DESCRIPTIVE, INSTRUMENTAL, AND ACCEPTABILITY ASSESSMENT OF REDUCED-CALORIE CUPCAKES PREPARED WITH ALTERNATIVE SWEETENERS

by

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(Under the Direction of RUTHANN SWANSON)

ABSTRACT

Blends of the high-intensity sweetener, Splenda®, and a bulk sweetener, Isomalt, may overcome functional limitations of commercially available alternative sweeteners, improving quality of products available to consumers.

Descriptive sensory analysis was conducted on six cupcake formulations [100% full-sugar control, three Splenda®:Isomalt blends (10:90, 20:80, 30:70), and two commercially formulated Splenda® blends]. Mixed model ANOVA ($p<0.05$) found few differences (cohesiveness, browned, sweetness only) between the 30:70 Splenda®:Isomalt blend and the control. Instrumental texture and color data supported sensory results. Principle Components Analysis revealed the control and 30:70 Splenda®:Isomalt blend were most similar.

Consumer panelists (n=125) evaluated acceptability (control, 30:70 Splenda®:Isomalt blend, two commercially formulated Splenda® blends). Nonsignificant trends suggested the control rated highest; 100% Splenda (sucralose/maltodextrin) blend, the lowest. Demographic, health, consumption frequency, and taste sensitivity data were collected. Significant relationships between taster status and consumption frequency of selected food groups were weak. Taster status and cupcake formulation acceptability were unrelated.

INDEX WORDS: alternative sweeteners, acceptability, taster status

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A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2007

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May, 2007

ACKNOWLEDGEMENTS

I would like to thank everyone who has helped me and supported me throughout my graduate school education. Each of you has impacted me, and by donating your time and energy to my education and this research project, you have given me an incredible gift. I have enjoyed working with each of you, and I am grateful that I had the opportunity to learn from such wonderful people. Thank you.

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CHAPTER 1

INTRODUCTION

Epidemic of chronic disease

Results from the 2003-2004 National Health and Nutrition Examination Survey (NHANES) indicate that 66.3% of the American adult population are overweight, which is defined as a body mass index (BMI) greater than 25.0 kg/m^2. Of this adult population, 32.2% are obese, which is defined as a BMI greater than 30.0 kg/m^2 (NCHS 2004). The prevalence of overweight and obesity is not limited to the United States; the obesity rates have increased worldwide making the consequences of excess body weight a global threat. Further this disease incidence has transpired across gender, race, ethnicity, and socioeconomic status (CDC 2004). In addition, the rates in children ages two to seventeen have increased, and currently, 24% of American children are obese (Center on an Aging Society 2002). The implications of these alarmingly increasing rates of obesity are serious. The direct and indirect costs of overweight and obesity contributed to 9.1% of the total U.S. medical expenditures in 1998. Total costs may have reached $78.5 billion, and nearly half of this amount was paid by Medicaid and Medicare (CDC 2006). Obesity is associated with increased risk of premature death, heart disease, type 2 diabetes, cancer, respiratory problems, arthritis, reproductive complications, gallbladder disease, and depression (USHHS 2006). Considering the increased prevalence of this disease and its associated health consequences, the total costs to date are actually much higher than $78.5 billion.

The etiology of obesity remains unclear. Most likely, the disease is the result of multiple causes, such as environmental factors, increased energy intake, decreased physical activity, and genetic factors. The United States Department of Agriculture (USDA) measures the food supply by monitoring food available for consumption, nutrients available for consumption, and the available food supply adjusted for spoilage, losses in the home, and losses in the marketplace. These three per capita food supply measurements suggest Americans consumed more food and several hundred more calories per person per day in the 1990's when compared to the 1970's (Putnam 1999).

From 1984 to 1994, the average daily calorie intake increased 14.7% or approximately 340 calories. This increase in calories is broken down into increased consumption of refined grain products (6.2%), fats and oils (3.4%), added sugars (3.4%), fruits and vegetables (1.4%), and meats and dairy products (0.3%). In addition, consumption of food away from the home likely contributed to this increase. In the 1970's, 34% of the food budget was spent on food consumed away from the home, but by the late 1990's, this portion of the food budget increased to 47%. When dining out, people generally eat more—the portions are larger, the caloric content higher, and they are encouraged to eat (Young and Nestle 2002). A study conducted by Young and Nestle (2002) illustrated that "marketplace food portions have increased in size and exceed the [USDA and FDA] standards," which could help explain the increase in daily calorie consumption.

To compound the effects of increased energy intake, rates of physical activity are declining across all ages, genders, and ethnicities. The Center for Disease Control and Prevention has surveyed American adults through the Behavioral Risk Factor

Surveillance Survey (BRFSS) to determine national estimates of leisure-time physical activity. This system has shown that the majority of Americans are not regularly physically active and do not meet the recommendation of 30 minutes of moderately-intense activity most days of the week. In fact, 54.6% of adults are not active enough to meet this recommendation (CDC 2003).

A chronic disease associated with excess caloric intake is type 2 diabetes. This is the sixth leading cause of death, and the leading cause of additional health complications, such as heart disease, stroke, adult blindness, kidney failure, and nontraumatic amputations (ADA 2003). The number of people with diabetes has increased from 5.8 million in 1980 to 14.6 million in 2005, but this estimate excludes undiagnosed individuals; therefore, the true estimate is approximately 20.8 million or 7% of the American population (CDC 2005). The cost of diabetes associated medical expenditures and loss of productivity increased to $132 billion in 2002, and the United States government spendt approximately $13,243 in health care costs for each diabetic individual compared to $2,560 for an individual who does not have diabetes (ADA 2003). Type 2 Diabetes usually develops as an insulin resistance disorder, where cells respond less efficiently to insulin and circulating levels of blood glucose remain high. Over time, the pancreas loses its ability to produce insulin contributing to elevated blood glucose levels as well. This disease is associated with older age, obesity, family history, impaired glucose metabolism, physical inactivity, and race/ethnicity (CDC 2005).

Diabetes management is characterized by good glycemic control, prevention of complications, and improved food choices and physical activity. Medical nutrition therapy for this disease no longer omits sugar and sugary foods from the meal plan.

Instead, the current recommendation is to control total intake of carbohydrates, including sugar, throughout the day by balancing the amount consumed at meals and snacks. This approach is more beneficial in managing blood glucose levels than focusing on the source or type of carbohydrate (Franz and others 2002).

Sugar consumption and trends

The most recent Continuing Survey of Food Intakes by Individuals (CFSII 1994-1996) illustrated that the average American consumes the equivalent of 20 teaspoons of sugar per day (Henkle 1999), and the Sugar Association (2004) claims that 60% of this consumption is from corn sweeteners with the remaining 40% from sucrose and other sweeteners. Cravings for sweet treats are natural; all humans are born preferring a sweet taste over the other basic tastes (Greeley 1992). However, overconsumption of sweets leads to excessive caloric intake, which can translate into weight gain and greater risk of associated health problems (Henkle 1999). In addition, sugar-containing foods can be categorized by glycemic index, which is a measure of carbohydrates' blood glucose-raising effects (Kris-Etherton and others 2001). Low glycemic index foods can reduce post-prandial glycemia, resulting in improved satiety, glucose control, and insulin response. Sugar substitutes, such as high intensity sweeteners and sugar alcohols, can elicit a reduced post-prandial glycemia (Franz and others 2002); therefore, sugar substitutes are a viable option to satisfy the sweet craving without overindulging in calories.

Currently, 180 million Americans purchase and consume low-calorie sweeteners, and their major reason for using them is to achieve better overall health (CCC 2004b). Health professionals agree that low-calorie sweeteners provide many benefits including improved weight maintenance, weight reduction, and management of diabetes, as well as promoting decreased risk of obesity and its associated health consequences (CCC 2004b). According to the American Dietetic Association, there is not enough evidence to support an unequivocal link between nutritive sweeteners and obesity; however, the substitution of nonnutritive sweeteners for the typical intake of 20 teaspoons of sugar per day could create a caloric deficit of approximately 380 calories per day. This reduction in calories could translate into 1 pound of weight loss every nine to ten days if the caloric deficit is not replaced with calories from other foods (American Dietetic Association 2004). Another study illustrated weight gain and increased risk for development of type 2 diabetes was associated with consumption of sugar-sweetened beverages in women; therefore, a reduction in sugar consumption from these beverages could reduce incidence of diabetes (Welsh and Dietz 2005). In addition, the incorporation of nonnutritive sweeteners into the diet has been shown to not only promote modest weight loss, but also, as part of a comprehensive weight control program, support long-term weight maintenance (American Dietetic Association 2004).

Although nonnutritive sweeteners (also known as high-intensity sweeteners) did not originate in response to the burgeoning of chronic disease, food additives, such as sucralose, sacchrin, acesulfame potassium, and aspartame, provide individuals dealing with diabetes and obesity with a mechanism for controlling their energy intake while satisfying their sweet tooth (American Dietetic Association 2004). In response, the food industry has incorporated the use of nonnutritive sweeteners in its production of a wide range of food products and beverages, and this has helped to reduce the overall caloric value of these items. Presently, a market demand for these sweeteners as well as their corresponding products exists within the Americas. The most popular low-calorie or sugar-free products consumed by Americans surveyed are diet soft drinks (58%), sugar-free/light noncarbonated beverages (53%), sugar-free frozen desserts (46%), sugar substitutes (46%), and sugar-free gum (43%) (CCC 2004a). Low-calorie or sugar-free baked products remain less popular, despite the continuing popularity of this product category. Between 2002 and 2004, the number of new introductions of products in the cakes, pastries, and sweet goods category increased from 187 to 281. The baked good category includes a variety of food products, that has continued to diversify as new trends in technology as well as consumer desires have emerged. As consumers demand more convenient and healthy alternatives, food products will be developed to meet their needs (Brinnehl 2005).

Role of sugar and sweeteners in cake

Cake is a popular sweet treat; people of all ages indulge in this product. A good quality cake is symmetrical with good volume, a fine grain, and a moist, tender crumb (Penfield and Campbell 1990). Sugar provides many functional characteristics to a baked product, including sweetness, browning, flavor enhancement, structure, tenderness, bulk, water activity control, and increased shelf-life (Alexander 1998; Paeschke 2003).

To formulate low-calorie products, high-intensity sweeteners (HIS) and low-calorie sweeteners are used. HIS are compounds that exhibit sweetening power at very low concentrations. They can be synthetic or naturally-occurring. Some examples of synthetic HIS are the following: saccharin, cyclamate, aspartame, alitame, acesulfame-potassium, and sucralose. These are particularly useful in the development of low-calorie foods because although they are caloric, they are present in such low concentrations in the final product that the calories contributed are negligible. In addition, HIS have been shown to reduce dental caries (Nelson 2000) and are considered safe for diabetics since they have little or no calories (Deis 2004).

Low-calorie sweeteners include sugar alcohols, otherwise known as polyols. These are derived from the reduction of sugar, and they include the following compounds: sorbitol, mannitol, xylitol, lactitol, maltitol, isomalt, and hydrogenated starch hydrolysates. Polyols provide an additional option to food developers because they can be used in sugar-free, reduced-calorie, and noncarcinogenic foods (Nelson 2000). In addition, sugar alcohols have been shown to have a reduced blood glycemic response compared to sugar, making them a possible option for individuals with diabetes (Deis 2004).

Artificial sweeteners have been successful in mimicking the sweetness of sugar in many products, especially beverages (Paeschke 2003). However, some high-intensity sweeteners are criticized for their artificial flavor, intense sweetness, uncharacteristically long sweet aftertaste, as well as bitterness, especially as an aftertaste. In the past, the successful incorporation of high-intensity sweeteners in non-beverage food systems has been difficult due to the complexity of replacing sugar (Paeschke 2003). By themselves, high-intensity and low-calorie sweeteners generally fail to provide the aforementioned functional characteristics of sugar that are necessary for an acceptable baked good. Generally, they are unable to inhibit starch gelatinization and protein coagulation needed for acceptable texture, do not undergo Maillard browning, and necessitate the addition of a bulking agent (Nelson 2000). In order to overcome quality limitations, a "multiple ingredient approach" where more than one sweetener is used allows sweeteners to act synergistically, and the resulting formulated products are more acceptable (CCC 2004a). With this approach, many new products and taste choices can be offered to consumers.

Consumer Food Choices

Consumers report "taste" as the most influential factor that governs their food choices and consumption even though chronic diseases, such as diabetes, heart disease, and obesity are directly linked to dietary choices (Duffy and Bartoshuk 2000). This suggests that food palatability affects overall nutrition and health. Further, a modified product's palatability will likely determine whether it will be successfully incorporated into the array of dietary choices made by individuals (American Dietetic Association 2004).

Consumers differ in their taste and smell sensitivity. The result is each product has an individualized flavor profile. Although medication use, diet composition, and illness can alter the ability to taste, genetics also play a role. Based on their genetic taste sensitivity, consumers are categorized into three groups—nontasters, medium tasters, and supertasters. Sensitivity to two bitter compounds-- phenylthiocarbamide (PTC) or 6-n-propylthiouracil (PROP) – is used as a screening tool for classification purposes (NIDCD 2004). Supertasters detect an intensely bitter taste when exposed to one of these bitter compounds; whereas, medium tasters detect some bitterness, and nontasters do not detect any bitterness (Ly and Drewnowski 2001). Among Americans, 25% are classified as nontasters, 50% as medium tasters, and 25% as supertasters. Effects of taster status on food choices have been reported (Drewnowski and Rock 1995). In addition, a link between taster status and body weight has been reported (Tepper 1999).

PTC sensitivity is related to increased sensitivity to the basic tastes as well as sensations detected by the trigeminal nerve. Recent research has shown that individuals, who are supertasters, also find the range of nutritive and nonnutritive sweeteners to be sweeter than individuals who are medium to nontasters (American Dietetic Association 2004). Effects on their perception of the commonly reported off-notes are unknown, and may be compound and product specific. Taste (quality) and nutritional profile remain the major barriers preventing consistent incorporation of modified food products into the diet for a long enough period to promote long-term dietary behavior change (McEwan and Sharp 2000).

Rationale

The taste mechanism is not fully understood, and tasting capabilities vary from individual to individual as well as throughout an individual's lifespan (Schiffman 1997). Assessment of taster status using PTC/PROP will allow those individuals with a genetic predisposition for increased taste sensitivity to be identified. The use of PTC/PROP status measurement as a screening tool by health professionals to categorize their clients into groups of non-tasters, medium tasters, and super-tasters may improve their understanding of their client's perception of the quality of food. Awareness of a relationship between taster status and acceptability of products prepared with HIS, specifically sucralose, should facilitate tailoring dietary intervention recommendations to increase compliance. Further, if a sweetener blend (sucralose and isomalt) produces a product more similar to the control than those currently available to consumers, acceptability of this modified product will likely increase, facilitating replacement of the higher sugar product in the diet.

Hypothesis

A purpose of this research study is to investigate the use of a sucralose:maltodextrin blend (Splenda®) and isomalt in the development and preparation of baked goods, specifically cake.

The full replacement of sugar in a baked cupcake by a ratio of Splenda to isomalt will be able to successfully overcome limitations associated with using HIS. The modified cupcake containing 20% Splenda® and 80% isomalt will be most similar to the 100% sucrose control based on descriptive sensory and instrumental data. In addition, this modified cupcake will be determined to be acceptable by the consumer panel, and a relationship between extent of cupcake acceptability and taster status of consumers will be found.

An additional purpose of this research is to determine if there is a relationship between taster status and the frequency of consumption of specific foods modified to improve their nutritional profile. Because tasters are more sensitive to oral stimuli, it is likely that food choice and consumption patterns of taster and nontasters differ. It is hypothesized that tasters will consume reformulated foods less often than do those individuals who are non-tasters. Finally, it is hypothesized that taster status will be inversely related to BMI.

Objectives

The objectives of this study include the following:

1. To develop a modified cupcake with the characteristics of the control cupcake made only with sugar.

   a. To establish a profile of the sensory characteristics of potential cupcake formulations with a trained descriptive panel.
   b. To instrumentally characterize the textural characteristics of the various cupcake formulations using TPA.
   c. To characterize the color of the formulations using an instrumental technique.
   d. To document the appearance of the cupcakes.
2. To determine consumer acceptability of the control full sugar cupcake, two cupcakes prepared with sucralose blends currently available to consumers, and the sucralose:isomalt blend that most closely matches the sensory characteristics of the control as determined by the descriptive panel.
3. To determine if there is a relationship between taster status and the acceptability of the cupcakes.
4. To determine if there is a relationship between taster status and the frequency of consumption of foods modified to enhance their nutritional profile.
5. To determine if there is a relationship between taster status and BMI.

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CHAPTER 2

REVIEW OF LITERATURE

Introduction

Fad diets come and go, but they leave their mark on industry. The low-carbohydrate diet trend resurfaced when diets, such as Atkins, South Beach, The Zone, and Sugar Busters regained popularity. All of these diets propose limiting the amount of carbohydrates in the diet below the USDA recommendation, which is that 45-65% of the diet be comprised of carbohydrates, preferably from whole grain sources (Department of Health and Human Services 2005). Simple carbohydrates are also referred to as 'added sugars,' and the USDA recommends that these added nutritive sugars make-up approximately 6-10% of total energy intake, which can translate into 6-18 teaspoons of added sugar each day depending on total caloric intake (ADA 2004). Subsequently, about 32 million Americans followed a low-carbohydrate, high-protein diet. In 2002, two thirds of the U.S. population consumed low-carbohydrate, high-protein foods regularly, and the consumption of low-carbohydrate foods increased by 21% in 2003 (Thomson 2004). Despite these low-carbohydrate fad diets, the U.S. cake market continued to grow with an increase of 2.5% every year after 2000. In 2005, the market was worth approximately $5 billion (Mintel 2006).

Companies involved in the cake market are caught between two consumer mindsets—the one focused on health and weight consciousness and the one focused on indulging and enjoying the "good things in life." Therefore, it is projected that growth will remain minimal in this area due to increasing competition from other categories. Besides the consumer focus on carbohydrate content of food, the change in nutrition labeling requirements has created a focus on trans fatty acids and the nutrition education focus will likely impact the cake industry in a negative way, especially for those consumers who are health conscious (Mintel 2006). As consumers' consumption patterns change, the focus of the baking industry must adjust as well because consumers' desires drive industry. Therefore, it is likely that the overall caloric, fat, and fiber content of baked goods will have to be adapted in order to maintain the appeal of baked goods, including cake, to all consumers (Thomson 2004). From a product development standpoint, meeting these divergent consumer wants is a major challenge.

In general, low-calorie food products have been developed to target specific dietary needs for individuals with medical problems, such as diabetes and heart disease; however with change in consumer interest, and increasing obesity rates, low-calorie foods are now targeted to all consumers (Thomson 2004). In recent years, low-calorie foods have improved in flavor, and their competitive price has helped to increase their market share. These improvements in quality have increased preference for these products. The most popular low-calorie and low-fat foods and drinks are low-fat dairy products and diet soft drinks. The consumers who are buying these products are generally not dieting, but they are trying to stabilize or decrease their body weight. Women are more likely to prefer low-calorie products than are men. Although consumption of low-calorie products has increased, problems remain in terms of their long-term acceptance. These problems are associated with the perception that their sensory characteristics are inferior, and consumers are doubtful about the product's nutritional content and health benefits (Sandrou & Arvanitoyannis 2000).

To achieve a reduction in calories of food products, the carbohydrate and/or fat content can be decreased, or the serving size of the product can be altered because fewer calories are contained in smaller portions. Also, the carbohydrate content can be manipulated by adding bulking agents or high fiber ingredients that are not absorbed, so their contribution to overall carbohydrate content can be subtracted from the final product carbohydrate value. This last modification method relates back to the glycemic index (GI) of carbohydrates—those foods with a high glycemic index are quickly digested in the body and contribute to a sharp increase in blood glucose; those with a low glycemic index are digested more slowly and do not cause such a spike in blood glucose (Thomson 2004). Generally, high glycemic foods contain a high concentration of simple carbohydrates, which are more refined sources, contain a high glucose or starch content, contain little soluble fiber, and have a texture that is soft, overcooked, and highly processed (Vermunt and others 2003). Certain sweeteners have a greater or lesser impact on blood glucose levels, and the low GI options can be used in food products to alter the carbohydrate content, so fewer grams of carbohydrate count (Thomson 2004). This has spurred the label claims—low impact and net—that appear on the packaging of modified food products. Although companies make claims regarding the benefits of their food products, the FDA regulates food labeling and approves health claims that are appropriate for packaging. At this time, the labels 'low impact carbohydrates,' 'net carbs,' have not been substantiated. To be considered a reduced-in-calorie or reduced-in-sugar food product, the product must be reduced by 25% of its calories or sugar as compared to the reference amount in the reference food. To be considered low-calorie, a serving of the product must be equal to or less than 40 calories, and currently, no definition exists for the low-sugar claim. However, claims regarding ‘no added sugar’ or ‘without added sugars’ may be made as long as no sugar or sugar-containing ingredient was added during processing. The only approved health claim that is related to sweeteners is the relationship between dietary noncariogenic carbohydrate sweeteners and dental caries (FDA 2007).

Because today’s consumers expect pleasurable food that is additionally lower in fat, sugar, and energy to maintain their health and well-being while preserving the sensory qualities that they have come to expect, such as flavor, mouthfeel, taste, and color, high intensity sweeteners must be used in conjunction with low-energy bulk sweeteners to create new low-calorie food products (Bornet 1994). With product modifications, it is important to select substitute ingredients that will help to replace the function of the ingredient(s) being omitted. Blending alternative sweeteners has developed into a preferred method to increase taste (quality) of low-calorie foods, thus improving their overall flavor, texture, and appearance of these foods. Alternative sweeteners can be categorized in several ways, such as by their chemical nature, applicability, level of intensity, chronological use, type of applications, and acceptability. The most widely recognized alternative sweeteners are high intensity sweeteners, such as sucralose, and low-energy bulk sweeteners, such as polyols, also known as sugar alcohols. Food product developers have successfully used blends of high intensity sweeteners, such as aspartame and acesulfame-K, to minimize their lingering sweetness and improve stability in certain food systems. Others have incorporated the polyol, maltitol, a bulk sweetener, with acesulfame-K to help mask the off-notes of the high intensity sweetener (Deis 2004). Additional possible combinations include polydextrose with lactitol, and fructose with xylitol (Thomson 2004). The purpose of blending is to adjust the overall sweetness temporal profiles or to mask existing off-tastes. When deciding which sweeteners to blend, it is important to consider sweetness, color, flavor, glycemic effects, viscosity, texture, water activity, humectancy, binding properties, crystallizing properties, and freeze-point depression. In many foods, one sweetener may predominate; however, this multi-ingredient approach allows manufacturers to more efficiently use combinations of sweeteners to better individualize their modified products (Deis 2002). When developing reduced-in-calorie cake, the key is to correctly blend a high intensity sweetener with a low-calorie bulk sweetener, so the sweetness profile, appearance, and texture can be matched.

Two broad categories of cake products exist. The first category includes shortening-based cakes; these cakes are characterized by their distinct crumb structure that is derived from the fat-liquid emulsion during mixing. The other category includes foam-type cakes; these cakes are characterized by the foaming and aerating properties of eggs that lend its unique structure and volume (Pyler 1988). The quality of cake is governed by the following three principles: the cake ingredients must be suitable for the type of cake being prepared, the ingredients must be balanced in the formula, and the cake must be prepared by adhering to optimal mixing and baking procedures (Pyler 1988). Overall cake quality is assessed by measuring cake volume, compressibility, breaking strength, and sensory evaluation. According to Penfield and Campbell (1990) a high-quality or “gold standard” cake should be symmetrical, have a fine crumb of small air cells with thin cell walls, be moist, and be tender. American Institute of Baking criteria for cake quality involves the assessment of its final volume, crust color, symmetry, tenderness, crumb color, aroma, taste, and texture. Signs of poor cake quality include decreased volume, dark or spotty crust color, peaked or uneven form, tough/rubbery/dry crumb, large air cells, off flavor, and crumbly/lumpy texture. The traditional nutrient content for shortened cakes is 53% carbohydrate, 14.6% fat, 5% water, and 25.1% water (Nutrient Data Laboratory 2007). Alterations in cake formulation can cause changes in the quality of the final cake; therefore, when making substitutions for the traditional ingredients, the functionality of the ingredient must be considered. The purpose of this research project was to make sweetener substitutions in shortened cake products.

Research involving reduced-calorie cake systems has varied: both the ingredients used as substitutes and the type of cake system chosen have differed. Substantial research within this category of baked goods is lacking. However, aspartame and fructose singularly and in combination have been investigated in prepared shortened cake brands (Hess and Setser 1983). The shortened cake prepared with added fructose was judged to be more tender than the cake prepared with only aspartame, and similar trends were found for the other textural and taste characteristics (Hess and Setser 1983). In another study, the effect of mixtures of sucrose with sugar substitutes on the final cake's properties were investigated (Askar and others 1987, Attia and others 1993). It was found that replacement of sucrose at levels greater than 25% resulted in a decrease of cake quality and acceptability (Askar and others 1987). In another study by Attia and others (1993), combining a bulking agent, polydextrose, with nonnutritive sweeteners and/or fructose improved the textural properties of the samples, and adding fructose enhanced the flavor of the modified cake formulas, which supports the findings by Hess and others (1983). The overall finding of these researchers was that it is important to incorporate a suitable bulking agent along with the sweetening agents in order to replace the functional roles of sugars in cake systems. The result was an overall improvement in quality (Lin and Lee 2005).

