TEXTURAL OPTIMIZATION OF REDUCED-CALORIE LAYER CAKES USING POLYDEXTROSE AND A GUM-EMULSIFIER BLEND

by

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INTRODUCTION

Millions of Americans, for cosmetic or therapeutic reasons, are on restricted calorie diets. Many of these dieters, concerned about the negative effects of sucrose and fat, consume lower calorie, sugar- and fat-free foods. As nutrition awareness increases, the demand for reduced-calorie products will continue to increase.

A number of diet beverages and desserts are currently available, but reduced-calorie baked goods are conspicuously deficient. The scarcity is partly a result of the enormous difficulties inherent in replacing sucrose and fat in baked products. In cakes, particularly, sugar and fat perform a variety of functions which are not compensated for easily by intense sweeteners or bulking agents.

Researchers have succeeded in developing cakes which are either sugar-free or shortening-free, but to date, no one has marketed a cake which is free of both ingredients. In addition, the prepared diet cakes and cake mixes currently available are often of lower quality than their full-calorie counterparts, and few consumers will pay the higher price for an inferior product. Lastly, cakes which are marketed as sugar- or fat-free frequently contain ingredient substitutions which make the "diet" product nearly as caloric as regular cake.

Therefore, a need exists for a high quality, reduced-calorie cake. The purpose of this study was to create a reduced-calorie layer cake comparable in overall quality to traditional high-ratio cake that would appeal to both diabetic or health-restricted and non-diabetic, health-conscious consumers. Specifically, the objective was to eliminate shortening and sucrose while maintaining standard cake texture, appearance, volume and mouthfeel. Sweetness and flavor development was not a goal of this research; levels of sweetener and flavoring were constant for each treatment to allow unconfounded evaluation of cake textural attributes.

Response surface methodology (RSM) was selected as the multivariate statistical technique to identify effects of each ingredient on cake attributes and to determine which combination of ingredient levels would optimize those attributes. Analysis of variance (ANOV) techniques were selected to validate findings from RSM studies. The sweetener/bulking agent/emulsifier blend optimized in this experiment could be used to develop commercial dry cake mixes for home use. The convenient mixes should produce reduced-calorie cakes more marketable than those currently available.

REVIEW OF LITERATURE

Mechanisms of Cake-Making

A cake batter is an extremely complex, multiphase system. Depending upon stage of mixing or type of batter, the batter may be an oil-in-water (O/W), water-in-oil (W/O), or as Shepherd and Yoell (1976) stated, actually a water-in-oil-in-water emulsion, as well as a foam, sol, colloid and suspension. Dispersed fat or water droplets are found in the continuous phase along with dissolved sugar and suspended solid particles of flour and protein.

Batters contain a large number of interlocking gas bubbles held in supporting liquid walls, and thus qualify as foams. Ramstad (1958) and Mizukoshi (1983a) emphasized the foam emulsion nature of cakes and the thermodynamic instability of foam systems.

Schuster and Adams (1984) made a distinction between the fat-containing batters described above and fat-free batters. Unlike the former type, where air is held in the shortening, air in lean batters is incorporated into the aqueous phase. Instead of fat, air cells are surrounded by a continuous film of sugar syrup and/or egg protein, and are stabilized by the egg proteins (Garibaldi et al., 1968).

During baking, both types of batter expand and "set" into light, sponge-like gels through starch gelatinization and protein coagulation. Heat transforms the gas-liquid emulsion of cake batter to the gas-solid emulsion of cake (Mizukoshi et al., 1980)

The baking cycle consists of three main stages:

I) Batter preparation/initial aeration (30-40 °C)
II) Batter thermal stability/early baking (40-70 °C)
III) Thermal setting/end of baking cycle (70-100 °C)

(Howard et al., 1968; Howard, 1972; Shepherd and Yoell, 1976).

Stage I) Pyler (1979) stated that the primary purpose of cake mixing is to bring about an extensive, homogeneous dispersion of the various cake ingredients, usually with maximum incorporation of air and minimum development of the flour gluten. In the classical multistage mixing method, fat and sugar are creamed to incorporate air in the fat phase; no air bubbles are found in the aqueous phase (Carlin, 1944). The air creamed into the fat particles serves as the foci or points of origin for cells in the cake. Bubbles support the cake structure until sufficient mechanical strength is achieved by thermal setting. Upon adding fresh egg and water, the sugar goes into solution and a W/O emulsion is formed. Addition of flour changes the batter to a multiphase structure.

In single-stage batters, such as commercial cake mixes, liquids are added to the dry ingredients and air is incorporated directly into the aqueous phase. This type of batter is less stable than creamed batter. Gas can diffuse, and because the pressure in a small bubble is larger than pressure in a large bubble, there is a tendency for large bubbles to absorb smaller ones and rise out of the cake (Handleman et al., 1961). Wootton et al. (1967) and Howard et al. (1968) found that soluble, foamable proteins were essential to incorporate and retain air and stabilize the batter.

Batter expansion and cake specific volume are correlated closely with the initial amount of air in the batter. No new cells are generated during baking (Carlin, 1944; Handleman et al., 1961) so the initial mixing stage is critical.

Stage II) A number of interactions occur during the early periods of baking. Hydrogenated or plastic shortening, if used, will begin to melt around 37-40 ^{o}C and release the air bubbles into the aqueous phase. Any W/O emulsion portions of the batter invert to O/W. In fat-free and single-stage batters and mixes using liquid shortenings, air cells already will be dispersed in this phase.

In the early stages of baking, batter viscosity decreases as temperature increases. In batters lacking foam stability, decreasing viscosity accelerates foam breakdown, and drainage from foam lamellae (walls) is increased. If the air cells are stabilized properly by egg proteins at the vapor/water interface, no apparent separation of either the fat, water or starch will occur. Mizukoshi (1983b) found that foam stability and drainage are influenced by air diffusion, surface viscosity and rigidity, temperature, batter composition and viscosity, and mutual repulsion of overlapping double layers around the foam air cells. Besides soluble (unhydrolyzed) proteins, polyvalent cations and surface active lipids were found essential for batter stabilization during this stage (Howard et al., 1968). The polyvalent ions from flour, leavening materials, egg, milk and salt interacted with acidic lipids like stearic acid to stabilize various interfaces.

Leavening agents begin to react, and as carbon dioxide, air and water diffuse into air bubble nuclei, the cells expand and batter volume increases. During this stage, the cake batter undergoes considerable bulk flow, because of convection currents. Cakes bake vertically from the bottom and radially from the periphery to the center; temperature increase is most gradual at the center of the cake (Yamazaki and Kissell, 1978; Mizukoshi et al., 1979).

Stage III) The third and final stage in the cake-making process is the thermal-setting or structural development stage. The batter changes from a fluid, aerated emulsion to a solid, porous network which will not shrink appreciably or collapse after removal from the oven (Howard, 1972). This stage is most critical of the three stages because the sponge-like character of cake structure determines its other qualities, e.g., volume, grain, symmetry, mouthfeel, and texture (Mizukoshi et al., 1980).

Around 65 °C, the batter viscosity gradient begins to change, so at very low shear rates the batter would seem to be thickening, whereas at high shears it is still thinning (Shepherd and Yoell, 1976). As viscosity increases, small bubbles are trapped, though large bubbles may continue to flow until a higher temperature is reached. Air bubble expansion becomes very rapid and violent at 70-80 °C and no longer follows convection patterns. At 90-100 °C the bubbles may be distorted from a spherical shape and come into contact with each other, forming tunnels and holes as the structure becomes fixed (Carlin, 1944).

The film containing the water and holding the air bubbles is evaporated or becomes bound (Yamazaki and Kissell, 1978). The heat setting of cake batters is attributed to protein coagulation and partial gelatinization of starch. Donelson and Wilson (1960) indicated protein was more important than starch in forming the cake structure; however, Howard et al. (1968) showed that thermal setting and cake structure development actually depended on undamaged starch particles. For cake to set, "free" water in the system must be absorbed. Though other ingredients compete, the starch can bind several times its weight in water. The starch swells and begins to gelatinize, and the sol of the cake batter starts to change to the gel-like structure of cake.

The formation of the continuous gel phase prevents expansion of the bubbles without a further pressure increase because the generated gas escapes. At this point, the cake stops expanding. Temperature gradients occurring in the batter cause portions of the cake to set at varying times. The crust, which receives maximum heat and is drier, sets first. Continued heating leads to further coagulation of the egg and flour proteins and starch gelatinization. The extent of water absorption by starch must be great enough to change the fluid phase into a solid, porous structure (Howard et al., 1968). The time at which this occurs determines the final appearance of the cake. Cake structure is further strengthened until the end of the baking process (Mizukoshi et al., 1980).

Gas/Air Bubbles: Cake Foam Structure

Cake texture, including grain, volume, tenderness and strength, is dependent upon the amount of air incorporated into the batter. Dunn and White (1939) showed that specific cake volume is correlated closely with the amount of air: half of the volume increase of a lean pound cake containing no chemical leavening agents was from the thermal expansion of air in the batter.

Angel, sponge and chiffon foam cakes rely entirely on air as the leavening agent. Mizukoshi et al. (1980) verified that cake batters from which air was removed completely did not rise at all when baked. Handleman et al. (1961) stated that pneumatic support provided by air bubbles maintains cake structure until mechanical strength is developed in the nongaseous phase. When the number of cells in batter is small and size is consequently large, the finished cake tends to have a coarse, open grain and low volume. In contrast, batter with a large number of tiny air cells results in a high volume, tender cake with fine, close grain. Thus, air is critical to cake structure and quality.

Cake batter may be mixed in several ways to obtain the final aerated emulsion. In cakes using plastic shortening, the air is trapped in the fat during creaming. When liquid shortening is used, or fat-free mixes are prepared, the air is incorporated directly into the aqueous phase. Air is incorporated physically into the batter during preparation by beating, whipping or placement under pressure (Schuster and Adams, 1984). Both fat-containing and fat-free batters are leavened by physical and/or chemical means.

Carlin (1944) first pointed out that no new air cells are formed during baking; all air cells which ultimately create cake texture are incorporated during mixing. Handleman et al. (1961) agreed that leavening gases only supplemented the pre-existing bubbles. They conducted extensive research on bubble action in cake batter and derived several equations to describe bubble mechanics. The most important, LaPlace's capillary pressure equation, is given in the relationship

$$P = \frac{2\gamma}{r}.$$

This equation illustrates that pressure (P) in a bubble is related to the radius (r) and the interfacial tension (γ). Thus, as a bubble's radius becomes increasingly small, its internal pressure becomes infinitely large, so that spontaneous nucleation of bubbles is nearly impossible.

The CO_2 and oxygen dissolve in water, and therefore do not provide the needed bubbles in cake. Nitrogen, which is less water soluble, appears to be the gas in the initial bubbles (Hoseney, 1986).

Each air bubble is surrounded by a surface film which contains water. When more air bubbles are present, more water is bound in the batter and the baked cake has a moister crumb. Air cells serve as collecting sites for gases generated by the baking powder and the steam produced. As baking begins, water vapor and CO_2 expand the air cells. Mattil (1964) demonstrated that thermal expansion of air is a minor factor in the leavening process; 90% of the increased volume during baking is due to increased pressure of steam in the air bubbles.

If many cells are present, the batter expands uniformly, resulting in a cake with thin cell walls, fine grain and smooth texture. If only a few air cells are present, the leavening gases aggregate in large masses. The large bubbles tend to migrate to the top of the cake and are lost, resulting in volume loss and cake layering: grain is dense and gummy at the bottom and progressively more open at the top (Mizukoshi, 1983a).

Handleman et al. (1961) also reported this phenomenon. Due to the higher pressure of smaller bubbles, the equilibrium concentration of dissolved gas in the fluid around a small bubble is higher than that surrounding a larger bubble. This solubilized gas will diffuse from the region of high concentration to the areas of lower concentration surrounding the larger bubbles. Small cells shrink and the large cells continue to increase in size. Leavening gas also seeks the larger, low pressure bubbles.

As the large bubbles grow and small bubbles disappear, the number of active nucleating sites is reduced, increasing the mean size of cells. Consequently, a greater number of bubbles attain critical buoyancy and escape from the batter. Handleman et al. (1961) calculated that the chance of loss of a bubble due to its buoyancy is proportional to the square of its radius and is inversely proportional to batter viscosity.

Although escaping bubbles reduce cake volume, loss of large bubbles early in the baking process actually may be beneficial. If large bubbles are expelled, the remaining small air bubbles are more uniformly sized, and the tendency for large bubbles to grow at the expense of small ones during later baking stages is reduced (Shepherd and Yoell, 1976).

Emulsifiers are effective in limiting the number of bubbles that reach a critically buoyant size and rise out of the batter. The use of emulsifiers results not only in a greater number of bubbles but also in a bubble distribution of smaller mean diameter and less spread. A large number of cells provides a great surface area to absorb the water vapor which condenses as the baked cake cools. Eating quality is improved because of increased moistness and more rapid flavor release (Shepherd and Yoell, 1976). The emulsified cake also has enhanced keeping quality.

Though emulsifiers are effective in incorporating air, a critical level is reached after which no improvement occurs. In fact, past this point, viscosity and volume decrease and cake shrinks because of overfine dispersion and weakened crumb structure (Birnbaum, 1978).

Emulsion and Foam Stability

Emulsions and foams are generally unstable. Upon standing, emulsion phases will separate because of coalescence, sedimentation or aggregation (Schuster and Adams, 1984). The supporting lamellae in foams may rupture and collapse, exhibiting drainage.

No comprehensive theory can account for the stability of the emulsion system in cake batters (Shepherd and Yoell, 1976). However, emulsion stability is improved by the following factors:

1) Reduced interfacial tension at water/oil surfaces.
2) Formation of strong interfacial films or steric barriers.
3) Increased viscosity of the continuous phase.
4) Increased electrostatic repulsion of dispersed droplets.

Interfacial tensions are reduced, through physical or chemical means, by adsorption and arrangement of molecules at the water surface. Soluble proteins are usually the molecules involved: as they uncoil or denature they interact to form a protecting "skin" that separates the phases (Townsend and Nakai, 1983; Poole et al., 1984). A thick, interfacial film encapsulates dispersed droplets within a protective coating and prevents lipid from destroying the protein-stabilized vapor/water interface (Howard, 1972). Phillips (1981) stated that the mechanical properties of these protein films are responsible for resistance to coalescence and flocculation. In an emulsion, stability is enhanced when adsorbed protein layers are thick, highly solvated and charged, as is true on either side of the protein's isoelectric point, or pI. Foam stability, on the other hand, tends to be maximized at the pI, where the rheological properties of the adsorbed films also are maximized.

Other solid particles, such as emulsifiers or gums, may stabilize emulsions by adsorption at the interface (Friberg, 1976). Carbohydrate polymers may further enhance stability by increasing viscosity of the continuous phase and impeding movement of dispersed droplets.

Adamson (1976) described monomolecular surface films, or monolayers, formed on the surfaces of emulsions. Monolayers occur in different physical forms depending on the attractive forces between the molecules, pressure and temperature. Monolayers vary in their ability to stabilize. Emulsion stabilization is enhanced by a multilayer structure as well. A multilayer organization creates a considerable energy barrier that prevents droplets from coming into close contact and coalescing (de Gennes, 1974).

Though emulsions have been defined classically as consisting of two phases, a third, liquid-crystallilne phase has been found to stabilize the system. Mesophases are aggregation states that exhibit properties of both liquids and crystalline bodies: the molecules are associated more than in the liquid state but less than in the solid. Mesophase interactions create additional repulsive forces at interfaces which stabilize emulsions (Friberg, 1976). In cakes, denatured egg lipoproteins may release phospholipid in the later stages of heating. This phospholipid may be present at the oil/water interface, forming a liquid crystalline phase and stabilizing the emulsion at the critical early stage of baking. A complete review of cake emulsions can be found in Shepherd and Yoell (1976).

Specific Gravity and Batter Viscosity

Mizukoshi (1985a) noted that rheological properties of cake batter during baking affect volume, contour, grain, texture, mouthfeel and flavor of the final cake. Pyler (1979) stated that the two important determinants of cake qualilty were batter specific gravity and batter temperature. Temperature influences viscosity of batter, which affects batter aeration and stability. Batters of appropriate consistency are aerated more readily to optimum and retain aeration during processing. Lee and Hoseney (1982) found specific gravity and viscosity were highly correlated and both affected grain quality. Thus, these two batter characteristics are difficult to distinguish.

