sodium Metabisulphite

Sodium metabisulphite (MBS) is used to modify the rheological properties of plain
sweet biscuit doughs (Wade, 1970; Kulp, 1994; Oliver, 1994; Oliver, Thacker and
Wheeler, 1995). MBS acts as a source of SO₂ permanently disrupting some of the disulphide bonds existing between adjacent gluten molecules. This decreases the extent of cross linking and weakens the elastic and cohesive properties of the gluten thereby reducing the likelihood of excessive dough shrinkage. In effect, glutenin proteins hydrate at a faster rate, water requirements are reduced and doughs are softer, requiring less mixing time to achieve optimum temperature. Sulphited doughs have increased extensibility and tend to form a smoother dough sheet more easily and have a greater surface sheen than non-sulphited doughs (Wade, 1970; Kulp, 1994; Oliver, 1994; Oliver et al., 1995).
2.5.2 Dough Mixing

As reported in Wade et al. (1969) and Wade (1971a), the following changes take place simultaneously during mixing:

i) intermingling of the ingredients to affect uniform distribution throughout the dough mass;

ii) dissolving of sugar, salt and chemicals in the dough water;

iii) hydrating of flour protein which breaks down the protein into fibrous strands;

iv) converting hydrated protein to gluten through kneading, which extends and tears the fibrous strands into films which become layered at optimum mixing and produces a dough of the desired consistency which is smooth, elastic and non-sticky;

v) the dough mass increases in temperature.

The time taken to complete the events within the mixing process are temperature and mixer dependent, being affected by mixer efficiency, speed and design. During mixing, there is a change in the energy levels of starch and protein, involving energy release and subsequent temperature rise in the dough mass (Li and Walker, 1992). Small mixers have better dispersing and blending actions resulting from a greater bowl surface area related to dough mass, hence heat exchange is extremely efficient compared to production scale mixers. The efficiency was reported by Manley (1991) to be due to the power being added as useful work rather than as heat via surface friction.
Dough formation is the result of the adhesion of the protein networks of individual flour particles to one another and their extension during kneading (Amend and Belitz, 1991). Extremely undermixed doughs are usually tacky and lack extensibility and elasticity. With continued mixing past optimum development and dough temperature, there is a breakdown of protein, resulting in a soft, wet and sticky dough which offers less resistance to mixing (Mani, Eliasson, Lindahl and Trägårdh, 1992; Hoseney, 1994), and becomes impossible to process. This is likely to be due to the temperature effect on the viscous components of the dough (Wade, 1971a).

Dough exhibits complex and complicated rheological behaviour (Bloksma and Nieman, 1975; Szczesniak, 1988; Rasper, 1993; Hoseney, 1994). As a viscoelastic material, dough combines the properties of a Hookean solid with those of a Non-Newtonian fluid (Rasper, 1993). The rheological properties are important as they provide dough structure and affect baked product quality (Bloksma, 1972).

The rheological properties are determined by the interaction of glutenins and gliadins and subsequent gluten development (Bushuk, 1985; Mani et al., 1992), and depend on the mechanical energy applied during mixing and the period of time allowed for structural recovery (Frazier, Fitchett and Russell Eggitt, 1985; Oliver et al., 1995). At rest, partial dispersion of the stresses generated during mixing occur and the stretched, hydrated proteins regain some of their original structure. Some bound water is released which increases the dough mobility and softness (Kulp, 1994). The changes are rapid initially and level off (Kulp, 1994) with permanent structural modifications of dough clearly apparent after 30 minutes (Frazier et al., 1985).
2.5.3 Sheeting

After mixing, protein is evenly distributed throughout the dough in small masses or strands. The function of sheeting is to compact and compress the dough and produce a smooth dough sheet of even thickness (Manley, 1991; Mani et al., 1992; Faridi and Faubion, 1994). Plain sweet doughs require 3 or more reductions with ratios between 1 and 2.5 at each pass (Levine and Drew, 1994).

Exceeding a ratio of 2.5 introduces considerable stress into the dough sheet and will result in oval shaped biscuits (Manley, 1991; Levine and Drew, 1994). Repeated sheeting in one direction also introduces a significant amount of stress through elongating or stretching, shearing and circulating. This reduces the extensibility and resistance to extension which may be due to the decrease in gluten orientation and crosslinking (Almond, 1989; Faridi and Faubion, 1994; Levine and Drew, 1994).

Dough sheets require sufficient relaxation to relieve some of the induced stress. During relaxation, the dough shrinks and thickens, so that the thickness at which the dough is cut determines the dough piece weight and influences packet length. Lapping, or turning the dough in a 90° angle, reduces the amount of stress on the dough sheet by making the stresses uniform in all directions, and by providing a means by which the dough can relax. The ability of the dough to spring back after the final reduction roll is a good indicator of a well relaxed dough which has not been excessively stressed (Almond, 1989; Manley, 1991; Faridi, 1994; Levine and Drew, 1994).
2.5.4 Dockering and Cutting

Dockering pins the dough piece to the cutting web prior to cutting and may contain an emboss or decoration (Manley, 1991). According to Almond (1989) the purpose of dockering is threefold. The dockers allow steam to escape during baking thereby preventing the biscuits from blowing (expanding excessively); help to stitch down the top surface preventing tenting (lifting of the centre of the biscuit off the band); and help heat to penetrate more evenly to the centre of thicker biscuits. After dockering, the biscuit shape is cut from the dough sheet (Manley, 1991). Some reciprocating cutters simultaneously docker and cut the dough pieces from the sheet.

2.5.5 Baking

Most product characteristics are determined by dough ingredients and preparation of the dough piece in mixing and sheeting. Baked product texture can be significantly affected by phase changes, chemical transitions, and heat and mass transfer phenomena which occur during baking (Velthuis, Dalhuijsen and de Vries, 1993). The main function of the oven is the removal of moisture (Almond, 1989) in a process which transforms a biologically unstable system into products of relative stability (Mowbray, 1994).

Biscuit baking is a dynamic process involving the 3 modes of heat transfer: conduction from surface contact, convection from the movement of hot air; and radiation by energy waves from the hot oven walls and heat source to the product (Miller, 1982; Almond,
Explanations of the processes and reactions involving the transformation of a raw dough piece into a baked product has been extensive (Almond, 1989; Gaines, 1990; Manley, 1991; Miller, 1982; Velthuis et al., 1993; Lawson, 1994; Mowbray, 1994). The baking curve by Manley (1991), is a comprehensive summary of the changes which occur during baking (Figure 2.2).

Figure 2.2 Changes Occurring During Baking.

2.5.6 Assessments of Dough and Baked Biscuit Texture.

2.5.6.1 Power Monitoring during Mixing

Attempts have been made to objectively measure the rheological properties of mixed doughs to eliminate human subjective assessments of dough properties (Wade, 1966). This has included relating ammeter or wattmeter readings to dough consistency in addition to a work input measuring apparatus (Wade, 1966). According to Westcott (1996), there is a distinction between measuring the instantaneous power developed at any point in time and the total work input done as measured by the wattmeter.

Power monitoring devices are used to follow power developed in AC electrical circuits with time. In DC circuits, voltage and current values are used to calculate power. A DC motor has current $I$ and potential difference $V_a - V_b = V_{ab}$

As charge passes, the electrical field does work on it. In a time interval $\Delta t$, an amount of charge $\Delta Q = I \Delta t$ passes and the work $\Delta W$ done by the electric field is given by the product of the potential difference (work per unit charge) and the quantity of charge:

$$\Delta W = V_{ab} \Delta Q = V_{ab} I \Delta t$$

Power $P$ is the rate of transfer of energy, and can be calculated for a DC motor using the following equation.

$$P = \frac{\Delta W}{\Delta t} = V_{ab} I$$
Current and voltage are not in phase in an AC circuit, except in the case of pure resistance. Instantaneous current and voltage are expressed as

\[ i = I_m \sin \omega t \]
\[ u = U_m \cos (\omega t + \phi) \]

where
- \( i \) = instantaneous current
- \( U_m \) = maximum voltage value
- \( I_m \) = maximum current value
- \( \omega \) = angular frequency
- \( \phi \) = phase angle between voltage and current
- \( u \) = instantaneous voltage

In a three phase AC system, current and voltage are out of phase and power is given by the following formula.

\[ P = \sqrt{3} U_m I_m \cos \phi \]

The difference between calculating power developed in a DC circuit versus an AC circuit is that the power factor (\( \cos \phi \)) must also be measured in an AC circuit. If neglected and only voltage and current are sampled, true power is not measured.

The mixing action imparts a force on the dough which is proportional to the shear strength and elasticity of the dough. Recording the power delivered by the mixer motor provides information about the rheological changes occurring during mixing which provides information on dough shear strength, consistency and elasticity (Voisey, Miller and Kloek, 1966; Bloksma, 1972). Power or mixing curves are characteristic for specific biscuit doughs.
The various phases of mixing are related to portions of the power curve as described by Wade (1966), Faridi (1990), Hoseney (1994) and Menjivar and Faridi (1994). During the initial stage of mixing (Figure 2.3), there is a fairly smooth and low rise in power due to the high proportion of free water until all ingredients become hydrated (A). This rising part of the curve reflects an increase in resistance with mixing time. As the ingredients form a cohesive mass, the band width thickens (B). The band width is related to dough cohesiveness and elasticity (Faridi, 1990).

On high speed mixing, power increases. With continued mixing, protein becomes hydrated forming fibrils that are aligned by the shearing action of the mixer and which progressively increases the resistance to extension. When all flour is hydrated the
proportion of free water decreases and the height of the curve increases to a peak of maximum dough development (C). The height of the curve is a measure of the doughs resistance to extension and is an indicator of dough stiffness (Faridi, 1990; Rasper, 1993).

With continued mixing, the dough becomes less elastic and the resistance to extension begins to decrease and the dough starts to breakdown (D). Spies (1990) attributed this to oxidation of some part of the water soluble fractions rather than shear thinning. The final consistency of plain sweet biscuit doughs is generally constant due to the limited gluten development (Hoseney, 1994).

The area under the power curve (E) is proportional to the energy or work required to mix the dough (Hoseney, 1994) which is calculated from integrating the power curve. Wade (1966) and Wade et al., (1969), extensively researched the effect of work input on plain sweet doughs with varied levels of sodium metabisulphite, water addition, mixing times and final dough temperature. These authors believed that total work input was an important parameter of dough mixing.
2.5.6.2 Texture Profile Analysis

The three main classes of texture and definitions are listed in Table 2.5. Szczesniak (1975) intended this classification for sensory and instrumental texture measurements.

Table 2.5

<table>
<thead>
<tr>
<th>Properties</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mechanical</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>The force necessary to attain a given deformation.</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>The extent to which a material can be deformed before it ruptures.</td>
</tr>
<tr>
<td>Viscosity</td>
<td>The rate of flow per unit force.</td>
</tr>
<tr>
<td>Springiness or Elasticity</td>
<td>The rate at which a deformed material goes back to its undeformed condition after the deforming rate is removed.</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>The work necessary to overcome the attractive forces between the surface of the food and the surface of the other materials with which the food comes in contact.</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
</tr>
<tr>
<td>Fracturability or Brittleness</td>
<td>The horizontal force at which a material fractures and fragments move away from the point where the vertical force is applied; a product of high degree of hardness and low degree of cohesiveness.</td>
</tr>
<tr>
<td>Chewiness</td>
<td>The energy required to masticate a food to a state ready for swallowing; a product of hardness, cohesiveness and springiness.</td>
</tr>
<tr>
<td>Gumminess</td>
<td>The denseness which persists throughout mastication; the energy required to disintegrate a semi solid food to a state ready for swallowing; a product of a low degree of hardness and high degree of cohesiveness.</td>
</tr>
<tr>
<td>2. Geometric</td>
<td>Due to the arrangement of food constituents and related to the size and hardness, particle shape and orientation or distribution</td>
</tr>
<tr>
<td>3. Other</td>
<td>Related to the perception of fat and moisture contents of food.</td>
</tr>
</tbody>
</table>

Dough consistency and rheology have profound effects on handling properties and on the textural quality of baked products (Szczeniak, 1988). According to Tschoegl et al., (1970), it is difficult to devise a procedure to deform dough whilst it maintains a well defined geometry so that the load deformation record can be translated into stress-strain relation. Methods, however need to be established to provide additional information on the rheological properties that affect dough and baked biscuit parameters.

The General Foods Texturometer was designed based on the concept that mechanical characteristics could be measured instrumentally (Laird, 1976). Instruments such as the Stable Micro Systems Texture Analyser (TX2) and Instron Universal Testing Machine are also capable of performing texture profile analysis with the ability to control the distance and rate of depression with various probes. The instruments imitate the action of the human jaw with 2 reciprocating motions which compress bite sized food objects. Bourne (1978) stated that depression should typically be 80-90% of the food whilst the depression of the Texturometer is 75%. An initial steep rise in force indicates a rigid and non-deformable product whilst low force curves for the second pass are typical of products with low cohesiveness and springiness (Bourne, 1990).

The application of texture profile analysis (TPA) provides a complete and realistic picture of mechanical characteristics (Loh, 1985). Its application to dough may provide more detailed information on rheological parameters than obtained from farinograph or extensograph measurements. Little investigation has been carried out using TPA for wheat flour doughs (Szczeniak and Hall, 1975), however further applications may help to define dough rheology and baked biscuit quality.
A typical texture-profile curve is illustrated in Figure 2.4. Seven textural parameters are measured or calculated from the curve. Calculations of these parameters (with the exception of viscosity) are included.

Figure 2.4  Texture Profile Analysis Curve and Analysis Parameters.

<table>
<thead>
<tr>
<th>Term</th>
<th>Unit</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>g</td>
<td>F1 or H1</td>
</tr>
<tr>
<td>Fracturability</td>
<td>g</td>
<td>F1</td>
</tr>
<tr>
<td>Springiness</td>
<td>no dimensions</td>
<td>L2/L1</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>no dimensions</td>
<td>A2/A1</td>
</tr>
<tr>
<td>Gumminess</td>
<td>g</td>
<td>H1 * (A2/A1)</td>
</tr>
<tr>
<td>Chewiness</td>
<td>g</td>
<td>H1 * (A2/A1) * L2/L1</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>g mm</td>
<td>A3</td>
</tr>
<tr>
<td>Resilience</td>
<td>no dimensions</td>
<td>A5/A4</td>
</tr>
</tbody>
</table>

Penetrometers were designed to measure the firmness or yield point of solid fats and similar products under controlled and specified conditions (Bourne, 1993) and are also used to assess the strength of baked goods (Loh, 1985). Miller (1985) investigated dough penetration and concluded that the results were operator dependent and sensitive to sample preparation, dough temperature, age of dough and formulation.

Temperature is known to affect dough consistency (Tschoegl et al., 1970; Bloksma and Nieman, 1975). Miller (1985) however indicated only a slight decrease in consistency for soft wheat flour doughs when the temperature was increased from 18-30°C. Miller (1985) thought that the dough water may also have contributed to the decrease in consistency.

2.5.6.3 Biscuit Probing

Puncture tests measure the force required to push a probe into food in which the puncture force is proportional to the area and perimeter of the punch (Bourne, 1993). The peak force resistance is generally considered a measure of hardness, firmness or toughness (Brennan, 1988; Bourne, 1990; Gaines, Kassabu and Finney, 1992). The main disadvantage of biscuit probing is that hard sweet biscuits are prone to fracture and shatter under penetration. Bourne (1990, 1993) overcame this by reducing the probe diameter. Gaines et al., (1992) stated that the edge effects of biscuits probably influence the hardness of all baked products, especially the outer 15% portion of the biscuit radius, hence probing should be centred around the inner 85% of the biscuit.
2.5.6.4 Biscuit Texture Meter

The Biscuit Texture Meter was designed by the British Baking Industry Research Association to measure the hardness of cookies and crackers (Wade, 1968). Bourne (1993) and Gaines (1994) indicated good correlations of saw times with sensory rankings for hardness.
CHAPTER 3
EQUIPMENT, MATERIALS & METHODOLOGY

3.1 TEST BAKERY EQUIPMENT

Detailed specifications of the test bakery equipment are shown in Appendix 9.1.

3.1.1 Experimental Dough Mixer

The experimental dough mixer (Figure 3.1) was designed as part of an Engineering Honours thesis (Loomes, 1993) in conjunction with Arnott’s Biscuits Limited and was manufactured by the Arnott’s owned engineering company (W&B Engineering, Smithfield, Australia). The mixer was scaled down from Arnott’s 1000kg capacity dough mixers to enable the mixing of less than 1kg biscuit doughs. No other known mixer is capable of mixing biscuit doughs of this size which emulate doughs mixed in production size mixers. The mixer is driven by a single phase, 3 HP permanent magnet DC motor of 2.2kW rating.

The mixer bowl jacket is connected to a TBC Special Waterbath and Unistat II Controller manufactured by Thermoline (Smithfield, Australia). Water circulates through channels within the mixer walls via a U21 model pump manufactured by the Little Giant Co. (Okalahoma, U.S.A). The horizontal drum mixer bowl, block arm configured blade and mixer sprags are constructed in stainless steel (Figure 3.2). Three sprags are positioned in the bottom of the mixer bowl, 6mm below the mixer shaft, 4mm from the block arms and 25mm apart. There is a 1mm clearance between the
block arms and the mixer bowl. One mixer sprag was drilled through to enable the insertion of a K-type thermocouple which was connected to a Digitron datalogger (Digitron Instrumentation Limited, U.K) to record temperatures during mixing. The mixer bowl has a perspex lid which limits the volume and constrains the dough as well as allowing for visual monitoring during mixing.

**Figure 3.1** Experimental Dough Mixer and Equipment.

![Computer and Monitor](image1.png)

![Power Monitor Box and Control Panel](image2.png)

![Mixer Bowl and Motor](image3.png)
Figure 3.2  Drawing of Mixer Bowl

(a) Longitudinal Section

(b) Cross Section

Mixer Bowl

Block Arm Blade

Mixer Shaft

Thermocouple Tip

Mixer Sprag

Water Channel

Block Arm Blade

Note: Drawing Not To Scale
3.1.2 Power Monitoring

The apparatus used for recording power consumption during mixing was developed by Lothain Holdings Pty Ltd (Belrose, Australia) and consists of a power monitor with a RS232 interface, portable PC computer, power monitoring software and a current transformer (CT). A CT ratio was selected so that the maximum current into the power monitor would not exceed its limit of 5 amps. The CT was connected between the power monitor and active phase of the mixer using the same phase as the power monitor.

The power monitor continuously senses the current and voltage from the mains and samples the current from the motor. This analogue input is then processed by the power monitor. The input is connected to a COM port on the computer. Digital data is converted to real power consumed using the number of active phases, the CT ratio and loops around the CT as factors in the conversion (Lothain, 1994).

The program is capable of calculating 200 data points per second. A data input of 10 points per second was selected for all power curves. The changes in the rate of energy consumption (work done) are calculated by integrating the area under the power curve. The calculated work done is displayed live on screen.
3.1.3 Sheeting Rolls

A pilot scale sheeting roll was obtained from the Agricultural Research Institute, Wagga Wagga (N.S.W, Australia). The sheeter has 2 gear and chain driven solid steel rolls, 152mm long x 94mm in diameter. Each roll has an external heater bar in contact with the surface to heat the rolls to a desired temperature. The chain drive from the gear box to the rolls is at a ratio of 33:1. The front and hopper view of the sheeting rolls are illustrated in Figure 3.3.

Figure 3.3  Dough Sheetig Rolls.

3.3.1 Front View  3.3.2 Hopper View
3.1.4 Docker and Cutter

Dough pieces were dockered and cut using an acetal moulded docker unit and a cutter unit. The docker pins are located at clock positions 12, 2, 4, 6, 8 and 10 with an additional docker in the centre (Figure 3.4). The docker pins are 2.5mm in width and approximately 9mm apart. The docker unit also has a ‘Savoy’ emboss. Dockering and cutting were manually performed in that sequence on commercial grade woven canvas webbing (Donald Don, Wetheril Park, Australia) which was obtained from Arnott’s Biscuit Factory (Homebush, Australia).

Figure 3.4 Docker and Cutter on Canvas Webbing.
3.1.5 Oven

Dough pieces were baked in a domestic 5.7kW wall oven, manufactured by St George Ranges Pty. Ltd (Peakhurst, Australia). The internal oven cavity is 480mm wide, 405mm high and 485mm deep. Initial experimentation resulted in optimum temperature control by the installation of a Shimaden temperature controller, a circulating fan and baffle plates.

Figure 3.5 Baking Oven.
3.1.6 Biscuit Texture Meter

A B.B.I.R.A biscuit texture meter (Figure 3.6) designed by Baker Perkins (Peterborough, England) was used to measure biscuit hardness. The meter contains a 4 inch circular blade with 64 teeth and rotates at a constant speed of 15 rpm. The counter measures the time in seconds taken to make a saw cut of standard dimensions into a standard stack (50-60mm) of biscuits which are positioned in the sample holder. A circular brush is positioned behind the blade to clean accumulated biscuit crumb from the teeth which ensures consistent sawing. The blade, sample holder and brush are enclosed within a fibreglass cover with a perspex door to allow for visual monitoring during the sawing process (Wade, 1968).

Figure 3.6 Biscuit Texture Meter.
3.1.7 Texture Analyser

A Stable Micro Systems (Haste Hill, England) texture analyser (TX2) was used to measure dough and biscuit properties. The TX2 consists of an XT-RA Dimension testing machine and Texture Analyser PC Software. The TX2 consists of a 25kg moveable load cell which performs tests in compression or tension. Figure 3.7 illustrates the set up for texture profile analysis and biscuit puncture. The software enables the capturing of data at 400 points per second.