Roles of Key Ingredients in Cake Systems

The major ingredients in shortened cakes include the following: flour, liquid, leavening agents, egg, sugar, shortening, and other flavoring ingredients. To produce a high quality cake, the tenderizing ingredients—sugar and fat, and the structural ingredients—flour and egg, must be balanced. Most of today's cake recipes are "high-ratio" cake formulas; therefore, the weight of sugar exceeds the weight of flour, and this improves the richness, moistness, and shelf-life of the final product (Penfield & Campbell 1990). Development of high-ratio cakes became possible with improvements in cake flour and cake shortening quality.

<u>Flour</u>

Cake flour is processed from soft wheat varieties because these varieties have low protein and ash contents. The role of cake flour is to act as a 'toughener' that forms gluten strands capable of lending sufficient strength, but that are not as tough and elastic as strands found in yeast-leavened products. This is important to ensure the crumb structure of the cake is satisfactory. Typical cake flour contains approximately 8.5% protein; however, ideally, cake flour that is used in high-ratio cakes should have protein content around 7.5-8.5%. In contrast to bread flour, the protein content affects the absorption capacity of cake flour to only a minor degree. The absorption capacity of cake flour is more dependent on the fineness of flour granulation, uniformity of flour particle size, and chlorination. Chlorination is generally applied to cake flour because it lowers the flour's pH, which improves its performance during baking. The baking performance is improved by the ability of chlorinated flour to provide uniform symmetry, volume, grain, and texture to the final cake product (Pyler 1988).

Shortening

The main functions of shortening in shortened cakes are to entrap air during the creaming process, which aids in leavening of cake batter and volume of finished product; to coat the protein and starch particles, so the gluten strands are disrupted making the crumb tender; and to emulsify large amounts of liquid in batter, which improves moistness and softness of final cake product. These cakes, unlike yeast-leavened products or foam-cakes, require fairly high levels of shortening in order to develop acceptable crumb texture, and shortening is considered to be the primary tenderizer. Shortening also improves the palatability and shelf-life of the final product (Pyler 1988).

Commercially, plastic and fluid shortenings and emulsifiers are available. The plasticity of shortening refers to its smooth texture, ability to deform under pressure and maintain its shape when set on a flat surface (American Soybean Association 2006) The hydrogenation process, which adds hydrogen ions to double bonds in fatty acid chains, has greatly impacted the cake industry. Hydrogenation has allowed liquid oils to be converted into semisolid or plastic fats that are more suitable in bakery applications because they allow air to be incorporated during the creaming step and have greater oxidative stability (Nawar 1996). Unfortunately in the process of saturating the double bonds in the fatty acid chains, the configuration can be transformed from *cis* to *trans*.

This alteration has nutritional implications, and research has demonstrated that trans-fatty acids are associated with increase risk of cardiovascular disease and coronary events because these fatty acids lower HDL cholesterol levels as well as increase lipoprotein(a) levels (Kris-Etherton and others 2001). This has led to the increased concern of trans-fatty acid content in food products by health professionals and consumers because hydrogenated vegetable shortening is found in a myriad of retail food products as well as restaurant foods. This health trend will have great implications on the cake and baked goods segment of the market. However, the characteristics of the gold standard for shortened cakes currently depend on the functional characteristics imparted by the hydrogenation process. Possible alternatives being investigated include interesterification using mixed fats and modified hydrogenation (Neville 2007).

Cake batters are an emulsion characterized by the dispersion of fat throughout the batter into small, irregularly shaped particles. The degree of dispersion depends on the amount and intensity of mixing (Pyler 1988). According to Pyler (1988), when the fat particles are closely examined, they contain numerous minute air bubbles that result from mixing. This phase of the batter is different from the aqueous phase, which is virtually air bubble free (Pyler 1988). The addition of emulsifying surfactants to plastic and liquid shortenings improves the fats ability to incorporate air cells during mixing and disperse throughout the batter into small particles, which is why they have been incorporated into shortenings (Pyler 1988, Penfield and Campbell 1990). Some examples of emulsifiers include the following: glyceryl lactopalmitates, polysorbates, and fatty acid propylene glycol esters. The conventional mixing method incorporates the greatest number of small air cells which can hold the leavening gases that result in a cake crumb with good volume, uniformity, and tenderness, thus improving the cakes overall eating quality (Pyler 1988). Hence, in cake preparation, the creaming of ingredients plays a crucial role in the final product quality.

Sugar

Sucrose, a crystalline disaccharide, has become the gold-standard sweetener in foods. The most common form of sucrose is white granulated sugar, and it is generally derived from sugar cane and sugar beets. Its availability, its long historical use, its ease of use, and its low cost have made it the sweetener of choice (Deis 2004). In addition, sugar is a multifunctional ingredient that contributes to the overall characteristics of a multitude of food products, including cake (Cooper 2006).

Sucrose is characterized by its clean, sweet taste. The taste profile of a substance is difficult to quantify; however, in the area of sweetness, all sweetening substances are compared to sucrose because it is considered to be the ideal sweetening agent. Although sweetness perception is dynamic, especially as the substance hits the tongue, intensifies in taste, and dissipates away, the rapid sweetness onset and short sweet taste persistence of sucrose is desired in all food and beverage systems (Ketelsen, Keay, and Wiet 1993). Time-intensity studies can be used to measure the rate, duration, and intensity of sweetness from various sweeteners. Various sweeteners have been investigated to determine if their taste profiles are similar enough to sucrose to make them suitable replacements for sucrose in food and beverage systems. The sweeteners—acesulfame-K, alitame, aspartame, cyclamate, fructose, saccharin, and sucralose—have been studied extensively to determine the extent to which each one matches the taste profile of sucrose (Ott, Edwards, and Palmer 1991; Ketelsen, Keay, and Wiet 1993). The major criticisms of these alternatives to sucrose are the following: rapid taste onset, delayed taste onset, lingering aftertastes, and bitterness. These problems with single sweetener alternatives spurred the effort to use multiple sweeteners synergistically because the use of two or more substances in a food or beverage system could minimize the limitations associated with using a single alternative sweetener as the sucrose replacement (Birch 1996).

In many bakery products, sugar dictates the acceptability of the final product because it contributes to not only the product's sweetness but also its structure and texture (Alexander 1998). Sugar is soluble in most dough and batter systems, and the total amount of sugar present in a formulation influences the final texture of the product. In cakes, the final volume, crumb texture, and cell size are important quality characteristics. Although sugar's primary function is to impart a desirable sweet taste, its other influences on cake systems are its effect on the gelatinization of starch and its effect on the denaturation of proteins (Pyler 1988, Cooper 2006). Basically, sugar influences the temperature at which the structure of cake will set because it raises the temperatures needed to gelatinize the starch and denature proteins while additionally providing tenderness by binding water to keep the crumb moist (Alexander 1998).

Baking is the heat and mass transfer process that occurs in the cake batter. Overall, the heat transfer and the rate of heat transfer control the final characteristics of cake (Dogan and Walker 1999). During baking, a series of changes occur within the batter under the presence of heat to transform it to a cake. The first change involves the fat melting; this causes the viscosity of the batter to decrease and allows the fat to form films around the air cell walls. Next, the leavening gases are formed, and they diffuse into the air cells. After the gases are formed, the proteins from the flour and eggs coagulate, the starch granules absorb water and swell, which initializes gelatinization. This is where sugar impacts gelatinization by increasing the temperature at which gelatinization occurs, thus delaying the setting temperature. Finally, when an internal temperature around 100 degrees C is reached, the sides and bottom of the cake will set from heat convection via the baking pan, and the center top of the product will set last (Hoseney, Wade, and Finley 1988). The changes in batter viscosity due to internal heating temperature have direct implications on the final characteristics of the baked cake. The viscosity is important in keeping the starch granules suspended as well as preventing the gas bubbles from coalescing together to create large holes in the final cake crumb. Because the sugar increases the gelatinization temperature of starch, as the cake cools, the structure sets at a higher temperature as well (Cooper 2006).

A key functional role of sugar in cake mixing is imparted in the creaming step. Creaming the fat and sugar allows the incorporation of tiny air cells in the fat that surround the sugar particles. As the cake bakes, these air cells fill with carbon dioxide, a byproduct of the chemical leavening system, and steam. This process creates the crumb texture of the final product. Therefore, the quality of the cake depends in part on the fineness and number of air cells developed during creaming (Alexander 1998).

Color is also an important attribute of baked goods. Incorporation of sugar into baked good formulations enhances the brown colors associated with crusts and crumb tops. The two reactions that contribute browning are caramelization and Maillard reaction. Caramelization is a reaction that forms browned pigments, which contribute to aroma, flavor, and color of the final product. This reaction can be manipulated by altering pH, temperature, or time; this reaction is not a major contributor to flavor and aroma development in cakes because the temperature required to achieve caramelization is 200 degrees C, which is not easily achieved during cake baking (Penfield and Campbell 1990).

The Maillard reaction involves a “complex network of nonenzymatic reactions resulting from an initial condensation between an available amino group and a carbonyl-containing moiety, usually a reducing sugar” (Oliver and others 2006). Simply, the reaction takes place between a reducing sugar and amine group; it is spontaneous and naturally-occurring, and it can be accelerated by heat and does not require any extraneous chemicals (Oliver and others 2006). A reducing sugar is a molecule that contains a carbonyl group that reacts to form a carboxylic acid group. Sucrose is a nonreducing sugar; however, during baking or other alterations of conditions due to changes in pH, temperature (>100˚F), or enzyme concentration, the disaccharide can be broken down into its monosaccharide components, glucose and fructose, allowing it to react with the amino acids present. These reactions (**Figure 2.1**) produce glycoconjugates that are not a single species; there are various glycoforms, and they are produced in combination with a vast array of poorly characterized products (Oliver and others 2006). Three stages of the reaction have been summarized as early, intermediate, and final. The initial phase, which involves the glycation or condensation reaction, has been well characterized. The product, glycosylamine, can undergo an irreversible Amadori rearrangement, which will yield a derivative of 1-amino-1-deoxy-D-fructose (BeMiller and Whistler 1996, Oliver and others 2006). The intermediate phase involves the degradation of the Amadori product, and at this point, some color is produced; however, the majority of the color is produced in the final stages when the melanoidins are produced (Oliver and others 2006).

In the presence of heat, this reaction contributes to the browned surface of baked goods, and also, helps to contribute to the pleasant aromas and flavors associated with cake (Alexander 1998).

Traditionally, cake is prepared with sucrose because sucrose lends sweetness as well as helps with texture and color of the final product. Therefore, replacing sucrose with other sweet chemical substances, such as high intensity sweeteners and polyols, has its limitations because no sweetener can perfectly match the sweetness profile and sensory characteristics imparted by sucrose. In the cake system, substitution of sugar with other ingredients must be carefully considered.

Replacement of Sugar with Splenda

High intensity sweeteners (HIS), also known as artificial or nonnutritive sweeteners, are compounds that exhibit sweetening power at very low concentrations. Many of these compounds have been found to be sweet and provide no calories because of their sweetness potency; however, as single sweetening agents, none can match the sweetness profile and functionality of sugar (sucrose) (Kemp 2006). Examples of HIS are the following: saccharin, neotame, aspartame, alitame, acesulfame-potassium, and sucralose. These sweeteners are particularly useful in the development of low-calorie foods because even those that contribute calories are present in such low concentrations in the final product that the calories are negligible. They are also cheaper than nutritive sweeteners when assessed based on equal sweetening power (Kemp 2006).

The major uses of HIS or low-calorie sweeteners include the following:

1. to provide a greater range of low-calorie food and beverage products,
2. to assist in weight management,

3. to assist in control of dental caries,
4. to assist in management of diabetes, through weight and carbohydrate management,
5. to enhance palatability of certain foods, such as those targeted for diabetics,
6. to enhance useability of pharmaceuticals and cosmetics,
7. to provide sweetness in times of sugar shortage,
8. and to assist in cost effectiveness of modified products (Kemp 2006).

Replacing sucrose with high intensity sweetener alternatives has limitations. Each alternative sweetener has its own sweetening profile and associated restrictions. Common alternative sweeteners, aspartame, acesulfame-K, and saccharin, have been criticized for characteristics, such as heat instability, sweetness and flavor loss, slow onset of sweet flavor, bitter/metallic/chemical tastes and aftertastes, etc (Kemp 2006). These limitations extend beyond just taste and flavor because when sugar is removed from a product textural and color characteristics are influenced as well.

Sucralose, known by the brand name Splenda®, is the only nonnutritive sweetener derived from sugar. It was developed in 1976 by Tate & Lyle Inc. Its chemical name is 1,6-dichloro-1,6-dideoxy-beta-D-fructofuranosyl-4-chloro-deoxy-alpha-D-galactopyranoside (Hutchinson and others 1999). This chemical is produced by a multi-step manufacturing process that selectively replaces three hydroxyl groups with three chlorine atoms on the sucrose molecule (**Figure 2.2**) (Nelson 2000, Lin and Lee 2005). The resulting sweetener is indigestible in humans, and animal studies have shown that the chemical cannot be hydrolyzed in the intestinal lumen and is largely excreted unchanged in the feces (Lin and Lee 2005). It contains zero calories, and is approximately 400-800 times sweeter than sucrose. Sucralose also has a clean taste with no aftertaste and exceptional stability when cooked or baked (Nelson 2000). Stability studies revealed that no products other than sucralose were detectable when cakes were baked at 180 degrees C (Hutchinson and others 1999), suggesting heat stablility at baking temperatures. In 1999, sucralose was granted approval by the Federal Drug Administration (FDA) as a "general purpose sweetener," and the acceptable daily intake is 5mg/kg of body weight/day.

Currently, sucralose is marketed in many forms. The most common forms are the packet for table use that contains sucralose, maltodextrin, and dextrose, and a bulk form for general purpose use that consists of sucralose and maltodextrin blended together, and is marketed as Splenda for baking (CCC 2004a). Maltodextrin is defined by the U.S. Food and Drug Administration as "nonsweet nutritive saccharide polymer that consists of D-glucose units linked primarily by (alpha)-1,4 bonds and that has a dextrose equivalent of less than 20." It is prepared by partial hydrolysis of corn starch or potato starch to produce a white powder or concentrated solution (Kuntz 1997).

The traditional role of maltodextrin was as a bulking agent or carrier, so it has been added to the high intensity sweeteners to facilitate their incorporation into beverages and food products. Over time, the roles of maltodextrin have expanded to encompass roles in fat replacement, nutritional supplements, and high-tech formation of films (Kuntz 1997). Splenda for baking, although easy to measure, could not achieve acceptable quality characteristics when added to baked goods formulations. So in 2004, Splenda, Inc. introduced a sucrose/sucralose blend called, Splenda® Baking Blend. This product was designed to overcome the quality limitations associated with the use of the sucralose/maltodextrin blend.

In many food systems, the replacement of sugar with intense sweeteners alone is unacceptable. Substitution alters the final product's quality characteristics as well as dilutes the overall nutritional content because the weight of the product is altered with the change in ingredients. Limitations of using sucralose in baked goods are its insolubility in fats and oils and its inability to participate in the Maillard browning reaction. Sucralose does lend sweetness to baked goods and it is stable when baked at high temperatures, but it is difficult to incorporate into cake batter because it cannot be creamed into the butter or shortening. This interferes with the final product's crumb and its overall texture and tenderness. In addition, the color of the final product can be different because sucralose does not undergo caramelization or Maillard browning because it is not a reducing sugar (Nelson 2000). To overcome these limitations, sucralose must be used in combination with additional sweetening bulking agents, so that the texture and color of the final product are acceptable and similar to the gold standard prepared with sucrose. Researchers have demonstrated that addition of maltodextrin and xantham gum with sucralose can improve flavor liking of modified muffin product when compared to the commercial counterpart (Khouryieh and others 2005). Lin and Lee (2005) demonstrated that sucralose and indigestible dextrin could be substituted for <50% of the sucrose in chiffon cakes, and the sensory and physiocochemical properties were comparable to the 100% sucrose chiffon cake control.

Replacement of Sugar with Isomalt

Low-energy bulk sweeteners can be used in proportion with high intensity sweeteners to compensate for volume loss associated with the replacement of sucrose with HIS alone. There are many possible low-energy bulk sweeteners; however, the sugar alcohols, fructooligosaccharides, and polydextrose are considered the most common examples of undigestible sugars (Bornet 1994). Sugar alcohols, otherwise known as polyols, are naturally-occurring; however, they are industrially produced by catalytic hydrogenation of the relevant saccharides at high temperatures. According to Bornet (1994), this process "converts the aldehyde function of sugar to a primary alcohol function, and its ketonic function into a secondary alcohol function." The resulting compounds include the following: sorbitol, mannitol, xylitol, lactitol, maltitol, isomalt, erythritol, maltitol syrups, and hydrogenated starch hydrolysates (Deis 2000, Nelson 2000).

Polyols provide an additional option to food developers because they can be used in sugar-free, reduced-calorie, and noncariogenic foods. These compounds comprise a unique group of carbohydrates because they have a lowered glycemic response, lower caloric density, and noncariogenic properties (Deis 2000). In addition, polyols have a lower sweetening power when compared to sucrose, although their individual taste profiles vary as does their range of sweetening power. Some sugar alcohols can contribute an intense cooling sensation. In addition, some are extremely water soluble; whereas, others, such as mannitol and isomalt are not. Their hygroscopic properties also vary—xylitol is very hygroscopic, but mannitol, isomalt, and erythiritol are not. In addition, the digestion and metabolism of sugar alcohols in the human body are limited. Because polyols have reduced blood glycemic and insulinemic responses when compared to sugar, they are a safe option for individuals with diabetes (Bornet 1994, Deis 2004).

There are three broad categories of polyols—monosaccharides, disaccharides, and mixtures. The monosaccharide category includes sorbitol, mannitol, xylitol, and erythritol. Sorbitol and mannitol contain six carbons and have been widely used in a range of food products. Xylitol is a 5-carbon polyol, and it is unique because it is active against dental caries, making it a common additive to toothpaste, chewing gum, mints, and lozenges. Erythritol has four carbons. It has a very low caloric density (0.2 kcal/g) and high digestive tolerance; however, its use has been limited to confectionary applications like chocolate, candies, coatings, as well as chewing gum (Embuscado 2006). The second category, disaccharides, includes maltitol, lactitol, and isomalt (a mixture of two disaccharides). These polyols have a caloric density around 2 kcal/g and are considered GRAS. Common applications are hard and soft candies, ice cream, baked goods, and low glycemic index foods (Embuscado 2006). The mixtures, or polymeric polyols, category is comprised of maltitol syrups and hydrogenated starch hydrolysates, which are closely associated with maltitol, sorbitol, and mannitol because their precursors are similar. These liquid polyol forms are used in sugar-free confectioneries, such as caramels, gummy bears, and jelly beans (Deis 2000).

Polyols exhibit a range of functionality in the following characteristics: caloric value, solubility in water, and cooling effect. Their functionality is not limited to these areas; polyols can be incorporated into a myriad of products, but the individual chemical selected should be based on its individual merits, such as applicability and cost. Mostly these compounds are a cost-effective means for producing sugar-free and noncariogenic foods that have a limited impact on blood glucose levels (Deis 2000). However, some special purposes have been identified for polyols, such as being incorporated for their humectancy in order to improve stability and shelf-life of nutritional bars, chewy cookies, and cakes. Also, polyols can be used to control color because these compounds will not brown as extensively as other sugars, and they do not react with other "sensitive" ingredients, such as enzymes, color additives, and flavor additives. Because of the diverse functionality of polyols, their potential use in a variety of applications is extensive, especially when products are tailored to consumer expectations (Deis 2000, Zumbe and others 2001).

Isomalt is a disaccharide sugar alcohol that lends two calories per gram. This sweetener is derived from sucrose, and is an equimolar mixture of two disaccharide alcohols (alpha-D-glucopyranosyl-alpha-(1,6)-sorbitol and alpha-D-glucopyranosyl-alpha (1,6)-mannitol. It is produced by catalytic hydrogenation of isomaltulose. Isomaltulose is produced by catalytic isomerization of sucrose by an enzyme system present in *Protaminobacter rubrum* bacteria; the enzyme rearranges the linkage between glucose and fructose (Bornet 1994). The resulting chemical compound comprises gluco-mannitol and gluco-sorbitol, and it is chemically and enzymatically more stable than sucrose, see **Figure 2.3** (CCC 2004b). This compound is 45-65% as sweet as sucrose. This compound is only partially fermentable by colonic bacteria and behaves like dietary fiber in the gut. Therefore, less energy is absorbed during digestion when compared to sucrose metabolism (CCC 2004b). More specifically, the bonds of the disaccharide polyols are partially hydrolyzed by the brush-border disaccharidases of the intestinal lumen leaving the monosaccharide component to be absorbed, and the monosaccharide alcohol moiety to diffuse through (Southgate 1995). In addition, isomalt exhibits a synergistic effect when combined with other polyols and high intensity sweeteners (Alonso and Setser

1994). The significant attributes of isomalt are (1) products have the same appearance and texture as ones containing sugar, (2) sweetness is not lost when heated, (3) it absorbs minimal amounts of water, which improves shelf-life, (4) it enhances flavor transfer in foods, and (5) it lacks the undesired “cooling” effect exhibited by other polyols (Nelson 2000). However, a laxative effect has been demonstrated when high levels of polyols are consumed (Alonso and Setser 1994). Currently, the company, Palatinit, producing isomalt is petitioning for generally-recognized as safe (GRAS) status from the FDA (CCC 2004b). The safety of isomalt has been evaluated by the World Health Organization’s Joint Expert Committee on Food Additives (JECFA), and it was concluded that an acceptable daily intake not be established, so the ADI is “not specified,” which is the safest category in which the JECFA can place a food ingredient (CCC 2006).

Taste Perception of Sugar and Artificial Sweeteners

The basic tastes are not definable because they are sensory sensations that result from the actual tasting of certain chemical substances, such as sucrose (sweet), sodium chloride (salty), citric acid (sour), and caffeine (bitter). Although sucrose tastes sweet, if the definition of sweetness was the taste of sucrose, then this definition would exclude other chemical compounds that taste equally sweet (Shallenberger 1998b) Different sweeteners do not share the same chemical properties; therefore, each has a unique taste profile that encompasses the impact or onset of time and the magnitude of its sensation at a given concentration, the temporal persistence characteristics of its sensation, as well as the presence or absence of other tastes or other tactile attributes, such as body or mouthfeel (Shallenberger 1998a). To create a partial picture regarding the taste profile of a substance, time intensity tests can be completed. In addition, the taste spectrum provides important information about the sensory sensations associated with particular chemical substances. The taste spectrum refers to the psychological assessment of a substance's taste compared to the basic tastes. To develop a taste spectrum, a trained descriptive panel must be used. Even with the panel's extensive experience, it can be very difficult to distinguish between sensations because some individuals can demonstrate taste blindness, where they cannot detect a particular basic taste or the combination of basic tastes may mask other flavors (Shallenberger 1998a). However, determining the taste profile and taste spectrum of a chemical substance is necessary to classify its performance and overall taste, so that the appropriate high intensity sweetener and/or polyol are selected for the correct food application.

For sweeteners, perceived sweetness and relative sweetness intensity are important distinguishing factors. Perceived sweetness intensity is the intensity of sweetness against its concentration. This function creates a sigmoid curve, which is also known as a psychometric function. The psychometric function can be interpreted as the stimulus percentage detected plotted as a function of intensity. Basically, the curve reflects that after recognition a near linear relationship exists until the upper limit of concentration is achieved, thus the intensity plateaus (Shallenberger 1998b, Levine 2000). The relative sweetness is a single score that allows other sweeteners to be compared to sucrose. Sucrose is assigned the reference value of 1.0 (Davis 1995). The relative sweetness represents both the taste profile and taste spectrum of a sweetener; however, these values can vary according to concentration. Generally, high intensity sweeteners have greater relative sweetness at a low concentration, and as the concentration increases, the relative sweetness decreases. The variation in relative sweetness can be attributed to three reasons. First, the dynamics of sensory perception influence relative sweetness. According to Shallenberger (1998a), to elicit a measurable or just-noticeable-difference, the increments between sensory stimuli must become larger and larger; this is considered one of the psychophysical laws proposed by E.H. Weber, and later clarified by G.T. Fechner (Levine 2000). Second, the perceived intensity of a chemical substance can be altered with changes in temperature. Lastly, adaptation occurs with repeated exposure to taste stimuli. Therefore, the perceived taste intensity will decrease from its initial level (Shallenberger 1998a).

