FUNCTIONALITY OF SUCRALOSE/MALTODEXTRIN: ISOMALT BLENDS IN YELLOW SHORTENED CUPCAKES OVER A 4-DAY STORAGE PERIOD

by

AIMEE ELIZABETH CHISAMORE

(Under the Direction of Ruthann Swanson)

ABSTRACT

High quality, reduced-sugar baked goods have potential to reduce carbohydrate and calorie consumption. In yellow shortened cupcakes, 100% of sugar was replaced with 100% Splenda®Granulated (SP99) and two ratios of Splenda®Granulated:isomalt, 40:60 (SP40) and 50:50 (SP50). A descriptive sensory panel (DSP) evaluated texture and flavor attributes 1 and 3-days post-bake. Texture Profile Analysis (TPA) was collected throughout the storage period. Consumer panelists (n=66) evaluated acceptability 1-day post-bake. Springiness and cohesiveness decreased whereas hardness and chewiness increased over time. Instrumentally SP99 was closest to the control in texture whereas the DSP found SP40 to be most like the control. Treatment flavor effects were found; isomalt/Splenda®Granulated moderated differences in attribute intensities when compared to the control. SP40 exhibited a flavor profile most similar to the control. Color, water activity, volume, and batter specific gravity supported DSP results. Reformulated cakes were in the neither acceptable nor unacceptable range in terms of overall acceptability. Sugar reduction was 94% for blends; calorie, 12-13%.

INDEX WORDS: Yellow shortened cake, High intensity sweetener(s), Sucralose, Isomalt, Maltodextrin, Flavor, Texture, Sensory evaluation, Instrumental Evaluation

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CHAPTER 1

INTRODUCTION

Cake, added sugar, and alternative sweetener consumption

Cake is a popular high-sugar snack and dessert that also is a source of added sugars in the diet. The Dietary Guidelines for Americans defines added sugars as those sugars eaten separately or added as ingredients in the production of foods (Johnson and Frary 2001). Sweetened grain products, which include cookies and cakes, contribute almost 13 percent of total intake of added sweeteners (Guthrie and Morton 2000). Recently cakes, and other baked products, have been targeted for reformulation with different sugar alternatives or blends of sugar alternatives to reduce calorie and added sugar intake. In general, reduced-calorie products made with alternative sweeteners are becoming increasingly popular. A 2004 survey reported that 84% of adults use low-calorie and/or sugar-free foods and beverages compared to 73% of adults in 1998 (Sigman-Grant and Hsieh 2005). As of 2007, reportedly 194 million adult Americans consumed low-calorie and sugar-free foods and beverages compared to 78 million in 1986 (CCC 2009). About 59% of Americans consume diet soft drinks and 49% use sugar substitutes (CCC 2009). In addition, reduced-sugar food consumers reportedly have higher quality diets with higher micronutrient intakes than full-sugar food consumers (Sigman-Grant and Hsieh 2005). In dietary recalls, reduced-sugar food consumers reported higher intakes of fruit, lower intakes of discretionary fat and added sugars, and equal or lower intakes of other foods (Sigman-Grant and Hsieh 2005).

Mean intake for added sweeteners across the US population is about 16% of total energy (Guthrie and Morton 2000). USDA's Food Guide suggested amount of added sugars in the diet is limited to no more than eight teaspoons a day when consuming a 2,000 kilocalorie diet (USDA & US DHHS 2005); this consumption level equivalates to 6-7% of total energy intake. Actual intake of added sweeteners in the diet far exceeds this level and has been increasing during the past 30 years. The Institute of Medicine advises that the maximum level of consumption of added sugars should be limited to 25% of energy intake because with any consumption over that amount dietary quality is decreased, specifically micronutrient levels (ADA 2004). There is no specific recommendation for an amount of added sugars appropriate for daily consumption, rather there are suggested amounts to be included at different kilocalorie levels without overconsuming the recommended kilocalorie level.

Obesity trends and associated chronic diseases

Obesity rates among adults have risen significantly during the past 20 years and now obesity affects 34% of the US adult population (CDC 2009a). About 66% of the US adult population is either overweight or obese (CDC 2009b). Overweight is defined as having a body mass index (BMI) between 25.0-29.9 and obesity is defined as having a BMI over 30.0. The obesity epidemic raises much concern because of its impact on Americans' health. Obesity increases the risk of many chronic diseases and other health conditions such as coronary heart disease, type 2 diabetes, cancer, hypertension, dyslipidemia, stroke, liver and gallbladder disease, sleep apnea and respiratory problems, osteoarthritis, and infertility (CDC 2009a).

Similar to obesity, diabetes has reached epidemic proportions in the US and in 2006 diabetes was the seventh leading cause of death. As of 2007, it is estimated that 23.6 million people or 7.8% of the population have diabetes. Around 80 percent of people with type 2 diabetes are overweight (CDC 2008). Weight loss is an important treatment recommendation for overweight individuals with diabetes to prevent complications (Franz and others 2002). Some common complications from diabetes are heart disease, stroke, high blood pressure, blindness, kidney disease, amputations, dental disease, nervous system damage, and impaired immune function (CDC 2008). People with diabetes can prevent these complications by controlling blood glucose levels, blood pressure, and blood lipids. Blood glucose management can be accomplished by controlling intake of carbohydrates, especially simple carbohydrates (Franz and others 2002).

Added sugars and links to weight gain

Prospective studies show a positive relationship between consumption of sweetened beverages and weight gain (USDA & US DHHS 2005) and diets high in sugars have been linked to varying health issues (Johnson and Frary 2001). Current evidence does not support a direct causal relationship between increasing sweetener intakes independent of energy intake and increasing obesity rates; however, reducing intake of added sugars lowers total caloric intake and promotes adequate nutrition (ADA 2004; Lichtenstein and others 2006). The lack of a correlation found in some studies between added sweeteners and obesity rates could partly be explained by underreporting of food intake, which is a known problem in dietary surveys, especially among overweight and obese individuals (Johnson and Frary 2001). Short-term studies suggest that substituting added sugar with low-energy sugar alternatives may result in lower caloric intake and some weight loss (Vermunt and others 2003). Alternative sweeteners can save an individual up to 16 kcal/tsp of sweetener and result in a loss of 380 kcal/day if nutritive sweetener intake was at 95 g (24 tsp) daily (ADA 2004). In the long term, use of alternative sweeteners rather than sugar may help with weight maintenance and allow people to enjoy the sweets they want without consuming as many calories.

Alternative sweeteners: high intensity sweeteners versus low-calorie

Alternative sweeteners generally fall into two categories: high intensity sweeteners (HIS) and low-calorie sweeteners. HIS include saccharin, aspartame, acesulfame-K, sucralose, and neotame. HIS range from 160-8,000 times sweeter than sucrose; thus, in food production only a small amount of the sweetener is necessary to provide sweetness equal to sucrose. HIS are considered “nonnutritive” and provide either none or negligible amounts of calories. Exact calorie amounts are presented in an ADA report (2004). They also produce either no or limited glycemic responses and thus are recommended for people with diabetes (ADA 2004). HIS are also noncariogenic, meaning they do not promote the production of dental caries. HIS provide consumers with a sweet taste similar to sucrose without sucrose’s caloric density. One disadvantage to HIS is their bitter, metallic, and lingering aftertastes and some cannot be used in baking because they lose their sweetening power once heated (aspartame). Another drawback to HIS in baking is that they provide little volume and thus products made with 100 percent replacement of a HIS for sucrose have met with limited success. Manufacturers will often combine HIS with a bulking agent (maltodextrin, polydextrose, polyols, even dextrose) to replace the nonsweet functional properties of sucrose in baked products. This method is referred to the multiple ingredient approach. In the multiple ingredient approach, the HIS provides the sweetness that sucrose would provide, but with no calories whereas the bulking agent provides the bulk, volume, and other functional roles important in specific products that sucrose would typically provide. Bulking agents do incorporate kilocalories into the nutrient content of the products. In addition, blending of sweeteners can cause sweetness synergy, which decreases the amount of sweeteners that are necessary and provides a better sweet taste profile (ADA 2004). A sweet taste profile includes the following components: sweetness intensity at a given concentration, time of onset, time of maximum intensity, temporal persistence, and presence of other basic tastes and tactile effects (Shallenberger 1998).

Low-calorie sweeteners include the sugar alcohols (polyols) sorbitol, mannitol, xylitol, erythritol, isomalt, lactitol, maltitol, trehalose, and hydrogenated starch hydrolysates. On average they provide about 2 kcal/g because they are not fully absorbed by the gut. Except for xylitol, all polyols are less sweet when compared to sucrose. Polyols also can serve as bulking agents, flavor enhancers, and stabilizers and are often used in combination with HIS to equal the sweetening power of sucrose while providing bulk necessary for the production of baked products. Other benefits of polyols include reduced glycemic responses, decreased dental caries risk, and prebiotic effects. However, if sugar alcohols are consumed in large amounts, greater than 30-50 g/day depending on the specific type, they can produce a laxative effect (ADA 2004).

Factors that influence consumer food choice: taste versus health issues

The 2009 Functional Foods/Foods for Health Consumer Trending Survey indicated that the majority of Americans (91%) believe they have control over their health and identify food and nutrition as being the biggest factor to improving health followed by exercise and family history (IFIC 2009). Sixty-four percent of the participants reported that they had made a change to improve the healthfulness of their diet in the past six months (IFIC 2009). However, taste remains the number one factor that influences food purchases (IFIC 2009). In addition, appearance, smell, and texture influence consumer food choice and if these sensory attributes are not perceived positively, then it is unlikely the food will be consumed (Eertmans and others 2001). Therefore, it is vital that reduced-sugar or sugar-free products have acceptable sensory characteristics that are similar to the unmodified product because consumers will not continue to purchase reduced sugar foods if they do not live up to their quality expectations. Thus, the high quality of modified food products is necessary and is of utmost concern to food scientists creating those products. Furthermore, long-term consumer acceptance of modified products depends on enjoyable taste. For shortened yellow cake, desirable characteristics are: fine air cell size, moist and tender crumb, and golden brown appearance (Nelson 2000).

Hypothesis

One hundred percent replacement of the granulated sugar in the formulation by the 40% Splenda® Granulated:60% isomalt alternative sweetener blend produces cupcakes with the quality attributes most similar to the 100% granulated sugar control.

Objectives

1. To establish a flavor and texture profile for each formulation by utilizing a trained descriptive sensory panel and to determine which formulation most closely mimics the 100% sucrose control.
2. To characterize each cupcake formulation instrumentally by Texture Profile Analysis, color, water activity, volume, and specific gravity.
3. To identify differences in flavor and texture of cupcakes over a 4-day storage period as assessed by a trained descriptive sensory panel and through instrumental assessment of texture.
4. To determine consumer acceptability of the control and sugar-replaced cupcakes.

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CHAPTER 2

REVIEW OF LITERATURE

Functional role of key ingredients in shortened cake and the multi-ingredient sweetener approach

One popular sweet dessert is cake. The two major types of cakes are shortening-based cakes, with a structure derived from a fat-liquid emulsion, and foam-type cakes, with a structure that relies mainly on egg foams (Pyler 1988). The gold standard for yellow shortened cake includes the following characteristics: fine air cell size; moist, tender, and velvety crumb; uniform golden brown appearance; and pleasant sweet flavor (AACC 2000; Nelson 2000). Formulas for typical shortened yellow cake are 25% sugar, 30% flour, 13% shortening, 15% eggs, and 15% milk (Pyler 1988). Sucrose plays many important roles in cakes including providing sweetness. Sucrose's sweetness profile is the standard against which other sweeteners are compared. A sweetness profile is defined as the complete set of sweetness attributes perceived by taste (Shallenberger 1998). No two sweet substances have the same sweetness profiles; however, blends of sweeteners tend to better match the sweetness profile of sucrose than do high intensity sweeteners when used individually (Hanger and others 1996).

Sucrose also contributes to caramelization and reducing sugars derived from sucrose contribute to Maillard browning, both of which provide characteristic browning, aromas, and flavors (McWilliams 2008). Caramelization is defined as the transformation of sugars while being heated at intensely high temperatures from colorless sweet substances to compounds ranging from pale yellow to dark brown in color and from caramel to burnt and bitter in flavor

(Pyler 1988). As a result of the high temperatures, the ring structures of the sugars break and the brown end-products that contribute new flavors and aromas are mostly unsaturated complex polymers such as glyceraldehyde, dihydroxyacetone, pyruvic acid, and pyruvaldehyde (Pyler 1988). The Maillard reaction results in nonenzymatic browning that requires an amino compound, a reducing sugar, and water and results in the formation of melanoidins (Daniel and others 2007). During the initial stage (colorless) the reducing sugars and amines condense to form glycosylamine, which then undergoes Amadori rearrangement (Figure 2.1). In the intermediate stage (colorless or yellow) the Amadori rearrangement products undergo dehydration and fragmentation; the amino acid undergoes degradation. In the final stage (highly colored) the aldol condenses, aldehyde-amine polymerizes, and a variety of melanoidins are formed with differences in their taste, aroma, and color intensity (Pyler 1988). Maillard browning is the major contributor to the baked cake crust color and the associated characteristic flavor.

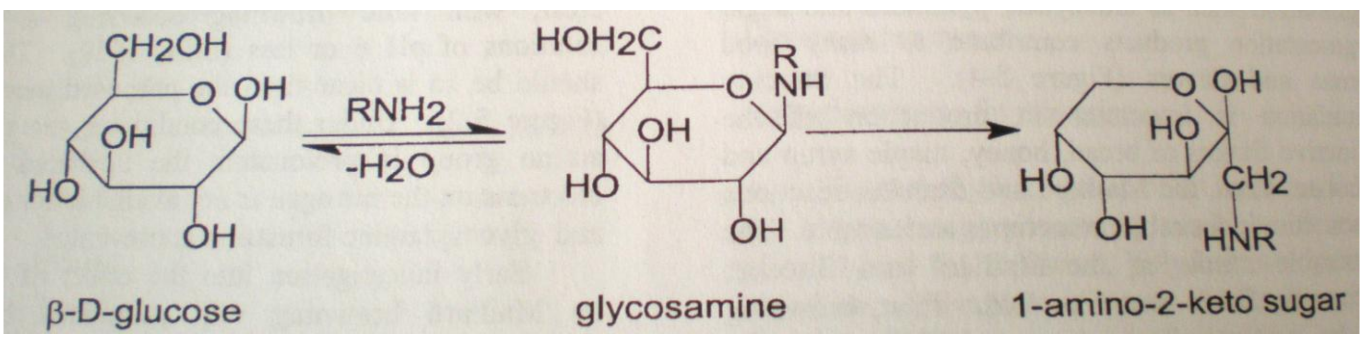

Figure 2.1: Early stage Maillard reactions-formation of glycosylamine and the Amadori rearrangement of a glycosamine to a 1-amino-2-keto sugar (Daniel and others 2007)

Sucrose acts as a tenderizer in the shortened cake system by delaying gluten formation and increasing the temperature of starch gelatinization and protein denaturation (Kulp and others 1991). Sugar also dilutes the protein structure thereby contributing to crumb fineness (Pyler 1988). Thus, sucrose contributes to the crumb characteristics of cake. In addition sucrose contributes to the structure of cake by adding bulk and volume; therefore, substitution of sucrose affects structural as well as sensory properties (Frye and Setser 1991; Kulp and others 1991). Also, sugar plays a role in the leavening process. When sugar is creamed into butter or shortening, air is incorporated into the batter by means of the sugar crystals carving tiny air pockets into the soft butter or shortening (Pyler 1988; McWilliams 2008). During baking, these pockets fill with steam and carbon dioxide and expand, affecting final crumb structure. Shortening also contributes to cake texture by acting as a tenderizer and moistener. Another role of sucrose is that it extends the shelf life of cakes by binding water and reducing water activity in baked cakes thereby interfering with microbial growth (McWilliams 2008). Flour predominately serves as a structure builder in cake or as a "toughener" and is largely responsible for the crumb of the cake. Flour acts as a "drier" too because of its high starch and protein content. Eggs serve several roles in cake; they act as structure builders, moisteners, and tenderizers. Milk serves as a moistener and enhances flavor in cake. Salt also enhances flavor. Baking powder acts as a tenderizer by contributing to the volume and lightness of cake (Pyler 1988).

