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CHAPTER I: INTRODUCTION AND JUSTIFICATION

A consensus remains among health and nutrition professionals that most Americans should lower their dietary intake of fat, saturated fat, and cholesterol (Gershoff, 1995). While 38% of total fat intake is currently consumed by Americans, the Nutrition Committee of the American Heart Association still recommends that Americans consume less than 30% of total calories from fat (Glueck et al., 1994). This guideline has been set to reduce the risk of diseases that have been associated with excessive intake of fat in the diet, such as coronary heart disease, obesity, hypertension, certain cancers (e.g. breast, colon, or prostate), and possibly gall bladder disease (Akoh, 1995). In 1994, the Nutrition Task Force (NTF) developed the “Eat Well” action plan to help accomplish the Health of the Nation’s targets on diet and nutrition (Richardson et al., 1994). Targets set for the year 2005, in diet and nutrition, include to reduce the average percentage of food derived from saturated fatty acids from 17% to no more than 11% and to reduce the average percentage of food energy derived from total fat from 38% to no more than 30%; in obesity, to reduce the proportion of men and women aged 16-64 who are obese from 8% for men and 12% for women to no more than 6% and 8%, respectively; and in blood pressure, to reduce mean systolic blood pressure in the adult population by at least 5 mm Hg (Richardson et al., 1994). Although, consumption of fat remains high, public concern and awareness regarding the role that diet plays in the potential for disease has increased (Shamil and Kilcast, 1992). In 1991, the Food Marketing Institute conducted a survey to rate shoppers’ nutritional concerns, and found that 42% of respondents listed fat content concerning them or their family most in food, followed by cholesterol (37%), and salt (21%) (Anonymous, 1992).

As long as health professionals continue stressing the importance of diet in the prevention of certain diseases, consumers will look for ways to reduce fat in their diets (Anonymous, 1992). In response to the current public health status, the food industry has provided solutions by reducing the fat, calorie, cholesterol and sodium content in various food products. A survey conducted in 1993, by the Calorie Control Council, found that 136 million American adults consume low-fat, reduced-fat or fat-free products, and that more than 6 in 10 consumers want more reduced-fat choices available (Hollingsworth, 1996). Food processors are responding, and as a result, more than 1,000 new low-fat and fat-free products have been introduced annually since 1990, according to the International Food Information Council Foundation (Hollingsworth,

1996). However, as fat content in foods is reduced, sensory characteristics are altered. Since most consumers enjoy the taste of high-fat foods, reduced-fat versions are often rejected because they do not match the taste and palatability of their full-fat counterparts. Bruhn et al. (1992) researched consumers' perception of high-fat foods and their attitudes toward lower-fat foods. Researchers found that the three most important factors respondents consider when shopping for food were taste (84%), product safety (71%), and nutrition (69%). To expand low-fat markets, fat-substitutes and combinations of fat-substitutes must reflect the complexity of the fat being replaced (Anonymous, 1992; Blenford, 1995).

Fats and oils impart many functional, nutritional and sensory properties in food products. Fat interacts with other ingredients to develop texture, mouthfeel, structure and lubricity in foods (Giese, 1996). Fat also acts as a flavor carrier, enhancing the perception of taste. Nutritionally, fat aids in the absorption of fat-soluble vitamins: A, D, E, and K (Giese, 1996). Since fat provides numerous qualities in foods, fat replacement becomes a difficult task (Jones, 1996). Fat replacers play a role in substituting some of fat's functions. Unfortunately, most fat replacers cannot recreate the functional and sensory properties of fat. Thus, a "systems approach" to fat replacement, using several carbohydrate, protein, or lipid-based ingredients individually or in combination is often used (Akoh, 1998).

Fat and calorie reductions continue to be a leading priority in baked product development (Bath, et al., 1992). In 1994, 544 new bakery ingredients were introduced, while in 1995, low-fat and low-calorie baked goods annual sales reached \$720 million (Shukla, 1995). Carbohydrate fat-replacers play an important role in mimicking the sensation of fat in baked goods, primarily by binding water and bulking of their solids. Carbohydrate-substitutes also aid in reducing fat because they provide 1-4 kcal/g rather than 9 kcal/g of traditional fats (Lindsay, 1996). Carbohydrate-substitutes include polydextrose, altered sugars, starch derivatives, cellulose, hemicellulose, and gums (Glueck et al., 1994).

The combination of carbohydrate-substitutes is becoming an interesting area in the development of reduced-fat baked goods. Specifically, maltodextrins and high-fructose corn syrup-90 (HFCS-90) can function as fat mimetics in flour-based dry mixes, baking systems, and fillings and icings. Maltodextrins and HFCS are nutritive polysaccharides obtained from the hydrolysis of corn starch. These plant-derived carbohydrates offer many benefits to product developers and ultimately consumers: (1) they are often more effective at reducing

water activity in a reduced-fat formula, compared to protein-based substitutes, (2) they are hydrophilic, available to bind water, creating a carbohydrate-water network that can mimic the texture of fat, (3) they are completely digestible as part of the normal metabolic process, (4) they are economical and consistently available, and (5) they are generally recognized as safe (GRAS), so no FDA approvals are needed. Maltodextrin use in baked goods such as cakes, muffins, and soft cookies is increasing, however, no one formulation will fit every application (Nonaka, 1997). Few studies have evaluated the performance of a maltodextrin-gel as a partial replacement for fat in a high-ratio white-layer cake formulation.

Therefore, the focus of the study was: (1) to evaluate the performance of a maltodextrin gel as a replacement (25, 50, 75, and 100%) for shortening along with high-fructose corn syrup-90 (HFCS-90), adjusted for sweetness in each treatment, in a high-ratio white-layer cake formulation; (2) to assess the effect of the maltodextrin gel on the physical qualities in the various cake treatments; and (3) to assess the effect of the maltodextrin gel on the sensory characteristics in the variations.

CHAPTER II: REVIEW OF LITERATURE

2.1 Functions of Fat in Food Systems

Fat is found in many different foods, and can be obtained from either animal or plant sources; only plant sources are cholesterol-free. Fats that are solid at room temperature are referred to as *fats*, while those that are liquid at room temperature are called *oils* (Bennion, 1995b). Collectively, fats and oils belong to a broad group of chemical compounds called *lipids*. Lipids are classified as triglycerides, phospholipids, and sterols. More than 95% of fats and oils fall into the triglycerides group (Giese, 1996). Triglycerides are made up of three fatty acids attached to a glycerol backbone. Fatty acids can vary in length and degree of unsaturation. Composition of the specific fatty acid determines the rheological properties of fats (McWilliams, 1993e). Most natural fatty acids contain an even number of carbons ranging from 4 to 24. The longer the fatty acid chain, the higher the melting point, and the more likely to be solid at mixing temperatures compared to shorter fatty acid chains (McWilliams, 1993e). Melting point of fatty acids is also affected by the degree of unsaturation. Saturated fatty acids contain all of the hydrogen atoms with which the carbon atoms can bond (Bennion, 1995b). Unsaturated fatty acids contain one or more double bonds between some carbon atoms. The higher the degree of unsaturation, the lower the melting point (McWilliams, 1993e). Fats that remain solid at room temperature appear to be a solid mass, when they are in fact crystals of fat in oil (McWilliams, 1993e). The crystalline nature determines the effectiveness of these solid fats in food preparation. There are four types of fat crystals: alpha (α), beta prime (β'), intermediate, and beta (β). Alpha crystals are extremely fine and unstable, quickly recrystallizing into the next crystalline form, β' . Beta prime crystals are very fine and stable; for baking purposes, using solid fats with β' crystals promotes a fine texture in the finished product (McWilliams, 1993e).

Fat contributes many functional properties in foods. One of the most important functions of fat is to tenderize baked products (Penfield and Campbell, 1990e). Moreover, fat affects the texture of foods: they produce a fine cell structure in cakes, affect the smoothness of crystalline candies and frozen desserts, contribute flakiness in pastries, etc. Fat interferes with gluten development by inhibiting contact between water and flour proteins (McWilliams, 1993e). Fat also improves the volume of baked products by incorporating and retaining air during the mixing

of the batter. Lipids also provide color, flavor, transfer heat and act as emulsifiers in food products.

2.1.1 Functions of Fat in Baked Products

Fats and oils, particularly shortening, are important ingredients in the production of quality baked goods. Since a solid fat at room temperature contains fat crystals in oil, the fat can be molded without breaking (Bennion, 1995e). This pliability in solid fat is referred to as the plasticity of fat. Plastic fats (e.g. shortening) influence the performance of fat in baked products and pastries (Bennion, 1995e). For example, plastic fats incorporate more air than non-plastic fats, producing higher volume cakes and flakier pastry crusts. Fat imparts tenderness, moistness, lubricity, flavor, color, structure, volume, and antistaling qualities in baked products.

Even though fat is an important functional ingredient in many foods, dietary guidelines suggest reducing dietary fat consumption to 30% or less of total daily energy intake. These recommendations have been given to reduce the risk of heart disease, obesity, certain types of cancers, and possibly gall bladder disease, that have been related with high fat intakes from various clinical, epidemiological, metabolic and animal evidence (Glueck, 1994). As consumers become aware of the need to reduce fat in their diet, the demand for healthy, flavorful, low-fat food increases. To meet this demand, the food industry has reduced the fat in various food products with the aid of fat substitutes. Each fat substitute has its own functions, advantages, and disadvantages, which food processors must understand in order to select the most effective fat substitutes for specific food applications.

2.2 Fat Substitutes

A true *fat substitute* is a substance that physically and chemically resembles triglycerides and can theoretically replace the fat in foods on a one-to-one, gram-for-gram basis (Akoh, 1998). These are generally referred as lipid-based substitutes. *Fat mimetics*, on the other hand, are substances that can imitate the organoleptic or physical properties of triglycerides, but cannot usually replace fat on a 1:1 basis (Akoh, 1998). Fat mimetics are commonly called protein- or carbohydrate-based substitutes. The three main categories of fat substitutes are lipid, protein, or carbohydrate-based fat substitutes.

2.2.1 Lipid-Based Fat Substitutes

Lipid-based fat substitutes are either triglycerides that have been modified and are partially absorbed, or are synthesized to have structures similar to triglycerides and are no longer metabolized in the body (Giese, 1996). Emulsifiers are used as fat extenders. Emulsifiers have hydrophilic and lipophilic properties that allow them to keep immiscible liquids suspended. Even though, emulsifiers contain the same calories as fat, 25-78% less is needed to produce fat-like characteristics (Glueck et al., 1994). Common emulsifiers are lecithin, mono- and diglycerides, oliglyceril esters, olysorbates, and sodium stearyl lactylate (Glueck et al., 1994).

One group of lipid-based fat substitutes are lipid analogs such as Salatrim®, Caprenin®, and the sucrose polyester, Olestra. Salatrim® (Nabisco, Inc.) is a family of structured triglycerides consisting of a mixture of long- and short-chain fatty acids esterified to a glycerol backbone (Gershoff, 1995). Salatrim® provides 5 kcal/g because the short-chain fatty acids provide fewer calories than the long-chain fatty acids. A GRAS petition was accepted by the U.S. Food and Drug Administration, in June, 1994, for use in chocolate, confections, baked goods, dairy products, and snack goods (Giese, 1996). Caprenin® (Procter & Gamble Co.) is a reduced-calorie triglyceride consisting of caprylic, capric, and behenic acids (Gershoff, 1995). Like Salatrim®, Caprenin® provides 5 kcal/g because behenic acid is only partially absorbed. A GRAS petition has been filed with the FDA for use in soft candies and confectionery coatings as a replacement for cocoa butter (Gershoff, 1995; Giese, 1996). Of the two previously mentioned lipid analogs, Olestra is the most extensively studied and publicized. It is produced by the esterification of sucrose with long-chain fatty acids (≥ 16 carbons) isolated from vegetable oils (Gershoff, 1995). Olestra is non-caloric because the large size and number of the fatty acids are not metabolized (Akoh, 1998). Since Olestra passes unmetabolized through the gastrointestinal tract, it has the potential to cause abdominal cramping, stool softening, and reduce the absorption of fat-soluble vitamins and nutrients (Akoh, 1998). Olestra was approved by the FDA in 1996 for use in baked and snack goods because it can withstand high-heat applications (Akoh, 1998).

