SUCROSE REDUCTION IN WHITE LAYER CAKE

by

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Abstract

The prevalence of diabetes along with the perceived impact of sugar on health in general has increased the demand for reduced-sugar and sugar-free baked products. Cakes typically contain large quantities of sucrose which affects not only flavor but also color, volume, and texture. This study evaluated the effect of replacing sucrose in white layer cakes with polydextrose and two artificial sweeteners: sucralose and stevia extract. White layer cakes were made using AACCI Method 10-90.01. Batter properties were evaluated by measuring specific gravity. Volume index was measured using a cake template (AACCI Method 10-91.01). Slice area, number of cells, number of holes, and wall thickness of the crumb were calculated and recorded using C-Cell Cake Imaging system. Control batter made with 135% water had a specific gravity of 0.90 g/cc and a cake volume index of 112. The cakes had a nicely golden brown, shiny surface. The crumb grain was fine with an even cell distribution. Optimum water level and baking time were obtained for each cake variation. Although replacing sucrose with polydextrose had no significant effect on specific gravity ($p>0.05$), a 25% replacement resulted in a cake with a volume index of 110, 50% with an index of 105, 75% with an index of 103, and 100% with an index of 97. The crumb grain was similar to the control cake. Adding sucralose and stevia yielded similar results, where lower volumes were recorded as polydextrose and sucralose/stevia were increased in the cake formula. Complete replacement of sucrose with polydextrose and sucralose or polydextrose and stevia produced an acceptable volume of cake. The number of holes and wall thickness of the crumb was not significantly different in any cake variation. Therefore, polydextrose and both sucralose and stevia are suitable as sucrose replacers in cakes.
Key indexing terms: cakes, polydextrose, stevia, sucralose.

Table of Contents

List of Figures v

List of Tables vii

Acknowledgements viii

Chapter 1 - Literature Review 1

Introduction 1

Sucrose functionality 2

Other ingredients functionality 4

Flour 5

Shortening 7

Egg Whites 8

Non-fat Dry Milk 9

Chemical Leavening Agents 10

Salt 11

Water 11

Artificial Sweeteners 12

Sucralose 12

Stevia Extract 14

Bulking Agent 15

Polydextrose 15

Conclusion 19

References 20

Chapter 2 - Sucrose Reduction in White Layer Cakes 25

Introduction 25

Objectives 26

Materials and Methods 27

Ingredients 29

Cake Formulation 29

Cake Preparation 30
Batter Specific Gravity 30
Measurement of physical and sensory analysis of cake 31
Cake Volume 31
C-Cell Cake Imaging System 31
Data Analysis 32
Results and Discussions 33
Cakes formulated using polydextrose 33
Cakes formulated using polydextrose and sucralose blend 37
Cakes formulated using polydextrose and stevia extract 42
Conclusions 46
References 47
Appendix A - SAS program 49

List of Figures

Figure 1.1 Effect of moisture content on gelatinization temperature of wheat starch (Adapted from Beleia et al 1996). 4

Figure 1.2 Schematic representation of changes that occur in a starch-water mixture during heating, cooling, and storage. I, Native starch granules; II gelatinization (associated with swelling [IIa] and the amylose leaching and partial granule disruption [IIb], resulting in formation of starch paste; III retrogradation: formation of an amylase network (gelation/ amylase retrogradation) during cooling of the starch paste [IIIa] and formation of ordered or crystalline amylopectin molecules (amylopectin retrogradation) during storage [IIIb]. (Adapted from Goesaert et al 2005).......... 6

Figure 1.3 Chemical structure of sucralose.......... 13

Figure 1.4 Stevia plant (a) and the chemical structure of stevioside (b).......... 14

Figure 1.5 Representative structure for polydextrose. R=H, sorbitol, sorbitol bridge or more polydextrose (Mitchell et al 2001).......... 16

Figure 1.6 Micrographs for the control batter and batters prepared with increasing quantities of polydextrose and sucralose (PD-SC) replacing sucrose (50% PD-SC and 100% PD-SC) obtained with light microscopy (A) and photographs of transversal and longitudinal sections of muffins prepared with increasing quantities of a polydextrose/sucralose mixture (B). (Adapted from Martinez-Cervera et al 2012). 18

Figure 2.1 Cake cut.......... 31

Figure 2.2 Volume index measurement.......... 31

Figure 2.3 Cake slice for C-Cell image analysis.......... 32

Figure 2.4 C-Cell cake images of control and polydextrose variations.......... 35

Figure 2.5 C-Cell images of cake crumb for control and polydextrose variations.......... 36

Figure 2.6 C-Cell cake images of control and cakes made with polydextrose and sucralose blend. 40

Figure 2.7 C-Cell images of control cake crumb and cake crumb from Polydextrose and Sucralose variations. 41

Figure 2.8 C-cell cake images for control and cakes made with polydextrose and stevia blend.. 44

Figure 2.9 C-Cell images of control cake and crumb of cakes made with Polydextrose and Stevia.. 45

List of Tables

Table 2.1 Cakes formulated using sucralose blend and stevia blend as sucrose replacement...... 27

Table 2.2 Specific gravity of batter and volume for control and cakes formulated using sucralose blend. 28

Table 2.3 Specific gravity of batter and volume for control and cakes formulated using stevia extract blend. 28

Table 2.4 Cake formulation (flour weight basis) 30

Table 2.5 Optimum water level and optimum baking time for cakes formulated using polydextrose. 33

Table 2.6 Specific gravity of batter and volume for control and cakes formulated using polydextrose. 34

Table 2.7 C-Cell data analysis for crumb of control and cakes made with polydextrose............ 36

Table 2.8 Optimum water level and optimum baking time for control and cakes formulated with polydextrose and sucralose blend. 37

Table 2.9 Batter specific gravity for control and cakes formulated using polydextrose and sucralose. 38

Table 2.10 C-Cell data analysis for control crumb and crumb of cakes made with polydextrose and sucralose. 41

Table 2.11 Optimum water level and optimum baking time for control and for cakes formulated with polydextrose and stevia extract blend. 42

Table 2.12 Batter specific gravity for control and for cakes formulated with polydextrose and stevia extracts. 43

Table 2.13 C-Cell data analysis for control crumb and crumb of cakes made with polydextrose and stevia. 45

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Chapter 1 - Literature Review

Introduction

In different parts of the world, cakes have different definitions, and ingredient functionality differs between cake types (Wilderjan et al 2013). A cake is essentially a semi-dry foam resulting from the setting of a fluid medium expanded by gas produced from dissolved chemicals (Yamazaki & Kissel 1978b). According to Pyler and Gorton (2009), cakes contain soft wheat flour, water (also supplied by liquid eggs and milk), sugar, shortening, flavors, and chemical leavening systems. Cakes are sweet, with a short, tender crumb, and a pleasing aroma and taste. Unlike dough, cake batter contains far more liquid and sugar (Pyler & Gorton 2009). Cake batter is a complex colloidal dispersion, a foamed fat-in-water emulsion containing suspended flour particles, dissolved sugar, and proteins in an aqueous phase (Kim 1994).

Because of their wide variety and the broad range of their formulations, cakes may be classed into two broad categories: (a) shortening-based cakes whose crumb structure is derived from fat-liquid emulsion created during batter processing and (b) foam-type cakes that depend on the foaming and aerating properties of eggs for structure and volume primarily (Conforti 2006; Pyler & Gorton 2009). Both types of cakes usually contain relatively high levels of sugar, shortenings, eggs, milk, and flavorings, in addition to soft wheat flour (Pyler & Gorton 2009).

Cake shortenings have improved in recent decades, so bakers can now incorporate more liquid into the batter, yielding more stable batters with finer and more uniform dispersion of fat and air, which then enabled bakers to make richer cakes, with higher moisture contents and extended shelf-life (Pyler & Gorton 2009). These cakes are commonly referred to as high-ratio or high-absorption cake. Layer cake is one type of high-ratio cake. White and yellow layer cakes are typical. Aside from a sweeter flavor, such cakes are tender, softer, and more attractive than low-ratio cakes (Kim 1994).

The rules for formula balance for high-ratio cakes, including layer cakes, are described by Pyler and Gorton (2009) as follows:

a) weight of sugar should exceed that of flour.
b) weight of eggs should exceed that of shortening.
c) weight of liquids (in eggs, milk, or added water) should slightly exceed the weight of the sugar.

Three major parameters that determine the quality of cakes are: (a) suitability of ingredients for type of cake being made, (b) appropriate and properly balanced formula, and (c) adherence to optimal mixing and baking procedures (Conforti 2006; Pyler & Gorton 2009). These three parameters have complex associations, so bakers and researchers often develop cakes using their own optimized formulation, ingredients, and baking methods. Therefore, understanding the role of each ingredient in the cake system is very important to quality. This study discusses how each ingredient affects cake quality.

Recent consumer demands for reducing the calorie content of cake has led to reducing sucrose levels in cake formula, which unfortunately produces lower quality cakes. Therefore, in addition to each ingredient's functionality, this chapter will also discuss artificial sweeteners and bulking agents that could improve reduced-sucrose cake systems.

Sucrose functionality

Sucrose is a principle ingredient in layer cakes. Sucrose is commercially obtained from sugar cane (*Saccharum officinarum*) and sugar beet (*Beta vulgaris ssp. vulgaris var. altissima*) (Tzia et al 2012). It is a non-reducing disaccharide, made up of one molecule of fructose and one molecule of glucose linked by an α-(1,2) glycosidic bond (Wilderjans et al 2013). Besides providing energy and sweetness to the cake (Frye & Setser 1992), it also has many other vital functions.

In cake batter formulation, when sucrose is added in its crystalline form, it acts as a drying agent. On the other hand, if it is liquid sugar or syrup, it acts as moistener (Pyler & Gorton 2009). In addition, it also functions as a tenderizer by limiting the water absorption capacity of the flour components, thus reducing gluten hydration and development (Kim 1994). The more sucrose added, the more tender the resulting cake. However, if too much sucrose is added, too little structure forms, and the cake does not rise, or it will rise and collapse as it cools

(Figoni 2004). Another important function of sucrose is that it increases volume by helping incorporate air into the fat during creaming (Conforti 2006). Kim (1994) stated that sucrose not only helps incorporate air but also stabilizes the emulsion and foam by acting as a bulking agent dissolved in water to increase batter viscosity.

Sucrose also helps brown the cake crust through caramelization (Conforti 2006) by reducing the caramelization point of the batter, allowing the cake crust to color at a lower temperature (Neelam et al 2005). Caramelization of sucrose requires a temperature of about 200ºC (Tzia et al 2012). In cake baking, as the sucrose level increases, the cake crust color becomes darker, but with very high levels of sugar, re-crystallization leads to a lightening of the crust appearance (Cauvain & Young 2006), resulting in a shiny brown crust color.

The setting of cakes in the oven is partly the result of starch gelatinization and egg protein coagulation (Delcour & Hoseney 2010). During cake baking, sucrose delays starch gelatinization and egg protein denaturation, both of which control setting the cake structure in the oven (Donovan 1977; Cauvain & Young 2006; Wilderjans et al 2013). Both temperature of starch gelatinization temperature and protein denaturation help prevent collapsed cake structure by providing sufficient strength to resist the stresses resulting from cooling (Kim 1994). At more than 30% moisture, the starch gelatinization temperature remains constant (Figure 1.1). When sucrose is dissolved in water, sucrose displaces part of water, decreasing the moisture content inside the wheat starch granule (<30%) and thus increasing the gelatinization temperature (Beleia et al 1996). Therefore, increasing sucrose concentration displaces more water, resulting in a higher starch gelatinization temperature. During the first stage of baking, elevated starch gelatinization temperature allows air bubbles to properly expand with carbon dioxide and water vapour before the cake sets (Yamazaki & Kissel 1978a), thus improving cake microstructure, porosity, and volume (Kim & Setser 1992). The resulting cake is also highly aerated and has a higher volume (Kim & Walker 1992).

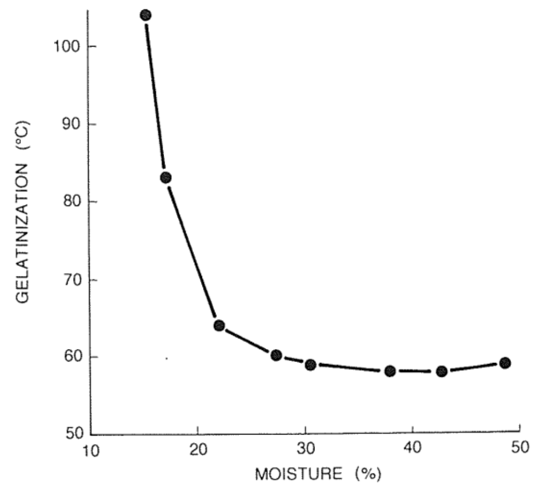

Figure 1.1 Effect of moisture content on gelatinization temperature of wheat starch (Adapted from Beleia et al 1996).