By definition, specific gravity is the ratio of the weight of a known volume of a substance to the weight of an equal volume of some standard material, usually water. A general inverse relationship exists between specific gravity and cake volume: lower specific gravity indicates high batter aeration and greater volume.

The optimum specific gravity for a cake is influenced by the formula, ingredient quality, mixing speed and time, temperature, and the type of equipment used. Ellinger and Shappeck (1963) noted that, of various alterations in ingredients, changes in sugar, shortening and liquid (water and eggs) were most influential on specific gravity, and ingredient changes may alter the optimum specific gravity.

Those authors found that optimum specific gravities were lower for cakes with fluid shortening than for those using plastic fat. The lower specific gravity indicated greater air incorporation; and fluid shortening cakes gave significant volume increases over cakes prepared with solid shortening. Specific gravity also relates to grain, texture, tenderness, fragility and peaking; the liquid shortening cakes had finer, more even grain and texture and better structure than plastic shortening cakes.

Viscosity of the batter is important in baking. The batter viscosity affects air retention and partly controls the rate at which bubbles are lost. Handleman et al. (1961) found an increase in viscosity reduces volume loss by preventing coalescence and increasing the critical size a bubble must attain to escape. Cake batter must be sufficiently viscous to keep flour particles suspended. If flour settles out before the cake sets, a dense, gummy layer is formed at the bottom. Correct batter viscosity is critical for permitting the cake to rise evenly and maintain its structure.

Viscosity of the continuous aqueous phase can affect emulsion stability. Viscosity is affected by the ratio of dissolved sugar, protein and other solids in the recipe. For example, tenderizers such as sugar, fat and water reduce batter viscosity. Viscosity is increased by the water-absorbing starch particles, which expand with increasing temperature.

Shortening

As the name implies, shortening or fat is used to shorten or tenderize cake and prevent formation of a tight gluten network. Shortening affects texture by off-setting the toughening influence of flour, milk and egg proteins. Fat serves as a dispersing agent for ingredients. As a leavening agent, fat increases the amount of air physically incorporated into the batter during creaming and mixing. Shortening supports high levels of liquids. Due to enhanced moistness and aeration, shortening improves cake mouthfeel and eating qualities. As a moisture and oxygen barrier, shortening improves keeping quality and extends shelf life.

Shortening is not essential for successful cake baking; in certain cakes, such as a true sponge, shortening is not used. Fat may be added to cakes in fat-containing ingredients such as eggs or milk. Plastic shortenings can be replaced with fluid shortenings--a substitution that allows great reductions in fat levels. In modern cake production, fats work generally in conjunction with surfactants or emulsifiers.

Crystalline Phases

Fats are specifically arranged in four distinct crystal lattice structures (Hoerr et al., 1966). Crystalline form refers to the order of molecules in the solid state of the fat. Each arrangement exhibits a distinguishing or characteristic x-ray spectrum. Polymorphism depends upon fat composition and processing conditions, such as pressure, temperature and rate of cooling. Treatment and compositional differences determine how the fat will function in various applications.

The four crystalline forms are alpha (α), beta prime (β'), intermediate (I), and beta (β) (Fig.1). The α form

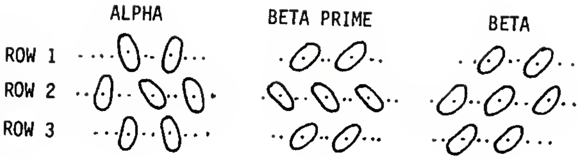


Figure 1 - Cross-sectional crystalline structures of fats (Lutton, 1972)

is produced on sudden cooling of a fat and has the lowest melting point. This form is the least stable; its transience during processing allows conversion to either β or β' forms (Shepherd and Yoell, 1976). Alpha-crystalline fats have good emulsifying and aerating activity and are dispersed easily (Schuster and Adams, 1984).

Beta prime glycerides have the second-lowest melting point and are fairly stable. They exhibit small (1 μm) needle- or rosette-like crystal forms which absorb oil readily. Beta prime crystals are characteristic of commercial cake shortenings (Hoerr at al., 1966).

The I and β forms exhibit larger (1-2 μm) needle-like crystals with poor oil-absorption capabilities. The β form is most stable, and has the highest melting point. Fats and pure triglycerides usually exhibit all four polymorphic forms, but assymetrical fats may exhibit only two or three crystalline modifications (Hoerr et al., 1966).

Emulsifiers

Emulsifiers are surface-active agents which enhance emulsion formation by modifying interfacial conditions. Prior to the 1930's, cake batter aeration, the size, number and distribution of air cells, was a function of mixing procedures and a shortening's crystalline form. With the advent of mono- and diglycerides around 1933, the era of cake emulsifiers was born. Mono- and diglycerides in shortening produced a finer dispersion of fat in the batter, giving a close grain structure with sufficient strength to hold increased levels of sugar and liquid. The resulting "high-ratio" cakes had increased volume and lightness and a longer shelf life than traditional non-emulsified cakes.

Shortenings with monoglycerides were effective only when the batter was mixed in multiple stages; precreaming was necessary to incorporate air. Though emulsifiers had facilitated aeration, the physical properties of the plastic shortening were still important.

Surfactants consist of hydrophilic and hydrophobic (lipophilic) portions. This ambiphilic nature allows the compounds to interact with at least two immiscible substances and helps them mix. Emulsifiers are adsorbed strongly on interfaces, resulting in reduced interfacial tension. This reduction decreases the energy required to disperse the fat and increases surface area. Emulsifiers allow fat droplets to be uniformly dispersed throughout the batter, which then permit incorporation of a large amount of tiny air bubbles. As a result of increased surface area, surfactants permit inclusion of great quantities of water.

Emulsifiers not only aid in emulsion formation but promote emulsion stability. Surfactants are arranged at the phase interfaces to form charged and steric barriers and achieve stable emulsions. Emulsifiers bring a repelling charge to the dispersed particles and form viscous, protective layers around them which prevent coalescence.

The function of surfactants has been described as an "anti anti-foam" (MacDonald, 1968). The batter foam is stabilized by a protective interfacial film which encapsulates the antifoaming fat and prevents it from coming into contact with the protein. The interfacial film or monolayer is found at the O/W interface. The layer is one molecule thick; hydrophilic surfactant "heads" are embedded in water while lipophilic "tails" are in oil. Surface tension reduction involves surfactants acting as individual molecules at very low concentrations. By covering the water surface, emulsifiers create a new oil surface. If more emulsifier is added after monolayer coverage has been achieved, a turning point, known as the critical micelle-forming concentration is passed. The additional surfactant molecules are forced into the bulk of the liquid and aggregate into micelles to stabilize the system (Stutz et al., 1973).

Micelles result from the tendency of the hydrophobic portions of surfactants to minimize contact with water. Lipophilic moieties orient toward the center, while hydrophilic portions extend out into the water. At high concentrations, emulsifier molecules associate to form other condensed phases besides micelles, including condensed monolayers and bilayer or lamellar forms (Greene, 1975). While monolayers are restricted to interfaces, condensed phases may be distributed throughout the system. Condensed phases are involved in formation of both emulsions and foams. Further descriptions of condensed phases and a thorough review of surfactants is found in Schuster and Adams (1984).

Hydrophilic-Lipophilic Balance

Based on emulsifiers' ambiphilic nature, Harris (1933) stated that a surfactant's suitability could be assessed by its hydrophilic-lipophilic equilibrium. Griffin (1949) quantified this concept by creating a 20-point Hydrophilic-Lipophilic Balance (HLB) scale.

Lipophilic surfactants are assigned low HLB ratings; those with hydrophilic nature have higher numbers. The turning point on the scale is around 10. According to MacDonald (1968), the following ranges can guide emulsifier applications:

3 - 6	W/O emulsifier
7 - 9	Wetting agent
8 - 18	O/W emulsifier.

However, HLB cannot always predict surfactant action. An example of this HLB inconsistency is seen in cake batters. Commonly-used emulsifiers such as mono-diglycerides or propylene glycol monostearate (PGMS) are lipophilic, with an HLB of 5 or less. They should result in a W/O emulsion, yet are being used to improve O/W batter emulsions (MacDonald, 1968). In complicated food systems where carbohydrates and proteins interact with the available lipophilic and hydrophilic groups on the emulsifier molecules, the HLB value is probably, at best, an initial orientation aid (Schuster and Adams, 1984).

Benefits of Emulsifiers

The use of emulsifiers in cake, either as components in fat or as individual additives, results in the following improvements in cake quality:

1) Improved mixing tolerance.
2) Greater air retention and specific volume.
3) Greater symmetry.
4) Enhanced eating quality due to increased moistness and faster flavor release.
5) Finer, uniform crumb structure and less tunnelling.
6) Greater crumb softness and tenderness.
7) Retardation of staling.
8) Improvement in performance of dried egg for use in cake mixes.
9) Greater specific volume for fat-sugar creams.
10) Cost savings by some reduction in expensive cake ingredients (Shepherd and Yoell, 1976; (Birnbaum, 1978).

Birnbaum (1978) concluded that, "Although cakes may differ substantially in their fat content, they are all definitely benefited by the incorporation of an emulsifier or combination of emulsifiers". Even fat-free cakes are improved by emulsifier action.

Emulsifier Form and Synergism

Natural emulsifiers such as those in egg yolks and polar flour lipids are highly functional in cake batter systems (Yamazaki and Kissell, 1978; Chung and Pomeranz, 1981). Howard (1972) stated that egg yolk lipids must be considered an important part of the total emulsifier system in yellow cake. Emulsifiers, which are added to the batters, are available in different physical forms ranging from liquid and soft plastic to flakes, powders and beads. When used in cake shortenings, the harder varieties tend to produce superior aerating and textural results (O'Brien, 1972).

While one surfactant may perform satisfactorily, blending two or more improves performance. Combinations exhibit synergism, allowing a better and wider range of activity than single emulsifiers (Schuster and Adams, 1984). Surfactant synergism has been noted by Buddemeyer and Moneymaker, 1961; Buddemeyer et al., 1962; Nash and Babayan, 1963; Wootton et al., 1967; MacDonald, 1968; Krog, 1977; Hartnett, 1979b; and Knightly, 1981.

Surfactants' chemical composition and physical form influences performance characteristics. For example, saturated surfactants provide optimum cake aeration and volume but produce dry texture and crumb harshness. Unsaturated surfactants impart a tenderizing effect but may weaken the gluten structure to such an extent that volume is reduced (Knightly and Lynch, 1966). However, blending the two types results in a high volume, fine-textured cake.

Wootton et al. (1967) found emulsifier mixtures decreased batter specific gravity and allowed more air incorporation than either emulsifier alone. Hydrophilic and lipophilic emulsifier blends frequently will outperform single surfactants, even at the same HLB (Knightly and Lynch, 1966). Knightly (1981) attributed the improved activity of multicomponent emulsifier systems to the orientation of the emulsifiers at the oil-water interface. The surface is covered better by a combination of different-structured emulsifiers because more emulsifier molecules can be concentrated on the surface and thus form a better protective layer with fewer gaps. Blends containing both hydrophilic and lipophilic surfactants are particularly effective.

As a batter is heated, emulsifier crystals eventually melt and lose their stabilizing properties. Thus, it is advantageous to use a combination of surfactants with different melting points; as the crystals of one emulsifier melt, the other crystals can continue to stabilize the batter. Buddemeyer et al (1962) found a 4-component system produced better results in cake than blends of two or three emulsifiers.

The specific qualities of each type of surfactant must be considered carefully before mixing. An inappropriate combination may result in overly tender texture, wet crust and low volume (Hartnett, 1979a).

Synergistic combinations of emulsifiers broaden the tolerance of the shortening to ingredient and processing changes, even when used in leaner-type cakes (O'Brien, 1972). Blends permit wider ranges in sugar, shortening and moisture levels. Hartnett (1979b) has shown that an emulsifier combination minimizes dependence of cake quality on shortening. At the optimum emulsifier level, solid triglycerides can be reduced to a minimum or even eliminated (Moncrieff, 1970; Kamel and Washnuik, 1983).

When surfactants are used, cake batters generally must be reformulated: O'Brien (1972) advised changes in cake balance when using multiple emulsifiers to take full advantage of their performance. The greatest change required would be increased moisture. Emulsifiers assume some of the aerating and tenderizing functions of crystalline fat, so other modifications could include reduction in sugar and shortening levels. Egg levels may be decreased or increased, depending on the type cake desired (O'Brien, 1972).

Emulsifiers are marketed frequently as a mix with other cake ingredients already included. The aerating or emulsifying agents are bulked with milk products (caseinate or nonfat dry milk) and maltodextrins or modified starch (Seibel et al., 1980). A matrix system sold by National Starch and Chemical Company under the trade name "N-Flate" contains an emulsifier blend with guar gum and pregelatinized waxy maize starch in a skim milk powder base (National Starch and Chemical Co., 1982). Such blends are suitable for preparation of cake mixes and are easy to handle.

Surfactant Level

The amount of emulsifier added to batter is critical in determining cake quality. In multistage cakes, volume increases linearly with increasing emulsifier concentration. The quality improvement is characterized also by symmetrical conformation, fine grain and tenderness, and an optimum level is reached after which no further improvement occurs. On the contrary, beyond a critical point, a reversal of quality results. Batter becomes thin and glossy. Cell distribution is uneven and texture is coarse. Because of an overfine dispersion of shortening, structure is weakened, the cake shrinks excessively upon cooling and volume is decreased (Carlin, 1944; Birnbaum, 1978). Kissell et al. (1974) found characteristics of overemulsification evident at concentrations yielding maximum cake volume.

Surfactant level is important in fat-free cakes in a different way. A small quantity of emulsifier has a destabilizing effect and actually reduces aeration capacity. Insufficient emulsifier levels can give a lower batter and cake volume than no emulsifier. This phenomenon can be the result of competition between emulsifier and egg protein at the air-water interface, which destabilizes the lipoprotein-protein boundary film. Only with an increased quantity of surfactant above a critical level can a closed film form around the air bubbles to stabilize the interfacial protein layer (Schuster and Adams, 1984). Shepherd and Yoell (1976) cited a report on fat-free cakes in which the optimum monoglyceride level increased with the amount of egg in the formulation.

Mechanics of Alpha-Tending Emulsifiers

The emulsifiers used in the foods industry are fat derivatives; their lipophilic moieties are fatty acids. For emulsifiers that also contain glycerol as a hydrophilic moiety, the relationship to fats is especially pronounced (Schuster and Adams, 1984). Thus, the classification by crystalline phases applies not only to shortenings but cake emulsifiers.

In their 1966 study, Hoerr and co-workers recommended the β' crystal as most effective in batter air stabilization and remarked that the α form was "not encountered in cake". Subsequent research and development, however, has permitted widespread use of α-tending cake emulsifiers. According to Wootton et al. (1967) and Krog (1977), α-tending emulsifers are superior to mono- and diglycerides. Alpha-tending surfactants result in even fat distribution and a high viscosity of the aqueous phase. Thus, they have a greater aerating capacity than β crystals. When α crystals are used, the creaming step is unnecessary and cakes or boxed mixes may be prepared in a single stage. Some surfactants which possess α crystallinity are listed in Table 1.

Investigation of α emulsifier functionality is a study in paradox because these compounds behave quite differently from the other crystalline forms. Alpha-tending emulsifiers generally exhibit a high HLB, indicating a strong attraction for water. A number of these surfactants also carry an electrical charge, unlike neutral, lipophilic monoglycerides. Unlike plastic shortenings and β emulsifiers, α additives allow incorporation of air directly into the aqueous phase.

Although α-tending emulsifiers are considered to be especially effective in aeration of single-stage batters, Wootton et al. (1967) and Howard et al. (1968) showed they are involved only indirectly in air incorporation; air is trapped in the aqueous phase by soluble protein. The foaming ability of dissolved protein is recognized widely (Townsend and Nakai, 1983; Poole et al., 1984), and in foam-like single-stage batters, soluble protein is the key aerating ingredient. Howard (1972) demonstrated the reducing effect of egg whites on batter density.