Figure 3.7 XT-TX2 Dimensions and Texture Analyser

3.7.1 TPA Set-Up. 3.7.2 Biscuit Puncture Set-Up.
<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>TYPE</th>
<th>MANUFACTURER</th>
<th>MEASURING ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td>PM11 - N</td>
<td>Mettler Toledo, AG</td>
<td>± 0.01g</td>
</tr>
<tr>
<td></td>
<td>AE 160</td>
<td>Mettler Instrumente, AG</td>
<td>± 0.001g</td>
</tr>
<tr>
<td>Thermometer</td>
<td>LCD (Digital)</td>
<td>Quartz</td>
<td>± 0.5°C</td>
</tr>
<tr>
<td></td>
<td>Rayner ST-2 (Infrared)</td>
<td>Raytek</td>
<td>± 1°C</td>
</tr>
<tr>
<td>Thermocouples</td>
<td>K-type</td>
<td>Arnott’s Biscuits Limited</td>
<td>± 1°C</td>
</tr>
<tr>
<td></td>
<td>J-type</td>
<td>Arnott’s Biscuits Limited</td>
<td>± 1°C</td>
</tr>
<tr>
<td>Biscuit Gauge</td>
<td>Rabone Chestman</td>
<td>Arnott’s Biscuits Limited</td>
<td>± 1mm</td>
</tr>
<tr>
<td></td>
<td>Vernier Callipers</td>
<td>Arnott’s Biscuits Limited</td>
<td>± 1mm</td>
</tr>
</tbody>
</table>
3.2 MATERIALS

3.2.1 Commercial Biscuit Doughs

Standard production biscuit doughs of plain sweet or cracker varieties were obtained from Arnott’s Biscuits Factory (Homebush) to be used in optimisation procedures.

3.2.2 Commercial Plain Sweet Biscuits

Standard production plain sweet biscuits were taken from the middle row of the post bake transfer web as Wade (1968) indicated that biscuit samples are most homogenous within the same row or channel. These biscuits were packaged in sealed cellophane bags and stored in a capped plastic container. These biscuits were used for development of methods for biscuit saw time and biscuit puncture.

3.2.3 Control Plain Sweet Biscuit Doughs

3.2.3.1 Ingredients

Ingredients were obtained from Arnott’s Biscuit Factory and stored in sealed plastic containers. Flour was stored in a sealed metal ingredient container capable of holding 50-75kg. All ingredients were tested prior to use, to ensure compliance with ingredient standards (Appendix 9.2). Fresh flour and ingredients were obtained during the course of the experimentation and were used only if they complied with the standards.

An improved version of polydextrose (Litesse™) was supplied by Pfizer Food Science (West Ryde, Australia). The specification for this ingredient is listed in Appendix 9.2.
3.2.3.2 Control Formulations

3.2.3.2.1 Plain Sweet (PS) Control

The recipe for a commercial plain sweet biscuit dough was modified so that the energy contributions from sugar and fat complied with the NH&MRC dietary targets (English, 1987). This formula is referred to as the PS Control and was used to determine the maximum reductions of sugar and fat (alone and in combination) using equal weight replacements of wheat starch (Chapter 5). The formulation is listed in Table 3.2.

Based on the PS Control, the maximised reductions of both sugar and fat were intended to be used as the control for polydextrose experimentation. Due to the high wheat starch content, discrimination between doughs with and without polydextrose addition was difficult. Therefore, the test bake formula (3.2.3.2.2) was selected.

3.2.3.2.2 Test Bake (TB) Control

A commercial plain sweet biscuit dough was optimised for test baking to allow discrimination between low protein flour varieties. The optimised procedure is summarised in Table 3.2 allowing comparison with the PS Control. The test bake formula (TB Control) was used to determine the functionality of polydextrose as a sugar and as a fat replacer (Chapter 6). The formula is listed in Table 3.2.

3.2.3.2.3 Polydextrose (PD) Control

The TB Control containing 100% polydextrose in replacement of sugar was used for assessing the fat sparing properties of polydextrose. This formula is referred to as the PD Control and is listed in Table 3.2.
<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Supplier</th>
<th>Weight (g)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour (7.5% protein, 12.0% moisture)</td>
<td>Defiance Mills</td>
<td>281.5</td>
<td>290.0</td>
<td>290.0</td>
<td></td>
</tr>
<tr>
<td>Vegetable Shortening</td>
<td>Meadow Lea</td>
<td>75.0</td>
<td>40.0</td>
<td>40.0</td>
<td></td>
</tr>
<tr>
<td>Icing sugar (3% wheat starch)</td>
<td>Manildra</td>
<td>60.0</td>
<td>60.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Invert Syrup (75% solids)</td>
<td>C.S.R</td>
<td>14.0</td>
<td>20.0</td>
<td>20.0</td>
<td></td>
</tr>
<tr>
<td>Golden Syrup (80% solids)</td>
<td>C.S.R</td>
<td>7.5</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Wheat Starch</td>
<td>N.B Love</td>
<td>9.5</td>
<td>10.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Full Cream Milk Powder</td>
<td>Bonlac</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>Chetham</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Ammonium Bicarbonate</td>
<td>Redox Chemicals</td>
<td>2.6</td>
<td>3.9</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>Sodium Bicarbonate</td>
<td>Redox Chemicals</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Sodium Metabisulphite</td>
<td>Redox Chemicals</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Domestic Supply</td>
<td>50.0</td>
<td>70.0</td>
<td>70.0</td>
<td></td>
</tr>
<tr>
<td>Polydextrose</td>
<td>Pfizer Food Science</td>
<td>0.0</td>
<td>0.0</td>
<td>60.0</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Total Mix Weight                         | 505.39            | 499.19     | 499.19   |          |</p>
<table>
<thead>
<tr>
<th>Manufacturing Procedure</th>
<th>PS Control</th>
<th>TB Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mixer</strong></td>
<td>Waterbath Temperature</td>
<td>38°C</td>
</tr>
<tr>
<td><strong>Mixing Procedure</strong></td>
<td>Preblend dry ingredients</td>
<td>Slow Speed mixing, 60rpm for 60 sec.</td>
</tr>
<tr>
<td></td>
<td>Combine all ingredients</td>
<td>High Speed mixing, 120rpm.</td>
</tr>
<tr>
<td></td>
<td>Final Dough Temperature</td>
<td>38-39°C</td>
</tr>
<tr>
<td><strong>Stand Time</strong></td>
<td>30 minutes</td>
<td>In insulated foam box.</td>
</tr>
<tr>
<td><strong>Sheeting Rollers</strong></td>
<td>Temperature</td>
<td>30 ± 2°C</td>
</tr>
<tr>
<td></td>
<td>Roller Speed</td>
<td>10 rpm</td>
</tr>
<tr>
<td></td>
<td>Reduction Gaps</td>
<td>7.5 (lap), 3.1, 1.7mm</td>
</tr>
<tr>
<td></td>
<td>Reduction Ratios</td>
<td>2.4, 1.8</td>
</tr>
<tr>
<td><strong>Baking</strong></td>
<td>Fan</td>
<td>On</td>
</tr>
<tr>
<td></td>
<td>Oven Temperature</td>
<td>180 ± 1°C</td>
</tr>
<tr>
<td></td>
<td>Baking Tray</td>
<td>Aluminium Baking Tray</td>
</tr>
<tr>
<td></td>
<td>Baking Time</td>
<td>13 minutes</td>
</tr>
</tbody>
</table>
3.3 METHODOLOGY

3.3.1 Equipment Preparation

Before commencement of experimentation, the mixer bowl waterbath, sheeting rolls and oven were heated to operating temperature to ensure standard operating procedures.

3.3.2 Dough Mixing

Flour was added to the mixer bowl first. Sodium metabisulphite, ammonium bicarbonate and sodium bicarbonate were dissolved in a portion of the dough water and added to the flour. All remaining ingredients were added into the mixer bowl and the lid replaced. All doughs were mixed on slow speed (60rpm). At 60 seconds, mixing was stopped and the dough was scraped from within the block arms and between the mixer sprags using a plastic spatula. After the lid was re-secured, mixing was recommenced on high speed (120rpm). Mixing was stopped when the final dough temperature reached 38-39°C and the dough was of standard consistency when assessed (pulled and stretched) by hand and as indicated by the shape of the power curve and final consistency. After mixing, the bowl was filled and cleaned by mixing 600mls of warm water at 200rpm for 2-3 minutes.

3.3.3 Power Monitoring

Baselines and dough mixings were measured in triplicate on consecutive days (6 replicates). A baseline corrected power curve was obtained by subtracting the average
baseline from the average mixing curve. Dough strength, consistency and elasticity were interpreted from the power consumption and bandwidth of the corrected power curves.

3.3.4. Dough Relaxation (Stand Time)

After mixing, the dough was placed into a plastic bag, gently moulded into a sausage shape (150mm long x 100mm diameter), wrapped in a tea-towel and stored in an insulated foam box to allow the dough to relax. The dough stand time was 30 minutes.

3.3.5 Dough Sheeting

The sausage shaped dough was placed into the hopper across the length of the rolls. After the first roll reduction through a 7.5mm gap, the dough was lapped (both ends folded towards the centre) and re-rolled across the machine direction. The dough sheet was then cut into two shorter sheets to facilitate ease of handling. Sequentially, both dough sheets were passed through gap setting 2.4mm and then 1.7mm.

For select experiments, the length of the dough sheet after each pass was observed for the resistance to sheeting extension and the degree of dough toughness and elasticity. Sheet reductions were held constant so that differences in dough rheology could be directly related to the dough formulation. A flow chart of the sheeting procedure is shown in Figure 3.8.1-3.8.6.
Figure 3.8  
Flow Chart for Dough Sheeting Procedure.

1. Dough in sausage form after stand time.  
2. First reduction through setting at 7.5mm.  
3. Lapping.  
4. Sheeting lapped dough through 7.5mm gap.  
5. Dough sheet cut in half across sheeting direction.  
6. Sheeting through 3.1mm gap.  
7. Sheeting through 1.7mm gap, with dough piece cut.  
8. Dockered and cut dough piece.  
3.3.6 Dockering and Cutting

After sheeting, the dough sheets were placed on the woven canvas cutting web. Ten dough pieces were manually dockered then cut from each dough sheet and weighed prior to baking. The end dough pieces were excluded due to the variation in weight. Dimensions of a single dough piece was measured from each sheet. Twenty five cut dough pieces were placed diagonally on the baking tray as illustrated in Figure 3.8.6. Raw dough weights (of 10 dockered and cut dough pieces) were measured prior to baking.

For select experiments, the degree of elasticity was determined by the dough spring back in which the height of the dough piece was divided by the final gauge gap, using the following formula.

\[
\text{Dough spring back} = \frac{h}{1.7}
\]

where; \( h \) = average dough piece height

Dough density was calculated using the formula;

\[
d = \frac{m}{v}
\]

where; \( m \) = mass of one dough piece
\( v \) = volume of one dough piece = \( l \times s \times h \times a \)

where, \( l \) = short diameter
\( s \) = long diameter
\( h \) = height
\( a \) = area constant 0.7854
3.3.7 Baking

The baking tray was placed directly onto the aluminium sheet on the centre shelf of the oven. Bake time was determined by degree of checking and reference to sensory assessments using an expert panel of three Arnott's employees. After baking, biscuits were allowed to equilibrate to room temperature which limited checking.

3.3.8 Biscuit Storage

Biscuits were sealed in cellophane bags and stored at room temperature in a capped plastic container for 6-8 days prior to texture and sensory assessments being conducted.

3.3.9 Biscuit Assessments

3.3.9.1 Moisture Loss

The difference between the raw dough weight and baked dough weight was used as an indicator of moisture removal from the dough pieces during baking. Mowbray (1994) indicated that subtracting the raw and baked weights throughout the baking process produced an accurate profile of the process of water removal.

3.3.9.2 Packet Length

Ten biscuits were positioned facing the same direction on the biscuit gauge and the slide moved to apply a small amount of pressure to the biscuits. The packet length of the biscuits was measured (± 1mm) from each dough sheet. For each formulation, the average of 12 packet lengths was reported.
3.3.9.3 Biscuit Dimensions

Dimensions for all biscuits were measured using vernier callipers across and with the direction of sheeting. The reported biscuit dimensions were obtained from the average of all biscuits from the same experiment. Biscuit densities were calculated for select experiments using the formula listed in 3.3.6.

3.3.9.4 Checking

All biscuits were visually assessed for the presence of cracks (checks) across the biscuit surface. The biscuit was held between the hands using index fingers and thumbs only. Using an even amount of pressure, the biscuit was gently pulled. Biscuits which separated on the pull were classified as checked. The number of checked biscuits was calculated and reported as an average % for each experiment set.

3.3.9.5 Biscuit Texture Meter

The texture meter was used to assess biscuit hardness and evaluate the effectiveness of the optimisation process. Biscuits fitting within a 5-6cm stack height were positioned in the sample holder of the texture meter.

3.3.9.6 Sensory Assessment

Biscuits from each formulation were assessed by an expert panel of three Arnott’s employees. Biscuits were assessed for appearance (sheen and colour), taste (foreign and aftertaste), texture (hardness, dryness, gumminess) and overall acceptability.
3.3.10 Energy Contributions

Energy contributions were calculated from the biscuit formula compensated for moisture loss during baking. Energy values for sugar and fat were used according to Standard R2 of the Australian Food Standards Code (Australian Food Standards Code, 1992).
CHAPTER 4
DEVELOPMENT AND OPTIMISATION OF PLAIN SWEET DOUGH AND BISCUIT PRODUCTION

4.1 INTRODUCTION

Plain sweet biscuit doughs generally require prolonged and intense mixing procedures. Critical dough parameters used as indicators of dough quality include dough water addition, total work input and final dough temperature (Wade et al., 1969; Wade, 1971a).

After mixing and sufficient stand time for dough relaxation, plain sweet biscuit doughs are passed through at least three sheeting roll reductions with reduction ratios between 1.0 and 2.5 (Levine and Drew, 1994). Excessive stress on the dough from either mixing or sheeting, is detrimental to the alignment of the gluten within the dough structure and consequently the appearance, shape and texture of the resultant biscuit (Levine and Drew, 1994).

The aim of this work was to develop and optimise procedures and conditions for plain sweet dough and biscuit production in the Arnott’s laboratory scale test bakery.
4.2 EXPERIMENTATION

The equipment in the Arnott's laboratory scale test bakery had never been used in combination to produce a biscuit dough or baked biscuit. The optimisation process involved the investigation of each piece of equipment to develop procedures which ensured consistent and reproducible results, and compared favourably with plain sweet biscuits made in production. The order of testing was reversed from biscuit manufacturing procedures to ensure complete optimisation and eliminate any synergistic effects. Once optimised, the procedure for manufacturing doughs and biscuits was evaluated using the PS Control. The flow charts below summarise the optimisation procedure followed for each piece of equipment and the optimised end result.

**Figure 4.1 Flow Chart of Experimental Procedure**

**Biscuit Texture Meter (4.2.1):** Biscuit saw times tested day 0 - day 30 for optimum storage time → Optimum 6-8 days

**Oven (4.2.2):**
- Measure temperature variability → Insert baffle sheets → Install Shimaden controller → Baking 200°C teflon tray → Poor temp. & checking
- Unacceptable → Fan Off → Baking 200°C teflon tray → Remove grill tray → Install circulating fan
- Poor baking tray buckles checking → Fan On
- Modified baffle plates → Baking 180°C aluminium tray → Optimum bake time 13 minutes at 180°C
Sheeting Rollers (4.2.3):

3 reductions
gap settings
7.5, 2.4, 1.7mm
16 rpm

→ Rough, poor sheet
→ Lapping 7.5mm
→ Smoother sheet, oval biscuit

Unacceptable

→ 12 rpm

Greatest packet length, softest texture

→ Increase in packet length, oval biscuits

→ Sheeting reduction 7.5, 3.1, 1.7mm

Optimised
7.5 (lap), 3.1, 1.7mm
10 rpm

Mixer (4.2.4):

Baselines

Dry → Unacceptable

Water → Clean → Consistent baselines

Water → Dirty → Unacceptable

Cracker Dough Mass

→ 200 - 700 g

→ 500g optimum

Water Bath

Water bath temp. 33, 35, 37, 39, 41°C
Dough temp. 40-42°C

Water bath 37°C

Mix to dough temp. 39 - 41°C

Water bath 39°C

Optimised dough temp. 38 - 39°C
Optimised water bath temp. 38°C

Mixer Speeds

→ 60 - 240 rpm
Dough temp. 38-39°C

Similar packet length

→ Optimum mixing procedure
60 rpm slow
120 rpm high
Figure 4.1  Flow Chart of Experimental Procedure (Continued)

PS Control (4.2.5): Mix Size

- 600g → Unacceptable
- 500g → Optimise water & MBS addition → PS Control formulation

Optimised sheeting
7.5 (Lap), 3.1, 1.7mm
10rpm

Slow speed 60rpm
high speed 120rpm
dough temp. 38-39°C

Optimised water bath temp. at 38°C

Optimised baking
180°C for 13 min.
on aluminium tray → Optimised PS Control biscuits
4.2.1 Biscuit Texture Meter

4.2.1.1 Saw Time Measurements

To determine the appropriate storage time for measuring of biscuit saw times, approximately 500 commercial plain sweet biscuits were obtained from the middle row of the transfer web prior to packaging. When cooled, biscuits were divided amongst 13 sealed cellophane bags, each containing 40 biscuits, and stored in a capped plastic container.

Biscuits were tested 3 hours after sampling and then on days 1, 2, 3, 6, 7, 8, 9, 10, 20 and 30. On each test day, 6 biscuit saw times were taken using biscuits from a single cellophane bag. The average, range and standard deviation was reported for each of the 11 test dates.

4.2.2 Oven

4.2.2.1 Temperature Variability

To produce a constant temperature chamber for baking, temperature profiles were measured throughout the oven cavity using K type thermocouples which were supported by the top oven rack. The thermocouple tip was suspended downward, at various positions, approximately 50mm above the centre oven rack to determine the degree of variability around the baking dough pieces.
4.2.2.2 Baking Conditions

To assess baking efficiency and performance of the oven, dough pieces were baked on a teflon coated, non stick tin baking tray (375 x 255 x 1 x 17mm high) and an aluminium baking tray (300 x 280 x 1.5 x 7mm high). Dough pieces were baked at 180°C for 13 minutes and 200°C for 10 minutes. The baking tray was positioned centrally, directly on the baffle plates. The observations made under these conditions were used to make alterations to further optimise the oven and baking efficiency.

4.2.3 Sheeting Rolls

4.2.3.1 Sheeting Reductions

To determine the optimum sheeting procedure for plain sweet biscuit dough, the dough was passed through the rollers 3 times with reduction ratios between 1 and 4. The roller temperature was maintained at 30±2°C. The roller speed was initially set at 16rpm. The procedure was optimised when the dough sheet was smooth and elastic, and biscuits were of consistent dimensions with a firm to moderate bite and slight surface sheen. As the biscuits were out of shape, roll speeds were adjusted (4.2.3.2).

4.2.3.2 Roll Speeds

In an attempt to produce more rounded biscuits, dough was sheeted at roll speeds 12rpm and 10rpm. Dough and biscuit dimensions, packet length, hardness and appearance were used to evaluate the effect of the reduced roll speed.
4.2.4 Experimental Dough Mixer

4.2.4.1 Baseline Optimisation

To determine the optimum method for ensuring consistent baselines, power curves were recorded during mixing with and without water, in a cleaned and uncleaned mixer. The average and standard deviation of 5 replicates were reported.

4.2.4.2 Dough Mass Optimisation

To determine the optimum dough mass to be accommodated by the mixer, 200-700g of commercial cracker doughs were re-mixed at 120rpm. Torque, power and mixing action were visually monitored to determine the most appropriate dough weight.

4.2.4.3 Water Bath Temperature Optimisation

This set of experiments was to determine an ideal water bath temperature which resulted in best quality dough and biscuits. Water bath temperatures were assessed at 33-41°C with 2 degree increments. The PS Control formula was standardised to 500g (4.3.4.2). All ingredients were added to the mixer bowl in a one stage process and mixed for 2 minutes on slow speed (60rpm), and 6 minutes on high speed (120rpm) to 40-42°C. Dough and biscuit parameters were evaluated for optimum development.

4.2.4.4 Final Dough Temperature Optimisation

Using the optimum water bath temperature (4.3.4.3), mixing times were altered to determine the optimum final dough temperature and mixing time.
4.2.4.5 Mixing Procedure Optimisation

PS Control doughs were mixed at constant slow and high speeds from 60rpm to 240rpm to the optimum final dough temperature (4.3.4.4). Dough and biscuit parameters were measured to determine the optimum mixing procedure.

4.2.5 PS Control Dough Formulation Optimisation

4.2.5.1 Mix Size

To determine the most appropriate dough mass, 500g and 600g of the PS Control formulation were produced. Both doughs were assessed during mixing by observation of the mixing action and the dough consistency as interpreted from the power curves. Torque was monitored visually during mixing.

4.2.5.2 Water and Sodium Metabisulphite Additions

Based on the PS Control dough mass of 500g, dough water and sodium metabisulphite addition were varied at ±10% of the PS Control level to determine optimum additions. Doughs were assessed for mixing performance and power consumption, whilst baked biscuits were assessed on biscuit height and packet length.