2.2.2 Protein-Based Fat Substitutes

Protein-based fat substitutes are derived from protein sources such as milk, egg, whey, or vegetable proteins (Giese, 1996). Some protein-based fat substitutes undergo microparticulation (sheared under heat), which produces microscopic round particles similar to fat particles that mimic the mouthfeel and texture of fat (Akoh, 1998). Simplese® (NutraSweet Kelco Co.) is a microparticulated protein-based fat mimetic that was given GRAS status in 1990 for use in frozen desserts and in 1994 for use in yogurt, cheese spreads, frozen desserts, cream cheese, and sour cream (Akoh, 1998). Simplese® cannot be used in high-temperature food applications, which could easily denature the proteins. On a dry basis Simplese® provides 4 kcal/g, whereas a hydrated gel provides 1 kcal/g.

2.2.3 Carbohydrate-Based Fat Substitutes

For several years, carbohydrate-based fat substitutes have been used to partially or fully replace fat. These mimetics are derived from cereals, grains, and plants that include digestible and nondigestible carbohydrates (Giese, 1996). Digestible carbohydrates provide 4 kcal/g, while nondigestible carbohydrates provide negligible calories. Examples of carbohydrate-based fat substitutes include polydextrose, pectin, cellulose, gums, and starch derivatives (modified starches, dextrans). Carbohydrate-based fat-substitutes provide some of the functions of fat by binding water, and providing texture, mouthfeel, and opacity (Giese, 1996).

Polydextrose is a bulking agent made by the random polymerization of glucose, sorbitol and citric acid. Polydextrose is an approved food additive often added to nonnutritive sweeteners to maintain texture, body and mouthfeel in low-calorie products (Glueck, 1994). It is also used as a humectant to replace fat or sugar in baked goods, chewing gum, salad dressings, etc. (Glueck, 1994).

Pectin consists of partial methyl esters of polygalacturonic acid that is found in all fruits and vegetables (Giese, 1996). Gels formed by pectin can be used to replace fat in various food products.

Different cellulose-based fat replacers can be obtained by the type of processing used: (1) mechanical grinding (e.g. powdered cellulose), (2) chemical depolymerization and wet mechanical disintegration (e.g. microcrystalline cellulose), and (3) chemical derivitization (e.g.

sodium carboxymethylcellulose, methylcellulose, and hydroxypropyl methylcellulose) (Akoh, 1998). Cellulose ingredients serve as dietary fiber because they pass through the gastrointestinal tract undigested (BeMiller and Whistler, 1996). Cellulose-based fat replacers are used to stabilize foams and emulsions, modify texture, increase viscosity, and add dietary fiber (Giese, 1996).

Gums or hydrocolloids are long-chain polymers of monosaccharides that easily dissolve in water and produce thickening or viscosity-increasing effects. Gums can be used with other gums or fat replacers to mimic the texture of fat. The most commonly used gums are guar, xanthan, locust bean gum, carrageenan, and gum arabic. Their thickening properties are used in salad dressings, soups and sauces, desserts and ice cream, dairy products, baked goods, etc.

Starches and starch derivatives provide many functions in fat replacements systems. When moist heat is applied to starch, the granules gelatinize, forming a mixture of thick, soft and creamy consistency. Starches are commonly derived from corn, potato, rice, wheat, and tapioca. However, most starches are further modified when used in fat replacement systems. Starches are modified by acid or enzymatic hydrolysis, to produce smaller polymers, or by cross-linking or substitution. Starches are effective in high-moisture systems such as salad dressings, low-fat spreads, meat emulsions, icings and fillings, and baked goods.

2.3 Carbohydrate-Based Fat Ingredients in Baked Products

Combinations of carbohydrate-fat replacers are often used in baked products because they can mimic the function of fat in these products. Desired characteristics of a high-quality cake include a golden brown color; high volume; fine even crumb; pleasing flavor; and a soft, velvety, moist and tender texture and mouthfeel. Different types of carbohydrate-replacers have been used to mimic these characteristics. Xanthan gum is added to the dry ingredients in baked goods as bulking agents, and is used as a stabilizer in cake batters (Glueck, 1994). Sodium carboxymethylcellulose (CMC) is used in baked goods to increase cake volume, improve cell structure, and stabilize cake batters.

Maltodextrin and HFCS offer possibilities in a cake batter. Maltodextrin provides a pleasing sensory profile of moisture, lubricity, texture, and taste (Nonaka, 1997). High-fructose corn syrup provides sweetness, color, humectancy, and tenderness. The benefits of using these two carbohydrate-based ingredients will be discussed further in the following sections.

2.3.1 Maltodextrin

Maltodextrins are nutritive polysaccharides derived from the acid or enzymatic hydrolysis of a starch. Maltodextrins are GRAS ingredients made from wheat, corn, potato, oat, or tapioca starch. Hydrolysis of starch in maltodextrins produces up to 20 dextrose units of varying polymer lengths, referred to as the dextrose equivalence (DE). Dextrose equivalence is defined as a measure of the reducing sugar content (Appl, 1991). The DE is inversely related to average molecular weight (BeMiller and Whistler, 1996). Typically, maltodextrins with higher DE (lower molecular weight) absorb more moisture (BeMiller and Whistler, 1996).

Maltodextrins can be used to replace fat in dry form or gel form. In dry form, maltodextrin provides 4 kcal/g, but when maltodextrin is hydrated, stirred, and cooled, a thermoreversible gel is formed, providing 1 kcal/g. The gel formed mimics the smooth texture and bland flavor of shortening. One ability of these high-molecular weight carbohydrates is to bind water, which builds body in baked goods better than other simple carbohydrates (Nonaka, 1997).

Maltodextrins are useful in a fat-reduced system to bind and control water, provide humectancy, build solids, and contribute a smooth mouthfeel.

2.3.2 High-Fructose Corn Syrup

High-fructose corn syrup is manufactured by enzymatically hydrolyzing a high-glucose corn syrup, isomerizing glucose into fructose (Appl, 1991). A typical HFCS contains 42% fructose. Higher fructose corn syrups (55, 90, and 100%) can be obtained by enrichment of the isomerized syrups (Appl, 1991).

High-fructose corn syrup provides many benefits in reduced-calorie and reduced-fat systems. High-fructose corn syrup improves texture, helps retain moisture, lowers water activity, and enhances flavor, color and sweetness. Texturally, fructose has a low tendency to crystallize, reducing the potential for graining (Nonaka, 1997). In addition, fructose does not invert in acidic conditions like sucrose does which eliminates the possibility of changes in texture during storage (Nonaka, 1997). Also, fructose's high hygroscopicity increases the perception of tenderness in baked goods. In baking systems, a desirable aroma, color, and flavor develop when the reducing property of HFCS reacts with proteins (Maillard Reaction). The intense sweetness of HFCS, especially of HFCS-90, allows use of 10-20% less sweetener per pound in most soft baked goods

(Nonaka, 1997). Finally, HFCS is effective at lowering water activity because it is a monosaccharide creating a high osmotic pressure (Nonaka, 1997).

2.4 Reduction of Fat in Cakes

Increasing public awareness of health and nutrition has increased the market for low-fat, low-calorie, low-cholesterol and low-sodium food products. Thus, the development of reduced-fat foods continues to be a goal of most food companies. The challenge that food scientists face when reducing the fat in foods is to maintain the functional processing benefits of fat in reduced fat systems.

The first step in substituting fat in foods is to understand the functionality of fat (Clark, 1994). More specifically, understanding the functionality of fat in the particular food system that will be modified. After identifying fat's role in this system, a fat-substitute or combination of fat substitutes that will mimic these functions can be chosen. Other factors that should be considered when choosing a fat substitute system are cost, availability, safety, and quality.

2.5 Function of Cake Ingredients

The main ingredients used in cake formulations are flour, sugar, fat, eggs, liquid, and leavening agents. Flavoring ingredients such as salt, vanilla, spices, coloring agents, etc. are also used in small amounts (Penfield and Campbell, 1990f). Each ingredient has its own function in cakes, and if slightly changed will alter final cake quality. Therefore, a proper balance of ingredients needs to be obtained to produce consistent high-quality cakes.

2.5.1 Formula Balance

Cake formulations are mainly based between the balance of tenderizing ingredients (sugar and fat) and structural ingredients (flour and egg) (Penfield and Campbell, 1990f). A basic guide for balancing cake ingredients was established by Lowe (1955), (McWilliams, 1993f):

1. The weight of the fat should not exceed the weight of the eggs.
2. The weight of the liquid, including fluid milk, water, and eggs, should equal or slightly exceed the weight of the sugar.
3. The weight of the sugar should not exceed the weight of the flour.

The latter guideline has been followed for many years. However, as cake flour and cake shortenings improved, it became possible to use larger amounts of sugar and liquid. Today, high-ratio (high-sugar) cake formulas are used frequently (Penfield and Campbell, 1990f). The sugar:flour ratio can vary, with 140:100 being the maximum and 125:100 being average for white and yellow cakes (Penfield and Campbell, 1990f). High-ratio cakes are richer, more moist, and more shelf stable than less rich formulas (Penfield and Campbell, 1990f).

2.5.2 Optimal Cake Characteristics

A high-quality cake has a high-specific volume and is symmetrical. The top of a layer cake needs to be flat for stacking (Penfield and Campbell, 1990f). The crumb of a high-quality cake is moist, elastic, has a fine grain, cells of uniform size, and thin cell walls. Crusts should be thin and tender (Bennion, 1995g).

2.5.3 Flour

Cake flour, chlorinated soft wheat flour, is used in cakes. Chlorinated cake flour improves the performance in high-ratio cakes (Bennion, 1995g). Chlorine breaks inter- and intramolecular hydrogen bonds and some peptide bonds in flour proteins, resulting in increased dispersibility. The percent of protein in flour determines gluten strength in baked products. Gluten proteins found in wheat flours give structure to baked goods. Soft wheat flours contain less than 10% protein, while hard wheat flours have more than 10% protein. Cake flour usually has about 7.5% protein, whereas all-purpose flour has about 10.5% protein. Soft wheat flours are preferred in soft baked goods, such as cakes because soft baked goods require a small amount of gluten formation. All-purpose flour, however, can be substituted in cakes using one cup minus two tablespoons of all-purpose flour to replace one cup of cake flour. Since little gluten is developed in cakes, the gelatinization of starch is more important to a cake's structure (Bennion, 1995g).

Flour contributes structure to cakes. If too little flour is used, the cake structure is weak and may fall, and the texture is coarse (Bennion, 1995g). If too much flour is used, a compact, dry cake is produced (Bennion, 1995g).

2.5.4 Sugar

Sugar adds sweetness to cakes. But more importantly, it affects texture, volume, moisture retention and color. Cake tenderness is increased because sugar delays the gelatinization of the starch and interferes with gluten development. Sugar increases cake volume by decreasing the cohesive forces (resistance to the movement of cake batter during baking) and allowing the batter to move more freely (Bennion, 1995g). Sugar also increases moisture retention and keeping quality of cakes by absorbing water. Finally, sugar adds color through Maillard browning.

Alternative sweeteners such as high-fructose corn syrup can replace sugar in cakes. High-fructose corn syrups can reduce caloric content in cakes, and increase moisture retention and color because they are sweeter, more hygroscopic and are reducing sugars.

Excessive amounts of sugar produce a coarse, thick-celled, gummy cake with a rough, sugary, and overly brown crust (Bennion, 1995g).

2.5.5 Fat

Fats contribute tenderness, air retention, flavor and a smooth, moist mouthfeel in cakes. Like sugar, fat interferes with gluten development, weakening the cake structure. Fineness and uniformity of grain is enhanced with fats of good creaming quality, compared to soft or liquid fats, unless methods of mixing are altered (Bennion, 1995g). Plastic fats aid in incorporating and retaining air in the form of small bubbles distributed throughout the batter. These bubbles serve as gas cell nuclei into which carbon dioxide and steam diffuse during baking (Penfield and Campbell, 1990f). Thus, the smaller the air cells, the larger the volume and finer the grain in the final cake. The larger and fewer the air cells, the lower the volume and coarser the grain.

2.5.6 Eggs

Eggs contribute structure, emulsification, volume, texture, color, flavor, and nutritive value. The easily coagulable proteins of egg contribute structure to cakes. Eggs that are gradually added to a creamed fat-sugar mixture aid in forming a stable emulsion, and retaining air, which will increase cake volume. When the optimum amount of egg is added to a cake mixture, fine cells and thin cell walls are produced (Bennion, 1995g). In contrast, the addition of too many eggs produces a tough, rubbery crumb.