Bulking agents are used to replace the "nonsweet functional properties of sucrose" and it appears that a combination of bulk replacers and high intensity sweeteners achieve more acceptable results because no bulk replacer or high intensity sweetener possesses all of sugar's characteristics (Ronda and others 2005). An array of bulking agents has been investigated such as fructose, dextrose, polydextrose, polyols, and maltodextrins. Hess and Setser (1983) found that layer cakes made with aspartame and fructose were more tender and uniform and had higher eating quality scores when compared to cakes made only with aspartame. Attia and others (1993) found that a combination of aspartame or acesulfame-K, fructose, and polydextrose in sponge cakes produced a product similar in acceptability to the control sample with 40% reduction in calories. When sucrose was replaced only by acesulfame-K or aspartame, a significant decrease in cake quality resulted, but when fructose was added to the sweetener blend the cake quality properties significantly increased (Attia and others 1993). Thus, literature reports suggest that a multi-ingredient sweetener and bulking agent combination for the replacement of sucrose in cake achieves better results when compared to replacement with only one alternative sweetener.

Alternative sweetener substitution for sucrose in cake

There has been little research conducted with alternative sweetener substitution in shortened cakes although more research has been conducted with sponge cake. Sponge cakes differ from shortened cakes because they rely primarily on egg protein for structure instead of sugar and flour as is the case in shortened cakes (Pyler 1988). Johnson and others (2006) used the following substitution ratios of Splenda® Granulated to isomalt: 10:90, 20:80, and 30:70 in yellow cupcakes. Splenda® Granulated is comprised of sucralose and maltodextrins. The 30:70 ratio most closely resembled the sucrose control cupcake. Johnson and others (2006) concluded that trends in cupcake characteristics as assessed with a descriptive sensory panel and instrumentally suggested isomalt blends with a higher ratio of Splenda® Granulated should be investigated. Cohesiveness, sweet, and browned were the only attributes that significantly differed in the 30:70 treatment from the control when evaluated within 24 hours of baking by a descriptive sensory panel (Johnson and others 2006). Staling was not assessed. Anecdotally, rapid staling is a major issue with sugar replacement in shortened cakes. Shelf-life is a major consideration when consumers select among available products (I'Anson and others 1990; Gelinas and others 1999). Staling is one component of shelf-life.

Pong and others (1991) conducted a study with cupcakes in which a combination of aspartame, fructose, and polydextrose replaced sucrose. The modified cupcakes had a lower standing height, higher specific gravity, firmer texture, higher moisture content, and lighter crust color (Pong and others 1991). In general, reformulation challenges seen with sugar-replaced cakes are lower volumes, higher specific gravities, lighter crust colors, and firmer textures.

More recently, McKemie (2008) investigated ratios of Splenda® Granulated and isomalt (30:70, 40:60, and 50:50) in two cookie types and found no significant differences in sensory attributes between the control and the 40% Splenda® Granulated, 60% isomalt blend formulations. The ratios investigated in cookies covered the range previously evaluated in shortened cakes and included the ratios which Johnson and others (2006) suggested may result in quality characteristics more similar to the gold standard in shortened yellow cake. As suggested by the trend in cake, a higher Splenda® Granulated: isomalt ratio (40:60) produced the best quality cookie. Effects of this ratio are unknown in shortened yellow cake.

Sucralose/maltodextrin blends

Sucralose is an intense sweetener that is 600 times sweeter than sucrose and provides no energy because it is poorly absorbed (ADA 2004). Because sucralose is poorly absorbed it does not raise blood glucose levels making it safe for people with diabetes (McNeil Nutritionals 2009a). Sucralose is a disaccharide that has three chlorine molecules that replace three hydroxyl groups on the sucrose molecule making it unrecognizable by the body and therefore indigestible (ADA 2004). See Figure 2.2 for the chemical structure of sucralose.

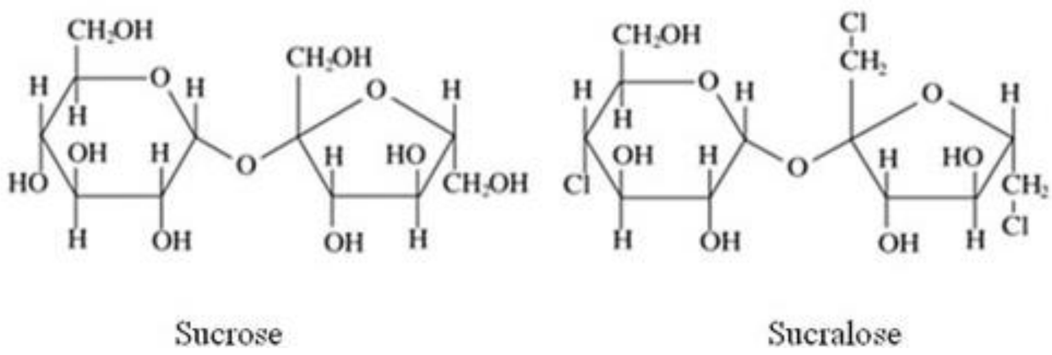

Figure 2.2: Structures of sucrose and sucralose (Rodero and others 2009)

Unlike some other alternative sweeteners, sucralose is heat stable, which makes it capable of being used as a sweetening agent in cooking and baking (ADA 2004). Sucralose is most commonly marketed as Splenda®, which is available in several different formulations. Splenda® Granulated, a general purpose sugar alternative contains sucralose and maltodextrin, a bulking agent. Maltodextrin is defined by the FDA as a nonsweet nutritive saccharide polymer that consists of D-glucose units linked predominately by alpha- 1, 4 bonds and has a dextrose equivalent of less than 20 (CFR 1998). Maltodextrins dilute the sweetness of sucralose while contributing bulk to the sweetener blend (Kuntz 1997) and providing approximately 4 kcal/g. Thus, consumers can use Splenda® Granulated in a 1:1 ratio for sugar in terms of volume, with sweetness intensity equal to that of an equal volume of sucrose (McNeil Nutritionals 2009b). However, because sugar has many more roles than just providing sweetness, the substitution of Splenda® Granulated for sugar works best only in formulations where sugar's major role is to provide sweetness such as fruit fillings and sauces (McNeil Nutritionals 2009b). Unlike high-intensity alternative sweeteners, maltodextrins can participate in Maillard browning reactions because they contain reducing sugars; however, quality characteristics of a standard baked product are typically not achievable with sucralose/maltodextrin blends alone (Kuntz 1997).

Sugar alcohols

Polyhydric alcohols (polyols) or sugar alcohols are naturally occurring compounds that are generally recognized as safe (GRAS) ingredients and are used as low-energy sweeteners in a variety of foods (McWilliams 2008). Polyols in general have a low glycemic response, low caloric density, noncariogenic properties, lower sweetness intensity when compared to sucrose, chemical stability, and low molecular weight; most polyols also exhibit a cooling effect and differ in their solubility in water. Cooling effect refers to polyols' negative heat of solution, which gives off a cooling sensation in the mouth (Deis 2000). In addition, polyols can exhibit a laxative effect if consumed in large quantities (ADA 2004).

Sugar alcohols are created by the hydrogenation of sugars and can be divided into three groups: monosaccharides, disaccharides, and mixtures. The monosaccharides include sorbitol, mannitol, xylitol, and erythritol. Sorbitol and mannitol are 6-carbon stereoisomers that are typically made from corn and have been used in a wide range of products. Sorbitol is soluble in water and contains 2.6 kcal/g, while mannitol is fairly insoluble in water and contains only 1.5 kcal/g. Xylitol contains 5 carbons, protects against dental caries, and has a pronounced cooling effect; therefore, it is used mainly in toothpaste, chewing gum, and mints. Xylitol's sweetness level is almost equal to that of sucrose and it is has a high solubility in water and is very hygroscopic. Erythritol is a 4-carbon sugar alcohol that only contains 0.2 kcal/g and has a high digestive tolerance. However, it has a low solubility, a pronounced cooling effect, and high cost (Deis 2000).

The disaccharide sugar alcohols are maltitol, lactitol, isomalt, and isomaltulose. Maltitol has 2.1 kcal/g and its sweetness is about 90% that of sucrose. Maltitol has a low cooling effect and high solubility. Lactitol provides 2.0 kcal/g and also exhibits a low cooling effect; lactitol can be used in baking. Like lactitol, isomalt provides 2.0 kcal/g, exhibits a low cooling effect, and can be used in baking. However, it is only 45-65% as sweet as sucrose (Deis 2000). Unlike the other disaccharide sugar alcohols, isomaltulose provides 4.0 kcal/g, but results in a low glycemic response compared to sucrose. Isomaltulose is also only 50% as sweet when compared to sucrose and can be used in baking (BENEO-Palatinit 2009).

Maltitol syrups and hydrogenated starch hydrolysates (HSH) comprise the mixture category of polyols. They are mixtures of hydrogenated polymers of various lengths with characteristics similar to the corn syrups and polyols from which they are made. Maltitol and HSH are used often in sugar-free confectioneries. Thus, sugar alcohols vary in caloric value, level of sweetness, molecular weight, solubility, cooling effect, humectancy, availability, and cost (Deis 2000). All of these factors must be taken into consideration when substituting sugar alcohols for sucrose in baked products.

One polyol with many functional characteristics that make it a good candidate for sucrose replacement in shortened cake is isomalt. Products made with isomalt have similar textures and appearances as those made with sucrose (Polyol Organization 2007). Although less sweet than sucrose, products made with isomalt do not lose their sweetness when heated, which means isomalt can be used in baked products. In addition, isomalt enhances flavor transfer in foods. Isomalt is a sugar alcohol made from sucrose and is a mixture of gluco-mannitol and gluco-sorbitol (Radowski 2006). In the production of isomalt (Figure 2.3), the linkage between glucose and fructose in sucrose is enzymatically rearranged and then two hydrogens are added to oxygen in the fructose component (Polyol Organization 2007). About half of the fructose constituent of the original disaccharide is changed to mannitol and the other half is converted to sorbitol.

Isomalt is more chemically and enzymatically stable than sucrose due to these molecular changes that occur in the production (Radowski 2006; Polyol Organization 2007).

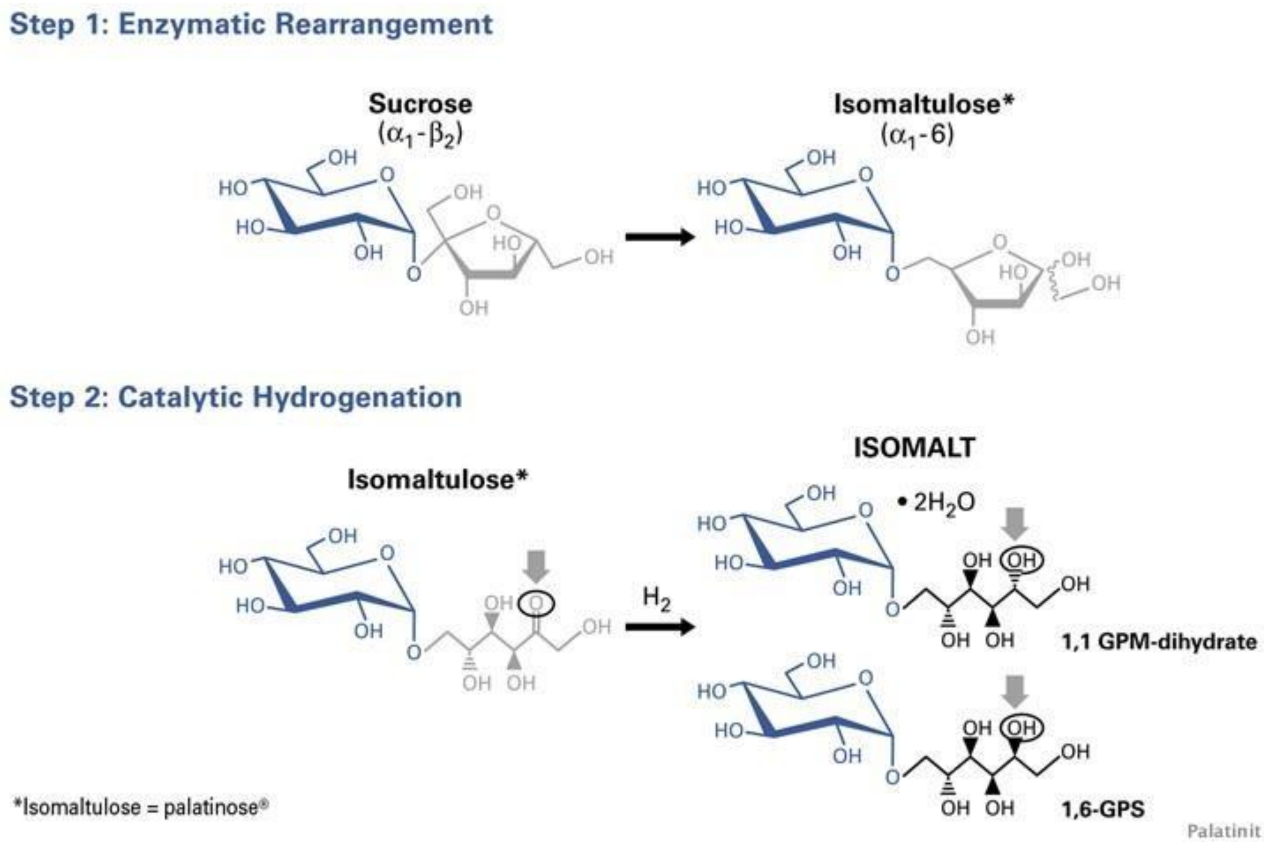

Figure 2.3: Production of isomalt (BENEO-Palatinit 2008)

Because isomalt only contributes 45 to 65% of the sweetness that sucrose provides (Radowski 2006), it is often used in combination with high intensity sweeteners. The intense sweetener raises the level of sweetness equal to that of sucrose while allowing isomalt to contribute bulk, texture, and mild sweetness; it also masks the bitter aftertaste of some intense sweeteners (Polyol Organization 2007). Therefore, isomalt's high chemical and heat stability, bulking ability, texture similar to sucrose, low cooling effect, flavor enhancing ability, and aftertaste masking ability makes it an excellent candidate for replacement of sucrose in cake, particularly when used in combination with an HIS to overcome the sweetness intensity which is lower than sucrose.

Isomalt only contributes two kilcalories per gram because intestinal enzymes cannot hydrolyze the disaccharide bond easily and thus less of it is digested and absorbed into the bloodstream (Radowski 2006). Isomalt also has a similar effect to dietary fiber in the gut and is a prebiotic because it increases bifidobacteria in the large intestine and is broken down into short chain fatty acids (Gostner and others 2005). Like other sugar alcohols, if isomalt is consumed in very large quantities (over 30 g/day), it could have a laxative effect due to malabsorption and can cause diarrhea (ADA 2004). Isomalt barely raises blood glucose or insulin levels after consumption and therefore has a low glycemic response (Radowski 2006). Another benefit of isomalt is that it does not promote tooth decay because oral bacteria cannot change isomalt into decay causing acids (Polyol Organization 2007).

Staling

Staling is a common problem in sucrose-substituted cakes. Ronda and others (2005) reported sponge cakes formulated with sugar-alternatives harden significantly in a storage test. However in this sponge cake study, isomalt greatly delayed cake staling when compared to the other bulking agents used. Staling is collectively referred to as a series of chemical and physical changes that occur after baking (Seyhun and others 2003). Staling results in flavor loss and increased firmness in crust and crumb (Swanson 2004). Two main processes thought to be involved are starch retrogradation and moisture losses. Starch retrogradation occurs when amylose and amylopectin are released from the starch granule, which increases crystallinity caused by cross-linkage of molecules; this in turn increases firmness of the crumb (McWilliams 2008). Sucrose suppresses the crystallization of amylopectin in starch gels and therefore reduces staling (I'Anson and others 1990). In addition, water tends to migrate from the center of the cake crumb to the crust, which also produces staling (McWilliams 2008). Splenda® Granulated contains extra starch (maltodextrins), and thus a possible reason for increased staling when using this sugar alternative may be increased starch retrogradation. Isomalt does not contain maltodextrins and acts as a bulking agent like sucrose, which may explain why Ronda and others (2005) saw isomalt delay cake staling.