4.2.5.3 Dough Mixing

Based on the 4.3.5.2, mixing speeds and times were determined. Biscuits were assessed on biscuit height, packet length and saw time.
4.2.5.4 Dough Sheeting

Dough produced using the optimised mixing procedure (4.3.5.3), was sheeted using the optimised gap settings and roll speed. Dough pieces were evaluated for spring back and dimensions. Biscuit dimensions were assessed for the degree of roundness.

4.2.5.5 Baking

Dough pieces were produced from the optimised mixing and sheeting procedures. During baking, a K-type thermocouple measured the dough piece temperature to determine the optimum bake time for the PS Control.

4.2.6 Evaluation of the Optimised Procedure and Results

Using the optimised procedure (4.3.5), the PS Control was mixed in triplicate on consecutive days (6 replicates). Power requirements, rheological dough properties and biscuit parameters were evaluated.
4.3 RESULTS AND DISCUSSION

4.3.1 Biscuit Texture Meter

As listed in Table 4.1, the time taken to saw through a stack of plain sweet biscuits was relatively constant over the 30 day period, only increasing from 20 to 23 seconds. As the saw times were so consistent, the saw time range and standard deviations were used to determine the appropriate storage time for saw time measurements.

Table 4.1  Average Saw Times, Range and Standard Deviations for Plain Sweet Biscuits over a 30 Day Period.

<table>
<thead>
<tr>
<th>Biscuit Age (Days)</th>
<th>Average Saw Time (Seconds)</th>
<th>Saw Time Range (Seconds)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 hours</td>
<td>20</td>
<td>15 - 23</td>
<td>3.54</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>15 - 23</td>
<td>3.13</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>18 - 22</td>
<td>1.64</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>20 - 23</td>
<td>1.10</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>20 - 23</td>
<td>1.03</td>
</tr>
<tr>
<td>7</td>
<td>22</td>
<td>20 - 23</td>
<td>1.21</td>
</tr>
<tr>
<td>8</td>
<td>22</td>
<td>21 - 23</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>22</td>
<td>19 - 24</td>
<td>1.64</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
<td>20 - 24</td>
<td>1.55</td>
</tr>
<tr>
<td>20</td>
<td>23</td>
<td>22 - 23</td>
<td>0.55</td>
</tr>
<tr>
<td>30</td>
<td>22</td>
<td>17 - 23</td>
<td>2.42</td>
</tr>
</tbody>
</table>
Least variability in saw time range and standard deviation was observed at day 20, but allowing this length of storage time was impractical. The variation in saw time range decreased over time (Table 4.1) with days 3 to 9 sharing a consistently low range of not greater than 3 seconds. Standard deviations were also consistently low at days 3, 6, 7 and 8 (Table 4.1). As the saw time at 3 days storage had increased from 21 (at day 2) to 22 seconds, and the effect of days 4 and 5 were not known, day 3 was not considered an optimum storage time for biscuits.

The most consistent saw time results were observed at days 6, 7 and 8. This provided an opportunity to alter storage time without affecting saw time results during experimentation. Therefore, a storage time of 6-8 days was considered optimum for consistent saw time measurements with day 7 preferred to ensure complete standardisation of the procedure.

Since saw times correlate well with sensory hardness (Bourne, 1993; Gaines, 1994), variation in saw time determined by variation in product formulation and procedures can be presumed to affect sensory hardness.
4.3.2 Oven

4.3.2.1 Temperature Variability

Temperature profiles recorded at the centre of the oven set at 180°C showed a temperature variation of 8°C in 8 minute cycles. Introduction of baffle plates can increase heating efficiency as stated by Pyler (1988). Two (aluminium) baffle plates (451 x 421 x 5mm) were therefore selected for their thermal properties and ability to increase heat mass and decrease temperature variation. The baffle plates were placed together on the centre oven rack. The grill tray was inserted into the bottom shelf and an additional oven rack placed on the top shelf. Temperature profiles of this configuration revealed a 5°C variation in temperature with a 7 minute cycling time. Hence the baffle plates and grill tray affected a 3°C reduction in temperature variation and a 1 minute reduction in cycling time.

As the temperature variation was still quite large at the centre of the oven (5°C), it was decided to select a more precise temperature controller and sensor to be positioned in the centre of the oven. Therefore the oven thermostat and sensor were disconnected and replaced with a J-type thermocouple attached to a Shimaden temperature controller. The J-type was selected because it had a greater emf response per change in degree Celsius, providing greater sensitivity. The thermocouple was supported by the top oven rack and was suspended downwards, 50mm above the baking surface.

To determine the effect of the Shimaden controller and J-type thermocouple in measuring temperature, a K-type thermocouple (connected to a Digitron datalogger)
was positioned 20mm in front of the J-type thermocouple. Both thermocouples were base tipped, resulting in more rapid temperature response. Profiles from the centre of the oven using the Shimaden controller and J-type thermocouple revealed a 4°C (179-183°C) variation with 5.5 minute cycles. A 14°C variation throughout the oven cavity was observed with the front right corner approximately 11°C cooler than the back left corner (Figure 4.2). Despite the decrease in cycling time, the temperature variation was still large throughout the entire baking chamber. The chamber however was more constant than the initial, unmodified oven, due to the increase in heat mass from the baffle plates and the greater precision in temperature control.

**Figure 4.2** Temperature Profile Within the Oven Cavity set at 180°C  
(using the Shimaden Temperature controller and sensor)

![Temperature Profile](image)

Note: the oven contained 2 baffle plates and a grill tray.
4.3.2.2 Optimum Baking Conditions

Once the temperature profile of the oven was established (4.3.2.1), commercial plain sweet dough was baked at 200°C for 10 minutes to assess baking efficiency and performance. As illustrated in Figure 4.3 (Fan Off), biscuits did not reach their preset temperature during baking. This was due to the slow rate of air flow and heat transfer within the oven due to the passive convection. The inefficiency of baking and product drying was also evidenced by a high percentage of checking within 24 hours of baking.

Therefore, to increase air flow and rate of heat transfer, a 150mm circulating fan was installed into the back left corner of the oven, 30mm from the left and 10mm from the bottom. The grill tray was removed as it stopped the motion of the fan. Commercial plain sweet dough pieces were then baked with the fan on. As illustrated in Figure 4.3 (Fan On), this resulted in a substantial increase in temperature rise when compared with baking without the fan.

Figure 4.3 Temperature Profile during Baking Plain Sweet Biscuit Dough at 200°C With and Without a Circulating Fan.

Note: the large temperature drops indicate when biscuits were placed into or removed from the oven.
As expected, the forced convection increased the rate of heat transfer into the dough as reported by Miller (1982) and Pyler (1988). The oven reached its present temperature within 6 minutes, compared to greater than 10 minutes without the fan. Therefore due to the installation of the fan, baking process efficiency improved substantially.

During baking, the teflon coated tray buckled, with the opposing corners lifting off the baffle plates. Subsequently the biscuits baked on this tray showed 45% checking, 24 hours after baking. Checking was postulated to be due to the combined effect of the tray buckling, short exposure to excessive heat and thermal shock from exposure to cool air after baking. According to Manley (1991), these factors contribute to the build up of stress from the shrinkage of starch which is relieved by the exterior of the biscuit cracking.

Before checking was addressed, the function of the baffle plates was re-evaluated in the forced convection oven at 180°C. Experiments with no, 1, 2 and 3 plates revealed that 1 baffle plate on the centre shelf and a smaller aluminium sheet (375 x 80 x 1mm) placed at the back of the oven on the top oven rack (to direct air flow), produced the smallest temperature variation and reduced cycling time when compared to 3, 2 or no sheets. Temperature profiling was measured with these modifications to the baffle plates.

Temperature profiles (Figure 4.4) indicated that the centre temperature maintained a 4°C variation but was 178-182°C instead of 179-183°C without the fan and additional sheets. The temperature in the front right position increased from 174-178°C to 178-
182°C, whilst the back left corner decreased from 184-187°C to 181-184°C. The range of temperature variation in the forced convection chamber was 6°C with cycling time less than 3 per minute compared to the initial temperature variation of 14°C with 5.5 minute cycles (Figure 4.2). This further improvement in temperature variation was attributed to alteration to the baffle plates, and efficiency of the circulating fan and controller.

**Figure 4.4**  Temperature Profile Within the Oven Cavity set at 180°C with the Circulating Fan On.

![Temperature Profile Graph](image)

Note: 1 baffle plate at the centre of the oven with a smaller aluminium sheet at the on the top shelf positioned at the back to direct air flow.

To reduce the contributing conditions for checking, the teflon coated baking tray was replaced with an aluminium baking tray (300 x 280 x 1.5mm). The front of the tray had a 7mm lip facing downwards which lifted the front of the tray from the baking surface. The oven temperature for baking was reduced to 180°C (to slow the baking process) and a series of dough pieces baked from 4 - 18 minutes. Dough pieces were
removed at 2 minute intervals and moisture loss, packet length and biscuit hardness recorded.

As illustrated in Figure 4.5, there was an almost linear increase in moisture loss during baking. After 14 minutes, the rate of moisture loss declined as biscuits began to lose bound water. This implied that the biscuits were in the final stage of baking as described by Manley (1991). Packet length peaked at 6 minutes, as the dough structure set whilst saw times were greatest at 10 minutes. After 12 minutes baking, the time taken to saw through the stack of biscuits remained constant (Figure 4.5).

**Figure 4.5**  **Moisture Loss, Packet Length and Saw Times during Baking**

Plain Sweet Biscuit Doughs at 180°C.

![Graph showing moisture loss, packet length, and saw time over bake time](image)

Based on the textural and sensory assessments, bake time for the plain sweet biscuit dough was determined to be 13 minutes. At this time, the biscuits were evenly baked as indicated by optimum bake colour, flavour development and the absence of checking. Allowing the biscuits to cool completely on the baking tray before storage ensured slow temperature equilibration which further reduced checking.
4.3.2.3 Oven Summary and Conclusion

The oven modifications consisted of the inclusion of a baffle plate, an aluminium sheet to direct air flow, a temperature controller and sensor and a circulating fan. With the Shimaden temperature controller set at 180±1°C, the temperature variation throughout the entire oven was 178 - 184°C.

The installation of the fan effectively improved baking efficiency. Biscuit checking reduced due to the constant temperature rise and rate of moisture removal as illustrated in Figure 4.4. Baking on the aluminium baking tray improved this process, compared to the teflon coated tin tray which buckled during baking.

A temperature chamber was produced which allowed for relatively precise control and monitoring of the oven temperature. This resulted in the optimised conditions for baking the PS Control biscuits being 13 minutes at 180°C.
4.3.3 Sheeting Rolls

4.3.3.1 Gap Settings

Initial gap settings were based on the sheet thickness of commercial plain sweet biscuit dough and were 7.5, 2.4 and 1.7mm (reduction ratio of 3.1 and 1.4). Dough pieces baked using these reductions and an arbitrary roller speed of 16rpm, produced biscuits with a dull and irregular surface. Therefore the second gap was increased one setting to a 3.1mm gap. This altered the reduction ratios to 2.4 and 1.8.

Biscuits baked from doughs passed through these gap settings increased 3.2mm in packet length. This was due to the sheeting reduction following the recommendations of Levine and Drew (1994). Almond (1989), Faridi and Faubion (1994) and Levine and Drew (1994) associated altered gap settings with changes in extensibility where too great a reduction alters the gluten network and results in permanent distortion of the dough sheet. The dough sheet however was still not as smooth as commercial dough.

Therefore, to produce a smoother dough sheet surface, the dough was lapped and re-rolled though the first gap setting (Figure 3.8). According to Levine and Drew (1994), lapping enables uniform distribution of stresses in all directions and results in a smoother dough sheet when compared with unlapped doughs. Lapping also allows the dough to relax. This may have accounted for the dough contraction in the lapped dough prior to cutting. The dough sheet was significantly smoother after lapping.
Therefore, sheeting reductions were considered optimised at 7.5mm (with lapping), 3.1mm and 1.7mm with reduction ratios 2.4 and 1.8 respectively. The resultant biscuits however were slightly oval with a dull and rough surface hence roll speeds were reduced for further investigation.

### 4.3.3.2 Roll Speeds

The roll speed was reduced to 12rpm and 10rpm which was the slowest speed achievable. Dough pieces sheeted at 10rpm had the greatest recovery as indicated by the increase in raw dough weight (Table 4.2). This implies optimum gluten development as indicated by the increased dough elasticity, biscuit height and packet length and decreased saw time when compared to 12 or 16rpm (Table 4.2).

<table>
<thead>
<tr>
<th>Dough and Biscuit Parameters</th>
<th>10 rpm</th>
<th>Roll Speed</th>
<th>12 rpm</th>
<th>16 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>77.9</td>
<td>76.1</td>
<td>75.8</td>
<td></td>
</tr>
<tr>
<td>Biscuit Dimensions (mm)</td>
<td>52.2 x 49.7</td>
<td>51.9 x 49.8</td>
<td>52.4 x 48.7</td>
<td></td>
</tr>
<tr>
<td>Biscuit Height (mm)</td>
<td>7.2</td>
<td>6.8</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>74.7</td>
<td>70.8</td>
<td>71.3</td>
<td></td>
</tr>
<tr>
<td>Saw Time (Sec.)</td>
<td>55</td>
<td>60</td>
<td>58</td>
<td></td>
</tr>
</tbody>
</table>

Biscuits produced from a roll speed of 16rpm were more oval than biscuits produced at 12rpm or 10rpm (Table 4.3). There were no differences in biscuit dimensions between 10rpm and 12rpm. The biscuits rolled at 10rpm had the greatest packet length, and were the least hard. Therefore, a roll speed of 10rpm was determined to produce optimum results.
4.3.3.3 Sheeting Roll Summary and Conclusion

It was therefore concluded that a roll speed of 10rpm was optimum for gluten development, facilitating greater recovery after sheeting and resulting in a more tender baked product. This is in agreement with Levine and Drew (1994) who stated that specific volume and textural properties of finished products are controlled by shear and or stretching of the dough during rolling. Therefore, a roll speed of 10rpm with sheeting reductions of 7.5mm with lapping, 3.1mm and 1.7mm was adopted as the standard sheeting procedure for these studies.
4.3.4 Experimental Dough Mixer

4.3.4.1 Baselines

Prior to dough mixing, it was important to determine a method for producing consistently low and reproducible baselines. Due to the construction of the mixer bowl, it was not possible to remove the shaft for cleaning. This resulted in dough particles remaining on and between the shaft and bowl wall. When dry, these particles increased mixing resistance and baseline power. Therefore baselines were measured with the mixer dry and filled with 600ml of water.

Baselines were measured prior to and after mixing, when the bowl had been thoroughly cleaned and dried. The results for power consumption and energy are shown in Table 4.3. In a cleaned mixer bowl, the average power was 47.1W (which was calculated from the average data points at each speed). The standard deviation of this power (taken from the band width) decreased significantly when the bowl was cleaned (Table 4.3). Therefore, cleaning the mixer bowl effectively immobilised solid dough particles and produced consistently low baseline measurements. Baselines were conducted in this manner throughout the thesis.

Table 4.3  Power and Energy Recorded for Baseline Measurements in an Empty Uncleaned and Cleaned Mixer Bowl.

<table>
<thead>
<tr>
<th>Mixer Condition</th>
<th>Slow Speed (60rpm)</th>
<th></th>
<th>High Speed (120rpm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Cleaned</td>
<td>45.07</td>
<td>3.18</td>
<td>2.73</td>
<td>48.31</td>
</tr>
<tr>
<td>Cleaned</td>
<td>46.58</td>
<td>1.71</td>
<td>2.81</td>
<td>47.17</td>
</tr>
</tbody>
</table>
4.3.4.2 Dough Mass

A high protein cracker dough was selected because it was tougher than the plain sweet dough. If the mixer could effectively manage the cracker dough, then it was anticipated that the plain sweet dough would not exceed the limits of the motor. Mixing results for the 200g-700g doughs indicated that the 500g mass covered the mixer shaft and allowed for sufficient mixing action while producing intermediate power and torque. Cracker dough weights greater than 600g exceeded the 12Nm torque limit of the motor which resulted in the motor tripping out on overload. Doughs less than 400g were inadequately mixed.

4.3.4.3 Water Bath Temperatures

Results for dough and biscuit parameters are listed in Table 4.4 for water bath temperatures 33-41°C. Based on the results, doughs mixed whilst the water bath was at 37°C and 39°C were considered optimum for all parameters, especially packet length. Therefore additional mixing experimentation was conducted at these water bath temperatures, whilst determining the optimum final dough temperature.

Table 4.4 Effect of Water Bath Temperature on Dough and Biscuit Parameters.

<table>
<thead>
<tr>
<th>Dough and Biscuit Parameters</th>
<th>Waterbath Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32°C</td>
</tr>
<tr>
<td>Raw Dough Weight (g)</td>
<td>66.5</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>55.4</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>57.0</td>
</tr>
<tr>
<td>Saw Time (sec)</td>
<td>41</td>
</tr>
</tbody>
</table>
4.3.4.4 Final Dough Temperature Optimisation

As illustrated in Figure 4.6, a reduction in the final dough temperature increased biscuit height and packet length and produced biscuits closer to optimum. When the final dough temperature was 39°C, irrespective of the water bath temperature or mixing time, packet length increased to 60mm. This indicated that 40-42°C was too hot for the PS Control. Manley (1991) also discovered this temperature effect in small scale mixers, whilst Wade et al., (1969) reported that final dough temperature affects packet length and baked biscuit quality.

**Figure 4.6  Effect of Water Bath Temperature on Final Dough Temperature and Packet Length.**

Doughs mixed to 40-42°C produced an extensible and elastic mass which was similar in consistency to commercial plain sweet doughs. It was postulated however that the additional work from the sheeting rollers overworked the dough, resulting in the observed reduction in packet length. Based on the similarity of results at water bath temperatures 37 and 39°C, the water bath was set at 38°C and doughs were mixed to a final dough temperature of 38-39°C for optimum packet length and baked biscuit
texture. Wade (1965) also found it necessary to adjust the water bath temperature close to the final dough temperature to ensure adequate heat transfer into the dough. In experiments using a laboratory scale Morton mixer, Wade (1970) also mixed plain sweet biscuit doughs to 39.4°C.

Therefore the experimental dough mixer water bath was set at 38°C and PS Control doughs mixed to an optimum dough temperature of 38-39°C. This procedure was considered optimum and was adopted as the standard mixing conditions for the PS Control dough and experimental formulations.

4.3.4.5 Mixer Speeds

A series of PS Control doughs were mixed at speeds 60rpm to 240 rpm to a final dough temperature of 38-39°C. This resulted in all packet lengths being similar irrespective of the mixer speed. This was due to the doughs being mixed to a constant dough temperature which Wade et al., (1969) documented to be the most important parameter in dough mixing. Therefore, an optimum mixing procedure had to be determined.

As the slowest speed of the experimental dough mixer was 60rpm, this was taken as the slow speed setting. Ingredients were mixed on slow speed for 60 seconds which allowed sufficient time for producing a homogenised mass. In commercial situations, high speed mixing increases by a factor of 2, hence high speed was set at 120rpm. Mixing to optimum temperature (38-39°C) was achieved in 4 minutes at 120rpm. Therefore the total mixing time for the PS Control using this procedure was 5 minutes.
4.3.4.6 Mixer Summary and Conclusion

Consistently low baselines ensured that the corrected power curve was not affected by dried or solid dough particles. Water added to the bowl during baseline readings further reduced baseline power variation. As confirmed with the cracker dough, a 500g dough mass was optimum for the experimental dough mixer with sufficient mixing action and intermediate power consumption. The water bath was set at 38°C and mixing stopped when the dough temperature reached 38-39°C. Mixer speeds of 60rpm and 120rpm ensured optimum gluten formation during 5 minutes total mixing.
4.3.5 PS Control Dough Optimisation

4.3.5.1 Mix Size

Based on visual monitoring during mixing, power consumption and energy increased as the dough mass increased from 500g to 600g. At the point of maximum dough development, the 500g dough consumed 200-250W whilst the 600g dough consumed 350-400W. This additional 150W of power was due to the larger dough mass and shear strength. The subsequent energy (work done) also increased (Table 4.5).

Table 4.5 Effect of mixing 500g and 600g PS Control Doughts on Energy (Work Done), Torque and Dough and Biscuit Parameters.

<table>
<thead>
<tr>
<th>Dough Size g</th>
<th>Slow Speed (60rpm)</th>
<th>High Speed (120rpm)</th>
<th>Raw Dough Weight g</th>
<th>Baked Dough Weight g</th>
<th>Packet Length mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy kJ</td>
<td>Torque Nm</td>
<td>Energy kJ</td>
<td>Torque Nm</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>7.07</td>
<td>4-6</td>
<td>251.13</td>
<td>6-7.5</td>
<td>65.2</td>
</tr>
<tr>
<td>600</td>
<td>8.35</td>
<td>4-7</td>
<td>387.25</td>
<td>9-9.5</td>
<td>66.4</td>
</tr>
</tbody>
</table>

Despite the increase in dough mass and mixing resistance, the differences between the raw and baked biscuit parameters were not significant (Table 4.5). These similarities in raw and baked biscuit parameters for each dough mass were presumed to be related to the constant final dough temperature. The increase in power for the 600g mass created more friction within the dough than the 500g mass, resulting in a faster rate of temperature rise as indicated by the slight reduction in mixing.

The maximum torque for the 500g dough was 6-7.5Nm (Table 4.5). The torque for the 600g dough was 9-9.5Nm which almost exceeded the limits of the motor. Therefore,
500g dough mass was considered optimum and permitted future ingredient manipulations without exceeding the limits of the motor, or requiring recipe re-scaling during experimentation. This PS Control mass of 500g was consistent with the initial experimentation which confirmed a 500g commercial cracker dough (4.3.4) as an optimum mass for the experimental mixer.