Table 1 - Alpha-tending emulsifiers

Diacetyl tartaric acid esters (DATEM or TEM)

Monoglycerides: acetylated
ethoxylated
lactylated
succinylated

Polyglycerol esters (PGE)

Polyexothylene sorbitan monostearate (Polysorbate 60)

Propylene glycol monostearate (PGMS)

Sorbitan monostearate (SMS)

Stearoyl-2-lactylate (SSL)

Emulsifying agents improve the formation of foam by egg proteins.

Though soluble protein is required for single-stage batters, foam stability is maintained only when an emulsifier is added. Surfactant efficiency is judged generally by its ability to decrease interfacial tension. Alpha-tending emulsifiers, ironically, demonstrate an apparent increase in interfacial tension. Wootton et al. (1967) explained the indirect effect of α -stable emulsifiers by their unique behavior at batter interfaces. Alpha additives assemble at the interface; when a critical concentration is reached that exceeds their solubility, the saturated emulsifiers precipitate or crystallize to form a thick, plastic-like film. The impermeable membrane encapsulates the dispersed fat droplets and prevents migration of the oil fraction into the aqueous phase of the batter. Immobilization protects the dissolved proteins from the anti-foaming actions of the lipids (Krog, 1977). As the strength of the interfacial film increases, the amount of air incorporated in the batter increases (Wootton et al., 1967).

As with other emulsifiers, α -tending surfactants perform better in combination than alone. The hydrophilic α -tending emulsifiers, like sodium stearoyl lactylate or polysorbates, increase fat distribution and increase viscosity of the aqueous phase. The higher viscosity promotes air incorporation by reducing film thinning in the foam lamellae. The more lipophilic α additives, such as PGMS, are especially effective in promoting fat globule aggregation. These are the surfactants which allow formation of the protective α-crystalline membranes (Krog, 1977).

The α-tending emulsifiers led to another breakthrough in cake baking technology: use of fluid shortenings. Liquid shortenings or oils alone cannot retain gas bubbles and act as anti-foaming agents. When α additives are used, the oil droplets are enclosed, stabilizing the protein-based foam.

Fluid shortenings are easy to handle, pump and meter (Knightly and Lynch, 1966). Batters made with liquid shortening require less mixing and exhibit lower specific gravity than those made with plastic shortening. Resultant liquid fat cakes have higher volumes, greater softness, tighter grain, finer texture, higher moistness, longer shelf life and better eating qualities than comparable plastic fat cakes. The combination of α agents and the single-stage method allows the addition of larger amounts of liquid and also tolerates changes in the formulation to make cakes more palatable (Seibel et al., 1980).

Historically, the polymorphic form of the solid shortening crystals has played a vital role in the development of cake quality. Alpha-tending surfactants permit the use of oils without concern for the solids index, and, largely, have obviated concern for crystalline form (Knightly, 1981). Emulsified fluid shortening systems can successfully replace the entire aerating function of solid fat (Moncrieff, 1970).

Alpha-tending emulsifiers are also effective in producing cakes which are totally free of shortening. Krog (1970) stated that the activity of emulsifiers in aerating fat-free batters depends upon the emulsifiers' physical form. In regard to specific gravity and cake volume, for example, the greatest activity was shown by a 20% monoglyceride gel, followed in decreasing order by a 15% dispersion, a blend sprayed with nonfat milk, and a crystallized spray (Birnbaum, 1978). The gel and dispersed forms had the greatest activity because they have the highest proportion of their monoglyceride surfaces in contact with water. The combination of monoglyceride and PGMS yields an especially stable and active aerating agent when it is in paste form (Schuster and Adams, 1984).

Hydrocolloids

Closely related in function to emulsifiers are hydrocolloids or "gums". Gum functions include the following:

thickening, increasing body or viscosity

flavor blending
binding moisture
improving appearance
stabilizing
bulking
masking off-flavors
smoothing flavors
improving uniformity
encapsulating
preventing gummy layers in cake (Glicksman and Farkas, 1966; Miller et al. 1967; Finberg, 1972; Sharma, 1981).

These polysaccharides are found in almost all commercial cake mixes. Gums' usefulness is based on their ability to modify the basic properties of water (Sharma, 1981). In addition, gums interact with starch and protein. Using gums in cake mixes changes the batter rheology and improves the appearance, texture, eating quality and shelf life of cakes (Lee et al., 1982). Specifically, cakes prepared with gums exhibit less cracking, greater symmetry and volume, more uniform texture and grain, finer cell structure, silkier crumb, less pasty mouthfeel and higher moistness than control cakes (Young and Bayfield, 1963; Kelco, undated).

Gums are effective in creating and maintaining a high degree of aeration in cakes. Gums increase the number of air cells incorporated and stabilize batters by:

1) Distributing moisture uniformly.
2) Increasing viscosity.
3) Forming mechanically stable interfacial films.
4) Forming complex aggregates with emulsified particles and strengthening their charge and/or solvation shell (Glicksman, 1969; Friberg, 1976; Lee and Hoseney, 1982).

By retaining water during baking, hydrocolloids partially counteract the decrease in viscosity of the sugar solution with increasing temperature. Thus, more gas is retained in the batter until the cake sets.

Watson and Johnson (1965) found carboxymethyl cellulose (CMC) and methylcellulose competed for water in batters and reduced starch gelatinization. Addition of gums lowers the temperature at which batter viscosity increases initially. Hydrocolloids interact not only with starch but with albumen, milk protein and wheat gluten. These gum-protein interactions may be responsible for increased strength and resilience in cake crumb structure (Kelco, undated).

Hydrocolloids improve tolerance to variations and stresses in production conditions. Specialty products such as reduced-calorie cakes are classified as "stressed", and as such, benefit from gum's tolerance-improving properties. Gums are effective not only in minimizing variations in the amounts of added water but also in masking differences in the functionality of other ingredients (Kelco, undated). In sugar-free cakes, for example, gums can cover the bitter aftertaste of intense sweeteners. Gums also supply the flavor-smoothing and blending characteristics of the sugar they are replacing (Glicksman and Farkas, 1966). In fat-free yellow cakes, xanthan gum was shown to increase volume and symmetry with no difference in added water (Kelco, undated).

One precaution in using hydrocolloids is to add only a small, predetermined amount. At high levels, cakes may exhibit low volume, coarse texture and gumminess (Young and Bayfield, 1963).

Starch Gelatinization

Though representing only 100 out of approximately 500 parts of ingredients in a cake batter, flour provides the major portion of cake structure (Miller and Trimbo, 1965). Holme (1966) and Kulp and Lorenz (1981) stated that baking performance results from interactions among the various flour fractions: gluten, pentosans, lipids and starch. The major component of flour, however, is starch, so it plays a critical role in the expansion and setting of cake structure. Starch provides a rigid network to prevent collapse upon cooling (Shelton and D'Appolonia, 1985).

According to Yamazaki and Kissell (1978), starch has "overriding importance in the successful balance of physical and chemical factors that result in a satisfying baked product". Miller and Trimbo (1965) found cake quality and structural development coincided with starch gelatinization at temperatures ranging from 30 - 96 °C. Later work by Mizukoshi et al. (1979) verified this correlation but reported starch changed viscosity and structure about 79 - 90 °C. The final state of starch contributes to the volume and textural attributes of a cake (Miller and Trimbo, 1965; Derby et al., 1975; Gough et al., 1978; Hoseney et al., 1978).

The term "gelatinization" describes a number of changes that occur when starch is heated in an aqueous medium. Under such conditions, starch changes from a water-insoluble substance to a partially soluble and hydrophilic one. As a result, much of the free water becomes bound with increasing temperature. The extent of gelatinization is a function of availability of water to the starch granule. In the complex gelatinization process, starch interacts with other batter components and competes for the available water. According to Hoseney and co-workers (1978), starch acts as a temperature-triggered water sink to set the cake.

When starch is added to water, the granules absorb some of the water and swell slightly (~ 5%). The birefringence or orderliness, exhibited by a characteristic Maltese cross in the granule, and the crystalline state are unchanged. Without heating, the water absorption and volume change are reversible.

Upon heating, the starch granule begins to take up larger quantities of water, and viscosity of the starch suspension increases. Once past a critical temperature, the amylose portion of starch retrogrades and swelling becomes irreversible. The starch gelatinizes with loss of birefringence, presumably as a result of dissociation or melting of the crystalline regions (Donovan, 1979). As the crystals melt, the ability of the granules to expand is increased dramatically.

Swelling does not become irreversible at a fixed temperature; gelatinization of the individual granules in water without added ingredients occurs over a range of about 10°C (~ 50-60°C). Lineback and Wongsrikasem (1980) stated that most wheat starches lose birefringence before 65°C, which is before maximum swelling or viscosity has been achieved.

Continued heating of the gelatinized starch in water is referred to as "pasting". If sufficient water is available, pasting results in additional, larger increases in viscosity. The starch granules swell greatly and burst, losing their inner amylose contents. The released soluble starch exudate and continued uptake of water by folded granule remnants increase viscosity rapidly.

Water uptake is determined partially by the starch granules' physical state. Shelton and D'Appolonia (1985) stated that damaged starch plays a large role in baking absorption. Slight damage of granules increases water absorption but excessive damage causes a decrease in cake volume and quality. Derby et al. (1975) said the effect of damage or pin-milling was due to release of starch and pentosans from the flour protein matrix. Separating starch from the protective protein allows greater contact between starch granules and water.

Before gelatinization occurs, starch granule internal bonds must be broken. After the bonds are broken, the granule expands and exposes its hydroxyl groups to form hydrogen bonds with water and swell as water is absorbed (Watson and Johnson, 1965). Though a small amount of damaged starch aids in early gelatinization, Howard et al. (1968) emphasized that intact starch granules are required for successful gelatinization and pasting during the thermal setting stage.

Starch solubilization or pasting is continuous and is not complete until the structure is totally soluble. In excess water, solubility would occur at a temperature exceeding 120 °C (Hoseney, 1986). Thus, in a cake batter, which only reaches 100 °C during baking, and where water is limited, the starch is never fully pasted. At low water levels, the loss of birefringence occurs over a temperature range of about 30 °C (Hoseney, 1986).

Deformation and folding of starch granules is a relative measure of the extent of gelatinization. Both swelling and deformation are much less in limited water. In "properly" baked cake, the starch retains a high degree of structural integrity with near maximum granule swelling and a small percentage of folded granules (Derby et al., 1975)

Flour chlorination is another important factor in gelatinization. High ratio layer cakes require chlorinated flour to prevent shrinkage or collapse during thermal setting or upon cooling. Chlorine reacts almost exclusively with the minor fractions associated with the starch granules--lipids, proteins and pigments--and particularly with those at the surface of the granules (Gough et al., 1978). These minor components, however, account for a relatively small portion of cake quality improvement (Donelson et al., 1984). Chlorinated flour lipids, for example, enhance batter expansion (Clements and Donelson, 1982; Gaines and Donelson, 1982a). However, most researchers agree that the bleach's cake - improving effects are centered in the major starch fraction (Sollars, 1958; Gough et al., 1978; Johnson and Hoseney, 1979).

The chemical changes in the minor surface components alter the properties of the starch and thus its behavior in the cake batter during baking. Those changes may alter the ability of starch to interact with other batter ingredients during gelatinization (Gilles et al., 1964; Youngquist and Hughes, 1969). For example, chlorine could react with hydrogen atoms of protein molecules, decreasing hydrogen bonding ability and increasing protein dispersibility. Chlorination increases initial swelling and amylose exudation of the starch granules and results in higher water absorption than in untreated flour (Telloke, 1985).

Differences between untreated and control flours may not be obvious until the final few minutes of baking. Chlorinated samples appear to gain stability at a point which coincides, more or less, with attainment of maximum batter temperature (Gough et al., 1978) Although gelatinization behavior is altered by chlorination, gelatinization temperature is not affected (Kulp et al., 1972; Cauvain et al., 1977; Telloke, 1985).

By increasing gel viscosity and thus, crumb strength, chlorine allows cakes to attain high levels of expansion in the oven, and minimizes shrinkage upon cooling (Gaines and Donelson, 1982a). In addition to improved volume and crumb strength, cakes from chlorinated flour exhibit dry, not sticky, crumb texture (Kissell and Yamazaki, 1979; Gaines and Donelson, 1982b).

As with other cake ingredients, levels of chlorine used are critical. With low chlorine dosage, batters expand well but shrink significantly from insufficient starch granule hydration. High chlorine inhibits expansion. In both cases, volume is low. Optimum chlorine level is a compromise between expansion and contraction rates (Kissell and Yamazaki, 1979). Thorough reviews of flour chlorination are found in Gough et al. (1978) and Telloke (1985).

Starch gelatinization is influenced by water availability, and water availability is determined by the formula used and the presence of other batter ingredients which compete with starch for water. Competing components include proteins, flour lipids and pentosans, sugar, shortening, gums and emulsifiers. An ingredient's influence on starch is mainly a result of its effect on the time and temperature of gelatinization onset.

Temperature is a major determinant of the extent of starch gelatinization (Hoseney et al., 1977) and the temperature at which gelatinization occurs affects batter and cake structure (Howard et al., 1968; Derby et al., 1975; Osman, 1975). Miller and Trimbo (1965) showed that any ingredient which allowed earlier gelatinization of the starch with the associated increase in batter viscosity improved the volume and textural qualities of the cake. Formula changes included increased water, decreased sucrose, replacement of part of the sucrose with monosaccharides, substitution of a starch with lower gelatinization temperature for part of the flour, and addition of certain salts.

Other authors (Longkhysen and Blankestijn, 1976; Longley and Miller, 1971; Hartnett, 1979a; Ebeler and Walker, 1984) have demonstrated that surfactants or emulsifiers inhibit swelling, delay pasting, and could increase the gelatinization temperature. Surfactants may simply be hydrogen bonding with the water in the system so water is not available for complete starch gelatinization.

Surfactant inhibition of starch swelling also can be explained by an extracellular and an intracellular mechanism. The first involves formation of a hydrophobic film surrounding the granule. This barrier retards penetration of water into the starch granule. Secondly, inhibition may be the result of surfactant complexing with amylose (Krog, 1977). By complexing with linear starch chains inside the granule and stabilizing amorphous regions, emulsifiers delay or prevent starch release during gelatinization (Longley and Miller, 1971; Osman, 1975). Surface starch complexing also retards starch crystallization or retrogradation and prevents cake staling during storage (Stutz et al., 1973).

Interactions of starch with sugar are recognized. Of cake ingredients, sucrose exerts the greatest influence on starch gelatinization (Jacobsberg and Daniels, 1974; Bean and Yamazaki, 1978). Sugar delays loss of birefringence and increases apparent gelatinization temperature to 90-97 °C (Hester et al., 1956; Blanshard, 1979; Bean et al., 1978); gelatinization in sugar cakes does not progress much beyond the initial stages. In the presence of sucrose, disintegration and folding of starch granules is reduced and the amount of soluble exudate decreased. Sugars do not affect pasting (Koepsel, 1977).

One way sugar influences gelatinization is by competing with starch for water. Sugars lower water activity and increase the chemical potential of water. Thus, a greater energy input is required and the temperature necessary for starch gelatinization is raised (Spies and Hoseney, 1982). By delaying gelatinization, sugar tenderizes the cake.

At equal water activity, not all sugars delay gelatinization to the same extent. In general, disaccharides delay gelatinization more than monosaccharides (Bean and Osman, 1959; Savage and Osman, 1978).

Bean and Yamazaki (1978) examined the effect of type and concentration of sugar in a lean cake formulation. They found optimum texture was produced by a sugar:water ratio that allowed starch to gelatinize in a range between 87.5 and 92 °C. Sugar concentrations which permitted gelatinization at these temperatures were 56% sucrose, 64% glucose and 68% fructose.

The relationship between corn syrup and gelatinization temperature also has been studied. Sugars containing higher molecular weight sugars have higher gelatinization temperatures than syrups containing lower molecular weight sugars (Koepsel and Hoseney, 1980). Redfern (1972), Volpe and Meres (1976) and Hartnett (1979b) replaced 25 - 60% of the sucrose in cakes with high fructose corn syrups (HFCS). Though the batters had higher specific gravity and gelatinized earlier than sucrose cakes, few textural problems were reported at these replacement levels. Hartnett (1979a) and Koepsel and Hoseney (1980) reported that complete replacement of sucrose by HFCS resulted in poor quality cakes with low volume and suboptimal textural characteristics.