2.5.7 Liquid

The liquid ingredient in cakes serves as a solvent for sugar, salt, and leavening agent. It disperses the fat and flour particles and hydrates the flour proteins and gelatinizes starch (Bennion, 1995g). Liquid also provides steam, which helps leaven the cake (Bennion, 1995g). If milk is used in the cake formulation, the carbonyl-amine reactants contribute to crust browning (Penfield and Campbell, 1990f).

Too little liquid may result in a cracked crust because of excessive batter viscosity. Too much liquid may result in a heavy cake with low volume (Penfield and Campbell, 1990f).

2.5.8 Leavening Agents

The three main leavening gases are air, steam, and carbon dioxide. Air is incorporated into cakes by beating eggs, creaming fat and sugar, or beating batters (Bennion, 1995g). Liquid ingredients in cakes provide steam, leavening the flour mixture. Carbon dioxide is produced by chemical leavening agents such as baking soda and baking powder. Sodium bicarbonate (baking soda) releases carbon dioxide, in the presence of an acid when it is heated. Baking powder contains mixtures of dry acid or acid salts and baking soda (Bennion, 1995f). Double acting powder (SAS-phosphate baking powder) releases carbon dioxide at two different times during the baking process. First, carbon dioxide is released when the dry ingredients are moistened. The calcium phosphate acid reacts with baking soda at room temperature. Then, carbon dioxide is released again when heat is applied. This occurs because sodium aluminum sulfate (SAS) requires heat and moisture to complete its reaction with baking soda (Bennion, 1995f). If too much leavening is added the cell walls expand beyond their limit and result in a coarse, irregular crumb. The addition of too little leavening insufficiently expands the cell walls, resulting in a compact, low volume product.

2.6 Cake Manipulation

A variety of mixing methods are used to combine shortened cake ingredients. The four most common methods used are: (1) conventional method, (2) conventional sponge method, (3) muffin method, and (4) quick-mix method (Bennion, 1995g). As cake ingredients improve, differences among mixing methods are not very great. Instead, changes in cake quality occur by the amount of manipulation that is applied. Undermanipulation of a cake batter may yield a cake

of good volume, but the texture is coarse and the cell walls are thick (Bennion, 1995g). Optimal amount of manipulation results in a cake of optimum volume, uniform texture, small cells, and thin cell walls (Bennion, 1995g). Overmanipulation of a cake batter may produce a fine texture, but tunnels are likely to be formed, and produce a compact cake of low volume (Bennion, 1995g). Even though sugar and fat in cake formulas retard gluten development, excessive overmanipulation may still toughen cakes.

CHAPTER III: MATERIALS AND METHODS

3.1 Experimental Design

The performance of a maltodextrin gel as a replacement (25, 50, 75, and 100%) for shortening along with HFCS-90, adjusted for sweetness in each treatment, were evaluated in a high-ratio white-layer cake formulation. Two controls were used to compare to the fat-replaced cakes: control A (100% fat with 100% sucrose) and control B (100% fat with 50% sucrose and 50% HFCS-90), which closely matched the sugar system of the fat-replaced cakes. A balanced incomplete block design (Appendix A) was used. Three randomly selected cake variations were prepared and evaluated during each block, with a total of ten blocks. These six cake variations were replicated five times. Objective measurements were taken for each replication throughout the experiment. Twelve panelists were trained in Quantitative Descriptive Analysis (QDA) to evaluate the six variations. After training, each panelist sampled three randomly selected cake variations, three times a week for three-and-a-half weeks. Each cake treatment was replicated five times during sensory evaluation.

3.2 Maltodextrin Sol-Gel Preparation

A 30 % (w/w) dispersion of a 10-dextrose equivalent (DE) corn maltodextrin (Casco 01900 Globe, Batch 2318195000, Cardinal, Ontario) was chosen from 25, 30, and 35 % concentration maltodextrin gels prepared during preliminary work. A percent solids (% solids) concentration of $64^{\circ} \pm 2^{\circ}$ was established for the selected maltodextrin gel concentration. This % solids concentration was found to produce maltodextrin gels that closely mimicked the appearance of a partially hydrogenated vegetable shortening. Before gels were prepared, the temperature that water boiled was determined by filling a 1-quart saucepan with distilled water to a depth of four inches or more (Conforti, 1998a). When the water boiled, an electric thermometer (Fisher-Scientific Traceable Thermometer, Model No. 97208221, Control Company, Arvada, CO) was held in the center of the water until the temperature remained constant. Temperature was recorded, and adjustments were made when recording gel temperatures. Sols were prepared by stirring maltodextrin and distilled water, until slightly dissolved, into a 2-quart saucepan that was situated on a stovetop range (Fridgidaire Electric Range, PC No. 1126638, Dayton, OH). The thermometer was suspended from a ring-stand so

that the bulb, without touching the bottom of the saucepan, was in the center of the solution (Conforti, 1998a). The pan was covered with a piece of aluminum pressed against the thermometer and sides of the pan. The solution was cooked over medium-high heat until boiling. The heat was reduced to medium-low and solution was partially covered, stirring occasionally, until slightly thickened (approximately 15-20 minutes); the maltodextrin solution should coat a spoon and large bubbles should be apparent in the saucepan. Once the solution started thickening and bubbles began forming, % solids measurements were taken until a % solids concentration of $64^{\circ} \pm 2^{\circ}$ was reached. Average temperature during thickening was $72^{\circ} \text{ C} \pm 1^{\circ} \text{ C}$. The sol was immediately transferred to a beaker using a rubber spatula, covered with plastic wrap, and cooled in the refrigerator (Holiday Refrigerator/Freezer, Model NT194 PW, Indianapolis, IN) at a temperature of 5.5° C for 24 hours until a gel formed.

3.3 Maltodextrin Sol-Gel Measurements

The % solids of each maltodextrin gel were recorded before and after cooling for 24 hours using the Leica Abbe Mark II Refractometer (Model No. 10494, Buffalo, NY). The % solids of every maltodextrin gel used was $64^{\circ} \pm 2^{\circ}$. The refractometer was calibrated before each use by measuring the refractive index (n_D) of distilled water. A drop of distilled water was placed on the measuring prism surface and allowed to stand undisturbed for 3-5 minutes, to obtain temperature stability. If properly calibrated, the n_D should be 1.3330 less 0.0001 for each degree above 20° C or plus 0.0001 for each degree below 20° C . If not calibrated, the proper reading must be determined using Chart 1 (n_D of Distilled Water at Various Temperatures) from the Leica Abbe Instrument Manual, the adjustment control rotated, and the READ button depressed until the display reads correctly. After the refractometer was properly calibrated, a maltodextrin gel sample was applied to a clean measuring prism surface, the prism cover closed, and illumination arm raised to illuminate the upper prism. The shadow line was adjusted to meet the cross hairs and the % Brix-TC (Temperature Compensated) read. The % Brix-TC mode automatically compensates for temperature differences and displays solution concentration as if its temperature was 20° C .

3.4 Cake Preparation

The selected white-layer cake formulations (Appendix B) and mixing procedures were derived from the Food Carbohydrates and Plant Pigments Laboratory Manual (Conforti, 1998b) and modified during pilot work. Each testing day, potential variations among samples were eliminated by using pasteurized liquid egg whites and obtaining remaining ingredients from their respective packages (McWilliams, 1993a). All of the ingredients (Appendix C) were purchased at local supermarkets, except for the 10-DE maltodextrin, high-fructose corn syrup-90 (HFCS-90), xanthan gum, and sodium carboxymethylcellulose (CMC). All cakes were prepared in a climate controlled ($\approx 21^{\circ}\text{C}$) laboratory (Room 335, Wallace Hall) at Virginia Polytechnic Institute and State University, in Blacksburg, Virginia. The amount of HFCS-90 and sucrose were decreased as fat replacement increased to compensate for the increased amount of maltose in the maltodextrin. This compensation was necessary to prevent cakes from being too sweet, gummy, coarse, and excessively brown. Prior to mixing, ingredients were weighed on a Sartorius portable top load balance (Type PT 1200-OUR, Bohemia, NY). The oven (Frigidaire Electric Range, PC No. 1126638, Dayton, OH) was preheated to 177°C and calibrated using an oven thermometer (Acu-Rite, USA). An 8-inch diameter, round cake pan was greased with canola vegetable oil cooking spray (Kroger Co., Cincinnati, OH), lined with wax paper, greased again, and set aside. The flour, nonfat dry milk, baking powder, salt, CMC, and xanthan gum were sifted with a Bromwell's measuring sifter (Michigan City, IN) into a 1-quart Pyrex mixing bowl (Pyrex, Corning, NY). Either shortening (control A and B), shortening and maltodextrin (partial fat replacement), or maltodextrin (full fat replacement) were creamed using a Black and Decker Heavy Duty Electric Mixer (Black & Decker, Inc., Cat No. M-175, Shelton, CT), connected to a Galab Universal Timer (Dimco-Gray Co., Model 171, Dayton, OH), in a 2.5 quart Pyrex mixing bowl for one minute at speed two. Sugar was added and creamed for two minutes at speed two. Remaining ingredients were added and mixed for one minute at speed one. The bowl was scraped with a rubber spatula, and batter mixed again for three minutes at speed four. The batter was weighed (590 g) into the cake pan and baked on the middle rack of the oven for 35-40 minutes, or until a toothpick pierced through the center of the cake came out clean. Each cake was immediately placed on top of a wire rack and allowed to cool in the pan for 10 minutes. After 10 minutes, cakes were removed from their pans and cooled on a wire rack for 30 minutes prior to analysis.

3.5 Objective Measurements

Objective measurements were batter specific gravity, cake volume and symmetry, crust and crumb color, moisture content, water activity (one hour after baking, and after 24 and 72 hours room temperature storage), crumb firmness, and degree of staling (one hour after baking, and after 24 and 72 hours room temperature storage).

3.5.1 Specific Gravity of Batter

Specific gravity was determined by dividing the weight of a material by the weight of an equal volume of water (Penfield and Campbell, 1990h). First, the weight of an empty container, such as a crystallizing dish or a graduated beaker with the capacity to hold 50 ml, was determined using a Sartorius portable top load balance (Type PT 1200-OUR, Bohemia, NY). Second, 50 ml of distilled water was added to the container and weighed. Third, the weight of the cake batter was measured, after ensuring that no air pockets remained. This was accomplished by pouring approximately 25 ml of cake batter into the container and tapping the container 12 times (Penfield and Campbell, 1990h). Excess batter was then poured until it reached the 50 ml mark, and tapped again 12 times. Any excess batter outside of the container was wiped off. Finally, 50 ml of cake batter, with air pockets removed, was weighed. Specific gravity was calculated as follows:

$$\text{Specific Gravity} = \frac{\text{Weight of filled container} - \text{weight of container}}{\text{Weight of water-filled container} - \text{weight of container}}$$

3.5.2 Volume and Symmetry

Volume and symmetry indices were recorded using a layer cake measuring template (Fig. 1) as described in AACC Method 10-91 (AACC, 1983). Cakes were sliced in half. The interior face of half of the cake was placed against the template. Volume index was calculated by adding the cake's height at the center and at points halfway between the center and the outer edges (Fig. 1):

$$\text{Volume Index} = B + C + D$$

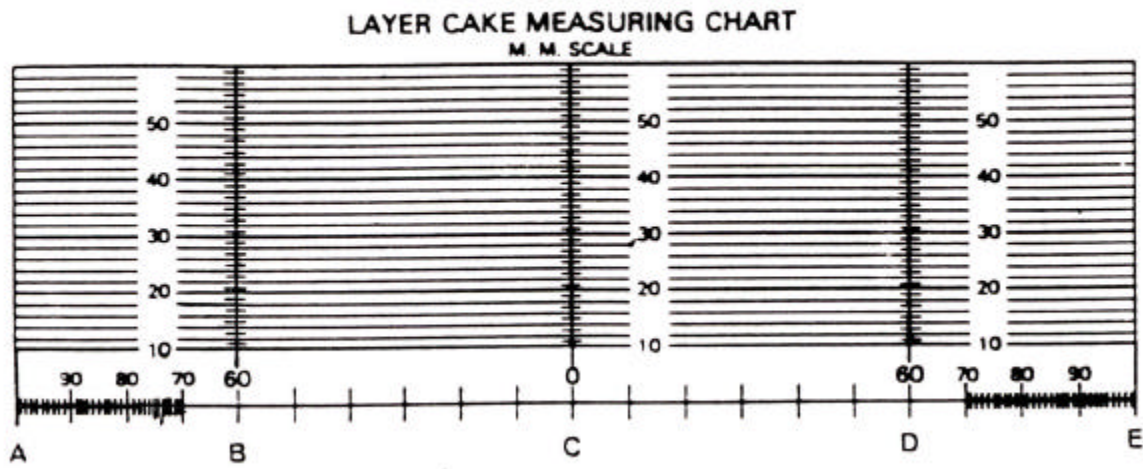


Figure 3.1. AACC layer cake measuring template

Symmetry index was calculated using the following equation:

$$\text{Symmetry Index} = (2C - B - D)$$

3.5.3 Crust and Crumb Color

Crust and crumb color were determined using a Hunter Color Lab Colorimeter (Model D25, Reston, VA) connected to a Toshiba T1000 System Unit (Model PA 7027U, Tokyo, Japan). The instrument was set to zero by placing a calibrated black tile on the sample port. A white tile was then placed to standardize the colorimeter. Crust and crumb color was analyzed by placing samples on the sample port. After the intact cake's crust L and b values were measured, the cake was cross-sectioned, and interior crumb was analyzed. The a value was not measured because this value is not commonly analyzed in bakery products. The L value (lightness) indicates how black or white a food is (McWilliams, 1993b), where 0 = black and 100 = white. The b value is a measure of hue, where $+b$ designates a yellow hue and $-b$ a blue hue.