4.3.5.2 Water and Sodium Metabisulphite Additions

Dough Water

Preliminary experimentation for the PS Control revealed that 50g of dough water was probably optimum, hence dough water levels of 45g and 55g were added to confirm this result. Doughs were assessed visually for mixing parameters only. The results are shown in Table 4.6.

Table 4.6 Effect of Varied Water Addition on Dough Mixing Properties.

<table>
<thead>
<tr>
<th>Mixing Curve Parameter</th>
<th>Dough Water Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45g</td>
</tr>
<tr>
<td>Time to hydrate completely (sec.)</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>Initial Power on High Speed (W)</td>
<td>250-275</td>
</tr>
<tr>
<td>Band width at final consistency (W)</td>
<td>230-260</td>
</tr>
<tr>
<td>Total Mixing Time (sec.)</td>
<td>280</td>
</tr>
</tbody>
</table>

Forty five grams of dough water (-10% addition) did not allow uniform mixing of ingredients into a homogeneous mass on slow speed, indicating insufficient dough water addition. This substantially increased the initial power at high speed as the first 30-60 seconds completed hydration and brought the dough mass together. The rate of
temperature rise was slightly faster in the dough containing 45g of water compared to the control and 55g dough water addition (Table 4.6).

With 55g of dough water, a homogeneous dough mass was achieved within 40-45 seconds. This was slightly less than for the PS Control (50g dough water). Due to the additional dough water, the dough was slightly softer as indicated by the reduced power consumption. This necessitated a slight increase in mixing to achieve the required final dough temperature due to the decrease in friction. The resultant dough was still softer and slightly stickier when compared to the PS Control. Wade (1970) and Manley (1991) have attributed these conditions to excess dough water addition and overmixing. Mani et al., (1992) also indicated that overmixed doughs offer less resistance to mixing which is consistent with the reduced power measured with this dough.

Dough water addition of 50g to the PS Control achieved a homogenous and uniform mass within 45-50 seconds. The dough was soft and elastic, with a good degree of resistance to extension as indicated by the band width and final consistency (Table 4.7). Therefore the dough water addition was maintained at 50g for the PS Control.

Sodium Metabisulphite

The effect of altered MBS did not affect dough or biscuit weight and packet length. All differences were within the experimental variation and were not considered significant. Based on flour weight, the level of MBS addition was similar to commercial formulations for plain sweet biscuits. Therefore, the PS Control formulation was considered optimum and the level of MBS addition was not changed.
4.3.5.3 Dough Mixing

The slow speed mixing procedure was optimised at 60rpm for 60 seconds. This allowed sufficient time for ingredient hydration and the formation of a cohesive mass. Mixing on high speed at 120rpm resulted in a dramatic increase in dough temperature resulting from an increase in power consumption and surface friction. The kneading action was sufficient to develop gluten and produce a viscoelastic dough. Therefore the mixing procedure was 60rpm for 60 seconds, followed by 120rpm for 4 minutes until the dough reached 38-39°C.

4.3.5.4 Sheeting

The results for dough pieces sheeted using the procedures described in 4.3.2 are shown in Table 4.7. The dough sheet was very smooth with a high sheen. The cut dough pieces were slightly ovate indicating that the dough exhibited elastic properties associated with gradual sheeting reductions. The ovate shape of the raw dough pieces are consistent with the cutter which is oval to allow the dough pieces to contract in the machine direction during baking, resulting in circular biscuits. After baking, the resultant biscuits were circular (Table 4.7) which confirmed that gluten alignment was optimised in sheeting.

<table>
<thead>
<tr>
<th>Table 4.7 Sheeting Results for the PS Control Dough.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
</tr>
<tr>
<td>Dough Dimensions (mm)</td>
</tr>
<tr>
<td>Dough Springback</td>
</tr>
<tr>
<td>Dough Density (g cm⁻³)</td>
</tr>
<tr>
<td>Biscuit Dimensions (mm)</td>
</tr>
</tbody>
</table>
4.3.5.5 Baking

Figure 4.7 illustrates the change in dough and oven temperature during baking of the PS Control dough at 180°C. The dough piece entered the oven at 25-30°C and increased rapidly to 105°C after 6 minutes after which the rate of temperature rise increased more slowly. This early rapid rise in temperature is postulated to be due to the evaporation of water from the biscuit surface as described by Almond (1989) and Manley (1991).

**Figure 4.7** Rise in Dough and Oven Temperature During Baking

PS Control at 180°C for 18 Minutes.

Top and bottom colour development for the PS Control was beginning to form at 10 and 12 minutes respectively. At 14 minutes, the biscuits were slightly overbaked with a slightly bitter aftertaste. At 16 minutes, the biscuit temperature was 140°C and the biscuits were excessively overbaked with deep colour penetration.

Based on the appearance, colour and flavour development, the bake time for the PS Control was determined to be 13 minutes at 180°C with the fan on. The resultant biscuits had a slight surface sheen and firm bite, with good colour and flavour development. These parameters are essential quality attributes for plain sweet biscuits.
4.3.6 Evaluation of the Optimised Procedure and Results

The PS Control was mixed at 60rpm for 60 seconds, followed by 120rpm for 4 minutes. Mixing was complete in 5 minutes with an average dough temperature of 38.7°C. The dough was soft and elastic and freely extended when pulled by hand. The dough exhibited a high sheen and was quite yellow in colour.

Figure 4.8 Baseline Corrected Power Curve for PS Control.

![Baseline Corrected Power Curve for PS Control](image)

Figure 4.8 shows the baseline corrected power curve (average of 6 replicates). Wade (1966), reported a fairly small rise in power where dough consists of small crumbs of material. As the crumbs coalesce with further hydration, the curve becomes more irregular in shape as displayed by the increase in band width (100-125W). This is due to dough formation in which the dragging of the dough past the block arms and mixer sprags alters the resistance to mixing.

High speed mixing increased power consumption initially to 225-250W. As mixing continued, the resistance decreased to 200-230W. At 180 seconds, the band width and
power began to increase. This suggests that hydration of ingredients is complete at 180 seconds as indicated by the increase in dough elasticity and resistance to extension. Both these factors are associated with maximum gluten development (Hoseney, 1994). The absence of the expected peak however, is likely to be due to the high fat content of the PS Control. This is due to the fat coating flour particles which prevents their hydration and subsequent full gluten development.

Dough pieces baked on the aluminium baking tray for 13 minutes at 180°C exhibited good, even bake colour with a slight surface sheen and smooth base. The biscuit parameters are listed in Table 4.8. Baked biscuits are illustrated in Figure 4.9.

<table>
<thead>
<tr>
<th>Table 4.8</th>
<th>Biscuit Parameters for PS Control.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>62.18</td>
</tr>
<tr>
<td>Dimensions (mm)</td>
<td>50.6 x 50.4 x 5.6</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>60.2</td>
</tr>
<tr>
<td>Density (g cm$^{-3}$)</td>
<td>0.55</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>41</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>0</td>
</tr>
</tbody>
</table>

The biscuits were almost completely circular and exhibited good height and packet length (Table 4.8). These parameters are associated with work input into the dough from both mixing and sheeting in which gluten development appeared to be gradual. The saw time increased compared to the commercial plain sweet biscuits due to the difference in biscuit dimensions. The PS Control biscuits were smaller and round thereby having a greater proportion of surface crust which increased the resistance to
sawing compared to the rectangular (70 x 35 x 6mm) commercial biscuits. No checking was recorded 48 hours after baking indicating that the baking process was optimised for the PS Control. The biscuits were typical of plain sweet biscuits but were slightly less sweet and more tender due to the altered proportions of sugar and fat to meet the 1995 NH & MRC dietary targets. Since the biscuit met the desired criteria, the procedure was considered optimum and used for evaluating sugar and fat reductions.

**Figure 4.9**  
**PS Control Biscuits.**
4.4 CONCLUSION

In a series of experiments and modifications, conditions were optimised to achieve a plain sweet biscuit dough which was similar to commercial dough and contained the attributes required for premium quality biscuits. A relatively constant temperature oven was achieved with acceptable temperature control and baking efficiency. Biscuits were assessed for sensory attributes and judged against quality criteria. Doughs and biscuits manufactured using the optimised procedure were of consistently high quality.
CHAPTER 5

DETERMINING THE MAXIMUM REDUCTION OF SUGAR & FAT IN THE PLAIN SWEET CONTROL

5.1 INTRODUCTION

Dough consistency depends on the development of a gluten network in which mixing of ingredients results in the contact and hydration of flour proteins which are converted to gluten during mixing. Sugar and fat delay hydration and prevent disaggregation and unfolding of the protein which reduces the viscoelastic properties of the dough and produces a more tender and moist baked product (Menjivar and Faridi, 1994). Sugar and fat also participate in colour and flavour reactions (Hoseney, 1994). Therefore, when sugar and fat are reduced, it is expected that biscuits will become harder, drier and less acceptable.

Replacing sugar and fat with wheat starch alters dough properties as wheat starch provides a suitable surface for strong gluten bonding (Shelton and D'Appolonia, 1985). Wheat starch competes for water with other ingredients thereby increasing dough water requirements (Patil, 1991; Lorenz, 1994). Wheat starch also acts as a filler in the matrices provided by gluten and other ingredients, diluting the gluten structure and introducing non-linearity into the dough (Faubion et al., 1985; Lorenz, 1994).

The aim of this set of experiments was to determine the rheological and textural effects of reducing sugar and fat, singularly and in combination, in a modified plain sweet biscuit formulation (PS Control) using wheat starch as the replacing ingredient.
5.2 EXPERIMENTATION

A modified plain sweet formulation (PS Control) was used (Table 3.2). The maximum reduction of sugar and fat, alone and in combination, was made using an equal weight replacement of wheat starch. Figure 5.1 shows the experimental progression with the components of successful reductions included in Table 5.1. The PS Control preceded each experimental set to allow for direct comparisons between experiments.

Figure 5.1  Flow Chart for Sugar and Fat Reductions in the PS Control.

* Dough unacceptable and experiment not continued.

Table 5.1  Experimental Plan for Sugar and Fat Reductions.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Sugar Addition (g)</th>
<th>Fat Addition (g)</th>
<th>Wheat Starch Addition (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS Control</td>
<td>60.0</td>
<td>75.0</td>
<td>9.5</td>
</tr>
<tr>
<td>50% Sugar Reduction</td>
<td>30.0</td>
<td>75.0</td>
<td>39.5</td>
</tr>
<tr>
<td>100% Sugar Reduction</td>
<td>0.0</td>
<td>75.0</td>
<td>69.5</td>
</tr>
<tr>
<td>PS Control</td>
<td>60.0</td>
<td>75.0</td>
<td>9.5</td>
</tr>
<tr>
<td>25% Fat Reduction</td>
<td>60.0</td>
<td>56.3</td>
<td>65.8</td>
</tr>
<tr>
<td>50% Fat Reduction</td>
<td>60.0</td>
<td>37.5</td>
<td>47.0</td>
</tr>
<tr>
<td>PS Control</td>
<td>60.0</td>
<td>75.0</td>
<td>9.5</td>
</tr>
<tr>
<td>50% Sugar + 25% Fat Redn.</td>
<td>30.0</td>
<td>56.3</td>
<td>58.2</td>
</tr>
<tr>
<td>75% Sugar + 37.5% Fat Redn.</td>
<td>15.0</td>
<td>46.8</td>
<td>82.7</td>
</tr>
</tbody>
</table>
5.3 RESULTS AND DISCUSSION

5.3.1 Dough Mixing

5.3.1.1 Sugar Reductions

In the PS Control, 100% sugar reduction was successfully achieved using wheat starch. As sugar was reduced, dough water requirements increased (Table 5.2). This was due to less sugar providing less competition with flour for hydration. The effect of added wheat starch on dough water requirements was in agreement with Patil (1991), Hoseney (1994) and Lorenz (1994) who stated that wheat starch exerts a considerable influence on added water requirements. Therefore, the increased dough water allowed for greater hydration of flour proteins and added wheat starch.

Table 5.2 Effect on Dough Mixing of Sugar Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PS Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Addition (g)</td>
<td>60.0</td>
<td>30.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wheat starch Addition (g)</td>
<td>9.5</td>
<td>39.5</td>
<td>69.5</td>
</tr>
<tr>
<td>Water Addition (g)</td>
<td>50.0</td>
<td>70.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Mixing 120rpm (seconds)</td>
<td>240</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Final Slow Speed Power (Watts)</td>
<td>100 - 125</td>
<td>130 - 150</td>
<td>195 - 230</td>
</tr>
<tr>
<td>Initial High Speed Power (Watts)</td>
<td>225 - 250</td>
<td>295 - 350</td>
<td>350 - 405</td>
</tr>
<tr>
<td>Final Consistency (Watts)</td>
<td>210 - 255</td>
<td>275 - 300</td>
<td>255 - 280</td>
</tr>
</tbody>
</table>
Figure 5.2  Baseline Corrected Power Curves for Plain Sweet Control and Doughs with 50% and 100% Sugar Replaced with Wheat Starch.

Figure 5.2.1  Plain Sweet Control

Figure 5.2.2  50% Sugar Reduction

Figure 5.2.3  100% Sugar Reduction
Power on slow and high speeds increased with each reduction in sugar (Table 5.2, Figure 5.2) which is consistent with an increase in dough toughness. Power on high speed increased to a maximum in the sugar reduced doughs (Figures 5.2.2-5.2.3). This was due to greater hydration of flour protein and gluten development in the absence of the water binding and moisturising properties of sugar. Increased hydration of wheat starch was also thought to have contributed to an increase in mixing resistance due to the strong bonding with gluten.

The rate of decline in power on high speed mixing in the sugar reduced formulations (Figure 5.2) was indicative of dough breakdown which occurs due to the decreased entanglement of the gluten structure (Faubion and Hoseney, 1990). This is postulated to be due to the wheat starch reducing the linear gluten matrix by scission of disulphide bonds within and between the gluten molecules as described by Hoseney (1994). The narrower band width also suggests that the reduced sugar doughs are less elastic.

The reduced addition of sugar and increased hydration of flour protein and wheat starch, affected a smaller temperature change at the beginning of slow speed mixing compared to the PS Control (Figure 5.3). During the first 10 seconds of mixing, when ingredients distribute throughout the mass and sugar, salt and chemicals begin to dissolve, the PS Control formulation declined 2°C (31-29°C), whilst the 100% sugar reduced dough declined only 1°C (31-30°C). This initial decline in temperature may be due to endothermic reactions involving the dissolution of sugar, or may be associated with energy required for hydrogen bond formation. Increased dough water (at 40°C) may also have contributed to this temperature difference.
Whilst mixing was stopped between slow and high speeds, the temperature rise in the 100% sugar reduced dough was 2°C compared to the PS Control which was less than 1°C (Figure 5.3). This increase may be due to the warming effect of the water bath (38°C), and suggests that the 100% sugar reduced dough may have greater heat transfer efficiency.

Li and Walker (1992) attributed dough temperature rise to the change in energy levels of starch and protein. Despite the increased hydration of protein and starch in the 100% sugar reduced dough, the rate of temperature rise was similar for both dough formulations (Figure 5.3). Due to the initial temperature difference, the sugar reduced doughs reached optimum dough temperature 60 seconds faster than the PS Control (Figure 5.3).

Despite the increase in dough water, the doughs became drier as sugar was reduced. This dryness was thought to be due to the loss of the moisturising effect of sugar and the water binding properties of the wheat starch.
5.3.1.2 Fat Reductions

A maximum reduction of 50% fat was successfully achieved in the PS Control using wheat starch (Table 5.3). The 75% fat reduced dough was sticky as reported by Kelly (1992) and Hegenbart (1993) and produced unacceptably dense biscuits with surface blistering. As fat was reduced, dough water requirements increased (Table 5.3) as the fat less effectively coated flour particles and allowed for greater hydration.

Table 5.3  Effect on Dough Mixing of Fat Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PS Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat Addition (g)</td>
<td>75.0</td>
<td>56.3</td>
<td>37.5</td>
</tr>
<tr>
<td>Wheat Starch Addition (g)</td>
<td>9.5</td>
<td>28.3</td>
<td>47.0</td>
</tr>
<tr>
<td>Water Addition (g)</td>
<td>50.0</td>
<td>65.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Mixing 120rpm (seconds)</td>
<td>240</td>
<td>180</td>
<td>140</td>
</tr>
<tr>
<td>Final Slow Speed Power (Watts)</td>
<td>110-130</td>
<td>140-155</td>
<td>175-205</td>
</tr>
<tr>
<td>Initial High Speed Power (Watts)</td>
<td>215-240</td>
<td>250-285</td>
<td>370-410</td>
</tr>
<tr>
<td>Final Consistency (Watts)</td>
<td>205-240</td>
<td>260-295</td>
<td>295-330</td>
</tr>
</tbody>
</table>

As indicated by the increase in mixing power, peak formation and possible gluten development, dough toughness increased (Table 5.3, Figure 5.4). Bloksma (1972) however, attributed dough toughness to the interaction of wheat starch with gluten. The effect of wheat starch was more pronounced at the 50% level, as indicated by the rapid rate of dough breakdown (Figure 5.4.3). Therefore, this substantial increase in power is speculated to be due to the increased gluten formation with the breakdown due to the disrupting effect of wheat starch on the gluten matrix.
Figure 5.4  
Baseline Corrected Power Curves for Plain Sweet Control and Doughs with 25% and 50% Fat Replaced with Wheat Starch.

Figure 5.4.1  
Plain Sweet Control

Figure 5.4.2  
25% Fat Reduction

Figure 5.4.3  
50% Fat Reduction
The decline in dough temperature at the beginning of slow mixing was more rapid and greatest for the PS Control (Figure 5.5). Therefore, the energy absorbed in the PS Control was greater than the fat reduced doughs which contained more dough water and wheat starch. The temperature at high speed mixing was similar for all formulations, but the rate of temperature rise was slightly different as indicated by the slope of the high speed portion of the curve (Figure 5.5).

Figure 5.5  Temperature Profile During Mixing for Plain Sweet Control and Doughs with 25% and 50% Fat Replaced with Wheat Starch.

Due to the initial difference in temperature and slightly different rates of temperature rise, the reduced fat doughs reached optimum dough temperature quicker than the PS Control (Figure 5.5). This temperature difference may have been due to less energy required to hydrate flour and starch compared to the PS Control which contained more fat and less free water. This increase in dough temperature is also due to the increased power consumed during mixing (Figure 5.4).

The reduced fat doughs were dull and grey compared to the yellow PS Control which exhibited moderate sheen. This loss of sheen and colour was due to the reduction in fat as described by Anon. (1992).
5.3.1.3 Sugar Plus Fat Reductions

A maximum combined reduction of 75% sugar and 37.5% fat was achieved in the PS Control formula (Table 5.4). Dough water increased which allowed for greater hydration of protein and wheat starch (Table 5.4, Figure 5.6). The 100% sugar and 50% fat reduced formulation was unacceptable and excluded from the experimental set.

Table 5.4 Effect on Dough Mixing of 50% Sugar and 25% Fat, and 75% Sugar and 37.5% Fat Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>Control Formula</th>
<th>50% Sugar + 25% Fat Reduction</th>
<th>75% Sugar + 37.5% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Addition (g)</td>
<td>60.0</td>
<td>30.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Fat Addition (g)</td>
<td>75.0</td>
<td>56.3</td>
<td>46.9</td>
</tr>
<tr>
<td>Wheat Starch Addition (g)</td>
<td>9.5</td>
<td>58.2</td>
<td>82.6</td>
</tr>
<tr>
<td>Water Addition (g)</td>
<td>50.0</td>
<td>80.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Mixing 120rpm (seconds)</td>
<td>240</td>
<td>130</td>
<td>140</td>
</tr>
<tr>
<td>Final Slow Speed Power (Watts)</td>
<td>95-105</td>
<td>175-200</td>
<td>190-230</td>
</tr>
<tr>
<td>Initial High Speed Power (Watts)</td>
<td>200-225</td>
<td>345-390</td>
<td>345-375</td>
</tr>
<tr>
<td>Final Consistency (Watts)</td>
<td>195-220</td>
<td>280-300</td>
<td>250-275</td>
</tr>
</tbody>
</table>

The power consumed and shape of the mixing curves for the sugar and fat reduced formulations were substantially different to the PS Control (Figure 5.6). As the dough was mixed on high speed, power in the sugar plus fat reduced doughs increased initially to peak, then proceeded to rapidly decline (Figure 5.6). This was speculated to be due to the disruptive effect of the added wheat starch. It was also thought that bound water may have been released from the gluten structure as suggested by Daniels (1975) which would agree with the observed decrease in mixing resistance.
Figure 5.6  Baseline Corrected Power Curves for Plain Sweet Control and Doughs with Sugar and Fat Replaced with Wheat Starch.

Figure 5.6.1  Plain Sweet Control

Figure 5.6.2  50% Sugar and 25% Fat Reduction

Figure 5.6.3  75% Sugar and 37.5% Fat Reduction
The initial decline in temperature was significantly greater in the PS Control than the sugar and fat reduced formulations (Figure 5.7). This is consistent with the observed trends for sugar reductions and fat reductions, suggesting that the additional wheat starch and water uses less energy in hydration and hydrogen bond formation, thereby reducing the temperature effect at the beginning of mixing.

**Figure 5.7  Temperature Profile During Mixing for Plain Sweet Control and Doughs with 50% Sugar and 25% Fat, and 75% Sugar and 37.5% Fat Replaced with Wheat Starch.**

The initial dough temperature and increased rate of temperature rise resulted in the sugar and fat reduced doughs reaching optimum dough temperature faster than the PS Control. Therefore, mixing times were substantially reduced (Table 5.4). The temperature profile also suggests that the mixing times for the sugar and fat reduced formulations should not have been different.