The ability to taste has been recognized as a "chemical sense," which means that different tastes are initiated by different chemical reactions. The prerequisite to taste is water solubility, and this reinforces the indication that taste is a chemical interaction. From the point food enters the mouth; it takes 50 milliseconds to elicit a taste response to the chemical substance(s) (Shallenberger 1998b). Although several theories for how we taste bitterness and sweetness have been hypothesized, the first proposed mechanism for the ability to taste sweet was developed by Shallenberger and Acree (Davis 1995). Certain functional groups lend a sweet taste, such as hydroxyl groups (–OH), amino groups (-NH), and ether oxygen (–NO_2). Shallenberger (1998b) discovered that the sweet taste-eliciting group of sugars was a glycol (-CHOH-CHOH-) unit, which could be viewed as a AH, B hydrogen bonding unit, thus he proposed the AH, B theory of sweetness. In the AH, B theory, a glucophore has pairs of these functional groups, making it a dipolar compound. Three components—the AH group, B group, and γ group—interact by donating and receiving protons to create sweetness sensations

(Shallenberger 1998a), and later it was discovered that bitterness sensations occur as well (Lindsay 1996). To elicit a sweet sensation, the charge on the dipole must be bilaterally symmetrical, which means the left and right forms are balanced. To elicit a bitter sensation, the charge on the dipole must be unbalanced or only a monopole is present. The γ component possesses a strong electron withdrawing power, which helps to elicit the intense sweet response from high intensity sweeteners (Lindsay 1996). Ultimately this theory is based on the ideas that the formation of intramolecular hydrogen bonds is responsible for the varying sweetness intensity of sugars and the sweetness is not only caused by a compound containing a pair of functional groups but also by a chemical reaction (Shallenberger 1998b).

Although the AH, B theory was the first mechanism used to explain how we perceive sweetness and bitterness, it leaves some questions unanswered. For example, the theory proposes that a dipole system will taste sweet; however, many compounds exist that contain dipole systems and do not taste sweet. Also, the theory suggests that only one receptor is available to elicit sweetness responses. In addition, it was felt that the theory did not adequately explain the sweetness sensations created from high intensity sweeteners, and finally, the theory failed to explain why the D-amino acids and sugars could taste sweet and their enantiomers (L-shaped counterparts) did not (Shallenberger 1998b). Some of these initial criticisms have been resolved. It is believed that initial sweetness must take place at the surface; therefore, the L-amino acids and sugars cannot topographically fit with the receptors. In addition, a third component (γ), was hypothesized to be a part of the AH, B mechanism. This third component, γ, is structurally located on the molecule to enhance the activity of the AH, B dipole, thus explaining the high intensity sweetness response elicited by high intensity sweeteners (Shallenberger 1998b). Additionally, it was discovered that chlorine atoms on chloroform are responsible for sweetness, and in chlorosucrose, they contribute to its intense sweetness (Shallenberger 1998b). This could explain the sweetening power of sucralose, which has chlorine atoms added selectively to the sucrose molecule to replace the hydroxyl groups.

An interesting phenomenon with high intensity sweeteners and polyols is the effect of their concentration on sweetness and bitterness detection and perception. A common criticism of alternative sweeteners is the bitter taste that accompanies their powerful sweetening potential; therefore, researchers have strived to understand this relationship (Horne and others 2002). The AH, B theory sheds light on the mechanism enabling the ability to taste both sweetness and bitterness. When sweet and bitter qualities are exhibited by a single compound, these qualities can be enhanced by slight modifications in the compound's structure that alter the ratio of sweet to bitter taste intensities (Schiffman and others 1995). The focus of a study conducted by Schiffman and others (1995) was to investigate the concentration effect on sweet and bitter taste properties for a range of nineteen sweet compounds, including high intensity sweeteners, polyols, and amino acids. They found that high intensity sweeteners tended to increase in bitterness as their concentration increased in solution; therefore, it is clear that the same chemical properties that contribute to bitterness may additionally be related to sweetness potency. For some sweet compounds, strong sweet sensations were not produced even at relatively high concentrations; however, the concentration-response relationship for bitterness and sweetness differed markedly across sweeteners. Unlike HIS, polyols tended to decrease in bitterness as sweetness and concentration increased (Schiffman and others 1995).

Artificial Sweeteners and Taste Sensitivity

Genetic variation in oral sensation has been studied extensively over the past two decades. The discovery that the ability to detect bitterness in two thiourea compounds is an inherited trait has impacted our understanding of dietary habits and health consequences (Snyder, Fast, and Bartoshuk 2004). This ability is related to increased sensitivity to other oral simuli—sweet, salty, and sour (Snyder, Fast, and Bartoshuk 2004), capsaicin (Karrer and Bartoshuk 1991), fat perception (Duffy and others 1996, Tepper and Nurse 1997), alcohol (Duffy and others 2004), as well as activity of the trigeminal nerve. The measurement of taster status involves the assessment of an individual's perception of bitterness by using two bitter compounds—phenylthiocarbmide(PTC) or 6-n-propylthiouracil (PROP) (NIDCD 2004). Based on taste sensitivity to bitterness, individuals are classified into three taster status classifications—nontasters, medium tasters, and supertasters. Supertasters detect an intensely bitter taste when exposed to one of these bitter compounds; whereas medium tasters detect some bitterness; and nontasters do not detect any bitterness (Ly and Drewnowski 2001). In addition to increased taste sensitivity, associations with sensory experience, dietary behavior, and disease risk have been identified (Snyder, Fast, and Bartoshuk 2004).

Recent research has shown that individuals, who are supertasters, also find the range of high intensity sweeteners and sugars to be sweeter than individuals who are medium to nontasters (ADA 2004). Studies have illustrated the presence of bitterness notes in the HIS, saccharin and acesulfame-K (Horne and others 2002). This has led researchers to conclude that supertasters may not consume HIS due to their bitterness component, yet other research has shown sweetening of solutions, especially caffeine solutions, can reduce differences in taster status, and it has been proposed that supertasters may be more likely to use caloric and non-caloric sweeteners than nontasters because sweeteners can mask inherent bitterness (Ly and Drewnowski 2001). In addition, studies comparing PROP tasters to nontasters and their sensory evaluation of three types of chocolate, which contained both caffeine and bitter polyphenols, found no significant differences between taster groups; therefore, the researchers hypothesized that the high sugar and fat content of chocolate suppressed the bitter sensations (Ly and Drewnowski 2001). The disagreement within the literature concerning consumer sensitivity to PTC and PROP and implications for consumption of HIS warrants further investigation.

Understanding genetic variation in taste would not have been possible without advancements in psychophysical techniques. Adaptations in these techniques have equipped sensory scientists with the capability of making comparisons across individuals (Bartoshuk 2000). Various scales have been used to estimate taste intensity of bitterness and categorize individuals into taster status classifications. Initially, S.S. Stevens, a Harvard psychologist, believed using a ratio scale to assess sensation was necessary to accurately measure perceived intensity. He devised the popular method—magnitude estimation. In this method, participants are asked to assign numbers to perceived intensities; however, this method of estimation cannot compare across subjects because individuals cannot share their sensory experiences with others (Bartoshuk 2000).

Although magnitude estimation was useful for making within-subject comparisons, it could not be used to compare among subjects or groups because the data did not identify the subjects' absolute perceived intensity—only the intensity of a stimulus compared to another stimulus (Snyder, Fast, and Bartoshuk 2004). Traditionally, labeled category scales, anchored with adjectives (weak/strong) were used to compare sensory intensities across individuals. The most common scale used to assess taste was a 9 pt scale—1=none, 3=slight, 5=moderate, 7=strong, and 9=extreme (Snyder, Fast, Bartoshuk 2004). Category scales do not have the aforementioned 'ratio' properties; therefore, Green and others (1996) developed a Labeled Magnitude Scale (LMS) that had intensity adjectives spaced to allow ratio properties to be assessed. The LMS is a "semantic scale of perpetual intensity characterized by a quasi-logarithmic spacing of its verbal labels" (Green and others 1996). The extreme anchor is labeled "strongest imaginable," see **Figure 2.4**, but additionally, it is anchored with the following descriptors—barely detectale, weak, moderate, strong, and very strong (Bartoshuk and others 2004). This scale permitted the participants interpretation of the perceived intensities of only oral sensations (Green and others 1996); however, one weakness with the LMS scale is that it assumed 'strongest imaginable' referred to the same perceived intensity across all taster categories. This meant that this scale could only successfully compare perceived intensities across all categories that had the same meaning to all three groups (Bartoshuk 2000). The general labeled magnitude scale (gLMS) was devised to allow valid across-group comparisons between nontasters, medium tasters, and supertasters. Bartoshuk and others (2004) modified the labeled magnitude scale (LMS) created by Green and collegues by stretching the scale to its maximum and changing the label for the highest point to “strongest imaginable sensation of any kind;” this revised scale is referred to as the general Labeled Magnitude Scale (gLMS). They hypothesized that by using a descriptor that was independent of taste, the gLMS could be used across groups to make accurate comparisons (Bartoshuk and others 2004). The gLMS is a 230mm vertical line that is considered to be 100 equally-spaced units. The labels were placed at log intervals—barely detectable (1.4), weak (6), moderate (17), strong (34.7), very strong (52.5), and strongest imaginable sensation of any kind (100) (Bartoshuk and others 2004).

Several research studies have been completed in order to validate the use of the gLMS scale. Snyder, Fast, and Bartoshuk (2004) determined that it is superior to the previously used category scales by conducting a series of experiments. Using methods of magnitude estimation tied to normalized sound tones allowed Bartoshuk and others to tie intensity descriptors to sounds for nontasters and supertasters. This illustrated that supertasters ‘very strong’ response was nearly twice as intense as ‘very strong’ for nontasters (Snyder, Fast, and Bartoshuk 2004). For oral sensations, Bartoshuk and others (2004) had subjects rate bitterness of PROP using the gLMS and magnitude matching. This study supported that the gLMS produced valid comparisons of oral sensation across taster status classifications because the bitterness ratings were similar among nontasters, medium tasters, and supertasters for each method. The gLMS has also been applied to pain scaling, and its ratio properties allowed researchers to examine differences across different types of pain (Snyder, Fast, and Bartoshuk 2004). Another application in which the gLMS was used was to correlate taste intensity and fungiform papillae density. In this study, the gLMS was compared against a standard category scale, and the gLMS produced robust correlations between taste intensity and fungiform papillae density; whereas, the category scale only illustrated correlations for bitter taste (Snyder, Fast, Bartoshuk 2004). From these research studies, it can be surmised that the gLMS is a superior scale that allows comparisons across group sensory experiences.

Quality/Acceptability Assessment and Sensory Evaluation

"Sensory evaluation is the scientific method used to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing" (IFT-SED 1981). This type of evaluation is quantitative because numerical values are collected in order to establish relationships between product characteristics and human perception (Lawless and Heymann 1999). Human sensory analysis is critical because instruments cannot duplicate the human response. Although human observation is highly variable, sensory analysis combines the use of the human sensory systems to measure product attributes with statistical analysis to determine if relationships discovered are in fact real (Lawless and Heymann 1999). These sensory methods are divided into two categories—product-oriented and consumer-oriented evaluation (Watts and others 1989).

Product-oriented evaluation involves trained panels, which consist of small groups of individuals selected for their sensitivity to the properties being studied, their descriptive ability, and their abstract reasoning capacity. Trained panelists provide objective and reproducible results because they understand the terms used during testing and can use them in a consistent manner while disregarding personal preferences during product evaluation (Meilgaard, Civille, & Carr 1999). Generally, descriptive tests are conducted with trained panels (Watts and others 1989). This descriptive analysis process involves assessment of product characteristics and the intensity of the characteristics on rating scales—interval or magnitude estimation scales (Meilgaard, Civille, & Carr 1999). The descriptive analysis techniques used to collect descriptive sensory data include the following methods: The Spectrum® descriptive analysis method, Flavor Profile, Quantitative Descriptive Analysis (QDA), Texture Profile, and Free-Choice Profiling. In addition, some descriptive analysis techniques are adapted and blended in various ways, and these are classified as generic descriptive analyses (Lawless and Heymann 1999).

The focus of consumer-oriented evaluation is to determine consumer preferences or opinions about a product. This type of evaluation usually involves a relatively large number of untrained product users, and it occurs toward the end of product development (Watts and others 1989, Lawless and Heymann 1999). The focus of consumer sensory testing is to determine whether the consumer likes the product, prefers it over another product, or finds the product acceptable based on its sensory characteristics (Lawless and Heymann 1999). For consumer sensory testing, 50 to 100 panelists should be used, and ideally, the sample distribution should be representative of the general or target population (IFT-SED 1981).

Descriptive Sensory Data

Descriptive analysis techniques are used to profile products and product category characteristics. The Sensory Spectrum® method was developed in the 1970's, and it is characterized by the extensive use of reference lists to describe flavor and texture attributes exhibited within a product or product category (Murray and others 2001). Trained panelists generate a panel-specific vocabulary, and the scales are standardized and anchored with multiple reference points. Therefore, the panelists are trained to use the scales identically, so the resulting data are absolute (Lawless and Heymann 1999).

The first step when using a Spectrum-like approach is to develop a frame of reference for the product category. Next, a lexicon of words attributable to the product category is created, and references are used to provide clear and distinct demonstrations of the terms and to better elucidate attributes in the product category. After these steps are completed, examples are presented to the panelists. The purpose of these examples is to illustrate a perceivable characteristic that describes the attributes, which the panel uses to generate a list of descriptors. This final step is important because it allows the lexicon to be refined to a list of descriptors pertinent to the product category being investigated, and it helps to remove any existing redundancy in terms (Civille & Lyon 1996). This process yields an attribute scorecard that each panelist fully understands and uses effectively to evaluate the product category during testing. The Spectrum® method has been used to conduct descriptive sensory analysis on a variety of product categories, such as foods, beverages, as well as personal care, home care, paper, and other products (Munz and Civille 1992)

Consumer Sensory Evaluation

Two main approaches to consumer sensory testing are either the measurement of consumer preference, where a product is selected over another one, or the measurement of consumer acceptance or liking, where a product is assessed by using category, line, or magnitude estimation scales (Lawless and Heymann 1999). To determine product preference, various tests can be conducted, such as paired preference testing. This technique looks at preference of one product directly against a second product; however, because the panelists are answering one preference question, little information is gained regarding individual product attributes (Lawless and Heymann 1999). To determine product acceptance, acceptance tests are conducted. These tests utilize hedonic scaling, otherwise known as "degree-of-liking" scales. The most common type of hedonic scale is the 9-point scale. Scales can be structured or unstructured, with descriptors or without descriptors (Lawless and Heymann 1999). The type of scale selected depends on the focus of the consumer sensory testing and the questions being asked about the product and its characteristics.

Instrumental Sensory Analysis

Instrumental techniques often explain results from sensory testing and allow for preliminary formula evaluation, without the expense of sensory analysts.

<u>Texture</u>

Various benchtop instruments can be used to assess texture in food products. The texture analyzer (TA) is an analytical tool that helps to characterize physical properties responsible for the product's texture and "feel" (Thibodeau & McGregor 2005). The TA assesses texture by conducting a variety of measurements on a variety of products because of its numerous attachments. A common method for assessing texture is to conduct a texture profile analysis (TPA) of all products. The TPA test consists of two compressions using a cylindrical probe to compress the sample by a percentage of its thickness to mimic two bites (Thibodeau & McGregor 2005). This test provides important data concerning textural attributes, like hardness, springiness, cohesiveness, and chewiness as well as to simulate the action of the human jaw, so the textural parameters can correlate with the sensory evaluation of those same parameters (Bourne 1982).

Szczesniak (1963) demonstrated the importance of standardizing the sensory texture attribute scales, so that the values for the instrumental parameters correlated to the descriptive sensory data provided by a trained panel to determine accuracy in evaluation as well as provide more information regarding the product. Figure **2.5** illustrates the type of graph generated from TPA. Hardness is the value of the height (max force in kg) of the first peak. Cohesiveness is the area under the second peak divided by the area under the first peak. Springiness is the distance under the second peak divided by the distance under the first peak, and chewiness is the product of hardness, cohesiveness, and springiness. This test has been successfully applied to chiffon cakes to measure hardness (Lin and Lee 2005) and muffins to measure all parameters associated with TPA (Khouryieh, Aramouni, and Herald 2005).

Color

Consumers assess acceptability of food by examining appearance, flavor, texture, safety, and nutritive value. Appearance is especially important because consumers are not likely to purchase or consume products that are not visually appealing (Setser 1984). Color, one aspect of appearance, is influenced by and related to many of the product's characteristics, but generally, color and flavor are directly linked. Moisture content, manufacturing processes, and ingredient color all impact overall product color. Generally, color assessment is used in quality control—to ensure consistency, to determine conformance to final product specifications, and to determine if changes are resulting from processing and/or storage conditions (Good 2002). For cake, the ingredients, baking temperature, and baking time influence final product color and consequently, final aroma and flavor. The Maillard reaction is instrumental in generating certain aromatic and flavor compounds in baked goods, so by assessing 'browness' of the final product, the quantitative impact of color can be categorized. To measure color instrumentally, filter colorimeters and color spectrophotometers are the two most common technologies used (Mabon 1993). Instrumental color measurement has been used to determine the effects of product modification, including the effect of calorie reduction on the appearance of cookies (Swanson and others 1999).

The criteria for color expression has been defined by the Commission Internationale de l'Eclairage (CIE), and the L*a*b* color space model (CIELAB) is the most widely used color measurement system in the food industry (Giese 2003). It provides uniform numerical values at a higher accuracy level that corresponds with color differences perceived by humans. The system measures L*, which indicates lightness, and a* and b*, which indicate color directions from red to green and yellow to blue, respectively (Giese 2003). The measurements provide important insight concerning the functional capabilities of high intensity and low calorie sweeteners used in modified products and facilitate further product manipulation at lower cost.

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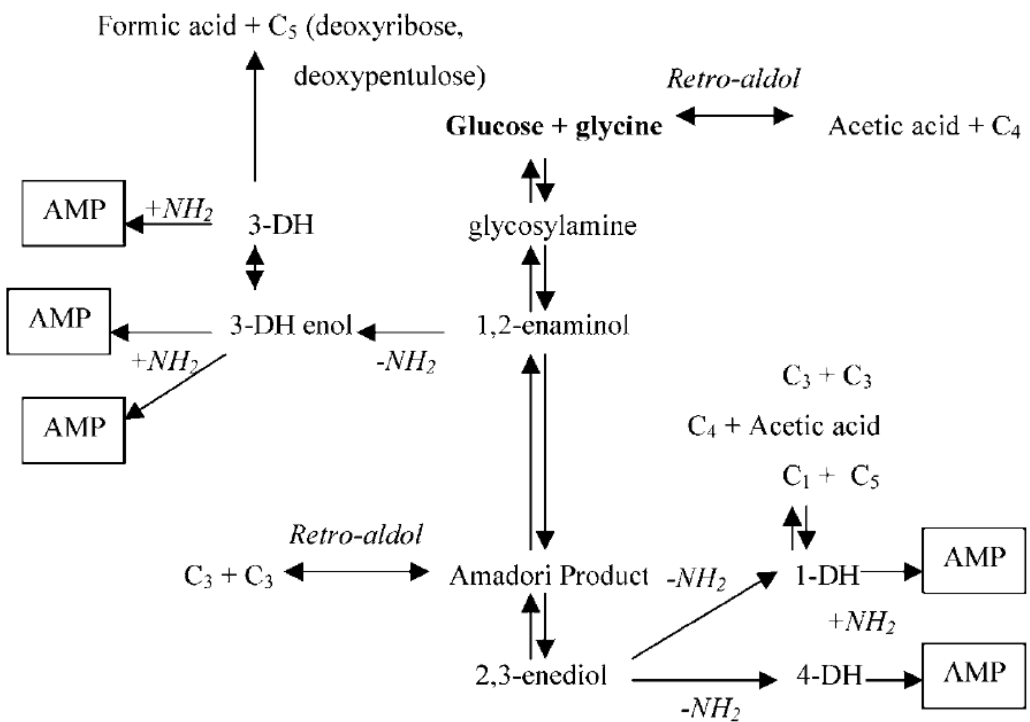

Figure 2.1 The Maillard reactions between glucose and glycine.

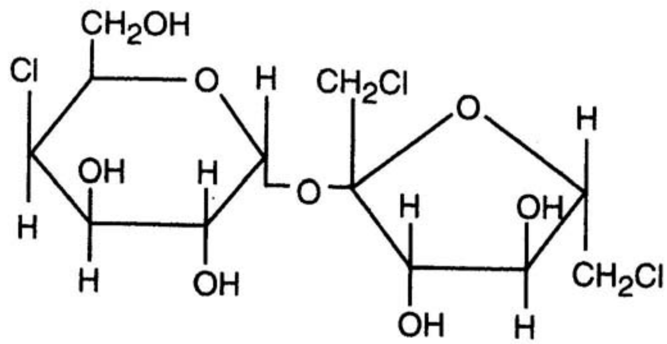

Figure 2.2 The chemical structure of sucralose.

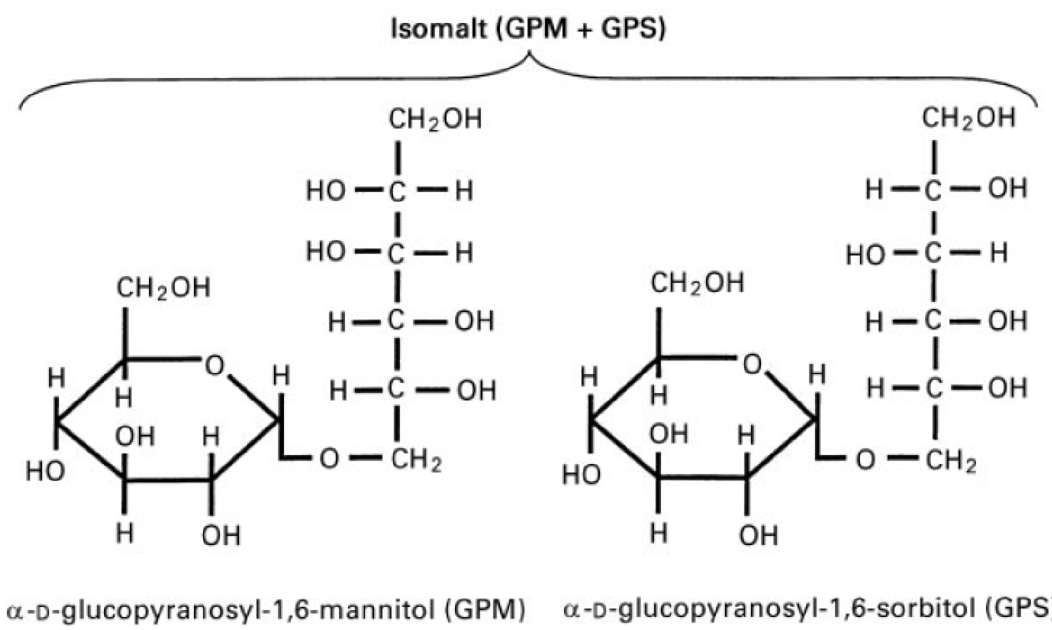

Figure 2.3 The structure of the two dissachrades that comprise isomalt.

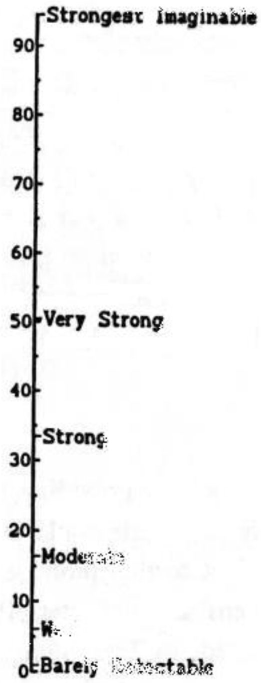

Figure 2.4 An example of the Labeled Magnitude Scale created by Green and others.

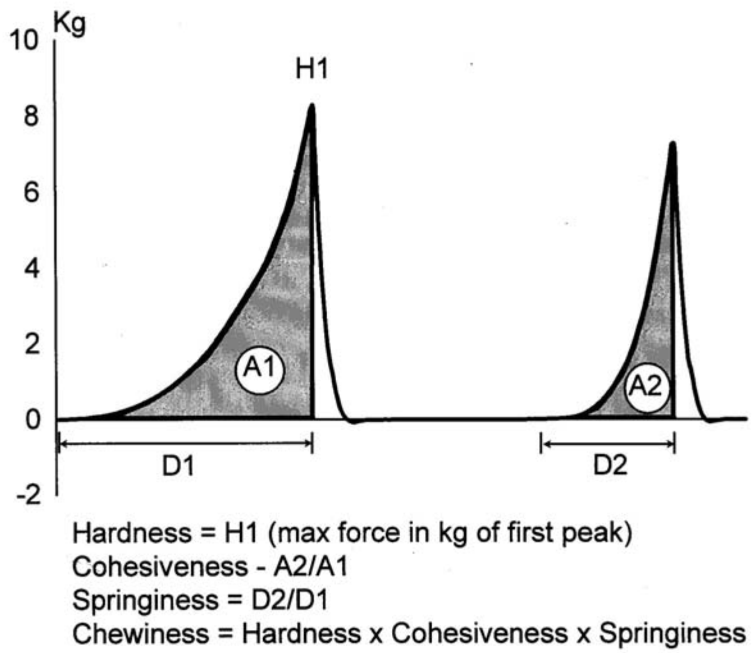

Figure 2.5 Texture profile analysis curve.

CHAPTER 3

MATERIALS AND METHODS

Experimental Design

Trained Sensory Panel and Instrumental Evaluation

A randomized, factorial design was used for sensory evaluation by the trained descriptive panel. Trained sensory panelists (n=9) evaluated six treatments: 100% sucrose, 100% Splenda® baking blend, 100% Splenda®, 10% Splenda®/90% isomalt, 20% Splenda®/80% isomalt, 30% Splenda®/70% Isomalt. The treatment prepared with 100% sucrose served as the control, and it was evaluated along with cupcakes prepared with two commercial products—Splenda® and Splenda® baking blend, as well as cupcakes prepared with three ratios of Splenda® to isomalt. Order of presentation was randomized and three replications were obtained. Cupcakes were randomly assigned for sensory and instrumental evaluation from each treatment bake. Factorial designs for each test are shown in **Table 3.1**.