In summary, combining isomalt, sucralose, and maltodextrin as a multiple ingredient sweetener system in cake has great potential to reduce calories and simple carbohydrates. Both isomalt and sucralose are stable when heated and do not lose their sweetness. Sucralose provides the sweetening power with no calories and maltodextrin and isomalt replace the bulk and texture that sugar would typically provide. Maltodextrin contributes no added sugars and isomalt contributes no added sugar and less kilocalories compared to sucrose. Both sucralose and isomalt have very low glycemic responses making the products suitable for people with diabetes. There is little research on Splenda® Granulated/isomalt blends in yellow cupcakes. Furthermore, finding a low-calorie sweetener blend that successfully produces a good quality shortened cake would allow individuals to enjoy this favorite dessert without the excess calories and added sugar, reducing the feeling of deprivation often associated with dietary restriction.

Sensory evaluation

Sensory evaluation is the measurement of the quality of a product based on information perceived from all five senses (Bourne 1982). No instrument can reproduce the exact human response to food and thus sensory analysis is necessary (Bourne 1982). Sensory evaluation is a "quantitative science in which numerical data are collected to establish lawful and specific relationships between product characteristics and human perception" (Lawless and Heymann 1998). Statistical differences are determined after sensory evaluation in order to conclude if the observed relationships between product characteristics and sensory responses are real and not uncontrolled variation in responses (Lawless and Heymann 1998). There are two major types of sensory panels, consumer panels and trained descriptive panels.

Consumer panels determine product acceptability and preference among products. Consumer panels can determine what attributes of a food are essential to consumer acceptance and the likely success of the product (Lawless and Heymann 1998). Consumer panels usually are conducted at the end of product development and ideally with 100 to 200 untrained panelists (Bourne 1982).

Trained descriptive sensory panels act as a human analytical instrument and allow for a profile of the food items evaluated to be established and compared against each other (Murray and others 2001). Thus, trained descriptive sensory panels are product-oriented (Lawless and Heymann 1998). One common approach to descriptive sensory analysis is the Spectrum® method, which was developed in the 1970s by Gail Vance Civille. When using the Spectrum® method, panelists are trained for several months. Training involves the development of long reference lists of sensory attributes within a product category. Panelists first create a list of characteristic sensory attributes by evaluating a variety of products that span the characteristics of those within the product category. Trained panelists then collectively develop a panel specific attribute list for a product. Intensity of the attributes present is also determined. Panelists are calibrated to measure attribute intensity by using universal references for flavor intensity, whereas texture references are specific for each texture attribute and differ with intensity of each attribute. Use of references for attribute identification and intensity ensure panelists consistently apply universal flavor and texture scores when evaluating the specific product. References greatly reduce variability in intensity assessments among panel members. Data from trained descriptive sensory panels can be compared against non-sensory data to determine if there are correlations between the two datasets (Murray and others 2001) and to facilitate the selection of the best non-sensory measure of product quality. Non-sensory assessments of product quality are typically less expensive and less time-consuming than continued descriptive sensory assessment of products.

Instrumental data collection

Texture, color, water activity, volume, and batter specific gravity are quality assessments commonly conducted on cake. Texture is a determinant of a high-quality cake. Crust color indicates browning and the perceived quality of cake (Good 2002). Water activity is an indicator of shelf life and stability (Fontana 2000). Volume indicates cake uniformity, symmetry, and overall quality whereas batter specific gravity indicates tenderness, grain, texture, and volume of cake (Pyler 1988; AACC 2000). All five parameters are affected greatly by sugar substitution in cake due to sugar's varied functional roles.

<u>Texture</u>

Texture is one quality characteristic of cake and a high quality cake is considered to have a fine air cell size and a moist, tender, and velvety crumb (AACC 2000; Nelson 2000). Texture characteristics can be measured using a Texture Analyzer, a universal testing instrument that measures stress-strain properties of foods with various attachments. The Texture Analyzer detects the amount of force exerted on the sample via an electronic load cell and a force-time relationship is depicted onto a computer screen. Textural Profile Analysis (TPA) is a compression test, also known as a "two bite test," in which a sample is compressed twice using a cylinder probe by a certain percentage to mimic the action of the jaw (Bourne 1982). Many textural parameters can be determined such as hardness, fracturability, cohesiveness, gumminess, springiness, adhesiveness, resilience, and chewiness. Figure 2.4 is a typical curve from a TPA test for yellow cake. These texture parameters can be correlated with texture attributes from trained descriptive sensory panels (Szczesniak and others 1963). Szczesniak and others (1963) developed standard sensory rating scales of texture attributes that covered the entire attribute intensity range in food products and found a high correlation between these intensities and values from instrumental texture analysis.

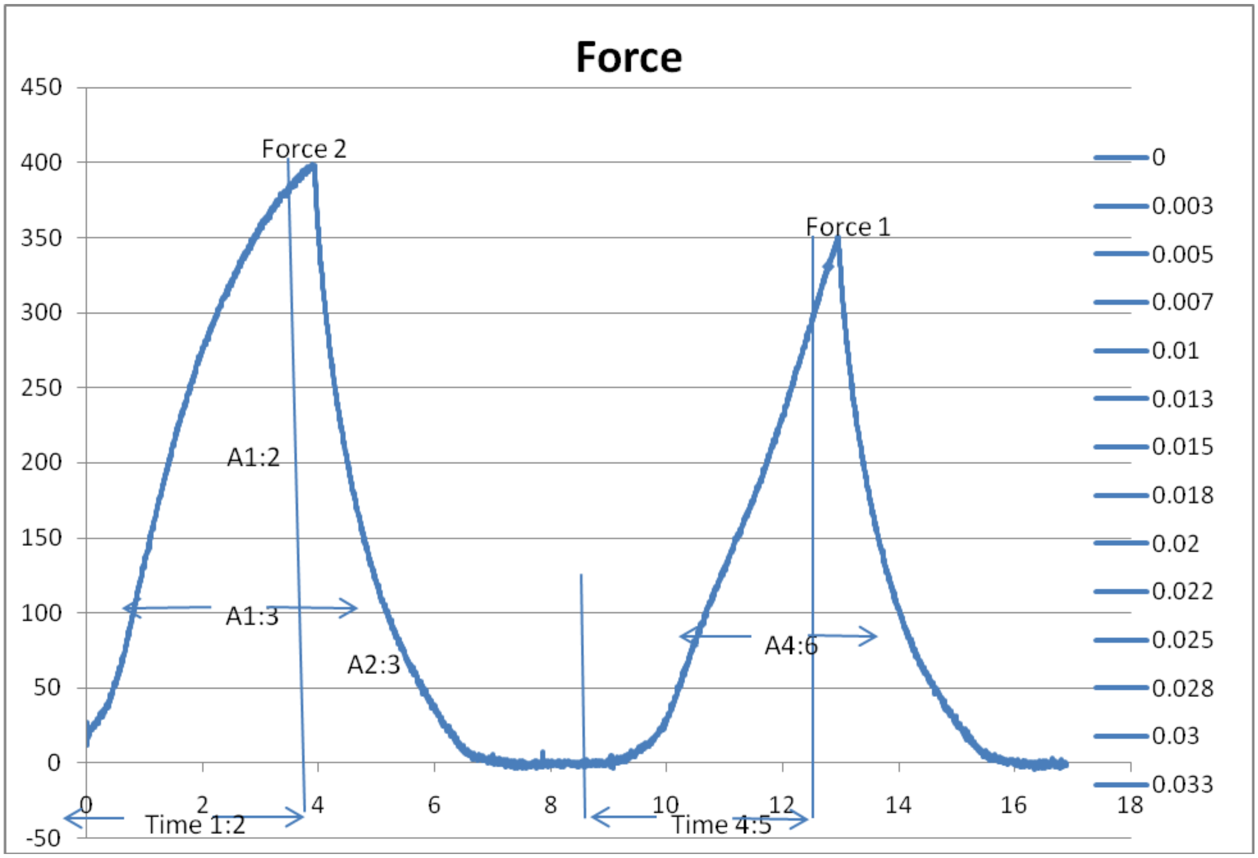

Figure 2.4: TPA curve (Bourne 1982) for yellow cake

Hardness is equal to Force 2, which is the height (max force in kg) of the first peak. Cohesiveness is equal to A4:6/A1:3, which is the area under the second peak divided by the area under the first peak. Springiness is equal to Time4:5/Time1:2, which is the distance under the second peak divided by the distance under the first peak. Chewiness is equal to the product of hardness, cohesiveness, and springiness. If TPA is conducted on consecutive days after a product has been baked, textural differences that occur during staling can be determined and compared as a function of the different treatments of the product. Also, because sugar affects the texture of cake by acting as a tenderizer and contributing to crumb moistness, differences due to sugar reduction and the specific sugar alternative system employed that occur in the texture of reduced sugar cakes can be analyzed with TPA.

Color

One of the first things that a person notices about a certain food is its appearance, which includes color. Appearance has a large impact on whether a person will consume a food and is related to its perceived quality (Good 2002). Color is a typical assessment conducted on cake to determine quality. In addition, most of the time color and flavor are directly connected (Good 2002). Such is the case for cake, where the color effects of Maillard browning and caramelization impact flavor of the final product. Surface color in cakes can be influenced by several factors such as baking conditions and specific ingredients in the formulation (Good 2002). Crumb color is influenced primarily by specific ingredients in the formulation including eggs, flour, and vanilla; baking temperature; and baking times (Good 2002). The two most common instrumental technologies for measuring color are tristimulus filter colorimeters and spectrophotometers (Mabon 1993). A spectrophotometer can measure color in products consistently and objectively without human bias (Mabon 1993). For cake, the results of the surface measurements show differences in browning between formulations whereas results from interior measurements show differences in crumb color, both of which are indicators of cake quality. One of the sugar replacement issues is that cake has a lighter crust color because many sugar alternatives cannot participate in Maillard browning reactions.

The Commission Internationale de I'Eclairage defines color expression and the L*a*b* color space model is the most commonly used color measurement system in the food industry (Giese 2003). L* represents lightness on a 0 to 100 scale where 0=black and 100=white and is an indication of saturation. a* represents the red-green axis (+a is redness and -a is greenness). b* represents the yellow-blue axis (+b is yellowness and -b is blueness). a* and b* combined are a measurement of hue. In the food industry, color measurement is important for quality control and determination of lot variations and quality differences of many ingredients, including sugar, that contribute to color differences (Mabon 1993). According to Good (2002) color assessment can be used to determine color changes that occur after storage or processing; to ensure consistency of ingredient color; and to determine conformity to product specifications. Measuring color instrumentally in reduced-sugar cakes determines the specific effects that sugar has on a product's color as well as the effects that sugar alternative systems have.

Water activity

Water activity is a measurement of the ratio of water vapor above any sample to the water vapor pressure of pure water at the same temperature (McWilliams 2008). The water activity of pure water is 1.0 and all food products will have a water activity level below 1.0. Water activity indicates how much free water is available in a food and is thus available to participate in chemical reactions that may alter shelf life and stability. If a product has no free water, then it will have an activity level of 0.00 (Fontana 2000). The lowest water activity level at which most food-spoiling bacteria will grow is around 0.90; foods with water activity levels over this level are at increased risk for the growth of various yeasts, molds, and bacteria. Many regulatory agencies incorporate the concept of water activity when defining food safety regulations such as critical control points and potentially hazardous foods. Water activity has also been integrated by regulatory agencies in defining policies regarding the growth of harmful microorganisms. Thus, water activity is important to food quality, stability, and safety (Fontana 2000). Among the functional roles of sugar is the control of water activity. Sugar binds water making it unavailable to participate in lipid oxidation, enzymatic activity, and growth of microorganisms. Cakes made with alternative sweeteners are potentially at a higher risk for microorganism growth and may have more free water available to participate in reactions important in staling. According to Fontana (2000) by measuring and controlling water activity in products, one can 1) predict which microorganisms will be sources of spoilage, 2) assess potential for nonenzymatic browning and lipid oxidation, 3) optimize physical properties of foods, such as texture and shelf life. Therefore, water activity is a common quality assessment conducted on cake to determine shelf life and stability.

Volume

Volume is another overall indicator of quality as is cake layer uniformity and symmetry and all are common quality assessments performed on cakes. Volume impacts perception of texture with cakes of appropriate volume. Volume can be measured several ways with different apparatuses. One approach to measuring volume is the American Association of Cereal Chemists Procedure (AACC Method 10-91), which uses a standardized template and formula to determine volume (AACC 2000). Figure 2.5 represents a template for use with a layer cake. In the figure, volume index is equal to the sum of the heights of B, C, and D and is determined by placing the template against the cut surface of a cake layer cut vertically in the center.

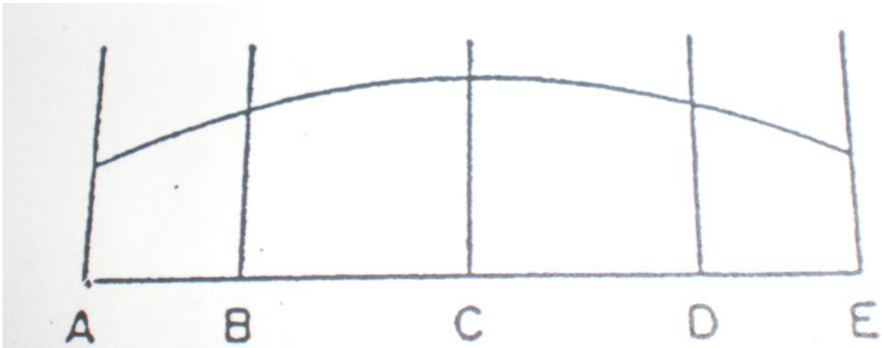

Figure 2.5: Volume template for layered cake (AACC 2000)

In a modified version, volume index can be obtained by photocopying a cross section of a sample and then measuring the heights of B, C, and D (see Figure 2.5) where C represents the middle of the cake, B represents midway between A and C, and D represents midway between C and E. Different formulations of cake can produce different volume indexes and cakes made with alternative sweeteners typically have lower volumes because sucrose in cakes contributes to the bulk and volume of cakes. Thus, determining the differences in volume in cakes made with alternative sweetener blends can provide insight on the capacity of the alternative sweetener blend's bulking ability as well as the final cake quality.

Batter specific gravity

Batter specific gravity is another quality assessment commonly conducted on cake systems because it is an indicator of final tenderness, grain, texture, and volume of cake (Pyler 1988) and thus can be used in comparing the quality of different product formulations. Batter specific gravity is a measure of the relative density of batter in comparison to the density of water (McWilliams 2008), and can be measured using the following formula: (Wt of filled container – Wt of container) / (Wt of water filled container – Wt of container) (Penfield and Campbell 1990). Batter specific gravity indicates how much air can be incorporated into the batter, which has a direct impact on final cupcake volume (Kim and Walker 1992). A high specific gravity indicates an under-aerated batter and a low volume. The typical specific gravity for yellow shortened cakes is 0.94-0.97 (Pyler 1988). As mentioned earlier, sucrose acts as a tenderizer in cake, contributes to crumb moistness, and adds bulk to cake, all of which affect the texture and volume of cake and thus specific gravity. Therefore, cakes made with alternative sweeteners usually have higher specific gravities largely due to the fact that they are missing the role of sucrose in leavening, which is reflected in a reduced volume (Pong and others 1991).

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CHAPTER 3

MATERIALS AND METHODS

Experimental design

Yellow cupcakes were prepared with sucrose, or isomalt, and/or Splenda® Granulated in four ratios: 100% sucrose (SP00), 40% Splenda® Granulated:60% isomalt (SP40), 50% Splenda® Granulated:50% isomalt (SP50), and 100% Splenda® Granulated (SP99); 100% of the sucrose was replaced with the sugar alternative. Sucrose was the only variable ingredient. Cupcakes prepared with 100% sucrose, the gold standard, served as the control. The gold standard exhibited the following characteristics: fine air cell size, moist and tender crumb, and golden brown appearance (Nelson 2000).