The effect of added wheat starch and reduced levels of sugar and fat, increased dough dryness and loss of sheen when compared to the PS Control.
5.3.1.4 Dough Mixing Discussion

The reduction of sugar and fat, alone and in combination, increased dough water requirements. As sugar and fat were reduced, their diminished effect on inhibiting and delaying flour hydration increased dough water requirements, resulting in increased gluten development. Hoseney (1994) and Lorenz (1994) also stated that wheat starch exerted a considerable influence on dough water requirement.

As sugar and fat were reduced in the PS Control, dough toughness and mixing power increased with greater flour hydration and gluten development. The proposed increase in gluten development was supported by this increase in power and peak development in the 50% sugar reduced and 25% fat reduced formulations. Hoseney (1994) also stated that peaks only occur in optimally mixed doughs when all flour particles are hydrated. When both sugar and fat were further reduced however, there was no evidence of a peak and dough breakdown accelerated (Figures 5.2.3, 5.4.3, 5.6.2, 5.6.3), indicating that greater levels of wheat starch more effectively reduced the linear gluten matrix (Hoseney, 1994).

Wheat starch is also involved in a strong union with gluten (Shelton and D'Appolonia, 1985) which increases the dynamic stiffness of the dough (Faubion et al., 1985). This suggests that wheat starch has also contributed to the increase in dough strength and power consumed during mixing as described by Bloksma (1972) and Hoseney (1994). As dough consistency rapidly declined during high speed mixing, it was hypothesised that the wheat starch inhibits gluten bonds from reforming, resulting in reduced dough
strength and elasticity. This reduction in elasticity is consistent with slightly narrower band widths at the end of mixing (Figures 5.2, 5.4, 5.6).

The reduced quantities of sugar and fat also affected the increase in power consumption, as sugar and fat both rheologically modify and reduce gluten development which results in a more tender product (Baxter and Hetser, 1958; Merritt and Bailey, 1948). Therefore, the reduced levels of these ingredients have also contributed to the increase in power and dough toughness.

All experimental formulations exhibited a smaller decline in temperature at the beginning of mixing when compared to the PS Control (Figures 5.3, 5.5, 5.7). This is postulated to be due to the energy involved in flour hydration in the presence of sugar and fat which both modify and delay gluten development. This suggests that starch hydration requires less energy, hence the effect on temperature is reduced.

The rate of temperature rise was not affected by the replacement of sugar with wheat starch as indicated by the similarity in the slopes for high speed mixing. When wheat starch replaced fat, however, the slopes increased proportionally when compared to the PS Control. When both sugar and fat were reduced, the rate of temperature rise was most different to the PS Control (Figure 5.7). As the sugar and fat reduced dough power curves were similar, it was postulated that the rise in temperature was associated with the change in energy levels of starch and protein as described by Li and Walker (1992).
Power consumption and mixing time were most affected by the reduction in fat due to reduced coating of flour and aeration of dough which in turn increased the resistance to mixing and resulted in increased dough toughness and tightness. Manley (1991) stated that tighter doughs have a more rapid temperature rise during mixing which supports this argument.

The shape and consistency of the power curves for the sugar and fat reduced doughs were quite different to the PS Control (Figures 5.2, 5.4, 5.6). Slow speed power increased with maximised reductions of sugar and or fat. At these maximised levels, initial hydration of ingredients on slow speed was severely delayed as indicated by the absence of the plateau which occurred in the PS Control doughs at 45-60 seconds. This delay in hydration is attributable to the increased addition of wheat starch.

At intermediate levels of sugar and fat reduction, the rise to peak suggested gluten development (Figures 5.2.2 and 5.4.2). The final consistency of these doughs was similar (250-300W) and slightly greater than the PS Control (200-250W). At maximised reduction levels however, the power increased substantially, then rapidly declined (Figures 5.2.3 and 5.4.3). The final consistency was greatest for the fat reduced dough (300-350W), and least for the PS Control (200-250W). The band widths were slightly narrower as the reduced sugar and fat decreased extensibility and elasticity as described by Manley (1991). The sugar plus fat reduced dough power curves (Figures 5.6.2-5.6.3) were similar in shape to the maximised sugar (Figure 5.2.3) and maximised fat reduced dough (Figure 5.4.3) power curves.
It was initially thought that the increase in dough mass from the additional dough water may have increased power consumption during mixing. As the work input was similar for all experimental doughs, the increase in power was not likely to have been due to the change in dough mass.

The effect of aged flour must be taken into consideration when comparing the effects of the combined reductions of both sugar and fat. Comparison of the three PS Control baseline corrected power curves (Figures 5.2.1, 5.4.1 and 5.6.1) shows a 10 Watt reduction in band widths for each PS Control. This is consistent with flour trends observed during flour storage in which extensibility decreased, resulting in reduced elasticity and packet length. With this in mind, the power required to mix the sugar plus fat reduced doughs may have been up to 50 watts greater if fresher soft flour had been used.
5.3.2 Dough Sheeting

5.3.2.1 Sugar Reductions

With each level of sugar reduction, raw dough weight, spring back and dough piece height decreased (Table 5.5). These reductions are consistent with the observed stretching and elongation of the dough during sheeting which implied a weaker and less elastic dough structure. This weaker structure is conclusively associated with the disruptive effect of the wheat starch which reduces the linear gluten matrix by scission of disulphide bonds within and between the gluten molecules (Hoseney, 1994). This reduces the ability of the gluten proteins to realign after sheeting which was confirmed by the increase in width in the direction of machining (Table 5.5). The reduction in bulking and viscosity provided by sugar may also have contributed to the change in dough dimensions. The reduction in sugar affected a slight reduction in dough density compared to the PS Control (Table 5.5).

Table 5.5 Effect on Sheeting of Sugar Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PS Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>74.45</td>
<td>66.54</td>
<td>61.74</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>1.23</td>
<td>1.18</td>
<td>1.21</td>
</tr>
<tr>
<td>Spring Back</td>
<td>1.76</td>
<td>1.65</td>
<td>1.47</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.0</td>
<td>50.0</td>
<td>50.1</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>51.3</td>
<td>51.5</td>
<td>51.7</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>3.0</td>
<td>2.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>
5.3.2.2 Fat Reductions

As fat was reduced, raw dough weight decreased (Table 5.6). All other parameters remained constant, except dough density which decreased slightly with each reduction in fat (Table 5.6). This is possibly caused by the reduced lubricating properties of the fat which increases surface friction, thereby reducing the ability of the dough to freely extend during sheeting. Increased dough tightness is consistent with the power curves which indicated that the fat reduced doughs were tougher than the PS Control (Figure 5.4).

As fat crystals can entrap air during mixing (Given, 1994), it was expected that the dough pieces would be more dense as fat was reduced. Further, the contribution of altered gluten development and wheat starch addition may have contributed to this decrease in density.

Table 5.6 Effect on Sheet of Fat Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PS Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>73.87</td>
<td>72.52</td>
<td>71.18</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>1.26</td>
<td>1.24</td>
<td>1.21</td>
</tr>
<tr>
<td>Spring Back</td>
<td>1.71</td>
<td>1.71</td>
<td>1.71</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>51.5</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.0</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>
5.3.2.3 Sugar Plus Fat Reductions

The combined reduction of sugar and fat resulted in a substantial reduction in raw dough weight, height and spring back (Table 5.7). The sugar and fat reduced doughs were similar to each other, as observed in the power curves and temperature profiles during mixing. This was attributed to the effect of the wheat starch in diluting the gluten matrix as observed in the sugar reduced doughs (5.3.2.1). Dough dimensions across and with the sheeting direction were the same as the PS Control (Table 5.7). Dough piece height however decreased which is consistent with reduced gluten alignment and elasticity.

Dough density decreased at the intermediate level and increased greater than the PS Control when maximised levels of both sugar and fat were replaced with wheat starch (Table 5.7). Altered dough density is thought to be due to the tight dough structure from the added wheat starch and reduced air cell formation due to the reduction in fat.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PS Control Formula</th>
<th>50% Sugar 25% Fat Reduction</th>
<th>75% Sugar 37.5% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>71.99</td>
<td>65.58</td>
<td>63.72</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>1.23</td>
<td>1.20</td>
<td>1.26</td>
</tr>
<tr>
<td>Spring Back</td>
<td>1.71</td>
<td>1.59</td>
<td>1.47</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>51.5</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.0</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>2.9</td>
<td>2.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>
5.3.2.4 Sheeting Discussion

As sugar was reduced, the dough sheet lost extensibility and elasticity which resulted in permanent deformation during sheeting. This was visible by the increase in dimensions in the machining direction from 51.3 to 51.7mm. As fat was reduced, dough toughness increased due to the surface friction from the reduced lubrication. This resulted in the dough maintaining constant dimensions, which affected a slight reduction in density. The maximised replacement of sugar and fat however, increased dough density.

It has been accepted that increased wheat starch as both sugar and fat were reduced, disrupted the linear gluten matrix, resulting in permanent deformation during sheeting and reduced dough piece height and spring back. It was also thought that swelling and possible gelatinisation of starch in the formulations with added wheat starch and dough water, or the gluten and starch interaction, contributed to the constant dough dimensions with and across the machine direction.

Despite the similar power curves for the sugar and fat reduced dough formulations, the differences in dough properties were most obvious during sheeting. Reduced sugar had a significant effect on dough dimensions, whilst the reduction in fat increased dough toughness and increased the resistance to extension and deformation. Merritt and Bailey (1948), Manley (1991) and Cauvain (1992a) reported that fat reduces extensibility, hence it was presumed that extensibility would increase with fat reduction due to the increase in gluten development. As this did not occur, wheat starch hydration and possible swelling was presumed to have affected the resistance to extension in combination with the increased dough tightness from the large reduction in fat.
5.3.3  Baking

5.3.3.1  Sugar Reductions

Based on sensory assessments, the biscuits exhibited good bake colour and degree of bake. It was presumed that the similarity in dough density (Table 5.5) allowed for sufficient moisture removal during baking, as indicated by the absence of checking (Table 5.8). Therefore, bake time was constant (Table 5.8).

Table 5.8  Effect on Baking of Sugar Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>PS Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bake Time (minutes)</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>62.18</td>
<td>48.60</td>
<td>47.72</td>
</tr>
<tr>
<td>Density (g cm(^{-3}))</td>
<td>0.55</td>
<td>0.55</td>
<td>0.65</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>50.4</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.6</td>
<td>49.8</td>
<td>49.0</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>5.6</td>
<td>4.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>60.2</td>
<td>48.6</td>
<td>39.2</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>41</td>
<td>54</td>
<td>78</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

As sugar was reduced, baked weight decreased (Table 5.8). Due to the contraction of the dough pieces across the machine direction at the 50% sugar reduced level, density was similar to the PS Control, whereas the 100% sugar reduced dough was more dense (Table 5.8). The main effect of sugar reduction was the contraction of dough pieces during baking and subsequent reduction in biscuit height and packet length (Table 5.8). During baking, sugar dissolves which increases the volume and spread of the dough piece, hence when sugar is reduced, there is reduced dissolution resulting in minimal
expansion during baking. With the reduction in sugar and additional dough water, it may be possible that starch gelatinisation has occurred as suggested by Kulp (1994). Wheat starch also controls product structure via its interaction with the protein matrix during heating (Faridi and Faubion, 1994). This may explain the increase in density in the 100% sugar reduced dough.

As sugar was reduced, biscuit saw time increased from 41 seconds to 78 seconds (Table 5.8) which suggests increased biscuit hardness. The sensory assessment however, indicated that hardness increased only slightly, with the 100% sugar reduced biscuit being most friable. This is due to the sensory assessment of hardness focussing on both the initial bite, which is affected by crust hardness, and crumb during breakdown. During sawing however, crust has a greater effect, especially when a greater number of biscuits are incorporated into the stack of the texture meter. Therefore, the increase in saw time was also due to the increased number of biscuits and proportion of crust within the stack, and accumulation of crumb between the blade and brush.

The reduced sugar biscuits were significantly paler, less sweet and drier than the PS Control. The reduction in colour is not attributable to the decreased levels of sucrose as sucrose is non-reducing and is possibly due to reduced caramelisation. The decreased sweetness was expected and coincided with an apparent increase in saltiness and milkiness. The dry mouthfeel was attributable to the reduced moisturisation from the loss of sugar and excess wheat starch addition. The sensory acceptability of the 50% sugar reduced biscuits was moderate with the 100% sugar reduced biscuits less acceptable due to the lack of sweetness, bake colour, poor internal texture and dryness.
5.3.3.2 Fat Reductions

At the 25% fat reduction level, a small percentage of the biscuits positioned at the temperature extremes of the oven checked. This necessitated an increase in bake time for the 50% level which resulted in 0% checking (Table 5.9). As fat was reduced, the rate of heat transfer was delayed, resulting in a slowing of the baking process as described by Abboud (1995) and Shukla (1995). This was confirmed visually by the delay in colour development during baking.

Table 5.9 Effect on Baking of Fat Replacement with Wheat Starch.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PS Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bake Time (minutes)</td>
<td>13</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>61.59</td>
<td>58.92</td>
<td>55.66</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>0.56</td>
<td>0.54</td>
<td>0.56</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>50.4</td>
<td>50.6</td>
<td>49.9</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>51.0</td>
<td>50.8</td>
<td>49.6</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>5.5</td>
<td>5.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>59.3</td>
<td>58.9</td>
<td>57.0</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>44</td>
<td>47</td>
<td>56</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>0</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

Baked dough weight decreased (Table 5.9). Dough pieces contracted slightly during baking, and had less height and packet length than the PS Control (Table 5.9). Due to the increased checking in the 25% fat reduced biscuits, it is expected that increasing bake time would reduce biscuit weight and produce constant density.
During baking fat melts, increasing the fluidity and spread of the dough pieces (Manley, 1991) hence it was expected and observed that the reduced fat doughs would contract, resulting in smaller biscuit dimensions. Dough contraction may also be related to the increased tightness of the reduced fat dough as indicated by the increased resistance to sheeting and deformation. Therefore the reduction in fat and additional wheat starch have resulted in greater dough contraction during baking than the PS Control.

The most obvious effect of fat reduction was the expected increase in saw time and biscuit hardness (Table 5.9). Fat reduction has been extensively documented to result in increased biscuit hardness (Nisbet et al., 1986; Manley, 1991) due to the reduction in tenderisation and inhibition of gluten development. The biscuits were also dry to taste which may be associated with the reduced lubrication and moistness due to less fat being present in addition to the dry mouthfeel associated with increased wheat starch. Hegenbart (1993) also reported increased dryness from starch addition.

The reduction in lubrication by fat was shown by the biscuits sticking slightly to the baking tray, as opposed to the control biscuits which slid easily from the tray surface. The reduced fat biscuits were also dull and paler in colour due to the reduced contribution of the fat in sheen and colour development. Hegenbart (1993) also stated that fat reduction reduced colour development and degree of browning.
5.3.3.3 Sugar Plus Fat Reductions

As sugar and fat were reduced together, bake time increased, resulting in 0% and 1% checking (Table 5.10) which suggested ideal moisture removal during baking. Baked weight, dimensions and packet length decreased as both sugar and fat were reduced (Table 5.10). During baking, dough pieces contracted with and across the sheeting direction when compared to the PS Control (Table 5.10). This is attributed to the reduction in fat as shown in Table 5.9.

Table 5.10  Effect on Baking of 50% Sugar and 25% Fat, and 75% Sugar and 37.5% Fat Replacement With Wheat Starch.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PS Control Formula</th>
<th>50% Sugar 25% Fat Reduction</th>
<th>75% Sugar 37.5% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bake Time (minutes)</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>59.84</td>
<td>51.04</td>
<td>47.65</td>
</tr>
<tr>
<td>Density (g cm(^{-3}))</td>
<td>0.55</td>
<td>0.64</td>
<td>0.68</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>50.4</td>
<td>50.0</td>
<td>49.5</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.9</td>
<td>49.3</td>
<td>48.8</td>
</tr>
<tr>
<td>Biscuit Height (mm)</td>
<td>5.4</td>
<td>4.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>57.6</td>
<td>44.8</td>
<td>40.8</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>38</td>
<td>69</td>
<td>137</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Biscuit density and hardness increased when compared to the PS Control (Table 5.10). The increase in density was due to the reduced tenderising and aerating effect of the lower sugar and fat levels in addition to the effect of increased wheat starch addition. The biscuits lacked sweetness and tenderness. The increase in hardness was also shown by the increased saw time (Table 5.10).
5.3.3.4 Baking Discussion

The tenderising effects of sugar and fat were demonstrated when maximum levels of sugar and fat were reduced in the PS Control and replaced with wheat starch. Sugar reduction had a significant effect on dough volume whilst fat reduction increased biscuit hardness as reported by Nisbet et al., (1986), Manley (1991) and Hoseney (1994). The reduction in fat necessitated an increase in bake time. This was due to the reduced heat transfer which slowed the baking process (Abboud, 1995; Shukla, 1995).

The increase in biscuit hardness was attributable to reduced tenderisation as less fat was spread in films throughout the dough structure. Peklo (1995) also reported that increased swelling of starch in the absence of sugar increases crumb firmness. Starch is generally inert in biscuits due to the low moisture content and high levels of sugar and fat (Kulp, 1994). Therefore, when the dough water is increased and sugar and fat are replaced with wheat starch, some functionality of starch hydration and possibly gelatinisation may contribute to this increase in biscuit hardness.

The sensory acceptability of the sugar and fat reduced biscuits was lower than the PS Control due to the reduced flavour intensity and pale and dull appearance. These parameters however, may be masked by the addition of flavours and colours. The most significant factor contributing to unacceptability was increased biscuit hardness, which is virtually impossible to tenderise without addition of fat, emulsifiers or enzymes.
5.3.4 Energy Contributions From Sugar and Fat

As shown in Table 5.11, dietary targets for sugar were more easily exceeded in the plain sweet biscuit formulation, resulting in less than 1% energy being derived from sugar in the 100% sugar reduced formulation. As expected, fat reduction was more difficult, with a maximum of 25% energy contribution achieved. Therefore, using wheat starch to replace sugar and fat in the PS Control biscuit formulation resulted in energy contributions exceeding the dietary targets with 8% energy from sugar and 25% energy from fat (Table 5.11).

Table 5.11 Percent Energy Contributions From Sugar and Fat.

<table>
<thead>
<tr>
<th>Formulation</th>
<th>% Energy Contributions From</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fat</td>
<td>Sugar</td>
</tr>
<tr>
<td>PS Control</td>
<td>35</td>
<td>12</td>
</tr>
<tr>
<td>50% Sugar Reduction</td>
<td>36</td>
<td>6</td>
</tr>
<tr>
<td>100% Sugar Reduction</td>
<td>36</td>
<td>&lt;1</td>
</tr>
<tr>
<td>25% Fat Reduction</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>50% Fat Reduction</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>50% Sugar and 25% Fat Reduction</td>
<td>29</td>
<td>7</td>
</tr>
<tr>
<td>75% Sugar and 37.5% Fat Reduction</td>
<td>25</td>
<td>8</td>
</tr>
</tbody>
</table>

| 1995 Dietary Targets                     | 35  | 12     |
| 2000 Dietary Targets                     | 30  | 12     |

The energy contributions from the commercial plain sweet formulation were almost equal for both sugar and fat at 20%. As the commercial formulation was modified to comply with the dietary targets, fat was substantially increased and sugar decreased, resulting in the PS Control formulation. This substantial increase in fat is thought to have limited fat reduction to 50%. Therefore, using a commercial plain sweet formulation, it is expected that greater than 50% reduction in fat is achievable. Hence the energy contributions from fat would be reduced to possibly 10-15%, which is significantly lower than the dietary targets (Table 5.11).

Reformulation of the maximised sugar and fat reduced biscuits using artificial sweeteners and sugar or fat substitutes in addition to colourings and flavourings will help to improve the sensory acceptability of these biscuits. These ingredients may allow for greater reductions in sugar and fat combined, resulting in biscuits with low energy contributions from sugar and from fat.
5.4 CONCLUSION

The PS Control was an acceptable base formulation for determining the functional properties of sugar and fat by their replacement with wheat starch. A 100% reduction in sugar and 50% reduction in fat were achieved without markedly affecting product quality acceptability. Combined, a 75% reduction in sugar and 37.5% reduction in fat exceed the NM&MRC dietary targets and provide a suitable base formulation for future work including sugar and fat replacers.
CHAPTER 6
DETERMINATION OF FUNCTIONAL PROPERTIES
OF POLYDEXTROSE AS A SUGAR AND FAT
REPLACER IN PLAIN SWEET BISCUITS

6.1 INTRODUCTION

To be able to significantly reduce the sugar or fat in plain sweet biscuits, appropriate ingredients must be selected which possess similar functional properties to the ingredients being reduced. Polydextrose was developed as a reduced energy replacement for sucrose and also has the ability to partially replace fat, flour and starch in many foods, including baked goods (Leibrand et al., 1985).

Polydextrose is a randomly bonded melt-condensation polymer of dextrose, containing small amounts of bound sorbitol and citric acid (Moppett, 1991). Polydextrose has been used to replace sucrose (Dartey and Biggs, 1987; Hood and Campbell, 1990) and fat (Torres and Thomas, 1981; Hewitt, 1993) in cakes, cookies and crackers. No published information was found to date describing the rheological effects of reducing sugar and or fat in plain sweet biscuits using polydextrose.