Consumer Sensory Panel and Instrumental Evaluation

A randomized, factorial design was used for the consumer sensory panel. In two separate sensory sessions, consumers (n=125 panelists) were recruited to evaluate four cupcake treatments—100% sucrose control, 100% Splenda® baking blend, 100% Splenda®, and 30% Splenda/70% Isomalt. Presentation order was randomized, and cupcakes were randomly assigned for sensory and instrumental evaluation. Factorial designs for each test are shown in **Table 3.1**.

Cupcake Formula Development

Six cupcake treatments were prepared: 100% sucrose, 100% Splenda® baking blend, 100% Splenda®, 10% Splenda®/90% isomalt, 20% Splenda®/80% isomalt, 30% Splenda®/70% isomalt according to the formulas and preparation steps outlined in **Table 3.2**. The formulas were developed from a basic yellow cupcake recipe (Gand 2004). The 100% sugar served as the control and was considered the gold standard product. Sugar was the only variable ingredient. Substitutions of Splenda®, Splenda® baking blend, and Splenda®/isomalt ratios for sugar were made according to the manufacturer's recommendations. The replacement of sugar by Splenda® products greatly reduced the weight of batter because the manufacturer recommends that substitutions match sugar by volume not weight (1 cup sugar = 210g; 1 cup Splenda = 30g). The formulas using these commercial products were adjusted, so that their yield matched the full-sugar control formula (Splenda 2004). Substitions of sugar by isomalt were made in 1:1 ratios because ingredients are similar in weight. Each cupcake formulation yielded at least 16 (4 oz.) individual servings.

A KitchenAid Stand Mixer (model K5SS, St. Joseph, MI) equipped with a paddle attachment was used to prepare the cupcake batters. The mixer was plugged into a timer (GraLab, U.S.A., Model 171) to monitor mixing duration at each stage of the cupcake batter preparation. To portion samples, a size 20 dipper (2 oz.) was used to keep batter volume consistent for all cupcake treatments. The sugar control and three treatments containing ratios of Splenda to isomalt were prepared following the conventional mixing method. The conventional mixing method involves creaming the fat and sugar to allow tiny air cells of fat to coat the sugar particles, so as the samples bake, these air cells fill with carbon dioxide and steam creating the crumb of the final product. In addition, sugar provides tenderness by binding water to keep the crumb moist (Alexander 1998). These characteristics are important attributes for cake, and the gold standard—the 100% sugar control—illustrates these factors. The two cupcakes containing Splenda® and Splenda® baking blend were prepared following the muffin method, which is manufacturer's recommendation when these sugar alternatives are used (Splenda 2004). The muffin method omits the creaming step. Because sucralose cannot be creamed, the sucralose/maltodextrin particles unlike the sucrose crystals do not carve tiny air cells in the fat but dissolve in the water of the butter making a curdled, liquidy mixture of Splenda and butter. In the muffin method, the flour, sucralose, and butter are incorporated together, so the flour acts as a buffer between the fat and sucralose to allow it to mix together more evenly.

To ensure heat was distributed evenly, cupcakes were baked in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE) for 12-17 minutes, depending on treatment. All cupcakes were baked in 12 cup muffin pans (Baker's Secret, Reston, VA) lined with baking cups (Cake Mate, Signature Brands, LLC, Oscala, FL). The full sugar control and three ratios of Splenda®/isomalt were baked for 17 minutes at 204.4˚C (400˚F); the 100% Splenda® and 100% Splenda® baking blend were baked for 12 and 15 minutes respectively at 204.4˚C (400˚F). Baking times varied because treatments containing only Splenda® products baked more rapidly than the other treatments. A higher oven temperature was used to promote browning of final products. Baking order of treatments was randomized.

Cupcake Ingredients and Purchasing

Ingredient sources are found in **Table 3.2**. The dry ingredients were purchased in bulk to minimize differences in the retail products due to lot. For cake flour, Splenda®, and Splenda® baking blend, adequate quantities from a single lot were unavailable, so lots were thoroughly combined and needed quantities were taken from the composite lots. These ingredients were stored in large, air-tight containers at room temperature. The wet ingredients were purchased at the beginning of each week for sample preparation over the next 4 days. A complete list of ingredients can be found in **Table 3.2**. The ingredients were weighed one day before baking; the dry ingredients were stored at room temperature in glass bowls covered with film (Reynolds Foodservice Film, Grant Park, IL) or in plastic 4 oz. cups with lids (Sweetheart, Highland Park, IL) and the wet ingredients were stored in the refrigerator in glass bowls covered with film. The preparation and baking of cupcake treatments occurred over the course of one day prior to sensory evaluation. The entire process of preparing and baking the cupcake treatments took approximately six hours to complete in the trained panel experiment and eight hours to complete in the consumer panel experiment. Order of treatment preparation was randomized for each replication and consumer sensory session.

All samples were cooled at room temperature on wire racks for 60 minutes prior to storage. The cooled samples were held at room temperature for approximately 12 hours in 8 oz. individual Styrofoam containers with lids (Dart Container Corp., Mason, MI) that had been pre-labeled with three-digit random number codes. For each day of trained panel data collection, six cupcake treatments were prepared. For each day of consumer panel data collection, four cupcake treatments were prepared. Baking order was randomized.

One day after baking, trained panelists (n=9) evaluated one sample from each of six cupcake treatments for flavor, texture, and aftertaste attributes, and the remaining samples from each treatment were used for instrumental texture profile analysis and color (n=6). Samples were randomly assigned to instrumental and sensory testing. The consumer panelists (n=125) evaluated the acceptability (appearance, texture, flavor, and overall) of ½ a sample from each of the four cupcake treatments, and randomly-selected samples (n=3) from each bake were used for instrumental texture profile analysis and color. All instrumental testing took place on the same day as sensory evaluation.

The results of nutrient analysis for cupcake treatments are presented in **Table 3.3**. ESHA Food Processor SQL (Salem, Oregon) was used to determine the nutritional content of each formulation. Isomalt was not an ingredient that existed in their product database; therefore, an ingredient profile for isomalt was added to the nutrient database, so the analysis on all cupcake formulations could be performed.

Descriptive Sensory Testing

Trained Panel

The trained panel (n=9) at USDA-ARS Russell Research Center (RRC) (Athens, GA) performed the descriptive sensory analysis. These individuals have been trained to evaluate sensory characteristics of a variety of food products, and this on-going descriptive panel functions as a human analytical instrument. The panel has been in existence for approximately ten years and receives compensation for their time and skills. At the time of joining the panel, individuals agreed to be involved in sensory analysis of on-going research projects. Panelists have been screened for taste and smell sensitivity.

At the start of each new project, panelists are informed about the product type being evaluated and product ingredients as they are identified by the panel during preliminary attribute development on the product category.

For this research study, a Spectrum-like approach was followed to introduce the product type to the panel (Meilgaard, Civille, & Carr 1999). First, a frame of reference was developed for the product category. Next, a lexicon of words attributable to the product category was created, and references were used to provide clear and distinct demonstration of the terms and to better elucidate attributes in the product category. After this was completed, examples were presented to the panelists. The purpose of these examples is to illustrate a perceptible characteristic that describes the attributes, and this allows a preliminary list of descriptors to be generated through panel agreement. This final step was important because it allowed the lexicon to be refined to a list of descriptors pertinent to the product category and removed any existing redundancy in terms (Civille & Lyon 1996). This process resulted in an attribute scorecard that each panelist fully understood and could use effectively to evaluate the product category during testing. The RRC trained sensory panel has extensive experience, so the training times were shortened to approximately 12-15 hours.

Attribute Development for Yellow Cupcakes

Attribute development for yellow cupcakes occurred in fall of 2004. Flavor, texture, and aftertastes of yellow cupcakes without frosting were evaluated. Seven of the nine panelists had prior experience with texture evaluations of bread. The bread texture attributes and definitions were utilized during cupcake attribute development. Through panel discussions and experience with cupcakes, the bread attributes roughness, dryness, amount of mealy/coarse/gritty particles, moisture absorption and gumminess were replaced with more cupcake specific attributes which included stickiness, denseness, moistness, and rate of dissolving. The panelists arranged the attributes in order of perceptions that are found during the natural eating process. Food references at varying intensities for the texture attributes were presented to the panel. These reference points were indicated on the ballot linescales in the computerized test.

The flavor attributes were developed utilizing laboratory-baked yellow cupcakes that covered a wide selection of ingredient and baking combinations. Numerous potential attributes were identified by the panel. Through the processes of cupcake experiences and panel discussions, the attribute list was preliminarily reduced in number, and similar attributes were grouped sequentially for evaluation. Four cupcakes that covered the various sweetening ingredients were presented to the panel on two preliminary testing days using a scoresheet that comprised 36 flavor attributes, 8 texture attributes, and 8 aftertastes. ANOVA and frequency tests were run on the data to determine the level of attribute usage and significance of sample differences for each attribute. A selection criterion of less than forty percent of responses >/= 2.0 was used to flag attributes for potential elimination due to low usage. Each flagged attribute was further checked for significant sample differences and for usage by sweetening ingredient to ensure that all product differences were accounted for. A shortened flavor scoresheet was presented to the panel for consideration. Through panel discussions, the scoresheet was further reduced by eliminating the attribute sugar, combining the aromatic attributes—flour and doughy/raw, and combining the aftertastes—burn and numbing/tingling. Flavor examples were presented for each attribute, and flavor intensity references presented

(Civille & Lyon 1996).

The final scoresheet included 8 texture attributes, 11 flavor attributes and 7 aftertaste attributes that were evaluated at 1 and 5 minutes post-swallow. The flavor attributes were presented in order of when the flavor notes were perceived by the panelists, and the basic tastes were separated out into another phase. This attribute development process also helped to prepare the panelists to use the Compusense® computerized sensory analysis system. Attributes, definitions, and references are found in **Table 3.4**.

The trained sensory panel profiled all six cupcake treatments for 26 attributes—11 flavor, 8 texture, and 7 aftertaste—one day post-bake on computerized 0-15 point linescales, where 0=none and 15=very much. Three replications were completed. Cupcakes were assigned three-digit random codes and presented in a random monadic order to panelists to prevent direct comparison between the samples. The computerized ballot and experimental design was set-up and the test was presented to panelists by using Compusense Five, version 4.6 software (Guelph, Ontario, Canada). Attributes were arranged in the six phases outlined in **Table 3.5**. The Compusense system allowed each panelist to record their responses on the linescale by positioning a cursor onto the scale with a computer mouse. For phases five and six, the panelists were prompted to wait before evaluating aftertastes/afterfeels after 60 seconds and five minutes. Panelists had the option to write additional comments about the samples after completing the test phases as well as after the evaluation of each sample. The panel rested for 10 minutes between samples in order to prevent taster fatigue, to allow them to cleanse their palates, and to reduce lingering effects of sweeteners. Palate cleansers (filtered water, baby carrots, red delicious apple slices, unsalted saltine crackers) were available.

The trained panelists performed their evaluations in individual computerized booths to eliminate interaction between panelists under low pressure, sodium vapor light (CML-18, Trimble house, Norcross, GA).

Consumer Panel

A consumer panel (n=125) evaluated four cupcake treatments—100% sugar, 100% Splenda®, 100% Splenda® baking blend, and 30% Splenda®/70% isomalt ratio—for acceptability. These four cupcake treatments were selected because statistically the 30% Splenda®/70% isomalt ratio was most similar to the 100% sugar control, and the Splenda product cupcakes were necessary to determine whether a relationship between artificial sweetener acceptability in a baked good and taster status existed. The consumer data were collected over two days. Past participants were not allowed to repeat the experiment. Presentation order of samples was randomized across the study. Each panelist was assigned a three-digit random code and each evaluated samples in individual sensory booths under white lighting. No direct interaction occurred between panelists or between panelists and researcher.

In the sensory booth, a consent form, four product evaluation forms, a demographics questionnaire, a food frequency questionnaire, and a taster status scorecard (**Appendices A-E**) were sequentially presented by the researcher to the panelist via a pass-through from the adjacent room. Once the consent form was signed, the panelists were monadically presented with four cupcake samples in cups coded with three-digit random numbers. Acceptability of overall appearance, overall texture, and overall flavor, as well as overall acceptability was assessed with unstructured, 15-cm lines with end anchors of ‘dislike extremely’ and ‘like extremely’. At the conclusion of product evaluation, demographic data were collected in order to characterize the panel. Food frequency questionnaire that assessed frequency of consumption of 36 foods and food categories containing alternative sweeteners was completed by consumer panelists to characterize food choice and consumption patterns. Finally, each panelist completed the taster status assessment. Taste intensity elicited by two filter paper strips, a control and one impregnated with PTC (0.3micrograms) (Flinn Scientific, Batavia, IL) was indicated on a 250-mm vertical line intensity linescale. This scale is known as a general labeled magnitude scale (gLMS). It is 100 equally-spaced units, and its labels are placed at log intervals—barely detectable (1.4), weak (6), moderate (17), strong (34.7), very strong (52.5), and strongest imaginable sensation of any kind (100) (Bartoshuk and others 2004). The panelists were provided written instructions on how to correctly complete the 250mm gLMS intensity linescale, and they were provided with palate cleansers (baby carrots) to remove residual taste from the PTC filter paper. Based on PTC scores, the participants were classified as—nontasters (0-12), medium tasters (12-82), supertasters (82+), after adjusting for level of response elicited by the control.

The entire evaluation process took approximately 15-25 minutes for panelists to complete. Evaluation of cupcakes assessment was first to prevent panelist’s bias, and taste intensity was last because the PTC can leave an aftertaste that would have altered panelists’ perception to products if this step had been before the acceptability evaluation. To verify no differences existed between these samples and those evaluated by the trained sensory panel, instrumental testing measurements were obtained. Day-to-day variation was assessed for the two panel days.

Instrumental Data Collection

Each cupcake treatment was evaluated for texture and color. In the trained panel experimental samples, six cupcakes per treatment were evaluated instrumentally; whereas, for the consumer panel experiment, three cupcakes per treatment were evaluated. A TA-XT2 (50-kg) Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) equipped with an acrylic 1 in. cylindrical, rounded probe and Texture Expert Exceed software (Stable Micro Systems, Surrey, England) was used to conduct texture profile analysis (TPA) of each cupcake sample. Data were exported to Excel® (Redmond, WA) and calculations were created to determine textural parameters. The TPA test consisted of two compressions on the center of a 2.5 cm. slice at 25% of the thickness of the slice. This test allowed quantitative texture data to be collected for the following parameters: hardness, cohesiveness, springiness, and chewiness. The TPA test parameters consisted of the following: a pretest speed at 3.0 mm/sec, a test-speed at 1.70 mm/sec, a posttest speed at 10mm/sec, a 5-second delay between compressions, an autotrigger that sensed the sample height, a trigger force of 20g, and a data acquisition rate at 200.0 pps. This procedure and compression percentage was recommended by the American Institute of Baking (AIB) when performing texture analysis on cake (AIB 2004).

The color of cupcake treatments was assessed by using a handheld Minolta Color Spectrophotometer with a viewing area of 8mm (Model CM-508-d, Minolta Co Ltd., Ramsey, N.J.) to measure both the exterior color and interior color of each sample. This instrument collected L*a*b* values from each cupcake sample. For this experiment, the specular (gloss) component was excluded. This measurement parameter is useful when evaluating products of varying texture, but since the cupcake treatments had uniform textures, this parameter was not necessary (Mabon 1993). Prior to use, the spectrophotometer was calibrated with a white standard calibration cap (CM-A70). L*a*b* values were collected at one point on the cupcakes exterior and one point on the cupcakes interior. To take a measurement, the spectrophotometer takes five readings and averages the three most similar readings. The exterior color measurement was taken on the center of the top of the cupcake unless a crack was present; when a crack was present, the reading was taken at the nearest intact portion of the cupcake surface. For interior color, samples were trimmed of edges—leaving a 2.5cm section for instrumental use on the TA, and the measurements were taken at the center of the one side, see **Figure 3.1**. The appearance of the cupcake crumb was documented for each sample and treatment by taking pictures of the uncompressed side with an Olympus 3000 ZOOM (Olympus America Inc., Melville, NY) digital camera in a MacBeth SpectraLight II Light Booth (Gretag Macbeth, New Windsor, NY) under cool white fluorescent illumination (color temperature 4,150 K) with no other illumination in the room. The sample was placed on a stand, covered with a 12.5cm x 20cm posterboard card painted with Munsell N/7 Standard (Sherwin Williams Latex SW1005Sylverado) to match the booth interior. The sample was positioned at approximately 45 degrees to the light source and 90 degrees to the camera lens. The digital camera was set to an aperture of 5.6, a shutter speed of 1/20s, and no flash was used. The images were saved as uncompressed .tif files, 1600 x 1200 pixels.

Statistical Analysis

Results of all sensory and instrumental tests were analyzed using SAS software (SAS for Windows, version 9.1, SAS Inc., Cary, NC).

Descriptive Sensory Analysis

PROC UNIVARIATE was used to produce normality plots for the purpose of verifying normal distribution of data and equal variance. If the data lacked normality or variance equality, the data were transformed to meet the assumptions necessary for valid analysis. Mixed model of analysis of variance (PROC MIXED) was used ($p<0.05$) to compare cupcake treatments. Least-square means and standard errors were generated. PDIFF was used for means separation. To determine similarity of samples based on descriptive sensory attributes, Principle Component Analysis (PCA) was used.

Consumer Sensory Evaluation

The demographic, food frequency consumption and taster status data were analyzed by PROC FREQUENCY and to identify basic in the data. Categorical techniques were utilized to organize consumer panelists into taster status groups—supertasters, medium tasters, and nontasters, and to organize the frequency of consumption trends into daily, weekly, and monthly consumption categories. The relationship between taster status and frequency of consumption for food groups was analyzed by Chi-square test and Spearman's Rank correlation statistic ($p<0.1$).

Instrumental Analysis

Mixed model of analysis of variance (PROC MIXED) was used ($p<0.05$) to compare cupcake treatments from the descriptive sensory analysis experiment. Least-square means and standard errors were generated. PDIFF was used for means separation. For the consumer sensory evaluation experiment, ANOVA ($p<0.05$) and SNK were used to identify significant differences between cupcake treatments.

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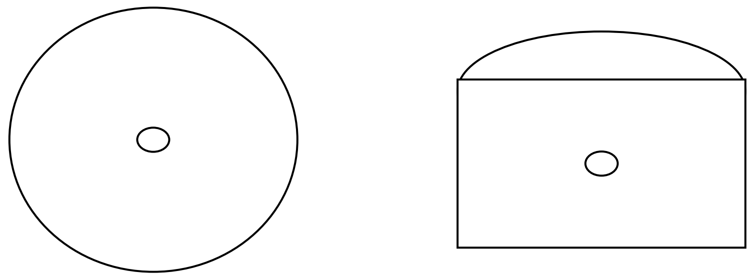

Exterior top of cupcake   Interior side of cupcake

Figure 3.1 Schematic of aperture location of Minolta color spectrophotometer (Model CM-508-d, Minolta Co. Ltd., Ramsey, NJ) color measurements on cupcake samples.

Table 3.1 Factorial design for sensory and instrumental test experiments.

Sensory Tests:	
Descriptive sensory analysis—cupcake profiling with trained panel	6x9x3[a]
Consumer sensory testing—cupcake acceptability	3x125x1[b]
Instrumental Tests:	
Texture Profile Analysis	6x3 or 6x1x4[c]
Color Spectrophotometer	6x3 or 6x1x4[d]

[a] cupcake treatments x judges x replications
[b] cupcake treatments x judges x replication
[c] cupcake treatments x samples (3 for consumer experiment, 6 for trained panel experiment) x 1 test of 2 compressions x replications; measured using a TA XT2 (50 kg) Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) equipped with a 1 in. cylindrical acrylic probe at a cross arm speed of 1.70 mm/sec.
[d] cupcake treatments x samples (3 for consumer experiment, 6 for trained panel experiment) x reading x replications; measured using a Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ)

Table 3.2 Cupcake formulations and preparation procedures.

Ingredients	Control[b] (g)	Splenda®[ac] (g)	Splenda® Blend[ac] (g)	10% Splenda[b]	20% Splenda[b]	30% Splenda[b]	Product Information
Cake flour	228.10	285.10	273.70	228.10	228.10	228.10	Reily Foods Company, New Orleans, LA
Granulated sugar	212.40						Savannah Foods and Industries, Savannah, GA
Splenda®		37.50		3.00	6.00	9.00	McNeil Nutritionals, Fort Washington, PA
Splenda® Blend			82.60				McNeil Nutritionals, Fort Washington, PA
Isomalt				183.90	163.40	143.00	Palatinit, NJ
Eggs	123.70	154.60	148.40	123.70	123.70	123.70	The Kroger Co., Cincinnati, OH
Whole milk	117.30	146.60	140.80	117.30	117.30	117.30	The Kroger Co., Cincinnati, OH
Butter	112.40	140.50	134.90	112.40	112.40	112.40	The Kroger Co., Cincinnati, OH
Vanilla extract	1.80	2.30	2.20	1.80	1.80	1.80	Tone's, Ankeny, IA
Baking powder	1.60	2.00	1.90	1.60	1.60	1.60	Tone's, Ankeny, IA
Salt	1.30	1.60	1.60	1.30	1.30	1.30	The Kroger Co., Cincinnati, OH

[a] Amounts of constant ingredients were increased proportionally to equalize formula yield.

[b] Procedure: 1. Cream butter in a Kitchen Aid Mixer (Model KS55 St. Joseph, MI) equipped with a paddle attachment for 30 sec on speed 4. 2. Add sugar and cream with butter 30 sec on speed 2; scrape down bowl. 3. Add eggs and vanilla and creamed mixture and blend for 1 minute on speed 4; scrape down bowl. 4. Sift flour, baking powder, and salt; set aside. 5. Add 1/3 flour mixture to creamed mixture; blend for 5 sec on stirring speed. 6. Add ½ milk to mixture; blend for 10 sec on stirring speed; scrape down bowl. 7. Add 1/3 flour mixture to creamed mixture; blend for 5 sec on stirring speed. 8. Add remaining milk; blend for 10 sec on stirring speed; scrape down bowl. 9. Add remaining flour to mixture; blend 10 sec on stirring speed; scrape down bowl. 10. Place baking cups (Cake Mate, Oscala, FL) into 12-cup muffin pan (Baker's Secret, Reston, VA); portion

cupcakes with #20 scoop. 11. Bake at 400°F for 17min in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE).
[c] Procedure: 1. Cream butter in a Kitchen Aid Mixer (Model KS55, St. Joseph, MI) equipped with a paddle attachment for 30 sec on speed 2. 2. Add Splenda® and flour to butter; blend for 1 minute at stirring speed; scrape down bowl. 3. In a second bowl, combine eggs, vanilla, and milk; set aside. 4. Add baking powder and salt to creamed mixture; blend for 10 sec at stirring speed. 5. Add 2/3 milk mixture to creamed mixture; blend for 45 sec at speed 4; scrape down bowl. 6. Add remaining milk mixture; blend 30 sec on speed 6; scrape down bowl. 7. Place baking cups (Cake Mate, Oscala, FL) into 12-cup muffin pan (Baker's Secret, Reston, VA); portion cupcakes with #20 scoop. 8. Bake at 400°F for 12 minutes in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE).

Table 3.3 Nutritional Analysis[a] of cupcake formulations (45g per serving).

Nutrients	Formulations[b]					
	Control	Splenda®:isomalt blends			Commercial Splenda blends	
	SP00	SP10	SP20	SP30	SP50	SP99
Calories (kcal)	169.5	133.5	131.8	130.1	149.0	139.6
Calories from fat (kcal)	60.5	57.0	57.0	57.0	64.6	67.2
Protein (g)	2.4	2.3	2.3	2.3	2.6	2.7
Carbohydrate (g)	24.9	21.9	20.9	19.8	16.9	15.0
Total Sugar (g)	13.7	0.7	0.7	0.7	5.1	0.5
Other carbohydrates (g)	10.9	21.1	20.1	19.1	11.6	14.2
Fat (g)	6.8	6.4	6.4	6.4	7.3	7.6
Saturated Fat (g)	4.0	3.8	3.8	3.8	4.3	4.5
Cholesterol (mg)	48.8	46.0	46.0	46.0	52.1	54.3
Dietary Fiber (g)	0.2	0.2	0.2	0.2	0.3	0.3
Sodium (mg)	57.7	54.3	54.3	54.3	62.3	63.5

[a] ESHA Food Processor Program SQL (Salem, Oregon)
[b] SP00=100% sugar, SP10=10%Splenda®/90%isomalt,
SP20=20%Splenda®/80%isomalt,
SP30=30%Splenda®/70%isomalt, SP50=100%Splenda® baking blend
(sucralose/sucrose), SP99=
100% Splenda® (sucralose/maltodextrin)

Table 3.4 Phases of evaluation for descriptive sensory analysis and attribute definitions for cupcake flavor, texture, and aftertaste profiling.