3.5.4 Moisture Content

Moisture content was determined using a Brabender Moisture Analyzer SAS 692 (C.W. Brabender Instruments, Inc., South Hackensack, NJ). Cake samples were cooled in a dessicator for one hour; were crumbled from the interior crumb of the cake; placed in a Teflon-lined circular metal pan (preweighed); and weighed to 10 g on a Sartorius portable top load balance (Type PT 1200-OUR, Bohemia, NY). After drying the oven was preheated to 130° C (approximately one hour), sample pans were placed into the oven and dried for one-and-a-half hours, or until the moisture readings reached equilibrium. After drying, the dried weight of each sample was calculated by subtracting the weight of the dried sample from the initial sample weight and pan weight. The percent moisture content was determined using the following formula:

$$\% \text{ Moisture Content} = \frac{[(\text{wt. of empty pan} + \text{wt. of initial sample}) - \text{wt. of dried sample}] (\text{g})}{\text{wt. of initial sample} (\text{g})} \times 100$$

3.5.5 Water Activity

Water activity was determined using a Decagon Aqua Lab CX-2 water activity meter (Pullman, WA). Water activity was performed on freshly baked cakes and cakes stored at room temperature (21-24°C) for 24 and 72 hours after baking. Samples were stored in Tupperware™ (RubberMaid, Inc., Wooster, OH) containers. Prior to testing samples, the meter was turned on and allowed to warm up for 30 minutes. The water activity meter was calibrated by filling a plastic disposable cup half full with a saturated potassium chloride solution which had a a_w similar to that of a shortened style cake. The cup was placed into the sample holder, and the knob turned to “READ” to take the a_w . The a_w of a saturated potassium chloride solution should be ± 0.003 the a_w , which is specified in the Decagon Aqua Lab Manual listed for various temperatures. Each sample was measured by covering the bottom of a plastic disposable cup with a small portion from the interior crumb of the cake, placing the cup into the sample holder, and taking the reading.

3.5.6 Crumb Firmness

Crumb firmness was determined using the Instron Universal Testing Machine (UTM, Instron Corporation, Model No. 1011, Canton, MA). A 2 in² cake sample was sliced two inches from the edge of the bottom half of each cake (the top half was used to measure volume and symmetry). The width and thickness of each sample was measured with a metric dial caliper (Bel-Art Products, Model No. 12122, Pequannock, NJ) and entered into the computer. Individual cake samples were placed under the compression probe assembly, with a platen gauge distance (the distance between sample and compression probe starting position) adjusted to 5 mm. An aluminum probe, 35 mm in diameter, compressed samples at a compression rate of approximately 15 mm/min.

3.5.7 Degree of Staling

A Perkin-Elmer Differential Scanning Calorimeter (Model DSC 7, Norwalk, CT) connected to a Perkin-Elmer Thermal Analysis Controller (Model TAC 7/DX, Norwalk, CT), Fisher-Scientific chiller/circulator (Model No. 9105, Pittsburgh, PA), and digital PC computer and monitor (Perkin-Elmer, Model DEC 433, Norwalk, CT) and plotter (Hewlett Packard, Model 7475A, San Diego, CA) were used to record the degree of staling. Thermal analysis was

performed on freshly baked cakes and cakes stored at room temperature (21-24°C) for 24 and 72 hours after baking. Samples were stored in Tupperware™ (RubberMaid, Inc., Wooster, OH) containers. One hour prior to analysis, the chiller was turned on. After the one hour warm-up time, DSC instruments, computer, monitor, and plotter were turned on. Prior to thermal analysis of samples, an indium standard weighing 5.692 mg and an empty reference pan were used to calibrate the DSC. If the onset temperature was $156.6 \pm 0.2^\circ \text{C}$, the instrument was calibrated; if not, the analyzer needed to be calibrated. The indium standard was heated from 50 to 175°C at a scan rate of 10°C/min. Prior to analysis, a 30 ± 0.3 mg sample of cake (from the crumb of a 2-in² sample taken two inches from the center edge of the cake) was weighed into a large volume, stainless steel pan (Perkin-Elmer, Norwalk, CT) using a Perkin-Elmer AD-6 Autobalance (Norwalk, CT). To insure even heat distribution during thermal analysis, the crumb sample was pressed against the bottom of the sample pan with a glass rod. A rubber O-ring was then placed inside a capsule lid. The capsule lid was placed on top of the sample pan and sealed by squeezing the capsule inside a crimper. The sample pan and empty reference pan were placed in the DSC 7 sample compartment head. Samples were heated from 18 to 140°C at a scan rate of 10°C/min. After each sample was run, endothermic peaks were plotted.

3.6 Sensory Evaluation: Quantitative Descriptive Analysis (QDA)

3.6.1 Selection of Panel Members

Twelve students (7 females and 5 males) from Virginia Polytechnic Institute and State University were recruited to participate in the sensory study; but only ten panelists successfully completed the study. Due to frequent absenteeism, two male subjects (Panelists 3 and 5) were dropped from the study. The ten panelists that completed QDA testing were between the ages of 22-34. Prior to sensory testing, the protocol for use of human subjects in sensory testing was approved by the Virginia Polytechnic Institute and State University Institutional Review Board (Appendix D).

3.6.1.1 Training

During the training period, panelists were introduced to preliminary and final testing procedures, which allowed them to build skills and confidence to achieve valid and reliable

results (Meilgaard et al., 1991b). Due to time constraints, panelists participated in four training sessions (approximately one hour each).

During the first training session, panelists were given information on fat's function in baked products, optimal cake characteristics, maltodextrin's use as a fat replacer, QDA testing, and training and testing protocol; they signed consent forms (Appendix D); and tasted three cake variations to develop terms and definitions and word anchors. Each panelist wrote a list of perceived attributes after tasting control A, the 50% fat-reduced cake, and the 100% fat-reduced cake. The investigator, who acted only as a facilitator, constructed a comprehensive list of terms generated by each panelist on a transparency. The group eliminated any overlapping terms and reduced the list to six attributes (Appendix E) that were used in the study. These six attributes were placed in order of importance and defined, and word anchors developed for each attribute to construct the testing scorecard (Appendix F).

In the second and third training sessions, panelists were rebriefed on use of the line scale and sampling protocol, and comprehension of generated attributes, definitions, and word anchors by evaluating reference samples for the word anchors of each attribute. In the second training session, panelists evaluated reference samples for the word anchors of the first three attributes (i.e. moistness, sweetness, and tenderness); the remaining three attributes (i.e. adhesiveness, cohesiveness, and height) were evaluated during the third training session. Reference standards were used to reduce panel variability and to help panelists gain confidence, individually and as a group.

For the second training session, control A was manipulated by adding 300 g of sugar and 300 g of HFCS-90 to reflect the extreme version of a *moist* and *sweet* cake; on the other extreme a *dry* and *bland* cake was formulated by using control A with no sugar and 100 g of water. Perceived moistness and sweetness were evaluated by comparing control A to the two manipulated extreme samples. To evaluate tenderness, control A was used as the example of a *tender* cake, while control A with no shortening and 200 g of sugar was used as the example of a *tough* cake.

For the third training session, control A with 120 g of shortening was used to reflect a *sticky* (adhesiveness) and *crumbly* (cohesiveness) cake. Control B with 250 g of cake flour, 2 g of CMC, 0.5 g of xanthan gum, 27 g of shortening, 160 g of egg whites, and 250 g of water was used to reflect a cake that was *not sticky* but *stays intact*. To evaluate height, control A was used

for the example of a *tall* cake; a *short* cake was made by using control A with no baking powder and 300 g of sugar, not creaming the fat and sugar, manipulating the batter at a lower speed (speed 2 for 3 minutes) to incorporate less air, and pouring half the amount of batter ($\approx 300\text{g}$) in the cake pan.

Subjects were instructed to refrain from eating, drinking, smoking or chewing gum 30 minutes before each training and testing session. A 1.5 in² cake sample of each attribute extreme was allowed to cool to room temperature (21-24° C), and wrapped in plastic wrap. Reference samples were placed on a paper plate divided into 3 sections with a black marker, and presented one attribute at a time per training session. Subjects were also provided with a scorecard, list of attribute definitions, napkin, pencil and a glass of room temperature water. Panelists were instructed to taste and evaluate cakes in a clockwise fashion, starting with the sample placed underneath the exclamation mark. After tasting each sample, panelists placed a vertical mark on a linear scale (15 cm in length, with vertical anchors placed 1.3 cm from each end) for their perceived intensity of each attribute. Subjects were also instructed to rinse with water between samples. At the end of the second and third training sessions, panelists discussed results, and with the aid of the investigator, resolved controversies, and clarified questions regarding any reference standards (Meilgaard et al., 1991b).

In the fourth training session, panelists performed a practice sensory test to determine the consistency of individual panelists and the panel as a whole. As in the first training session, the three cake samples presented were control A, the 50% fat-reduced cake, and the 100% fat-reduced cake. Each cake sample (1.5 in²) was allowed to cool to room temperature (21-24° C), wrapped in plastic wrap, and randomly assigned a three-digit code, obtained from the random numbers table (Meilgaard et al., 1991c). Panelists evaluated samples in individual partitioned booths with neutral gray walls, under fluorescent light, in the sensory evaluation laboratory located in 337-A Wallace Hall, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, which is maintained at a temperature of 21-22°C. Each panelist received samples in an individually randomized order of presentation. Samples were placed on paper plates in the same fashion as described previously. A plastic tray with a scorecard, list of attribute definitions, coded samples, napkin, pencil and a glass of room temperature (21-24°C) water was passed through a sliding door. Panelists followed the same sampling protocol as described for the

second and third training sessions. At the end of the fourth training session, results for approximate attribute intensities were discussed for each sample.

3.6.1.2 Testing Procedures

Twelve panelists evaluated three randomly selected cake variations, in an individually randomized order of presentation, three times a week for three-and-a-half weeks. Each cake treatment was replicated five times during the sensory evaluation. Panelists were split into two time blocks (11:15 a.m. and 1:00 p.m.) to taste cake samples three times a week. Testing sessions lasted approximately 15 minutes. Sample preparation, testing location, test room environment, and testing protocol were the same as followed for the fourth training session.

3.7 Statistical Analysis

Statistical analysis was conducted using the Statistical Analysis System (SAS Institute, Inc., SAS Circle, Box 8000, Cary, NC). A balanced incomplete block (BIB) design was used (Appendix A) to evaluate objective and sensory data. Statistics were reported at a significance level of 0.05. Analysis of variance (ANOVA) was used to establish significant differences among the six cake treatments for all of the objective results, except for a_w and degree of staling. Autoregressive analysis was used to determine if the treatment-by-time interactions for a_w and degree of staling were significant. For all of the objective results, Tukey's multiple comparisons test was used to detect significant differences between treatments.

For QDA, the location of marks from the line scales were converted to numbers (in cm) by manually measuring the position of each mark with a ruler, from the left-end of the line scale to the right-end. ANOVA was used to examine significant differences among all of the cake treatments for each sensory attribute. Significant differences between treatments were analyzed using Tukey's multiple comparisons test.