The randomized factorial design used for all components of the experiment is shown in Table 3.1. In Phase 1, cupcakes were evaluated by instrumental techniques and a trained descriptive sensory panel. Four replications were conducted for all instrumental tests and three replications were conducted for descriptive sensory evaluations in this phase of the study. Batter specific gravity was measured on three samples from each of the four cupcake formulations. The color of the exterior surface and interior surface of six samples from each of the four cupcake formulations was collected. Water activity and volume measurements were collected on six samples from each of the four cupcake formulations. Texture Profile Analysis (TPA) was performed on six samples from the four cupcake formulations over the course of four storage periods. The storage periods were bake-day, one day post-bake, two days post-bake, and three days post-bake. Seven trained descriptive sensory panelists evaluated the four cupcake formulations over the course of two storage periods. Storage periods were one day post-bake and three days post-bake. In Phase 2, consumer sensory panelists (n=66) evaluated three cupcake formulations (SP00, SP40, and SP99) one day post-bake. Specific formulations evaluated by consumer sensory panelists were selected based on the results of the descriptive sensory evaluation and instrumental assessments conducted in Phase 1. Batter specific gravity, color, TPA, water activity, and volume measurements were also collected on the samples prepared for consumer sensory evaluation in the same manner as they were for those prepared for the trained descriptive sensory panel.

Table 3.1: Factorial designs for sensory and instrumental tests

Phase 1-Product characterization	
Instrumental tests	
Batter specific gravity	4x3x4[a]
Color	4x6x2x4[b]
TPA	4x6x4x4[c]
Water activity	4x6x4[a]
Volume	4x6x4[a]
Sensory test	
Trained panel	4x2x7x3[d]
Phase 2-Consumer acceptability	
Instrumental tests	
Batter specific gravity	3x3x5[a]
Color	3x6x2x5[b]
TPA	3x6x4x5[c]
Water activity	3x6x5[a]
Volume	3x6x5[a]
Sensory test	
Consumer panel	3x1x66x1[d]

[a] formulations x samples x replications
[b] formulations x samples x locations x replications
[c] formulations x samples x storage periods x replications
[d] formulations x storage periods x panelists x replications

Cupcake preparation

The cupcakes were prepared with a standardized formula and method of preparation and baking order was randomized for each replication. The constant ingredients in the SP99 formulation were increased proportionally to equalize its formula yield to that of the other formulations. Each formula yielded approximately 48 cupcakes when batter was portioned with a #20 scoop. Despite consistent volume, batter weight per cupcake ranged from 31-34 g. Diameter of the baked cupcake was 7 cm. SP00 weighed approximately 32g, SP40 weighed 31 g, SP50 weighed 31 g, and SP99 weighed 34 g. SP00, SP50, and SP40 were prepared by the creaming method in which sucrose and isomalt form air pockets while being creamed into butter, contributing to a batter with less density. The SP99 was prepared using the muffin method because the sucralose/maltodextrin blend cannot be successfully creamed into butter (McNeil Nutritionals, LLC 2009). Instead sucralose/maltodextrin dissolves into the water of butter, resulting in a curdled mixture. The muffin method overcomes this mixing issue by combining all dry ingredients; when flour is incorporated in the same mixing step as the sucralose/maltodextrin blend present more even mixing results. Therefore, mixing methods were optimized for each formulation.

All ingredients were weighed one day prior to cupcakes being prepared. Dry ingredients were stored covered at room temperature and wet ingredients were stored covered in the refrigerator at 3ºC. Milk, butter, and eggs were bought at the beginning of each preparation week whereas the dry ingredients were bought in bulk for use throughout the study to minimize differences in products. Multiple lots of cake flour, sugar, isomalt, and Splenda® Granulated were combined to avoid any differences due to lot and the necessary amounts for each replication were taken from the combined lots for each bake. A rotary oven (National Manufacturing Co. Inc., Lincoln, NE) was used to bake the cupcakes at 176ºC. The oven was conditioned before the first cupcake formulation was baked by placing a 22.8 cm cake pan half-filled with water in the oven at 176ºC for 30 minutes (AACC 2000). The oven was conditioned so that the oven environment for the first bake was the same as it was for subsequent bakes on a given day. Baked cupcakes were cooled on cooling racks at ambient temperature for 45 minutes. They were then stored in coded individual 8 oz. Styrofoam® containers with plastic lids (Dart Container Corp., Mason, MI) at 20 ºC until needed for subsequent instrumental or sensory evaluation. Specific samples were randomly assigned to all evaluations. All formulations and ingredient information are presented in Table 3.2. Weight calculation of Splenda® Granulated was based on an equivalent volume of sugar as recommended by the manufacturer (McNeil Nutritionals, LLC 2009). When comparing weight/per unit volume, 1 cup sugar= 200 g and 1 cup Splenda® Granulated=27 g. To be consistent, the weight calculation of isomalt was also based on an equivalent volume of sugar, where 1 cup isomalt=192 g.

Table 3.2: Formulas and product information for yellow shortened cupcakes prepared with sugar alternatives

Ingredients	SP00[a] (g)	SP40[a] (g)	SP50[a] (g)	SP99[b] (g)	Product Information
Granulated sugar	460	0	0	0	Imperial-Savannah LP (Sugar Land, TX)
Splenda® Granulated	0	24.8	31.1	83	McNeil Nutritionals, LLC (Fort Washington, PA)
Isomalt	0	265	220.8	0	BENEO-Palatinit, Inc. (Morris Plains, NJ)
Unsalted butter	178	178	178	237.3	Sam's West Inc. (Bentonville, AR)
Shortening	128	128	128	170.7	J.M. Smucker Co. (Orrville, OH)
Water	32	32	32	42.7	
Large eggs	236	236	236	314.7	Crystal Farms Inc. (Chestnut Mt., GA)
Vanilla extract	5.3	5.3	5.3	7	Ach Food Co. Inc. (Memphis, TN)
Cake flour	460	460	460	613.3	Reily Foods Co. (Swans Down, LA)
Baking powder	28.4	28.4	28.4	37.9	Claber Girl (Terre Haute, IN)
Salt	4	4	4	5.3	Kroger Co. (Cincinnati, OH)
Whole milk	494.4	494.4	494.4	659.2	Kroger Co. (Cincinnati, OH)

[a]Method of preparation for SP00 (100% sucrose), SP40 (40% Splenda® Granulated:60% isomalt), and SP50 (50% Splenda® Granulated:50% isomalt):

1. Combine flour, baking powder, and salt in a large bowl.
2. Combine sugar or Splenda® Granulated and isomalt, shortening, butter, and water. Cream at highest speed for 2 minutes with a Kitchen Aid stand mixer model #K5SS (KitchenAid USA, St. Joseph, MI) and paddle attachment. Scrape bowl after 1 minute and continue to mix for 1 minute more.

3. Add eggs and vanilla and then scrape the bowl.
4. Mix on speed 6 for 30 seconds, scrape the bowl, and mix for 30 more seconds on speed 6.
5. Add ¼ of the flour mixture and ¼ of the milk every 20-30 seconds at the lowest speed, starting and ending with the flour mixture.
6. Scrape the bottom and sides of the bowl and mix on speed 2 for 1 minute.
7. Portion batter with a #20 scoop into cupcake pans, 12 cupcakes per pan, lined with paper muffin cups (Solo Cup Company, Oshkosh, WI). Bake for 17 minutes.
8. Cool on racks for 45 minutes.

[b]Method of preparation for SP99 (100% Splenda® Granulated):

1. Cream butter, shortening, and water for 1 minute and 30 seconds on speed 4.
2. Gradually add Splenda® Granulated and flour to creamed mixture and mix on the lowest speed for 2 minutes. Scrape bowl.
3. Combine eggs, vanilla, and milk in a separate bowl and set aside.
4. Add baking powder and salt to creamed mixture and stir for 30 seconds at lowest speed.
5. Gradually add milk mixture to creamed mixture on the lowest speed and blend for 1 minute at speed 4. Scrape bowl. Blend for 30 seconds on speed 6.
6. Follow steps 7 and 8 above.

Instrumental data collection

Batter specific gravity, color, texture, water activity, and volume were measured for each cupcake formulation on bake day. Texture measurements (TPA) also were obtained on bake day and everyday thereafter until three days post-bake. Figure 3.1 outlines the order that the instrumental tests were performed per formulation for each replication.

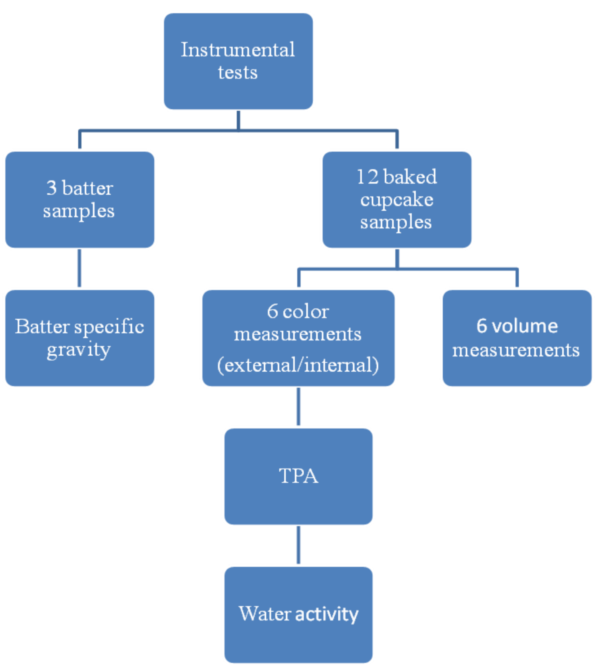

Figure 3.1: Flowchart for instrumental tests performed per formulation per replication

Batter specific gravity

Batter specific gravity was measured using the following formula: (Wt of filled container – Wt of container) / (Wt of water filled container – Wt of container) (Penfield and Campbell 1990). Three samples per formulation per replication were measured on bake day. Batter for each of the samples was scooped into a 2 oz. soufflé cup (Solo Cup Company, Highland Park, IL) and leveled off. The soufflé cup was tapped 7-10 times on the counter to ensure there were no air bubbles in the portioned batter and then the cup was filled with additional batter and leveled if necessary before being weighed. A second soufflé cup was completely filled with distilled water and weighed. In addition the weight of the empty soufflé cup was measured.

Color

Color measurements were taken with a CM-2600d Minolta spectrophotometer (Minolta Corp., Ramsey, NJ), using the 10 degree observer function and illuminant F6, specular component excluded. The specular component is normally included when taking measurements of products with different textures; however, all the cupcake formulations had similar textures and thus the specular component was not necessary (Mabon 1993). The spectrophotometer was calibrated with a white standard calibration cap (CM-A145) prior to measurement of the cupcake samples. Measurements (L*, a*, and b*) were first taken in the center of the top surface of six cupcakes per formulation per replication on bake day. Then measurements were taken of the interior surface of the slices removed from the center of the cupcakes prior to textural analysis. A 2- cm vertical slice was obtained from each cupcake by first cutting off a 1-cm slice measuring from the outside edge using a wooden bread slicer and roasting knife. Then a 2-cm thick piece was sliced from the cut end. L* represents lightness on a 0 to 100 scale where 0=black and

100=white and is an indication of saturation. a* represents the red-green axis (+a is redness and -a is greenness). b* represents the yellow-blue axis (+b is yellowness and -b is blueness).

<u>Texture Profile Analysis</u>

Texture characteristics were measured using a modified procedure from the American Institute of Baking (AIB) Standard Procedure (AIB 2009). A TA-XT2 *plus* Texture Analyzer (Texture Technologies, Scarsdale, NY), equipped with a 50-kg load cell, was used to conduct a Texture Profile Analysis (TPA) for each cupcake formulation. Texture Exponent 32 v4,0,13,0 software was used to extract data from the time-force curve (Figure 3.2).

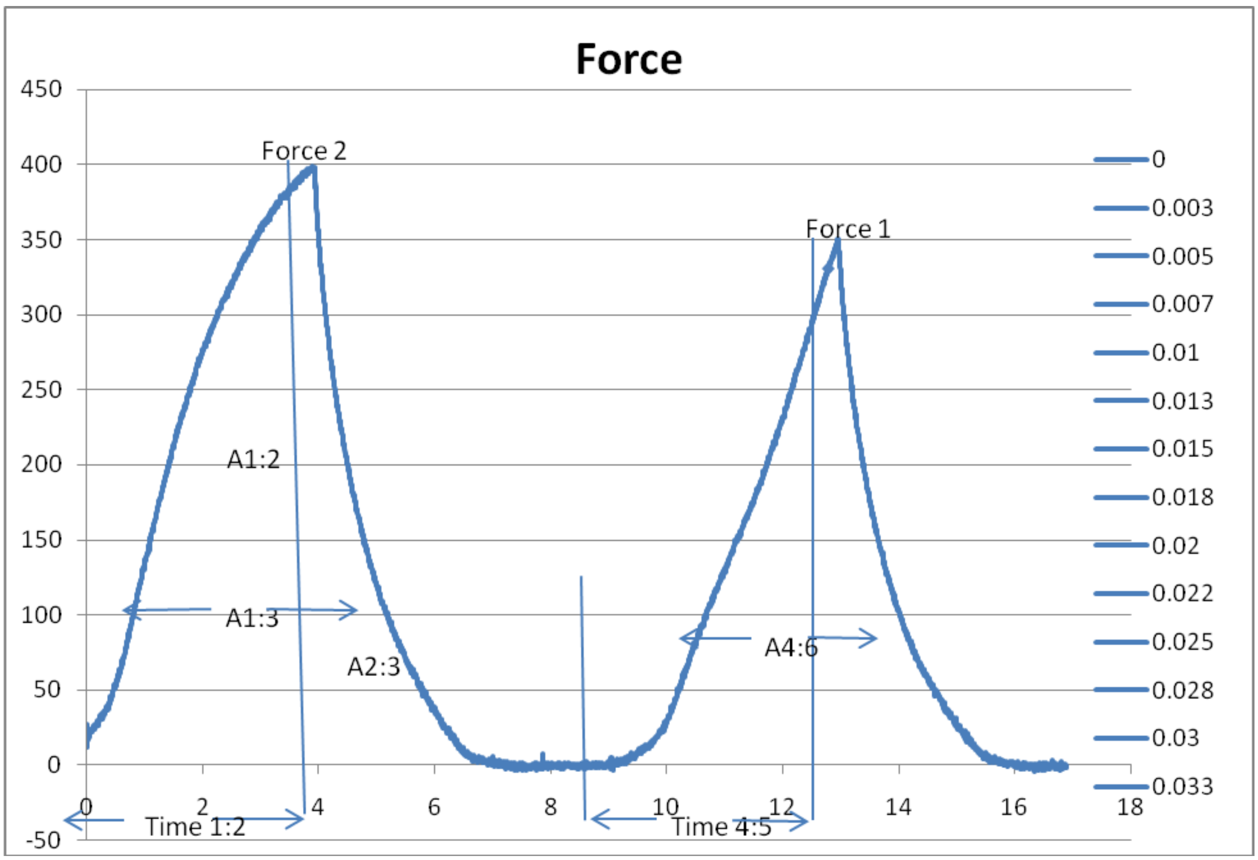

Figure 3.2: TPA curve (Bourne 1982) for yellow cake where hardness= Force 2, cohesiveness= A4:6/A1:3, springiness= Time4:5/Time1:2, and chewiness= hardness x cohesiveness x springiness

A 2.5 cm diameter acrylic cylinder probe with rounded edge was used to compress the crumb in the center of each slice removed from the center of the cupcakes as recommended by the AIB; a compression level of 25% was employed. The TPA test parameters were a pretest speed of 3.0 mm/sec, test speed of 1.7 mm/sec, post-test speed of 10 mm/sec, 5 second delay between compressions, and a trigger force of 20 g. Six cupcakes per formulation per replication were tested on bake day and on each day throughout the four-day storage period. Hardness, springiness, cohesiveness, and chewiness of each cupcake sample were recorded (Figure 3.2) to determine differences in texture among the treatments and texture changes that occurred over a four-day storage period.

Water activity

Water activity was measured with an AquaLab CX-2 (Decagon Devices, Inc., Pullman, WA) on the center slice of six cupcakes per formulation per replication on bake day. Water activity was measured on the same cupcake samples used for TPA analysis (Figure 3.1). The six slices per formulation were ground for 30 seconds with a Cuisinart Mini-Prep Processor DLC-1 (Cuisinart, East Windsor, NJ) and combined to form a composite sample. Then six aliquots per formulation were removed for water activity analysis (Curley and Hoseney 1984).