Attribute	Definition	References
Phase 1: Evaluate with your fingers. Compress the sample 25% and release. Evaluate:		
1. Springiness	Amount/degree the sample returns to its original shape. (0=not springy, 15=very springy)	Cream cheese (0), marshmallow (9.5), gelatin (15).
2. Stickiness	Amount of sample that sticks to fingers. (0=none, 15=very much)	No references
Phase 2: Chew the sample and evaluate each attribute at the times indicated.		
1. Hardness	Force to bite the sample with the front teeth. First bite. (0=soft, 15=hard)	Cream cheese (1), cheese (4.5), olive (6), almond (11), lifesaver (14.5)
2. Denseness	Compactness of the cross section. (0=airy, 15=dense)	Cool whip (1), club cracker (4), malted milk ball (6), fruit jellies (13)
3. Cohesiveness	Distance you can into the sample before it breaks, cracks, or crumbles. First bite. (0=crumbly to 15=deforms)	Cornbread (1), cheese (5), soft pretzel (8), raisin (10), starburst (12.5), gum (15)
4. Moistness	Amount of moisture in the product. First 5 chews. (0=dry, 15=wet)	Saltine cracker (0), water (15)
5. Rate of dissolving	Rate the sample dissolves when mixed with saliva during chewdown. (0=slow, 15=fast)	Cream cheese (slow), powdered sugar (fast)
6. Chewiness	Amount of work to chew the sample to get it ready to swallow. Evaluate near spit out/swallow. (0=not chewy, 15=chewy)	Rye bread (1.75), gum drop (5.75), tootsie roll (12.75)
Phase 3: Aromatics: evaluate while chewing the sample. Evaluate the aromatic taste sensation associated with:		
1. Buttery	Heated/baked butter	Use flavor intensity references, soda 2 (saltine cracker), grape 4 (grape Kool-Aid), orange 7 (Minute Maid orange juice), orange 9.5 (Tang), grape 10 (Welch's grape juice), cinnamon 12 (Big Red chewing gum)
2. Vanilla	Vanilla flavoring	
3. Doughy/flour	Heated wet white wheat flour	
4. Soda/baking powder	Baking soda or baking powder	
5. Eggy/custard	Cooked eggs	
6. Browned	The caramelization of sugars	

7. Cardboard/dry milk	Slightly oxidized fats and oils, reminiscent of wet cardboard packaging or nonfat dry milk	
Phase 4: Basic tastes. Taste on tongue stimulated by:		
1. Sweet	Sugars and high potency sweeteners	Solutions: sweet 5, 10
2. Salt	Sodium salts, especially sodium chloride (table salt)	Solutions: salt 5, 10
3. Sour	Acids	Solutions: sour 5, 10
4. Bitter	Caffeine or quinine	Solution: bitter 5
Phase 5: Aftertastes/afterfeels; evaluate 1 minute after swallow.		
1. Metallic	A flat chemical feeling factor stimulated on the tongue by metal coins	Use flavor intensity references and basic taste references.
2. Baking soda	Aromatic taste sensation associated with baking soda	
3. Sweet-chemical	Taste on the tongue stimulated by artificial sweeteners such as sucralose (Splenda)	
4. Bitter	Taste on the tongue stimulated by caffeine or quinine	
5. Sour	Taste on tongue stimulated by acids	
6. Numbing/burning/tingling	Chemical feeling factor associated with artificial sweeteners	
7. Astringent	Chemical feeling factor on the tongue and surfaces of the mouth described as dry/puckering and associated with alum	
Phase 6: Aftertastes/afterfeels; evaluate 5 minutes after screen 2.		
1. Metallic	A flat chemical feeling factor stimulated on the tongue by metal coins.	Use flavor intensity references and basic taste references.
2. Baking soda	Aromatic taste sensation associated with baking soda	
3. Sweet-chemical	Taste on the tongue stimulated by artificial sweeteners such as sucralose (Splenda)	
4. Bitter	Taste on the tongue stimulated by caffeine or	

	quinine
5. Sour	Taste on tongue stimulated by acids
6. Numbing/burning/tingling	Chemical feeling factor associated with artificial sweeteners
7. Astringent	Chemical feeling factor on the tongue and surfaces of the mouth described as dry/puckering and associated with alum

CHAPTER 4

INSTRUMENTAL AND DESCRIPTIVE SENSORY ANALYSIS OF BAKED YELLOW CUPCAKES PREPARED WITH NUTRITIVE AND HIGH INTENSITY SWEETENERS

Summary

Availability of acceptable, high quality reduced-in-sugar foods may reduce simple carbohydrate and calorie consumption. Modified foods that closely match sensory attributes of standard products are most acceptable. Splenda® (sucralose/maltodextrin blend) provides sweetness with fewer calories than sugar, but its flavor profile and functional performance in baked goods differs from sucrose. Use of a commercially available sucralose/sucrose blend (50:50) in cake reportedly overcomes these limitations. However, isomalt, a polyol, with functional characteristics similar to sugar, may further lower simple carbohydrate levels and produce a baked product with attributes similar to the full-sucrose control. A trained sensory panel (n=9) using the Spectrum-like approach profiled six cupcake formulations. The 100% sucrose control was compared to two commercial products (100% Splenda® or 50% sucralose/50% sucrose baking blend), and three Splenda® and isomalt blends (10% Splenda®/90% isomalt, 20% Splenda®/80% isomalt, and 30% Splenda®/70% isomalt). Over three replications, 26 attributes (11 flavor, 8 texture, 7 aftertaste) were profiled 1 day post-bake on a 0-15 point linescale with Compusense 5 v4.6 software. Principle Component Analysis revealed 30% Splenda®/70% isomalt produced a cupcake most similar to the sucrose control. The control exhibited low intensities of vanilla, baking soda, doughy, eggy, cardboardy, salty, browned, buttery, sour, and bitter flavors (<3.2); sweetness rated 7.3. Control cupcakes exhibited low to moderate springiness, stickiness, denseness, moistness, and rate of dissolving (4.2-5.7). Chewiness, cohesiveness, and hardness rated <3.7. Mixed model of analysis of variance revealed texture, flavor, and aftertaste attributes of this 30%Splenda®/70% isomalt cupcake did not differ from the control, except for cohesiveness, browned, and sweetness ($p>0.05$). Instrumental texture and color analysis supports descriptive sensory analysis that 30%Splenda®/70%isomalt cupcake formulation best matches the full-sugar control. Calorie reduction was 24%.

Introduction

The rates of chronic disease are rapidly rising across ethnicity, gender, and age groups. Currently, 66% of the American adult population is obese and/or overweight (NCHS 2006). Diabetes is becoming more widespread with the number of diagnosed cases increasing from 5.8 million in 1980 to 14.6 million in 2005, and the American Diabetes Association estimates that 20.8 million Americans have diabetes (CDC 2005). Although evidence is lacking to support an unequivocal link between nutritive sweeteners and chronic disease (ADA 2004), trends in chronic disease incidence suggest that over-consumption of sweets contributes to excessive caloric intake (Henkle 1999). The United States Department of Agriculture (USDA) recommends that added nutritive sugars make up approximately 6-10% of total energy intake, which translates into 6-18 teaspoons of added sugar each day depending on calorie energy intake (ADA 2004). However, consumption of sugars and high-sugar foods greatly exceeds the recommendations made by the USDA. The most recent CFSII (Continuing Survey of Food Intakes by

Individuals 1994-1996) found that the US adult population consumed an average of 25g of sugars and sweets per day. NHANES (National Health and Nutrition Examination Survey 1988-1994) revealed the median daily intake of added sugars ranged from 40-120g per day across population groups (ADA 2004).

Cake is a popular dessert and snack item that is traditionally prepared with sugar. One serving (68g) of shortened cake contains approximately 245 calories, 36g carbohydrate, 3.6g protein, and 9.9g fat (Nutrient Data Laboratory 2007). According to Guthrie and Morton (2000), 12.9% of total added sugar intake of all people 2 years and older is from sweetened grain products, which includes cakes and cookies. This category ranked third in highest percentage of total added sugar intake behind the food categories—regular soft drinks and sugars/sweets (Guthrie and Morton 2000). Thus, the food industry has responded by developing and marketing lower calorie and sugar options for beverages, snacks, and baked goods. These products were originally targeted to individuals with specific medical problems, such as diabetes, obesity, and heart disease (Sandrou and Arvanitoyannis 2000), but now are targeted to all consumers (Thomson 2004). And in recent years, low-calorie foods have improved in flavor, and their competitive price has helped to increase their market share. These improvements in quality have increased preference for these reduced-in-calorie food and beverage products—the most popular ones being low-fat dairy products and diet soft drinks (Sandrou and Arvanitoyannis 2000).

Low-energy sweeteners lend fewer or no calories when compared to sugar, and they are considered to be possible replacements for sugar in the diet. The most widely recognized alternative sweeteners are high intensity sweeteners (HIS), such as sucralose, and low-energy bulk sweeteners, such as sugar alcohols or polyols. The taste properties of HIS and polyols have been investigated by time intensity techniques, physiocochemical tests, and descriptive analysis, but most published research has focused on working with a single alternative sweetener as opposed to blends of two or more alternative sweeteners. Sensory data comparing alternative sweeteners to sucrose is especially limited. Using time intensity difference testing, both total sweetness duration and sweetness aftertaste were evaluated for several HIS, including sucralose. No differences were found when sucralose was compared to a 5% sucrose solution (Ketelsen and others 1993). By conducting descriptive analysis, other researchers found blending HIS to be beneficial because the off-flavors, bitterness, and sweetness aftertastes were minimized, and the overall flavor profiles more closely matched sucrose than did any single HIS. This lead the researchers to conclude that descriptive analysis provided valuable insight regarding the differences in single HIS and blends of HIS not only for the attribute sweetness, but also for other attributes, such as off-tastes (bitterness and off-flavor) and aftertastes (bitterness and sweetness) (Hanger and others 1996). Additional work with HIS and bulk sweeteners revealed that these types of alternative sweeteners can be used in “binary” combinations that utilize the functional roles of bulk sweeteners and the intense sweetness of HIS to enhance taste quality, improve processing, and decrease costs to the food industry (Hutteau and others 1998). Some examples of where food product developers have successfully used blends of high intensity sweeteners and bulk sweeteners include the following:

1. aspartame and acesulfame-K, to minimize their lingering sweetness and enhance their stability in certain food systems; and

2. maltitol, a bulk sweetener, with acesulfame-K to help mask the off notes of the high intensity sweetener (Deis 2004).

The purpose of blending is to adjust the overall sweetness temporal profiles or to mask existing off-tastes. However when deciding on the appropriate sweeteners to blend in a specific application, it is important to consider color, flavor, glycemic effects, viscosity, texture, water activity, humectancy, binding properties, crystallizing properties, and freeze-point depression in addition to sweetness. In many foods, one sweetener may predominate, yet this multi-ingredient approach allows manufacturers to more effectively use combinations of sweeteners to better individualize their modified products (Deis 2002).

Sucrose, a crystalline disaccharide, has become the gold standard sweetener in foods because of its availability, long historical use, ease of use, and low cost (Deis 2004). It acts as a multifunctional ingredient that contributes to the overall characteristics of a multitude of food products (Cooper 2006). In cake systems, its functional role is complex, and this has made replacing sugar with high-intensity and low-energy sweeteners difficult.

Although sugar's primary function is to impart a desirable sweet taste, it additionally influences the product's structure and texture by impacting the gelatinization of starch and denaturation of proteins in the food system (Pyler 1988, Cooper 2006). In the baking of cakes, sugar influences the temperature at which the structure will set by raising the temperature at which the starch molecules will gelatinize and protein molecules will denature, and it provides tenderness by binding water to keep the cake crumb moist (Alexander 1998). In the preparation of cakes, sugar is important in the mixing of the cake batter because creaming the fat and sugar allows tiny air cells in the fat to surround the sugar particles. This promotes an even crumb texture while the cake bakes, thus impacting the final product's quality (Alexander 1998). Finally, the incorporation of sugar into cakes enhances the brown colors associated with crusts and crumb tops because of the Maillard reaction. Without the reducing sugars that become available when sucrose is heated, this reaction would not take place and the pleasant aromas and flavors associated with cake would not develop (Alexander 1998).

High intensity sweeteners, also known as artificial or nonnutritive sweeteners, are compounds that exhibit sweetening power at very low concentrations. Many of these compounds have been found to be sweet and provide no calories because of their sweetness potency; however, as single sweetening agents, none can match the sweetness profile and functionality of sucrose (Kemp 2006). Sucralose, a popular sugar substitute, is the only nonnutritive, high intensity sweetener derived from sugar. It is sold under the name Splenda®, and this sweetener is produced by substituting three chlorine atoms for three hydroxyl groups on the molecule. The resulting sweetener compound is indigestible in humans, and animal studies have demonstrated that the chemical cannot be hydrolyzed by the intestinal lumen and is largely excreted unchanged in the feces (Lin and Lee 2005). Sucralose is calorie free, has a clean taste, and is approximately 400-800 times sweeter than sucrose (Nelson 2000, CCC 2004a). Stability studies have revealed that no products other than sucralose were detectable when cakes were baked at 180 degrees C (Hutchinson and others 1999), suggesting heat stability at baking temperatures. In 1999, sucralose was granted approval by the Food and Drug Administration (FDA) as a "general purpose sweetener," and the acceptable daily intake is 5 mg/kg of body weight/day.

In many food systems, the replacement of sugar with intense sweeteners alone is unacceptable because the final product's characteristics are greatly altered, and its energy density and fat content changes due to the loss in product volume. Limitations of using sucralose in baked goods include its insolubility in fats and oils. Sucralose is difficult to incorporate into cake batter because it cannot be creamed into the butter or shortening. This interferes with the final product's crumb and its overall texture and tenderness. In addition, the surface color of the final product can be different because sucralose does not undergo Maillard browning. Upon heating it is not broken down into a reducing sugar (Nelson 2000). To overcome these limitations, sucralose must be used in combination with bulking agents, so that the texture and color of the final product are acceptable and similar to the gold standard prepared with sucrose. Researchers have demonstrated that addition of maltodextrin and xantham gum with sucralose can improve flavor liking of a modified muffin product when compared to its counterpart—the commercial no-sugar-added, low-fat muffin mix prepared according to the manufacturer's instructions (Khouryieh and others 2005). Lin and Lee (2005) demonstrated that sucralose and indigestible dextrin could be substituted for <50% of the sucrose in chiffon cakes, and the sensory and physiocochemical properties were comparable to the 100% sucrose chiffon cake control.

Sucralose is readily available to consumers in bulk as a sucralose:maltodextrin blend, known as Splenda® for baking. Maltodextrin is defined by the FDA as "nonsweet nutritive saccharide polymer," and it is added to HIS to facilitate their incorporation into beverages and food products (Kuntz 1997). Splenda® for baking, although easy to measure, could not achieve acceptable quality characteristics when added to formulations for baked good products. So in 2004, Splenda®, Inc. introduced Splenda® baking blend. This product was designed to overcome the quality limitations associated with the use of the sucralose/maltodextrin blend. This product is a sucralose:sucrose blend formulated specifically for baking.

In addition to maltodextrin and sucrose, low-energy bulk sweeteners also can be used in combination with high intensity sweeteners to compensate for some of their limitations. There are many possible low-energy bulk sweeteners; however, the sugar alcohols, fructooligosaccharides, and polydextrose are considered the most common examples (Bornet 1994). Sugar alcohols, also known as polyols, provide an option to food developers because they can be used in sugar-free, reduced-calorie, and noncariogenic foods because of their unique characteristics (Deis 2000). Additionally, polyols have a lower sweetening power when compared to sucrose, and their individual taste profiles vary as does their range of sweetening power. Isomalt is a disaccharide sugar alcohol that lends two calories per gram. It is derived from sucrose, and is an equimolar mixture of two disaccharide alcohols (Bornet 1994), but after processing, the resulting chemical compound comprises gluco-mannitol and gluco-sorbitol, which is more chemically and enzymatically stable than sucrose. This compound is 45-65% as sweet as sucrose. Currently, the company, Palatinit, producing isomalt is petitioning for generally-recognized as safe (GRAS) status from the FDA (CCC 2004b). The safety of isomalt has been evaluated by the WHO's Joint Expert Committee on Food Additivies (JECFA), and it was concluded that an acceptable daily intake not be established. Because no ADI is established, isomalt is considered to be in the safest category in which

JECFA can place a food ingredient (CCC 2006).

The significant attributes of isomalt are (1) products have the same appearance and texture as ones containing sugar, (2) sweetness is not lost when heated, (3) products have improved shelf-life, (4) flavor transfer in foods is enhanced, and (5) it lacks the undesired "cooling" effect exhibited by other polyols (Nelson 2000). However, a laxative effect has been demonstrated when high levels of polyols are consumed (Alonso and Setser 1994).

The purpose of this study was to evaluate the flavor, texture, and aftertaste effects on yellow cupcakes when sucrose was replaced with alternative sweeteners. Three Splenda®: isomalt ratios, two commercially formulated Splenda® blends, and the control were evaluated. A trained descriptive sensory panel evaluated flavor, textural, and aftertaste attributes of the control and reformulated yellow cupcakes. In addition, instrumental analysis of textural and color characteristics was obtained to profile the cupcake formulations, and the cupcake appearances were documented. Another objective was to create a cupcake that had fewer calories, total carbohydrate, and total sugars when compared to the full-sugar control.

Materials and Methods

<u>Cupcake Formulations</u>

Cupcake formulations were developed using four different sweet ingredients; sugar, Splenda®, Splenda® baking blend, and isomalt (**Table 4.1**). Sweetener in the control formulation was 100% sucrose. Splenda® and Splenda® Baking Blend each replaced 100% sucrose present. Three Splenda®:isomalt ratios (10:90, 20:80, 30:70) that replaced 100% of the sucrose also were evaluated. All remaining proportions of ingredients were identical in all cupcake treatments. Sources for all ingredients remained constant.

Cupcake Preparation

Cupcake treatments containing 100% Splenda® and 100% Splenda® baking blend® were prepared using the muffin method as suggested by the manufacturer. The control and formulations containing isomalt were prepared by the conventional creaming method to maximize functional effects. Cupcakes were baked one day prior to sensory and instrumental evaluation. All products were baked in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE) at 400°F for 12-17 minutes depending on formulation, cooled for 60 minutes under ambient conditions, and stored in individual, Styrofoam® containers with lids (Dart Container Corp., Mason, MI). Containers were labeled with three-digit random codes. Three replications were conducted.

Nutritional Analysis

Nutritional analysis was conducted on all cupcake formulations with ESHA Food Processor SQL computer program (Salem, OR).

Training of Sensory panel

Flavor, texture, and aftertaste attributes of baked yellow cupcakes formulated with Splenda®, Splenda® baking blend, and ratios of Splenda® and isomalt were assessed by a trained sensory panel (n=9). Twenty-six attributes (11 flavor—includes aromatics and basic tastes, 8 texture, and 7 aftertastes) were developed and evaluated using a Spectrum-like approach. This descriptive sensory approach utilizes an extensive reference list that allows panelists to describe and rate intensity of the product flavor and texture attributes exhibited.

The panelist training involved the following steps:

1. sampling a wide range of yellow cupcakes with different sensory properties;
2. generating a list of flavor and textural attributes present in cupcakes and agreeing on attribute definitions and order of appearance;
3. refining the attribute list to produce a sensory scorecard; and
4. calibrating the panelists to uniformly apply the universal texture and flavor intensity scales for each attribute (Meilgaard, Civille, & Carr 1999).

Typically, panelist training requires about 50 hours. The extensive experience of this trained panel reduced the training time required to approximately 30 hours. The trained panel acted as a human analytical instrument. The descriptive sensory data generated during testing allowed a product profile for each cupcake formulation to be established.

Sensory Descriptive Analysis

Sensory evaluation was conducted in individual computerized booths under low-pressure sodium vapor lights using Compusense Five v4.6 software (Guelph, Ontario, Canada). Twenty-six sensory attributes (11 flavor, 8 texture, and 7 aftertaste) were evaluated on 0-15 point linescales. Panelists evaluated six cupcake treatments each session with 10 minute breaks between samples to allow for palate cleansing and to decrease taster fatigue. Samples were coded with 3-digit random codes. Palate cleansers (baby carrots, unsalted saltines, and water) were provided. The presentation order was randomized to avoid position bias. Three replications were obtained.

Instrumental Analysis

Each cupcake treatment was evaluated for texture and color with instrumental techniques. Six cupcakes per treatment were evaluated per replication. Three replications were obtained.

A TA-XT2 (50-kg) texture analyzer (Scarsdale, NY) equipped with an acrylic 1 in. cylindrical, rounded probe was used to conduct texture profile analysis (TPA) of each cupcake sample at room temperature. The samples were compressed at the center of a 2.5 cm. slice that was obtained from the center of the cupcake, by trimming off two sides of cupcake samples. The texture parameters were determined with pretest speed at 3.0mm/s, test-speed at 1.70mm/s, posttest speed at 10.0mm/s, compression distance 25% of cupcake sample's height, 5-second delay between two compressions, and trigger force at 20.0g. This procedure and compression percentage was recommended by the American Institute of Baking (AIB) for texture profile analysis of layer cake samples (AIB 2004). Data points were analyzed by Texture Expert Exceed Version 1.22 Software (Surrey, England) to generate a TPA curve.

A handheld Minolta Color Spectrophotometer with a viewing area of 8mm (Model CM-508-d, Minolta Co Ltd., Ramsey, N.J.) was used to measure both the exterior and interior color of each sample. The specular (gloss) component was excluded. Prior to use, the spectrophotometer was calibrated with a white standard calibration cap (CM-A70). To take a measurement, the spectrophotometer takes five readings and averages the three most similar readings. The exterior color measurement was taken on the center of the top surface of the cupcake unless a crack was present; when a crack was present, the reading was taken at the nearest intact portion of the cupcake surface. For interior color, samples were trimmed of exterior edges, and the color measurements of the crumb were taken at the center of the sample (**Figure 4.1**). Appearance was documented with an Olympus 3000 ZOOM camera digital camera (Olympus America Inc., Melville, NY) in a MacBeth SpectraLight II Light Booth (Gretag MacBeth, New Windsor, NY) under cool white fluorescent illumination (color temperature 4,150K) with no other illumination in the room (**Figure 4.2**).

Statistical Analysis

Results of all sensory and instrumental tests were analyzed using SAS software (SAS for Windows, version 9.1, SAS Inc., Cary, NC). PROC UNIVARIATE was used to produce normality plots for the purpose of verifying normal distribution of data and equal variance. If the data lacked normality or variance equality, the data were transformed to meet the assumptions necessary for valid analysis. Mixed model of analysis of variance (PROC MIXED) was used ($p<0.05$) to compare cupcake treatments. Least-square means and standard errors were generated. PDIFF was used for means separation. Principle Component Analysis (PCA) was used to determine similarity of samples based on descriptive sensory attributes. Principle component analysis (PCA) was conducted with Senstools v.3.1.4 (OP & Product Research BV Utrecht, Netherlands).

Results and Discussion

Nutritional Analysis

Nutritional analysis (ESHA Food Processor, SQL Salem, OR) revealed that the 30%Splenda®/70%isomalt cupcake formulation contained the least amount of calories (130 kcal/serving). The full-sugar control cupcake contained the most calories (169.5 kcal/serving), followed by the cupcake formulations containing 100% Splenda® and 100% Splenda® baking blend. However, these formulations contained the least amount of total grams of carbohydrate, at 15.0g and 16.9g. This might be due to how the two investigated sweeteners were classified in the ESHA Food Processor ingredient database.

The sweetener, Splenda®, was in the current database; however, isomalt was not, so a nutrient profile for this ingredient was created by using the information from Palatinit. This is illustrated in the ‘other carbohydrates’ category of the nutritional analysis. For the Splenda®:isomalt ratios, the amount of other carbohydrates equals the amount for total carbohydrate, and this could explain why nutritionally these cupcakes contain more total carbohydrate; however, all this carbohydrate is not absorbed because the compound is not completely broken down in the gastrointestinal tract. Therefore, the Splenda®:isomalt ratios as a substitution had the greatest effect on the overall calorie reduction as well as total grams of sugar reduction when compared to the full-sugar control and two Splenda®-containing formulations. The nutritional analysis data are presented in **Table 4.2**.

<u>Instrumental Analysis</u>

Appearance of the crumb of the cupcakes is found in **Figure 4.2**. Instrumental color assessment (**Table 4.3**) revealed no significant differences for interior color across cupcake formulations. For exterior color, significant differences in all color parameters were found due to formulation. The exterior color of the Splenda®:isomalt blends most closely matches the sucrose control. The cupcake formulations prepared with 100% Splenda® and 100% Splenda® Baking Blend were significantly lighter (L*) than all other formulations; these formulations were also less yellow (b*). For all the color measurements, the full-sugar control did not differ from the 10%Splenda®/90%isomalt and 20%Splenda®/80%isomalt formulations; however, the control was significantly different from 30%Splenda®/70%isomalt for b* only, indicating this reformulation resulted in a cupcake that was less yellow than the control.