Another important role of sucrose is the effect on the water activity of baked products (Cauvin &Young 2000). High concentrations of sucrose in cake reduces water activity and restricts the ability of microorganisms to grow (Cauvin & Young 2006), thus improving cake shelf-life. Because of its longer product shelf-life, cakes containing high levels of sucrose can remain on the market shelf longer, while retaining better quality; consumers tend to prefer such cakes. The hygroscopic nature of sucrose also helps to retain moisture in cakes (Neelam et al 2005), thus increasing softness and moistness of cakes (Figoni 2004).

Other ingredients functionality

Cake is a complex system. For the success of a cake, the batter should have appropriate and properly balanced formula as well as suitable ingredients. Different types of cakes need different kind of ingredients and formula balance. Each ingredient has its own special functionality. Sucrose is not the only functional ingredient in cake making. In layer cake formula, basic ingredients used other than sucrose are: flour, shortening, baking powder, non-fat dry milk, egg whites, salt, and water. These ingredients have different roles to make high quality cakes and their functionality will be further discussed in this section.

Flour

Wheat flour consists mainly of starch (~70-75%), water (~14%), and protein (~8-14%) (Wilderjans et al 2013). In general, flours milled from soft wheat are used for cookie and cake making, while hard wheat flour is used for bread baking. Soft wheat has low protein content, so the flour milled from soft wheat has low water absorption capacity and poor tolerance to mixing and fermentation (Neelam et al 2005). These flour characteristics are suitable for cake making because cake requires neither optimum gluten development nor fermentation. For cakes, the flour of choice is cake flour, which is pure white and has a very fine, silky soft texture (Conforti 2006). The soft wheat flour intended for use in high-sugar layer cakes usually consists of the lowest protein (ranging from7.5% to 8.5%) and ash contents (Cathcart 1951; Pyler & Gorton 2008). The weak protein in soft wheat means minimal gluten development and low water absorption during mixing (Bushuk & Scanlon 1993), both of which are important in high ratio cakes. If the flour contains high protein, more gluten will be developed during mixing, thus producing a tough and chewy cake which is not desirable.

Essentially, flour serves as a structure builder in cake making (Kim 1994; Neelam et al 2005; Conforti 2006). Starch, the main component of flour, consists of the glucose polymers amylose and amylopectin. Typically, levels of amylose are 25-28% and amylopectin 72-75% (Colonna & Bulleon 1992 in Goesaert et al 2005). At room temperature and in sufficient water, starch granules absorb up to 50% of their dry weight of water (Goesaert et al 2005). The granules then swell. When the starch suspension is heated above its gelatinization temperature (60-76ºC), it undergoes a series of changes that eventually lead to the irreversible destruction of the molecular order of the starch granule (Goesaert et al 2005). This process is termed gelatinization (Figure 1.2). Through both processes of water absorption and gelatinization, starch helps the cake set and contributes to cake crumb structure formation (Conforti 2006) as well as helping maintain the structure when the cake is cooled and stored (Cauvain & Young 2006). Kim (1994) agreed that the gelatinization of starch helps control structure and produce a baked cake that does not collapse as it cools. According to Donovan (1977), swelling of starch granules during baking gives the final crumb its form and removes excess water from the system. The starch gelatinization temperature, which is determined by moisture and sugar levels in the cake, affects the development of cake volume (Kim & Walker 1992). In addition, starch also competes for water with the sugars and proteins, increases the viscosity of cake batters, and helps improve grain and texture (Pyler & Gorton 2008).

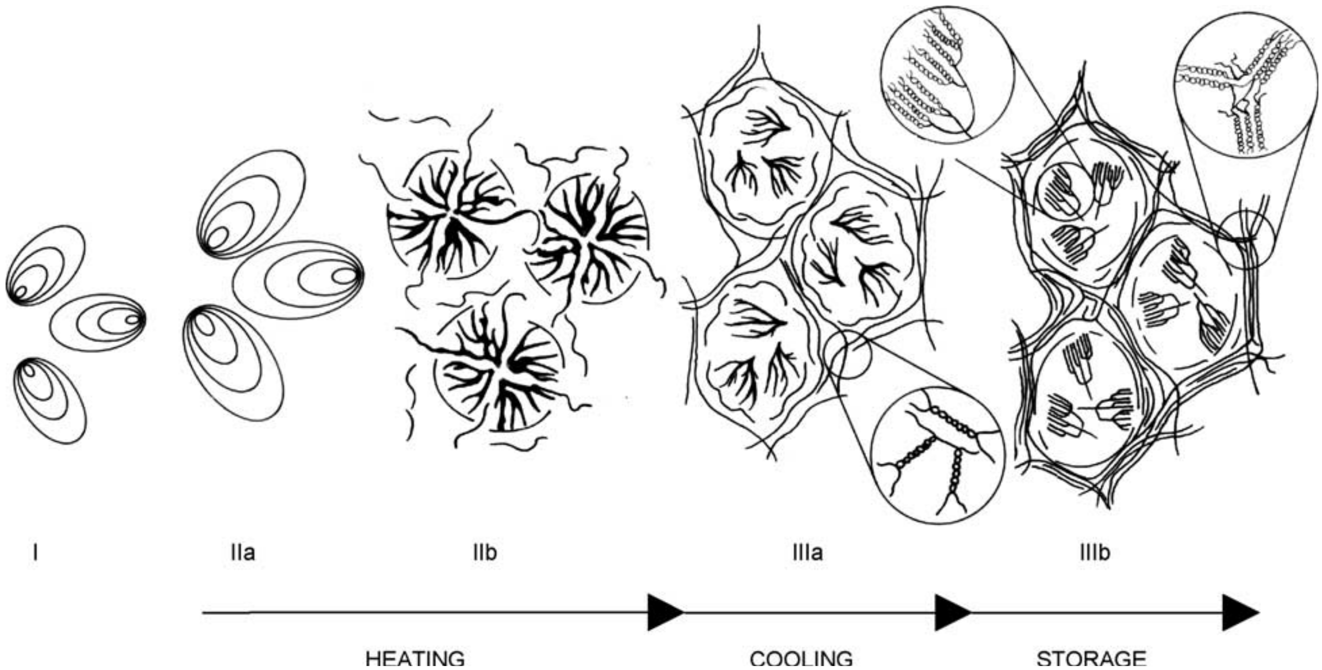

Figure 1.2 Schematic representation of changes that occur in a starch-water mixture during heating, cooling, and storage. I, Native starch granules; II gelatinization (associated with swelling [IIa] and the amylose leaching and partial granule disruption [IIb], resulting in formation of starch paste; III retrogradation: formation of an amylase network (gelation/ amylase retrogradation) during cooling of the starch paste [IIIa] and formation of ordered or crystalline amylopectin molecules (amylopectin retrogradation) during storage [IIIb]. (Adapted from Goesaert et al 2005).

Flour for high-ratio cakes are generally be treated with chlorine gas (Delcour & Hoseney 2010). During chlorination, flour is treated with at the rate of 0.5 to 2.5 oz per cwt of flour (Pyler & Gorton 2008) to reduce the flour's pH. The pH of flour is reduced during the chlorination through the reaction of chlorine with organic materials, producing hydrochloric acid. Generally, a pH of 4.7-5.2 is desired for most high-ratio cakes (Delcour & Hoseney 2010). Chlorination greatly improves baking performance including the symmetry of product form, cake volume and grain, and texture (Yamazaki & Kissel 1978b). Chlorination results in increased starch granule swelling as oxidized starch forms, more easily dispersed gluten with possibly changed lipid structure on starch granules, which means higher water absorption and increased viscosity at the same temperature (Gough et al 1978; Kim 1994; Delcour & Hoseney 2010). As a result, cakes do not collapse in the oven or during cooling. In a baking test using chlorinated flour versus unchlorinated flour, the chlorinated flour increased batter viscosity, made the product more uniform, and increased cake crumb strength (Gough et al 1978). In addition, batters made from chlorinated flours retain gas better and for longer times than those prepared from unchlorinated flour (Kissel &Yamazaki 1979).

Shortening

In layer cakes, the internal grain and the final volume are highly influenced by the characteristics of the shortening (Stauffer 1993). Shortening is the primary tenderizing agent in cake (Conforti 2006). Shortenings make cakes tender by coating structure builders: gluten proteins, egg proteins, and starch granules. Shortening actually delaysthem from absorbing water and forming structure (Figoni 2004). Thus, shortening helps produce a softer, tenderer, and better cake (Neelam et al 2005).

In white layer cake production, besides giving sufficient strength to cake batter, shortening also supports the structural characteristics developed by leavening (Pyler & Gorton 2008). During mixing, air must be incorporated into the batter. Shortening, as it is creamed, traps the air as very small cells and bubbles (Kim 1994; Neelam et al 2005; Pyler and Gorton 2008) and keeps these gas bubbles from coalescing, which yields a finer and softer crumb structure and grain (Neelam et al 2005; Cauvain and Young 2006). The small cells created during creaming of shortening eventually expand during baking in a uniform way thus producing high volume of cake with uniform crumb grain distribution. If large bubbles are incorporated during mixing, then during baking, the bubbles are further expanded by the leavening gas; if many of them are large enough, they rise to the surface of the cake and escape (Stauffer 1993). The end result is flatter cake.

Another important function of shortening is it acts as moisture barrier, which improves the shelf life of baked products significantly.. Fat can prevent excessive migration of moisture, which can cause the cake to become soggy by picking up moisture or dry out if it loses moisture

(Podmore 1997). In addition, the free water can support the growth of microbes and bacteria which then spoil the cake, thus reducing the cake quality and shelf life. Therefore, the presence of shortening in cake formula not only produces soft and moist cake but also helps extend the shelf life through microbial activity control.

When an emulsifying agent is added to shortening, emulsifying properties of fat is enhanced (Podmore 1997). Batter using this shortening has higher viscosity and more stability, and the air is more finely distributed (Podmore 1997). High-ratio plastic shortening, sometimes called emulsified shortening, commonly has added emulsifiers like mono- and diglycerides (Figoni 2004). An emulsifier in the shortening not only reduces the tendency of the fat to change crystal form during storage (Cauvain & Young 2006), but it also helps incorporate small air bubbles into the fat, which adds more air to the batter (Cauvain & Young 2006; Conforti 2006). Using high-ratio shortening yields moister, tenderer cake with a finer crumb (Figoni 2004).

Egg Whites

Whole eggs have both egg white and egg yolk (Wilderjans et al 2013), with the yolk suspended in the egg white (Pyler & Gorton 2008). The protein content of egg white is about 9.7-10.6%, depending on the age of the hen (Kiosseoglou & Paraskevopoulou 2006). Egg white, in its natural state, is essentially an aqueous protein solution, and its ratio of thin to thick components can vary considerably between individual samples (Pyler & Gorton 2008). The egg white contains in dry matter about 85% of the total protein content of an egg (Frampton 1997), consisting chiefly of a complex mixture of proteins (mainly ovalbumin, conalbumin, ovomucoid, ovomucin, avidin, and ovoglobulin) (Pyler & Gorton 2008) with about 0.5% mineral salts (Conforti 2006).

In layer cakes, egg whites function primarily as binders and secondarily as emulsifiers (Pyler & Gorton 2008). At room temperature, egg whites can help build the structure of the cakes by increasing batter viscosity by incorporating air bubbles during mixing (Delcour & Hoseney 2010). In addition, during mixing, egg whites stabilize the incorporated gas cells (in the fat phase) that migrate from the fat to the aqueous phase (Wilderjans et al 2013). Different egg white proteins can form stable foam by fast conformational rearrangement together with film formation around the gas cells (Mine 1995). The globulin protein of egg white is a good foaming agent while ovomucin contributes to a stable foam (Mine 1995).

Egg whites also help build the structure of cakes through protein denaturation during baking. During the final stages of baking, both starch gelatinization and egg protein coagulation occur, so liquid batter changes to solid form (Guy & Pithawala 1981). At high baking temperatures, egg whites set, which involves at least three phenomena: denaturation, aggregation, and gelation. Each increases batter viscosity tremendously, changing the batter to solid form and thus setting the cake (Delcour & Hoseney 2010). From a different perspective, egg whites are used in white layer cake because the yellowness contributed by the yolk is not wanted in this kind of layer cake (Cauvain & Young 2006).

Non-fat Dry Milk

Dry milk solids are commonly produced by spray-drying or roller-drying (Pyler & Gorton 2008), where most of the water (about 3-5%) from fat-free or whole milk is removed to produce non-fat dry milk (NFDM) or dry whole milk (Figoni 2004). After drying at a high temperature, milk powder has a water absorbing capacity of 100-125% of its weight; milk powder actually absorbs more water than flour, which can absorb 58-64% of its weight (Yang 2006). Thus adding milk powder to the cake batter can elevate the water-absorbing capacity of the batter, so more liquid is needed to balance the cake formula.