The aim of this set of experiments was to determine the functional properties of polydextrose (Litesse™) in a plain sweet dough (TB Control) and biscuit and its effects on dough and biscuit properties whilst maximising sugar and fat reductions.
6.2 METHODOLOGY

6.2.1 Texture Profile Analysis (TPA)

After mixing and 30 minutes stand time, the third dough replicate was used for texture profile analysis (TPA) using the TX2 (Figure 3.7.1). The TPA method is detailed in Appendix 9.3.1. The TX2 software automatically calculates the textural properties (as described in Table 2.5) and displays the values on screen. Three TPA tests were performed on each of the dough replicates. The data for the replicates was averaged by the TX2 software to produce a super-average graph from which TPA values were calculated.

6.2.2 Biscuit Puncture

In addition to the biscuit assessments detailed in 3.3.9, biscuits were also punctured on the TX2 using a 4mm diameter solid metal rod and a platform with a 9mm hole (Figure 3.7.2). Details of the method are included in Appendix 9.3.2. Eight biscuits from each replicate with similar bake colour, were punctured in the same position (above the ‘Savoy’ emboss and between the docker holes) to eliminate site puncture variation. Data was averaged over biscuits and replicates by the TX2 software and then plotted. The TX2 automatically calculated peak height and hardness. It was anticipated that biscuit puncturing would allow distinction to be made between crust hardness and internal biscuit hardness which could be compared with biscuit saw times and visual observations of the biscuit interior.
6.3 EXPERIMENTATION

Using an equal weight replacement with polydextrose, maximum reductions of sugar and of fat were determined in the TB Control (Table 6.3). A maximum addition of 60g of polydextrose was possible as levels greater than 80g, even with reduced levels of dough water, produced excessively sticky doughs. The progression of experimentation is displayed in Figure 6.1. The experimental plan for the sugar and fat reductions using polydextrose is summarised in Table 6.1.

Figure 6.1 Flow Chart for Polydextrose Experimentation

* Dough unacceptable and experiment not continued.

Table 6.1 Experimentation for Sugar and Fat Reductions Using Polydextrose.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Sugar Addition (g)</th>
<th>Fat Addition (g)</th>
<th>Polydextrose Replacement (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB Control</td>
<td>60</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>50% Sugar Reduction</td>
<td><strong>30</strong></td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>100% Sugar Reduction</td>
<td>0</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>TB Control</td>
<td>60</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>25% Fat Reduction</td>
<td>60</td>
<td><strong>30</strong></td>
<td>10</td>
</tr>
<tr>
<td>50% Fat Reduction</td>
<td>60</td>
<td><strong>20</strong></td>
<td>20</td>
</tr>
<tr>
<td>PD Control</td>
<td>0</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>10% Fat Removal</td>
<td>0</td>
<td><strong>32</strong></td>
<td>60</td>
</tr>
<tr>
<td>20% Fat Removal</td>
<td>0</td>
<td><strong>36</strong></td>
<td>60</td>
</tr>
</tbody>
</table>
6.4 RESULTS AND DISCUSSION

6.4.1 Dough Mixing

6.4.1.1 Sugar Reduction with Polydextrose

Reductions of 50% and 100% sugar were successfully achieved using polydextrose without affecting dough water addition (Table 6.2). This suggests that polydextrose has a similar affinity for water as sucrose. Torres and Thomas (1981) attributed the similarity between polydextrose and sugar to the water soluble nature of polydextrose. Dough mixing times were similar for the TB Control and 50% sugar reduced dough, whilst the 100% sugar reduced dough required an additional 30 seconds to achieve optimum dough temperature (Table 6.2).

Table 6.2 Effect on Mixing of Sugar Replacement with Polydextrose.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>TB Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Addition (g)</td>
<td>60.0</td>
<td>30.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Polydextrose Addition (g)</td>
<td>0.0</td>
<td>30.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Water Addition (g)</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Mixing 140rpm (seconds)</td>
<td>240</td>
<td>240</td>
<td>270</td>
</tr>
<tr>
<td>Final Slow Speed Power (Watts)</td>
<td>95 - 105</td>
<td>95 - 110</td>
<td>95 - 105</td>
</tr>
<tr>
<td>Initial High Speed Power (Watts)</td>
<td>300 - 325</td>
<td>320 - 340</td>
<td>300 - 320</td>
</tr>
<tr>
<td>Time to Peak (seconds)</td>
<td>150</td>
<td>230</td>
<td>n/a</td>
</tr>
<tr>
<td>Power at Peak (Watts)</td>
<td>305 - 330</td>
<td>300 - 320</td>
<td>n/a</td>
</tr>
<tr>
<td>Final Consistency (Watts)</td>
<td>290 - 310</td>
<td>290 - 320</td>
<td>275 - 290</td>
</tr>
</tbody>
</table>
The TB Control and 50% sugar reduced doughs were most similar in final consistency, power consumption and band width (Table 6.2, Figure 6.2). The 100% sugar reduced dough however, consumed less power, resulting in a slightly concave shaped power curve (Table 6.3, Figure 6.2). There was an apparent delay in the time to peak development for the 50% sugar reduced dough, and no peak observed in the 100% sugar reduced dough (Table 6.2). The difference between power at peak and final consistency was 5Watts for the 50% sugar reduced dough, compared to 20Watts for the TB Control (Figure 6.2).

This delay in peak and apparent reduction in gluten development is in agreement with Anon. (1992), Cauvain (1992b), Mitchell (1992) and Hewitt (1993), that polydextrose reduces the uptake of water by flour protein which reduces gluten development. These authors however reported their findings based on cookies and cakes which are rheologically quite different to plain sweet biscuit doughs.

At the beginning of mixing, the dough temperature of the reduced sugar formulations containing polydextrose, increased rapidly when compared to the TB Control (Figure 6.3). This was thought to be due to the extensive hydrogen bonding of the polydextrose. Simic (1992) thought that the potential for polydextrose to interact through hydrogen bonding was due to the large number of OH groups, low molecular weight and amorphous structure. As polydextrose is highly water soluble, it is also assumed that less energy was required to dissolve polydextrose, compared to the energy required to dissolve sugar in the TB Control.
Figure 6.2   Baseline Corrected Power Curves for Test Bake Control and Doughs with 50% and 100% Sugar Replaced with Polydextrose.

6.2.1  Test Bake Control

6.2.2  50% Sugar Reduction

6.2.3  100% Sugar Reduction
Complete hydration was thought to have occurred at 180 seconds due to the presence of a peak in the power curve of the TB Control (Figure 6.2.1). The dough temperature for all formulations at this point was 38°C. The order of temperature rise reversed after 180 seconds, resulting in the 100% sugar reduced dough requiring an additional 30 seconds mixing to achieve optimum dough temperature.

**Figure 6.3**  Temperature Profile During Mixing Test Bake Control and Doughs with 50% and 100% Sugar Replaced with Polydextrose.

![Temperature Profile Graph](image)

This may suggest increased hydrogen bonding in the TB Control after gluten development which results in the increased rate of temperature rise when compared to the doughs containing polydextrose (Figure 6.3). The polydextrose may be forming less hydrogen bonds or forming weaker bonds within the gluten structure, as shown by the slower rate of temperature rise (Figure 6.3).
6.4.1.2 Fat Reduction with Polydextrose

In the TB Control, 25% and 50% reductions in fat were achieved without affecting dough water addition or sensory acceptability (Table 6.3). Dough toughness increased slightly (50-100Watts) as fat was reduced (Table 6.3, Figure 6.4). Due to this small increase in power, it was suspected that polydextrose has a tenderising effect as reported by Giese (1993).

**Table 6.3 Effect on Mixing of Fat Replacement with Polydextrose.**

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>TB Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat Addition (g)</td>
<td>40.0</td>
<td>30.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Polydextrose Addition (g)</td>
<td>0.0</td>
<td>10.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Water Addition (g)</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Mixing 140rpm (seconds)</td>
<td>240</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Final Slow Speed Power (Watts)</td>
<td>95 - 105</td>
<td>100 - 115</td>
<td>100 - 115</td>
</tr>
<tr>
<td>Initial High Speed Power (Watts)</td>
<td>310 - 340</td>
<td>335 - 355</td>
<td>360 - 380</td>
</tr>
<tr>
<td>Time to Peak (Seconds)</td>
<td>150</td>
<td>190</td>
<td>240</td>
</tr>
<tr>
<td>Power at Peak (Watts)</td>
<td>300 - 340</td>
<td>320 - 350</td>
<td>350 - 375</td>
</tr>
<tr>
<td>Final Consistency (Watts)</td>
<td>280 - 310</td>
<td>315 - 335</td>
<td>355 - 380</td>
</tr>
</tbody>
</table>

There was an obvious delay in gluten development with polydextrose addition as indicated by the shift in peak development (Table 6.3, Figure 6.4). This may suggest that polydextrose inhibits hydration of flour proteins, thereby inhibiting gluten development in a manner similar to sugar or fat. Simic (1992) hypothesised that polydextrose displaces bound water into free water. Therefore it may be possible that during this process, flour hydration and gluten development are delayed. This however
Figure 6.4  Baseline Corrected Power Curves for Test Bake Control and Doughs with 25% and 50% Fat Replaced with Polydextrose.

6.4.1  Test Bake Control

6.4.2  25% Fat Reduction

6.4.3  50% Fat Reduction
is contradictory to reports by Anon. (1992), Cauvain (1992b), Mitchell (1992) and Hewitt (1993), that polydextrose reduces gluten development.

The difference in the initial dough temperature in slow speed mixing was very small (Figure 6.5). The TB Control increased in temperature more gradually when compared to the fat reduced doughs (Figure 6.5). The rate of temperature rise was similar for all formulations, with the fat reduced doughs reaching optimum dough temperature 30 seconds quicker than the TB Control (Table 6.3, Figure 6.5). If the plateau at approximately 31.5°C of the 25% fat reduced dough was the same as the TB Control and 50% fat reduction, the temperature curves during high speed mixing would have been very similar (Figure 6.5).

**Figure 6.5** Temperature Profile during Mixing Test Bake Control and Doughs with 25% and 50% Fat Replaced with Polydextrose.
6.4.1.3 Fat Removal in the Polydextrose (PD) Control

The PD Control was used to determine the fat sparing properties of polydextrose in plain sweet doughs containing 100% polydextrose in replacement for sugar. Levels of up to 30% fat were removed from the PD Control. As levels of 30% produced extremely hard biscuits, a maximum of 20% fat removal was determined in the polydextrose base formulation.

As fat was removed, dough water remained constant (Table 6.4). Power increased slightly with each level of fat reduction (Table 6.4, Figures 6.6) as the doughs became tougher. All power curves showed a broad negative peak which suggested limited gluten development (Figure 6.6). The absence of a positive peak is due to the effect of polydextrose on gluten formation (Figure 6.6).

Table 6.4 Effect on Mixing of Fat Removal in the Polydextrose (PD) Control.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PD Control Formula</th>
<th>10% Fat Reduction</th>
<th>20% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Addition (g)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Fat Addition (g)</td>
<td>40.0</td>
<td>36.0</td>
<td>32.0</td>
</tr>
<tr>
<td>Polydextrose Addition (g)</td>
<td>60.0</td>
<td>60.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Water Addition (g)</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Mixing 140rpm (seconds)</td>
<td>270</td>
<td>270</td>
<td>240</td>
</tr>
<tr>
<td>Final Slow Speed Power (Watts)</td>
<td>95 - 105</td>
<td>100 - 115</td>
<td>100 - 120</td>
</tr>
<tr>
<td>Initial High Speed Power (Watts)</td>
<td>300 - 320</td>
<td>320 - 345</td>
<td>330 - 360</td>
</tr>
<tr>
<td>Final Consistency (Watts)</td>
<td>275 - 290</td>
<td>290 - 310</td>
<td>310 - 335</td>
</tr>
</tbody>
</table>
Figure 6.6  Baseline Corrected Power Curves for Polydextrose Control and Doughs with 10% and 20% Fat Removed.

6.6.1 Polydextrose Control

6.6.2 10% Fat Removal

6.6.3 20% Fat Removal
As illustrated in Figure 6.7, the rate of temperature rise was very similar for the PD Control and doughs with fat removed. The initial rate of temperature rise from 29-33°C occurred within the first 30 seconds, then levelled in order of fat reduction (Figure 6.7). This rapid increase in temperature rise suggests an increase in energy from hydrogen bonding of polydextrose within the dough structure as hypothesised by Simic (1992). After 150 seconds, the rate of temperature rise was the same, suggesting that the mixing time for all doughs should have been constant (Table 6.4, Figure 6.7).

**Figure 6.7  Temperature Profile During Mixing Polydextrose Control and Doughs with 10% and 20% Fat Removed.**
6.4.1.4 Dough Mixing Discussion

Dough water requirements were not affected by the addition of polydextrose as a sugar or fat replacer. This is possibly due to the water soluble nature of polydextrose which suggests that polydextrose has a similar affinity for or effect on water as sucrose and fat together. In wheat flour doughs however, Simic (1992) reported a positive correlation of polydextrose addition with reduced water absorption. As this effect was not observed in the TB Control, it was assumed that the interaction of other dough ingredients affected the rate and degree of hydration. The constant water requirements may also be due to the rate of dissolution of polydextrose as described by Torres and Thomas (1981). This ease of polydextrose dissolution also affected the initial rise in dough temperature on slow speed mixing for all formulations (Figure 6.3, 6.5, 6.7).

Power consumption decreased slightly, as sugar was replaced with polydextrose (Figure 6.2). This reduction in power and dough toughness may be due to tenderising properties of polydextrose and effect on gluten development (Brennan, 1988; Anon., 1992; Cauvain, 1992b; Giese, 1993; Hewitt, 1993), or may be related to water mobility within the dough structure as described by Armbrister and Setser (1994).

There was a delay in peak development when 50% of the sugar and 25% and 50% of the fat were replaced with polydextrose. In all instances the peak was less defined, suggesting less gluten development when compared to the TB Control. Rasper (1993) stated that ingredient additions and interactions may affect the chain length of proteins thereby delaying or enhancing the rate of peak development. This suggests that
polydextrose may interact with the flour proteins as hypothesised by Simic (1992). It is therefore hypothesised here that in plain sweet doughs, polydextrose inhibits gluten development.

Power consumption increased slightly when polydextrose replaced fat in the TB Control (Figure 6.4), and when fat was removed from the PD Control (Figure 6.6). Fat reduction using wheat starch however, was shown to significantly increase mixing resistance and dough toughness (5.3.2). Therefore the tenderising effect of polydextrose is thought to contribute to this small increase in power consumption.

An increase in mixing resistance and dough strength was also reported in wheat flour doughs by Simic (1992) who hypothesised that polydextrose enhanced crosslinking between protein polymers which in turn imparts resilience and strength to the dough. In plain sweet biscuit doughs however, dough toughness is affected by the interaction of other dough ingredients as well as the effect of polydextrose on gluten formation rather than a single effect of polydextrose as observed by Simic (1992).

Polydextrose replacement for sugar or fat had a significant effect on the initial rate of temperature rise on slow speed mixing. As polydextrose was added, the initial rate of temperature rise increased more than the TB Control. This also occurred when sugar and fat were replaced with wheat starch (5.3.1), in which the PS Control also showed a slower rate in initial temperature rise. This temperature difference is presumed to be due to the energy required for dissolution of polydextrose compared to sugar, and the increased hydrogen bonding involving polydextrose.
Dartey and Biggs (1986; 1987), Frye and Setser (1993) and Rosenthal (1995), reported lumping in cookies and cakes when polydextrose was added in replacement for sucrose or fat. Lumping, however was not observed in any of the experimental plain sweet biscuit doughs. This was postulated to be due to the difference in formulations, shear mixing action and rate of dissolution. Biscuit doughs however were confirmed to be gummy and lacked extensibility when assessed by hand after mixing. This was verified by texture profile analysis (6.4.2).

Based on mixing, the effect of polydextrose addition in replacement for sugar and fat was not notably different to the TB Control. Polydextrose appeared to have minimal effects on dough rheological properties when compared to the replacement of sugar and fat with wheat starch (5.3.1). In plain sweet biscuit doughs, polydextrose was a functional bulking agent allowing a maximum reduction of 100% sugar and 50% of fat without detrimentally affecting sensory acceptability.
6.4.2 Texture Profile Analysis

6.4.2.1 Sugar Reduction with Polydextrose

The texture profile analysis for the sugar reduced doughs is displayed graphically in Figure 6.8 with results shown in Table 6.5. As sugar was replaced with polydextrose, dough toughness increased as indicated by the increase in initial stress and peak hardness (Table 6.5). This however contradicts the final dough consistency as indicated by the power curves (Figure 6.2) and may be due to the slow speed at which TPA was performed compared to the high shear mixing action. The difference in dough temperature during mixing and TPA analysis may also contribute to this effect.

Figure 6.8 Texture Profile Analysis graph for Test Bake Control and Doughs with 50% and 100% Sugar Replaced with Polydextrose.
Table 6.5  Texture Profile Analysis for Test Bake Control and Doughs with 50% and 100% Sugar Replaced with Polydextrose.

<table>
<thead>
<tr>
<th>Texture Profile Parameter</th>
<th>TB Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Hardness 1 (g)</td>
<td>2070</td>
<td>2349</td>
<td>2656</td>
</tr>
<tr>
<td>Peak Hardness 2 (g)</td>
<td>1605</td>
<td>1838</td>
<td>1996</td>
</tr>
<tr>
<td>Initial Stress (dyns/cm²)</td>
<td>$1.969 \times 10^5$</td>
<td>$2.049 \times 10^5$</td>
<td>$2.290 \times 10^5$</td>
</tr>
<tr>
<td>Resilience</td>
<td>0.042</td>
<td>0.034</td>
<td>0.035</td>
</tr>
<tr>
<td>Springiness</td>
<td>0.353</td>
<td>0.349</td>
<td>0.300</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.302</td>
<td>0.302</td>
<td>0.281</td>
</tr>
<tr>
<td>Chewiness</td>
<td>221</td>
<td>248</td>
<td>224</td>
</tr>
<tr>
<td>Gumminess</td>
<td>625</td>
<td>710</td>
<td>745</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>-278</td>
<td>-219</td>
<td>-245</td>
</tr>
</tbody>
</table>

The decrease in resilience and springiness suggested that the doughs did not return to their original shape after deformation. This is consistent with reduced cohesiveness and increased disruption of the gluten network with subsequent loss of elasticity. This effect was also observed during sheeting. The dough was least adhesive at the 100% sugar replacement level, and most chewy and least adhesive at the 50% sugar replacement level (Table 6.5). Gumminess increased (Table 6.5) which was consistent with the feel of the dough, reduced extensibility and also with reports by Neville and Setser (1986), Dartey and Biggs (1987) and Pong et al., (1991).
6.4.2.2 Fat Reduction with Polydextrose

As fat was replaced with polydextrose, dough hardness increased as indicated by the greater peak heights (Figure 6.9) and initial stress (Table 6.6). The replacement of fat with polydextrose produced an increase in all calculated TPA parameters (Table 6.6). Most of these increases were incremental with the level of fat reduction, except for springiness, cohesiveness and adhesiveness which were greatest at the 25% fat reduced level (Table 6.6).

Figure 6.9 Texture profile analysis graph for Test Bake Control and Doughs with 25% and 50% Fat Replaced with Polydextrose.
Table 6.6  Texture Profile Analysis of Test Bake Control and Doughs with 25% and 50% Fat Replaced with Polydextrose.

<table>
<thead>
<tr>
<th>Texture Profile Parameter</th>
<th>TB Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Hardness 1 (g)</td>
<td>2029</td>
<td>2114</td>
<td>2616</td>
</tr>
<tr>
<td>Peak Hardness 2 (g)</td>
<td>1618</td>
<td>1777</td>
<td>2173</td>
</tr>
<tr>
<td>Initial Stress (dyns/cm²)</td>
<td>2.122 x 10⁵</td>
<td>2.146 x 10⁵</td>
<td>2.288 x 10⁵</td>
</tr>
<tr>
<td>Resilience</td>
<td>0.040</td>
<td>0.041</td>
<td>0.043</td>
</tr>
<tr>
<td>Springiness</td>
<td>0.303</td>
<td>0.324</td>
<td>0.312</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.302</td>
<td>0.333</td>
<td>0.323</td>
</tr>
<tr>
<td>Chewiness</td>
<td>186</td>
<td>228</td>
<td>264</td>
</tr>
<tr>
<td>Gumminess</td>
<td>613</td>
<td>704</td>
<td>846</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>-253</td>
<td>-303</td>
<td>-259</td>
</tr>
</tbody>
</table>

Therefore the addition of polydextrose in replacement for fat produced significantly harder doughs which required a greater force in deformation, hence the resultant increase in texture profile parameters compared to the TB Control (Table 6.6). The increase in cohesiveness was contradictory to the effect of polydextrose in shortbread cookies (Neville and Setser, 1986) which decreased in cohesiveness. This is most probably due to the difference in formulation.
6.4.2.3 Fat Removal in the Polydextrose (PD) Control

As fat was removed from the PD Control, dough toughness increased as indicated by the increase in peak hardness and initial stress (Figure 6.10, Table 6.7). This is consistent with the increase in power consumed during mixing (Figure 6.6). Resilience, cohesiveness, gumminess and chewiness increased whilst dough springiness and adhesiveness decreased. All changes were consistent in direction (Table 6.7).

Figure 6.10 Texture Profile Analysis Graph for Polydextrose Control and Doughs with 10% and 20% Fat Removed.
Table 6.7  Texture Profile Analysis for Polydextrose Control and Doughs with 10% and 20% Fat Removed.