Instrumental textural assessment (**Table 4.4**) revealed significant differences due to cupcake formulation for the parameters—hardness, cohesiveness, springiness, and chewiness ($p<0.05$). Sucrose substitution with 100% Splenda® (SP99) and 100% Splenda® baking blend (SP50) resulted in cupcakes that were significantly harder than were the other formulations; however, those formulated with Splenda®:isomalt blends did not differ from the control. The full-sugar control cupcake was more cohesive and more springy than were the modified formulations, regardless of the alternative sweetener system selected. The Splenda®:isomalt blends resulted in the greatest decrease in both parameters. Chewiness of the cupcakes prepared with Splenda®:isomalt blends did not differ from the control. Both Splenda® and Splenda® baking blend substitutions resulted in cupcakes that were significantly more chewy than was the control. The Splenda®:isomalt blends appear to better match the textural attributes of the control than do the commercially available Splenda® blends, despite not duplicating the texture of the full-sugar control for all parameters when assessed instrumentally.

<u>Sensory Descriptive Analysis</u>

Mixed model of analysis of variance (PROC MIXED) revealed the full-sugar control exhibited low to moderate springiness, stickiness, denseness, moistness, and rate of dissolving (4.0-5.6). For the attributes chewiness, cohesiveness, and hardness, the control rated <3.8 (**Table 4.5**). For flavor, the control exhibited low intensities of vanilla, baking soda, doughy, eggy, cardboardy, salty, browned, buttery, sour, and bitter attributes (<3.3); sweetness rated 7.4 (**Table 4.4**). The LS-means for texture, flavor, and aftertaste attributes of all six cupcake formulations plotted on truncated lines in the low to medium intensity range are found in **Figures 4.3, 4.4,** and **4.5**.

Significant differences due to formulation existed for all texture sensory attributes (**Table 4.5**) ($p<0.05$). The full-sugar control was significantly different from all formulations in springiness. Use of the commercial Splenda® baking blend (SP50) rather than the Splenda®:maltodextrin blend (SP99) significantly altered the perception of stickiness, rate of dissolving, and chewiness; no effect was found on the perception of the remaining attributes evaluated. When compared to the sucrose control, springiness and stickiness were less intense than was found for the control when the baking blend (SP50) rather than original Splenda® blend (SP99) was incorporated; differences in hardness were also overcome with incorporation of the Splenda® baking blend. The 100% Splenda® baking blend (SP50) cupcake formulation was not significantly different from the control for the attributes—denseness, cohesiveness, moistness, rate of dissolving, and chewiness. The original Splenda® blend (SP99) cupcake was significantly different from the control for the attributes—rate of dissolving, hardness, stickiness, and springiness, and was found to be more hard, more dense, and more cohesive than the other formulations (**Table 4.5, Figure 4.3**). Generally, use of the Splenda® baking blend (SP50) rather than the Splenda®:maltodextrin blend (SP99) results in a cupcake with sensory characteristics that more closely match the sucrose control. These substitutions resulted in a reduction of 20-30 calories, 8-9g of carbohydrate, and 8-13 g sugar per serving with lower levels of reduction associated with use of the Splenda® Baking Blend.

When the original Splenda®: maltodextrin blend was combined with isomalt to enhance its functionality, there was no increase in calories or sugar in the cupcakes (**Table 4.2**). The lowest Splenda®:isomalt blend cupcakes are less springy, less hard, less dense, less cohesive, less moist, and less chewy than the full-sugar control and the formulations containing the commercial Splenda® blends. However, increasing the ratio of the Splenda®:maltodextrin blend to isomalt resulted in a cupcake that more closely matched the sensory attributes of the control (**Table 4.5**). At 30% Splenda® and 70% isomalt ratio, the highest ratio evaluated, textural differences from the control were found only for springiness and cohesiveness. Trends suggest that higher ratios of Splenda®/maltodextrin blend to isomalt may overcome these textural differences.

The panelists did not detect a perceptible difference in intensity of the following flavor notes regardless of formulation: baking powder, eggy, cardboard, salt, and sour (**Table 4.6, Figure 4.4**). The intensity for baking powder ranged from 1.57-1.91, for eggy, from 2.41-2.97; for cardboard from 1.48-2.01; for salt from 1.58-2.02; and for sour from 1.39-1.64 for all cupcake formulations. The cupcake formulations prepared with the commercial Splenda® blends were significantly different from the control for the attributes buttery, vanilla, browned, and sweet. Substituting the original Splenda®:maltodextrin blend (SP99) for sucrose reduced the perceived intensity of buttery, vanilla, browned, and sweet flavor attributes and increased the perception of bitterness and doughy.

The formulation with the Splenda® baking blend (SP50) rather than the Splenda®/maltodextrin blend (SP99) eliminated the differences from the control for doughy and bitterness, but did not overcome the decrease in intensity found for the buttery, vanilla, browned, and sweet attributes. Among the cupcakes formulated with varying ratios of Splenda®/maltodextrin:isomalt blends (SP10, SP20, SP30), few differences in flavor attribute intensities were found. When compared to the Splenda®

baking blend (SP50), few significant differences were found when ratios of 20%Splenda®/maltodextrin:80%isomalt and above were evaluated. These results suggest that the Splenda®/maltodextrin:isomalt blend at the higher ratios than these evaluated will produce a cupcake that will not differ from those prepared with the Splenda® baking blend (SP50). However, use of the isomalt blends rather than the Splenda® baking blend will result in a reduction in both calories and sucrose levels. In addition, use of the isomalt blends resulted in a cupcake in which the buttery note equaled that found in the control. As with the commercial Splenda® products alone, these isomalt blends did not overcome the decrease in the browned and sweet notes associated with the reformulation, although trends suggest that higher ratios may do so (**Table 4.6**).

For the aftertaste attributes, sour was the only aftertaste to be significantly different (**Table 4.7**); intensities reported were in the low range of the scale. The fact that sweet and bitter aftertastes were not significantly different from the control, suggests that the Splenda®/maltodextrin:isomalt blends and commercial Splenda® blends have overcome the reported lingering sweet and bitter aftertastes associated with alternative sweeteners (Wiet and Beyts 1992). No significant replication differences existed.

<u>Principle Component Analysis</u>

PCA, a statistical technique, produces new unnamed composite variables from the 25 sensory attributes evaluated by the panelists by combining those that are correlated. The composite variables or principal components generated are uncorrelated with each other. The two principal components retained explained 68.54% of the variance found among the six formulations. The results for the six cupcake formulations are displayed in 2 dimensions (**Figure 4.6**). The points close to one another have similar values and indicate the presence of similar sensory attributes. The principle components were not interpreted to identify latent variables.

On PCA plots, the 100% Splenda® and 100% Splenda® baking blend® cupcake formulations plotted similarly but not close to the control. The inclusion of isomalt altered the product characteristics, and the 30% Splenda®/70% Isomalt and 100% sucrose control cupcake formulations plotted most similarly (**Figure 4.6**).

Conclusions and Implications

The 30%Splenda®®/70% Isomalt reduced overall calories by 24%, total carbohydrates (g) by 20%, and total sugar (g) by 93%. The descriptive sensory data illustrates that the 30% Splenda®/70% Isomalt cupcake better matches the 100% sucrose control for sensory attributes when compared to the other Splenda®/Isomalt ratios and to the two formulations prepared with commercially-formulated Splenda® products. The instrumental data support this conclusion as well. Overall, substituting blends of Splenda®:isomalt for sucrose resulted in superior cupcakes when compared to the 100% Splenda®/maltodextrin blend and 100% Splenda® baking blend substitutions.

The commercially-available product Splenda®/maltodextrin blend was not a suitable substitute for sugar in baked goods. Use of the Splenda®:sucrose baking blend overcame some of the limitations associated with the use of original sucralose:maltodextrin blend but did not duplicate the functional roles of sucrose. 30%Splenda®/70%isomalt appears to equal or exceed the functional performance of the commercially-available Splenda® (sucralose/sucrose) baking blend in functionality while improving the nutritional profile. It is important that more options for consumers are made available, so that traditionally high sugar foods that are enjoyed by everyone can be prepared with fewer calories, carbohydrates, and sugar. Research has illustrated that substituting alternative sweeteners for sugar in the diet can promote weight loss by creating a deficit in daily caloric intake. Product development of a blend that combines Splenda® (sucralose/maltodextrin) and isomalt to sell to consumers or to food service could help promote dietary changes that would decrease risk for overweight and obesity as well as their associated chronic diseases.

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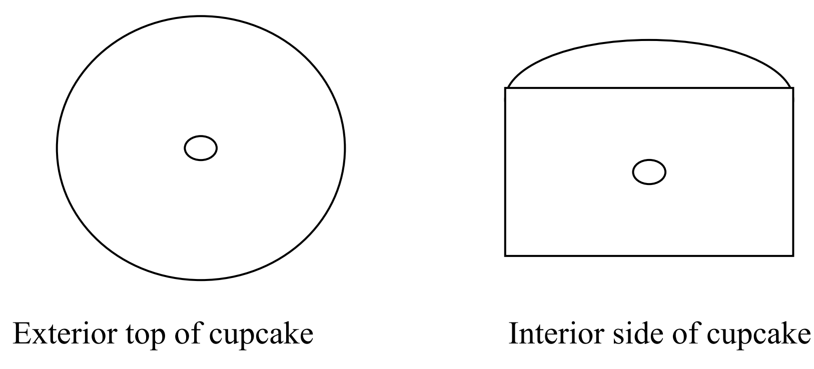

Figure 4.1 Schematic of aperture location of Minolta Color Spectrophotometer measurements on cupcake samples.

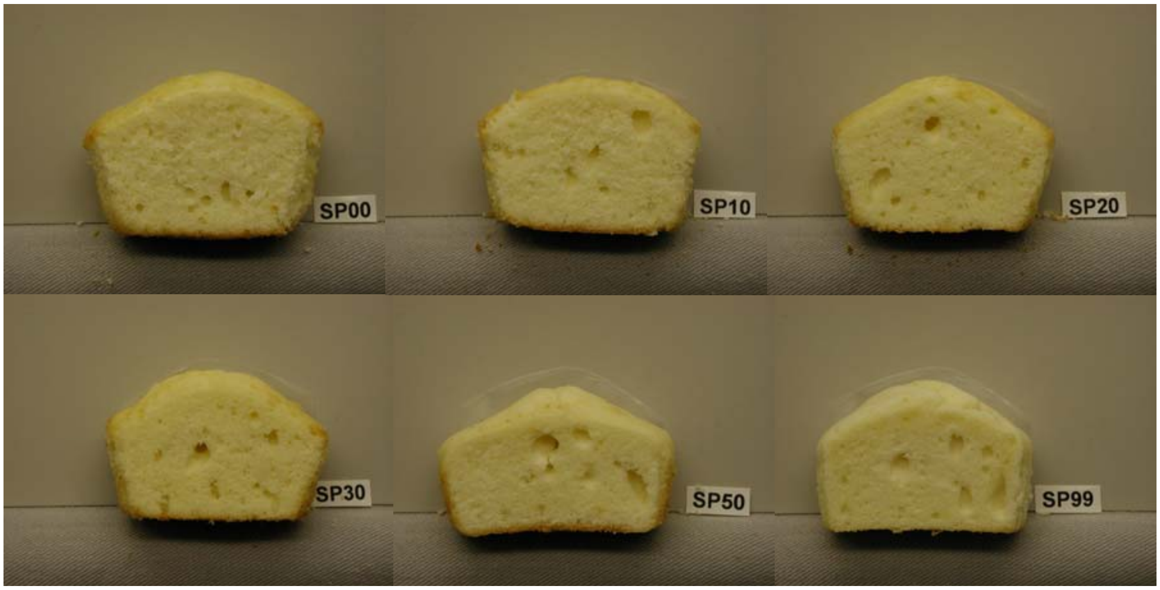

Figure 4.2 Pictures of cross sections of six cupcake formulations taken by Olympus 3000 ZOOM (Melville, NY) digital camera in a MacBeth SpectraLight II Light Booth (Gretag Macbeth, New Windsor, NY) under cool white fluorescent illumination.

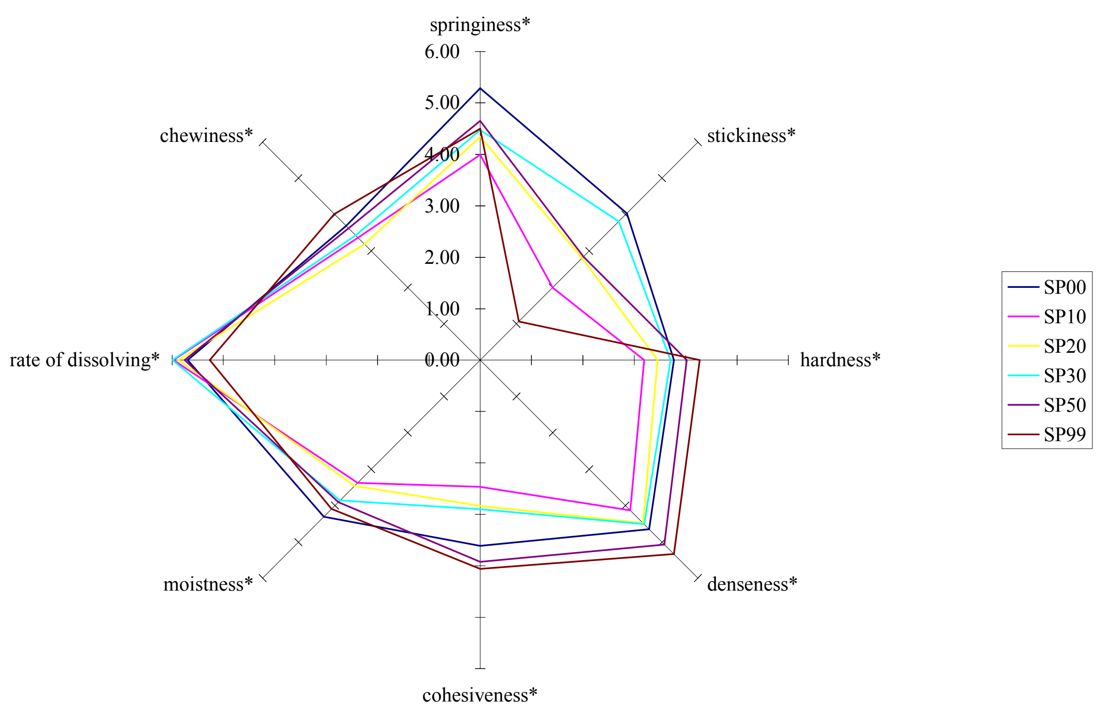

Figure 4.3 Descriptive sensory analysis for texture analysis, n=9; *denotes significant differences.

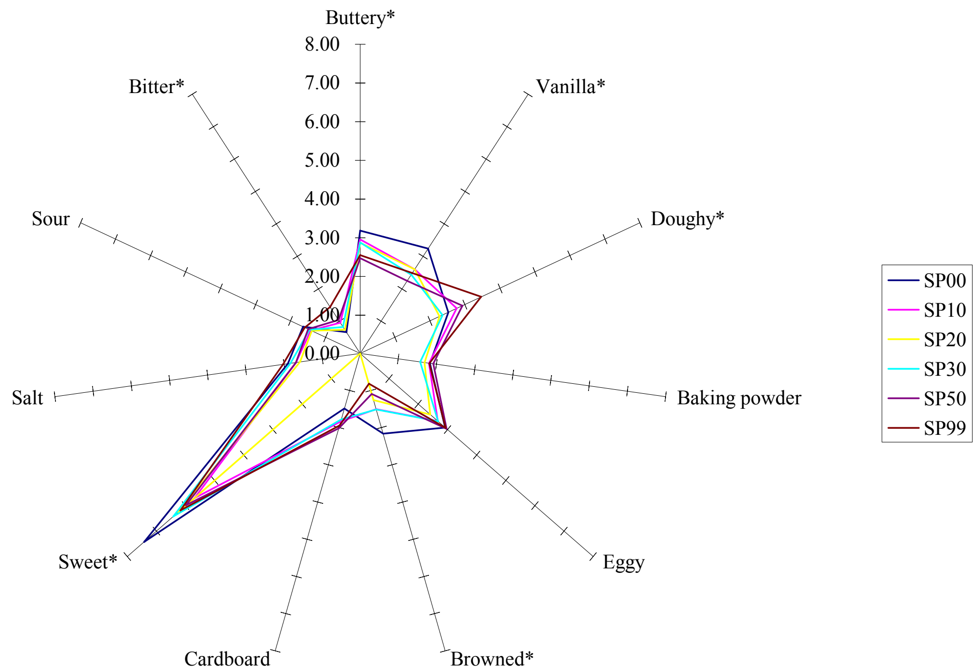

Figure 4.4 Descriptive sensory analysis for flavor attributes, n=9, * denotes significant differences.

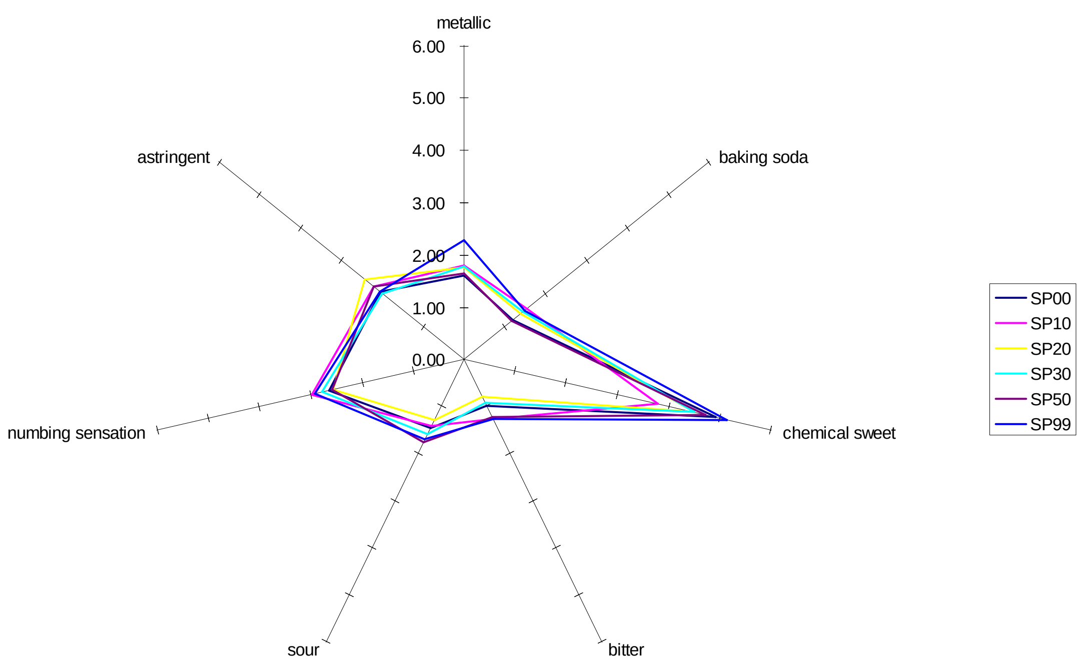

Figure 4.5 Descriptive sensory analysis for aftertaste attributes, n=9; *denotes significant differences.

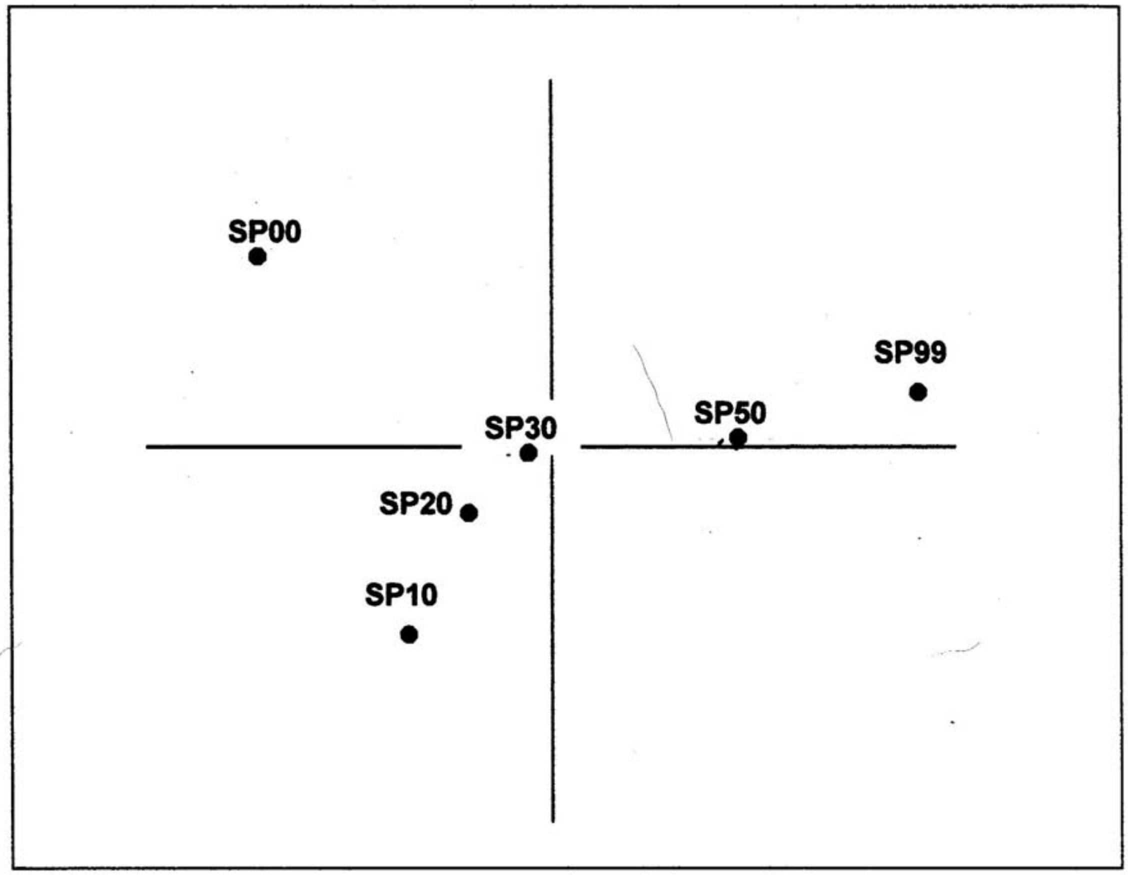

Figure 4.6 PCA plot of cupcake formulations based on flavor and texture attributes from descriptive sensory analysis (n=9 across 3 replications for modified products; n=9 across 2 replications for the control).

Table 4.1 Cupcake formulations and preparation procedures.

Ingredients	Control[b] (g)	Splenda®[ac] (g)	Splenda® Blend[ac] (g)	10% Splenda[b]	20% Splenda[b]	30% Splenda[b]	Product Information
Cake flour	228.1	285.1	273.7	228.1	228.1	228.1	Reily Foods Company, New Orleans, LA
Granulated sugar	212.4						Savannah Foods and Industries, Savannah, GA
Splenda®		37.5		3.0	6.0	9.0	McNeil Nutritionals, Fort Washington, PA
Splenda® Blend			82.6				McNeil Nutritionals, Fort Washington, PA
Isomalt				183.9	163.4	143.0	Palatinit, NJ
Eggs	123.7	154.6	148.4	123.7	123.7	123.7	The Kroger Co., Cincinnati, OH
Whole milk	117.3	146.6	140.8	117.3	117.3	117.3	The Kroger Co., Cincinnati, OH
Butter	112.4	140.5	134.9	112.4	112.4	112.4	The Kroger Co., Cincinnati, OH
Vanilla extract	1.8	2.3	2.2	1.8	1.8	1.8	Tone's, Ankeny, IA
Baking powder	1.6	2.0	1.9	1.6	1.6	1.6	Tone's, Ankeny, IA
Salt	1.3	1.6	1.6	1.3	1.3	1.3	The Kroger Co., Cincinnati, OH

[a] Amounts of constant ingredients were increased proportionally to equalize formula yield.

[b] Procedure: 1. Cream butter in a Kitchen Aid Mixer (Model KS55 St. Joseph, MI) equipped with a paddle attachment for 30 sec on speed 4. 2. Add sugar and cream with butter 30 sec on speed 2; scrape down bowl. 3. Add eggs and vanilla and creamed mixture and blend for 1 minute on speed 4; scrape down bowl. 4. Sift flour, baking powder, and salt; set aside. 5. Add 1/3 flour

mixture to creamed mixture; blend for 5 sec on stirring speed. 6. Add ½ milk to mixture; blend for 10 sec on stirring speed; scrape down bowl. 7. Add 1/3 flour mixture to creamed mixture; blend for 5 sec on stirring speed. 8. Add remaining milk; blend for 10 sec on stirring speed; scrape down bowl. 9. Add remaining flour to mixture; blend 10 sec on stirring speed; scrape down bowl. 10. Place baking cups (Cake Mate, Oscala, FL) into 12-cup muffin pan (Baker's Secret, Reston, VA); portion cupcakes with #20 scoop. 11. Bake at 400°F for 17min in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE).

[c] Procedure: 1. Cream butter in a Kitchen Aid Mixer (Model KS55, St. Joseph, MI) equipped with a paddle attachment for 30 sec on speed 2. 2. Add Splenda® and flour to butter; blend for 1 minute at stirring speed; scrape down bowl. 3. In a second bowl, combine eggs, vanilla, and milk; set aside. 4. Add baking powder and salt to creamed mixture; blend for 10 sec at stirring speed. 5. Add 2/3 milk mixture to creamed mixture; blend for 45 sec at speed 4; scrape down bowl. 6. Add remaining milk mixture; blend 30 sec on speed 6; scrape down bowl. 7. Place baking cups (Cake Mate, Oscala, FL) into 12-cup muffin pan (Baker's Secret, Reston, VA); portion cupcakes with #20 scoop. 8. Bake at 400°F for 12 minutes in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE).