In cake production, milk solids or milk powder contribute to a nice brown crust color because of the Maillard browning reaction of proteins and lactose (Pearce et al 1984; Figoni 2004). Lactose, as one sugar component in milk, controls browning and thus contributes to an even, stable brown color after less baking time at a lower temperature than sucrose (Bennion & Bamford 1997). Adding non-fat dry milk to white layer cake batters influenced air cell size, foam stability and emulsification in batters, produced layering in the final cake structure and reducing moisture loss during baking (Pearce et al 1984). Milk solids also improve flavor, richness, and taste appeal as well as the nutritional value of the cakes (Neelam et al 2005). In addition, the milk components like proteins, lactose, and milk fat prevent starch retrogradation, or staling, in the crumb (Figoni 2004) by adding to moisture retention, which contributes to shelf life with longer apparent freshness and keeping quality (Neelam et al 2005).

Chemical Leavening Agents

Nearly all cake products get their leavening from chemical reactions of leavening agents. Depending on the product type and specifications, chemical leavening systems may be added either as individual components with baking soda and selected leavening acids incorporated separately in appropriate ratios or as prepared baking powders that meet product requirements (Pyler & Gorton 2008). Baking powder comprises (usually) sodium bicarbonate, acids used to provide a source of carbon dioxide, and a filler (Figoni 2004; Cauvain &Young 2006), typically corn starch. The filler keeps the bicarbonate separate from the leavening acid to prevent premature reaction and acts as a coating to standardize the strength of baking powder (Pyler & Gorton 2008). In the presence of liquid and heat, baking powder undergoes a chemical reaction that produces CO_2, which causes the product to rise or increase in volume (Conforti 2006). The reaction equation of acid salts with sodium bicarbonate, influenced by heat and moisture, is

$$HX + NaHCO_3 \longrightarrow NaX + H_2O + CO_2$$

Acetic salt + sodium bicarbonate ⟶ neutral sodium salt + water + carbon dioxide

The amount of carbon dioxide released from the baking powder chemical reaction depends on baking soda content in the mixture and baking acid that reacts with it (Cauvain & Young 2006). To leaven cakes, double acting baking powder is usually used (Kim 1994). The first leavening acid acts at room temperature to help nucleate the batter (Delcour & Hoseney 2010). The second leavening acid reacts during the baking stage, producing carbon dioxide which then diffuses into air cells (Kim 1994). The leavening action must be timed so that the gas is produced while the batter can still expand (Delcour & Hoseney 2010).

In our study, the first leavening acid used is monocalcium phosphate, monohydrate (MCP), which is a very fast leavening agent that releases 70-80% of the carbon dioxide of sodium bicarbonate during the final two minutes of mixing, thereby producing cake batters with a high viscosity and high volume with improved pan fill (Pyler & Gorton 2008). The second leavening acid is sodium aluminium phosphate (SALP) which has a slow initial release of carbon dioxide, is relatively stable at low batter temperatures, and releases carbon dioxide rapidly at baking temperatures; its reaction products have no taste (Pyler & Gorton 2008). SALP is also suitable for use in batters that are likely to stand for long periods before baking (Thacker 1997).

Salt

Salt (sodium chloride) is added to enhance the natural flavor of other ingredients used in cake making and thus improve the overall flavor of the cakes (Neelam et al 2005; Cauvain & Young 2006). Additionally, salt also cuts down the sweetness of the cake (Neelam et al 2005). Salt is also important to control the product water activity, thus improving product shelf-life (Cauvain &Young 2000).

Water

Even though water is the simplest and the cheapest ingredient used in baked products formulation, it is a significant part of baking, influencing final product quality and product shelf-life (Cauvain & Young 2000). The first important function of water is, during mixing, to hydrate, solubilize, and disperse all other ingredients in cake batter (Figoni 2004; Cauvain & Young 2006). The amount of water added must be optimized to achieve good handling properties of batter (Cauvain & Young 2006) and to form an appropriate cake structure (Cauvain & Young 2008). The water required for this purpose may be added as water or may be derived from other ingredients like egg and liquid milk (Cauvain & Young 2008). The water added affects the batter viscosity which is very important during baking (Figoni 2004; Delcour & Hoseney 2010). Having a viscosity that is too low not only causes large bubbles to rise to the surface and escape, but will also result in a rubbery layer of cake because starch granules accumulate at the bottom of the cake pan (Delcour & Hoseney 2010).

Secondly, water provides sufficient moisture for starch gelatinization (Kim 1994). Starch gelatinization occurs at 60-76 ºC, when starch granules absorb water, softening and swelling and sometimes exploding in the process (Neelam et al 2005), contributing to cake structure. The amount of water used in cake batters is highly associated with the amount of sugar in the recipe (Cauvain & Young 2006). Since high sucrose levels in layer cakes affect starch gelatinization (Kim 1994), the total liquid added in the formula should exceed the amount of sugar by 25-30%. Too much liquid results in peak cake while too little liquid gives a sunken appearance (Kim 1994).

Thirdly, water interacts with other ingredients in the cake formula. Baking ingredients are mixtures of many compounds. Each compound has its own unique properties, and they do interact with water. Water, a polar substance, has interactions with other polar ingredients (*hydrophilic*) and with other non-polar ingredients (*hydrophobic*) (Chieh 2006). Starch is *hydrophilic* and proteins have both *hydrophilic* and *hydrophobic* groups, where both of these compounds absorb water leading to formation of crumb structure of the baked goods (Chieh 2006). Water is also important for the production of carbon dioxide gas where it solubilises the baking powder components which then initiates the baking powder reactions and carbon dioxide gas is produced.

Artificial Sweeteners

In previous sections, all cake ingredients functionality has been discussed in details. There is no doubt that each of ingredients has undeniable important roles in making good cakes. However, the fact that cake has a high calorie content is also a big concern among consumers because excessive intake of high calorie food leads to some chronic diseases like diabetes and obesity. The high calorie content of cake is highly associated with the high amount of sucrose used in the formula. Therefore, food developers and researchers nowadays attempt to produce low-calorie cakes so that the consumers have a healthier lifestyle. One way to reduce calorie in cakes is by reducing the amount of sucrose in cake formula or by substituting sucrose with zero-calorie artificial sweeteners. Sucralose and stevia extracts are high intensity sweeteners that commonly used as sucrose replacer in cake formulation. These two unique sweeteners will be further discussed in the next sections.

Sucralose

Sucralose was discovered by British researchers in 1976 (Kroger et al 2006). It is a chlorinated disaccharide (Gautam et al 2012). Sucralose (1,6-dichloro-, 1,6-dideoxy-β-D-dructofuranosyl-4-chloro-deoxy-α-D-galactopyranoside) is synthesized from sucrose by selectively replacing 3 hydroxyl groups with chlorine atoms (Kroger et al 2006; Lin & Lee 2005) (Figure 1.3). It is a zero-calorie sweetener that is 600 times sweeter than sucrose (Gieses 1993; Wallis 2003; Martinez-Cervera et al 2012) but can range from 400-800 times sweeter, depending on desired sweetness and product formulation (Chapello 1998). Sucralose tastes like sugar, has no unpleasant or bitter aftertaste (Gieses 1993), and is non-caloric, non-carcinogenic, and proven safe for human consumption (Wallis 2003). Sucralose contains no calories because it is not hydrolyzed in the intestinal lumen, not converted to energy in the body. It is poorly absorbed by experimental animals and is excreted largely unchanged in the feces (Chapello 1998; Sims et al 2000). Sucralose is highly soluble in water and alcohol (Giese 1993), chemically compatible with all common food ingredients, and stable in a wide range of pH levels and thermal processes (Chapello 1998). Thus, it could be a suitable sweetener for bakery products (Barndt & Jackson 1990).

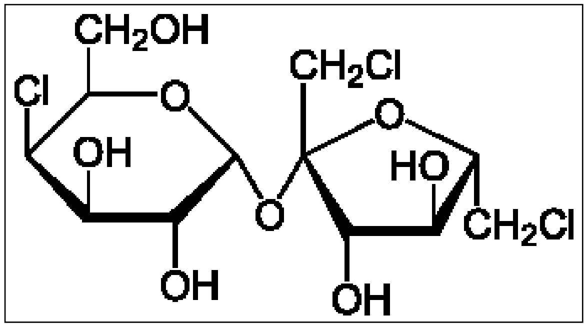

Figure 1.3 Chemical structure of sucralose.

Although sucralose provides the sweetness and crystallization properties of sucrose, it cannot mimic the structural contribution of sucrose to baked products (Martinez-Cervera et al 2012). It cannot create bulk properties in the cake batter as sucrose does. As a result, sucralose must be combined with other substances to match sucrose's bulking properties. A few previous studies reported that replacing sucrose with sucralose up to 50% has produced acceptable products: chiffon cake formulated with a mixture of sucralose and a type of indigestible dextrin in chiffon cakes (Lin & Lee 2005), reduced-fat chiffon cake containing 50% erythritol-sucralose (Akesowan 2009), and muffins using sucralose and polydextrose (Martinez-Cervera et al 2012). In these three studies, 100% sucrose replacement brings significant decrease in acceptability due to texture failure.

Stevia Extract

Stevia rebaudiana Bertoni, a plant indigenous to the northern part of Paraguay in South America, is the source of strongly sweet *ent*-kaurenoid diterpene glycosides stevioside, rebaudioside A and several other steviol glycosides (Lindley 2012; Zahn et al 2013)(Figure 1.4a). These glycosides can be easily extracted with water, purified, concentrated, and dried (Carakostas et al 2008). Several terms refer to the sweetening agent extracted from this plant, including stevia, stevioside, and steviol glycosides (Kroger et al 2006).

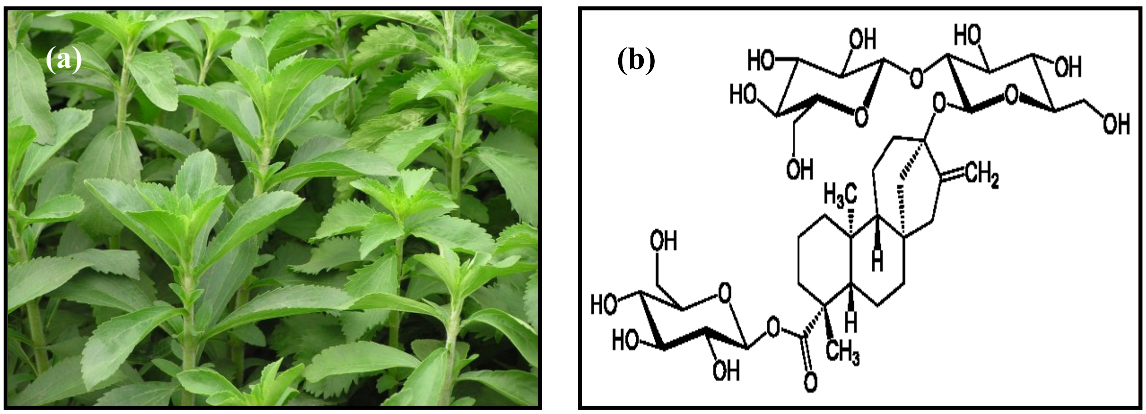

Figure 1.4 Stevia plant (a) and the chemical structure of stevioside (b).

Stevioside, a (1'-2)-linked disaccharide-containing substance, is present in the stevia leaves (Sardesai & Waldshan 1991) (See Figure 1.4b). It is the major sweet substance of this plant (5-10% of dry weight) and is 300 times as sweet as sucrose (Giese 1993; Kroger et al 2006; Manisha et al 2012). It has steviol as its aglycone and is attached to three glucose molecules (Abdel Salam et al 2009). According to Giese (1993), stevioside is somewhat bitter and has an undesirable aftertaste. Stevioside was only developed and distributed as commercial sweetener in Japan in 1970s although it has been known to be sweet for more than 100 years (Kinghorn et al 2001).

Recently, a few studies have investigated the quality of baked products formulated using stevia extract. In 2009, Abdel-Salam et al formulated and evaluated the low calorie functional yogurt cake using stevia extract. They concluded that sugar in regular yogurt cake can be replaced by a hot-water extraction of stevia as sweetener to produce low calorie yogurt cake. Manisha et al (2012) studied the interactions between stevioside , liquid sorbitol, hydrocolloids, and emulsifiers as a replacement for sugar in cakes. An acceptable quality of sugar-free fenugreek cake using stevioside, liquid sorbitol, xanthan gum, polysorbate-60, and debittered fenugreek seed powder was achieved. In a most recent study, Zahn et al (2013) formulated muffins using rebaudioside A and different fibers as a partial replacement for sucrose. They concluded it was possible to partly replace sucrose in muffin-type bakery products with a purified steviol glycoside (rebaudioside A). They also suggested focusing on bulk sugar replacers to obtain properties of standard products. Based on these studies, stevia can provide sweetness to baked products but cannot replace or imitate sucrose functionalities. Therefore, it must be combined with other bulking agents in the formula to obtain products with qualities similar to those products that contain sucrose.