Volume

Cupcakes designated for volume determination were sliced in half. Then volume was measured using a modified version of the American Association of Cereal Chemists Procedure (AACC Method 10-91) for standing height on six samples per formulation per replication on bake day (AACC 2000). The cupcakes were xeroxed for measurement rather than using the template as described in AACC Method 10-91. Heights of the xeroxed cupcakes were measured at points B, C, and D identified in Figure 3.3 below, where C represented the middle of the cupcake, B represented the point midway between A and C, and D represented the location midway between C and E. Volume index= B+C+D.

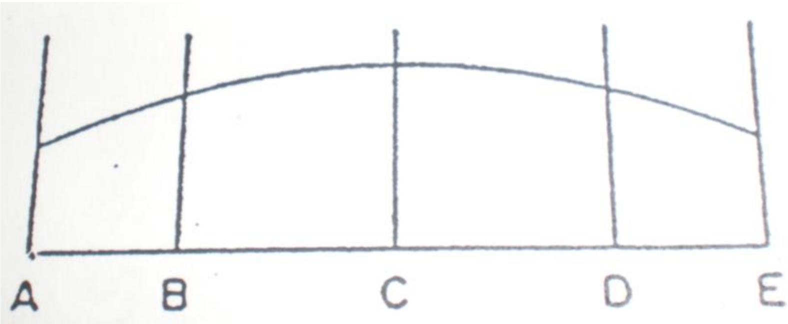

Figure 3.3: Volume template for layered cake (AACC 2000)

Trained descriptive sensory panel data collection

The trained panel (2 males and 5 females) at the USDA-ARS Russell Research Center assessed texture, flavor, and aftertaste attributes of the cupcakes (Table 3.3); three replications were obtained. Together the panel acted as a human analytical instrument and produced a flavor and texture profile of each cupcake formulation.

Before panelists joined the panel they were screened for taste and smell sensitivity and agreed to participate in a wide-variety of on-going research projects. This particular panel has been in existence for about 15 years and has had prior experience with cupcakes made with alternative sweeteners so training time was reduced to 10 hours. In a previous study, the panelists had been trained for several months using the Spectrum®-like method (Meilgaard and others 1999) with yellow cupcakes made with alternative sweetener blends (Johnson and others 2006). Using the Spectrum®-like approach, Johnson and others (2006) first introduced the product category to the panelists and the panelists created a long list of texture and flavor attributes present in the presented samples. The trained panelists then collectively developed an attribute list for the cupcakes after evaluating a variety of yellow cupcakes and generated 0-15 point scales (0=none and 15=very much) that were anchored with references (Table 3.3). This process created an attribute scorecard for the cupcakes, agreed upon by the panel. Attributes were ordered based upon their appearance during consumption. Eight texture, 11 flavor, 7 aftertaste attributes were evaluated at 1 and 5 minutes post-swallow.

During the training period for this experiment, panelists reviewed the previously developed texture, flavor, and aftertaste attributes and definitions. Panelists were presented references (Table 3.3) at various intensities on each linescale for texture, flavor, and aftertaste attributes in order to ensure they consistently applied intensity scores. Then panelists practiced using the scorecard by evaluating cupcakes made with a variety of ratios of sweeteners and constant ingredients. Panelists were first presented with a Sara Lee pound cake (Sara Lee Corp., Downers Grove, IL) sample as a warm-up sample on these practice sessions as well as on testing days and they used the cupcake scorecard to evaluate the pound cake sample. The pound cake was also a reference identified on their ballot linescales. Panelists' performances were assessed by analyzing the standard deviations from their evaluations of the cupcakes on training days. If standard deviations larger than 2.0 were found on certain attributes, then those attributes were discussed and worked on again the next training day.

Panelists evaluated the four formulations one day post-bake and after three days post-bake in individual computerized booths under low-pressure sodium vapor lights to mask color differences. Compusense Five v.4.8.8 (Compusense Inc., Guelph, Ontario, Canada) software was used. The cupcakes were presented to the panelists monadically in individual 8 oz. Styrofoam® containers with plastic lids (Dart Container Corp., Mason, MI). The Styrofoam® containers were coded with three-digit random codes and placed on the panelists' sensory trays along with a glass of water. The scorecard consisted of 8 texture attributes, 11 flavor attributes, and 7 aftertaste attributes. Panelists were prompted with the aftertaste attributes 60 seconds after they completed the last flavor attribute. Panelists evaluated each attribute on the scorecard on 0-15 line scales with 5-10 minute breaks after each sample to prevent taster fatigue. Apples, baby carrots, unsalted saltine crackers, water, and seltzer water were available for the panelists to cleanse their palates during the breaks. Order of cupcake presentation was randomized for each replication.

Table 3.3: Attributes, definitions, and references used by trained descriptive sensory panel

Attribute	Definition	References
Phase I: Evaluate with your fingers. Compress the sample 25% and release. Evaluate:		
Springiness	Amount/degree the sample returns to its original shape	Cream cheese (0), marshmallow (9.5), pound cake (12), gelatin (15)
Stickiness	Amount of sample that sticks to the fingers	Pound cake (1)
Phase II: Chew the sample and evaluate each attribute at the times indicated.		
Hardness	Force to bite the sample with the front teeth	Cream cheese (1), pound cake (4.5), olive (6)
Denseness	Compactness of the cross section	Cool whip (1), nougat (4), pound cake (7), fruit jellies (13)
Cohesiveness	Distance you can bite into the sample before it breaks, cracks, or crumbles	Cornbread (1), pound cake (4), soft pretzel (8), gum (15)
Moistness	Amount of moisture in the product	Saltine cracker (0), pound cake (13)
Rate of dissolving	Rate the sample dissolves when mixed with saliva during chewdown	Cream cheese (slow), cotton candy (fast)
Chewiness	Amount of work to chew the sample to get it ready to swallow	Rye bread (1.8), gum drop (5.8), tootsie roll (12.8)
Phase III: Aromatics: evaluate while chewing the sample. Evaluate the aromatic taste sensation associated with:		
Buttery	Heated/baked butter	A universal flavor intensity scale was used; flavor intensity references were: soda 2 (saltine crackers), grape 4.5 (grape Kool-Aid), orange 7 (Minute Maid orange juice), grape 10 (Welch's grape juice), cinnamon 12 (Big Red chewing gum)
Vanilla	Vanilla flavoring	
Doughy/flour	Heated wet white wheat flour	
Soda/baking powder	Baking soda or baking powder	
Eggy/custard	Cooked eggs	
Browned	Caramelization of sugars	
Cardboard/stale	Slightly oxidized fats and oils, reminiscent of wet cardboard packaging or nonfat dry milk	

Phase IV: Basic tastes. Taste on tongue stimulated by:		
Sweet	Sugars and high potency sweeteners	Sucrose solution (w/v) in water: 2%(2), 5%(5), 10%(10), 15%(15)
Salt	Sodium salts, especially sodium chloride (table salt)	NaCl solution (w/v) in water: 0.2%(2.5), 0.35%(5), 0.5%(8.5)
Sour	Acids	Citric acid solution (w/v) in water: 0.05%(2), 0.08%(5)
Bitter	Caffeine or quinine	Caffeine solution (w/v) in water: 0.05%(2), 0.08%(5)
Phase V: Aftertastes: evaluate 1 minute after swallow.		
Metallic	A flat chemical feeling factor stimulated on the tongue by metal coins	Used flavor intensity universal scale and basic taste references.
Baking soda	Aromatic taste sensation associated with baking soda	
Sweet-chemical	Taste on the tongue stimulated by artificial sweeteners such as sucralose	
Bitter	Taste on the tongue stimulated by caffeine or quinine	
Sour	Taste on the tongue stimulated by acids	
Numbing	Chemical feeling factor associated with artificial sweeteners	
Astringent	Chemical feeling factor on the tongue and surfaces of the mouth described as dry/puckering and associated with aluminum	

Consumer panel

A consumer panel (n=66) was conducted to determine acceptability of the SP00, SP40, and SP99 cupcake formulations. These formulations were selected based on the results of the descriptive sensory evaluation and instrumental assessments. The samples were labeled with three-digit random codes and presented in Styrofoam® containers with plastic lids (Dart Container Corp., Mason, MI) monadically to the panelists for evaluation. Presentation order of the samples was randomized. Room temperature water, baby carrots, and unsalted top saltine crackers were used as palate cleansers between samples. Panelists were identified only with a 3-digit judge number and were assigned to an individual sensory booth where they were asked to sign a consent form and evaluate the three formulations. A structured 9-point hedonic scale with

1=dislike extremely and 9=like extremely was used to evaluate appearance, flavor, texture, and overall acceptability of the three formulations. At the end of the evaluation, panelists were asked to complete a demographic questionnaire that allowed the panel to be profiled. Consent forms, scorecards, samples, and questionnaires were presented to the panelists by the researcher via a pass-through from the neighboring room. All procedures were approved by the Institutional Review Board at the University of Georgia. To verify that there were no differences between the samples evaluated by the trained panel, instrumental measurements were taken in the same manner as they were for the trained descriptive sensory panel.

Nutrient analysis data collection

All four formulations were analyzed with ESHA Food Processor SQL (version 9.7.0, 2004, ESHA Research, Salem, OR) to determine the nutritional content. Isomalt values were obtained from BENEO-Palatinit (Morris Plains, NJ) and entered into the database. These values were based on 1 g of isomalt contributing 2 kilocalories. The serving size was based on the weight of the batter portioned with a leveled #20 scoop for each formulation.

Statistical analysis

Statistical Analysis Software (version 9.1.3, 2002, SAS Institute Inc, Cary, NC) was used to analyze all results of sensory and instrumental tests. PROC UNIVARIATE was used to determine if the data had a normal distribution and equal variance. Log transformations were performed to normalize the data when appropriate. A mixed model of analysis of variance for repeated measures (PROC MIXED) was used to compare formulation effects ($p<0.05$) from instrumental tests and the trained descriptive sensory panel. Least-square means and standard errors were obtained. PDIFF was used for LS-means separation. When significant treatment x storage interactions occurred, Sauerthwaite (ddfm=satterth) was used to obtain LS- means and standard errors. PROC CORR was used to determine correlations between TPA and the texture attributes from the trained descriptive sensory panel. A model of analysis of variance (PROC GLM) was used to determine acceptability of the formulations from the consumer sensory panel. PDIFF was used for LS-means separation ($p<0.05$). PROC FREQUENCY was used to analyze the demographic questionnaire and create a profile for the consumer panel. PROC STEPWISE was used to create a stepwise multiple regression equation to explain variability in overall acceptability.

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CHAPTER 4

RESULTS AND DISCUSSION

Nutritional analysis

Calorie reduction was 12-13% when the Splenda® Granulated/isomalt blends were substituted for sucrose in yellow shortened cupcakes (Table 4.1). The 100% Splenda® Granulated formulation resulted in a negligible decrease in calories due to the 25% increase in proportion of ingredients required to equalize its yield to that of the other formulations. Total sugar reduction was much greater in the cupcakes than was calorie reduction. All modified cupcakes resulted in 93-94% total sugar reduction. The Splenda® Granulated/isomalt blends could be labeled “sugar-free” due to sugar content being less than 0.5 g per serving (FDA 2009). Because the 100% Splenda® Granulated formulation contains more than 0.5 g per serving, it meets the criteria for reduced-sugar, but not sugar-free (FDA 2009). All modified formulations could be labeled “reduced-sugar.”

The fat and sodium content per serving increased when compared to the control in all sucrose-substituted cupcakes. These occurred due to dilution differences in the modified products. Therefore, the reformulated cupcakes were more nutrient-dense (Table 4.1), with the density increasing as the percentage of Splenda® Granulated in the formulation increased.

Appearance of cupcake formulations

The control cupcake had a golden brown crust, rounded symmetrical top with fairly uniform thin-walled cells in the crumb (Figure 4.1). The Splenda® Granulated/isomalt blends were fairly similar in appearance. They had a slightly golden brown crust, fairly flat top, and the crumb exhibited thin-walled cells with occasional tunnels. The 100% Splenda® Granulated formulation had a pale crust, peaked center, and an uneven crumb with several large tunnels and holes. Because visual textural deficiencies detract consumers from the quality of the food, the visual defects of the 100% Splenda® Granulated cupcake may play a role in perceived texture and acceptability (Szczesniak 1981). Violations of learned visual textural connotations in the cake, such as large tunnels and holes instead of a fine crumb, detract from acceptability.

The control formula used was not a high-ratio formulation; rather, it was a lean shortened cake formula. According to the bakers percentage calculations where flour equaled 100%, the control formula was comprised of 100% sugar, 38.7% butter, 27.8% shortening, 7.0% water, 51.3% eggs, 1.2% vanilla, 6.2% baking powder, 0.9% salt, and 107.5% milk. Thus, because it was a lean formula it is expected to not be as sweet, rich, tender, moist or to have as high a volume when compared to a high-ratio formula, which uses a higher amount of sugar than flour, eggs than shortening, and liquids than sugar (Pyler 1988; Penfield and Campbell 1990). However, due to high water levels in this lean formula, it may not be less moist or tender when compared to a high-ratio cake. These water levels were possible because cake flour allows more liquid to be absorbed without creating a tough crumb as occurs when all-purpose flour is used due to cake flour's increased surface area, chlorination, and low protein content (Penfield and Campbell 1990). In addition, the incorporation of a shortening containing emulsifiers for a portion of the fat also decreases toughness because it allows more liquid to be incorporated (Pyler 1988). Emulsifiers also impact volume and fine texture because they promote air incorporation and even dispersion of shortening, increasing the number and evenness of the sites for air incorporation. The shortening used had mono and diglycerides in the blend.

Phase 1: Product characterization

Batter specific gravity and cupcake volume

Batter specific gravity is an indicator of final tenderness, grain, texture, and volume of cake. Volume is an overall indicator of quality and allows layer uniformity and symmetry to be determined (Pyler 1988). Neither batter specific gravity nor cupcake volume (Table 4.2) differed significantly for any of the treatments. The fact that both were not significant was not surprising considering batter specific gravity and cake volume are closely related. Batter specific gravity indicates how much air can be incorporated into the batter, which has a direct impact on final cupcake volume (Kim and Walker 1992). A high specific gravity indicates an under-aerated batter and a low volume; thus, specific gravity and volume have an inverse relationship (Pyler 1988).

It was expected that the sucrose-substituted cupcakes would have significantly higher batter specific gravities and lower cupcake volumes when compared to the control considering their formulations contained no sucrose. Sugar contributes to volume and leavening when it is creamed into fat thereby incorporating air into the batter by means of sugar crystals carving air pockets into the fat; this decreases specific gravity (Pyler 1988; Frye and Setser 1991). The pockets expand with steam and carbon dioxide during baking, increasing volume (Pyler 1988). Other studies conducted with sugar-replaced cakes have found higher batter specific gravities and lower cake volumes when compared to their sugar-containing counterparts (Pong and others 1991; Ronda and others 2004). Isomalt and maltodextrin also contribute to the bulk and volume (Kuntz 1997; Radowski 2006) and this may be a possible reason why the modified formulations did not have significantly different batter specific gravities and cupcake volumes in this study. Thus, it appears substitution with Splenda® Granulated and isomalt in combination produces acceptable batter specific gravities and cupcake volumes. For the 100% Splenda® Granulated cupcake, the lack of significant difference in volume likely reflects the peaked appearance and associated tunneling present in the crumb, which are undesirable characteristics in cake. Tunnels are formed from expansion of gas in the batter and are usually the result of overmixing, or perhaps coalescing of larger air cells. In this case, they were most likely formed due to sucralose's inability to be creamed into fat and the lack of resulting fine air cells distributed throughout the batter. The ideal cupcake should be symmetrical without low edges or high peaked centers (AACC 2000). The cupcake prepared with Splenda® Granulated alone did not exhibit these characteristics.