Table 4.2 Nutrient Analysis[a] of cupcake formulations (45g per serving).

Nutrients	Formulations[b]					
	Control	Splenda®:isomalt blends			Commercial Splenda blends	
	SP00	SP10	SP20	SP30	SP50	SP99
Calories (kcal)	169.5	133.5	131.8	130.1	149.0	139.6
Calories from fat (kcal)	60.5	57.0	57.0	57.0	64.6	67.2
Protein (g)	2.4	2.3	2.3	2.3	2.6	2.7
Carbohydrate (g)	24.9	21.9	20.9	19.8	16.9	15.0
Total Sugar (g)	13.7	0.7	0.7	0.7	5.1	0.5
Other carbohydrates (g)	10.9	21.1	20.1	19.1	11.6	14.2
Fat (g)	6.8	6.4	6.4	6.4	7.3	7.6
Saturated Fat (g)	4.0	3.8	3.8	3.8	4.3	4.5
Cholesterol (mg)	48.8	46.0	46.0	46.0	52.1	54.3
Dietary Fiber (g)	0.2	0.2	0.2	0.2	0.3	0.3
Sodium (mg)	57.7	54.3	54.3	54.3	62.3	63.5

[a] ESHA Food Processor Program SQL (Salem, Oregon)
[b] SP00=100% sugar, SP10=10%Splenda®/90%isomalt, SP20=20%Splenda®/80%isomalt, SP30=30%Splenda®/70%isomalt, SP50=100%Splenda® baking blend (sucralose/sucrose), SP99= 100% Splenda® (sucralose/maltodextrin)

Table 4.3 Exterior and interior L*a*b* color[ae] for cupcake formulations[b].

Parameter[c]	LS-means ± standard error[d]						p-value
	Control	Splenda®:isomalt Blends			Commercial Splenda® Blends		
	SP00	SP10	SP20	SP30	SP50	SP99	
Exterior: L*	79.86bc±1.26	79.56c±1.07	82.37b±1.07	83.14b±1.07	86.49a±1.07	86.41a±1.07	0.0012
a*	2.54ab±0.65	3.20a±0.53	1.10b±0.53	0.62b±0.53	0.33b±0.53	0.05b±0.53	0.0146
b*	41.37a±2.09	40.46ab±1.71	36.71ab±1.71	35.64b±1.71	29.11c±1.71	22.17d±1.71	0.0002
Interior: L*	80.92±2.09	81.36±1.70	82.32±1.70	80.96±1.70	81.99±1.70	77.44±1.70	0.4444
a*	-0.71±0.10	-0.70±0.08	-0.77±0.08	-0.71±0.08	-0.49±0.08	-0.56±0.08	0.3136
b*	24.18±1.68	23.20±1.48	25.20±1.48	25.67±1.48	24.97±1.48	24.70±1.48	0.6517

[a] n=18 for all modified products; n=12 for the control.
[b] SP00=100% sucrose control, SP10=10%Splenda/90% isomalt, SP20=20%Splenda/80%isomalt, SP30= 30%Splenda/isomalt, SP50=100% Splenda Baking Blend (sucralose/sucrose), SP99=100% Splenda (sucralose/maltodextrin)
[c] Minolta Color Spectrophotometer Model CM-508-d, Minolta Co Ltd., Ramsey, N.J. with 8 mm viewing area.
[d] LS-means followed by the same letter are not significantly different; Mixed model analysis of variance (SAS, Cary, NC).
[e] 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.

Table 4.4 Texture Profile Analysis[a] for cupcake formulations[c].

Parameter[b]	LS-means ± standard error[d]						
	Control	Splenda®: isomalt Blends			Commercial Splenda® Blends		p-value
	SP00	SP10	SP20	SP30	SP50	SP99	
hardness (g)	724.46b±86.28	761.85b±70.46	925.14b±70.46	926.05b±70.46	1208.67a±70.46	1307.44a±70.46	0.001
cohesiveness	0.50a±0.009	0.41b±0.007	0.41b±0.007	0.41b±0.007	0.45c±0.007	0.42b±0.007	0.000
springiness	0.94a±0.005	0.89d±0.004	0.91d±0.004	0.90cd±0.004	0.92b±0.004	0.92bc±0.004	0.002
chewiness	354.38b±32.22	284.49b±26.91	353.52b±26.91	347.14b±26.91	510.74a±26.91	513.93a±26.91	0.000

[a] n=18 for all modified products; n=12 for the control.

[b] TA-XT2 (50-kg) Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) equipped with an acrylic 1 in. cylindrical, rounded probe and Texture Expert Exceed software (Stable Micro Systems, Surrey, England)

[c] SP00=100% sucrose control, SP10=10%Splenda/90% isomalt, SP20=20%Splenda/80%isomalt, SP30=30%Splenda/isomalt, SP50=100% Splenda Baking Blend (sucralose/sucrose), SP99=100% Splenda (sucralose/maltodextrin)

[d] LS-means followed by the same letter are not significantly different; Mixed models analysis of variance (SAS, Cary, NC).

Table 4.5 Descriptive analysis[a] for texture attributes of cupcake formulations[b].

Attribute	LS-means ± standard error[c]						p-value
	Control	Splenda®: isomalt Blends			Commercial Splenda® Blends		
	SP00	SP10	SP20	SP30	SP50	SP99	
springiness	5.28a±0.43	3.99c±0.41	4.34bc±0.41	4.47bc±0.41	4.65b±0.41	4.50bc±0.41	0.0047
stickiness	4.04a±0.55	1.99c±0.48	2.80ab±0.48	3.81a±0.48	2.84bc±0.48	1.06d±0.48	0.0001
hardness	3.77bc±0.27	3.19d±0.25	3.45cd±0.25	3.70bc±0.25	4.02ab±0.25	4.27a±0.25	0.0001
denseness	4.65ab±0.40	4.13c±0.37	4.48bc±0.37	4.51bc±0.37	5.07a±0.37	5.33a±0.37	0.0011
cohesiveness	3.61a±0.42	2.46b±0.40	2.83b±0.40	2.90b±0.40	3.92a±0.40	4.06a±0.40	0.0001
moistness	4.30a±0.34	3.37b±0.32	3.45bc±0.32	3.85ac±0.32	3.90a±0.32	4.09a±0.32	0.0002
rate of dissolving	5.69ab±0.58	5.97a±0.57	5.87a±0.57	5.99a±0.57	5.75a±0.57	5.26b±0.57	0.0189
chewiness	3.69ab±0.39	3.36bc±0.38	3.19c±0.38	3.43bc±0.38	3.62b±0.38	4.02a±0.38	0.0003

[a] n=9 across 3 replications for all modified products; n=9 panelists across 2 replications for the control; sensory scale range from 0 (not perceptible) to 15 (high intensity)

[b] SP00=100% sugar, SP10=10%Splenda®/90%isomalt, SP20=20%Splenda®/80%isomalt, SP30=30%Splenda®/70%isomalt, SP50=100%Splenda® baking blend (sucralose/sucrose), SP99=100% Splenda® (sucralose/maltodextrin)

[c] LS-means followed by same letter are not statistically different; Mixed model analysis of variance (SAS, Cary, NC).

Table 4.6 Descriptive analysis[a] for flavor attributes of cupcake formulations[b].

Attribute	LS-means ± standard error[c]						p-value
	Control	Splenda®: isomalt Blends			Commercial Splenda® Blends		
	SP00	SP10	SP20	SP30	SP50	SP99	
Buttery	3.18a±0.40	2.95ab±0.39	2.86ac±0.39	2.87ac±0.39	2.47c±0.39	2.55bc±0.39	0.0359
Vanilla	3.23a±0.42	2.60b±0.40	2.60b±0.40	2.43b±0.40	2.24b±0.40	2.48b±0.40	0.0019
Doughy	2.52bcd±0.42	2.77bc±0.41	2.27d±0.41	2.35cd±0.41	2.92b±0.41	3.46a±0.41	0.0001
Baking powder	1.83±0.44	1.80±0.43	1.69±0.43	1.57±0.43	1.91±0.43	1.81±0.43	0.7041
Eggy	2.92±0.47	2.66±0.45	2.41±0.45	2.68±0.45	2.97±0.45	2.93±0.45	0.1792
Browned	2.16a±0.33	1.50b±0.32	1.25bc±0.32	1.51b±0.32	1.09bc±0.32	0.82c±0.32	0.0001
Cardboard	1.48±0.49	1.83±0.48	1.91±0.48	1.77±0.48	2.01±0.48	1.94±0.48	0.2388
Sweet	7.43a±0.60	5.70c±0.59	6.26b±0.59	6.42b±0.59	5.99bc±0.59	6.18bc±0.59	0.0010
Salt	1.90±0.35	1.69±0.34	1.58±0.34	1.83±0.34	1.69±0.34	2.02±0.34	0.1503
Sour	1.64±0.37	1.41±0.36	1.39±0.36	1.46±0.36	1.49±0.36	1.59±0.36	0.7101
Bitter	0.66b±0.33	0.96b±0.31	0.73b±0.31	0.82b±0.31	1.04ab±0.31	1.43a±0.31	0.0010

[a] n=9 panelists across 3 replications for all modified products, n=9 panelists across 2 replications for the control; sensory scale from 0 (not perceptible) to 15 (high intensity)

[b] SP00=100% sugar, SP10=10%Splenda®/90%isomalt, SP20=20%Splenda®/80%isomalt, SP30=30%Splenda®/70%isomalt, SP50=100%Splenda® baking blend (sucralose/sucrose), SP99=100% Splenda® (sucralose/maltodextrin)

[c] LS-means followed by the same letter are not significantly different; Mixed model analysis of variance (SAS, Cary, NC)

Table 4.7 Descriptive analysis[1] for aftertaste attributes of cupcake formulations[3].

	LS-means ± standard error[4]						
Attributes	SP00[2]	SP10	SP20	SP30	SP50	SP99	p-value
Metallic	1.69±0.49	1.79±0.48	1.76±0.48	1.72±0.48	1.64±0.48	2.21±0.48	0.2639
baking soda	1.32±0.34	1.55±0.32	1.39±0.32	1.44±0.32	1.15±0.32	1.49±0.32	0.2250
Sweet	5.04±0.87	3.78±0.85	4.50±0.85	4.42±0.85	4.71±0.85	5.05±0.85	0.3379
Bitter	0.92±0.36	1.27±0.33	0.79±0.33	0.93±0.34	1.21±0.33	1.28±0.34	0.2469
Sour	1.57b±0.38	1.41b±0.37	1.30b±0.37	1.56b±0.37	1.76a±0.37	1.66a±0.37	0.0033
numbing/tingling	2.65±0.66	2.98±0.66	2.54±0.66	2.79±0.66	2.57±0.66	2.94±0.66	0.3333
Astringent	2.12±0.48	2.21±0.46	2.43±0.46	2.02±0.46	2.22±0.46	2.08±0.46	0.6147

[1] n=9, sensory scale range from 0 (not perceptible) to 15 (high intensity).
[2] SE different due to removal of poor formulation from second replication.
[3] SP00=100% sucrose control, SP10=10%Splenda/90% isomalt, SP20=20%Splenda/80%isomalt, SP30=30%Splenda/isomalt, SP50=100% Splenda Baking Blend (sucralose/sucrose), SP99=100% Splenda (sucralose/maltodextrin)
[4] LS-means followed by the same letter are not significantly different.

CHAPTER 5

PTC SENSITIVITY: IMPACT ON CUPCAKE ACCEPTABILITY AND FREQUENCY OF CONSUMPTION OF FOODS PREPARED WITH ALTERNATIVE SWEETENERS

Abstract

Consumers primarily choose foods based on taste. An inherited ability to detect bitterness from phenylthiocarbamide (PTC) indicates increased global taste sensitivity and allows classification of people into three categories: supertasters, medium tasters, and nontasters. Relationships between taster status and food selection have been suggested. In this study, 125 individuals (M=14; F=111) completed a frequency of consumption questionnaire that included 36 foods and/or food categories that contained artificial sweeteners. Acceptability of the sugar control and cupcakes prepared with sucralose was assessed on a 15-cm linescale. Demographic and health data were collected. Participants were: Caucasian (88%) and nonsmokers (89%); 47% routinely used medications/drugs. Taster status was assessed by rating bitterness of a PTC impregnated filter paper (0.03mcg) and a blank control on a 250mm general labeled magnitude scale (gLMS). Spearman's rank correlations revealed significant but weak relationships ($p<0.1$) between taster status and frequency of consumption for: reduced-fat cheese ($r=-0.16$), sweet baked goods prepared with artificial sweeteners ($r=-0.20$), reduced-fat sweet baked goods/pastries ($r=-0.16$), low-sugar baked goods ($r=-0.16$), and low-sugar baked goods ($r=-0.19$). Chi-squares revealed few significant relationships ($p<0.1$) between taster groups (11% supertasters, 70% medium tasters, and 19% nontasters) and consumption

frequency. Supertasters consumed artificially sweetened coffee and baked goods prepared with sugar, brown sugar, or honey less frequently. Increased sensitivity was associated with less frequent consumption of artificially sweetened baked goods and low-carbohydrate baked goods. ANOVA ($p>0.05$) revealed no differences in cupcake acceptability with taster group. Taster status has limited impact on consumption of the selected foods prepared with artificial sweeteners.

Introduction

Chronic diseases, such as diabetes, heart disease, and obesity, are directly related to diet, suggesting that food choice and consumption affects overall nutrition and health status. Currently, 7% of the U.S. population suffers from diabetes--14.6 million diagnosed; 6.2 million undiagnosed (ADA 2006). It is estimated that 65 million Americans suffer from high blood pressure, and 1.2 million Americans will have a first or recurrent coronary attack this year (AHA 2006). In addition, 66.3% of Americans age 20 and older are overweight and/or obese (NCHS 2004). Although evidence is lacking to support an unequivocal link between nutritive sweeteners and chronic disease (ADA 2004), trends in chronic disease incidence suggest that over-consumption of sweets contributes to excessive caloric intake, which leads to weight gain and a greater risk of chronic disease (Henkle 1999). In women, weight gain and increased risk for development of type 2 diabetes has been specifically linked to consumption of sugar-sweetened beverages (Welsh and Dietz 2005).

Consumption of sugars and high-sugar foods greatly exceeds the recommendations by the United States Department of Agriculture (USDA), the Institute of Medicine, and the World Health Organization (WHO). The most recent CFSII

(Continuing Survey of Food Intakes by Individuals 1994-1996) found that the US adult population consumed an average of 25g of sugars and sweets per day. NHANES (National Health and Nutrition Examination Survey 1988-1994) revealed the median daily intake of added sugars, any sweetening agent added during food processing or home preparation, ranged from 40-120g per day across all population groups (ADA 2004). Conversely, the USDA recommends that added sugar intake range from 6-10% of energy, which equals approximately 6 to 18 teaspoons per day depending on total energy intake. The Institute of Medicine, which sets the Dietary Reference Intakes, recommends that the intake of added sugars be no more than 25% of energy. Finally, a recommendation that no more than 10% of energy come from added sugars is made by the World Health Organization (ADA 2004).

Low-energy sweeteners, also known as nonnutritive, high-intensity, artificial sweeteners, as well as sugar alcohols or polyols, lend fewer or no calories to food products when compared to sugar. They are considered to be feasible replacements for sugar in the diet. Theoretically, replacement of sugar by low-energy sweeteners would alter the body's overall energy balance, and subsequently, create a caloric deficit that would promote weight loss and a decrease in the incidence of associated chronic diseases. The substitution of nonnutritive sweeteners for an intake of 20 teaspoons of sugar per day could create a caloric deficit of approximately 320 calories (ADA 2004). A decrease in body weight is associated with replacement of sucrose or high fructose corn syrup with artificial sweeteners in beverages in supplementation studies (Vermunt and others 2003). The effects of incorporation of aspartame-sweetened products into energy-restricted diets of obese individuals to determine if substitution contributed to weight loss were assessed.

There was no significant difference in the short-term weight loss (7.5kg vs. 5.8kg) when the test group and the control group were compared; however at 1-year and 2-year follow-ups, the group that substituted with aspartame-sweetened products had regained significantly less weight when compared to the control group (mean weight loss of 5.1kg) (Vemunt and others 2003). This suggests that incorporation of products containing high intensity sweeteners into the diet is a useful method to promote weight management and its associated benefits over the long-term. The potential contribution of reformulated products to an individual's success at long-term dietary behavior change has also been recognized by the American Dietetic Association (2004); yet, the importance of maintaining products' palatability was also identified.

Initially, low-calorie beverages and food products were developed to target specific dietary needs for individuals with diagnosed medical problems, such as diabetes, obesity, and heart disease; however, with the shift in consumer interest and an increased interest in prevention in the health care community, these modified foods are now targeted to all consumers (Thomson 2004). For the consumer, quality (taste) and nutritional profile of modified products remain the major barriers to dietary incorporation. If these barriers are not overcome, the benefits associated with the use of modified food products' as a replacement for the standard product will fail to be realized (MacEwan and Sharp 2000). Until more is learned regarding individual sweetener preferences, the consumer's ability to make more informed food choices that complement their preferences will remain limited (Warnock and Delwiche 2005).

Although artificial sweeteners allow formulation of reduced-calorie foods and beverages, each sweetener has distinct characteristics that influence its functionality as an ingredient. In order to overcome limitations from the use of a single artificial sweetener, a “multiple ingredient approach” can be adopted that allows manufacturers to more effectively use combinations of sweeteners to optimize the sensory characteristics of their modified products (Deis 2002). The synergistic capability of sweeteners has been demonstrated (Deis 2004, Thomson 2004), and studies have shown that using this approach produces more acceptable formulated products (CCC 2004). Sucralose remains a popular sugar alternative among consumers. Recently, new blends of this non-nutritive sweetener have been made available directly to consumers through retail outlets; alternative blends that include polyols are receiving attention in the culinary sector.

Genetic variation in taste perception impacts sensitivity to oral stimuli, such as sweet tastes—especially from certain artificial sweeteners, bitter tastes, and salty tastes (Snyder, Fast, and Bartoshuk 2004), the burn of capsaicin (Karrer and Bartoshuk 1991), perceivable fat content in foods (Duffy and others 1996, Tepper and Nurse 1997), and alcohol (Duffy, Peterson, and Bartoshuk 2004). Influences on the acceptance of sweet, fatty, and bitter foods and beverages have been documented (Duffy and Bartoshuk 2000). Therefore, it is likely that acceptability of foods containing alternative sweeteners as well as food choice and consumption patterns of tasters and nontasters may differ.

Genetic variation in taste can be identified by assessing taster status. This classification method places individuals into three groups based on the genetic ability to detect bitterness of phenylthiocarbamide (PTC) or 6-n-propylthiouracil (PROP). The classifications include the following: nontasters, those individuals who cannot detect PROP/PTC bitterness; medium tasters, those individuals who rate PROP/PTC as moderately bitter; and supertastsers, those individuals who rate PROP/PTC as extremely bitter. Tasters are considerably more sensitive to oral stimuli than are nontasters. Identifying differences in perception or acceptance of alternative sweeteners according to taster status may allow for development of more palatable low-energy food products (Warnock and Delwiche 2005).

The purpose of this research project was to investigate whether self-reported BMI, health status, and consumption of foods and food products formulated or prepared with alternative sweeteners were associated with taster status classification. Relationships between taster sensitivity and the acceptability of cupcakes prepared with sugar, and alternative sweetener blends were also investigated.

Materials and Methods

Participant profile and food frequency questionnaire

Participants (n=125) completed a demographic questionnaire and answered a series of health- and diet-related questions. Topics included on the questionnaire are the following: gender, age category, class standing, ethnicity, smoking preference, medication use, existing medical conditions, self-perception of body weight, height and weight statistics, and diet preferences. The self-reported height and weight data were used to calculate the body mass index (BMI) (Hammond 2000).

In addition, participants reported frequency of consumption of 36 commonly consumed foods or food categories on 7-point category scales, where consumption patterns were divided into never, less than one time per month, 1-3 times per month, 1-3 times per week, 4 or more times per week, 1-3 times per day, and 4 or more times per day. These categories were then grouped by monthly, weekly, and daily consumption frequency for statistical analyses. Specific foods and food groups were incorporated into the food frequency questionnaire based on the most popular low-calorie foods and beverages (CCC 2004b).

Taster Status

The epidemiological approach outlined by Drewnowski, Kristal, and Cohen (2001), was used to determine taster status of participants. One-hundred twenty five consumers participated in this study. Modifications included use of PTC, rather than PROP, to elicit the taste response. Participants also reported perceived intensity on a general labeled magnitude scale (gLMS) as suggested by Bartoshuk and others (2004), rather than the traditional 9-point intensity scale. The end anchors on the descriptive magnitude scale were ‘barely detectable’ and ‘strongest imaginable sensation of any kind.’ The 250-mm gLMS intensity axis on the scorecard was also labeled from 0 to 100 on an interval scale as suggested by Shultz and Cardello (2001) to facilitate data retrieval. Participants indicated the perceived taste intensity elicited by a control and a PTC (0.3mcg) impregnated filter paper (Flinn Scientific, Batavia, IL) (Ly and Drewnowski 2001). Order of evaluation was held constant to avoid carryover effects. The panelists were provided with written instructions on how to evaluate the control and PTC impregnated filter paper strips. Participants first moisten their mouths and then placed the strip on the tongue for 10 seconds before evaluating the intensity. Palate cleansers (distilled water, baby carrots, and unsalted saltines) to remove any residual taste from the PTC filter paper were provided. Based on PTC scores, the participants were classified as—nontasters (0-12), medium tasters (12-82), supertasters (82+), after adjusting for level of response elicited by the control (Delwiche 2005).

Cupcake formulation and preparation

Participants evaluated the acceptability of four yellow cupcake treatments:100% full-sugar control and 100% sugar replacement with 30%Splenda®®/70%isomalt, 100%Splenda®Baking Blend, 100%Splenda®. All ingredients and their sources, except for the sweetening system, remained constant in all formulations (Table 5.1). Both Splenda® baking blend and Splenda® are readily available in the consumer marketplace, and they have been recommended for use in the consumer marketplace. Previous descriptive sensory panel evaluation of flavor, textural, and aftertaste attributes in cupcakes formulated with blends over a range of Splenda® to isomalt levels was used to identify the blend that produced a cupcake with characteristics most similar to the control. The 30%Splenda®/70%isomalt blend best matched the full-sugar control, which was considered the gold standard product (Gand 2004). The optimal product characteristics that characterize the gold standard are determined by the mixing method as well as the ingredients selected. Therefore, the full-sugar control and 30%Splenda®/70%isomalt were prepared following the conventional mixing method. Because isomalt has a similar crystalline structure similar to sugar, it can be incorporated by creaming. The two cupcake formulations containing Splenda® and Splenda® baking blend were prepared following the muffin method, as suggested by the manufacturer (Splenda 2004) to optimize ingredient functionality; these ingredients cannot be successfully incorporated using the conventional mixing method.

All cupcakes were baked in a rotary oven (National Manufacturing Co., Inc., Lincoln, NE). The full sugar control and 30%Splenda®/70%isomalt ratio were baked for 17 minutes at 204.4˚C (400˚F); the 100% Splenda® and 100% Splenda® baking blend were baked for 12 and 15 minutes respectively at 204.4˚C (400˚F). Baking times varied because treatments containing only Splenda® products baked more rapidly than the other treatments. A higher oven temperature was used to promote browning of final products. Baking order of treatments was randomized.

<u>Sensory and instrumental evaluation</u>

Acceptability of cupcake appearance, texture, and flavor, as well as overall acceptability were evaluated on 15-cm linescales, where 0 = low acceptability, 15 = high acceptability. Data were collected in two panel sessions. Participants on panel session were not allowed to repeat the experiment. Presentation order of samples was randomized across the study. In an individual sensory booth under white lighting, participants completed a consent form, evaluated four cupcake formulations, and completed a demographics questionnaire, a food frequency questionnaire, and a taster status scorecard (**Appendices A-E**) The four cupcake samples were presented in cups coded with three-digit random numbers monadically. Palate cleansers—distilled water, unsalted crackers, and baby carrots—were available to the participants throughout their participation. The entire evaluation process took approximately 15-25 minutes for panelists to complete. Evaluation of cupcakes assessment was first to prevent panelist's bias, and taste intensity was last because the PTC can leave an aftertaste that would have altered panelists' perception of products if this step had been before the acceptability evaluation. Day-to-day variation was assessed for the two panel days and data were pooled across the two days for analysis.

Texture and color of the cupcakes were characterized instrumentally on three randomly selected samples from two replications. A TA-XT2 texture analyzer (Texture

Technologies Corp., Scarsdale, NY) equipped with a 50-kg load cell and Texture Expert Exceed software (Surrey, England), was used to generate a texture profile, following the protocol of the American Institute of Baking (AIB 2004). Both the exterior and interior color (L*a*b* values) of each sample was assessed with a Minolta Spectrophotometer (Model CM-508-d, Minolta Co Ltd., Ramsey, N.J.) with the specular (gloss) component excluded; this instrument has viewing area of 8mm.