Bulking Agent

In general, in cake formulation, substituting sucrose with only artificial sweeteners like sucralose or stevia extracts produces a very dense cake. Since these artificial sweeteners can only provide sweetness but cannot mimic other sucrose vital functionalities, other ingredients need to be added to cake formula to help support the cake system as well as increase the cake volume. Bulking agents, which replace the nonsweet functional characteristics of sucrose, are usually used as alternatives to sucrose in bakery products (Giese 1993). The common bulking agent used in cake formulations is polydextrose, which will be discussed in the next section.

Polydextrose

Polydextrose is a bulking agent that supplies only 1 kcal per gram (Attia 1993) compared to 4 kcal/g provided by sucrose (Carroll 1990). Polydextrose is indigestible in the small intestine but incompletely fermented in the large intestine, so it does have calorie content (Auerbach & Dedman 2012). When added to food as an ingredient, it contributes no sweetness or flavor to the product (Torres & Thomas 1981).

Polydextrose is prepared commercially by vacuum bulk polycondensation of a molten mixture of food-grade starting materials: glucose, sorbitol, and either citric acid or phosphoric acid in approximately an 89:10; 0.1-1 mixture (Mitchell et al 2001). The final product of this reaction is a weakly acidic, water soluble polymer that contains small amounts of bound sorbitol and either citric or phosphoric acid (Mitchell et al 2001).

Polydextrose is a complex molecule, highly branched with many glucose linkages (Figure 1.5), where the R group may be hydrogen, glucose, or a continuation of polydextrose polymer (Mitchell et al 2001). All possible glycosidic linkages with the anomeric carbon of glucose are present: α and β (1-2), (1-3), (1-4), and (1-6), with some branching; the 1-6 linkages predominate (Auerbach & Dedman 2012). This structure means polydextrose is water-soluble and also a reduced-calorie compound (Mitchell et al 2001).

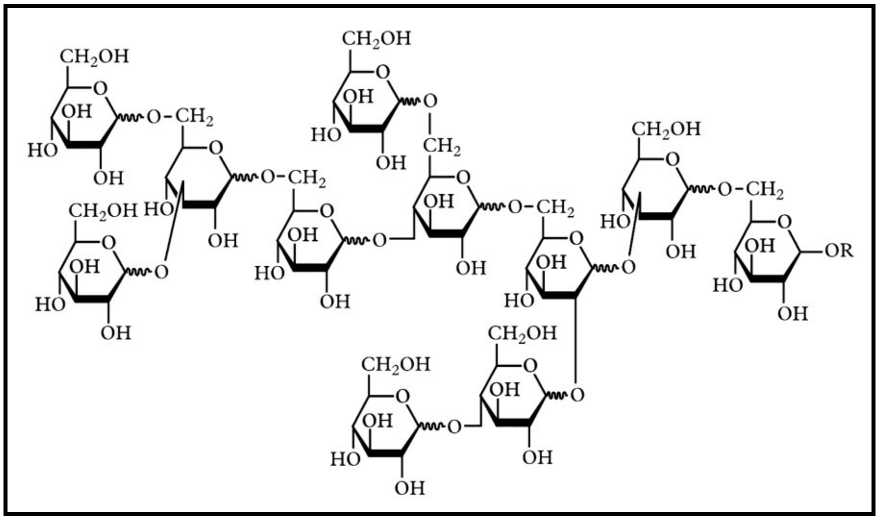

Figure 1.5 Representative structure for polydextrose. R=H, sorbitol, sorbitol bridge or more polydextrose (Mitchell et al 2001).

Polydextrose is designed to be the ultimate companion ingredient to high-intensity sweeteners where it can replace the physical functionality of high calorie ingredients like sugar (Mitchell et al 2001). Polydextrose provides the bulk, texture, mouthfeel, and functional attributes of caloric sweeteners (Alonso & Setser 1994; Burdock & Flamm 1999) and therefore may be used as bulking agent, formulation aid, and texturizer (Giese 1993). Polydextrose has its own unique functionalities as well. It contributes to batter viscosity, has excellent water solubility (soluble to approximately 80% at 25ºC), acts as humectant in food products where it controls the rate of moisture gain or loss thus prevents staling (Giese 1993; Mitchell et al 2001). The increase in batter viscosity caused by polydextrose helps retain the leavening gas in chemically leavened bakery products (Alonso & Setser 1994) thus contributing to volume, tenderness, structure, and eating quality of cake-type products (Mitchell et al 2001). Good flavor and color, good symmetry, and acceptable eating characteristics were reported in brownies and layer cakes made with polydextrose as a partial sucrose replacement (Setser & Racette 1992).

In cake baking, sucrose increases starch gelatinization and protein denaturation temperatures allowing the cake time to rise. Polydextrose raises the temperature at which starch gelatinization occurs but does not affect the temperature at which egg denatures (Rosenthal 1995). Pateras et al (1994) showed an increase in bubble size variation and average bubble size after high concentrations of polydextrose were added to cake batter. Bubbles expanded more slowly in polydextrose batters during baking.

Hiscazmaz et al (2003) conducted a study on the effect of polydextrose-substitution on the cell structure of the high-ratio cake system. Using a 25% sugar replacement level gave a product similar to high-ratio cake in batter characteristics, porosity, and cell size and shape distributions. However, a significant decrease in cake height was recorded because of the decrease in crack-like cells and an increase in small sphere-like cells as more sugar is replaced with polydextrose in the cake formula. Polydextrose substitution confined most of the bubbles to the normal size range yet also caused thinner batters. The same research team (Kocer et al 2007) found similar results for the batter of a high-ratio cake formulation in which sucrose was replaced by polydextrose although the batter was even less stable. However, as polydextrose-substitution levels increased, they concluded that polydextrose decreased the average bubble size and increased bubble size uniformity, thus better distributing the gas phase into the cake batter. Martinez-Cervera et al (2012) also reported a decrease in average bubble size when sucrose was replaced with a mixture of polydextrose and sucralose (Figure 1.6). According to these researchers, reduced bubble size could be the consequence of lower consistency of the sucrose-reduced batters, favoring bubble buoyancy. In addition, using the same beating energy during batter mixing may have allowed larger air cells to coalesce and escape while retaining the small ones. In principle, a larger number of small gas nuclei in the batter is good for final quality because this favors the formation of tiny air cells that can enlarge during baking, which in turn favors height and volume gain (Martinez-Cervera et al 2012). Therefore, the decrease in bubble size average contributed to the low volume of baked muffins (Figure 1.6).

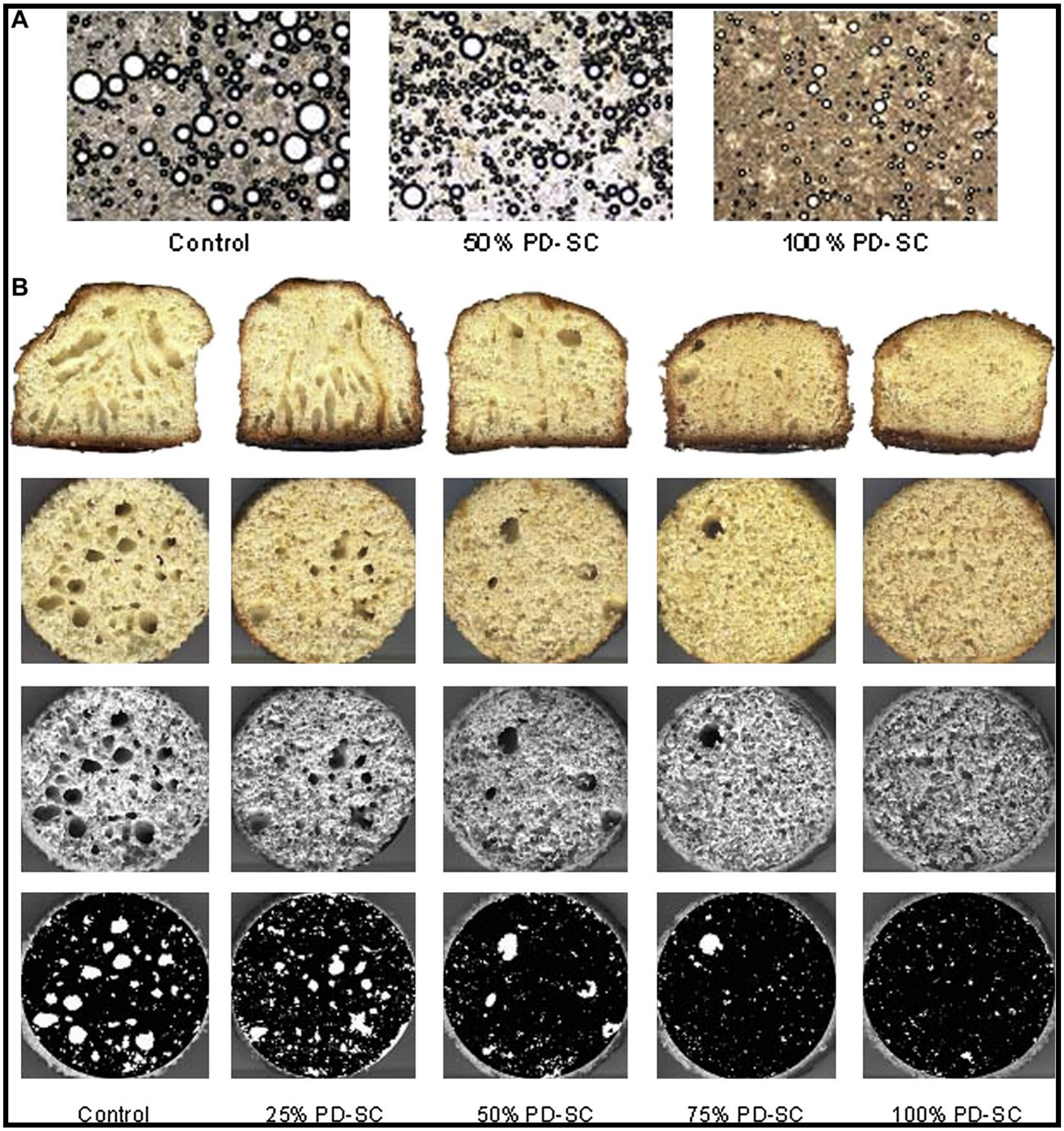

Figure 1.6 Micrographs for the control batter and batters prepared with increasing quantities of polydextrose and sucralose (PD-SC) replacing sucrose (50% PD-SC and 100% PD-SC) obtained with light microscopy (A) and photographs of transversal and longitudinal sections of muffins prepared with increasing quantities of a polydextrose/sucralose mixture (B). (Adapted from Martinez-Cervera et al 2012).

Conclusion

All ingredients have important roles in making a good cake. A cake system is very complex but does not rely on only one ingredients for success. Optimal mixing and baking procedures are also important in cake making. However, having suitable ingredients and a balanced cake formulation will produce a high quality cake.

Sucrose not only provides sweetness to the cake but also has other vital functions, delaying starch gelatinization and protein denaturation, assisting in incorporation of air cells during creaming, providing good grain structure, flavor, and texture to the product as well as contributing to browning the cake crust. Starch and gluten protein in flour provide structure to cake even though gluten development must be minimal for cake. During mixing, fats in shortening trap the air in very small cells and bubbles, which yields a finer and softer crumb structure and grain. In layer cakes, egg whites primarily function as binders and secondarily as emulsifiers. Besides sucrose, the non-fat dry milk contributes to a nice brown crust through the Maillard browning reaction of proteins and lactose. Chemical leavening agents leaven cake by introducing sufficient CO_2 gas into the batter, thus increasing the cake volume while salt, on the other hand, only provide flavor to cake. As the cheapest ingredient, water contributes to CO_2 production by interacting with baking powder and to starch gelatinization in the cake system.

For reduced-sucrose cake formulation, using polydextrose as a bulking agent and artificial sweeteners to provide the sweetness seemed reasonable and should result in a cake as good as cake containing 100% sucrose. Polydextrose, however, can imitate only some of sucrose physical characteristics although it works very well in creating bulk properties in cake system. Sucralose and stevia are both suitable sweeteners for reduced-calorie or sugar-free bakery products. Incorporating these three ingredients into white layer cake formula should yield a high quality reduced-sucrose cake.