<table>
<thead>
<tr>
<th>Texture Profile Parameter</th>
<th>PD Control Formula</th>
<th>10% Fat Reduction</th>
<th>20% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Hardness 1 (g)</td>
<td>2656</td>
<td>2822</td>
<td>3038</td>
</tr>
<tr>
<td>Peak Hardness 2 (g)</td>
<td>1996</td>
<td>2131</td>
<td>2317</td>
</tr>
<tr>
<td>Initial Stress (dyns/cm²)</td>
<td>2.290 x 10⁵</td>
<td>2.317 x 10⁵</td>
<td>2.370 x 10⁵</td>
</tr>
<tr>
<td>Resilience</td>
<td>0.035</td>
<td>0.038</td>
<td>0.042</td>
</tr>
<tr>
<td>Springiness</td>
<td>0.300</td>
<td>0.296</td>
<td>0.295</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.281</td>
<td>0.284</td>
<td>0.288</td>
</tr>
<tr>
<td>Chewiness</td>
<td>224</td>
<td>238</td>
<td>258</td>
</tr>
<tr>
<td>Gumminess</td>
<td>745</td>
<td>803</td>
<td>875</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>-245</td>
<td>-233</td>
<td>-210</td>
</tr>
</tbody>
</table>

The increase in initial stress and reduction in springiness (Table 6.7), implied reduced elasticity which was observed during sheeting. The removal of fat from the PD Control caused a substantial increase in gumminess when compared to the effect of polydextrose in sugar and fat reduction (Table 6.5, 6.6).
6.4.2.4 Texture Profile Analysis Discussion

As polydextrose was used to replace sugar and fat and further reduce fat in the 100% sugar reduced dough (PD Control), dough toughness increased. The fat reduced doughs were the hardest as indicated by the greatest force and initial stress measured during penetration. The area under the curves increased with the increase in peak hardness which Kunerth (1985) suggests is indicative of increased dough strength. The final consistency of the power curves however do not correlate with the TPA values for hardness. This was thought to be due to the difference in dough temperature at the end of mixing (40-42°C), compared to the dough temperature at time of TPA (30-35°C). Miller (1985) however reported that soft doughs are least affected by changes in temperature greater than 23°C when compared to high protein doughs. Therefore, the effect of dough temperature on TPA needs to be further investigated.

Cohesiveness increased when polydextrose replaced fat (Table 6.6, 6.7) and decreased when polydextrose replaced sugar (Table 6.5). According to Bourne (1993), cohesiveness is related to the make up of internal bonds and is the extent to which a material deforms prior to rupturing. The change in cohesiveness is consistent with the increase and decrease in power consumption and dough consistency at the end of mixing. Armbrister and Setser (1994) also reported similarities in dough consistency for cookies made with 0% and 50% fat replacement with polydextrose. Darrey and Biggs (1987) reported that when polydextrose was used in replacement for fat in crackers, the doughs were less cohesive. This may be due to the high protein content of the flour. Neville and Setser (1986) and Lim et al., (1989) also reported reduced
cohesiveness of dough mass when polydextrose was used in replacement for sucrose. This is consistent with the observed results for the plain sweet dough.

Gumminess is the product of a low degree of hardness and a high degree of cohesiveness and is related to density and the energy required to disintegrate a semi-solid food (Brennan, 1988). All formulations containing polydextrose increased in gumminess. Increased gumminess was also reported by Dartey and Biggs (1986; 1987), Neville and Setser (1986) and Pong et al., (1991), who reported increased gumminess in reduced energy cookies and cakes which contained elevated levels of polydextrose.

Adhesiveness was not affected by polydextrose addition, as all doughs exhibited a consistently low degree of adhesiveness. Manley (1991), reported that a high adhesiveness is usually accompanied by low hardness, hence the opposing effect of low adhesiveness with high hardness may be expected.
6.4.3 Dough Sheeting

6.4.3.1 Sugar Reduction

Raw dough weight increased as sugar was replaced with polydextrose with the 50% sugar reduced dough showing a greater increase in raw dough weight and density (Table 6.8). Dough spring back also increased (Table 6.8), indicating an increase in dough toughness and resistance to extension and deformation. This is consistent with TPA results (Table 6.5) for springiness and resilience, rather than an increase in elasticity. The doughs containing polydextrose had the same dimensions and contracted slightly when compared to the TB Control (Table 6.8).

Visual observation of the sheeting process revealed that the addition of polydextrose reduced dough sheen and smoothness. The dough also became thicker and more dense. At the 100% sugar reduced level, the dough was slightly holey and exhibited an orange peel surface. Sheeting extension decreased substantially and the dough felt extremely gummy. Increased gumminess is consistent with TPA results (6.4.2.1).

Table 6.8 Effect on Sheeting of Sugar Replacement with Polydextrose.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>TB Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>74.71</td>
<td>83.11</td>
<td>81.33</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>1.1</td>
<td>1.17</td>
<td>1.15</td>
</tr>
<tr>
<td>Spring Back</td>
<td>1.94</td>
<td>2.06</td>
<td>2.06</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.7</td>
<td>50.5</td>
<td>50.5</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>51.7</td>
<td>51.0</td>
<td>51.0</td>
</tr>
<tr>
<td>Dough Piece Height (mm)</td>
<td>3.3</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>
6.4.3.2 Fat Reductions with Polydextrose

Raw dough weights and dough density increased as polydextrose replaced 25% and 50% of the fat (Table 6.9). Dough dimensions and spring back were similar to the TB Control except for the slight increase in dough piece height (Table 6.9). Hence, at the 25% fat reduction level, the dough exhibited slightly greater elasticity and consistency and was slightly tougher and more resistant to sheeting. This increase in elasticity is consistent with increased springiness and cohesiveness from TPA results (6.4.2.2). As fat was replaced with polydextrose, the dough colour became more white and dull compared to the yellow TB Control. At the 50% reduction level, the dough was slightly sticky and had reduced extension during sheeting.

Table 6.9 Effect on Sheet of Fat Replacement with Polydextrose.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>TB Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>74.33</td>
<td>80.29</td>
<td>84.96</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>1.14</td>
<td>1.19</td>
<td>1.30</td>
</tr>
<tr>
<td>Spring Back</td>
<td>1.88</td>
<td>1.94</td>
<td>1.88</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.5</td>
<td>50.5</td>
<td>50.5</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>51.5</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Dough Piece Height (mm)</td>
<td>3.2</td>
<td>3.3</td>
<td>3.2</td>
</tr>
</tbody>
</table>
6.4.3.3 Fat Reduction in the Polydextrose (PD) Control

Raw dough weight and density increased as fat was removed from the PD Control (Table 6.10). Dough piece dimensions and spring back were constant except for the slight reduction at the 10% level of fat removal. During weighing of the dough pieces, it was observed that the dough pieces lost 0.001g per second. This loss in moisture may have contributed to the reduced ability of the dough to stretch during sheeting. The removal of fat also reduced elasticity and gumminess as confirmed by TPA (6.4.2.3).

Table 6.10 Effect On Sheet of Fat Removal in the Polydextrose (PD) Control.

<table>
<thead>
<tr>
<th>Dough Parameter</th>
<th>PD Control Formula</th>
<th>10% Fat Removed</th>
<th>20% Fat Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Dough Weight (g)</td>
<td>81.33</td>
<td>84.98</td>
<td>85.64</td>
</tr>
<tr>
<td>Density (g cm$^{-3}$)</td>
<td>1.15</td>
<td>1.22</td>
<td>1.20</td>
</tr>
<tr>
<td>Spring Back</td>
<td>2.06</td>
<td>2.00</td>
<td>2.06</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>50.5</td>
<td>50.5</td>
<td>50.5</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>51.0</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Dough Piccc Height (mm)</td>
<td>3.5</td>
<td>3.4</td>
<td>3.5</td>
</tr>
</tbody>
</table>
6.4.3.4 Sheet ing Discussion

The addition of polydextrose to replace sugar and fat and remove fat, produced tougher doughs with increased resistance to sheeting. Doughs were more dense and less elastic which was indicated by the increase in raw dough weight and relatively constant dough dimensions.

Pateras et al. (1994), reported an increase in density in cakes containing polydextrose due to the number and size of air bubbles. This may be related to ingredient interactions due to the amorphous structure of polydextrose, compared to the crystalline nature of sucrose. Polydextrose lacks the ability to promote fat crystal aggregate breakdown to a more favourable size distribution during mixing (Pateras et al., 1994), hence may contribute to the increase in density as polydextrose was used in replacement for fat.

The increased resistance to extension is consistent with the increased hardness as polydextrose was used to replace sugar and fat. This may be due to the tight network consequential to the hydrogen bonding of polydextrose with protein molecules.
6.4.4 Baking and Texture Assessments

6.4.4.1 Sugar Reduction with Polydextrose

Results for the biscuits made with polydextrose replacements for sugar are shown in Table 6.11. Bake time was increased to ensure complete moisture removal and optimum bake colour, but resulted in 1% and 5% of biscuits checking. Biscuit density increased as did shrinkage with the sheeting direction (Table 6.11). This is also typical of excessively stressed doughs and is likely to be related to the doughs increased resistance to extension observed during sheeting.

Table 6.11 Effect on Baking of Sugar Replacement with Polydextrose.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>TB Control Formula</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bake Time (minutes)</td>
<td>15</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>58.94</td>
<td>65.55</td>
<td>64.31</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>0.48</td>
<td>0.50</td>
<td>0.51</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>50.6</td>
<td>49.7</td>
<td>49.4</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>51.2</td>
<td>51.0</td>
<td>51.3</td>
</tr>
<tr>
<td>Biscuit Height (mm)</td>
<td>6.1</td>
<td>6.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>63.6</td>
<td>71.6</td>
<td>64.3</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>50</td>
<td>43</td>
<td>44</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Biscuit height and packet length increased substantially for the 50% sugar reduced biscuits and slightly for the 100% level when compared to the TB Control (Table 6.11). This is thought to be due to the ability of polydextrose to affect the starch gelatinisation temperature and increase air bubble size, which results in increased volume during
baking. As shown in Figure 6.11 however, there appears to be a larger number of smaller air cells in the sugar reduced biscuits compared to the TB Control. However, polydextrose addition did not markedly affect the appearance of the internal biscuit structure. Hence the increase in raw dough weight may be the primary contributing factor of increased packet length.

**Figure 6.11**  Internal Biscuit Structure for TB Control (A), 50% (B) and 100% (C) Sugar Reduced Biscuits using Polydextrose.

Due to the replacement of sugar with polydextrose, the time required to saw through the stack of biscuits was consistently lower than the TB Control (Table 6.11). This reduction in biscuit hardness may have been due to the greater number of smaller air cells and layering of the internal structure (Figure 6.11). The increase in biscuit height and reduced number of biscuits within the stack may also contribute to the reduced saw time due to difference in the proportion of crust and biscuit interior.
Biscuit probing confirmed that the replacement of sugar with polydextrose reduced biscuit hardness (Figure 6.12). The force required to probe the crust and biscuit interior decreased in order of sugar reduction. Reduced biscuit hardness is speculated to be due to the tenderising properties of polydextrose as described by Freeman (1982), Altschul (1989) and Giese (1993). It is therefore hypothesised that the amorphous structure of polydextrose may have affected the biscuit texture differently to the crystalline structure of sucrose as described by Torres and Thomas (1981).

Figure 6.12  Biscuit Puncture Assessment for Test Bake Control and Biscuits with 50% and 100% Sugar Replaced with Polydextrose.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>TB Control Form.</th>
<th>50% Sugar Reduction</th>
<th>100% Sugar Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crust Hardness (g)</td>
<td>3321</td>
<td>3253</td>
<td>3049</td>
</tr>
<tr>
<td>Internal Biscuit Hardness (g)</td>
<td>2465</td>
<td>2171</td>
<td>2283</td>
</tr>
</tbody>
</table>
As indicated by the biscuit puncture curve (Figure 6.12), the crust hardness decreased slightly as sugar was replaced with polydextrose. However, the internal structure however for the doughs containing polydextrose required a smaller force to puncture than the TB Control (Figure 6.12). The 100% sugar reduced dough did not display a negative peak between the crust and internal structure as illustrated in Figure 6.12. The slight delay in the internal peak and continued probing through the 50% sugar reduced biscuit may be related to the increased biscuit height (Table 6.11).
6.4.4.2 Fat Reduction with Polydextrose

Despite the increase in bake time, a small percentage of biscuits containing polydextrose in replacement for fat checked (Table 6.12). This increase in bake time was primarily due to the reduced heat transfer rate consequential to the reduction in fat. As fat was replaced with polydextrose, biscuit density decreased (Table 6.12). As the biscuit dimensions were similar, the change in density was attributed to the increase in biscuit height as observed in Figure 6.13. As polydextrose replaced fat, biscuit saw times decreased slightly (Table 6.12), indicating that polydextrose addition affected a reduction in biscuit hardness, thereby producing a more tender biscuit.

Table 6.12  Effect on Baking of Fat Replacement with Polydextrose.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>TB Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bake Time (minutes)</td>
<td>15</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>58.33</td>
<td>63.18</td>
<td>66.90</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>0.47</td>
<td>0.45</td>
<td>0.44</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>50.8</td>
<td>50.9</td>
<td>50.7</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>51.3</td>
<td>51.2</td>
<td>51.4</td>
</tr>
<tr>
<td>Biscuit Height (mm)</td>
<td>6.1</td>
<td>6.8</td>
<td>7.4</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>63.8</td>
<td>72.5</td>
<td>79.6</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>49</td>
<td>44</td>
<td>43</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>0</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

As fat was replaced with polydextrose, the internal biscuit structure appeared to have a slightly more linear alignment, suggesting a larger number of smaller air cells (Figure 6.13). This may have contributed to the increase in expansion during baking and subsequently greater biscuit height (Table 6.12).
Figure 6.13 Internal Biscuit Structure for TB Control (A), 25% (B) and 50% (C) Fat Reduced Biscuits using Polydextrose.

There was a slight but insignificant decline in crust hardness between the TB Control and fat reduced biscuits (Figure 6.14). The force required to penetrate the internal biscuit layers however increased substantially as fat was replaced with polydextrose. As shown in Figure 6.14, the time taken to maximum internal biscuit hardness increased with each level of fat reduction. This was due to the increase in biscuit height (Table 6.12, Figure 6.13).

The decrease in saw times (Table 6.12) however indicated a slight reduction in hardness which correlates with the slight reduction in biscuit crust hardness (Figure 6.14). The effect of less biscuits within the stack is also thought to contribute to the reduction in saw time due to less crust being present.
Figure 6.14  Biscuit Puncture Assessment for Test Bake Control and Biscuits with 25% and 50% Fat Replaced with Polydextrose.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>TB Control Formula</th>
<th>25% Fat Reduction</th>
<th>50% Fat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crust Hardness (g)</td>
<td>3389</td>
<td>3388</td>
<td>3372</td>
</tr>
<tr>
<td>Internal Biscuit Hardness (g)</td>
<td>2309</td>
<td>2605</td>
<td>3593</td>
</tr>
</tbody>
</table>
6.4.4.3 Fat Removal in the Polydextrose (PD) Control

Bake results for the removal of fat in the PD Control formulation are shown in Table 6.13. Bake time increased slightly but resulted in a small percentage of biscuits checking. Biscuit densities for the fat reduced doughs were similar. Biscuit dimensions contracted with and across the direction of sheeting, with an increase in biscuit height and packet length being observed.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>PD Control Formula</th>
<th>10% Fat Removed</th>
<th>20% Fat Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bake Time (minutes)</td>
<td>17</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Baked Dough Weight (g)</td>
<td>64.31</td>
<td>67.34</td>
<td>67.40</td>
</tr>
<tr>
<td>Density (g cm⁻³)</td>
<td>0.51</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Width With (mm)</td>
<td>49.4</td>
<td>49.3</td>
<td>49.0</td>
</tr>
<tr>
<td>Width Across (mm)</td>
<td>51.3</td>
<td>51.0</td>
<td>50.7</td>
</tr>
<tr>
<td>Biscuit Height (mm)</td>
<td>6.3</td>
<td>6.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Packet Length (mm)</td>
<td>64.3</td>
<td>76.3</td>
<td>76.7</td>
</tr>
<tr>
<td>Saw Time (seconds)</td>
<td>44</td>
<td>43</td>
<td>45</td>
</tr>
<tr>
<td>Checking (%)</td>
<td>5</td>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

Biscuit saw times were almost constant indicating similar biscuit hardness. Pateras et al., (1994), reported that the crystallinity of sucrose is important during aeration as it improves the ability of the fat to take up and retain air. As the PD Control had 100% polydextrose addition in replacement for sugar, it is hypothesised that in plain sweet biscuits, air inclusion is not affected by the amorphous structure of polydextrose in replacement for sugar. This is verified by the increase in biscuit height and packet
length (Table 6.13). All biscuits required a similar force to puncture the crust as illustrated in Figure 6.15, with the removal of fat affected a reduction in crust hardness. The internal biscuit hardness increased as fat was removed (Figure 6.14). The slight delay in reaching internal peak hardness was due to the increased biscuit height (Table 6.13).

**Figure 6.15**  
Biscuit Puncture Assessment for Polydextrose Control and Biscuits with 10% and 20% Fat Removed.

<table>
<thead>
<tr>
<th>Biscuit Parameter</th>
<th>PD Control Formula</th>
<th>10% Fat Removed</th>
<th>20% Fat Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crust Hardness (g)</td>
<td>3036</td>
<td>3308</td>
<td>3243</td>
</tr>
<tr>
<td>Internal Biscuit Hardness (g)</td>
<td>2169</td>
<td>2487</td>
<td>2540</td>
</tr>
</tbody>
</table>
6.4.4.4 Biscuit Texture Discussion

In all formulations, polydextrose affected a slight reduction in crust hardness (Figures 6.12, 6.14, 6.15). The changes in the degree of hardness for the interior biscuit structure appeared to correlate with changes in biscuit density. For the sugar reductions, the interior biscuit hardness decreased with an increase in density (Table 6.11), whilst the opposite effect occurred with the fat reductions. Hence, when polydextrose was used in replacement for fat, biscuit density decreased (Table 6.12, 6.13), resulting in an increase in internal biscuit hardness (Figure 6.14, 6.15). This implies that density is not the only contributing factor affecting biscuit hardness. Therefore the amorphous structure of polydextrose may be contributing to this effect on biscuit tenderness and density.

Polydextrose was effective in replacing sugar and fat and in providing a suitable base for fat removal. This resulted in an increase in biscuit height and packet length (Table 6.11-6.13). The increase in biscuit height and packet length is speculated to be due to the ability of the polydextrose to increase air bubble size as reported in sponge cakes (Simic, 1992; Pateras et al., 1994). The ability of polydextrose to alter the starch gelatinisation temperature in a manner similar to sucrose (Kim and Setser, 1992), thereby allows a longer time for leavening gases to expand the structure as reported by Neville and Setser (1986). This is thought to contribute to the increase in biscuit height. Lim et al., (1989), also stated the amorphous structure of polydextrose increases viscosity and mouthfeel, which may also contribute to the rise during baking. Regression analysis also indicated that raw dough weight correlated with packet length.
Therefore the increase in dough weight as polydextrose replaced sugar and fat, may contribute to the observed increase in biscuit height and packet length when compared to the TB and PD Controls.

Polydextrose also consistently produced a softening effect on biscuit hardness. This is related to the tenderisation properties of polydextrose as described by Neville and Setser (1986) and Giese (1993). This decrease in hardness was shown by the reduced saw times and decreased crust hardness by biscuit puncture. This effect of polydextrose reducing hardness in the plain sweet biscuit is contradictory to reports by Neville and Setser (1986), Dartey and Biggs (1987) and Lim et al., (1989) who reported that polydextrose addition increased biscuit hardness and fracturability in cookies and crackers.
6.4.4.5 Sensory Evaluation

The TB Control was a crisp, plain sweet biscuit with a moderate bite. The biscuit was crunchy with a slightly dry mouthfeel when chewed. As polydextrose replaced sugar in the formula, sweetness decreased as expected with a non-sweet and slightly bitter aftertaste. The biscuits appeared to be slightly crisper and harder on the first bite which is consistent biscuit puncture results. Upon chewing, the biscuits containing polydextrose were similar in crunchiness compared to the TB Control.

Biscuits containing polydextrose were moister than the TB Control. This is due to the tenderising and humectant properties of polydextrose. All biscuits containing polydextrose increased in gumminess as reported by Neville and Setser (1986), Pong et al. (1991) and Campbell et al., (1994) and indicated by TPA results. At the 100% sugar replacement level, the biscuits were very mouth drying and required additional saliva prior to swallowing. This dryness is typical of the effects of bulking agents. Bake colour was similar, due to polydextrose participating in Maillard reactions (Figure 6.16, 6.17). The biscuit surface was very smooth, with a slight sheen and smooth bottoms with fine crumb and holes.

Figure 6.16 TB Control Biscuits.
As fat was replaced with polydextrose, the initial bite of the biscuits were equally hard, but the internal texture was more crunchy. As fat was decreased, bake colour was slightly paler, but the biscuits exhibited a smooth surface and slight sheen (Figure 6.18). A slightly bitter and acidic aftertaste was detected in the fat reduced biscuits. When fat was removed from the PD Control, biscuit hardness increased. The biscuits were more gummy and contained very small holes on the base. There was no significant difference in the appearance of the experimental biscuits, except in the biscuit colour from the degree of bake. Simic (1992) and Armbrister and Setser (1994), however reported an increase in colour of cakes and cookies due to polydextrose addition.
6.4.6 Energy Contributions

As listed in Table 6.14, the addition of polydextrose in replacement for sugar and for fat, reduced the total energy as well as affecting a change in energy contributions from sugar and from fat. This reduction in total energy was due to polydextrose contributing only 4.2kJ per gram, compared to sugar (17kJ) and fat (37kJ). This resulted in an 11% reduction in total energy when polydextrose replaced 100% sugar and a 9% energy reduction when 50% of the fat was replaced with polydextrose compared to the TB Control. A 13% reduction in total energy was achieved when fat was removed from the PD Control (Table 6.14).