To substitute HFCS for sucrose, cake reformulation is required (Ash, 1979; Hartnett, 1979a). Generally, water level must be reduced to compensate for the moisture in the syrup. Changes in leavening systems have been shown to improve HFCS' functionality: by using high amounts of a slow-acting agent, the leavening process can be timed more efficiently with the set point temperature of the cake, improving not only volume and texture but color. (Hartnett, 1979a) Fructose, a reducing sugar, is especially susceptible to nonenzymatic, Maillard browning. This reaction is decreased at pH levels below 6.0, so additional leavening acid, which reduces pH, is desirable. Gluconodeltalactone (GDL), in particular, has been selected for use in fructose cakes (Volpe and Meres, 1976; Anon., 1980a). GDL allows the necessary increase in leavening with less solids (Morris, 1981).

Emulsifiers have been shown to counteract the negative effects of HFCS (Hartnett, 1979b; Osberger and Olinger, 1985); Hartnett stated emulsifier use was "integral" to the transition from sucrose to HFCS in cake.

Blends of mono- and diglycerides with polysorbate 60, with and without sorbitan monostearate, were effective in altering gelatinization rate and time to produce cakes comparable to sucrose cake.

Early efforts to replace sucrose with intense sweeteners have been unsuccessful. The alternative sweeteners do not affect the gelatinization properties of starch as sugar does (Kim et al., 1986).

Sucrose and Sweeteners

Apart from its obvious role as a sweetener, sucrose contributes the following physical properties to cake systems:

texture (crystallinity; enhanced air incorporation),
solubility,
hygroscopicity/moisture binding,
preservation/shelf life extension,
nutritive solids source/calories,
flavor blending and enhancing,
good dispersibility,
carmelization/crust color development,
stability,
bulking/volume, and
tenderization: reduced gluten hydration and development; delayed starch gelatinization; retarded egg white coagulation and denaturation

(Beck and Ziemba, 1966; Harper, 1975; Dziezak, 1986).

No other sugar, syrup or intense sweetener alone provides all of the functional characteristics of sucrose. Therefore, though use of an alternative sweetener in cake may be desirable for cost or health purposes, sucrose replacement is not a simple matter.

The Calorie Control Council (1983) reemphasized that "no single sweetener provides an all-purpose, low-calorie ideal". However, blends of sweeteners may be used to accentuate the strengths of individual sweeteners and compensate for their limitations (Beck, K.M., 1978). For example, saccharin has a bitter aftertaste but excellent stability, while aspartame has little or no aftertaste and poor stability. When the two are combined, they yield products with enhanced taste and improved shelf life. This particular blend is recommended by the Calorie Control Council (1985).

Every nutritive and non-nutritive sweetener has a characteristic time-intensity impact profile (Redlinger, 1986). Some sweeteners have a sharp initial sweetness which dissipates quickly; others are perceived more gradually from onset to maximum sweetness but maintain a higher residual sweetness. By merging selected sweeteners, sweetness perception profiles can be rounded and tailored to the needs of an individual product.

By combining intense sweeteners (saccharin, aspartame or acesulfame K) with small amounts of fructose, van Tornout et al. (1985) successfully matched sucrose's flavor in soft drinks. The synergisms of a number of sweetener combinations have been described by Stone and Oliver (1969); Yamaguchi et al., 1970; Moskowitz, 1975; Moskowitz and Klarman, 1975; and Hyvonen et al., 1978).

Though sucrose's sweetness may be matched satisfactorily in cakes, sugar's textural attributes are much more difficult, if not impossible, to replace. Compensating for sucrose's bulking and structural properties, in particular, is a formidable challenge.

Intense sweeteners are 200 - 400 times sweeter than sucrose. As a result of their concentrated nature, only a tiny amount of sweetener is required to produce a degree of sweetness similar to sugar. Since sugar has a sizable bulk volume, substitution of low calorie sweeteners necessitates the addition of a filler simply to increase the bulk density of the mix (Glicksman and Farkas, 1966). Bulking agents allow sweeteners to be extended to replace sugar on a volume-for-volume basis.

Ideally, a bulking agent should provide the benefits of sugar without the calories or it should be able to function at lower concentrations (Beereboom, 1978; Monsanto, Inc., undated). Some currently used bulking agents include:

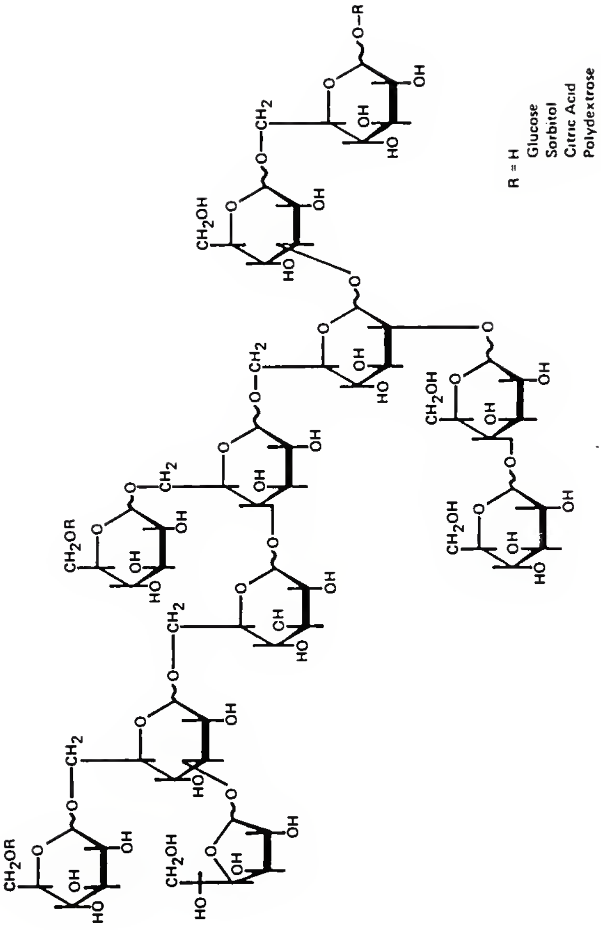
cellulose derivatives,
hydrocolloids,
maltodextrins,
modified starches,
sucrose esters,
silica gel, and
polyhydric alcohols (polyols); maltitol,
    sorbitol, mannitol, xylitol
(Beck, K.M., 1978; Beereboom, 1978).

Many of these ingredients, unfortunately, have a high cost and are tolerated poorly, resulting in diarrhea or intestinal distress. Others are not rapidly soluble or are extremely viscous. Some, notably the polyols, are nearly as caloric as sugar itself, which negates the effect of sweetener substitution (Beereboom, 1978). Most importantly, bulking agents cannot duplicate the effect of sucrose on the thermal-setting properties of starch and gluten in cakes. Instead of the light, fluffy-textured product expected, bulking materials sometimes result in dense, tough or soggy cakes. A bulking agent that does not seem to have these inherent limitations and which shows potential for use in the baking industry is polydextrose.

Polydextrose

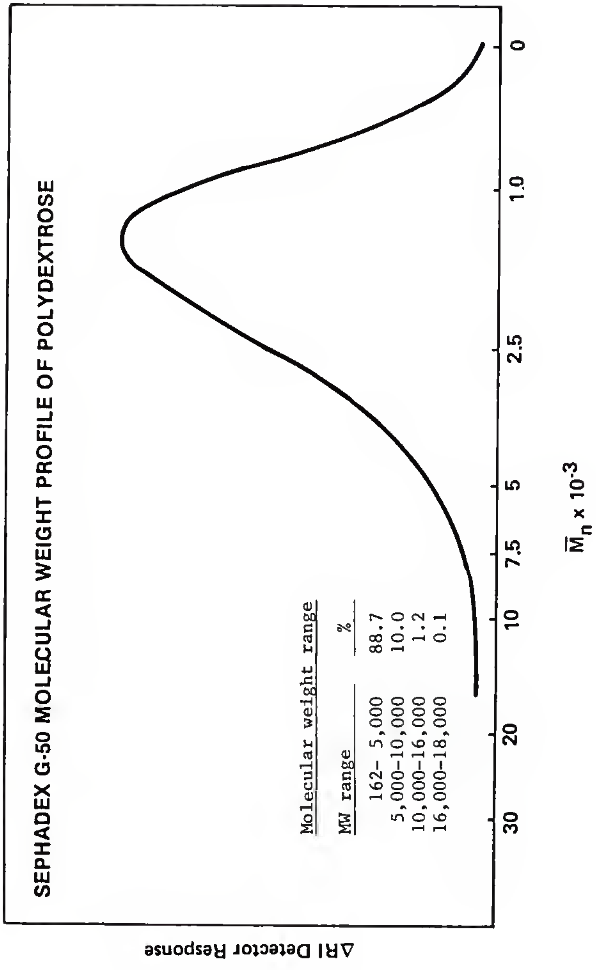
Polydextrose was developed specificallly to satisfy the need for a low-calorie bulking or texturizing agent in the manufacture of reduced-calorie foods. Polydextrose is a water-soluble, randomly bonded condensation polymer of dextrose, containing minor amounts of bound sorbitol and citric acid (Fig. 2). Hydroxymethyl furfural and 1,6-anhydroglucose are present at low levels as by-products of sucrose carmelization (Smiles, 1982). Polydextrose has an optical rotation of +60 and an average molecular weight distribution of 162 - 18,000 (Fig. 3). Polydextrose powder has a pH of 2.5 - 3.5. Polydextrose K, the powder buffered with potassium bicarbonate, and Polydextrose N, a 70% solution partially neutralized with potassium hydroxide, have pH values of 5.0 - 6.0 (Blake, 1986).

Figure 2 - Hypothetical structure of polydextrose repeating unit (Allingham, 1982)



R = H
Glucose
Sorbitol
Citric Acid
Polydextrose

Figure 3 - Molecular weight profile of polydextrose (Allingham, 1982)



SEPHADEX G-50 MOLECULAR WEIGHT PROFILE OF POLYDEXTROSE

Molecular weight range

MW range	%
162- 5,000	88.7
5,000-10,000	10.0
10,000-16,000	1.2
16,000-18,000	0.1

Polydextrose forms a clear melt above 130 ^{o}C in a manner similar to sucrose. Unlike sugar, though, polydextrose will not crystallize (Torres and Thomas, 1981). In solutions of equal concentration, the viscosity of polydextrose is somewhat greater than that of sugar or sorbitol, thus polydextrose can improve body and mouthfeel. Polydextrose is not heat-sensitive and has good storage stability (Freeman, 1982).

Though it has many of the technological properties of sugar, polydextrose contributes no sweetness to cakes. By combining polydextrose with varying levels of intense sweeteners, sweetness and bulk density can be regulated carefullly and independently over a wide range.

Polydextrose is metabolized only partially, resulting in a caloric utilization value of one calorie per gram (Figdor and Bianchine, 1983). Polydextrose is tolerated well in the amounts likely to be ingested in foods: its mean laxative threshold is 90 g/day, compared to 70g/day for sorbitol, a commonly used bulking agent (Allingham, 1982). Clinical studies have shown that polydextrose does not affect absorption and utilization of vitamins, minerals and essential amino acids. Polydextrose causes no significant increase in blood glucose levels or insulin demand and is, therefore, an acceptable component of diabetic foods (Allingham, 1982).

Polydextrose has been approved by the Food and Drug

Administration as a bulking agent, formulation aid, humectant and texturizer. No maximum use levels have been established, but under good manufacturing practices, the quantity of polydextrose cannot exceed the amount reasonably required to accomplish an intended technical or functional effect (Pfizer, 1985a). Polydextrose can replace a portion of fat and flour and partially or totally replace sugar in cake (Smiles, 1982). The bulking agent provides not only the bulk but also the appropriate texture and mouthfeel qualities normally provided by sugar and fat (Dziezak, 1986).

Polydextrose has been incorporated successfully in a number of baked goods, including cakes, brownies and cookies. Both in-home mixes and prepared products are sold. Weight Watchers, Inc., which incorporates the ingredient in their frozen reduced-calorie pies and cakes, is one of the largest users of polydextrose (Pfizer, 1985b).

The successful use of polydextrose in cakes may be due to its sucrose-similar effects on starch gelatinization. Kim et al. (1986) compared the effect of sucrose with polydextrose and intense sweeteners on phase transitions of starch-water systems using differential scanning calorimetry (DSC). The initial gelatinization temperature for the starch-water system was increased from 56.2 ^{o}C to 66.0 ^{o}C when 25% sucrose was added. The intense sweeteners did not alter the starch-water system, but 25% polydextrose increased the onset temperature to 65.0 ^{o}C, comparably to sucrose. The DSC thermograms of the cake batters likewise showed that phase transition effects of polydextrose resembled those of sucrose; increases in onset and peak temperatures by sucrose and polydextrose were nearly identical.

The authors proposed that polydextrose might be delaying starch gelatinization by the dual mechanism described by Spies (1981) and Spies and Hoseney (1982). Polydextrose may increase gelatinization temperature by:

1) decreasing water activity or
2) interacting with starch chains in the amorphous regions of the granules.

Decreasing the water activity actually increases the amount of water available to the starch (Spies, 1981). When starch chains are linked in the crystalline regions, flexibility is decreased and more energy is required to pull apart or melt the crystallites. The increased energy requirement results in a higher gelatinization temperature.

Spies and Hoseney (1982) suggested that larger oligosaccharides bridged chain gaps and formed more links than mono- and disaccharide molecules to stabilize the amorphous regions. However, if molecules are too large, they can not enter the granule. If a sizable portion of the polydextrose was composed of small rather than large molecules (Allingham, 1982), polydextrose might enter the granule and stabilize crystallite regions. Kim et al. (1986) concluded that since polydextrose and sucrose alter thermal setting properties of starch similarly, polydextrose could serve effectively as a functional replacement for sucrose.

Factors Affecting Cake Quality

Besides mixing conditions and batter stability, cake characteristics are affected by factors such as batter and oven temperature, pan size, position of the pans in the oven, and even the pan material. For example, pans with dark or dull surfaces that absorb heat are fast-baking pans; bright, shiny pans that reflect heat are slow-baking pans. Fast-baking pans produce cakes of more even texture and higher volume than slow-baking pans. However, cakes baked in slow-baking pans have flatter, less peaked tops than those baked in fast-baking pans. Texture and volume are optimized in cakes where heat penetration is rapid and uniform.

The ingredients used are crucial to cake quality. The complex batter system contains a large number of highly reactive components which are modified upon interactions with other components (Howard, 1972). A change in one ingredient requires an adjustment in the proportions of either one or several others. The key criterion in formulating layer cakes is balancing the functional properties of one essential ingredient against all other ingredients. Formula balance determines final quality of the cake (Mizukoshi, 1985b).

According to Coughlin (1947), ingredients may be classified into the following categories:

1) Tougheners/structure builders.
2) Tenderizers.
3) Moisteners.
4) Dryers.
5) Flavorers.

Paton et al. (1981) studied influence of various ingredients on structure cohesiveness during baking. They verified that cake structure results from opposing action of toughening and tenderizing ingredients. Additionally, moisturizers and driers need to be balanced for an optimum cake. Toughening ingredients include flour and milk or egg proteins. Sugar, egg yolk lipids, shortening and liquids contribute to product tenderness.

Davies (1937) demonstrated the essentiality of formula balance by altering levels of sugar, fat, leavening agent and water in high-ratio cakes. Decreasing sugar by 25% resulted in smaller volume and tougher, tighter structure than the control cakes. Decreasing fat by the same amount increased volume but created a coarse grain and harsh texture. Too little flour affected cake similarly to an excess of fat or sugar, yielding a weak structure and overfine texture. Excess flour produced a compact, dry cake in which tunnels formed readily.

Increased leavening resulted in high volume and coarse grain; cakes with insufficient baking powder were low in volume, with a fine, close grain and soggy texture. When liquids were increased, volume decreased but the cakes were moist and tender. As liquids were reduced, volume increased but texture was harsh and dry and grain was coarse.

Later work by Mizukoshi (1985b) also emphasized balance. He demonstrated that function of whole egg and sucrose depends upon concentration and these ingredients can actually perform as either tougheners or tenderizers. In measuring shear modulus (strength) of ingredients, Mizukoshi showed that fat and oil acted oppositely in structural development with fat increasing and oil decreasing the modulus. He also concluded that emulsifiers slightly increase shear modulus and flour's toughening effect is greater than the tenderizing influence of sugar.