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Chapter 2 - Sucrose Reduction in White Layer Cakes

Introduction

Cakes are sweet baked goods that are consumed by people from all over the globe. Cakes typically contain large quantities of sucrose. High ratio cakes have a sucrose-to-flour ratio exceeding 1.0 (Delcour and Hoseney 2010) while low ratio cakes contain less sucrose than flour or equal levels of sucrose and flour (Conforti 2006). Sucrose is a primary ingredient in cake. In the cake system, sucrose delays starch gelatinization and protein denaturation (Wilderjan et al 2013). Sucrose also assists in incorporating air cells into the batter during creaming and provides good grain structure, flavor, and texture to the product (Manisha et al 2012). Sucrose participates in the caramelization, which occurs during baking to yield a nice brown color to the cake crust. Furthermore, Delcour et al (2010) also noted that sucrose functionality in cake baking also includes controlling setting temperature, structure fixation, and collapse.

Besides its undeniable vital functions, sucrose also contributes to the high calorie content in cake and excessive consumption of sugar leads to various chronic diseases like diabetes. In today's lifestyle, many people are concerned about reducing calorie intake in their diet to stay healthy. One method of reducing calorie intake is to limit sucrose in the diet. In addition, there is a constant demand for foods suitable for diabetics (Ronda et al 2005). For these reasons, various food products available in the market, including baked goods, are formulated using artificial sweeteners to reduce or replace sucrose.

Many studies have investigated the functionality of different artificial sweeteners in several bakery products including sucralose in muffins (Martinez-Cervera et al 2012), sucralose in biscuits (Savitha et al 2008), erythritol-sucralose in chiffon cakes (Akesowan 2009), stevioside in cake (Manisha et al 2012), stevia leaves in yogurt cake (Abdel-Salam et al 2008), polyols in sponge cakes (Ronda et al 2005), dextrin and sucralose in chiffon cake (Lin & Lee 2005), and aspartame and/or Acesulfame-K in sponge cake (Attia et al 1993). However, research on using artificial sweeteners in high ratio cake white layer cake is limited. In addition, artificial sweeteners can only provide sweetness to the cake but cannot mimic the functionalities of sucrose, creating an obstacle to using artificial sweeteners in food research as well as in food industries. Therefore, using other additional ingredients like bulking agents to overcome this hurdle can help improve the quality of reduced-sucrose cake.

Objectives

This study examined the interaction between one bulking agent (polydextrose) and two high intensity sweeteners (sucralose and stevia extract) in white layer cake formulation.

The objectives of this study were:

1) To evaluate the effect of replacing sucrose in white layer cakes with artificial sweeteners; and

2) To evaluate the impact of bulking agent and artificial sweeteners in white layer cakes.

Materials and Methods

Preliminary results

Preliminary research was performed to see the effect of using artificial sweeteners as sucrose replacer. For control, cakes were formulated using the Sundberg two-stage white layer cake formula (Sundberg et al 1953). The cake formula used sucralose blend and stevia blend to the same sweetness level as sucrose. A cup of sugar (211g) equals to 26.0 g of sucralose blend; and also equals to 32.6 g of stevia extract blend so both sucralose blend and stevia blend were added in differing amounts for each variation (Table 2.2). Sucralose and stevia blend were added at 25%, 50%, and 75% of sucrose replacement.

Table 2.1 Cakes formulated using sucralose blend and stevia blend as sucrose replacement.

Variation	*Sugar (%)*	*Sucralose (g)*	*Stevia (g)*	*Water (%)*	*Bake Time (min)*
Control	100	-	-	130	20
Sucralose25	75	4.2	-	130	20
Sucralose50	50	8.3	-	130	20
Sucralose75	25	12.5	-	130	20
Stevia25	75	-	5.2	130	20
Stevia50	50	-	10.4	130	20
Stevia75	25	-	15.6	130	20

Referring to Table 2.2, it can be seen that the specific gravity for Control cake differs significantly from other three variations. Even though the batter for Control had the highest value of specific gravity, the final baked cake had the highest volume of 107 due to the 100% sucrose content which gives good incorporation of air during mixing thus yielding a high volume of cake. The decrease of sucrose level in the formula has shown a significant reduction in cake volume. All cakes volume differed significantly between each other. The lowest volume of 59 was recorded in cake containing the least amount of sucrose (25%) in the formula and 75 % of sucralose blend. It is obviously seen that least sucrose in the cake batter causes least air incorporation, thus contribute to lowest final volume of cake. In addition, these results indicated that sucralose blend can only provide sweetness to cake but does not contribute to cake volume.

Table 2.2 Specific gravity of batter and volume for control and cakes formulated using sucralose blend.

Variation	*Specific Gravity*	*Volume*
Control	1.00 ± 0.01^{a}	107^{a}
Sucralose25	0.96 ± 0.00^{b}	94^{b}
Sucralose50	0.96 ± 0.01^{bc}	72^{c}
Sucralose75	0.94 ± 0.01^{d}	59^{d}

*Values are means ± SD for three replications

**Means with different superscript letters within the same column are significantly different at $p<0.05$.

Table 2.3 shows that the specific gravity for Control cake differ significantly from other three variations. Cake volume decreased significantly with the decrease of sucrose level in the formula. All cakes differed significantly between each other. The lowest volume of 65 was recorded in cake containing the least amount of sucrose (25%) in the formula and 75 % of stevia blend. Similar to results obtained in previous table, stevia blend can only provide sweetness to cake but does not contribute to cake volume.

Table 2.3 Specific gravity of batter and volume for control and cakes formulated using stevia extract blend.

Variation	*Specific Gravity*	*Volume*
Control	1.00 ± 0.01^{a}	107^{a}
Stevia25	0.96 ± 0.02^{b}	95^{b}
Stevia50	0.93 ± 0.01^{c}	76^{c}
Stevia75	0.86 ± 0.01^{d}	65^{d}

*Values are means ± SD for three replications

**Means with different superscript letters within the same column are significantly different at $p<0.05$.

Based on results obtained in this preliminary work, we concluded that both sucralose blend and stevia blend do not give any contribution to improve the cake volume in reduced-sucrose cakes. We also found that these cakes need another ingredient (i.e. bulking agent) that could possibly improve the cake volume. Therefore, later, polydextrose was used as bulking agent in the formula and the results of next experiments will be further discussed in the next results and discussions section. In addition, the sucrose replacement in cake using polydextrose and either sucralose blend or stevia blend were also done.

Ingredients

Chlorinated super cake flour was provided by Mennel Milling Company (Fostorio, OH). It contained 13.72% moisture, 7.38% protein, and 0.336% ash, with a pH of 4.25. Fine granulated sugar was procured from United Sugars Corporation (Minneapolis, MN). Vegetable shortening emulsified with mono- and diglycerides was purchased from Stratas Food (Memphis, TN). Instant nonfat dry milk and powdered egg whites were both obtained from Honeyville Farms (Honeyville, Utah). Double-acting baking powder (containing Sodium aluminum phosphate (SALP) and Mono calcium phosphate (MCP)) was obtained from Clabber Girl Corporation (Terre Haute, IN). Salt was procured from the local grocery store.

Sucralose blend (McNeil Nutritionals, LLC, Fort Washington, PA) and stevia extract blend (Cumberland Packing Corp, Brooklyn, NY) were purchased from local grocery store. Polydextrose was purchased from Tate and Lyle Corporation (London, UK).

Cake Formulation

Control cake and all variations were formulated using the Sundberg two-stage white layer cake formula (Sundberg et al 1953) presented in Table 2.1. All ingredient levels presented in Table 2.1 are based on flour weight. Both artificial sweeteners were added to the same sweetness level as sucrose based on 1 cup to 1 cup weight calculation. A cup of sugar (211g) equals the sweetness level of 26.0 g of sucralose blend and 32.6 g of stevia extract blend. Sucralose and stevia blend were added at 25%, 50%, 75%, and 100% of sweetness of sucrose. Polydextrose was added with all other dry ingredients at levels of 25, 50, 75, and 100% of sucrose substitution.

Table 2.4 Cake formulation (flour weight basis)

Ingredients	100% Sucrose (Control)	75% Sucrose	50% Sucrose	25% Sucrose	0% Sucrose
Cake flour	100.0	100.0	100.0	100.0	100.0
Sugar	135.0	101.3	67.5	33.7	-
Poydextrose	-	33.7	67.5	101.3	135.0
Sucralose blend	-	4.2	8.3	12.5	16.6
Stevia blend	-	5.2	10.4	15.6	20.8
Shortening	45.0	45.0	45.0	45.0	45.0
Dried egg white	12.5	12.5	12.5	12.5	12.5
Nonfat dry milk	12.0	12.0	12.0	12.0	12.0
Salt	2.5	2.5	2.5	2.5	2.5
Baking powder	5.0	5.0	5.0	5.0	5.0
Water	Optimum	Optimum	Optimum	Optimum	Optimum

*Water level was optimized at different level for each variation.

Cake Preparation

Cakes were prepared using the AACCI Standard Method 10-90.01 procedure (AACC 1999). All dry ingredients were combined and transferred into the mixing bowl. Shortening and 60% of the water were added. The batter was mixed for 0.5 min at low speed in a Hobart N-50 mixer, scraped down, and then mixed at medium speed for 4 min. Half of the remaining water was then added into the mixing bowl, and the batter was mixed again at low speed for 0.5 min. Again, the batter was scraped down and mixed for 2 min at medium speed. The remaining water was added, and the batter was mixed for another 0.5 min. The batter was scraped down and mixed for 2 min at medium speed. For baking, 400 g batter was scaled into a 8" round cake pan lined with parchment paper and baked at 190 ºC. Baking time for control was 20 min while other formulations' baking time varied. The cakes were cooled in the pan for 30 min and then removed. All cake variations were baked in triplicate, and the average for each cake variation was recorded.

Batter Specific Gravity

Specific gravity of cake batter was calculated by dividing the weight of a standard measure of the batter by the weight of an equal volume of water. The average of three readings is reported.

Measurement of physical and sensory analysis of cake

Cake Volume

After cooling for 30 min, the cake was cut in half (Figure 2.1) and its volume was measured using AACCI Method 10-91.01 standard cake volume template. The volume index was calculated as B + C + D (Figure 2.2). Three cakes were baked per treatment. The average of three readings is reported.

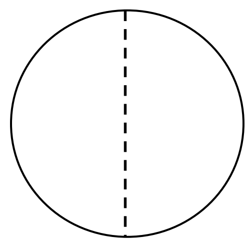


Figure 2.1 Cake cut

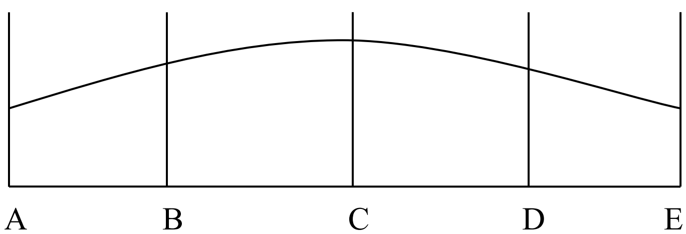


Figure 2.2 Volume index measurement

C-Cell Cake Imaging System

A cake was sliced in half across the diameter, and then a 1 cm wide longitudinal slice was taken from one of the halves. From the other half, a square cube shape crumb (Figure 2.3) was obtained using a template (8 cm x 8 cm x 1.5 cm). Both the longitudinal slice and the cube were scanned in a C-Cell instrument (Calibre Control International Ltd., Appleton, Warrington, UK) using the standard method for collecting images and the standard C-Cell software for data analysis. Average slice area, number of cells, number of holes, and wall thickness of the crumb were calculated and recorded.

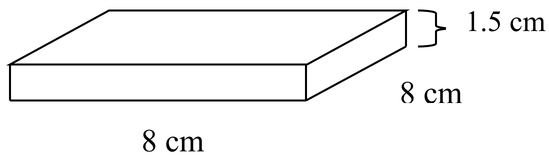


Figure 2.3 Cake slice for C-Cell image analysis

Data Analysis

Data were statistically analyzed using ANOVA with different experimental groups appropriate to the completely randomized design with three replicates each. The GLM procedure by SAS was used for ANOVA analysis. The Tukey method was conducted for pairwise comparisons between treatments (Appendix A).

Results and Discussions

Cakes formulated using polydextrose

Cakes were formulated using the Sundberg two-stage white layer cake formula (Sundberg et al 1953). Polydextrose was added at 25%, 50%, 75% and 100% of sucrose replacement and will be referred as Poly25, Poly50, Poly75 and Poly100 for discussion. With a very complex molecule, highly branched with varied glucose linkages, polydextrose is a humectant (Mitchell et al 2001). Thus, in response to this hygroscopic characteristic, more water was added to cake formulated using polydextrose to achieve the optimum batter and cakes. As the polydextrose level increased in cake formulation, the amount of water added to the batter was also increased to optimum level for each cake variation. The optimum water level was determined once no depression in the center of the cake was observed after baking.