Color

For exterior color (Table 4.3), there were significant differences found for all parameters due to formulation. Compared to the other treatments, the crust of the control was significantly darker, redder, and yellower, which is largely due to the fact that sucrose contributes to caramelization and Maillard browning (Pyler 1988). Sucralose, a high intensity sweetener, does not undergo Maillard browning or caramelization (Nelson 2000) because it is structurally different from sugar due to the addition of chlorine molecules. Isomalt under typical conditions also does not participate in Maillard browning because during its production the reducing sugar of the intermediate, isomaltulose, converts into an alcohol (Cargill 2009). Acids can cleave bonds and release glucose from isomalt, allowing limited participation in Maillard browning under specific conditions. However, maltodextrins present in Splenda® Granulated can contribute to Maillard browning (Kuntz 1997). In addition, lactose in milk can participate in Maillard browning. The SP40 formulation was the closest in exterior color to the control even though it did not contain the greatest amount of maltodextrins. Therefore, it appears a blend of

Splenda® Granulated and isomalt contributes more to exterior browning as opposed to Splenda® Granulated alone.

For interior color (Table 4.3), only a* was significantly different due to treatment. There were no significant differences for a* between the control, SP40, and SP99. Although SP50 differed from the control, it did not differ from the SP40 blend. This suggests that isomalt is responsible for the less green character of the crumb of cupcakes prepared with the Splenda® Granulated/isomalt blends.

Water activity

All modified treatments had significantly higher water activity (Table 4.2) when compared to the control and all formulations were significantly different from one another. Thus, this suggests that sugar does a better job binding water than does Splenda® Granulated or isomalt. These results are expected considering sucrose binds water in cake and therefore lowers water activity (McWilliams 2008) whereas sugar alternatives have limited capacity to bind water. SP40's water activity was the closest to the control. However, in terms of microbial growth and shelf-life there were no real differences in safety and stability within the range reported because water activity levels over 0.90 put the cupcakes at increased risk for lipid oxidation, decreased shelf-life, and growth of various microorganisms (Fontana 2000).

Texture Profile Analysis

Crumb structure of shortened cakes is derived from the fat-liquid emulsion created during mixing (Pyler 1988). Desirable structure is characterized by thin-walled cells of uniform size. Texture of the crumb should be soft, pliable, and smooth (AACC 2000). Staling post-bake is associated with an increase in firmness in crust and crumb (Swanson 2004) and a loss of moisture, which results in increases in hardness and chewiness, and decreases in springiness and cohesiveness.

Hardness, cohesiveness, springiness, and chewiness of the crumb were measured instrumentally using the TPA method (Table 4.4). Values were extracted from the time/force curves as described by Bourne (1982).

Both treatment and storage effects on crumb texture were found; the treatment x storage interaction was significant. The change in parameter intensity over the storage period followed the same pattern for all attributes except chewiness, although the extent and rate at which the changes occurred varied with treatment. Overall, springiness and cohesiveness decreased, whereas hardness and chewiness increased. Examination of the treatment x storage interaction reveals that chewiness in the modified cupcakes as opposed to the control was actually lower one day post-bake than was found on bake day. However, by day 3, chewiness of all of these modified samples exceeded that of the control formulation at the same storage point. In addition treatment x storage interactions were seen for changes in springiness; the 100% Splenda® Granulated substitution exhibited the smallest decrease in springiness among the modified formulations evaluated. Generally, the greatest changes occurred by day 3 and the most rapid changes over the storage period for all attributes occurred with sugar replacement with the 50:50 Splenda® Granulated: isomalt blend.

Storage effects are attributed to processes involved in staling, specifically starch retrogradation and moisture losses (Pyler 1988). Sugar plays a key role in determining the texture of the final baked cupcake and changes that occur over the storage period. In shortened cake, sugar dilutes the starch present, competes for water, and delays gelatinization and coagulation of the protein during baking (Kulp and others 1991). In the modified products, maltodextrins and isomalt are the primary dilutors of the starch. Unlike sugar, which binds water, isomalt in baked goods absorbs very little water, increasing water availability for starch gelatinization (Polyol Organization 2007). Crumb rigidity is also impacted by the extent to which starch gelatinizes and then reassociates or retrogrades (Pyler 1988). Isomalt also does not inhibit protein coagulation (Nelson 2000), ultimately affecting crumb rigidity. Although maltodextrins have good water retention ability, they can gelatinize and reassociate. However, the higher levels of moisture held by the maltodextrins may result in a softer and more tender crumb prior to reassociation and explain the delay in increased chewiness found in the modified products over the storage period. Staling causes an increase in firmness in crust and crumb (Swanson 2004) and a loss of moisture, which results in increases in hardness and chewiness, and decreases in springiness and cohesiveness.

Descriptive Sensory Analysis

Texture

Springiness, hardness, cohesiveness, and chewiness were assessed using sensory techniques. In addition, moistness, stickiness, rate of dissolving, and denseness were evaluated. All of these attributes had been identified by the panelists as important in profiling cupcakes during panel training. Although there were no significant treatment x storage interactions (Table 4.5) found for any textural attributes, panelists found storage effects across all treatments typical of staling: springiness, cohesiveness and moistness decreased, and hardness increased as storage period increased. No changes in chewiness, stickiness, rate of dissolving, or denseness were found. That the panelists found no significant treatment x storage effects even though these differences were detected instrumentally suggests that the texture differences found in the cupcakes were below the panel's detection threshold. The panel used a 0 to 15-point line scale to indicate different intensities while the Texture Analyzer can detect tiny differences in grams between different treatments. Overall, the TPA appeared to detect smaller differences among samples than were found by the descriptive sensory panelists.

In terms of treatment, overall the panel found the control cupcake exhibited low to moderately low hardness, deneseness, cohesiveness, and chewiness (2.77-4.15), and moderately high springiness, stickiness, moistness, and rate of dissolving (7.00-8.67). When Splenda® Granulated alone replaced the sucrose, all textural attributes except springiness differed significantly from the control. Blending isomalt with Splenda® Granulated appeared to decrease these textural differences. According to the descriptive panelists, the 40% Splenda® Granulated:60% isomalt blend produced a cupcake with textural characteristics most similar to the sucrose control; only cohesiveness and moistness, which increased and decreased respectively, differed significantly.

For the four characteristics measured instrumentally as well as by descriptive sensory panelists, there was general agreement in the direction of difference from the control, although order of the treatments differed when ranked based on extent of difference from the control. It is important to note that only humans can truly *assess* texture; machines measure physical properties, not sensory properties (Bourne 1982). However, the two texture measurements are often correlated (Bourne 1982). In general, instrumentally the SP99 sample was closest to the control whereas SP40 was found to be most like the control by the sensory panelists, with SP99 exhibiting the greatest deviation from the control. Therefore, no strong correlations were found between descriptive panel and TPA measurements based on matched storage days 1 and 3 (r values ranged from 0.00-0.22 for all attributes; p = 0.16-0.99). The relative treatment order for intensity of all attributes was consistent when evaluated with either assessment method. It should be noted that all deviations from the control for these characteristics were relatively small, whether assessed by the descriptive panelists or measured instrumentally. These attributes in this product may be more complex when assessed via mouthfeel than is possible to detect when simply subjected to compressive forces as is done instrumentally. Although color differences were masked during evaluation, shape and overall appearance of the crumb were not (Figure 4.1). Appearance characteristics were not assessed by the descriptive sensory panelists in this study.

Flavor

For aromatic attributes assessed by the panel (Table 4.6), there were no significant treatment x storage effects. For basic taste attributes assessed by the panel (Table 4.6), there was a significant treatment x storage effect found for the attribute saltiness. The panel found SP99 on storage day 3 to be significantly saltier when compared to the other formulations. The panel also found SP99 to be significantly saltier on storage day 3 when compared to day 1. However, differences were limited to less than 1 unit on a 0 to 15-point linescale and all values fell in the moderately low range of the scale. There were no significant differences found in flavor intensity in terms of storage alone for any of the attributes.

When treatment effects were examined across all storage periods, significant treatment effects on the perception of the intensity of flavor attributes were found. Overall the panel found all flavor attributes for the control to be in the low range (1.05-3.67) except for sweetness, which was in the high range (10.74) of the 0 to 15-point scale. Sweetness intensity of the control was significantly greater than was found for all other formulations. Thus, sweetness intensity of the modified products did not equal the sweetness intensity of the control. Substitution of Splenda® Granulated alone resulted in the greatest decrease in sweetness intensity when compared to the control. However, blending Splenda® Granulated and isomalt moderated the extent to which perceived sweetness intensity decreased. Similar trends were found for buttery, vanilla, and eggy; isomalt in combination with Splenda® Granulated moderated the decrease in attribute intensity found with Splenda® Granulated incorporation alone. This perceived decrease in intensity may have to do with a flavor masking effect of the incorporation of the maltodextrins in Splenda® Granulated in the formulas. The attributes cardboardy, baking soda, and doughy increased with sugar replacement with again the greatest impact found when only Splenda® Granulated was incorporated. For the attribute browned, defined by the panel as the caramelization of sugars, there were no significant differences found between the control and the blends containing isomalt despite significant differences found in surface browning when assessed instrumentally. Even though not in the concise definition used by the panel, the browned flavor attribute encompasses Maillard browning as well and its similar flavor and aroma to caramelization. Therefore despite the lack of actual caramelization of sugars and limited Maillard browning, it appears isomalt in combination with Splenda® Granulated gives a perceived browned note more similar to sucrose than does Splenda® Granulated alone. In addition, it appears there is an inverse relationship between doughy and browned. As the percentage of Splenda® Granulated increased in the formulas, the perceived intensity of doughy increased while the attribute browned decreased.

Bitterness intensity of the control and Splenda® Granulated/isomalt blends did not differ; however, the 100% Splenda® Granulated cupcakes were significantly more bitter than was found for all other formulations. This demonstrates that the Splenda® Granulated/isomalt blends, using the multiple ingredient approach, overcame the negative bitterness taste that is often perceived with use of alternative sweeteners (Hanger and others 1996). Overall, cupcakes prepared with 40% Splenda® Granulated and 60% isomalt exhibited a flavor profile most similar to the sucrose control.

Aftertastes

For aftertastes assessed by the panel (Table 4.7) there were no significant differences found for the attributes in terms of treatment x storage or storage, which is a positive result. Aftertastes are assessed in sugar substitution studies because typically sugar alternatives, especially high intensity sweeteners, leave strong metallic, bitter, sweet, numbing, and/or astringent aftertastes that are perceived negatively (Hanger and others 1996). The only significant difference in terms of treatment was for the attribute baking soda. In this case, the 100% Splenda® Granulated had a significantly greater baking soda aftertaste when compared to the control. This indicates that Splenda® Granulated when substituted at the 100% level for sucrose may impart a baking soda aftertaste in cupcakes. There were no significant differences found between the control and the Splenda® Granulated and isomalt blends for presence of a baking soda aftertaste, indicating that isomalt moderates the aftertaste intensity.

Phase 2: Consumer Acceptability

Consumer Panel Profile

The consumer panel was comprised of 85% females and 15% males with 50% being between the ages of 21 and 23. Approximately 15% were 24-26 years old, 14% were 18-20 years old, and 11% were 30-39 years old. The panel was predominately white (86%) followed by African-American (9%) and Asian (5%). Fifty percent of the panelists reported eating cake several times a year and 33% reported eating cake once a month. About 24% of the panel drank beverages sweetened with sugar substitutes daily, 20% several times a week, and 21% several times a month. Forty-four percent reported consuming foods other than beverages prepared with sugar substitutes.

Cupcake Acceptability

Acceptability of the control and two formulations identified as most like the control in Phase 1 of this study (SP40 and SP99) was assessed one-day post-bake (Table 4.8). The same instrumental tests previously conducted were repeated (Tables 4.9, 4.10, 4.11) over the same 4-day storage period. Generally, these results were the same as those found for these formulations in Phase 1. Batter specific gravity, but not volume, was significantly different in Phase 2 unlike Phase 1; however, the LS-means in Phase 2 were almost identical to those found in Phase 1. For TPA, in terms of treatment, the difference found in chewiness in Phase 1 was not found in Phase 2, and there were also no significant treatment x storage effects found for hardness and cohesiveness in Phase 2. TPA LS-means in both phases of the study were in the same numerical range.

For the reformulated products, the appearance of the SP40 formulation was found to equal the acceptability of the control, with the appearance of the SP99 cupcake being less acceptable. Instrumentally, the color of the SP40 sample was found to be most like the control in both Phase 1 and Phase 2 of this study. Flavor of the reformulated products did not differ from each other, although both were less acceptable than the control. In Phase 1 of the study the descriptive sensory panelists evaluated 11 flavor attributes and identified deviations in intensity from the control. These differences in flavor attributes detected by the descriptive panelists were apparently great enough to impact relative acceptability of the formulations. Other flavor attributes not assessed by the descriptive panel may have been influential as well. Texture acceptability differed significantly due to formulation. Texture of both samples was less acceptable than the control with SP40 being the least acceptable. Instrumental characteristics of the SP40 sample were found to differ more than the SP99 sample from the control when measured in both phases of this study. However, descriptive sensory panelists evaluating texture in Phase 1 indicated that the textural attributes of the SP40 more closely duplicated the control. TPA measurements appear to reflect the influences on texture acceptability better than the texture attributes evaluated by the descriptive panel.

Overall acceptability results (Table 4.8) suggest that the consumer panelists prefer a cake with characteristics that differ from those evaluated in this study. The control was rated in the slightly acceptable range of the scale, whereas the reformulated cakes were in the neither acceptable nor unacceptable range of the scale. Overall acceptability of the reformulated products did not differ from each other, although both were less acceptable than the control. A high-ratio cake, which is sweeter than the lean formula cake that served as the control in this study, with a finer and more tender crumb, may serve as the mental standard against which these panelists were evaluating these formulations. Further, if a cake prepared from a cake mix was the mental standard, characteristics of the control likely exhibited even greater deviations. Cakes prepared from cake mixes are high-ratio cakes and have an extremely soft, light, and fluffy crumb. Approximately 64% of US households use dry cake mixes (Mintel 2007). The three most popular brands of cake mixes are Betty Crocker, Duncan Hines, and Pillsbury. The specific mixes that are most popular are Betty Crocker SuperMoist Cake, Duncan Hines Moist Deluxe, and Pillsbury Moist Supreme Cake, respectively (Mintel 2007). Therefore, the specific type of cake mix most commonly used exemplifies the standard cake against which the consumer panelists most likely compared the cupcakes. Finally, most shortened layered cakes are consumed with frosting. It is unknown to what extent the acceptability of shortened cake, in general, is influenced by the frosting and it is also unknown the extent to which the interplay of the resulting multi-component system drives acceptability. Panelists were queried about the frequency they consumed cake and about their use of products sweetened with alternative sweeteners but they were not asked to describe their ideal cake or indicate if they consumed shortened layer cakes with frosting.

A stepwise multiple regression analysis revealed that 86% of the variability in overall acceptability was accounted for by the acceptability of the texture, flavor, and appearance of each sample with each characteristic accounting for 69 %, 15%, and 2% of the variability respectively. How often panelists consumed cake and used alternative sweeteners were also included in the regression analysis; however, they did not further explain variability in overall acceptability. The texture x appearance interaction was not significant when introduced into the regression model, suggesting that panelists did not use the textural clues provided through appearance in their assessment of texture acceptability in this study. It should be noted that panelists were asked to evaluate acceptability of appearance prior to their assessment of the acceptability of the texture of the cupcake. These results do suggest that factors other than those queried in this study, come into play when consumers are evaluating the overall acceptability of a cake product.