CHAPTER IV: RESULTS AND DISCUSSION

4.1 Objective Measurements

4.1.1 Specific Gravity of Batter

Measurement of a batter's specific gravity estimates the amount of air incorporated into a batter such that a lower specific gravity is indicative of a batter with more air and viscosity (Penfield and Campbell, 1990a). A viscous batter helps keep air bubbles from rising out of the batter while a less viscous batter with a higher specific gravity allows large bubbles to coalesce, rise to the surface and leave the batter (Bath et al., 1992; Kim and Walker, 1992). The specific gravity of a batter can also be related to a cake's volume (Penfield and Campbell, 1990d). That is, the greater the total cake volume, the less its weight per unit volume and the lower its specific gravity. Adequate air incorporation is necessary to produce a cake of high volume. Creaming of fat and sugar, and type of fat used contribute to volume in cakes. Plastic fats, such as shortening, which are more moldable, produce high volume cakes. Thus, specific gravity was determined to evaluate the effect of higher increments of maltodextrin gel on the amount of air incorporated into the batter and its relationship to cake volume.

Table 1 shows the mean specific gravity values of the six cake batter treatments. Significant differences ($P < 0.05$) were found among treatments. Controls A and B, and treatment C (25%) had significantly lower specific gravity values ($P < 0.05$) compared to treatments D (50%), E (75%), and F (100%); except that treatments B and C were not significantly different ($P \geq 0.05$) from D. Treatments B through D also had significantly lower ($P < 0.05$) specific gravity values compared to treatments E and F. Maltodextrin added in dry form is speculated to bind water and control viscosity, which aids in gas retention (Sobczynska and Setser, 1991). However, when maltodextrin was hydrated, batter viscosity decreased and specific gravity increased because the maltodextrin gel was not as plastic as shortening and thinned upon shearing. In fact, as the percentage of shortening was replaced with increased levels of maltodextrin, the average specific gravity increased (Table 1). Since both controls had significantly lower specific gravity ratios ($P < 0.05$) when compared to the fat replaced cakes, theory predicts a higher volume cake. The following section will compare the specific gravity of the batters and cake volume.

Table 4.1. Mean¹ specific gravity values of the six cake treatments.

Treatment ²	Specific Gravity
A	0.9017 _a ± 0.0120
B	0.9762 _{ab} ± 0.0204
C	0.9957 _{ab} ± 0.0244
D	1.0293 _b ± 0.0120
E	1.1418 _c ± 0.0237
F	1.1761 _c ± 0.0228

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

4.1.2 Volume and Symmetry

High quality cakes should have a high specific volume and be symmetrical with a flat top for stacking (Penfield and Campbell, 1990f). Fat or shortening aid in producing high volume cakes by incorporating and retaining air during the creaming stage (Penfield and Campbell, 1990f). Thus, volume and symmetry were measured to evaluate the effect of substituting a maltodextrin gel for shortening in the cake formulation.

Table 2 compares the volume and symmetry indices of each cake variation. Significant differences ($P < 0.05$) for volume were found among the six treatments. Treatment F (100%) produced a cake with a volume significantly lower ($P < 0.05$) than any other cake. Results in Table 1 indicated a decrease in air incorporation as shortening replacement increased. Based on this relationship, cake volume was expected to decrease (Table 1); as anticipated, cake volume (Table 2) generally decreased as the amount of air incorporation decreased. Control A (lowest specific gravity ratio) distinctly exhibited the highest volume, while the 100% reduced cake (highest specific gravity ratio) produced the lowest volume cake. Although most of the fat-reduced cakes (25, 50 and 75%) had lower volumes than control A, differences in volume indices were not significant ($P \geq 0.05$), and these fat-replaced treatments had volumes similar to control B. Therefore, significant undesirable decreases in volume seem to be evident only with the complete replacement of shortening. This apparent difference in volume found in the 100% fat-replaced cake can be explained because it had the highest batter specific gravity and lowest batter viscosity, which is not conducive to the retention of leavening gases during heating and formation of the final cake structure (Bath et al., 1992). The batter was probably not sufficiently viscous to minimize the coalescence of gas bubbles, which causes loss of leavening gases found during baking as large bubbles rise to the surface and escape (Penfield and Campbell, 1990f). A decrease in batter viscosity and cake volume generally found in the replaced cakes can be attributed to the maltodextrin gel's thinning upon creaming and partial substitution of sucrose with HFCS-90 which increased the liquid ratio and decreased the retention of incorporated air (Penfield and Campbell, 1990f).

No significant differences ($P \geq 0.05$) for symmetry indices were found among all of the cake variations (Table 2). Symmetry values approaching zero indicate symmetry and are desirable (Bath et al., 1992). The 100% fat-reduced formula (treatment F) resulted in cakes with

Table 4.2. Mean¹ volume and symmetry indices of the six cake treatments.

Treatment²	Volume Index (mm)³	Symmetry Index (mm)³
A	135.9 _a ± 4.2	16.3 _a ± 3.5
B	122.2 _a ± 4.2	14.1 _a ± 3.5
C	122.7 _a ± 4.2	16.5 _a ± 3.5
D	121.2 _a ± 4.2	14.8 _a ± 3.5
E	122.1 _a ± 4.2	17.4 _a ± 3.5
F	95.4 _b ± 4.2	3.8 _a ± 3.5

¹ Values in columns with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Calculated according to AACC Method 10-91 (AACC, 1983).

symmetry indices close to zero that were short and flat-topped. The other treatments produced cakes with slightly-to-moderately rounded top surfaces.

4.1.3 Crust and Crumb Color

The appearance of food is very important because the consumers' purchasing decisions are largely based on the expected appearance of certain foods. Often, the sensory attribute deemed most critical in foods is color (McWilliams, 1993b). In bakery products, uniform, golden brown crusts are desired (McWilliams, 1993b). Browning of cakes occurs in the crust and crumb, but is most apparent in the crust of a cake. Browning, a result of Maillard reaction and some caramelization, occurs most rapidly when monosaccharides are contained in a cake (McWilliams, 1993d).

Crust color values are illustrated in Table 3. With respect to crust *L* values, control A was significantly darker ($P < 0.05$) than treatment E (75%), but not significantly different ($P \geq 0.05$) from the other treatments. Control B was significantly darker ($P < 0.05$) than treatments C (25%), D (50%), and E, but not significantly darker than treatments A and F (100%). Finally, treatment F, like treatment A, was only significantly darker than treatment E. Crust *b* values displayed fewer differences: treatment E was significantly less yellow ($P < 0.05$) compared to all of the cakes, except for treatment F. Overall, when comparing *L* and *b* values, control B produced the darkest crust and treatment E produced the lightest crust. Control B resulted in the darkest crust because the reducing ability of fructose is necessary to induce Maillard browning. Fructose's high solubility allowed it to decompose and brown rapidly. Treatment F demonstrated comparable browning because of its 50:50 ratio of sucrose and HFCS-90. However, treatment F's complete substitution of fat with a maltodextrin gel also contributed to its golden color. Maltodextrin contains the disaccharide maltose, which like fructose, is a reducing sugar. Sucrose, on the other hand, does not have reducing ability because its reducing groups (glucose's aldehyde carbon and fructose's keto carbon) are "tied up" (Penfield and Campbell, 1990g).

Table 4.3. Mean¹ crust color values of the six cake treatments.

Treatment ²	L value ³	b value ⁴
A	74.40 _{ac} ± 1.92	45.31 _a ± 1.97
B	66.81 _{ac} ± 1.92	46.72 _a ± 1.97
C	80.16 _{ab} ± 1.92	43.03 _a ± 1.97
D	79.04 _{ab} ± 1.92	42.27 _a ± 1.97
E	85.81 _b ± 1.92	31.64 _b ± 1.97
F	72.73 _{ac} ± 1.92	39.37 _{ab} ± 1.97

¹ Values in columns with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ L value = lightness (100) to darkness (0)

⁴ b value = yellow (+) to blue (-)

Crumb color values are presented in Table 4. Significant differences ($P < 0.05$) were observed in L and b values among cake treatments. Results of the crumb L values indicated that treatment F (100%) was significantly darker ($P < 0.05$) than the other cake treatments. The crumb b values showed that control A was significantly less yellow ($P < 0.05$) when compared to the other cake formulations; and that treatment F had a significantly ($P < 0.05$) yellower crumb. Overall, both L and b values indicated that treatment F produced a significantly ($P < 0.05$) darker crumb when compared to the other treatments. It is interesting to note, however, that control B, which produced a darker crust (Table 3) resulted in light crumb values (Table 4).

4.1.4 Moisture Content

The moisture content (the quantitative determination of total water content) of a food is one indication of a food's stability and quality (Pomeranz and Meloan, 1994). Moistness is a favorable sensory attribute in baked products because it is synonymous with a soft, tender product. However, too much moisture promotes microbial growth (Nonaka, 1997). Hydrophilic polymers such as CMC, xanthan gum, and maltodextrin, have a high affinity for water and can retain moisture in foods. HFCS, a hygroscopic sweetener, also acts as a humectant by drawing in moisture from the air into the cake. An increase in moistness was observed as the percentage of shortening was replaced with the maltodextrin gel (Table 5). However, significant differences ($P < 0.05$) were only evident when comparing treatments E (75%) and F (100%) to control A. No significant differences ($P \geq 0.05$) were seen among treatments B through D. Overall, treatments B through F had higher percent moistures than control A because these cakes contained HFCS-90 and/or gums and maltodextrin, which have more hygroscopic and hydrophilic properties than sucrose alone. Both maltodextrin and HFCS-90 work as humectants, allowing more moisture to be absorbed and retained from the atmosphere. This ability to retain moisture also enhances the keeping quality of these products. Thus, increasing the replacement of shortening with a maltodextrin gel increased the percent moisture.

Table 4.4. Mean¹ crumb color values of the six cake treatments.

Treatment ²	L value ³	b value ⁴
A	94.28 _a ± 0.59	14.60 _a ± 0.41
B	96.08 _a ± 0.59	17.04 _b ± 0.41
C	95.29 _a ± 0.59	17.39 _b ± 0.41
D	94.70 _a ± 0.59	17.79 _b ± 0.41
E	92.06 _a ± 0.59	17.99 _b ± 0.41
F	88.03 _b ± 0.59	21.33 _c ± 0.41

¹ Values in columns with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ L value = lightness (100) to darkness (0)

⁴ b value = yellow (+) to blue (-)

Table 4.5. Mean¹ percent moisture values of the six cake treatments.

Treatment²	Moisture (%)
A	33.02 _a ± 1.25
B	36.91 _{ab} ± 1.25
C	37.32 _{ab} ± 1.25
D	38.22 _{ab} ± 1.25
E	40.85 _b ± 1.25
F	39.80 _b ± 1.25

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

4.1.5 Water Activity

Water is a component of all foods that contributes to physical differences among food and the changes that food undergoes (Penfield and Campbell, 1990c). Shelf stability of foods is influenced by its water activity. Water activity (a_w) is an indication of “free” water (i.e. not chemically or physically bound) in a sample and is defined as the ratio of the vapor pressure of a food sample to the vapor pressure of pure water (McWilliams, 1993c):

$$a_w = \frac{\text{Vapor pressure of water in sample}}{\text{Vapor pressure of pure water}}$$

Products with no “free” water will have a a_w of 0.000, while a product such as pure water will have a a_w of 1.000. Since microorganisms need water to survive, the greater the a_w in a product, the higher the product is susceptible to microbial growth and spoilage. A food product’s a_w can be reduced in the presence of certain water-binding agents such as sugar, salt, starches, maltodextrins, gums, etc. However, decreases in a_w are attributed to dryness and crumbling in baked products.

Autoregressive analysis indicated that the treatment and storage time interaction for a_w (Table 6) was significant ($P < 0.05$). Water activity decreased over time as water was lost from the cakes (Fig. 3). No significant differences ($P \geq 0.05$) were found among treatments over time, except for control B. Similarly, no significant differences ($P \geq 0.05$) were found among treatments during each time period, except 24 hours after storage, when control A was found to have a significantly lower ($P < 0.05$) a_w compared to treatment E (75%). Overall, data indicated that a_w increased as the level of maltodextrin gel increased. These results were not expected because the fat-replaced cakes contained HFCS-90, gums, and maltodextrin, which all should have been more effective in lowering a_w due to their ability to bind water, thereby, leaving less “free” water available. In fact, the use of bulking agents such as corn syrups and maltodextrins to replace water has become a way to preserve various products (Yackel and Cox, 1992). However, with a higher a_w value, the fat-replaced cake will be reduced in shelf-life. On the other hand, the fat-reduced cakes higher a_w , even 72 hours after storage, will promote a more moist and less crumbly product. This theory holds true because as a_w increased (Table 6) moisture content increased as well (Table 5).