Though a number of ingredients are incorporated into cake batter, not all are necessary for cake formation. Howard (1972) classified cake ingredients as essential or nonessential (Table 2). Water is important in all baked goods, but especially in cake batters. Fat, flour, egg and sugar are the other principal components of cake; Mizukoshi (1983a) included gas as a critical ingredient.

pH

Table 2- Ingredients used in layer cakes [a]

Ingredients	Source	Essential	Non-essential
Proteins (soluble and insoluble)	Flour	X	
	Egg	X	
	Milk	X	
Carbohydrates (soluble and insoluble)	Sucrose		X
	Dextrose		X
	Lactose		X
	Starch (from flour)	X	
	Thickeners		X
Lipids	Shortening		X
	Emulsifiers	X	
	Flour lipids		X
	Milk lipids		X
	Egg yolk lipids	X (in yellow cakes)	
Other	Sodium chloride		X
	Leavening acids	X	
	Sodium bicarbonate	X	
	Flavor		X
	Color		X
	Water	X	

[a] Source: Howard, 1972.

Cake pH is usually in the neutral range, between 6.5-7.5. Changes in pH have a definite effect on cake volume and grain, texture, color and flavor. While variations occur with cake type, general trends may be noted. Cake volume increases with pH; in some cakes, the crumb will become crumbly. If pH is increased more than one pH unit above normal, volume decreases. A decrease in volume is likewise noted when pH is reduced. Cakes which are excessively acidic or alkaline will be too fragile to handle in production (Ash and Colmey, 1973).

Cake grain becomes closer and increasingly fine as the pH becomes more acidic. As pH is raised above the optimum range, the grain becomes coarse, open and thick-walled, resulting in a harsh texture. As batter pH is increased, the degree of crust browning will increase because of the Maillard reaction and carmelization. Both of these reactions are accelerated under alkaline conditions. The effect of pH on crumb color varies by cake type. White cakes have a creamy or pale yellow crumb at a high pH and a bright white crumb at acidic pH. Yellow layer and sponge cakes are lightly-colored at low pH but have a rich yellow crumb when slightly alkaline (Ash and Colmey, 1973).

Flavor is affected by pH. In general, cake flavors are most pronounced if the cake is neutral or slightly acid. A cake which is too acidic will have a tart or sour "bite". At high pH, cake flavor will be soapy or soda-like.

The batter pH affects starch gelatinization (Howard, 1972) and emulsion stability. Classical O/W batter emulsions are generally more stable under acidic conditions. A study by Ash and Colmey (1973) revealed batters were stable over a pH range of 5.0 to 6.0 but destabilized above this range. Broken emulsions were evidenced by a curdled appearance and droplets of free oil.

Alterations in cake formula or ingredient sources influence batter and cake pH. Corn syrup, cake flour, milk, dextrose, fruit, some emulsifiers and certain leavening agents reduce pH. The pH is increased by eggs, cocoa, baking soda, and possibly water (Ash and Colmey, 1973).

Leavening Agents

Leavening agents give volume and lightness, so may be classified as tenderizers. Light, fine-grained cakes are achieved by first forming many tiny gas bubbles in the batter and by then timing the desired expansion of these bubbles during baking to coincide with the thermal setting of the structure (Kichline and Conn, 1970). Most of the CO_2 should be released before the product reaches its setting temperature. If all CO_2 is released prematurely, the residual gas is insufficient to raise a cake to its proper volume before setting. The cake may rupture or crack. If the leavening agent is too slow, CO_2 may be released after the cake structure has formed, resulting in coarse texture or even collapsed structure (Ash and Colmey, 1973).

Hoseney (1986) emphasized the importance of timing in leavening action. Gas must be produced early enough that batter can still expand but not so early that a major part of the gas may diffuse out. If gas is released too late, the batter will not expand and cake grain may be destroyed by the excess pressure developed.

The choice of a fast- or slow-reacting baking powder depends on several factors, including processing steps, baking time, and cake size. Generally, layer cakes require a leavening agent which releases gas gently and uniformly throughout the baking cycle. Along with sodium bicarbonate, "double - acting" baking powders contain at least two acidic components with different reaction rates. The agents are designed to first generate gas in the batter at room temperature and later react during heating.

Too little baking powder results in a heavy, compact cake. Increasing the leavening increases cake volume until the optimum quantity is reached; beyond that point, volume decreases and the cake falls. Excess baking powder may produce bitterness, coarse texture, and a harsh, gummy crumb.

In addition to gas production, leavening agents may affect cake structure through their ionic effects on other ingredients. Kichline and Conn (1970) found that, of the cations present, calcium and aluminum contributed most markedly to structure in terms of fine grain, resiliency and thin cell wall size.

Gummy Layers

Aberrations in viscosity, formulation and processing may result in gummy layers in cakes. Miller et al. (1967) conducted a comprehensive study of this defect and defined a gummy layer as one having greater density, higher moisture content and a higher degree of starch gelatinization than normal cake crumb. Gummy layers or spots may appear at the top, bottom or even the middle of cake, though they usually appear at the bottom.

Undermixing is not responsible for formation of gummy spots or layers in cake mixes. Miller et al. (1967) found that cakes had a tendency to layer when greater than normal amounts of water were used. They determined that gumminess resulted from movement of moisture into one section from other portions of the batter, and this transfer resulted from either temperature gradients or from bubbles rising, and settling out of liquid.

Mizukoshi (1983a) also attributed gummy layers to drainage and lack of foam stability. As viscosity decreases in the early stages of baking, drainage from unstable foam lamellae is accelerated. This drainage flows down and accumulates at the bottom of the cake. Further temperature increases cause starch swelling and gelatinization in the continuous phase and increase batter viscosity. As the heat sets the foam structure, drainage stops, but the drainage pool at the bottom of the cake changes to an undesirable gummy layer (Mizukoshi, 1983b).

Miller et al. (1967) confirmed earlier work on temperature gradients (Trimbo and Miller, 1966) which showed that the hottest region of a cake is the outside bottom. They found moisture migrates from the cooler core to the hot, outer gelatinizing layer. The investigators concluded that the presence of sugar in a cake batter alters the flour-water binding relationship so water is more free to migrate than in a simple flour-water dispersion. Flours differ in their tendency to cause layering, but pin-milling and chlorination will reduce or eliminate gumminess. Gough et al. (1978) reported that cake crumb structure is weakened without flour chlorination. Gas cells become compressed to an unevenly textured crumb, and waxy cores may form just under the center of the upper crust.

Addition of 0.5% (total weight basis) guar gum or CMC to batter was effective in preventing moisture migration and gummy layers, even with excess water (Miller et al, 1967). However, in mix cakes made with unbleached flour, the gums were less effective, demonstrating these additives can not replace the function of flour chlorination. The CMC or guar gum permitted development of a uniform structure of equal moisture distribution, but the authors were uncertain how the adjuncts worked. The effectiveness may not be due to increased viscosity, or even the incorporation of additional air, but may instead be related to the stabilizing ability of guar gum and CMC to keep water absorbed and prevent batter settling.

Tunnelling

Another defect encountered in cake baking is tunnelling. Tunnelling refers to the development of elongated voids which start near the bottom and proceed upward, generally at an angle, toward the center of the baked cake. Tunnelling does not have a great effect on volume but does detract considerably from internal appearance and texture (Trimbo and Miller, 1973).

Holes and tunnels are caused by large steam pockets, which are trapped during the thermal stage, and result from temperature gradients in the batter. Trimbo and Miller (1973) proposed that formation of a top crust is a prerequisite for tunnel development since crust restricts the escape of gas bubbles during baking. Since the crust forms first at the periphery, rising air bubbles are forced to slant toward the more fluid, less resistant center of a cake to escape. Once the internal structure of a portion of the cake has set sufficiently, new tunnels do not form or fluid batterdoes not move from adjacent areas into already formed tunnels.

The following factors influence tunnelling:

1) Mixing - If few air cells are incorporated in mixing, the leavening gases accumulate in large masses and migrate to the top of the cake, producing tunnels, holes and peaks. Ellinger and Shappeck (1963) found overmixing results in collapsed air cells at the bottom of the cake and coarseness and tunnelling at the top. Trimbo and Miller (1973), however, noted no difference in tunnelling when batter mixing time was varied from two to eight minutes or when different mixer types were used.

2) Liquid Level - Cakes prepared with low liquid levels were more prone to tunnelling than those with high liquid levels, probably because of higher initial viscosity in the former. Above a certain water level, or when batter density approaches 1.0, tunnels again disappear (Trimbo and Miller, 1973).

3) Sugar:Flour Ratio - Cakes with a low sugar:flour ratio exhibit more tunnelling than cakes made with a high sugar:flour ratio. Cakes with increased sugar remain fluid for a longer period of time, allowing air to escape and therefore preventing tunnels.

4) Other Ingredients - Egg yolks were effective in

preventing tunnels (Trimbo and Miller, 1973). Emulsifiers such as SSL also may reduce tunnelling.

5) Pan Liner - Removal of pan liners resulted in decreased, more randomly-distributed tunnels. Since size and orientation of cake tunnels is dependent on temperature gradient, the effect of the liners was attributed to rate of heat transfer (Trimbo and Miller, 1973).

6) Pan Size - Eight-inch pans exhibit a greater extent of tunnelling than nine-inch pans (Trimbo and Miller, 1973).

7) Oven Type - When microwave ovens were used, technically no tunnelling resulted because a crust was not formed and steam escaped before the batter set. However, the microwaved cakes developed large, vertical holes or steam "chimneys" during early baking which remained open even after structure setting. Trimbo and Miller (1973) also found no difference between conventional gas and electric ovens.

8) Temperature - Tunnelling is more severe in cakes baked at 400 °F (204 °C) than in cakes baked at 350 °F (177 °C). Trimbo and Miller (1973) noted that no tunnels developed at temperatures of 300 °F (149 °C) or lower. At low baking temperatures, the tunnels that do appear are vertically oriented (not slanted) and quite small in diameter. The effect of lowering temperature

could result from more even distribution of heat and steam or delayed gelatinization and crust formation which allows gas to escape vertically through the soft surface.

Diet and Health

Diet appears to be a critical factor in the etiology of many diseases. The consumption of sugar and fat, in particular, has been correlated with a number of ailments. Although the evidence relating these foods to medical conditions is frequently contradictory and controversial, sugar and fat have been linked with dental caries, dermatitis, cardiovascular disease (including hypertension and atherosclerosis), hypertriglyceridemia, hypoglycemia, diabetes, diverticular disease, allergies, hyperactivity, obesity, and cancer (Levy, 1973; Ahrens, 1974; Brown, 1974; Wynder, 1975; Beck, C.I., 1978; Gori, 1979; Alfano, 1980; Leveille, 1980; Miller, 1980; Clark et al., 1985). Some of the strongest epidemiological and laboratory evidence implicates sucrose and dietary fat in the development of dental caries, diabetes, cardiovascular disease and obesity.

Dental Caries

The association between sugar intake and dental caries long has been recognized (Miller, 1980). A policy statement issued by the American Dental Association in 1976 acknowledged the undisputed fact that "frequent use of sucrose is the major cause of dental decay". In addition, numerous reports (Brown, 1974; Stephan, 1974; Dwivedi, 1978; Alfano, 1980; Leveille, 1980; Miller, 1980) attribute dental caries to sugar consumption. Makinen and

Philosophy (1972) concluded that sucrose was the most cariogenic common sugar. Dr. Abraham Nizel, a nutrition professor at Tufts University, stated that if sugar was eliminated entirely from the diet, Americans would reduce dental caries 70 - 80% (Pangborn and Larson, 1975).

Diabetes Mellitus

Sucrose has been implicated as a causative agent in diabetes; studies show that high-sugar diets both hasten the onset and aggravate the intensity of the disease (Cohen et al., 1972; Campbell, 1973; Sedan, 1973; Brown, 1974; Gori, 1979). Diabetes is characterized by an abnormally high level of glucose in the blood and urine. A Health, Education and Welfare (HEW) Department report (1978) attributed 37,000 deaths per year directly to diabetes and another 100,000 to diabetes-induced complications. For example, a high percentage of diabetics have elevated blood lipid levels and resulting increased incidence of coronary artery and peripheral vascular disease (Chase and Glasgow, 1976). Diabetes is the fourth leading cause of death in the United States (HEW, 1978).

Cardiovascular Disease

The possible relationship between coronary heart disease and sugar consumption was noted first by Yudkin (1957). Further epidemiological evidence (Yudkin and Roddy, 1964; Yudkin and Morland, 1967) reinforced the hypothesis that coronary patients had higher sugar intake than control subjects. Heart attack is the nation's number one killer, claiming nearly one million lives a year (Vinson, 1978). Pangborn and Larson (1975) stated that 5 - 10% of those heart attacks may be traced to excess consumption of sugar. Keys (1971) and Grande (1975), however, found that mortality from cardiovascular disease is correlated to intake of saturated fat more than sucrose.

In studying disease-diet interactions, certain changes in diet are observed as affluence level increases. The simultaneous increase in fat and sweetener consumption makes it difficult to distinguish the health changes from sucrose from those derived from fat (Leveille, 1980). One or both ingredients may be causative components of cardiovascular disease. Whatever the cause, coronary disorders seem to be related directly to diet (Dayton and Pearce, 1969).

Obesity

Excess weight or obesity has been cited repeatedly as the nation's leading health problem (Beck, K.M., 1978; Scala, 1978). As an abnormal physiological condition, obesity places considerable strain on the body's systems and often results in diabetes, cardiovascular disease and other disorders. Obesity may aggravate conditions such as gout or gall bladder disease (Dwivedi, 1978). Of perhaps graver significance, excessive caloric intake has been linked to the incidence of cancer. Gori (1979) reported that of all dietary treatments, caloric restriction was most effective in preventing tumor formation.

Dr. William Conner (1975), at a panel hearing on Nutrition and Human Health, testified that "the vast majority of Americans suffer from an overabundance of food". The National Academy of Sciences' Food and Nutrition Board recommended in 1968 that all adults reduce their caloric intake. Nutritionists generally agree that most obese persons consume excess calories (Lee et al., 1969)

Though the total consumption of calories in excess of energy output and not sucrose alone causes obesity (Leveille, 1980), sugar contributes empty calories to the diet. Pangborn and Larson (1975) stated that the average American consumes 500 - 600 calories per day in the form of sucrose, contributing to overnutrition or obesity. In addition, fat, which yields twice as many calories per gram as sugar, is being consumed at increasing rates, intensifying the weight problem.

Diet Cures What Diet Causes

The nutrition-related disorders described above can be prevented or treated with dietary modifications. For example, reduction of blood glucose concentrations is critical in preventing the complications of diabetes and may be achieved through a controlled diet (Cahill et al., 1976; Maugh, 1976; Dwivedi, 1978; Chase, 1979). Diet has been described as the "cornerstone" of therapy for diabetic patients, but, until recently, physicians largely ignored diet therapy in treating other illnesses (Dwivedi, 1978). Health professionals are becoming aware that special diets and specially-formulated foods can be used effectively in managing a number of disorders.

The diet modifications for diabetes and other diseases are similar to the prudent dietary guidelines recommended for all Americans (USDA and USDHHS, 1985). These include:

avoidance of overweight,
increased consumption of complex carbohydrates,
reduced consumption of refined or processed sugars,
reduced consumption of fat, especially saturated fat.

Restricting the amount of sucrose and fat in the diet is difficult for several reasons. First, man has a strong propensity for consuming sweets. Sweetness is the most compelling of food qualities, and this drive is evidenced not only at birth but even before birth (Osberger and Linn, 1978; Miller, 1980; Clark et al., 1985). Second, sugars and fats give pleasure, and excluding them from the diet deprives man of the most satisfying diet components (Dwivedi, 1978). If the desire for sweetness, especially, is not fulfilled, the diet may not be followed (Anon., 1980b).

A survey involving diet therapy for diabetics (Holland, 1968) showed that only 53% of the respondents adhered to their prescribed regimen. Another poll revealed only 17% of diabetics wished to avoid sweets completely (Dwivedi, 1978). Chase (1979) stated that "kicking the sweet-tooth habit" can be as hard as overcoming an alcohol or drug dependence. Children could find following a diabetic diet and remaining emotionally well-adjusted especially difficult. They may feel deprived by being denied certain foods or by exclusion from social meals (Dwivedi, 1978).