Statistical Analysis

Descriptive statistics were used to summarize the demographic, taster status, and food frequency data. Cupcake sensory and instrumental data ($p<0.05$) were also analyzed with ANOVA and SNK, when appropriate. Chi-square analysis ($p<0.1$) was used to identify relationships between taster status and consumption frequency as well as taster status and BMI. Spearman's Rank correlations were used to identify relationships between taster status and consumption of frequency. All data were analyzed using SAS (version 9.1, SAS Inc., Cary, NC).

Results and Discussion

Respondent Profile

125 students, faculty, and staff from the University of Georgia participated in this study. The study population was 11% male and 89% female, 58% were between the ages of 21-23 years, and 88% were Caucasian. According to self-reported height and weight data, 65% of the population was normal weight, which is defined as having a BMI value between 19.0 and 24.9; 10.4% was underweight; 14.4% overweight; and 9.6% obese. 10% were smokers, and 48% used drugs routinely. In addition, 75% followed special diets, mostly low-fat, low-calorie, or vegetarian diets. This college-aged convenience

sample is not representative of the American population by gender, age, ethnicity, and BMI.

Taster Status

Within the sample, nearly three-fourths of the study population was comprised of medium tasters (70%). Nontasters made up 19%, and supertasters made up 11%. The typical distribution of taster groups within the American population is 25% nontasters, 50% medium tasters, and 25% supertasters; therefore, this study sample does not resemble the typical distribution (NIDCD 2004), although use of the gLMS assessment tool rather than a 9-point intensity scale may have better differentiated among taster groups. The Chi-square analysis between BMI and taster status revealed no significant relationship ($p<0.1$), suggesting that BMI class was not related to taster status classification. Regression analysis would be necessary to totally control for confounding variables; BMI is influenced by age, sex, ethnicity, education, income, and tobacco use. However, due to use of a convenience sample of college students, little variability was found in age, sex, ethnicity, education, or tobacco use.

Sensory Data

Cupcake Acceptability

Appearance, flavor, texture, and overall acceptability of four cupcake treatments were evaluated by the participants. No significant differences between acceptability of the four cupcake formulations were found, although trends emerged. The 100% full-sugar control was rated higher than the three other formulations for all acceptability attributes, and the 100% Splenda® formulation was rated the lowest for all attributes when compared to all other formulations (**Table 5.1**). No significant differences were found in acceptability of the four cupcake treatments, due to taster status groups (**Table 5.1**).

Instrumental Data

Texture

Texture was measured by conducting an instrumental texture profile analysis on samples of the cupcake formulations to assess the parameters—hardness, cohesiveness, springiness, and chewiness. Replication differences apparent between the two consumer panel days were for the parameters hardness (p=0.0257) and chewiness (p=0.0419). This difference can be explained due to the 100% Splenda® formulation, which varied significantly between replication 1 and 2 (**Table 5.2**), confirming that Splenda® does not perform consistently in baked products. Significant differences were identified between formulations for the parameters—hardness and chewiness. The hardest and chewiest cupcakes were the formulations containing commercial Splenda® blends, which did not differ from each other. The full-sugar control and 30% Splenda®/70% isomalt blend cupcakes were significantly less hard and chewy than were the cupcakes prepared with commercially formulated Splenda® blends. Differences in cohesiveness and springiness were not found.

Color

For the color data, formulation differences were apparent. These differences can be attributed to the inability of sucralose to facilitate Maillard browning. The four cupcake treatments were significantly different for all exterior color values and the interior color b value. These data are shown in **Table 5.3**. Both the cupcake formulations containing Splenda®—100% Splenda®, 100% Splenda® Baking Blend—

differed with formulation. In L*a*b* color space, the L* describes lightness, a* describes red to green, and b* describes the range from blue to yellow. The L* values are particularly significant in this study because they help to quantify the extent of browning, the full-sugar control was the darkest, which alludes to more browning; the full-Splenda® was the lightest, which suggests less browning.

Frequency of Consumption and Taster Status Trends

Chi-square analysis revealed few significant relationships ($p<0.1$) between taster status classification and food choice and consumption patterns. However, tasters, medium and supertasters, consumed coffee sweetened with artificial sweeteners less frequently than nontasters, and no differences in consumption of black coffee or coffee sweetened with sucrose due to taster status were found. Previously, Ly and Drewnowski (2001) have suggested that addition of sucrose to black coffee may mask bitterness present. A similar effect may not occur with nonnutritive sweetener addition. Tasters also eat sweet baked goods less frequently, whether the sweetener is a nutritive or nonnutritive one. As PTC sensitivity increases, sweet baked goods made with artificial sweeteners and low- carbohydrate baked goods and pastries were consumed less frequently. Spearman's Rank correlations revealed significant but weak relationships between frequency of consumption and taster status (**Table 5.4**). Previous studies suggest that supertasters and medium tasters were more likely to rate the perceived sweetness of sucrose and saccharin solutions as more intense than nontasters (Drewnowski and others 1997). Hedonic studies revealed that as taste sensitivity increases, "dislike" of solutions increasing in sucrose concentration increased (Drewnowski and others 1997). Duffy and Bartoshuk (2000) found in their female study population that liking of sweet foods decreased as sensitivity to PROP bitterness increased.

Conclusions and Implications

Although acceptability of the cupcake formulations did not differ significantly, trends revealed the full-sugar control was consistently rated the highest, and the 100% Splenda®/maltodextrin blend was consistently rated the lowest for all sensory acceptability attributes by consumer panelists. Instrumental assessments suggest that differences exist that may have influenced acceptability ratings by more discriminating panelists. Standard deviations suggest diverse opinions about the acceptability of these cupcakes. However, taster status did not impact acceptability of cupcake treatments prepared with varying levels of sugar, Splenda®, and isomalt.

Taster status also appears to have limited impact on frequency of consumption of the selected foods prepared with alternative sweeteners. Both the Chi-square analysis and Spearman's Rank correlations revealed few significant and strong relationships between taster status classification and food choices and consumption patterns. Spearman's Rank correlations revealed frequency of consumption of sweet goods made with alternative sweeteners and low-carbohydrate baked goods and pastries were consumed less frequently as PTC sensitivity increased. Although, the relationship is a weak one, it is a consistent relationship across several food groups.

Some debate has centered on nutrition education approaches. Should nutrition interventions and messages be targeted to a group of individuals or tailored for a single individual (Kreuter 2000)? Will more focused education promote better client compliance? When it comes to food choices and consumption patterns, the main motivator continues to be taste (Duffy and Bartoshuk 2000). Therefore, it is not surprising that MacEwan and Sharp (2000) found that quality of modified food products, such as low-calorie/carbohydrate baked goods, remains the major barrier preventing their incorporation into the daily diet. In addition, for dietary incorporation to occur, it is important that the reduction in energy nutrients be large enough to warrant selection (MacEwan and Sharp 2000). Meeting both criteria remains a product development challenge.

Based on the results of this study which revealed few significant and strong relationships between taster status and frequency of consumption of foods containing alternative sweeteners, nutrition education messages do not need to be tailored to an individual based on their taster status classification. Instead, these nutrition education messages should target the barriers for consumers' incorporation of modified products into their diet, such as quality and nutritional profile and can be directed toward a broader audience. Further, the focus of health professionals should shift from reducing energy intake alone to facilitating behavioral change coupled with dietary incorporation of healthier selections by addressing these two barriers.

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Table 5.1 Acceptability[a] of four cupcake formulations by taster status classification (n=125).

Taster status	Formulations[b] 100% full-sugar control (SP00)	30%Splenda®/ 70%isomalt (SP30)	100% Splenda® Baking Blend (SP50)	100% Splenda® (SP99)
	----------means ± standard deviations----------			
	Appearance			
Nontaster	8.8±2.4	7.1±2.5	6.6±2.7	5.3±3.0
Medium taster	8.4±2.8	6.7±2.8	5.6±3.3	4.7±3.1
Supertaster	9.5±3.4	7.6±3.5	5.6±3.3	4.3±3.8
All participants	8.6±2.9	6.9±2.9	5.8±3.2	4.7±3.2
	Texture			
Nontaster	8.2±3.1	5.5±1.9	5.5±3.1	5.6±3.4
Medium taster	8.0±3.2	5.7±2.9	5.7±3.2	5.9±3.4
Supertaster	9.5±3.5	6.6±3.5	4.9±3.6	4.6±3.2
All participants	8.2±3.3	5.8±2.8	5.7±3.2	5.6±3.4
	Flavor			
Nontaster	8.8±2.6	7.2±2.4	6.9±3.4	7.0±2.8
Medium taster	8.5±3.2	6.6±3.1	6.9±3.2	6.6±3.2
Supertaster	9.6±3.8	6.6±3.1	6.3±3.2	5.5±3.5
All participants	8.7±3.2	6.8±3.0	6.7±3.3	6.6±3.1
	Overall Acceptability			
Nontaster	8.6±2.6	6.6±1.9	6.6±2.7	6.4±2.6
Medium taster	8.7±2.9	6.3±2.8	6.4±3.0	6.1±3.0
Supertaster	9.1±3.6	6.9±3.3	5.4±2.5	4.6±3.1
All participants	8.8±2.9	6.4±2.7	6.3±2.9	6.0±3.0

[a] 9-point hedonic scale where 1=dislike extremely, 9=like extremely; $p>0.05$ according to ANOVA.

[b] SP00=100% sucrose control, SP30=30% Splenda/70% isomalt blend, SP50=100% Splenda Baking Blend (sucralose/sucrose), SP99= 100% Splenda (sucralose/maltodextrin)

Table 5.2 Texture Profile Analysis[a] of cupcake formulations[c].

Parameter	Means ± standard deviations[b]				p-value
	100% full-Sugar control (SP00)	30%Splenda®/ 70%isomalt (SP30)	100% Splenda® Baking Blend (SP50)	100% Splenda® (SP99)	
hardness(g)	794.80b±69.64	1049.30b±106.66	1540.69a±361.30	1626.27a±646.43	0.0003
cohesiveness	0.49a±0.011	0.41c±0.013	0.46b±0.022	0.44b±0.012	0.0001
springiness	0.94a±0.006	0.90bc±0.004	0.91b±0.012	0.91b±0.006	0.0001
chewiness	368.90b±30.35	393.49b±50.93	655.94a±149.13	664.09a±253.78	0.0004

[a] measured by TA-XT2 (50-kg load cell) Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) equipped with an acrylic 1 in. cylindrical, rounded probe and data analyzed with Texture Expert Exceed (Stable Micro Systems, Surrey, England).
[b] $p<0.05$ according to ANOVA, means followed by different letters are significantly different according to SNK. Means are across 3 samples and 2 replications.
[c] SP00=100% sucrose control, SP30=30%Splenda/70%isomalt blend, SP50=100% Splenda Baking Blend (sucralose/sucrose), SP99=100% Splenda (sucralose/maltodextrin).

Table 5.3 Exterior and interior L*a*b* color[ad] of cupcake formulations[c]

Parameter		means ± standard deviation[b]				
		100% full-sugar control (SP00)	30% Splenda/ 70% isomalt (SP30)	100% Splenda Baking Blend (SP50)	100% Splenda (SP99)	p-value
Exterior:	L*	84.30a±0.60	84.19a±2.32	86.39b±1.37	86.50b±1.21	0.0146
	a*	-0.09b±0.15	0.17a±0.24	0.38a±0.19	0.25a±0.13	0.0024
	b*	30.50a±1.95	28.40b±1.16	27.46b±2.04	21.80c±2.54	0.0001
Interior:	L*	84.38±1.35	82.06±2.53	84.98b±1.08	80.85b±5.04	0.1521
	a*	-0.87±0.06	-0.65±0.28	-0.58±0.15	-0.25±0.57	0.0622
	b*	22.05b±0.67	24.50ab±2.33	25.33a±2.55	26.83a±1.92	0.0068

[a] measured by Minolta Color Spectrophotometer (Model CM-508-d, Minolta Co Ltd., Ramsey, N.J.) with specular gloss component excluded.
[b] $p<0.05$ according to ANOVA, means followed by different letters are significantly different according to SNK. Means are across 3 samples and 2 replications.
[c] SP00=100% sucrose control, SP30=30%Splenda/70%isomalt blend, SP50=100% Splenda Baking Blend (sucralose/sucrose), SP99=100% Splenda (sucralose/maltodextrin).
[d] 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.

Table 5.4 Spearman's Rank coefficient correlations ($p<0.10$) for frequency of consumption[a] of certain food groups by taster status[b] (n=125).

Food Product	r-value	p-value
Reduced-fat cheese	-0.16	0.072
Sweet baked goods prepared with artificial sweeteners	-0.20	0.026
Reduced-fat sweet baked goods/pastries	-0.16	0.070
Low-sugar baked goods	-0.16	0.075
Low-carbohydrate baked goods	-0.19	0.038

[a] 36-item frequency of consumption questionnaire where categories consumption=daily, weekly, monthly.
[b] based on PTC (0.3mcg) scores: nontasters (0-12), medium tasters (12-82), supertasters (82+) on a gLMS labeled with anchors: 1.4=barely detectable and 100=strongest imaginable sensation of any kind.

CHAPTER 6

CONCLUSIONS

Alternative sweeteners provide opportunities to consumers and food developers because these chemical substances can be used to replace sugar in foods and beverages. Over time, it has become clear through research and product development efforts that blending alternative sweeteners creates superior food and beverage products that exhibit a taste profile more similar to sucrose. This is advantageous for both companies and consumers. Companies produce a product that consumers will purchase, and consumers get a product with a satisfying taste and expected quality attributes, which motivates them to incorporate these foods and beverages into their diet. By incorporating a low-calorie substitute for regularly consumed foods, a caloric deficit can be created, thus promoting a reduction in risk for chronic disease. Two major barriers to dietary incorporation of modified products remain: 1) an altered quality profile, and 2) the perception that the improvement in nutritional profile is not large enough to warrant dietary incorporation of an inferior quality product (MacEwan and Sharp 2000).

One popular treat is cake. Traditionally, it is prepared with sugar (sucrose) because the sugar is responsible for many of its quality characteristics. Functional roles of sucrose in cake include sweetness, browning, flavor enhancement, structure, tenderness, bulk, water activity control, and shelf-life (Alexander 1998; Paeschke 2003). A high quality cake is symmetrical with a good volume, a fine grain, and a moist, tender crumb (Penfield and Campbell 1990). Substituting alternative sweeteners for sugar in cake is difficult because generally, one or more of the functional roles of sugar cannot be performed by the alternative sweeteners. Limitations, such as lingering sweet and bitter tastes, associated with alternative sweeteners can be overcome by blending sweeteners to replace sugar. Blending of alternative sweeteners can be utilized to improve the flavor, texture, and aftertaste profiles of various products, including baked goods (Deis 2004, Thomson 2004). Research has demonstrated that tasters, individuals who detect bitterness of PTC or PROP, are more sensitive to oral stimuli, which impacts their food acceptance of sweet, fatty, and bitter foods (Duffy and Bartoshuk 2000). In addition, supertasters find the range of high intensity sweeteners and sugars to be sweeter than individuals who are medium to nontasters (ADA 2004). Identifying these differences in perception or acceptance of alternative sweeteners may allow for the development of more palatable low-calorie food products (Warnock and Delwiche 2005), overcoming the barriers to dietary incorporation for some consumers.

Research Project Findings

Blending a low-energy bulk sweetener, isomalt, with a high intensity sweetener, Splenda® (sucralose/maltodextrin) in baked yellow cupcakes produced cupcakes that were more similar to the full-sugar control than were the commercially formulated Splenda® blends currently available to consumers. Descriptive sensory analysis revealed that the blend of 30%Splenda®/70%isomalt best matched the full sugar control for flavor, texture, and aftertaste attributes despite some significant differences in specific attributes when compared to the 20%Splenda®/80%isomalt blend, 10%Splenda®/90%isomalt blend, and two commercially formulated Splenda® blends—100% Splenda® (sucralose/maltodextrin) blend and 100% Splenda® Baking Blend (sucralose/sucrose). Principle Components Analysis revealed no cupcake formulation was exactly the same as the full-sugar control although the 30% Splenda:70% isomalt blend was most similar to the sucrose control. Instrumental analysis supported these findings, although more differences from the control were found through instrumental testing than were identified by the descriptive sensory panel. These instrumental assessments are very sensitive, and it is unlikely consumers would identify differences not found by the descriptive panel.

This 30% Splenda:70% isomalt formulation along with the full-sugar control, the 100% Splenda® (sucralose/maltodextrin) blend, and the 100% Splenda® Baking Blend (sucralose/sucrose) was tested in the consumer sensory analysis experiment. This experiment revealed no significant differences in acceptability of flavor, texture, appearance, and overall; however, trends were found. The full-sugar control was rated higher than the 30% Splenda®:70% isomalt blend and the two commercially formulated Splenda® blends. The 100% Splenda® formulation was rated the lowest. The standard deviations suggest wide variability in acceptability of these modified formulations among these consumers.

Acceptability did not differ with taster status classification. The taste sensitivity data revealed that the study sample was made up of 19% nontasters, 70% medium tasters, and 11% supertasters. Analyzing the frequency of consumption for specific foods by taster status revealed few significant relationships. Significant relationships were found for the food categories—reduced-fat cheese, sweet baked goods prepared with artificial sweeteners, reduced-fat sweet baked goods, low-sugar baked goods, and low-carbohydrate baked goods. All exhibited an inverse relationship with PTC taste sensitivity. However, all significant relationships were weak. No relationship between taster status and BMI was found.

Implications of Research Project

The taste mechanism is not fully understood, and tasting capabilities vary from individual to individual as well as throughout an individual's lifespan (Schiffman 1997). Approximately, 200,000 Americans experience chemosensory problems each year. Also, medicines, diet composition, and illnesses can alter the ability to taste (NIDCD 2004). By using PTC/PROP status measurement as a screening tool to categorize their clients into groups of non-tasters, medium tasters, and super-tasters, health professionals could potentially improve their understanding of their client's ability to taste, and may enable these professionals to tailor dietary interventions based on their client's food choices/preferences, potentially increasing dietary compliance.

According to this research project, a relationship did not exist between taster status and acceptability of cupcakes prepared with alternative sweeteners, specifically sucralose and isomalt. The most appropriate approach would be to target dietary interventions to at-risk populations for whom these are popular products, regardless of taste sensitivity.

The Splenda®:isomalt blend produced a product more similar, though not identical, to the control than those currently available to consumers. However, consumer acceptability results suggest that this blend will not overcome the quality barrier to dietary incorporation, although nutritional effects should be adequate to justify consumer selection of these products. Therefore, future research in this area should determine if an alternative Splenda®:isomalt blend will more closely match the full-sugar control.

Because the trends from the descriptive sensory analysis and instrumental analysis revealed that as the amount of Splenda®: isomalt increased the quality of the product increased, the following additional ratios should be investigated: 40%Splenda®/60% isomalt, 50%Splenda®/50% isomalt, and 60% Splenda®/40% isomalt. Further, the ratio that most closely matches the control should be incorporated into other baked products to determine its performance. If successful in a myriad of products, this would support the marketing of the identified blend to food service and consumers for baking purposes.

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APPENDICES

APPENDIX A

Consumer sensory panel consent form

I, ___________________________ , agree to participate in a research study titled "Taster Status and Baked Good Acceptability" conducted by Hillary Johnson from the Department of Foods and Nutrition at the University of Georgia (542-4910) 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 stop taking part without giving any reason and without penalty. 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 investigate the relationship between taster status, acceptability of a baked good, and food choices.

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

- Read and sign consent form. (1-2 minutes)
- Evaluate baked products according to sensory and texture scorecards (10-20 minutes)
- Complete demographic and consumption data questionnaires. (1-2 minutes)
- Test my taster status by placing a PTC impregnated filter paper (0.3 micrograms) on my tongue and indicating the extent to which a taste is perceived on the corresponding scorecard. (1-2 minutes)
- Cleanse my palate with distilled water, unsalted crackers, and carrots; however, use of these palate cleansers at the conclusion of the assessment of taster status is a personal decision. (1-2 minutes)

Following my participation, I will be offered commercial snacks and beverages upon leaving the study testing site. Students in FDNS 4610 who have selected participation on this sensory panel as an extra credit option will receive class credit. No additional compensation will be offered.

At the levels used in these tests, there is no known risk from tastants used in assessing taster status. Slight distaste may occur among sensitive individuals. I will be provided palate cleansers (water, crackers and carrots) to remove any residual tastes after testing for taster status. 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 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 Hillary Johnson at 542-4910.

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.

Hillary Johnson__________	__________________________	_________
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; E-mail Address IRB@uga.edu

APPENDIX B

Cupcake product evaluation form

Cupcake Scorecard

Panelist______ Sample Number______

Please taste each cupcake and evaluate its appearance, texture, flavor, and overall acceptability. Place a mark across the line (______) indicating the degree to which you like each characteristic in the sample. Please rinse between samples, and eat some cracker and/or carrot before sampling the next product.

Overall Appearance:

____

dislike extremely like extremely

Overall Texture:

____

dislike extremely like extremely

Overall Flavor:

____

dislike extremely like extremely

Overall Acceptability:

____

dislike extremely like extremely

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. **Class standing (if applicable):**
___1st year ___2nd year ___3rd year ___4th year ___5th year ___6th year ___7+ year

4. **Do you consider yourself to be…?**
________White
________African-American
________Native American
________Hispanic
________Asian
________Other

5. **Do you smoke cigarettes, cigars, or use other tobacco products?**
_____ yes _____ no

6. **Are you taking any medications (prescribed or over-the-counter) at this time?**
_____ yes _____ no

7. **Mark any of the following medical conditions that affect you.** (Check all that apply)
____ Hypertension _____ Sinus Problems _____ Diabetes
____ Heart-related _____ Dental Problems/Braces/Dentures
____ Nutrient deficiency _____ Food Allergy: ____________

8. **Do you consider yourself to be…?**
_____ overweight _____ underweight ______ normal weight

9. **Weight:** _______ **lbs**

10. **Height:** ____**ft.** ____**in.**

11. **Do you follow any of the following special diets? (**Check all that apply)
_____ Vegetarian
_____ High Protein
_____ Low Fat
_____ Low Calorie
_____ Low Sodium
_____ Lactose-free
_____ Other, please specify _______________________________

Thank you!!

APPENDIX D

Food frequency of consumption questionnaire

Code: _____

Think about how often you ate the foods listed below within the last year. Please indicate the response that best describes how often you ate each food. Check only one answer for each food.

	Frequency of Consumption						
How often did you consume the following foods during the last year? (Check the best response)	Never	Less than 1/month	1-3 x per month	1-3x per week	4+ x per week	1-3 x per day	4+ x per day
1. Diet Soda Drinks							
2. Regular Soda Drinks							
3. Coffee with or without cream sweetened with sugar							
4. Coffee with or without cream sweetened with artificial sweetener							
5. Black Coffee							
6. Black Tea sweetened with sugar							
7. Black Tea sweetened with artificial sweetener							
8. Black Tea unsweetened							
9. Beer/Wine							
10. Low-carbohydrate alcohol							
11. Reduced-fat milk (2%, 1%, skim)							
12. Fruit juice/Non-carbonated carbonated beverages							
13. Sugar-free/light fruit juice/non-carbonated beverages							
14. Regular Yogurt							
15. Nonfat Yogurt							
16. Yogurt sweetened with artificial sweeteners							
17. Full fat cheese							

18. Reduced-fat cheese							
	Frequency of Consumption						
How often did you consume the following foods during the last year? (Check the best response)	Never	Less than 1/month	1-3 x per month	1-3x per week	4+ x per week	1-3 x per day	4+ x per day
19. Frozen yogurt							
20. No sugar added frozen yogurt							
21. Low-carbohydrate frozen yogurt							
22. Ice cream							
23. Reduced-fat/light/fat-free ice cream							
24. Sorbet							
25. Soy- or Rice-based Ice cream							
26. Regular chewing gum							
27. Sugar-free chewing gum							
28. Sweet baked goods made with white sugar, brown sugar, or honey							
29. Sweet baked goods made with artificial sweeteners.							
30. Reduced-fat sweet baked goods/pastries							
30. Low-sugar sweet baked goods/pastries							
31. Low-carbohydrate baked goods/pastries							
32. Reduced-fat chips/snacks							
33. Reduced-sugar snacks							

Do you use sugar alternatives, such as Splenda, Equal, or Sweet One, etc. in foods you prepare? _______ yes _______ no

Do you use sugar alternatives, such as Splenda, Equal, or Sweet One, etc. in beverages you prepare?
_______ yes _______ no

Thank you!!!

APPENDIX E

Taster status scorecard

It is important to our study that you evaluate both paper strips. *Thank you!*

Judge Number________

Taster Status Assessment

<u>Now, Please evaluate the one with the green dot on the bag.</u>

You have two paper strips. Please eat a bite of cracker to remove any taste remaining from evaluating the cupcakes.

1. Take a sip of water to moisten your mouth. Swallow the water.
2. Remove the strip from the bag with the **green** dot.
3. Place the paper strip on your tongue to moisten it. Leave it your tongue for about 10 sec.
4. Replace the used strip in the bag.
5. Did you detect a taste?
   Yes_______
   No_______

6. Did you detect a taste?
______yes ________no (Check one)

If yes, what taste was present?
____

If yes, please indicate how strong the taste was on the scale below.

Second paper strip (green dot)
Place a slash mark (/) across the line on the scale below to indicate how strong the taste is.