Table 2.5 Optimum water level and optimum baking time for cakes formulated using polydextrose.

Polydextrose Variation	*Sugar (%)*	*Polydextrose (%)*	*Water (%)*	*Bake Time (min)*
Control	100	0	130	20
Poly25	75	25	130	20
Poly50	50	50	135	23
Poly75	25	75	135	23
Poly100	0	100	135	26

After the optimum water level was achieved and cakes were baked at the same temperature (190 ºC), it was determined that baking time should be increased as well because the batter contains more water than the Control (130%) and thus needs longer time in the oven for complete baking with no depression in the center of the cake. The optimized water levels and baking times for each cake variation are shown in Table 2.5. Cake Poly100 (contains no sucrose) requires the highest amount of water and longest baking time due to the highest level of polydextrose (100%) in the formula. Table 2.6 shows the effect of sucrose reduction and sucrose replacement with polydextrose on specific gravity; specific gravity did not differ significantly ($p>0.05$) from variation-to-variation. The specific gravity of batter is a very important physical property since it represents total air holding capacity of the batter during mixing (Manisha et al

2012). The more air incorporated into the batter, the lower its specific gravity (Pyler & Gorton 2009). However, the final volume depends not only on the air incorporated into the batter but also its ability to retain air during baking (Frye & Setser 1991).

Table 2.6 Specific gravity of batter and volume for control and cakes formulated using polydextrose.

Polydextrose Variation	***Specific Gravity***	***Volume***
Control	0.90±0.04[a]	112[d]
Poly25	0.94±0.03[a]	110[cd]
Poly50	0.91±0.03[a]	105[bc]
Poly75	0.91±0.04[a]	103[ab]
Poly100	0.93±0.06[a]	97[a]

*Values are means ± SD for three replications

**Means with different superscript letters within the same column are significantly different at $p<0.05$.

Both starch gelatinization and protein denaturation are important to cake setting during baking, and both processes must occur simultaneously for optimal cake volume (Donovan 1977). The low volume in cakes containing bulking agents (other than sucrose) is due to the decrease in batter stability during the heating stage and to changes in the thermosetting mechanism (Ronda et al 2005). Polydextrose elevates the starch gelatinization temperature but not the protein denaturation temperature (Rosenthal 1995). This causes a premature thermosetting of protein, beginning at the crust, which is in direct contact with the heating medium (Ronda et al 2005). In turn, this reduces the heat transfer rate and produces a vapor pressure build-up, causing inadequate expansion of individual bubbles (Hicsasmaz et al 2003), thus yielding a low final volume. Martinez-Cervera et al (2012) found a similar pattern of final volumes in muffins containing polydextrose and sucralose. They also reported that the excessively early thermosetting is associated with reduced sucrose content; moreover, polydextrose had no effect on the protein denaturation temperature.

The reduction in the cake volume with the increase of polydextrose in cake formula can be seen in Figure 2.4. Even though polydextrose produces a lower volume of cake as compared to Control, the cake shows no dip in the center which indicates that polydextrose works well as bulking agent to replace sucrose.

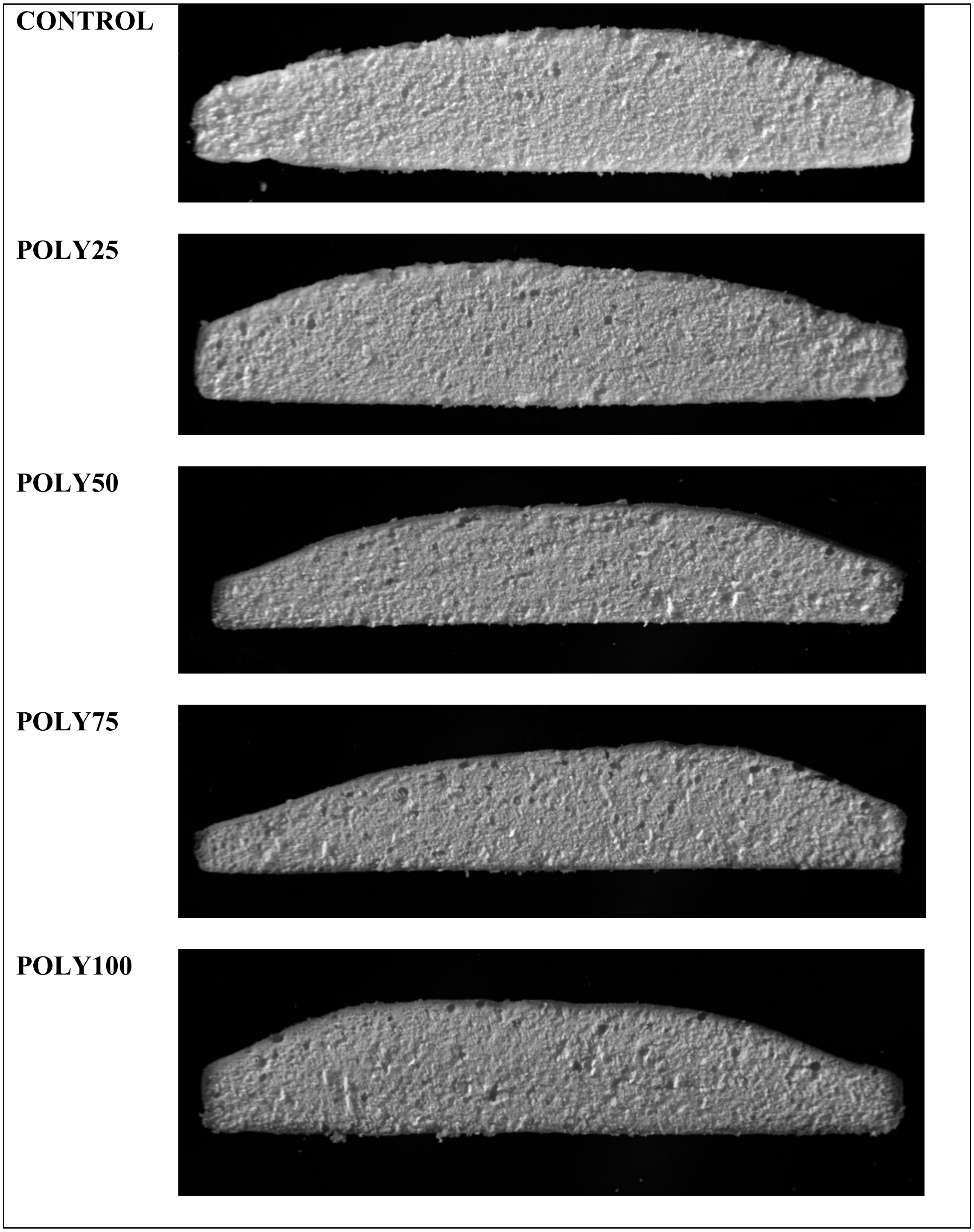


Figure 2.4 C-Cell cake images of control and polydextrose variations.

*Control cake contains 100% sucrose
**Poly25 contains 75% sucrose and 25% polydextrose
***Poly25 contains 50% sucrose and 50% polydextrose
****Poly25 contains 25% sucrose and 75% polydextrose
*****Poly100 contains 100% polydextrose

C-Cell Software provided the slice area, number of cells, number of holes, and cell wall thickness (see Figure 2.5).

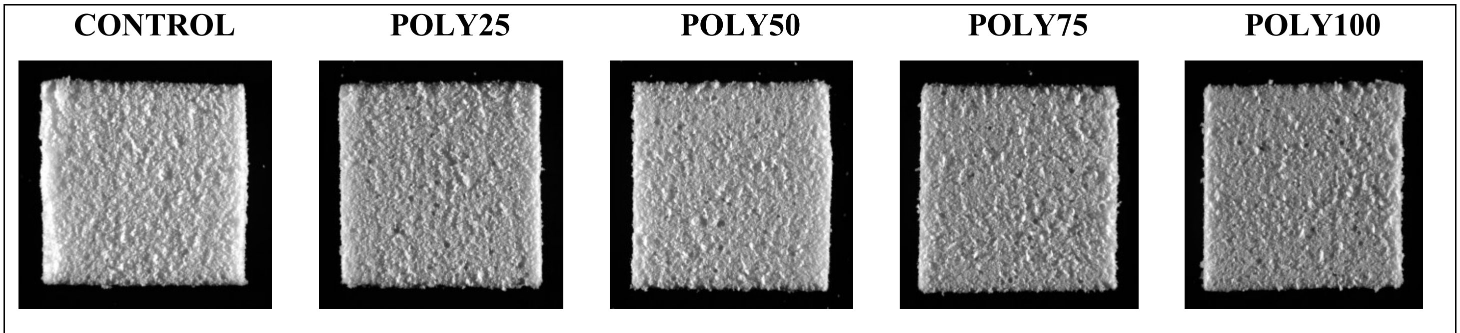


Figure 2.5 C-Cell images of cake crumb for control and polydextrose variations.

Table 2.7 provides the data on gas cells. Cakes showed no significant differences ($p>0.05$) in the number of holes and cell wall thickness, which indicates that polydextrose can produce cakes with as few holes as the control cake. The numbers of cells in the crumbs of cakes made using different levels of polydextrose did show significant differences ($p<0.05$). Compared to control, the highest number of cells (3940) was recorded in crumb from cake containing 25% polydextrose. Cake formulated using 75% polydextrose had the fewest cells. .

Table 2.7 C-Cell data analysis for crumb of control and cakes made with polydextrose.

Polydextrose Variation	*Slice Area (mm^2)*	*Number of Cells*	*Number of holes*	*Wall Thickness (mm)*
Control	6122	3749[b]	0.00[a]	0.446[a]
Poly25	6251	3940[ab]	0.00[a]	0.437[a]
Poly50	5946	3635[ab]	0.33[a]	0.441[a]
Poly75	5758	3490[a]	0.33[a]	0.447[a]
Poly100	5892	3578[a]	0.28[a]	0.441[a]

*Values are means for three replications

**Means with different superscript letters within the same column are significantly different at $p<0.05$.

*** n=3

Fewer cells indicate either fewer air bubbles incorporated into the cake batter or more coalescence in the batter (Zhou 1998). Visual observation indicates the cells in the cake crumbs are evenly distributed. In principle, a larger number of small gas nuclei in the batter is a good indicator of final quality because that favors the formation of tiny air cells that can enlarge during baking (Martinez-Cervera et al 2012), which then contribute to high final volume of cake. Kocer et al (2007) reported that when sucrose was replaced with polydextrose in high ratio layer cake formula, polydextrose helped distribute the gas phase into the batter by decreasing average bubble sizes and increasing bubble size uniformity with increased polydextrose substitution. Hicsasmaz et al (2003) suggested the even bubble size distribution meant polydextrose supported fat functionality. Batter made with polydextrose could imitate cake batter made with sucrose in bubble size distribution (Hicsasmaz et al 2003). Cakes containing polydextrose had evenly distributed cells in final crumb structure, even though the number of cells varied between formulations.

Cakes formulated using polydextrose and sucralose blend

The cake formula with polydextrose used sucralose blend to the same sweetness level as sucrose. A cup of sugar (211g) equals to 26.0 g of sucralose blend, so sucralose blend was added in differing amounts for each variation (Table 2.8). When sucralose blend was incorporated into the formula, however, more water was needed. Sucralose blend is water soluble and acts as drier in cake batter. For this reason, the water level was increased for each cake variation to obtain an optimum water level.

Table 2.8 Optimum water level and optimum baking time for control and cakes formulated with polydextrose and sucralose blend.

Polydextrose Variation	***Sugar (%)***	***Polydextrose (%)***	***Sucralose (g)***	***Water (%)***	***Bake Time (min)***
Control	100	0	0	130	20
Poly25 + Sucralose	75	25	4.2	135	23
Poly50 + Sucralose	50	50	8.3	135	26
Poly75 + Sucralose	25	75	12.5	140	26
Poly100 + Sucralose	0	100	16.6	145	26

Cakes containing more polydextrose and sucralose blend required not only more water but also additional baking time. Polydextrose is, as previously state, highly hygroscopic and thus more water is needed for an optimal batter and more time required to fully bake the batter at

190ºC. Cake containing 0% sucrose (100% poydextrose and sucralose blend) needed the most water (145 ml) and the longest baking time (26 min). After baking, this cake showed no depression in the center of the cake, and all batters were fully baked with an acceptable volume.

The effect on specific gravity of sucrose reduction and sucrose replacement with polydextrose and sucralose blend can be seen in Table 2.9. Specific gravity of the control batter did not differ significantly from Poly100+Sucralose and Poly75+Sucralose ($p>0.05$) although it did differ significantly from Poly25 +Sucralose and Poly50 + Sucralose. However, among four batters containing polydextrose and sucralose blend, all batters showed no significant difference.