A third difficulty in modifying diet is inadequate availability or quality of "allowed" foods. Many patients find it inconvenient to stay on special diets (Anon., 1980c). According to Beereboom (1978), availability of quality, low-calorie foods could provide the consumer with enough additional motivation to endure a diet plan. Within the snack and dessert area, especially, "low-calorie foods as dietary aids can have a most positive impact." Because they are conventional foods of reduced calorie content, diet products make it easier for a person to adhere to a diet (Finberg, 1972). Rather than placing emphasis on special foods for diabetics, Chase (1979) recommended development of commercial sugar-free foods for all people.

Sweet Solutions

Based on these reasons, a need exists to develop high quality, palatable and fulfilling foods that resemble normal foods in appearance and flavor (Dwivedi, 1978). A dietary regimen would be followed more easily if the foods on the diet were as satisfying as the formerly enjoyed foods. Too often, products are formulated with the nutritional label as the prime objective, and hedonic considerations are ignored. Carol Williams, nutrition administrator for the Kroger Company, flatly stated that,

> "People eat food, not nutrition. They'll eat some foods because they like them, some foods because they are good for them, and some foods they are not going to eat no matter what you tell them (Johnson, 1984)."

Dieters wish to receive maximum gratification in a regime demanding minimum restriction of former eating pleasures (Osberger and Linn, 1978).

Low-calorie foods appear to be a worthwhile objective as well as a sizeable market (Beck, C.I., 1978). According to a recent survey conducted for the Calorie Control Council (1984), over 68 million American adults consume low-calorie foods and beverages, an increase of more than 60% over the prior six years. A portion of this growth is due to the increasing number of diabetics (estimated at 10 - 20 million, Anon., 1980b) and other health-related dieters. Artificially sweetened foods offer variety and are useful in disease management (Beck, K.M., 1978). Chase (1979) stated that

> "the use of artificial sweeteners has probably done more for control of blood and urine glucose levels in patients with diabetes, and possibly even with obesity, than have all diets put together."

However, not all low-calorie, sugar-free or fat-free products are being used for therapeutic purposes. Scala (1978) distinguished intrinsic "real" health needs and "hedonic" pleasure or vanity needs. Many dieters simply want to maintain an attractive physical appearance. Nearly half of those interviewed in a 1980 study reported someone in their household was dieting for weight control (General Mills, 1980). Johnson (1984) reported recent polls in which over half of U.S. women were dieting and a total of 80 million Americans were trying to control their weight.

Consumers' Increasing Health and Weight Consciousness

Consumers are becoming increasingly knowedgeable and concerned about how diet can alleviate or prevent medical problems and promote good health (Anon., 1980b). Kamel and Washnuik (1983) attributed the increase of dieters and the growing demand for low-calorie foods to improved nutritional awareness and public health education. For example, 53% of consumers surveyed considered sugar content when making food purchases and 45% selected alternatives with less sugar (General Mills, 1980). The number of consumers making health-influenced buying decisions is expected to continue to increase (Johnson, 1984).

The average dieter is no longer the elderly diabetic or overweight housewife: according to the Second Woman's Day/FMI Family Food Study, today's typical dieter is likely to be in a higher socioeconomic bracket than the non-dieter, counts calories, is concerned about nutrition, and uses special "light" and low-calorie foods (Zbytniewski, 1982). Sugar sales are down and non-nutritive sweetener sales are up: Americans reportedly consumed an amazing 15.8 pounds of saccharin and aspartame per capita in 1984, compared with 6.1 pounds in 1975 (Anon. 1985; Clark et al., 1985).

Diet food and beverage sales are already growing at triple the rate of all foods and are projected to represent a $41.2 billion market by 1990 (Anon., 1984a). Of this amount, reduced-calorie foods alone will account for half. According to Bill Fagnano, co-owner of the Pro-Portion diet foods franchise, "The consumer is always looking for something new in reduced-calorie items" (Lewis, 1985). This is evidenced by a recent report in New Product News which said that 91 new low-calorie foods were introduced in 1983 compared to 60 in 1982 and 42 in 1981 (Johnson, 1984). Tim Metzger, vice president of a successful chain of reduced-calorie sweet shops in New York, stated

> "we're looking to attract the consumer who has the heightened awareness for healthful eating, the one

> who may prefer rich, fattening desserts, but can't afford to have them. We want to serve all those who are concerned about weight control and the various health concerns regarding diet."

If the present trend in consumer nutrition awareness continues, an increased willingness to pay the higher cost for dietetic foods will result (Dwivedi, 1978). C.I. Beck (1978) stated that these foods fulfill a need which is not only ethical but profitable, and both therapeutic and marketing needs will be met if low-calorie versions are formulated for foods with a high caloric density.

Reduced-Calorie Desserts

An area representing high caloric density, i.e., high sugar and fat content, and ripe for development is reduced-calorie desserts. Many a diet has come to a premature demise over a "gooey" dessert. Though dieters have become more health conscious and are saying "no" to certain food ingredients, few are willing to completely forego their passion for sweets. "People are searching for trade-offs," says Susan Barlow, director of First National's Consumer Center. "They don't want to feel they have to starve themselves or give up everything they love to maintain a healthy diet" (Johnson, 1984). Dieters quite literally want to have their cake and their diet, too.

The reduced-calorie dessert market is beginning to grow: diet gelatins, puddings, cookies and whipped toppings are available. But one industry expert cautions grocers not to get too "diet happy" with shoppers. "Consumers have a built-in gratification scale," she says. "They're more willing to compromise on low-gratification items such as beverages and condiments to save calories than they are on high-gratification products" (Zbytniewski, 1982).

Sara Lee Kitchens learned that lesson nine years ago when they tried to market reduced-calorie "Light and Luscious" desserts--and failed. Peg Ransom, a spokeswoman for the company, stated, "We found that when someone made room for dessert, they went for broke." She added, however, that the company was ahead of its time and ahead of today's "fitness craze". Sara Lee may try the products again (Lewis, 1985). Mona Doyle, President of Consumer Network, agrees that the market is ripe for quality desserts. "Taste is a very sharp concern. There is a great willingness on behalf of the consumer to spend for flavor" (Johnson, 1984).

Complications in Formulating Diet Desserts

According to Finberg (1972), "The rate of growth of low-calorie foods is limited only by the ability of the foods industry to develop products comparable in quality to their high-calorie counterparts." Although a number of diet products are available, a dearth of high quality desserts is noted. This shortage is a result of both consumer skepticism of reduced-calorie desserts and the difficulties inherent in creating such products.

In most foods, reduction of the amount of ingredients sufficient to cause a significant caloric reduction leads to losses of appearance, texture and mouthfeel which are detectable by the consumer (Beereboom, 1978). Since baked desserts are complex systems of fat, protein and carbohydrates, low-calorie versions are particularly difficult to reformulate. Modification of one ingredient affects levels of other ingredients. Beck and Ziemba (1966) stated that development of acceptable reduced-calorie cookies or cakes requires one to literally "start from scratch with new products and process modifications."

The major dry ingredient in high-ratio cake is sucrose. When this sugar is replaced by intense, non-nutritive sweeteners to reduce calories, problems arise immediately. Intense sweeteners are 200 - 400 times sweeter than sucrose, so only minute quantities are required for equal sweetness. Ingredient bulk or volume is reduced drastically. Sugar accomplishes more in the cake than sweetening, or even providing bulk. Tenderization is achieved by increasing the gelatinization temperature of starch and the coagulation temperature of proteins, allowing longer time for the leavening gases to expand the structure and improve mouthfeel and volume.

The other ingredient targeted for reduction or omission in a low-calorie cake is shortening. Fat prevents formation of a tight gluten network and aids in the incorporation of air to improve volume, texture and mouthfeel in a layer cake. If both sugar and shortening are removed, the resulting "cake" is flat, gummy and tough. Though a wide array of bulking agents, gums, emulsifiers and related ingredients is available, formulation of reduced-calorie cakes remains a complicated and frustrating process.

A number of investigators have succeeded in creating reduced-calorie cakes (Morris, 1981; Freeman, 1982; National Starch and Chemical Company, 1982; Hess and Setser, 1983; Kamel and Washnuik, 1983). Several reduced-calorie cake mixes are available commercially from companies such as Batterlite®, Sweet 'n' Low ™, and Estee. However, diet cakes are generally low quality, obvious imitations of their high-calorie archetypes and most dieters are not willing to purchase them. As one consumer reporter explains, dieters "won't give up high quality or taste in something they expect to be rich, such as cheesecake" (Zbytniewski, 1982).

To be successful, a dietetic dessert must satisfy the drive for sweetness, provide the density and bulk of fat, and offer convenience, all at reduced calorie content (Scala, 1978). In addition, the original eating characteristics must be retained and the product must remain indistinguishable in appearance, taste and texture from higher-calorie counterparts to which the customer is accustomed (Moirano, 1966).

One company, Weight Watchers, Inc., has successfully created reduced-calorie cakes. Sales of Weight Watchers® cakes and pies increased 140% from 1983 to 1984, and the desserts account for 20% of the company's extensive frozen foods business (Lewis, 1985). Yet, these products have several shortcomings. Though appropriate for the average dieter, they still contain sugar and fat, which prohibits or restricts their use by those on therapeutic diets. Although the cakes are relatively lower in calories, they are not dietetic: a specified portion (2.5 oz) of Weight Watchers® German chocolate cake, for example, contains 200 calories. A need exists in the marketplace to develop cakes that are not only high quality but truly reduced in calories.

Product Optimization Techniques

Optimization of all aspects of a food product is the goal in product development (Giovanni, 1983). If optimization is defined as a process for developing the best possible product of its type, then, from a given set of ingredients, an optimal formulation is the best possible formulation.

A variety of attributes determine the overall quality of each product. Theoretically, if these attributes are present to specific degrees and in exact combinations, they will result in an ideal product. Realistically, however, no single formula or set of properties yields an optimal product. A number of combinations of levels and characteristics can yield highly acceptable products (Schutz, 1983).

Traditional Methods

Traditionally, product improvement and optimization was accomplished by painstaking modification of one variable at a time. In food development, such an experimentation method is obsolete and inefficient (Moskowitz, 1983). Most food products are complex systems containing many ingredients and subject to a number of processing steps. Cardello and Maller, (1984) stated that one food product may have as many as 40 or more descriptive attributes and a number of instrumental measurements that can be obtained from them. Therefore, the single-factor experiment, which assumes that changes occur in a vacuum, is illogical.

Kissell and Marshall (1962), early employers of multiple factor optimization, stated that products result from ingredient variables which can not be assumed to act independently. A change in one ingredient necessarily modifies the optimum level of another. For example, the effect on a baked product of variations in ingredient A in a batter composed of A + B + C + D may depend on the specific levels chosen for B, C and D. Kissell concluded that in "piecemeal" experiments, the ingredient-interaction effects are difficult to isolate and results of variation may not be directly comparable.

Disadvantages of Univariate Analysis

Giovanni (1983) listed several disadvantages of using the classical one-factor method. The two major shortcomings are:

1) It requires a large number of experiments, money and time.
2) It may be ineffective. Since the experimenter uses only educated guesses to specify the various test ingredient levels, the true optimum may remain undetermined.

Need for Multivariate Analysis (MVA)

Multiple-factor optimization traces its roots back to the early 1950's and even before that time. As the complexity of food products and competition between manufacturers increased, the need for efficient optimization methods became evident. Multivariate statistical analyses were designed to simplify the relationships that exist within a complex array of data by isolating and identifying redundancies (Bieber and Smith, 1986).

Box and coworkers (1951, 1954) are among those who created multifactorial statistical designs; Kissell (1967) and Powers (1968; Powers and Keith, 1968) are especially noteworthy as pioneering the use of these techniques in the food industry. A detailed review of the beginnings of this methodology is found in Hill and Hunter (1966).

Concurrent progress in computer technology greatly advanced development of MVA optimization techniques, and many of MVA's advantages are directly attributable to computer utilization. Computer use, though not required for MVA, certainly is more rapid and efficient than manual data calculation and model development. The following discussions of MVA's benefits assume its application with computers.

Advantages of MVA

Systematic, multivariate procedures have a number of advantages over univariate trial-and-error techniques. The primary benefit is improved efficiency. The MVA optimization requires only limited studies and allows collection of a large amount of data from a small number of experimental observations. Mulltiple factor techniques thus increase the quantity of results generated while decreasing research time and cost (Henika, 1982). Whereas traditional product development may require six months to a year, computer-based optimization may accomplish the same goal in months or weeks (Moskowitz and Jacobs, 1984).

Besides improving quantity and efficiency, MVA enhances data quality and provides a degree of certainty or confidence about results. The role of each factor or ingredient's impact on various parameters is defined clearly so researchers can pinpoint changes that will improve a product (Moskowitz, 1983). Though MVA procedures do not guarantee development of an optimum product, they provide a precise focus or guide to create such a product and enhance the probability of success (Schutz, 1983; Sidel and Stone, 1983).

In addition to elucidating hidden relationships among the variables, MVA increases the opportunity for unexpected results that might otherwise remain undiscovered. MVA can answer pro-active "what if" questions that could lead to other profitable areas of study (Moskowitz and Jacobs, 1984).

In summary, multivariate optimization is an efficient, high technology process requiring minimal effort and expense to develop improved products with a high probability of market success.

Types of Multivariate Techniques

Cardello and Maller (1984) listed the following multivariate techniques as most important for the food industry:

cluster analysis.
factor analysis.
multidimensional scaling.
multiple regression.
response surface methodology.

These statistical procedures are all methods of identifying the basic relationships underlying observed data. However, though similar in many ways, there are important differences regarding the questions each method is designed to address and the interpretation of their results (Bieber and Smith, 1986). Schutz (1983) noted that each approach has particular advantages and disadvantages in developing optimal products. Following is a brief description of the various MVA techniques:

Cluster Analysis

Cluster analysis (CA) is a method for separating data by determining how many distinct groups of variables exist and assigning each variable to a group (Bieber and Smith, 1986). Each group or cluster contains elements that are similar in function yet different from the other clusters. The heterogeneity between clusters indicates how many separate functions are being exhibited while homogeneity within clusters reflects the degree of their duplication

(Bieber and Smith, 1986). The goal of CA is representation of the similarities among the elements to discern the presence of clusters within the data. A theoretical position with the data can be confirmed, exploration of hypotheses about the data's organization, and guidance of further investigations can be accomplished using CA.

Factor Analysis

Like CA, factor analysis (FA) is aimed at identifying similarities among a set of variables to reduce the original number of variables (Cardello and Maller, 1984). Variables are grouped as either clusters (in CA) or factors (in FA). However, in CA, interactions are qualitative and in FA are quantitative. In CA, relationships belong only at the endpoints of a continuum; an element either belongs to a discrete cluster or it does not. In FA, relationships between the stimuli and factors may exist anywhere along the continuum from zero to unity (Bieber and Smith, 1986). Use of FA is a means of quantifying the gradations between "all" and "none".

Unlike CA, FA procedures allow assessment of several variables simultaneously. Common regions or areas of overlap may be thought of as covariance between the factors. Factor analysis, which actually applies to a number of statistical techniques, may be used to search for underlying constructs among a group of measures or to test hypotheses about the existence of such constructs (Cardello and Maller, 1984).

Multidimensional Scaling

Whereas CA and FA are designed to reveal similarities among stimuli data, multidimensional scaling (MDS) is based on underlying differences. In the first two methods, attributes are selected before data collection begins; in MDS, the objective is to uncover those attributes. In MDS, pairs of stimuli are judged and interstimulus relationships (proximities) are quantified through correlation coefficients. The resulting matrix of proximities is a multidimensional geometric configuration similar to a map in which all of the stimuli are represented as points in space (Cardello and Maller, 1984). The goal of MDS is to produce a map in which the interstimulus distances most closely match the associated proximities. Similar stimuli are in close proximity, while stimuli perceived as different are located at a distance from one another.

According to Bieber and Smith (1986), a quantification of the dimensional appropriateness of any solution is the degree of disparity between the originally observed and reconstructed differences. This reorganization of data allows visual inspection of the relationships within the data. Use of MDS allows interpretation of the relationships among the points without requiring an interpretation of the dimensions.

The three methods listed above, CA, FA, and MDS, involve only first-order linear regressions. Realistically, second- and third-order polynomial regression equations may be needed to give the dependent variable a high degree of predictability. The following two factorial techniques for obtaining data allow fitting of polynomial equations to data sets (Cardello and Maller, 1984).