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Sucrose g / 100g</th>
<th>Fat g / 100g</th>
<th>Total Energy (kJ)</th>
<th>% Energy Contribution From Sugar</th>
<th>From Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB Control</td>
<td>14.6</td>
<td>11.7</td>
<td>1870</td>
<td>13.3</td>
<td>23.2</td>
</tr>
<tr>
<td>50% Sugar Reduction</td>
<td>7.3</td>
<td>11.7</td>
<td>1770</td>
<td>7.0</td>
<td>24.5</td>
</tr>
<tr>
<td>100% Sugar Reduction</td>
<td>0.0</td>
<td>11.7</td>
<td>1670</td>
<td>0.0</td>
<td>25.9</td>
</tr>
<tr>
<td>25% Fat Reduction</td>
<td>14.6</td>
<td>9.1</td>
<td>1790</td>
<td>13.9</td>
<td>18.9</td>
</tr>
<tr>
<td>50% Fat Reduction</td>
<td>14.6</td>
<td>6.6</td>
<td>1700</td>
<td>14.6</td>
<td>14.4</td>
</tr>
<tr>
<td>10% Fat Removal</td>
<td>0.0</td>
<td>10.8</td>
<td>1650</td>
<td>0.0</td>
<td>24.2</td>
</tr>
<tr>
<td>20% Fat Removal</td>
<td>0.0</td>
<td>9.8</td>
<td>1630</td>
<td>0.0</td>
<td>22.2</td>
</tr>
</tbody>
</table>

The energy contributions from sugar and fat in the test bake biscuit were less than the NH&MRC guidelines for fat (30%) and slightly above the guideline for sugar (12%). Because of the reduced energy value of polydextrose, the reduction in sugar and total
energy resulted in increased energy contribution from fat (Table 6.14). Despite this
decrease in total energy, the energy contribution from fat was less than the guidelines
recommendation of 30%. The 100% replacement of sugar with polydextrose also
affected a 0% energy contribution from sucrose in the PD Control (Table 6.14).

Similarly, when fat was replaced with polydextrose, the energy contribution from sugar
increased slightly (Table 6.14), whilst the energy contribution from fat at the 50%
replacement level was reduced to 14.4%. This is consistent with the recommendation
in 5.3.4, that reduced energy contributions from fat can be achieved using a typical
plain sweet formulation.

Using polydextrose to replace sugar and or fat, effectively reduces the total energy
contribution (Table 6.14). Therefore, when both levels of sugar and fat are reduced, as
in the PD Control, the energy contributions from sugar and from fat significantly
exceed the dietary targets. At the 100% sugar reduced level with 20% fat removed,
energy contributions from sugar and from fat were 0% and 22.2% respectively. There
was also a 1.9% reduction in total fat and a 14.6% reduction in sugar from the TB
Control.
6.5 CONCLUSION

Polydextrose was found to be an effective, functional replacer for sugar and for fat in a plain sweet biscuit formulation without detrimentally affecting the sensory acceptability. The resulting biscuits had large reductions in total energy, and substantially exceeded the energy recommendations from fat and from sugar when 100% of the sugar was replaced with polydextrose and 20% of the fat was removed.
CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

Optimisation of the test bakery equipment to achieve consistent and reproducible plain sweet doughs and biscuits involved a series of modifications and experimentations. Mixing speeds and temperatures were determined, and produced doughs which were rheologically typical of commercial plain sweet biscuit doughs. Upon sheeting and baking in a constant temperature oven, biscuits were rounded with a slight surface sheen and high degree of sensory acceptability.

Using the optimised manufacturing procedure and a modified plain sweet biscuit dough, it was shown that by using wheat starch, substantial reductions in sugar and in fat were achieved without significantly affecting sensory acceptability. When combined levels of sugar and fat were significantly reduced however, biscuits became harder and decreased in acceptability.

Polydextrose (Litesse™) was found to be an effective bulking agent in a typical plain sweet biscuit dough. Significant proportions of sugar and of fat were separately replaced with equal weights of polydextrose without affecting dough water addition or sensory acceptability. A formulation containing 100% polydextrose in replacement for sugar with 20% fat removed could be an acceptable base formulation for future work using artificial sweeteners, colourings and flavourings and fat mimetics to produce a lite biscuit.
Reduction of fat in biscuits to meet low fat labelling criteria (less than 3g/100g) was reported to be difficult and challenging (Kelly, 1992; Shukla, 1992) due to the low moisture content. Biscuits made with this very low level of fat were reported to be excessively hard and unacceptable. This is part of the reason why so few biscuits with reduced sugar and fat are available on the Australian and international biscuit markets, and why the interest in and demand for sugar and fat replacers has increased.

Recent technological advancements have resulted in ingredient suppliers designing fat mimetics specifically for baked goods. It has been suggested, that a combination of soluble and insoluble fat replacers produce optimum fat reduction in baked goods (Ang, 1993). Based on the experimentation and literature, it is recommended that sugar reduction may be achieved using 100% sugar replaced with polydextrose in addition with artificial sweeteners such as Alitame™ or Sucralose™ (Stamp, 1990). Fat reduction may be achieved using Oatrim™ (Inglett, 1990) and emulsifiers Panodan (Flack, 1992) and Dur-Lo (Jones, 1995).

Whilst using polydextrose in the plain sweet biscuit formulation, an increase in time to peak development suggested that polydextrose may delay gluten formation. This was thought to be due to a displacement of water during mixing. This hypothesis however is contradictory to Anon. (1992) and Cauvain (1992b), who reported that polydextrose reduces the uptake of water, thereby reducing gluten development. Microscopic investigation of dough at various stages of mixing, may be used to determine the effect of polydextrose on gluten in plain sweet doughs.
The application of differential scanning calorimetry (DSC), may also be used to determine the degree of bound water within the dough and biscuit. This may provide information on the binding properties of polydextrose with water and gluten and determine if polydextrose has an ability to displace water during mixing. DSC may also be used to investigate the effect of polydextrose on starch gelatinisation in the plain sweet dough and biscuit.

It is recommended that biscuits containing low levels of sugar and fat be assessed for moisture content and water activity. Biscuits should be evaluated during their shelf life for loss of acceptability, and changes to flavour and texture. Measuring the changes in texture may be achieved using the biscuit puncture method.
REFERENCES


Armbrister, W.L., and Setser, C.S. 1994. Sensory and physical properties of chocolate chip cookies made with vegetable shortening or fat replacers at 50 and 75% levels. Cereal Chemistry 71(4) 344-351.


Inglett, G.E. 1990. USDA’s Oatrim replaces fat in many food products. Food Technology 44(10) 100.


LaBell, F. 1992. Oat bran has high beta-glucans level. Food Processing 53(7) 84,86.


CHAPTER 9
APPENDIX

9.1 TEST BAKERY EQUIPMENT SPECIFICATIONS

9.1.1 Experimental Dough Mixer Specifications

Bowl
Dimensions 111mm x 126 mm

Motor
Single phase, 3HP, permanent DC Motor, 2.2 kW rating.
Speed 0 - 650rpm
Torque 0 - 12Nm
Manufacturer Baldor Electric Co., Fort Smith, USA.

Metal Sprays
Number 3
Shape Elongated, cone
Dimensions 47mm long x 8.4mm at base, 5.2mm at tip

Water Bath
Model TBC Special, 15 Amp., 240 V.
Manufacturer Thermoline, Smithfield, Australia.

Temperature Control
Model Unistat II Controller, 1050W, 240V
Manufacturer Thermoline, Smithfield, Australia.

Water Bath Pump
Model Type U21, 230V, 250/60H, 0.80/0.60Amp., 130/100W, 2400/3000rpm
Manufacturer Little Giant Pump Co., Oklahoma.
9.1.2 Sheet Roll Specifications

**Motor**
- **Model**: I/M A 5756a-K, 1/2 HP, 935 rpm, 400/440 AC, 1.1 Amp.
- **Manufacturer**: Crompton and Parkinson Pty. Ltd. (Australia)
- **Supplier**: Mangrovite Industries Limited (Australia)

**Temperature Control**
- **Model**: PF - 6AIR-M

9.1.3 Oven Specifications

- **Model**: St George Imperial Delux Wall Oven 370
- **Cavity**: 480 x 408 x 485 mm
- **Dimensions**: Oven 300W, Grill 2700W, Rotisserie 50W
- **Fan**
  - Dimensions: 150mm diameter
  - **Manufacturer**: Westinghouse, Pagewood, Australia.
- **Controller**
  - **Model**: SR41-1Y-OOCO
  - **Manufacturer**: Shimaden Co., Ltd., Tokyo, Japan.
- **Digitron**
  - **Operating Temperature**: 0-50°C
  - **Temperature Range**: -40°C - +160°C ± 0.3°C
  - **Model**: SF10
  - **Manufacturer**: Digitron Instrumentation Limited, UK.
- **Psion Organiser**
  - **Model**: XP
  - **Manufacturer**: Psion UK PLC, England.
9.1.4 TA.TX2 Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td>Maximum force</td>
<td>25kg</td>
</tr>
<tr>
<td>Force Accuracy</td>
<td>0.025%</td>
</tr>
<tr>
<td>Speed Range</td>
<td>0.1 - 10 mm / second</td>
</tr>
<tr>
<td>Modes</td>
<td>Force or distance in tension or compression</td>
</tr>
<tr>
<td>Operating Temp.</td>
<td>0 - 40°C</td>
</tr>
<tr>
<td>Power Supply</td>
<td>220-240V (AC) 50Hz ± 15%</td>
</tr>
<tr>
<td></td>
<td>110V (AC) 60Hz ± 15%</td>
</tr>
</tbody>
</table>

9.1.5 Analytical Balances Specifications

**PMII-N**

100/115V 50-60HP 100mA

**AE 160**

115/220V 50/60HZ 160mA 10VA
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<table>
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<tr>
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<tr>
<td>Flour</td>
<td>Moisture: 10.0 - 14.0%</td>
</tr>
<tr>
<td></td>
<td>Protein: 7.5-8.5%</td>
</tr>
<tr>
<td></td>
<td>Farinograph Water Absorption: 52-59%</td>
</tr>
<tr>
<td></td>
<td>Extensograph Height: 170-230 BU</td>
</tr>
<tr>
<td></td>
<td>Extension: 15-18cm</td>
</tr>
<tr>
<td>Wheat Starch</td>
<td>Moisture: Not greater than 13%</td>
</tr>
<tr>
<td></td>
<td>Protein: Not less than 0.5%</td>
</tr>
<tr>
<td>Vegetable Oil</td>
<td>Shot Melting Point: 43 ± 3°C</td>
</tr>
<tr>
<td></td>
<td>NMR Solids 20°: 35 ± 5</td>
</tr>
<tr>
<td>Icing Sugar</td>
<td>Moisture: Less than 0.1%</td>
</tr>
<tr>
<td></td>
<td>Wheat Starch: 2-4%</td>
</tr>
<tr>
<td>Invert Syrup</td>
<td>Moisture: 24-26%</td>
</tr>
<tr>
<td></td>
<td>Reducing Sugars: Greater than 90%</td>
</tr>
<tr>
<td>Golden Syrup</td>
<td>Moisture: 22-26%</td>
</tr>
<tr>
<td></td>
<td>Reducing Sugars: 42-47%</td>
</tr>
<tr>
<td></td>
<td>Sucrose: 24-28%</td>
</tr>
<tr>
<td>Full Cream Milk Powder</td>
<td>Fat: Not less than 26%</td>
</tr>
<tr>
<td></td>
<td>Moisture: Not greater than 5%</td>
</tr>
<tr>
<td></td>
<td>Protein: 27.5 ± 2.5%</td>
</tr>
<tr>
<td>Salt</td>
<td>Assay: Not less than 99.6%</td>
</tr>
<tr>
<td>Sodium Metabisulphite (Na$_2$S$_2$O$_5$)</td>
<td>Assay: Not less than 95%</td>
</tr>
<tr>
<td>Sodium Bicarbonate (NaHCO$_3$)</td>
<td>Assay: Not less than 99%</td>
</tr>
<tr>
<td>Ammonium Bicarbonate (NH$_4$HCO$_3$)</td>
<td>Assay: Not less than 97%</td>
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# Polydextrose Certificate of Analysis

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Pfizer Inc., Terre Haute, Indiana</th>
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<tr>
<td>Lot Number</td>
<td>V39151-S6820 - 25P</td>
</tr>
<tr>
<td>Product Code</td>
<td>S6820</td>
</tr>
<tr>
<td>Date of Manufacturer</td>
<td>15 September, 1993</td>
</tr>
<tr>
<td>Date of Analysis</td>
<td>26 May, 1994</td>
</tr>
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<table>
<thead>
<tr>
<th>Appearance</th>
<th>White to cream coloured powder</th>
</tr>
</thead>
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<tr>
<td>Assay as Polydextrose</td>
<td>94.3%</td>
</tr>
<tr>
<td>Levoglucosan</td>
<td>2.3%</td>
</tr>
<tr>
<td>Glucose</td>
<td>2.8%</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>1.9%</td>
</tr>
<tr>
<td>Water</td>
<td>0.5%</td>
</tr>
<tr>
<td>pH</td>
<td>3.4</td>
</tr>
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9.3 TEX​TURE ANALYSER METHODS

9.3.1 Texture Profile Analysis Method

Objective
Texture profile analysis of biscuit dough by depressing the cone 20mm into 150g of biscuit dough, then waiting 10 seconds for the second pass. TPA is carried out on the super average graph.

TA-TX2 Settings

<table>
<thead>
<tr>
<th>Option</th>
<th>T.P.A</th>
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<tr>
<td>Pre-test Speed</td>
<td>1.0 mm/s</td>
</tr>
<tr>
<td>Test Speed</td>
<td>3.0 mm/s</td>
</tr>
<tr>
<td>Post-Test Speed</td>
<td>10.0 mm/s</td>
</tr>
<tr>
<td>Distance</td>
<td>20.0mm</td>
</tr>
<tr>
<td>Hold Time</td>
<td>10 seconds</td>
</tr>
<tr>
<td>Trigger Force</td>
<td>Auto - 100g</td>
</tr>
<tr>
<td>Data Acquisition Rate</td>
<td>400pps</td>
</tr>
<tr>
<td>Force Threshold</td>
<td>50 g</td>
</tr>
<tr>
<td>Cone Dimensions</td>
<td>30mm diameter x 34mm long</td>
</tr>
<tr>
<td>Surface Area</td>
<td>117.70 mm²</td>
</tr>
</tbody>
</table>

Sample Preparation
After mixing, the dough rests for 30 minutes whilst the sample cup is conditioned at 30-35°C. Cut the dough into three portions, approximately 150g each. Using the sample lid, squash a dough portion singularly into the sample cup. Place the sample cup with dough under the cone and conduct TPA.

Observations
The peaks should be clearly defined. Doughs exhibiting fracturing, or which are excessively sticky should be discarded. The upper force limit for plain sweet doughs is approximately 3000g.
9.3.1 Biscuit Puncture Method

**Objective**

Biscuit hardness measurement by penetrating a 4mm diameter probe (SMS P/4), 5mm into the biscuit surface. The probe should be centred above the 9mm hole in the platform.

**TA-TX2 Settings**

- **Mode:** Measure Force in Compression
- **Option:** Return to Start
- **Pre-test Speed:** 1.0 mm/s
- **Test Speed:** 1.0 mm/s
- **Post-Test Speed:** 10.0 mm/s
- **Distance:** 5.0 mm
- **Trigger Force:** Auto - 5g
- **Data Acquisition Rate:** 400pps
- **Force Threshold:** 200 g
- **Sample Dimensions:** 4mm diameter x 45 mm long
- **Sample Area:** 12.56 mm²

**Sample Preparation**

Samples are removed from their packets prior to puncturing. Biscuits are positioned centrally on the platform with a 9mm hole.

Note: Ensure that the probe will not penetrate a docker hole, over the emboss or close to the biscuit edge. Penetrate in the same position for all biscuits.

**Observations**

A higher force is expected at the baked biscuit surface, especially closest to the biscuit edges. This is followed by a second peak as the probe penetrates the biscuit internal texture. Force fluctuation will result from the open biscuit structure and from the size and variation in air cells. The open structure may result in poor repeatability. Biscuits which fracture should be discarded.
DEVELOPMENT OF BISCUITS
WITH REDUCED LEVELS OF
SUGAR AND FAT

DIANNE S. ROSS

M.Sc (Hons)

Submitted in partial fulfilment of the requirement
for the Degree of Master of Science

Faculty of Food Science and Technology
University Of Western Sydney, Hawkesbury
Richmond, N.S.W., Australia

March, 1996.
PLEASE NOTE

The greatest amount of care has been taken while scanning this thesis,

and the best possible result has been obtained.
DECLARATION

The study presented in this thesis is original and was completed by the author, a postgraduate student in the Faculty of Food Science and Technology, University of Western Sydney, Hawkesbury, N.S.W, Australia, under the supervision of Professor Geoff Skurray.

I certify that the work presented in this thesis has not been submitted to any other University, or Institution for any degree of qualifications. Any help received in preparing this thesis and all sources used, have been acknowledged.

[Signature]
Dianne S. Ross
ACKNOWLEDGEMENTS

This thesis would not have been possible without the financial support of Arnott’s Biscuits Limited. Thanks is also due to Pfizer Food Science for support through the Pfizer Research Scholarship. The author would like to sincerely thank her industrial supervisor, Tas Westcott for his knowledge, time, support and friendship during the planning, experimentation and writing of this thesis, and her academic supervisor Geoff Skurray for always being there when needed. Thanks and appreciation are also extended to Annesley Watson and Ada De Palo for their patience and assistance in editing and compiling this thesis, and for their friendship, guidance and encouragement. The author would also like to thank her family and friends for their support over the past 4 years.
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<td>Baked Dough Weight</td>
<td>The baked weight of 10 raw dough pieces.</td>
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<td>Checking</td>
<td>Fine fractures in biscuit due to internal stresses from moisture equilibration after baking; can result in breaking. Assessed by pull-test.</td>
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<tr>
<td>Checking - visual</td>
<td>Cracks visible to the naked eye which do not necessarily result in biscuit separating on the pull test.</td>
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<tr>
<td>Crumbly</td>
<td>Easily breaks into separate small particles; friable texture.</td>
</tr>
<tr>
<td>Development</td>
<td>Expansion of dough during baking due to the varying property of doughs to retain gas as it is produced.</td>
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<tr>
<td>Dockers</td>
<td>Holes deliberately made in dough sheet to tie surfaces and layers (laminae) together to ensure the biscuit does not balloon during baking.</td>
</tr>
<tr>
<td>Dull</td>
<td>Lacking sheen, gloss or shine.</td>
</tr>
<tr>
<td>Emboss</td>
<td>Indented and distinct pattern on biscuit produced by roll or cutter and which should be reproduced exactly on each biscuit.</td>
</tr>
<tr>
<td>Gloss</td>
<td>A property of surfaces that are smooth and reflective.</td>
</tr>
<tr>
<td>Mouthfeel</td>
<td>Tactile (feeling) sensations perceived in the mouth during or after the ingestion of a food. Sensations may be caused physically or chemically.</td>
</tr>
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<td>Orange Peel Surface</td>
<td>Small blisters (2-3mm across) like the surface of orange peel.</td>
</tr>
<tr>
<td>Packet Length</td>
<td>The length of the 10 biscuits.</td>
</tr>
<tr>
<td>Raw Dough Weight</td>
<td>The weight of 10 dockered and cut dough pieces.</td>
</tr>
<tr>
<td>Saw Time</td>
<td>The time (sec.) required to saw through a stack of biscuits.</td>
</tr>
<tr>
<td>Sheen</td>
<td>Low level of shine on biscuit surface due to correct baking, fermentation, enzyme action or oil spray. Not as shiny as the gloss that would be expected on chocolate.</td>
</tr>
<tr>
<td>Smooth</td>
<td>Flat even surface.</td>
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ABSTRACT

The market drive exists to develop lite foods in Australia. Extensive research has been conducted in the area of dairy products and processed meats. Some research has been carried out on cookies, crackers and cakes, whilst little has been done on plain sweet biscuits. As plain sweet biscuits have a considerable share of the Australian biscuit market, the potential for reducing sugar and fat in this variety was investigated.

An optimised procedure was developed for small scale plain sweet biscuit manufacture. Using this optimised procedure, the functional properties of sugar and of fat were determined using wheat starch as the replacing ingredient. Reductions of up to 100% sugar and 50% fat were successfully achieved separately using wheat starch. Doughs with a combined reduction of 75% sugar and 37.5% fat produced biscuits which were harder than the control and lacked surface sheen and bake colour. Energy contributions from sugar and fat in this formulation were below the NH&MRC dietary targets.

The functional properties of polydextrose (Litesse™) as a sugar and a fat replacer were also determined. Replacements of up to 100% sugar and 50% fat were separately achieved using polydextrose without significantly affecting sensory acceptability. Up to 20% fat was successfully removed from the formulation containing 100% polydextrose in replacement for sugar. The total energy was reduced, with the energy contribution from fat being below, whilst sugar was slightly above the NH&MRC dietary targets.