The most air was incorporated into cake batter containing 50% polydextrose and 8.3 g of sucralose blend as indicated its specific gravity (0.89). Total air holding capacity during mixing is associated with final volume. The batter with the lowest specific gravity should yield the highest cake volume. However, in this experiment, the control cake batter had the highest specific gravity (0.95) but still produced the highest cake volume (113). This data proved that cake volume does not necessarily depend on only the specific gravity value but also the batter's ability to retain air during baking (Frye & Setser 1991).

Table 2.9 Batter specific gravity for control and cakes formulated using polydextrose and sucralose.

Polydextrose + Sucralose	*Specific Gravity*	*Volume*
Control	0.95 ± 0.04^{b}	113^{d}
Poly25 +Sucralose	0.91 ± 0.00^{a}	109^{cd}
Poly50 + Sucralose	0.89 ± 0.02^{a}	103^{b}
Poly75 + Sucralose	0.92 ± 0.02^{ab}	99^{ab}
Poly100 + Sucralose	0.92 ± 0.01^{ab}	95^{a}

*Values are means ± SD for three replications

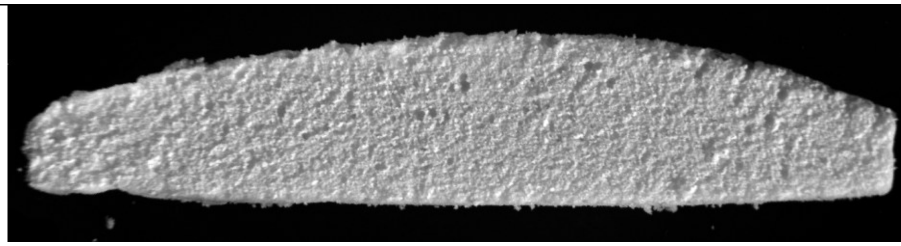
**Means with different superscript letters within the same column are significantly different at $p<0.05$.

The same volume reduction of cakes using polydextrose and sucralose can be seen in Table 2.6The final volumes decreased as polydextrose and sucralose blend increased in the formulation (Figure 2.6). Control had the highest volume (113), which is highly related to the amount of sucrose (100%) in the formula. Sucrose provides good aeration during batter mixing, incorporating more air bubbles, and thus yielding a high final volume. Our results were similar to those of Mitchell et al (2012), who showed polydextrose can provide volume to cakes.

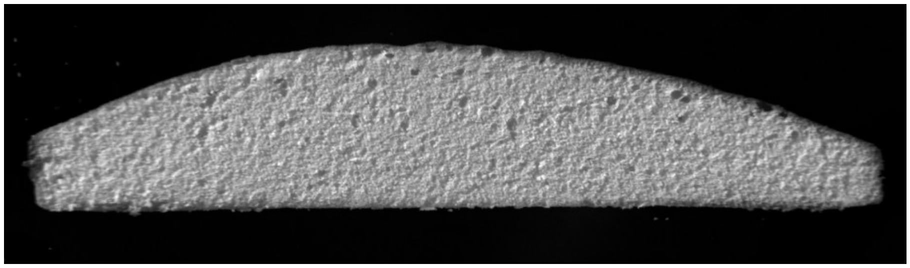
Moreover, although cake containing 100% polydextrose and highest level of sucralose blend (Poly100+Sucralose) yielded the lowest volume of all variations, polydextrose actually helped give good symmetry to the cake (Setser & Racette 1992). In another study done by Martinez-Cervera et al (2012), muffins were formulated using sucralose and polydextrose. They gained similar reduction pattern in volume with the increase of polydextrose and sucralose in muffin formulation.

Although sucralose provides the sweetness and crystallization properties of sucrose, it cannot mimic the structural contribution of sucrose to baked products (Martinez-Cervera 2012). It cannot create bulk properties in the cake batter as sucrose does. In our experiment, we found that sucralose blend can only provide sweetness to the cake without contributing to good volume. A highly significant difference ($p<0.0001$) was recorded for the volume of the control (100% sucrose) and the cake with Poly100+Sucralose (0% sucrose). The differences in the cake volume can be seen in Figure 2.6.

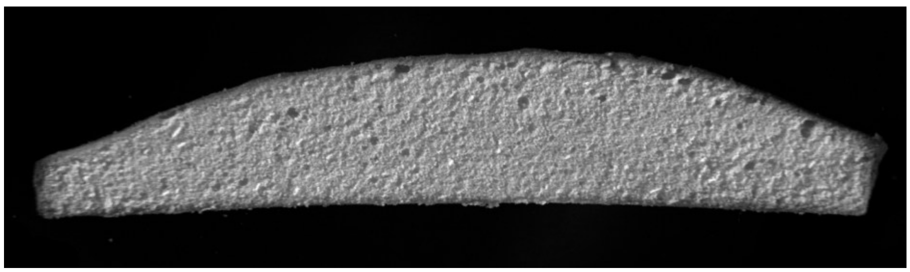
CONTROL



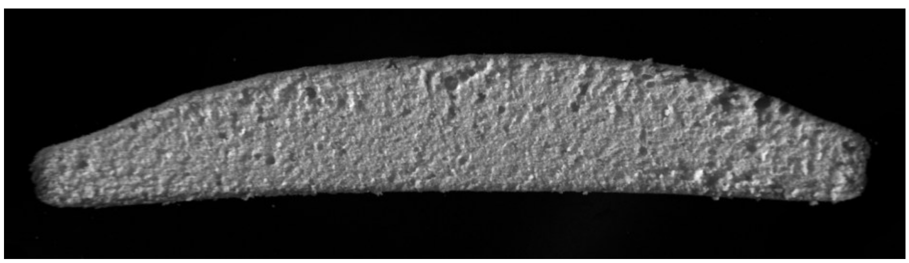
POLY25
+
SUCRALOSE



POLY50
+
SUCRALOSE



POLY75
+
SUCRALOSE



POLY100
+
SUCRALOSE

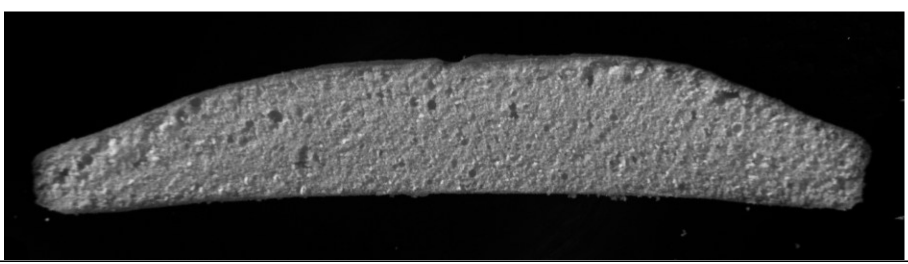


Figure 2.6 C-Cell cake images of control and cakes made with polydextrose and sucralose blend.

*Control cake contains 100% sucrose
**Poly25 + Sucralose contains 75% sucrose, 25% polydextrose and 4.2 g sucralose
***Poly25 + Sucralose contains 50% sucrose, 50% polydextrose and 8.3 g sucralose
****Poly25 + Sucralose contains 25% sucrose, 75% polydextrose and 12.5 g sucralose
*****Poly100 + Sucralose contains 100% polydextrose and 16.6 g sucralose

Table 2.10 shows no significant differences (p>0.05) in the number of cells, number of holes, and cell wall thickness in any of the cakes. This C-Cell crumb data indicates that polydextrose and sucralose blend are a good combination for replacing sucrose in layer cakes. Although they cannot fully imitate sucrose functionalities, especially in producing good volume, polydextrose and sucralose blend are suitable substitutes for sucrose. The C-Cell images in Figure 2.7 show no significant differences among the crumb characteristics of any of the cakes.

Table 2.10 C-Cell data analysis for control crumb and crumb of cakes made with polydextrose and sucralose.

Polydextrose Variation	*Slice Area (mm2)*	*Number of Cells*	*Number of holes*	*Wall Thickness (mm)*
Control	6216	3827^{a}	0.34^{a}	0.442^{a}
Poly25 + Sucralose	5820	3729^{a}	0.00^{a}	0.431^{a}
Poly50+ Sucralose	5931	3712^{a}	0.32^{a}	0.436^{a}
Poly75 + Sucralose	5926	3744^{a}	0.24^{a}	0.443^{a}
Poly100 + Sucralose	5736	3694^{a}	0.38^{a}	0.444^{a}

*Values are means for three replications

**Means with different superscript letters within the same column are significantly different at p<0.05

*** n=3

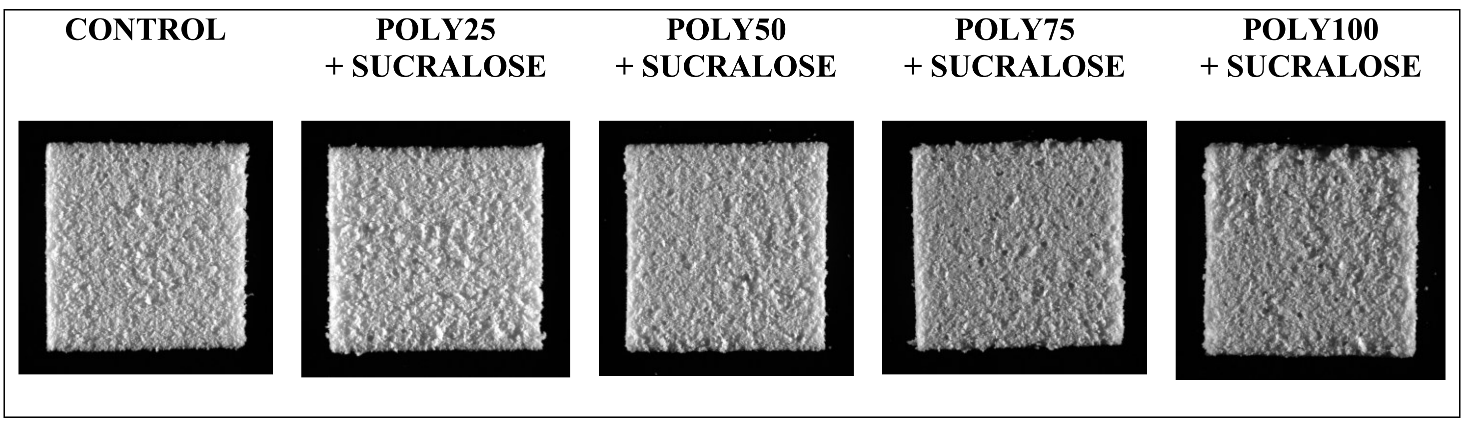


Figure 2.7 C-Cell images of control cake crumb and cake crumb from Polydextrose and Sucralose variations.

Cakes formulated using polydextrose and stevia extract

Stevia blend was added into the polydextrose cake formula to the same sweetness level as sucrose. A cup of sugar (211g) equals to 32.6 g of stevia extract blend. Therefore, different amounts of stevia blend were added to each variation (Table 2.11). As determined for the Polydextrose/Sucralose blend variations, more water is needed for cake batter containing polydextrose and stevia blend. Like sucralose, stevia blend also acts as drier in cake batter, and polydextrose is a humectant. For these reasons, more water was added as polydextrose and stevia blend levels were increased in the cake formula. The more water was added to the batter, the more time was needed to bake the cake.

Table 2.11 Optimum water level and optimum baking time for control and for cakes formulated with polydextrose and stevia extract blend.

Polydextrose Variation	*Sugar (%)*	*Polydextrose (%)*	*Stevia (g)*	*Water (%)*	*Bake Time (min)*
Control	100	0	0	130	20
Poly25 + Stevia	75	25	5.2	135	23
Poly50 + Stevia	50	50	10.4	140	26
Poly75 + Stevia	25	75	15.6	140	29
Poly100 + Stevia	0	100	20.8	145	29

As with other variations, this variation required more water in the batter because more stevia blend powder was added to the formula. Therefore, cake containing 0% sucrose (100% poydextrose and stevia blend) needed the most water (145ml) and the longest baking time (29min). The cake crust, however, was very dark because of the baking time. The cake was fully baked with no depression in the center. A lower oven temperature (<190 ºC) with same amount of water and bake time might provide a more acceptable crust color to the cake.