Table 4.6. Mean¹ water activity (a_w) values of the six cake treatments for three storage times.

Treatment ²	Storage Time ³ (h)		
	Time 1	Time 2	Time 3
A	0.9052 _{a,x} ± 0.0069	0.8880 _{a,x} ± 0.0069	0.8886 _{a,x} ± 0.0069
B	0.9111 _{a,x} ± 0.0069	0.8945 _{ab,xy} ± 0.0069	0.8873 _{a,y} ± 0.0069
C	0.9045 _{a,x} ± 0.0069	0.8999 _{ab,x} ± 0.0069	0.8931 _{a,x} ± 0.0069
D	0.9070 _{a,x} ± 0.0069	0.9002 _{ab,x} ± 0.0069	0.8938 _{a,x} ± 0.0069
E	0.9168 _{a,x} ± 0.0069	0.9156 _{b,x} ± 0.0069	0.9070 _{a,x} ± 0.0069
F	0.9067 _{a,x} ± 0.0069	0.9053 _{ab,x} ± 0.0069	0.8973 _{a,x} ± 0.0069

¹ In a column, values with like letters (a, b, c) indicate no significant difference ($P \geq 0.05$); in a row, values with like letters (x, y, z) indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
 B = Control (with 50% sucrose & 50% HFCS-90)
 C = 25% Fat-replacement
 D = 50% Fat-replacement
 E = 75% Fat-replacement
 F = 100% Fat-replacement

³ Storage Times: Time 1 = 1 h after baking
 Time 2 = 24 h after storage
 Time 3 = 72 h after storage

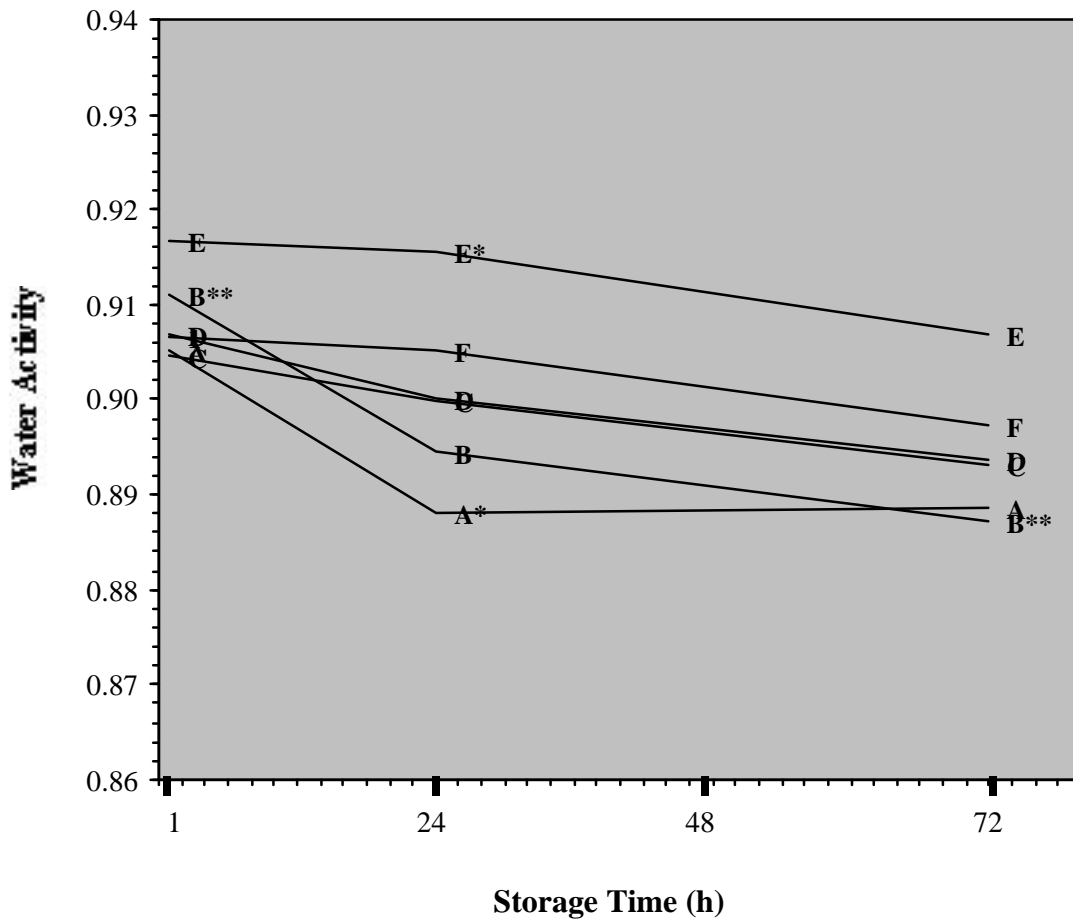


Figure 4.2. The effect^{*, **} of storage time on the water activity of six cake treatments. **A**, Control (100% shortening and 100% sucrose); **B**, Control (100% shortening and 50% sucrose and 50% HFCS-90); **C**, 25% fat replacement; **D**, 50% fat replacement; **E**, 75% fat replacement; **F**, 100% fat replacement.

* Data points with one asterisk represent significant differences between treatments within a time period.

**Data points with one asterisk represent significant differences between storage times within a treatment.

4.1.6 Crumb Firmness

Several factors are known to affect the texture of cakes, such as the amount of fat, sugar, manipulation and liquid. In fact, one of the most important functions of fat is to tenderize baked products (Penfield and Campbell, 1990e). Thus, crumb firmness was analyzed to assess cake tenderness as a result from the replacement of fat with a maltodextrin gel. Crumb firmness values for the white-layer cake formulations are presented in Table 7. Significant differences ($P < 0.05$) were found among the six cake treatments. Control A, and treatments C (25%) and E (75%) were significantly softer ($P < 0.05$) than treatment F (100%), with control A resulting in the softest cake. No significant differences ($P \geq 0.05$) were found among control B and treatment D (50%) and any of the other cake treatments. Overall, all cake variations, except for the 100% fat-replaced cake, did not differ significantly ($P \geq 0.05$) with respect to crumb firmness. Therefore, the partial replacement of shortening with a maltodextrin gel did not significantly affect firmness in cakes, except with the complete substitution of fat with a maltodextrin gel. Treatment F produced the firmest cake because no fat was available to interfere with gluten development, consequently developing a cohesive, solid gluten structure (Penfield and Campbell, 1990e). Furthermore, the firmest cake (Table 7) resulted in the least aerated (highest specific gravity; Table 1) and lowest volume cake (Table 2).

4.1.7 Degree of Staling

Staling (retrogradation) is a strong limiting factor in the shelf stability of baked foods (Staley, 1991). Retrogradation of baked products occurs immediately after baking is completed and cooling begins. Retrogradation is dependent on the product formulation, the baking process, and storage conditions (Lindsay, 1996). Effects of staling in baked goods include changes in texture of the crust (soft and leathery) and crumb (dry and firm), and loss of moisture and flavor (Eliasson and Larsson, 1993). Prominence has been given to amylopectin retrogradation because amylose retrogradation may be largely complete upon cooling to room temperature, whereas amylopectin retrogradation requires more time than amylose retrogradation due to amylopectin's branched structure and higher molecular weight (BeMiller and Whistler, 1996). During retrogradation, starch molecules, particularly straight-chain amylose molecules, associate closely together pushing water out of the gel network. As starch molecules continue to associate they form an ordered crystalline structure (Bennion, 1995d). As a result, there has been a large

Table 4.7. Mean¹ crumb firmness values of the six cake treatments.

Treatment²	Crumb Firmness (force/kg)
A	0.2585 _a ± 0.1304
B	0.5429 _{ab} ± 0.1383
C	0.4477 _a ± 0.1304
D	0.6390 _{ab} ± 0.1493
E	0.3435 _a ± 0.1304
F	1.2368 _b ± 0.1493

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

amount of evidence between the relationship of the migration of water from the crumb to the crust on textural changes (Giovanelli et al., 1997). Fat extends the shelf-life of bakery products by coating starch granules, inhibiting the reassociation of starch molecules during retrogradation. Carbohydrate ingredients can also extend freshness, primarily by binding water and aiding in moisture retention (Kulp et al., 1991).

Differential scanning calorimetry (DSC) is a technique used to measure the enthalpy (ΔH) required to melt the crystallization of starch. For the purpose of the investigation, the melting of recrystallized amylopectin (Eliasson and Larsson, 1993) was investigated. DSC is a direct measure of heat needed to remove the staling endotherm (Hebeda and Zobel, 1996a). According to autoregressive analysis (Table 8), the treatment-by-storage time effect was found to be significant ($P < 0.05$). The degree of staling in cakes significantly increased ($P < 0.05$) over time for all treatments, except for control A. Instead, control A's rate of staling significantly increased ($P < 0.05$) after 72 hours storage. Data for treatment differences during each storage time indicated that cake treatments did not differ significantly ($P \geq 0.05$) one hour after baking; while, 24 hours after storage, control A showed a significantly slower rate ($P < 0.05$) of staling compared to treatment F (100%), with all other treatments having no significant differences ($P \geq 0.05$) in degree of staling; and control A staling significantly less ($P < 0.05$) than all other treatments 72 hours after storage, with treatment F showing the highest rate of staling ($P < 0.05$). Overall, the control cakes, particularly control A, staled less than the fat-replaced cakes (Fig. 4). Moreover, the degree of staling increased as the percentage of maltodextrin increased. This outcome did not confirm the expectation that maltodextrin's water binding capacity would reduce staling in cakes, by competing with starch fractions for water and reducing a_w , thus hindering water redistribution (Schiraldi et al., 1996). Furthermore, the fact that staling increased as moistness increased and a_w remained constant over time, provided further evidence that water migration and evaporation might not play a strong role in cake staling. Instead, cake staling could be more strongly affected by starch retrogradation. This indicates that the presence of fat plays a strong role in preventing starch retrogradation. As previously mentioned, fat inhibits starch retrogradation by surrounding starch granules and preventing starch reassociation. Staling results concurred evidence for this theory because as the amount of shortening decreased, staling increased.

Table 4.8. Mean¹ enthalpy (ΔH) values (J/g) of the six cake treatments for three storage times.