Multiple Regression Analysis

Multiple regression analysis (MRA) is a means of relating sensory and instrumental data sets. A series of predictor variables, such as instrumental measurements, are used to predict the magnitude of a dependent variable, such as a sensory attribute. The MRA approach to optimization is especially useful when 1) little is known about attributes and their relationship to a product's acceptance and 2) the number of dimensions or variables is very large (Schutz, 1983).

In MRA, a set of approximately 20 competitive and/or experimental products is assembled. These products are analyzed by quantitative descriptive analysis (QDA) or other appropriate sensory techniques as well as chemical and physical means. The measured independent variables are analyzed by MRA to determine relative importance of variables and identify those properties and levels which are most important to overall quality or acceptance. In addition, MRA computes percent variance in the dependent variable, i.e., consumer acceptance or optimization. The properties of an optimum product are then calculated and a model developed (Schutz, 1983).

In MRA, the model utilized is a linear and additive one. Such a model assumes that the relationship between independent variables and the dependent variable(s) is essentially linear and no interactions exist among variables (Schutz, 1983). Though the determination of relationships contained in the data set enhances the efficiency of product development, Schutz cautions that optimization is not a substitute for market research evaluation of products. The focus of research resources and screening potential new products for more extensive market research should be guided by MRA.

Response Surface Methodology

Like MRA, response surface methodology (RSM) is used to identify critical variables and select the combination that will optimize a product. In RSM, quantitative data from appropriate experimental designs are used to determine and simultaneously solve multivariate equations (Giovanni, 1983). The technique examines only certain fixed levels of the independent variables and their corresponding interactions. The effect of the different factor levels on the product is known as a response.

Response surface methodology derives its name from the regression or response surfaces defined when independent variables in a regression equation are varied and the dependent variable is plotted as a function of these variables. The response surface refers to the equation or to the geometrical surface which the equation describes (Cardello, 1984). Response surface models are used to examine interactions among the variables and predict how the product will change with combined alterations in the ingredient levels.

By inserting values of variables into the proper equations, combinations of levels can be computed for a specified factor set that will yield an optimum response (McLellan, et al., 1984). The RSM can identify the overlap area of variable levels in which several specifications are simultaneously fulfilled. Alternatively, response contours may be plotted to show various combinations of ingredient levels that produce the same level of optimization or acceptability (Cardello, 1984).

RSM vs MRA

Use of MRA assumes that the relationship between independent variables and the dependent variable is linear and involves no interactions. In contrast,RSM is designed specifically to develop nonlinear equations. Moskowitz (1983) recommended RSM for optimization, which requires interpolation among tested levels of ingredients. In addition, a number of food technologists have reported success with RSM in product development (Henselman et al., 1974; Cooper et al., 1977; Daley et al., 1978; Lowry, 1979; Min and Thomas, 1980; Lah et al., 1980; Johnson and Zabik, 1981; Henika, 1982; Lee and Hoseney, 1982; Giovanni, 1983; McLellan et al., 1984; and Motycka et al., 1984).

When the number of variables is large and little is known of the variables' effects on the product, MRA is appropriate; RSM is appropriate when the number of variables is relativelly small and ingredient effects have been determined in prior studies.

Necessary Assumptions in RSM Optimization

Giovanni (1983) stated that the effective use of RSM is dependent upon five assumptions:

1) Factors which are critical to the product are known.
2) The region of interest where the factor levels influence the product is known.
3) Factors vary continuously throughout the experimental range tested.
4) There exists a mathematical function which relates the factors of the measured response.
5) The response defined by this function is a smooth surface.

The optimization researcher must have an intimate understanding of materials, tools and processes as well as the marketing objectives. According to Fishken (1983), knowledge of the overall system is the initial requirement for a successful product. And, RSM enables the experimenter to grasp this comprehensive scheme and achieve optimization by following a set of flexible rules.

Steps in RSM Process

The general steps in the RSM optimization process are:

1) Ingredient screening.
2) Identification of critical factors.
3) Determination of range of ingredient levels.
4) Design of experimental plan.
5) Preparation of designated samples.
6) Evaluation of samples.
7) RSM data analysis and interpretation.
8) Calculation of models.
9) Preparation of optimized products.
10) Evaluation and validation of optimized products.

Ingredient Screening

In RSM, important variables are isolated in preliminary trials and then varied systematically. Thus, the importance of the initial screening step must not be underestimated. Fishken (1983) recommended that screening include a broad range of options and cautions that, since RSM works equally well with poor or good components, care should be taken to select the premier ingredients.

Factor Identification and Level Determination

Not all ingredients and processing steps have the same impact on product quality. Critical factors which most influence a food's sensory and physical properties and cause the greatest product variation must be identified. Once the essential variables have been determined, researchers use them as a basis to predict the combinations that will yield an optimum product. Fishken (1983) stated that the most critical step in optimization is setting ingredient levels for the design of the test products. The range selected must be fairly broad to encompass the physical specifications of the samples. Levels selected must not be "just noticeably" different but "discernibly" different.

At the planning stage, some "technological craftsmanship" becomes necessary (Fishken, 1983). Investigators must use their intellect, experience and skill to determine appropriate ingredient ranges. If there are truly optimal formulations, then ingredient levels must be higher and lower than the optimal values. Once high and low extremes have been identified, the mid or optimal level may be estimated.

Experimental Design

The next step of optimization involves designing the experiment. Many different experimental designs can cover the range of product formulations, including both full factorial and partial factorial designs. The full factorial plan tests a full set of combinations which the product developer formulates.

A partial factorial design allows the researcher to test only a fraction of the combinations possible and still develop a representative array of products

(Moskowitz, 1983). The design is based on a central formula or point which is expected to be at or near the anticipated peak of the variables' response surface (MacDonald and Bly, 1966). The design depends on a symmetrical selection of variation increments around the center compositions (Kissell, 1967). The experimental plan represents statistically the entire range of specified factor levels but emphasizes the critical samples closest to the midpoint (Giovanni, 1983).

By selecting this subset of product formulations, an RSM partial-replicate design reduces the number of samples to be tested. Factorial RSM designs often are used in conjunction with ANOV techniques to allow isolation of optimal levels of treatments (Moskowitz, 1983). In finalizing the design, researchers must determine the number of replications to be performed and the number of physical and sensory responses to be measured.

Data Analysis and Interpretation

After samples are prepared and evaluated, quantitative data is obtained for statistical analysis. Prior to generating RSM models, a scanning process will reveal if relationships between variables and responses are linear or nonlinear, i.e., quadratic or cross-product. Relationships between ingredients and sensory perceptions are often linear, while ingredient levels and sensory attributes are related nonlinearly to consumer acceptance

(Moskowitz, 1983). If linear, then the optimal ingredient level can be anticipated to be at the high or low extremes tested. If nonlinear, the investigator can estimate reasonably the range in which the optimum will lie (Fishken, 1983).

By means of appropriate data analysis, variables are related and optimization statements are obtained (Sidel and Stone, 1983). Several optimum factor combinations likely will be determined by RSM; the important independent variables may be combined in numerous ways to yield optimum products. The equations represented by the different response surfaces can be solved simultaneously to determine the optimum product areas for all measured characteristics.

Giovanni (1983) recommmended cooperative interpretation of results by the statistician, product developer, sensory scientist and all others involved in data collection. Analyses of the RSM models and plots involve strict statistics but still require subjective artistry, creativity and intuition. Sidel and Stone (1983) emphasized that

> "resources in sensory evaluation and the availability of statistical models are intended to expand the intellectual limits about products and provide a perspective that is not readily apparent by other means. The creative efforts are still an integral part of the system."

Validation and Follow-Up

Once optimal levels have been identified and ingredient interactions are understood, the results are used to develop optimum product formulations. These products are evaluated in follow-up validation experiments to confirm their consistency with the models. Moskowitz (1983) recommended that this vital "fine-tuning" stage be accompanied by actionable consumer feedback. A final caution is not to extrapolate results beyond the limits of the study (Giovanni, 1983).

Limitations to RSM Process

There are five limitations to remember in using RSM:

1) Experimental factor variation must be controlled to prevent misleading conclusions.

2) Critical factors of the product may not be correctly specified or sufficiently defined, resulting in an inaccurate description of the optimum product.

3) If the range of factors tested is too broad or narrow to specify the optimum, the optimum product may not be determined.

4) Good statistical practices such as randomization and blocking must be used to prevent bias or determination of an incorrect mathematical model to describe the optimum.

5) Over-reliance on the computer can lead to inaccurate results. The experimenter must use judgment and product knowledge to draw appropriate conclusions (Giovanni, 1983).

In summary, RSM is an effective and powerful statistical technique that allows researchers to simultaneously test several selected variables. Designs reduce the observations necessary by selecting only a limited, critical subset of samples from the entire experimental range. A data base is developed from the observations, and equations are derived which quantitatively define relationships between variables and response. By generating response models from a number of tested product variables, researchers can predict characteristics of similar product formulations without actually testing them. The effect of all combinations of variables in the test range on the selected responses may be calculated. From these models and graphs, optimum products may be targeted and developed.

MATERIALS AND METHODS

The study was divided into three phases according to the RSM design:

I) PRELIMINARY experiments to determine critical variables

II) RSM OPTIMIZATION

III) VALIDATION of optimal ingredient levels by ANOV

RSM Optimization

A summary of the preliminary investigation is found in Appendices A-1 and A-2. As a result of the preliminary work, a cake formulation was generated as the starting point for RSM optimization and critical ingredient variables were identified. A complete listing of final ingredients, suppliers, specification and lot numbers appears in the Appendix, Table A-3. Whenever possible, ingredients were obtained at the beginning of the study in quantities sufficient for the entire investigation. Fresh eggs were obtained weekly from a local market.

Experimental Design and Data Analysis

A central composite, multiple response surface design was used to systematically determine the relative influence of the five ingredients and to optimize the cake qualities. The experimental plan included the five variables at five levels: the design center point or zero level, based on the starting cake formula, and two units above and below that base point (Table 3). These

Table 3- The experimental design[a]

	Variable				
Sample number	N-Flate™	Water	Polydextrose	Leavening agent	Fructose
	$\underline{x}_1$	$\underline{x}_2$	$\underline{x}_3$	$\underline{x}_4$	$\underline{x}_5$
1	-1	-1	-1	-1	1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	1
7	-1	1	1	-1	1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	1
11	-1	1	-1	1	1
12	1	1	-1	1	-1
13	-1	-1	1	1	1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	1
17	-2	0	0	0	0
18	2	0	0	0	0
19	0	-2	0	0	0
20	0	2	0	0	0
21	0	0	-2	0	0
22	0	0	2	0	0
23	0	0	0	-2	0
24	0	0	0	2	0
25	0	0	0	0	-2
26	0	0	0	0	2
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

5 $\underline{x}$-variables N = 32 treatment combinations 1/2 replicate of a 2^5 factorial + star design + 6 points in the center.

[a] Source: Cochran and Cox, 1966.

ingredient levels encompassed the range likely to produce high volumes and fine-textured cakes.

Each of the five variables was combined with selected levels of the other ingredients. To compare each level of all five ingredients in all possible combinations would require preparation of 3,125 cakes. According to the RSM design, one set of 32 treatment combinations, (the half replicate of a 2^5 factorial), can be used to predict all other combinations (Table 3). Actual formulations used are listed in Appendix, Table A-4. Seventeen physical and sensory dependent variables (responses) were measured for each treatment. Cakes were prepared, two per session, in random order. As data were analyzed by RSM, the computer interpolated between the known points of the representative cakes to calculate and project theoretical characteristics of untested cake formulas.

Cake preparation

Ingredients were weighed at the beginning of each baking period. Eggs were allowed to warm to room temperature (24 + 2 ^{o}C). The pH of distilled water was determined and adjusted to 7.0 + 0.02 with distilled water from other sources. Water and eggs were mixed together and dry ingredients were blended similarly prior to incorporation in the cakes. The preparation method used in this study is given in Table 4.

After baking, the cakes cooled 30 min before removal

Table 4 - Preparation method for yellow cakes

Mixing step	Speed setting[a]	Time (min)
1) Blend dry ingredients.	2	1.0
2) Gradually add eggs and water.	2	0.5
3) Scrape.	-	-
4) Blend all ingredients.	10	4.0
5) Scale 320 g batter into greased, waxed paper-lined 6" (15.2 cm) metal pan.		
6) Bake at 350 °F (177 °C) for 30 min.[b]		

[a] Kitchen Aid mixer, Hobart Mfg. Co., Troy, OH. Model K5-A, with wire whip.

[b] Rotary hearth oven, National Mfg. Co., Lincoln, NE. Model 280C.

from pans and placement on wire racks for 30 min additional cooling. Cakes were evaluated within three hrs for physical and sensory characteristics.

Physical measurements

The following responses were determined according to procedures given in Appendix A-5:

specific gravity
batter pH
cake pH
batter water activity
cake water activity
volume
symmetry
uniformity
percentage shrink.

In addition, cakes were photographed using the Xerox photocopier to document visual textural characteristics. The half of each cake not used for evaluation was placed in a moisture- and vapor-proof polyvinyl chloride storage bag, sealed, and frozen at $-25 + 5\ ^{o}C$

Sensory evaluation

For this phase, two investigators, experienced in sensory textural analysis, evaluated sample cakes to describe and define each textural characteristic. Sucrose control cakes were appraised to establish standard values for comparison. The validation phase which followed utilized a panel of five persons. For some studies, small panels are advantageous. Chambers and co-workers (1981) found a three-membered, extensively trained and experienced panel was easier and less time-consuming to conduct, and resulted in lower residual error mean squares than an eight-membered, less experienced panel.

Cake textural quality was evaluated one to three hours after baking. Six-cm cubes from the centers of the cakes were cut and placed on paper plates. Crust was removed by panelists after evaluating crust stickiness and softness and prior to determining the other attributes.

Cell uniformity, size and thickness; density, moistness, gumminess, crust stickiness and softness were measured to assess changes in cake quality with formula modifications. A computerized, 60-point linear scaling system with descriptive anchors, adapted from McLellan and Cash (1983), was used. Cakes with greatest cell uniformity, most even cell size, thinnest cell walls, etc., were given highest scores. A sample score card is shown in the Appendix, Form A-1. Attributes appeared individually on the computer screen.

Validation by ANOV

Though the same basic formula and preparation methods employed in the RSM optimization phase were followed, several modifications were made. These included:

1) usage of a standard level of N-Flate™ (22.5 %, flour weight basis, or fwb; 27 g, total batter weight, tbw).
2) elimination of fructose.
3) incorporation of a single intense sweetener blend in all treatments (0.2 g each aspartame and saccharin, tbw, 0.17% fwb).

4) addition of 0.03 g (0.025% fwb) color (Orange lake blend #9815, Warner Jenkinson Co.).

5) Replacement of waxed paper liners with greasing and flouring of pans.

6) reduction of the amount of batter in each pan from 320 g to 300 g.

7) extension of baking time from 30 to 32 min.

Complete rationale for each of these changes are given in the Results and Discussion section.

Experimental design

This validation phase was designed to focus on the optimum ingredient ranges generated by the RSM studies. Effects of four levels of water, three levels of polydextrose and two levels of leavening agent on cake texture were determined. The variable amounts and the twenty-four treatment formulas are shown in Table 5. Table 6 summarizes the variable levels used in the RSM and ANOV phases of the study.

Using a randomized, complete block design for three replications, cakes were evaluated by selected physical measurements and by a highly trained sensory panel. Cakes were prepared and served in random order.

Physical measurements

In this phase, specific gravity, batter viscosity, volume, symmetry, uniformity and percentage shrink were determined as described in Appendix, Table A-5.