Table 2.12 shows the Poly50 + Stevia cake had the lowest specific gravity, which indicates that more air was incorporated during mixing of this batter. There was no significant difference in specific gravity of control and Poly25 + Stevia ($p<0.05$) but control differed significantly with other four polydextrose/stevia blend variations. Sahi and Alava (2003) noted that air incorporation during mixing depends both on aeration process (beater speed and design) and on the physico-chemical properties of the batter (viscosity and surface tension), which are determined by formulation.Referring to Table 2.12, the final volume of cakes decreased as the amount of polydextrose and stevia blend increased. In comparison analysis, control and Poly100 + stevia (0% sucrose) differed the most (p = 0.0001). Reducing sucrose by 25% produced a cake that did not differ significantly from control (p>0.05). However, as more polydextrose was added, the cakes differed significantly from control. The containing polydextrose and stevia blend had lower volume, showing that stevia blend, like sucralose blend, can only provide sweetness to the cake. It cannot help improve cake volume. The difference in the cake volume can be seen in Figure 2.8.

Table 2.12 Batter specific gravity for control and for cakes formulated with polydextrose and stevia extracts.

Variation	*Specific Gravity (g/cc)*	*Volume*
Control	0.94 ± 0.05^{b}	112^{d}
Poly25 + Stevia	0.90 ± 0.02^{ab}	108^{cd}
Poly50 + Stevia	0.87 ± 0.02^{a}	104^{bc}
Poly75 + Stevia	0.88 ± 0.03^{a}	100^{ab}
Poly100 + Stevia	0.90 ± 0.04^{a}	95^{a}

*Values are means ± SD for three replications

**Means with different superscript letters within the same column are significantly different at p<0.05.

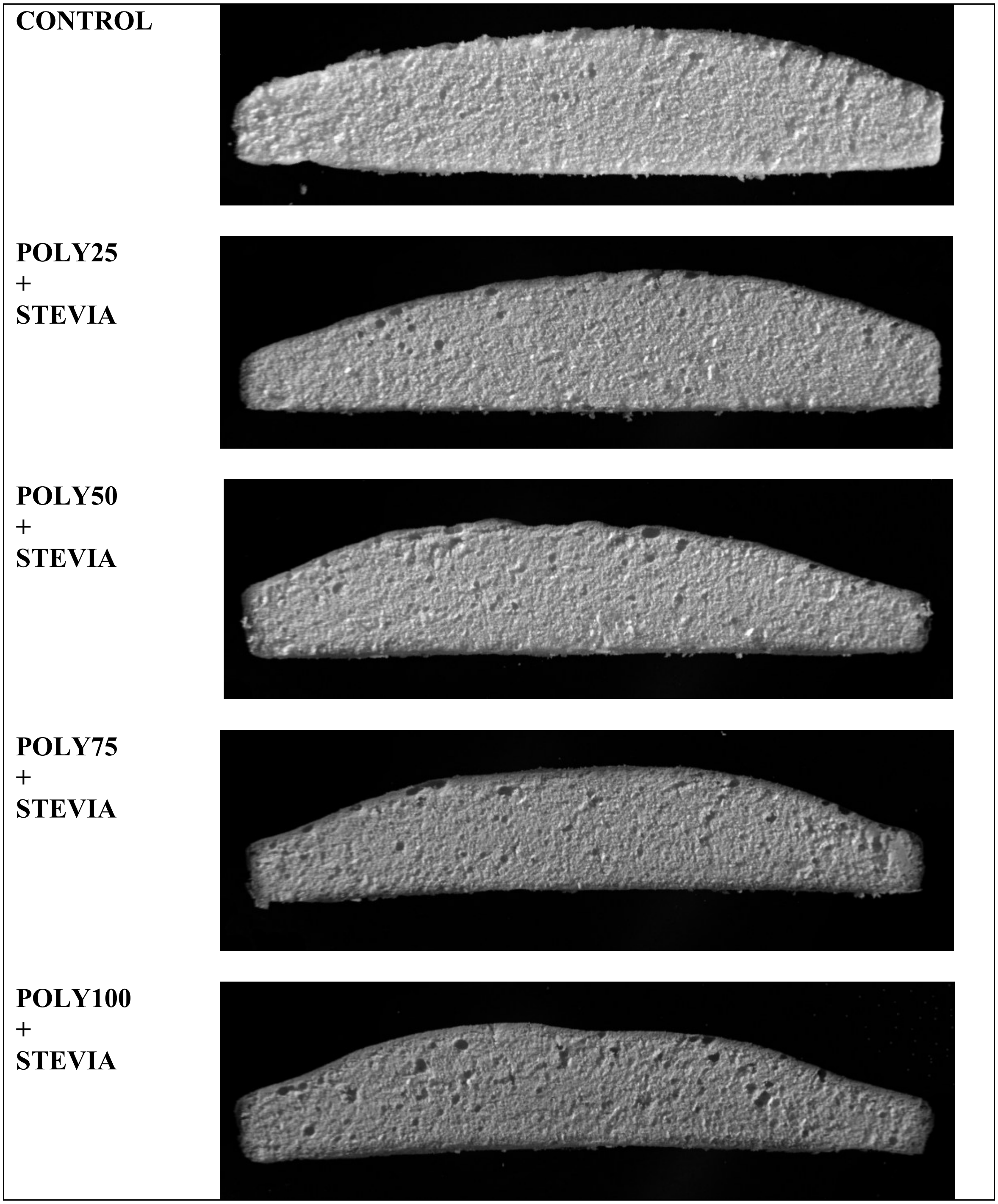


Figure 2.8 C-cell cake images for control and cakes made with polydextrose and stevia blend.

*Control cake contains 100% sucrose
**Poly25 + Stevia contains 75% sucrose, 25% polydextrose and 5.2 g stevia
***Poly25 + Stevia contains 50% sucrose, 50% polydextrose and 10.4 g stevia
****Poly25 + Stevia contains 25% sucrose, 75% polydextrose and 15.6 g stevia
*****Poly100 + Stevia contains 100% polydextrose and 20.8 g stevia

Table 2.13 shows no significant differences ($p>0.05$) in the number of cells and cell wall thickness in all cakes. For number of holes the Control differs significantly to other four variations. These data indicate that, on the basis of crumb, polydextrose and stevia blend would be a good combination of ingredients to replace sucrose in layer cakes.

Table 2.13 C-Cell data analysis for control crumb and crumb of cakes made with polydextrose and stevia.

Polydextrose Variation	***Slice Area (mm2)***	***Number of Cells***	***Number of holes***	***Wall Thickness (mm)***
Control	6148	3583^{a}	0.01^{b}	0.452^{a}
Poly25 + Stevia	5816	3447^{a}	0^{a}	0.451^{a}
Poly50 + Stevia	5857	3654^{a}	0^{a}	0.437^{a}
Poly75 + Stevia	5739	3438^{a}	0^{a}	0.448^{a}
Poly100 + Stevia	5653	3474^{a}	0^{a}	0.444^{a}

*Values are means for three replications

**Means with different superscript letters within the same column are significantly different at $p<0.05$.

*** n=3

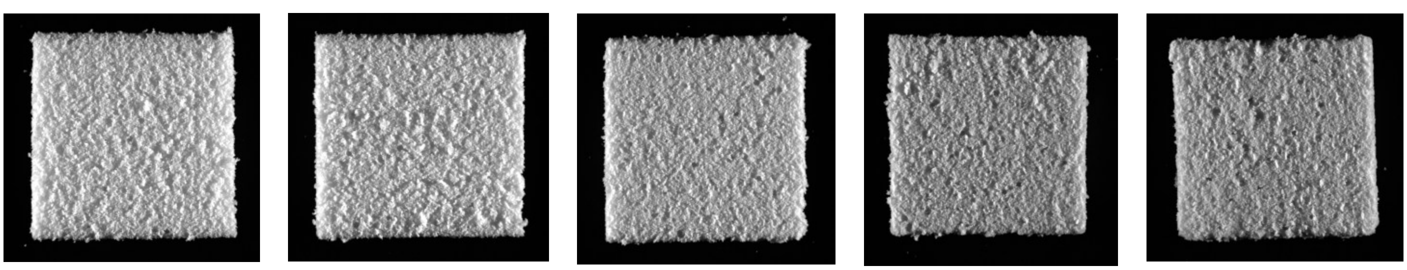


Figure 2.9 C-Cell images of control cake and crumb of cakes made with Polydextrose and Stevia.

Conclusions

Replacing sucrose with polydextrose in a cake formula made little difference to batter specific gravity. Adjusting water level and baking time provided cakes with no depressions in the center. Cake volume was gradually reduced as polydextrose level increased in each variation. Adding sucralose blend and stevia blend provided sweetness to the cakes but did not contribute to cake volume. In 25% sucrose reduction, cakes containing 75% sucrose + 25% polydextrose + stevia blend or sucralose blend had almost the same volume as the control. Formulation containing 0% sucrose, with either 100% polydextrose + sucralose blend or 100% polydextrose + stevia blend, yielded an improved volume of cakes as compared to cake containing neither sucrose nor any bulking agent. Polydextrose is thus an appropriate bulking agent to replace sucrose while sucralose blend and stevia blend are suitable artificial sweeteners for zero-calorie or reduced-calorie cakes.

The results of this experiment suggest more research is needed to investigate other bulking agents suitable as sucrose replacers. Furthermore, other fibers like cellulose powder or polyols like maltitol and xylitol could be combined to obtain acceptable volume in reduced-sucrose cakes. In addition, sensory profile analysis or consumer testing on the final cakes as well as shelf-life study can also be done for product quality measurement and marketability.

References

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Appendix A - SAS program

1) Cakes Formulated using Polydextrose

/*Gravity stands for Specific Gravity*/

```
proc glimmix data=clip;
      class Polydextrose;
      model Gravity = Polydextrose;
      lsmeans Polydextrose/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s 
Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Volume stands for Cake Volume*/

```
proc glimmix data=clip;
      class Polydextrose;
      model Gravity = Polydextrose;
      lsmeans Polydextrose/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s 
Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Area stands for Slice Area*/

```
proc glimmix data=clip;
      class Polydextrose;
      model Area = Polydextrose;
      lsmeans Polydextrose/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s 
Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Cells stands for Number of Cells*/

```
proc glimmix data=clip;
      class Polydextrose;
      model Cells = Polydextrose;
      lsmeans Polydextrose/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s 
Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Holes stands for Number of Holes*/

```
proc glimmix data=clip;
      class Polydextrose;
      model Holes = Polydextrose;
```

```
      lsmeans Polydextrose/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s
Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Wall stands for Wall Thickness*/

```
proc glimmix data=clip;
      class Polydextrose;
      model Wall = Polydextrose;
      lsmeans Polydextrose/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s
Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

2) Cakes Formulated using Polydextrose and Sucralose

/*Gravity stands for Specific Gravity*/

```
proc glimmix data=clip;
      class Sucralose;
      model Gravity = Sucralose;
      lsmeans Sucralose / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Volume stands for Cake Volume*/

```
proc glimmix data=clip;
      class Sucralose;
      model Volume = Sucralose;
      lsmeans Sucralose / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Area stands for Slice Area*/

```
proc glimmix data=clip;
      class Sucralose;
      model Area = Sucralose;
      lsmeans Sucralose / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Cells stands for Number of Cells*/

```
proc glimmix data=clip;
      class Sucralose;
      model Cells = Sucralose;
      lsmeans Sucralose / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Holes stands for Number of Holes*/

```
proc glimmix data=clip;
      class Sucralose;
      model Holes = Sucralose;
      lsmeans Sucralose / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Wall stands for Wall Thickness*/

```
proc glimmix data=clip;
      class Sucralose;
      model Wall = Sucralose;
      lsmeans Sucralose / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

3) Cakes Formulated using Polydextrose and Stevia Extract

/*Gravity stands for Specific Gravity*/

```
proc glimmix data=clip;
      class Stevia;
      model Gravity = Stevia;
      lsmeans Stevia/ pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Volume stands for Cake Volume*/

```
proc glimmix data=clip;
      class Stevia;
      model Volume = Stevia;
      lsmeans Stevia / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Area stands for Slice Area*/

```
proc glimmix data=clip;
      class Stevia;
      model Area = Stevia;
      lsmeans Stevia / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
```

```
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Cells stands for Number of Cells*/

```
proc glimmix data=clip;
      class Stevia;
      model Cells = Stevia;
      lsmeans Stevia / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Holes stands for Number of Holes*/

```
proc glimmix data=clip;
      class Stevia;
      model Holes = Stevia;
      lsmeans Stevia / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

/* Wall stands for Wall Thickness*/

```
proc glimmix data=clip;
      class Stevia;
      model Wall = Stevia;
      lsmeans Stevia / pdiff adjust=tukey ;  *Tukey(-Kramer)'s Adjustment;
      output out=residuals residual=residual predicted=predicted;
run; quit;
```

** To import data from Microsoft Office Excel to SAS 9.3, this code was used:

```
PROC IMPORT OUT=clip DATAFILE= "G:\Poly.Spec.xlsx"
DBMS=xlsx REPLACE;
GETNAMES=YES;
run;
proc print data=clip;
run;
```