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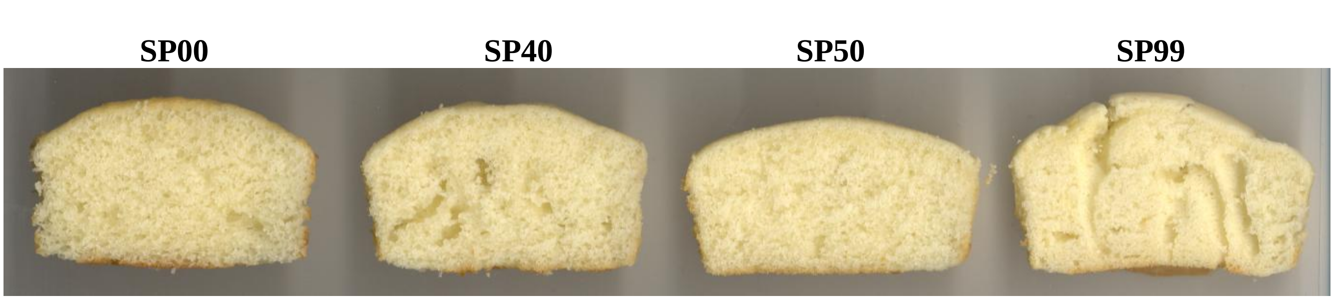

Figure 4.1: Appearance of crumb of four cupcake formulations

Table 4.1: Nutritional analysis[a] of cupcake formulations (31-34[b] g per serving)

	Formulations[c]			
Nutrients	**SP00**	**SP40**	**SP50**	**SP99**
Calories (kcal)	102.85	89.55	90.34	104.00
Calories from fat (kcal)	44.90	47.48	48.47	59.36
Protein (g)	1.34	1.42	1.45	1.77
Carbohydrate (g)	13.33	11.25	10.84	9.31
Total sugar (g)	7.68	0.44	0.45	0.55
Other carbohydrates (g)	5.53	6.26	6.49	8.60
Fat (g)	4.99	5.28	5.39	6.60
Saturated fat (g)	2.12	2.24	2.29	2.80
Cholesterol (mg)	22.59	23.89	24.39	29.87
Dietary fiber (g)	0.12	0.13	0.13	0.16
Sodium (mg)	78.52	83.04	84.77	103.65

[a]ESHA Food Processor SQL (version 9.7.0, 2004, ESHA Research, Salem, OR)
[b]SP00 32 g/serving, SP40 31 g/serving, SP50 31 g/serving, SP99 34 g/serving; all formulations were 7 cm in diameter
[c]SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt, SP99=100% Splenda® Granulated

Table 4.2: Phase 1: Batter specific gravity[a], water activity[b], and volume[c] of cupcake formulations[d]

	LS-Means				
	SP00	**SP40**	**SP50**	**SP99**	**SEM**
Specific gravity	0.75	0.72	0.73	0.77	0.01
Volume	8.80	7.88	7.48	8.13	0.37
Water activity[e]	0.92a	0.94b	0.95c	0.98d	0.00

[a] LS-means are across 4 replications with 3 analysis per replication. Specific gravity was determined using the method described in Penfield and Campbell (1990).
[b] LS-means are across 4 replications with 6 analysis per replication. Water activity was measured using an AquaLab CX-2 (Decagon Devices, Inc., Pullman, WA). Aliquots were taken from composite samples as described by Curley and Hoseney (1984).
[c] LS-means are across 4 replications with 6 analysis per replication. Volume was measured using a modified version of AACC 10-91 (AACC 2000).
[d] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt; SP99=100% Splenda® Granulated.
[e] LS-means followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF.

Table 4.3: Phase 1: Exterior and interior L*a*b* color[ab] for cupcake formulations[c]

	LS-Means				
Parameter[de]	**SP00**	**SP40**	**SP50**	**SP99**	**SEM**
Exterior:					
L*	67.41a	76.77b	77.42b	80.60c	0.96
a*	5.46c	0.92b	0.51b	0.15a	0.37
b*	37.29d	30.06c	28.08b	23.76a	0.78
Interior:					
L*	79.98	80.86	79.76	80.52	0.56
a*	-1.21a	-1.12ab	-1.04b	-1.20a	0.07
b*	18.13	19.38	19.92	19.18	0.48

[a] LS-means are across 4 replications with 6 analysis per replication
[b] L*= lightness axis where 0=black, 100=white; a*=red-green axis where positive values are red, negative values are green; b*=yellow-blue axis where positive values are yellow, negative values are blue
[c] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt; SP99=100% Splenda® Granulated
[d] CM-2600d Minolta spectrophotometer (Minolta Corp., Ramsey, NJ) with 10 degree observer function and illuminant F6, specular component excluded
[e] LS-means within each parameter followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

Table 4.4: Phase 1: Texture Profile Analysis[a] of cupcake formulations[b]; storage effects[c], treatment effects[d], and interaction effects[e]

	Attribute	Day	LS-Means ± SEM
	Springiness	0	0.94d±0.00
		1	0.90c±0.00
		2	0.87b±0.00
		3	0.84a±0.00
	Hardness	0	297.75a±15.25
	(g)	1	358.31b±15.25
		2	516.68c±16.52
Storage		3	563.96d±16.52
	Cohesiveness	0	0.64d±0.01
		1	0.53c±0.01
		2	0.46b±0.01
		3	0.43a±0.01
	Chewiness	0	176.95a±8.66
	(g)	1	171.40a±8.66
		2	208.66b±9.39
		3	201.55b±9.39

			SP00	SP40	SP50	SP99	SEM
	Springiness		0.89b	0.87a	0.88b	0.91c	±0.00
Treatment	Hardness (g)		300.25a	475.03bc	567.01c	394.41b	±25.52
	Cohesiveness		0.57c	0.48a	0.47a	0.54b	±0.01
	Chewiness (g)		147.54a	195.16b	227.99b	187.87ab	±14.54
	Springiness	0	0.94v	0.94v	0.93v	0.94v	±0.00
		1	0.90au	0.89au	0.90au	0.92bu	±0.00
		2	0.87bt	0.85at	0.88bt	0.90ct	±0.00
		3	0.84bs	0.82as	0.83abs	0.88cs	±0.00
	Hardness	0	192.12as	326.19bcs	382.31cs	290.36bs	±29.80
	(g)	1	276.97at	396.31bct	427.61ct	332.33abt	±29.80
		2	348.37au	558.18bu	691.58cu	468.60bu	±32.38
Treatment		3	383.54au	619.42cu	766.52du	486.34bu	±32.38
x Storage	Cohesiveness	0	0.66bv	0.62abu	0.62av	0.65abu	±0.01
		1	0.59cu	0.50at	0.48au	0.56bt	±0.01
		2	0.54ct	0.42as	0.42at	0.48bs	±0.01
		3	0.49bs	0.39as	0.37as	0.47bs	±0.01
	Chewiness	0	119.01as	190.67b	222.32bt	175.78bst	±17.03
	(g)	1	148.82t	177.64	187.57s	171.59s	±17.03
		2	163.54at	206.44ab	262.84bt	201.82abt	±18.52
		3	158.79at	205.88ab	239.22bt	202.31abt	±18.52

[a] LS-means are across 4 replications with 6 analysis per storage day per replication; TA-XT2 (50 kg) *plus* Texture Analyzer (Texture Technologies, Scarsdale, NY) equipped with an acrylic 1 in. cylindrical, rounded probe and Texture Exponent 32 v4,0,13,0 software

[b] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt; SP99=100% Splenda® Granulated

[c] LS-means within each attribute and storage day followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

[d] LS-means within each attribute and treatment followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

[e] LS-means within each attribute and treatment (a, b, c, d) across storage days (s, t, u, v) followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

Table 4.5: Phase 1: Descriptive analysis[a] for texture attributes of cupcake formulations[b]; storage effects[c], treatment effects[d], and interaction effects

	Attribute	Day	LS-Means ± SEM
Storage	Springiness	1	8.76b±0.79
		3	7.69a±0.79
	Stickiness	1	6.40±0.94
		3	6.00±0.94
	Hardness	1	3.95a±0.18
		3	4.30b±0.18
	Denseness	1	4.33±0.34
		3	4.17±0.34
	Cohesiveness	1	3.13b±0.50
		3	2.92a±0.50
	Moistness	1	7.79b±0.72
		3	7.18a±0.72
	Rate of dissolving	1	7.19±0.49
		3	7.06±0.49
	Chewiness	1	3.63±0.43
		3	3.64±0.43

	Attribute	SP00	SP40	SP50	SP99	SEM
Treatment	Springiness	8.65	7.92	8.09	8.25	±0.80
	Stickiness	7.00b	7.42b	6.78b	3.62a	±0.96
	Hardness	3.77a	3.96a	4.31b	4.47b	±0.20
	Denseness	4.15ab	3.95a	4.36bc	4.54c	±0.35
	Cohesiveness	2.77a	3.12bc	2.94ab	3.27c	±0.51
	Moistness	8.67b	7.28a	6.87a	7.10a	±0.73
	Rate of dissolving	7.69c	7.32bc	6.95ab	6.54a	±0.51
	Chewiness	3.40a	3.39a	3.90b	3.86b	±0.44

	Attribute	Day	SP00	SP40	SP50	SP99	SEM
Treatment x Storage	Springiness	1	9.17	8.65	8.57	8.65	±0.84
		3	8.13	7.19	7.60	7.85	±0.84
	Stickiness	1	6.74	7.77	7.30	3.78	±1.00
		3	7.25	7.07	6.24	3.46	±1.00
	Hardness	1	3.72	3.79	4.03	4.27	±0.22
		3	3.82	4.13	4.58	4.67	±0.22
	Denseness	1	4.24	4.01	4.31	4.76	±0.37
		3	4.05	3.90	4.41	4.32	±0.37
	Cohesiveness	1	2.88	3.12	2.98	3.55	±0.52
		3	2.66	3.11	2.91	2.98	±0.52
	Moistness	1	9.15	7.79	6.92	7.30	±0.75
		3	8.19	6.78	6.83	6.91	±0.75
	Rate of dissolving	1	7.85	7.64	6.92	6.36	±0.54
		3	7.53	7.01	6.99	6.72	±0.54
	Chewiness	1	3.37	3.34	3.91	3.90	±0.45
		3	3.43	3.43	3.89	3.82	±0.45

[a] n=7 across 3 replications for both storage periods for all formulations; sensory scale ranged from 0 (not perceptible) to 15 (high intensity)
[b] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt; SP99=100% Splenda® Granulated
[c] LS-means within each attribute and storage day followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF
[d] LS-means within each attribute and treatment followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

Table 4.6: Phase 1: Descriptive analysis[a] for flavor attributes of cupcake formulations[b]; storage effects, treatment effects[c], and interaction effects[d]

	Attribute	Day	LS-Means ± SEM
	Buttery	1	2.35±0.20
		3	2.28±0.20
	Vanilla	1	3.40±0.29
		3	3.29±0.29
	Doughy	1	2.64±0.23
		3	2.70±0.23
	Baking soda	1	1.85±0.43
		3	1.88±0.43
	Eggy	1	2.28±0.22
		3	2.19±0.22
Storage	Browned	1	1.79±0.31
		3	1.77±0.31
	Cardboard	1	2.15±0.30
		3	2.22±0.30
	Sweet	1	10.21±0.41
		3	9.99±0.41
	Salt	1	3.32±0.18
		3	3.34±0.18
	Sour	1	2.20±0.31
		3	2.13±0.31
	Bitter	1	1.48±0.39
		3	1.53±0.39

			SP00	SP40	SP50	SP99	SEM
	Buttery		2.59c	2.32b	2.34b	2.02a	±0.20
	Vanilla		3.67c	3.46bc	3.26ab	2.97a	±0.30
	Doughy		2.06a	2.66b	2.80b	3.16c	±0.24
	Baking soda		1.55a	1.82b	1.91b	2.19c	±0.44
	Eggy		2.47c	2.28bc	2.16ab	2.02a	±0.23
Treatment	Browned		1.90b	1.81b	1.85b	1.55a	±0.31
	Cardboard		1.80a	2.19b	2.22b	2.52b	±0.31
	Sweet		10.74c	10.17b	10.05b	9.46a	±0.43
	Salt		3.23a	3.20a	3.29a	3.62b	±0.19
	Sour		2.17	2.10	2.11	2.29	±0.31
	Bitter		1.05a	1.44a	1.41a	2.12b	±0.40
	Buttery	1	2.54	2.31	2.45	2.08	±0.22
		3	2.64	2.32	2.22	1.95	±0.22
	Vanilla	1	3.71	3.66	3.27	2.94	±0.32
		3	3.63	3.25	3.26	3.00	±0.32
	Doughy	1	2.07	2.57	2.80	3.11	±0.25
		3	2.06	2.76	2.80	3.20	±0.25
	Baking soda	1	1.50	1.84	1.94	2.11	±0.45
		3	1.60	1.80	1.87	2.27	±0.45
	Eggy	1	2.62	2.30	2.12	2.06	±0.24
		3	2.33	2.26	2.19	1.98	±0.24
Treatment x Storage	Browned	1	1.94	1.86	1.79	1.57	±0.32
		3	1.86	1.77	1.91	1.54	±0.32
	Cardboard	1	1.64	2.04	2.30	2.60	±0.34
		3	1.96	2.33	2.14	2.43	±0.34
	Sweet	1	10.74	10.25	10.26	9.60	±0.47
		3	10.73	10.08	9.85	9.32	±0.47
	Salt	1	3.40	3.28	3.26	3.36s	±0.22
		3	3.06a	3.12a	3.32a	3.88bt	±0.22
	Sour	1	2.34	2.08	2.12	2.26	±0.32
		3	2.00	2.12	2.10	2.31	±0.32
	Bitter	1	1.16	1.29	1.40	2.09	±0.42
		3	0.94	1.60	1.42	2.15	±0.42

[a] n=7 across 3 replications for both storage days for all formulations; sensory scale ranged from 0 (not perceptible) to 15 (high intensity)
[b] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt; SP99=100% Splenda® Granulated
[c] LS-means within each attribute and treatment followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF
[d] LS-means within each attribute and treatment (a, b) across storage days (s, t) followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

Table 4.7: Phase 1: Descriptive analysis[a] for aftertastes of cupcake formulations[b]; storage effects, treatment effects[c], and interaction effects

	Attribute	Day	LS-Means ± SEM				
	Metallic	1	3.51±0.66				
		3	3.54±0.67				
	Baking soda	1	2.53±0.22				
		3	2.40±0.23				
	Sweet	1	7.89±1.41				
		3	7.70±1.42				
Storage	Bitter	1	1.79±0.22				
		3	1.60±0.22				
	Sour	1	2.27±0.61				
		3	2.08±0.61				
	Numbing	1	4.31±1.10				
		3	4.22±1.10				
	Astringent	1	2.78±0.37				
		3	2.76±0.37				
			SP00	**SP40**	**SP50**	**SP99**	**SEM**
	Metallic		3.31	3.66	3.50	3.62	±0.67
	Baking soda		2.11a	2.45ab	2.53ab	2.77b	±0.25
	Sweet		7.37	7.75	8.07	7.98	±1.43
Treatment	Bitter		1.65	1.64	1.64	1.83	±0.23
	Sour		2.33	2.06	2.08	2.24	±0.62
	Numbing		4.02	4.36	4.28	4.41	±1.11
	Astringent		2.64	2.80	2.84	2.80	±0.38
	Metallic	1	3.24	3.75	3.40	3.65	±0.68
		3	3.38	3.57	3.61	3.60	±0.68
	Baking soda	1	2.14	2.74	2.34	2.89	±0.29
		3	2.08	2.16	2.72	2.64	±0.30
	Sweet	1	7.71	7.86	8.37	7.61	±1.45
		3	7.02	7.64	7.76	8.36	±1.46
Treatment	Bitter	1	1.58	1.84	1.71	2.02	±0.25
x Storage		3	1.72	1.45	1.57	1.64	±0.26
	Sour	1	2.47	1.97	2.18	2.46	±0.63
		3	2.18	2.14	1.97	2.02	±0.63
	Numbing	1	4.09	4.40	4.45	4.30	±1.11
		3	3.94	4.31	4.10	4.52	±1.11
	Astringent	1	2.49	2.74	2.96	2.94	±0.39
		3	2.80	2.86	2.73	2.66	±0.40

[a] n=7 across 3 replications for both storage days for all formulations; sensory scale ranged from 0 (not perceptible) to 15 (high intensity)
[b] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP50=50% Splenda® Granulated: 50% isomalt; SP99=100% Splenda® Granulated
[c] LS-means within each attribute and treatment followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

Table 4.8: Phase 2: Acceptability[a] of three cupcake formulations (n=66)

	Formulations[b]			
	SP00	**SP40**	**SP99**	
Attribute		**LS-means**		**SEM**
Appearance	6.18b	5.73b	4.79a	0.22
Texture	6.27c	4.26a	5.27b	0.21
Flavor	6.67b	5.15a	5.14a	0.22
Overall Acceptability	6.59b	4.94a	5.15a	0.20

[a] 9-point structured hedonic scale where 1=dislike extremely and 9=like extremely; LS-means across each row followed by different letters are significantly different ($p<0.05$) according to a general linear model (PROC GLM) and LS-means separation with PDIFF

[b]SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP99=100% Splenda® Granulated

Table 4.9: Phase 2: Batter specific gravity[a], water activity[b], and volume[c] of cupcake formulations[d]

	LS-Means			
	SP00	**SP40**	**SP99**	**SEM**
Specific gravity[e]	0.75ab	0.72a	0.78b	0.01
Volume	8.83	8.03	8.05	0.33
Water activity[e]	0.92a	0.94b	0.98c	0.00

[a] LS-means are across 5 replications with 3 analysis per replication. Specific gravity was determined using the method described in Penfield and Campbell (1990).