Treatment ²	Storage Time ³ (h)		
	Time 1	Time 2	Time 3
A	0.0224 _{a,x} \pm 0.0383	0.0751 _{a,x} \pm 0.0383	0.2079 _{a,y} \pm 0.0383
B	0.0003 _{a,x} \pm 0.0383	0.1330 _{ab,y} \pm 0.0383	0.5524 _{b,z} \pm 0.0383
C	0.0526 _{a,x} \pm 0.0383	0.2031 _{ab,y} \pm 0.0383	0.5383 _{b,z} \pm 0.0383
D	0.0520 _{a,x} \pm 0.0383	0.2112 _{ab,y} \pm 0.0383	0.5606 _{b,z} \pm 0.0383
E	0.0784 _{a,x} \pm 0.0383	0.2199 _{ab,y} \pm 0.0383	0.5593 _{b,z} \pm 0.0383
F	0.0617 _{a,x} \pm 0.0383	0.2360 _{b,y} \pm 0.0383	0.7863 _{c,z} \pm 0.0429

¹ In a column, values with like letters (a, b, c) indicate no significant difference ($P \geq 0.05$); in a row, values with like letters (x, y, z) indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Storage Times: Time 1 = 1 h after baking
Time 2 = 24 h after storage
Time 3 = 72 h after storage

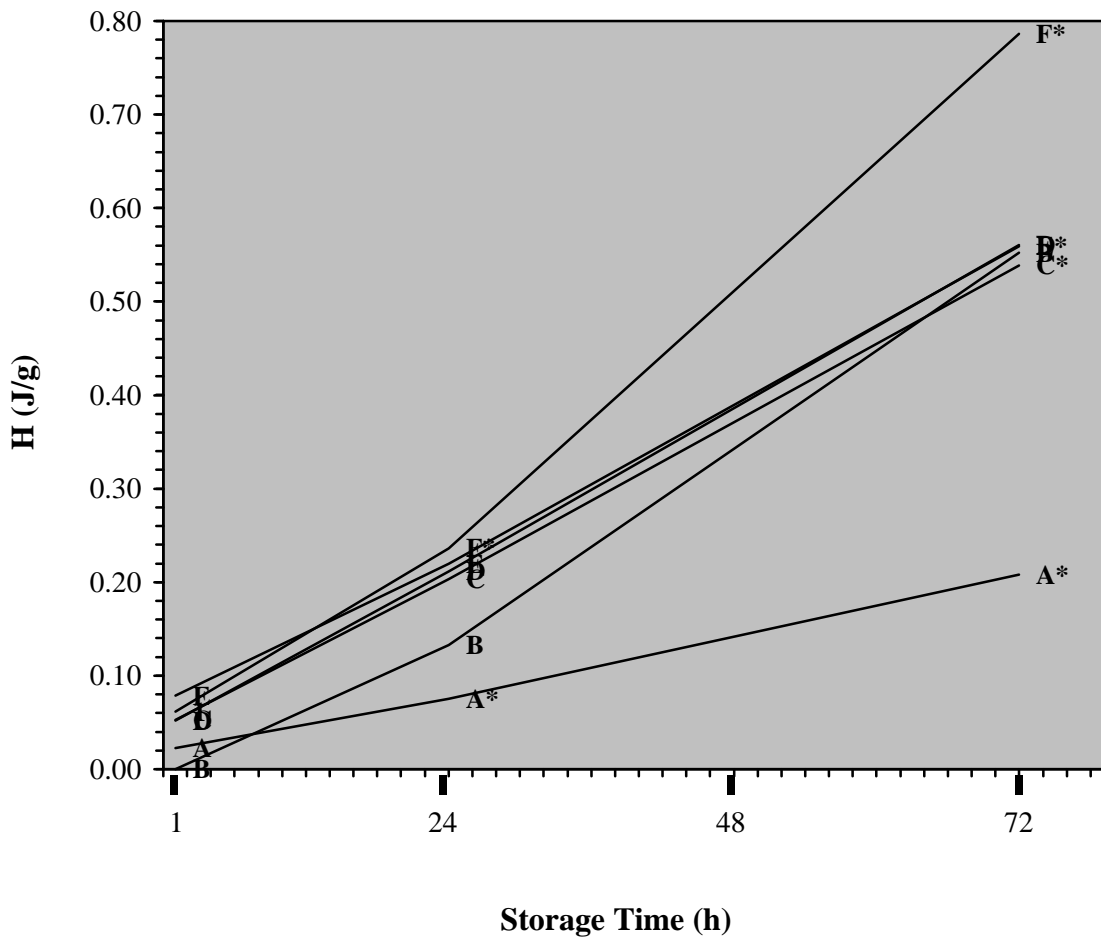


Figure 4.3. The effect ^{***} of storage time on the staling rates of six cake treatments. **A**, Control (100% shortening and 100% sucrose); **B**, Control (100% shortening and 50% sucrose and 50% HFCS-90); **C**, 25% fat replacement; **D**, 50% fat replacement; **E**, 75% fat replacement; **F**, 100% fat replacement.

* Data points with an asterisk represent significant differences between treatments within a time period.

** Significant differences ($P < 0.05$) were found between the three storage times for every treatment.

4.2 Sensory Evaluation

According to Bennion (1995a), the food choices that consumers make are influenced by many factors such as income, culture, religion, and health concerns. Yet for most people, most importantly, foods must be palatable, if they are to be eaten. Palatability of foods is determined by different sensory sensations, such as odor, appearance, taste, and mouthfeel. Foods prepared comprise various flavor profiles, partly because individuals vary in their ability to intensify and experience flavor. However, sensitivity to pleasurable encounters with food can be heightened as more about food characteristics is learned.

The perceived sensory attributes of foods consist of appearance, texture and flavor (taste and aroma). Panelists in this study generated attributes that fell into the three categories described above. During testing, the sensory panel kept into consideration that high-quality cakes should have a high volume, a moist and tender texture that is not too soggy, sticky or crumbly, and a moderately sweet flavor. The following sections summarize the results.

4.2.1 Quantitative Descriptive Analysis

Sensory methods are used because instruments can only detect a portion of the total flavor and texture attributes in a given food product (Hebeda and Zobel, 1996b). Quantitative Descriptive Analysis (QDA) is a descriptive test used to identify and quantify sensory characteristics of a product by a group of trained panelists (Penfield and Campbell, 1990b). The analysis is useful in correlating sensory with objective testing, and at the same time, in characterizing sample differences to guide the product developer in modifying product characteristics to meet consumer demands (Larmond, 1977). Accurate evaluation of attributes requires careful selection of terms to be evaluated, establishment of appropriate references as standards, and use of easily understood scales to quantify changes (Hebeda and Zobel, 1996b).

4.2.2 Textural Characteristics

Texture is an important characteristic in consumer's perception of food and purchasing decisions. Meilgaard et al. (1991a) defines texture as the "sensory manifestation for the structure of products in terms of their: (1) reaction to stress by the kinesthetic sense in the muscles of the hand, fingers, tongue, jaw, or lips (e.g. adhesiveness, cohesiveness, hardness, etc.), and (2) tactile feel properties measured by the tactile nerves in the surface of the skin of the hand, lips, or

tongue (e.g. oiliness, tenderness, moistness, etc.)”. Because the surface of the skin, lips, tongue, etc. are more sensitive than other parts of the body, they can detect smaller force, particle size, thermal and chemical differences. Moreover, studies and surveys have shown that certain textures are universally preferred over others (crispy, crunchy, tender, etc.) while others are disliked (tough, soggy, crumbly, etc.) (Bennion, 1995a).

4.2.2.1 Moistness

Panelists defined moistness (Appendix E) as the amount of wetness perceived within the mouth. Significant differences ($P < 0.05$) for moistness were found among treatments (Table 9). The panel rated control A as the driest ($P < 0.05$) cake, while treatment F (100%) was found to be significantly more moist ($P < 0.05$) when compared to the other versions. Meanwhile, control B did not differ significantly ($P \geq 0.05$) from treatment C (25%) or E (75%). Treatment C was also not significantly different ($P \geq 0.05$) from treatment D or E. In general, all of the cakes were found to be relatively moist because even the lowest ranked cake (control A), had a mean moistness score of 5.1. Subjective moistness scores correlated with the objective percent moisture values (Table 5): an increasing trend in moistness was generally observed. Moreover, perceived moistness and objective percent moisture generally increased as the level of maltodextrin gel increased. Thus, the maltodextrin gel’s hydrophilic properties enhanced moisture retention in cakes.

4.2.2.2 Tenderness

Tenderness was described as the amount of chewing resistance (Appendix E). Significant differences ($P < 0.05$) for tenderness were found among the six treatments (Table 10). Control A was rated the most tender cake, but was only significantly ($P < 0.05$) more than treatment E (75%) and F (100%). Treatment F, in contrast, was significantly ($P < 0.05$) the toughest cake when compared to all other treatments. These two findings correlated with results for the objective measurement of firmness (Table 7). Panelists found no significant differences ($P \geq 0.05$) between control B and treatment C (25%), although significant differences ($P < 0.05$) were found among treatments D (50%), E, and F.

Table 4.9. Mean¹ sensory scores for moistness of the six cake treatments.

Treatment²	Moistness³
A	5.08 _a ± 0.27
B	6.69 _b ± 0.27
C	8.17 _{bc} ± 0.27
D	8.50 _c ± 0.27
E	8.25 _{bc} ± 0.27
F	10.15 _d ± 0.27

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Moistness: the intensity of dryness (0) to moistness (15) when a cake was sampled.

Table 4.10. Mean¹ sensory scores for tenderness of the six cake treatments.

Treatment²	Tenderness³
A	10.59 _a ± 0.31
B	10.86 _{ad} ± 0.31
C	9.94 _{ade} ± 0.31
D	9.13 _{ae} ± 0.31
E	7.28 _b ± 0.31
F	3.43 _c ± 0.31

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Tenderness: the intensity of toughness (0) to tenderness (15) when a cake was sampled.

Similarly, no significant differences ($P \geq 0.05$) were found between treatments C and D, although significant differences ($P < 0.05$) were found between treatments E and F. Finally, panelists rated treatment E as being significantly more tender ($P < 0.05$) than treatment F, but significantly less tender ($P < 0.05$) than the other cakes. Overall, treatments A through E were considered tender (sensory scores between 7.3 and 10.9). As expected, tenderness scores decreased as fat was reduced. The main function of fat is to tenderize baked goods by interfering with gluten development (Penfield and Campbell, 1990e).

4.2.2.3 Cohesiveness

Panelists characterized cohesiveness as the extent to which the cake remains intact during handling and chewing (Appendix E). Significant differences ($P < 0.05$) for cohesiveness were found among cake treatments (Table 11). Cake crumbliness decreased as the level of maltodextrin gel increased. Therefore, treatment F (100%) was rated as the least crumbly cake ($P < 0.05$) when compared to all other treatments. Panelists detected no significant differences ($P \geq 0.05$) between the following cake pairs: controls A and B, control B and treatment C (25%), treatments C and D (50%), and treatments D and E (75%). Ratings for tenderness (Table 10) were related to cohesiveness scores: as cakes became less crumbly, tenderness decreased (as fat was reduced). Again, another example where fat played a contributing role in the quality characteristics of cakes.

4.2.2.4 Adhesiveness

The panel defined adhesiveness as the degree to which the cake adheres to the teeth and palate (Appendix E). Significant differences ($P < 0.05$) for adhesiveness were found among cake treatments (Table 12). Panelists rated treatment F (100%) as the least significant sticky ($P < 0.05$) cake when compared to all other treatments. No significant differences ($P \geq 0.05$) in adhesiveness were detected among the other cake treatments. There was a trend, however, in which adhesiveness decreased as the level of maltodextrin gel increased. According to the results, adhesiveness was related to cohesiveness (Tables 11 and 12, respectively). Panelists judged a crumbly textured cake as being sticky and a less crumbly cake as being less sticky.

Table 4.11. Mean¹ sensory scores for the cohesiveness of the six cake treatments.

Treatment²	Tenderness³
A	9.93 _a ± 0.43
B	9.61 _{ab} ± 0.43
C	7.74 _{bc} ± 0.43
D	7.01 _{cd} ± 0.43
E	5.36 _d ± 0.43
F	1.99 _e ± 0.43

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Cohesiveness: the degree of crumbliness; not crumbly = 0 and crumbly = 15

Table 4.12. Mean¹ sensory scores for the adhesiveness of the six cake treatments.

Treatment²	Adhesiveness³
A	9.13 _a ± 0.44
B	8.52 _a ± 0.44
C	9.41 _a ± 0.44
D	8.66 _a ± 0.44
E	7.53 _a ± 0.44
F	5.21 _b ± 0.44

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Adhesiveness: the degree of stickiness; not sticky = 0 and very sticky = 15

It is possible that a crumbly cake was more adhesive because this type of texture required and absorbed more saliva to dissolve and bind granules within the mouth; in doing so, more cake pieces adhered to the teeth and palate.

4.2.3 Appearance

A product's appearance strongly influences a consumer's decision because oftentimes, it is the only attribute that consumers can base their purchasing decisions on (Meilgaard et al., 1991a). Consequently, if the appearance of a food is not appealing or does not match the consumer's idea of what the food should look like, it may be rejected without being tasted (Bennion, 1995a). Appearance characteristics include color, size and shape, surface texture, and clarity. Height was examined by the panelists and the results are listed in the following section.

4.2.3.1 Height

Height represented the degree of upward distance (Appendix E). Significant differences ($P < 0.05$) for height were found among cake treatments (Table 13). Treatment F (100%) was significantly the shortest ($P < 0.05$) cake when compared to all of the other cakes. Although, no significant differences ($P \geq 0.05$) in height were detected among the other treatments, treatments A through E were given relatively tall height scores. Therefore, it appears from the results that the height or volume of a cake was significantly affected by the complete replacement of fat. As expected, however, cake height generally decreased as the amount of shortening was reduced. These findings correlated with the objective results for volume (Table 2). As previously mentioned, fat aids in air retention, batter viscosity and volume.

4.2.4 Taste

Taste is the most important factor consumers consider when shopping for food (Bruhn et al., 1992). Since fat acts as a flavor carrier, the perception of taste is enhanced. Taste sensations are produced when salty, sweet, sour, or bitter substances dissolved in solution are detected by the taste buds. The perception of sweetness was measured by the panelists, and the results are presented in the following section.