[b] LS-means are across 5 replications with 6 analysis per replication. Water activity was measured using an AquaLab CX-2 (Decagon Devices, Inc., Pullman, WA). Aliquots were taken from composite samples as described by Curley and Hoseney (1984).

[c] LS-means are across 5 replications with 6 analysis per replication. Volume was measured using a modified version of AACC 10-91 (AACC 2000).

[d] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP99=100% Splenda® Granulated.

[e] LS-means followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF.

Table 4.10: Phase 2: Exterior and interior L*a*b* color[ab] for cupcake formulations[c]

	LS-Means			
Parameter[de]	**SP00**	**SP40**	**SP99**	**SEM**
Exterior:				
L*	67.74a	76.75b	80.17c	0.89
a*	4.80c	0.86b	0.17a	0.50
b*	37.08c	30.71b	24.58a	0.89
Interior:				
L*	79.59	79.95	79.55	0.88
a*	-1.07	-1.01	-1.06	0.14
b*	17.74	18.87	19.12	0.52

[a] LS-means are across 5 replications with 6 analysis per replication
[b] L*= lightness axis where 0=black, 100=white; a*=red-green axis where positive values are red, negative values are green; b*=yellow-blue axis where positive values are yellow, negative values are blue
[c] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP99=100% Splenda® Granulated
[d] CM-2600d Minolta spectrophotometer (Minolta Corp., Ramsey, NJ) with 10 degree observer function and illuminant F6, specular component excluded
[e] LS-means within each parameter followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

Table 4.11: Phase 2: Texture Profile Analysis[a] of cupcake formulations[b]; storage effects[c], treatment effects[d], and interaction effects[e]

	Attribute	Day	LS-Means ± SEM
	Springiness	0	0.94d±0.00
		1	0.90c±0.00
		2	0.87b±0.00
		3	0.85a±0.00
	Hardness (g)	0	259.85a±15.52
		1	328.48b±16.49
		2	451.40c±17.76
Storage		3	489.46d±17.76
	Cohesiveness	0	0.64d±0.01
		1	0.54c±0.01
		2	0.47b±0.01
		3	0.45a±0.01
	Chewiness (g)	0	154.46a±9.24
		1	160.58a±9.75
		2	184.91b±10.40
		3	183.30b±10.40

			SP00	SP40	SP99	SEM
	Springiness		0.89b	0.87a	0.91c	±0.00
	Hardness (g)		295.15a	458.95b	392.79b	±24.68
Treatment	Cohesiveness		0.57c	0.48a	0.53b	±0.01
	Chewiness (g)		144.34	182.97	185.12	±14.91
Treatment x Storage	Springiness	0	0.94v	0.93v	0.94v	±0.00
		1	0.90au	0.89au	0.92bu	±0.00
		2	0.87bt	0.85at	0.90ct	±0.00
		3	0.84bs	0.82as	0.88cs	±0.00
	Hardness (g)	0	185.83	305.12	288.62	±26.88
		1	272.61	381.71	331.13	±28.57
		2	343.50	543.87	466.84	±30.76
		3	378.67	605.11	484.59	±30.76
	Cohesiveness	0	0.66bv	0.61av	0.64abu	±0.01
		1	0.59cu	0.49au	0.55bt	±0.01
		2	0.54ct	0.41at	0.47bs	±0.01
		3	0.49bs	0.38as	0.46bs	±0.01
	Chewiness (g)	0	115.30	175.32	172.77	±16.00
		1	146.07	166.30	169.36	±16.88
		2	160.37	195.41	198.94	±18.02
		3	155.62	194.85	199.42	±18.02

[a] LS-means are across 5 replications with 6 analysis per storage day per replication; TA-XT2 (50 kg) *plus* Texture Analyzer (Texture Technologies, Scarsdale, NY) equipped with an acrylic 1 in. cylindrical, rounded probe and Texture Exponent 32 v4,0,13,0 software

[b] SP00= 100% sugar (control), SP40=40% Splenda® Granulated: 60% isomalt, SP99=100% Splenda® Granulated

[c] LS-means within each attribute and storage day followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

[d] LS-means within each attribute and treatment followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

[e] LS-means within each attribute and treatment (a, b, c) across storage days (s, t, u, v) followed by different letters are significantly different ($p<0.05$) according to mixed model analysis of variance (PROC MIXED) and LS-means separation with PDIFF

CHAPTER 5

CONCLUSIONS

Obesity rates have risen significantly during the past 20 years and now obesity affects 34% of the US adult population (CDC 2009a). About 66% of the US adult population is either overweight or obese (CDC 2009b). The obesity epidemic raises much concern because of its associated health problems such as type 2 diabetes, coronary heart disease, cancer, hypertension, and dyslipidemia (CDC 2009a). Similar to obesity, diabetes has reached epidemic proportions in the US and in 2006 diabetes was the seventh leading cause of death. Around 80 percent of people with type 2 diabetes are overweight (CDC 2008). People with diabetes can prevent complications by controlling blood glucose levels, blood pressure, and blood lipids. Blood glucose management can be accomplished by controlling intake of carbohydrates, especially simple carbohydrates (Franz and others 2002).

Diets high in sugars have been linked to varying health issues (Johnson and Frary 2001). Reducing intake of added sugars lowers total caloric intake and promotes adequate nutrition (ADA 2004, Lichtenstein and others 2006). Short-term studies suggest that substituting added sugar with low-energy sugar alternatives may result in lower caloric intake and some weight loss (Vermunt and others 2003). In the long term, use of alternative sweeteners rather than sugar may help with weight maintenance and allow people to enjoy the desserts they want without consuming as many grams of sugar or calories.

Cake is a popular high-sugar snack and dessert that also is a source of added sugars in the diet. Recently cakes, and other baked products, have been targeted for reformulation with different sugar alternatives or blends of sugar alternatives to reduce calorie and added sugar intake. Sucrose plays many important roles in cake other than just sweetening such as browning, structure, tenderness, volume, water activity control, and shelf-life (Pyler 1988; Nelson 2000). High intensity sweeteners (HIS) provide either none or negligible amounts of calories and produce either no or limited glycemic responses; however, they often have bitter, metallic, and lingering aftertastes and provide little volume to the structure of cake (ADA 2004). Thus, high-quality cakes are often not achievable with replacement of sugar by HIS alone. Often HIS are combined with bulking agents such as polyols in the multiple ingredient approach to replace the nonsweet functional properties of sucrose in baked products (ADA 2004) and produce more acceptable cakes. In addition, staling is a common problem in sucrose-substituted cakes because sucrose reduces processes involved in staling. Staling results in flavor loss and increased firmness in crust and crumb (Swanson 2004).

In this study, 100% of the sugar in yellow shortened cupcakes was replaced with isomalt and/or Splenda® Granulated (sucralose and maltodextrin). The control cupcake was made with 100% granulated sugar. 100% sugar replacement with Splenda® Granulated and two ratios of Splenda® Granulated: isomalt were investigated.

No significant differences were found for batter specific gravity, volume, or interior color (except a*) due to formulation. Thus, it appeared substitution with Splenda® Granulated and isomalt in combination produced acceptable batter specific gravities and cupcake volumes due to the ability of these sugar alternatives to add bulk and facilitate air incorporation. For the 100% Splenda® Granulated cupcake, the lack of significant difference in volume likely reflected the peaked appearance, which is an undesirable characteristic in cake that occurs due to tunneling.

Exterior color, water activity, and TPA differed significantly between formulations. The exterior color of the SP40 cupcake was most similar to the control even though it did not contain the greatest amount of maltodextrins, which unlike sucralose and isomalt, contribute to Maillard browning. Therefore, it appeared a blend of Splenda® Granulated and isomalt contributes more to exterior browning as opposed to Splenda® Granulated alone.

All modified treatments had a significantly higher water activity when compared to the control with SP40 being closest to the control. However, because all water activity levels were over 0.90, in terms of microbial growth and shelf-life there were no real differences in safety and stability between the formulations (Fontana 2000).

The treatment x storage interaction was significant for TPA; springiness and cohesiveness decreased whereas hardness and chewiness increased over the storage period. Generally, the greatest changes occurred by day 3 and the most rapid changes over the storage period for all attributes occurred with sugar replacement with the 50:50 cupcake. Storage effects were attributed to processes involved in staling, specifically starch retrogradation and moisture losses (Pyler 1988).

No significant treatment x storage interaction was found by the descriptive sensory panel in terms of texture, but similar treatment and storage effects were found. Springiness, cohesiveness and moistness decreased, and hardness increased as storage period increased. No changes in chewiness, stickiness, rate of dissolving, or denseness were found. Instrumentally SP99 was closest to the control in texture whereas SP40 was found to be most similar to the control by descriptive sensory panelists. Deviations for these texture characteristics were relatively small and texture differences found in the cupcakes may have been below the panel's detection threshold. It is also possible that the sensory panelists may have subconsciously considered appearance and associated expectations in their assessment. Although color differences were masked during evaluation, shape and overall appearance of the crumb were not and the SP99's crumb was remarkably different compared to the other formulations. It would be interesting to blindfold the panelists while they assess texture and flavor and compare those results against this study to determine if appearance biased the panelists in any way.

No significant storage or storage x treatment flavor effects (except saltiness for SP99) were found. Significant treatment flavor effects were found; isomalt in combination with Splenda® Granulated moderated differences in attribute intensities when compared to the control. The perceived decreases in intensities of sweetness, buttery, vanilla, and eggy in the sucrose-substituted cupcakes may have to do with a flavor masking effect of the incorporation of the maltodextrins in Splenda® Granulated in the formulas. Splenda® Granulated/isomalt blends, using the multiple ingredient approach, overcame the negative bitter taste that is often perceived with use of alternative sweeteners (Hanger and others 1996). Numbing and astringency post-swallow were not detected. Overall SP40 exhibited a flavor profile most similar to the control.

Overall acceptability from the consumer panel revealed the reformulated cakes to be in the neither acceptable nor unacceptable range. However, the control was rated only in the slightly acceptable range and thus the results suggest that the panelists preferred a cake with characteristics that differed from those evaluated in this study, such as a high-ratio cake prepared from a boxed mix. Approximately 64% of US households use dry cake mixes (Mintel 2007) and thus this may have been the mental standard against which the consumers compared the cakes. In addition, most shortened cakes are consumed with frosting. More research is necessary to determine the extent to which the acceptability of shortened cake is influenced by frosting. In the future, it may be helpful to ask consumer panelists to describe their ideal cake and indicate if they consume shortened cakes with frosting or how often they consume shortened cake without frosting. It would then be possible to take those factors into consideration when determining acceptability of sucrose-substituted cakes.

Sugar reduction in the Splenda® Granulated/isomalt blends was successful (94%) although calorie reduction was only 12-13%. The formulations would be an appropriate dessert choice for people with diabetes and others watching their sugar consumption because it meets the criteria for the label “sugar-free” (FDA 2009) and most likely elicits a lower glycemic response compared to a sucrose formulation. However, the exact reduction in glycemic response that sucrose-replaced cakes generate is unknown and would be another area for future research.

Overall the 40:60 Splenda® Granulated: isomalt blend appeared to produce a cupcake most similar to the sucrose control except in terms of texture. Texture differences and its relative importance in overall acceptability needs further attention in the formulation before an optimal Splenda® Granulated: isomalt ratio can be determined. More research is necessary in texture evaluation procedures to determine which procedure best relates to what is important to consumers in terms of texture acceptability. Also, substitution should be conducted in a high-ratio formulation to produce cakes that are most similar to the standard commonly consumed.

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APPENDICES

APPENDIX A

CONSUMER SENSORY PANEL CONSENT FORM

Consent Form:

I, ________________________________, agree to participate in a research study titled "Factors that affect acceptability of yellow cupcakes" conducted by Aimee Chisamore from the Department of Foods and Nutrition at the University of Georgia (542-5133) under the direction of Dr. Ruthann B. Swanson, Department of Foods and Nutrition, University of Georgia (542-4834). I understand my participation is voluntary. I can refuse to participate or stop taking part without giving any reason without penalty or loss of benefits to which I am otherwise entitled. I can ask to have all of the information about me returned to me, removed from the research records, or destroyed.

The purpose of this study is to identify factors that influence acceptability and selection among various cupcake formulations.

If I volunteer to take part in this study, I will be asked to do the following things:

- Read and sign a consent form (1-2 minutes)
- Evaluate cupcakes according to sensory scorecards (10-15 minutes)
- Complete a demographic and consumption questionnaire (5-10 minutes)
- Cleanse my palate with distilled water, unsalted crackers, and carrots between tasting samples (1-2 minutes)

Following my participation, I will be offered commercial snacks and beverages upon leaving the study testing site. No additional compensation will be offered.

There are no known risks for any of the ingredients used in the preparation of the cupcakes. I will be provided palate cleansers (water, crackers, and carrots) between samples. However, I will not use any palate cleansing agent to which I am allergic. Food allergies that I have include ____(please list).

I will be assigned an identifying number, and this number will be used on all questionnaires and evaluation forms I fill out. However, there is no way to connect specific responses with a specific individual once the test is completed. No individually identifiable information about me, or provided by me during the research will be shared with others, except if necessary by law.

In the event that my participation in this study results in a medical problem, treatment will be made available. However, my insurance company or I will be billed for the costs of any such treatment. No provision has been made for payment of these costs or to provide me with other financial compensation.

If I have further questions about the study, I can call Dr. Ruthann Swanson at 542-4834 or Aimee Chisamore at 542-5133.

--OVER--

Consent Form:

I understand the procedures described above, and my additional questions have been answered to my satisfaction. I agree to participate in this research study, and I have received a copy of this consent form for my records.

Aimee Chisamore________	________________________	______
Name of Researcher	Signature	Date
Ruthann Swanson__________	________________________	______
Name of Research Advisor	Signature	Date
__________________________	________________________	______
Name of Participant	Signature	Date

Please sign both copies, keep one and return one to the researcher.

Additional questions or problems regarding your rights as a research participant should be addressed to Chairperson, Institutional Review Board, University of Georgia, 612 Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-3199; Email address IRB@uga.edu

APPENDIX B

CUPCAKE EVALUATION FORM

Cupcake Scorecard

Panelist________ Sample number ____

Please sample each cupcake and evaluate its appearance, texture, flavor, and overall acceptability. Place a mark above the number indicating the degree to which you like each characteristic in the sample. Please drink water between samples, and eat some cracker and/or carrot before sampling the next product.

Overall Appearance:

dislike extremely __ __ __ __ __ __ __ __ __ like extremely
1 2 3 4 5 6 7 8 9

Overall Texture:

dislike extremely __ __ __ __ __ __ __ __ __ like extremely
1 2 3 4 5 6 7 8 9

Overall Flavor:

dislike extremely __ __ __ __ __ __ __ __ __ like extremely
1 2 3 4 5 6 7 8 9

Overall Acceptability:

dislike extremely __ __ __ __ __ __ __ __ __ like extremely
1 2 3 4 5 6 7 8 9

Thank you!!

APPENDIX C

DEMOGRAPHICS QUESTIONNAIRE

Panelist number_______

Demographic Questionnaire

1. **Gender** ________Male ________Female

2. **Please check your age category:**
___18-20 ___21-23 ___24-26 ___27-29 ___30-39 ___40-49 ___50+

3. **Do you consider yourself to be…?**
_______White
_______African-American
_______Native American
_______Hispanic
_______Asian
_______Other

4. **How often do you eat cupcakes or cake?**
_______Daily
_______Several times a week
_______Several times a month
_______Once a month
_______Several times a year
_______Never

5. **How often do you consume beverages sweetened with sugar substitutes?**
_______Daily
_______Several times a week
_______Several times a month
_______Once a month
_______Several times a year
_______Never

6. **Do you consume food products other than beverages prepared with sugar substitutes?**
_______ yes _______ no

If yes, what food products? ____
____
____