Table 4.13. Mean¹ sensory scores for the height of the six cake treatments.

Treatment²	Height³
A	10.56 _a ± 0.39
B	8.82 _a ± 0.39
C	10.26 _a ± 0.39
D	10.00 _a ± 0.39
E	9.77 _a ± 0.39
F	3.91 _b ± 0.39

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Height: short = 0; tall = 15

4.2.4.1 Sweetness

The preference for sweet foods develops at an early age. However, the perception of sweetness varies individually, due to genetics, concentration of the sweetener, temperature, viscosity, and pH (Bennion, 1995c). In general, research has shown that individuals have a low sensitivity for sucrose (Meilgaard et al., 1991b). In this study, panelists defined sweetness as the perceived amount of sugar content (Appendix E).

Significant differences ($P < 0.05$) for sweetness were found among cake treatments (Table 14). A change in the degree of sweetness was perceived in cakes with greater than 50% fat replacement. That is, treatments E (75%) and F (100%) were significantly less sweet ($P < 0.05$) than the other treatments. However, cake formulations that contained HFCS-90 and sucrose were slightly sweeter than control A (100% sucrose). Overall, treatments A through D were perceived as moderately sweet. However, sweetness scores for treatments E and F were not rated as being bland (6.4 and 5.2, respectively). It appears that fat acts as a flavor carrier. Once the fat is decreased, sweetness decreased in the product.

Table 4.14. Mean¹ sensory scores for sweetness of the six cake treatments.

Treatment²	Sweetness³
A	8.29 _a ± 0.30
B	8.76 _a ± 0.30
C	8.38 _a ± 0.30
D	8.38 _a ± 0.30
E	6.37 _b ± 0.30
F	5.23 _b ± 0.30

¹ Values with like letters indicate no significant difference ($P \geq 0.05$).

² Cake Treatments: A = Control (with 100% sucrose)
B = Control (with 50% sucrose & 50% HFCS-90)
C = 25% Fat-replacement
D = 50% Fat-replacement
E = 75% Fat-replacement
F = 100% Fat-replacement

³ Sweetness: bland = 0; sweet = 15

CHAPTER V: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Summary

Public awareness has grown regarding the role diet plays in increasing the risk of developing chronic diseases. Excess dietary fat has become American's major nutritional concern, as more diseases become associated with the excessive intake of fat. In response to consumers rising concern with dietary fat, the food industry has provided a variety of reduced-fat and nonfat alternatives of food products. However, many fat-modified foods are rejected by consumers because they do not match the taste and palatability of their full-fat counterparts. Since fat imparts many quality attributes to food, food scientists are employing a systems approach to fat replacement. The food industry will continue to develop fat-modified foods to meet consumer's needs.

Desserts provide great eating pleasure – adding a gratifying finale to a meal. More importantly, desserts play an important role in the social and cultural context of our lives. For example, a cake has become a symbol for celebrating the birth of an individual. However, these delicious treats are often full of fat and calories.

The combination of maltodextrin and HFCS in a system with gums offer possibilities in reducing the fat in cakes while providing a pleasing sensory profile. Maltodextrin and HFCS-90 compliment each other by reducing calories, retaining moisture, and improving texture. In addition, when hydrated maltodextrin mimics the texture of fat, allowing it to replace fat (1:1) in food systems, while HFCS enhances the flavor, color, and sweetness of foods.

The specific gravity of a batter can be related to a cake's volume. Controls A (100% shortening and 100% sucrose) and B (100% shortening and 50% sucrose and 50% HFCS-90), and treatment C (25%) had significantly lower ($P < 0.05$) specific gravity values when compared to treatments D (50%), E (75%), and F (100%). Specific gravity results indicated a decrease in air incorporation as fat replacement increased. The maltodextrin gel was not as plastic as shortening, and thinned upon creaming. Therefore, as the substitution of fat with maltodextrin increased, batter viscosity decreased. This decrease in batter viscosity, however, only significantly decreased ($P < 0.05$) the volume of treatment F. Even though the other fat-replaced cakes (25%, 50%, and 75%) had lower volumes than the controls, differences were small and

non-significant ($P \geq 0.05$). Results for the sensory evaluation of height were similar to the objective results for volume: treatment F had a significantly ($P < 0.05$) low height when compared to the other treatments. Treatment F's batter was probably not sufficiently viscous to retain leavening gases during baking and produced a cake of low volume. Cake volume was significantly ($P < 0.05$) affected with the complete replacement of fat with a maltodextrin gel. No significant differences ($P \geq 0.05$), however, were observed among treatments for cake symmetry.

Comparison of crust L and b values indicated that control B produced a dark crust ($P < 0.05$) with a light crumb ($P < 0.05$), while treatment E (75%) produced a light crust ($P < 0.05$) and treatment F a darker crumb ($P < 0.05$). Browning was more apparent in cakes with HFCS-90 due to fructose's high-solubility and reducing capability, which causes it to decompose and brown rapidly.

Control A was significantly ($P < 0.05$) less moist than treatment E (75%) and F (100%). No significant differences ($P \geq 0.05$) were found for percent moisture among the other treatments. Moistness scores obtained from QDA were comparable to those from the objective analysis of moisture. Control A was rated as the driest cake ($P < 0.05$), while treatment F was perceived as being more moist ($P < 0.05$) when compared to the other cake treatments. The higher degree of moistness found in treatments B through F can be related to the hygroscopic properties of HFCS and maltodextrin. Control A was probably perceived by panelists as the driest cake due to fat's lubricity, which allowed the cake samples from control A to slide down in the mouth, giving little time for moistness to be perceived. Hydrophilic ingredients from the fat-reduced cakes, on the other hand, absorb more moisture; therefore the fat-replaced cakes could linger in the mouth longer for a higher moistness to be perceived. Although the results did not indicate many significant differences in moisture, an increasing trend in percent moisture and perceived moistness was observed as the replacement of fat with the maltodextrin gel increased.

No significant differences ($P \geq 0.05$) in water activity were found among treatments over time, except for control B. Similarly, no significant differences ($P \geq 0.05$) were found among treatments during each time period, except 24 hours after storage, when control A exhibited a significantly lower ($P < 0.05$) water activity compared to treatment E (75%). Although water activity, overall, was not significantly different ($P \geq 0.05$) among treatments or times, results indicated that water activity increased as the amount of maltodextrin gel increased. The fat-reduced cakes containing gums, HFCS-90, and maltodextrin should have been more effective in

lowering water activity due to their ability to bind water. Consequently, the fat-reduced cakes could be reduced in shelf-life, but not in moistness, as seen from the percent moisture results.

Treatment F was significantly ($P < 0.05$) firmer than control A, and treatments C (25%) and E (75%). Results of tenderness scores showed that treatments E and F were significantly ($P < 0.05$) more tough compared to the other treatments. However, treatment E was still considered tender because it had a mean sensory score of 7.3. Treatment F produced objectively, the firmest and subjectively, the toughest cake. Furthermore, treatment F also resulted in the cake with the highest specific gravity and lowest cake volume. Therefore, the partial replacement of shortening with a maltodextrin gel did not strongly affect firmness or tenderness, except with the complete substitution of fat with a maltodextrin gel.

In contrast to the treatment-by-time results of water activity, degree of staling significantly increased ($P < 0.05$) over time for all treatments, except for control A. Treatment differences for each storage time indicated that treatments did not differ significantly ($P \geq 0.05$) one hour after baking; while, 24 hours after storage, control A staled significantly less ($P < 0.05$) than treatment F (100%); and control A staling significantly less ($P < 0.05$) than all other treatments 72 hours after storage, with treatment F showing the highest rate of staling ($P < 0.05$). Staling results demonstrated that even though the degree of staling, like percent moisture and water activity, increased as the percentage of maltodextrin increased, differences were usually not significant ($P \geq 0.05$) unless fat was completely substituted with the maltodextrin gel. The fact that the maltodextrin gel did not reduce staling by binding water, provides evidence for fat's role in preventing starch retrogradation.

In general, cake crumbliness decreased as the level of maltodextrin gel increased. The control cakes were significantly more crumbly ($P < 0.05$) compared to all of the fat-replaced cakes. However, cohesiveness scores for the 25, 50 and 75% fat-replaced cakes indicated these treatments as being moderately crumbly, a desirable trait for high-quality cakes. Thus, cake cohesiveness seems to only be affected by the full-replacement of fat.

Cake adhesiveness decreased as the level of maltodextrin gel increased. However, treatment F (100%) was the only cake rated significantly least sticky ($P < 0.05$). Therefore, the maltodextrin gel did not strongly affect adhesiveness ratings compared to the controls. In fact, panelists rated the fat-replaced cakes as being comparably adhesive or less adhesive than the controls.

Changes in the perceived degree of sweetness became evident in cakes with greater than 50% fat substitution. Therefore, treatments E (75%) and F (100%) were rated as being significantly less sweet ($P < 0.05$) compared to the controls, while the other fat-substituted treatments were rated as being comparably sweet to the control cakes.

5.2 Conclusions and Recommendations for Future Research

Fat contributes many functional properties to a baked product. Therefore, when fat is reduced, the physical and sensory characteristics are altered. As a result, food researchers must understand the function that fat plays in the food system being altered, in order to employ a fat-substitute or combination of fat-substitutes that will most closely mimic the properties of fat.

Satisfactory cakes were made with the replacement of shortening with a maltodextrin gel. Cake volume and perceived height were only affected with the complete-replacement of fat. The crust color of all of the fat-replaced cakes were comparable to control A; the strongest differences in crumb color were seen in the 100% fat-reduced cake. Percent moisture and perceived moistness were enhanced with the combination of a maltodextrin gel and HFCS-90. The combination of a maltodextrin gel and HFCS-90 also did not seem to increase the water activity of the fat-reduced cakes over time when compared to the control cakes. Comparison of crumb firmness and perceived tenderness among the fat-replaced cakes and the controls showed that the cake treatment most strongly affected by the replacement of fat was the fat-free treatment. In contrast, the combination of a maltodextrin gel and HFCS-90 did affect the degree of staling. Moreover, staling increased in all cake treatments over time, except for control A which emphasized the role of fat in the staling process.

The process of cake staling is not well understood. Therefore, further research is recommended in this area. Specifically, future studies should be conducted to measure percent moisture and crumb firmness over time, in order to correlate these changes with the time changes found in water activity and degree of staling. Research should also be conducted to experiment with various combinations of fat-replacers in order to find a replacement system that will most effectively inhibit cake staling.

Results from QDA indicated that panelists found all of the fat-replaced cakes, except the 100% fat-reduced version, to be comparable to the control cakes. The 100% fat-replaced cake was the only treatment that the panel rated as being different (too cohesive) from the controls.

Similarly, differences in adhesiveness were apparent in the fat-free cake. Changes in sweetness became distinguishable with greater than 50% fat replacement.

Although ratings from the QDA panel indicated that the fat-replaced cakes were comparable to objective analysis, additional sensory research should be conducted to determine consumer acceptability and cake preference. In addition, affective tests of staled cakes (e.g. up to 72 hours) should be set up to see if cakes are equally accepted compared to fresh cakes and to control cakes that are stale.

In conclusion, physical and sensory tests indicated that the combination of a maltodextrin gel and HFCS-90 resulted in a satisfactory cake. However, the study showed that there was a limit for substitution to take place. Satisfactory products were produced up to a 75% limit. Therefore, some fat was still needed in the product, but the results indicated that a successful substitution could be made with the combination of a maltodextrin gel and HFCS-90. Continuing research is needed to investigate the effect of these two ingredient combinations on product quality in baked goods.

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Appendix A
Experimental Design

Table A.15. Balanced incomplete block design^a for objective measurements and QDA.

Block	Cake Treatments ^b		
1	A	B	E
2	A	B	F
3	A	C	D
4	A	C	F
5	A	D	E
6	B	C	D
7	B	C	E
8	B	D	F
9	C	E	F
10	D	E	F

^a $t=6, k=3, r=5, b=10, I=2, E=.80$

^b Cake Treatments: A = Control (with 100% sucrose)
 B = Control (with 50% sucrose & 50% HFCS-90)
 C = 25% Fat-replacement
 D = 50% Fat-replacement
 E = 75% Fat-replacement
 F = 100% Fat-replacement

Appendix B
Cake Formulations