Sensory evaluation

Table 5 - Experimental design for 3 x 4 x 2 factorial validation experiment with varying levels of polydextrose, water and leavening agent

	Ingredients					
	Polydextrose		Water		Leavening	
Treatment	g	% fwb [a]	g	% fwb	g	% fwb
1	75	62.5	80	66.7	8	6.7
2	75	62.5	95	79.2	8	6.7
3	75	62.5	110	91.7	8	6.7
4	75	62.5	125	104.2	8	6.7
5	85	70.8	80	66.7	8	6.7
6	85	70.8	95	79.2	8	6.7
7	85	70.8	110	91.7	8	6.7
8	85	70.8	125	104.2	8	6.7
9	95	79.2	80	66.7	8	6.7
10	95	79.2	95	79.2	8	6.7
11	95	79.2	110	91.7	8	6.7
12	95	79.2	125	104.2	8	6.7
13	75	62.5	80	66.7	9	7.5
14	75	62.5	95	79.2	9	7.5
15	75	62.5	110	91.7	9	7.5
16	75	62.5	125	104.2	9	7.5
17	85	70.8	80	66.7	9	7.5
18	85	70.8	95	79.2	9	7.5
19	85	70.8	110	91.7	9	7.5
20	85	70.8	125	104.2	9	7.5
21	95	79.2	80	66.7	9	7.5
22	95	79.2	95	79.2	9	7.5
23	95	79.2	110	91.7	9	7.5
24	95	79.2	125	104.2	9	7.5

[a] Flour weight basis.

Table 6 - Cake formula variations throughout the study (%, flour weight basis)

	Variable levels					
Ingredient			RSM phase			ANOV phase
Cake flour			100.0			100.0
Egg white, dried			1.3			1.3
Salt			1.7			1.7
Whole egg, fresh			83.3			83.3
Vanilla, powdered			0.8			0.8
Sodium saccharin			0.4			0.2
Aspartame			-			0.2
Fructose, crystalline	0.0	8.75	17.5[a]	26.25	35.8	-
N-Flate™ matrix	15.0	17.5	20.0[a]	22.5	25.0	22.5
Water, distilled	80.0	100.0	120.0[a]	140.0	160.0	66.7 79.2 91.7 104.2
Polydextrose	50.0	62.5	75.0[a]	87.5	100.0	62.5 70.8 79.2
Leavening agent	5.0	6.25	7.5[a]	8.75	10.0	6.7 7.5

[a] Center design point for response surface methodology; starting cake formulation from preliminary phase.

Panel selection and training

Five professional panelists associated with Kansas State University (KSU) Sensory Center evaluated all cakes. These panelists were experienced in sensory evaluation and had been trained initially during six months of daily 3-hour sessions. All had been associated professionally with the Sensory Center for at least 18 months. The procedures for this study had been approved previously by the Human Subjects Committee of the College of Human Ecology at KSU (Appendix, Forms B-1 and B-2). The experiment was described briefly to participating panelists who read and signed a statement of informed consent (Appendix, Form B-3).

During ten hours of specialized training, various sensory exercises familiarized panelists with analysis of cake textural and sweetener attributes. Panelists discussed and defined terms, developed a cleansing and rinsing procedure, participated in refining the score card and determined the amount of sample and method for tasting. Complete details of training appear in Appendix, A-6.

Sample evaluation

Unstructured, 60-point scales were used to record intensities of each characteristic on both the computer and back-up score cards (Appendix, Form C). Characteristics are described in Appendix, A-6a.

Descriptive terms and additional comments or corrections were recorded on the score sheets. All scales were anchored with appropriate baked products, which had been established during training. Test cakes were compared to standard sucrose-containing pound and yellow layer cakes (Betty Crocker) as determined and positioned for references during training. The standard cakes were available for reference at each session.

Sensory textural attributes assessed were cell uniformity, overall cake density and gumminess. In addition, panelists evaluated maximum and residual sweetness and bitterness to ascertain textural and other ingredient effects on these tastes.

Panelists began each session by tasting a "warm-up" cake sample to prevent bias against the first sample evaluated. Moskowitz (1985) found that, on a position basis, the first product in a test sequence shows greatest variability. A poorly established frame of reference against which to rate the product is believed to be the cause. Once panelists taste and judge a sample, a reference is established and variability diminishes considerably in the second position. Therefore, Moskowitz recommended providing panelists with a warm-up product prior to actual evaluation. In this study, warm-up samples similar to the cakes being scored were tasted but not evaluated formally.

Panelists used timers to insure adequate time for evaluation and recovery between samples. A cleansing and rinsing procedure using sliced, raw carrots, one-half percent milk and deionized/distilled water was developed during training and followed before tasting and between each sample to minimize carry over effect.

Four random samples were evaluated during each session. Each cake sample was divided into two portions; the smaller section was used to assess gumminess while the larger was employed to evaluate the remaining attributes (Fig. 4).

Sample preparation

Thirty minutes prior to serving, crust was removed and the cake sliced into six pie-shaped wedges. Each wedge was cut near the small end to divide it into two portions for specialized evaluation (Fig. 4). Samples were placed on white, plastic plates and coded with three-digit random numbers. An unlabeled warm-up sample was placed in the center of the plate and the cakes were covered loosely with plastic wrap to prevent drying.

Analysis of data

A 4 x 3 x 2 (water x polydextrose x leavening) treatment combination was used to compare measurements from various treatments. Three replications of this validation experiment were made and data was evaluated by ANOV procedures of the Statistical Analysis System (SAS

Step 1. Crust removed

Step 2. Cake cut into 6 equal wedges (approx. 6.5x6.5x6.5x3.5 cm)

Step 3. Wedges subdivided

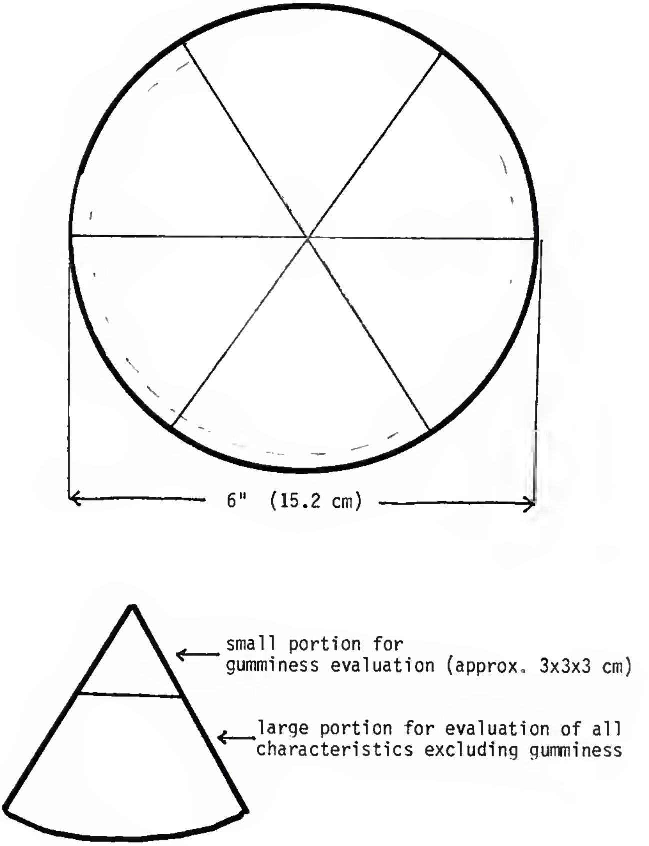


Figure 4 - Preparation of samples for sensory evaluation

Institute). The ANOV for physical measurements was as follows:

SOURCE OF VARIATION		DF
Replication (R)		2
Polydextrose (P)		2
Water (W)		3
P x W		6
Leavening Agent (L)		1
P x L		2
W x L		3
P x W x L		6
Error		42
	TOTAL	67

The ANOV for sensory data was as follows:

SOURCE OF VARIATION		DF
Replication (R)		2
Polydextrose (P)		2
Water (W)		3
P x W		6
Leaven (L)		1
P x L		2
W x L		3
P x W x L		6
R x P x W x L		46
Panelist (N)		4
P x W x L x N		92
Error		192
	TOTAL	359

Means were compared and when significant differences were found, these were separated by least significant differences (LSD) procedures ($p < 0.05$).

RESULTS AND DISCUSSION

Optimization: response surface methodology

The overall effects of ingredients on texture, which were determined by RSM are summarized in Table 7. Polydextrose was the most influential ingredient, followed by water. Though leavening and fructose affected the same number of variables, fructose was judged to be expendable because of its limited improvement value. Thus, fructose was not included in the validation phase of the study. Other changes in formulation and preparation are listed in the Materials and Methods section. Complete rationale for modifications are as follows:

1) From RSM analysis, increasing or decreasing levels of N-Flate within the small experimental range had negligible effects. Therefore, a standard, moderate level of the ingredient was selected to allow greater focus on the variables which were affected by alteration.

2) Fructose's slightly beneficial influence on browning, cake symmetry, flavor and crust cracking were outweighed by its negative effect on gumminess. In addition, from a marketing standpoint, elimination of this carbohydrate sweetener reduced calories and would allow promotion of a "sugar-free" cake.

3) The main objective of this study was to optimize cake texture, so optimization of sweetener and flavoring systems was not a priority. By using a standard level of sweetener, the effects of other ingredient levels on sweetness and bitterness perception could be studied.

4) Without coloring, the experimental cakes were a pale yellow hue. Since appearance influences sweetness perception (Pangborn, 1960; Pangborn et al.,1963; Pangborn and Larson, 1975; Johnson and Clydesdale, 1982) and the cakes were being compared to commercial cake mixes, augmentation and adjustment of the color of the test cakes was necessary to prevent color bias.

Table 7- Overall ingredient effects[a] on texture determined by response surface methodology

	Ingredient				
Characteristic	N-Flate™	Fructose	Leavening	Water	Polydextrose
Specific gravity	X				
Batter pH			X		X
Cake pH			X		X
Batter A_w		X		X	
Cake A_w		X		X	X
Volume				X	X
Symmetry		X			
Softness			X		X
Cell size				X	X

[a] Significant at $p \leq 0.05$

5) Cakes tended to tunnel, a condition partially dependent on temperature gradient and rate of heat transfer. Removal of waxed paper liners has been shown to alter size and orientation of tunnels (Trimbo and Miller, 1973), so liners were not used during validation.

6) Cakes had gummy layers under the top crust, possibly due to excess batter in a small pan. By reducing the amount, batter had more room to expand, volume was maintained but water lost, and gumminess was slightly alleviated.

7) Extending the baking time reduced gumminess by allowing increased evaporation of water from the crust. The increased browning enhanced cake appearance.

The F-ratios, probabilities, R-squares and coeffficients of variation from RSM analyses for physical characteristics are given in Table 8. No significant quadratic or cross-product ingredient interactions were noted; all regressions were linear. Batter and cake pH were significant ($p < 0.01$ and 0.0001, respectively). pH values varied from 6.9-7.6, within the normal, neutral range reported by Ash and Colmey (1973). These authors found that when cake batter pH exceeds 7.5 and becomes alkaline, cake texture is coarse, open and thick-walled.

Water activity (Aw) readings were high, ranging from 0.93- 0.97 in both batters and cakes. Though Aw was significantly affected by ingredients, the differences among treatments did not appear to influence cake qualities. Redlinger (1986) reported that Aw was not related to sweetness intensity.

F-ratios, probabilities, R-squares and coefficients

Table 8- F-ratios, probabilities, R-squares and coefficients of variation from response surface methodology regression analyses for physical characteristics of cake

Characteristic	Linear F-ratio (PR)	Quadratic F-ratio (PR)	Cross-product F-ratio (PR)	Total regression F-ratio (PR)	R-square	Coefficient of variation
Specific gravity	7.88 (.0086)	1.28 NS	1.27 NS	2.93 NS	0.893	0.037
pH batter	10.17 (.0041)	0.58 NS	0.28 NS	2.83 NS	0.890	0.017
pH cake	144.98 (.0001)	0.62 NS	0.67 NS	36.74 (.0001)	0.991	0.0087
Aw batter	19.31 (.0006)	3.53 NS	1.28 NS	6.35 (.0091)	0.948	0.0052
Aw cake	40.38 (.0001)	2.42 NS	1.25 NS	11.32 (.0015)	0.970	0.0041
Volume	19.37 (.0006)	0.78 NS	1.29 NS	5.68 (.013)	0.942	0.032
Symmetry	9.72 (.0047)	0.90 NS	1.00 NS	3.16 NS	0.9002	0.455
Uniformity	0.31 NS	1.04 NS	1.03 NS	0.85 NS	0.709	999.99
Shrinkage	4.40 (.039)	1.20 NS	0.41 NS	1.60 NS	0.821	0.092

[a] Probabilities shown in parentheses; NS - not significant.

for sensory characteristics are shown in Table 9. Cell size and softness, the two significant characteristics, similarly display only linear regressions. These findings were typical; relationships between ingredients and sensory attributes frequently are linear (Moskowitz, 1983). R-squares for both physical and sensory factors were high, ranging from 70 - 99%. R-square, or coefficient of multiple determination, describes measure of fit of the responses to the fitted surface. The high percentages obtained in this study indicate that most of the deviation was explained by the prediction equation and was not affected by other, unmanipulated ingredients. Response surface regression coefficients for physical and sensory characteristics are given in the Appendix, Tables A-7 and A-8.

Contour Plots

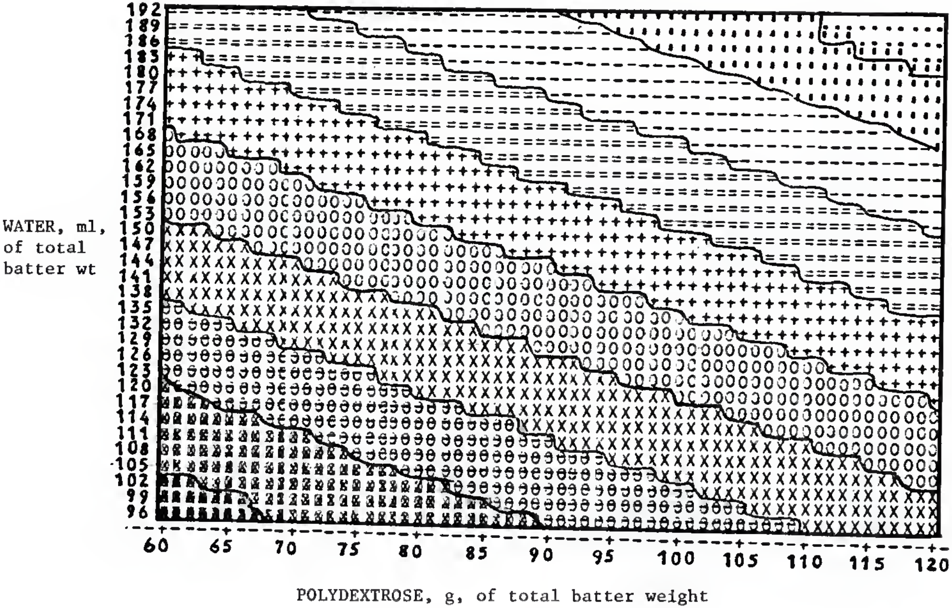
In RSM, contour plots are generated which show graphically the impact of independent variables on dependent variables. Figure 5 displays volume index as a function of polydextrose and water levels (g, based on total batter weight, or tbw). Fructose level is 0, and leavening agent is 12 g, tbw, the highest level used in the study. A strong inversely linear relationship is noted; volume is greatest when polydextrose and water levels are lowest. The optimum range is indicated by the dark region in the lower left portion of the plot.

Table 9- F-ratios, probabilities, R-squares and coefficients of variation from response surface methodology regression analyses for sensory characteristics of cake

Characteristic	Linear F-ratio (PR)	Quadratic F-ratio (PR)	Cross-product F-ratio (PR)	Total regression F-ratio (PR)	R-square	Coefficient of variation
Cell uniformity	2.20 NS	0.32 NS	1.81 NS	1.53 NS	.814	.224
Cell size	5.61 (.022)	2.59 NS	2.91 NS	3.50 (.048)	.909	.104
Cell thickness	2.36 NS	0.32 NS	1.50 NS	1.42 NS	.802	.161
Density	1.69 NS	1.94 NS	0.84 NS	1.33 NS	.791	.193
Moistness	2.78 NS	0.63 NS	0.80 NS	1.25 NS	.782	.170
Gumminess	3.17 NS	1.19 NS	0.83 NS	1.51 NS	.811	.480
Crust stickiness	2.20 NS	0.69 NS	0.53 NS	0.99 NS	.738	.232
Softness	10.22 (.0041)	0.65 NS	1.68 NS	3.56 (.046)	.910	.147

[a] Probabilities shown in parentheses; NS = not significant.

Figure 5 - Contour plot of volume index from response surface methodology optimization experiments; higher values represent higher volumes, thus optimal area is in lower left corner.



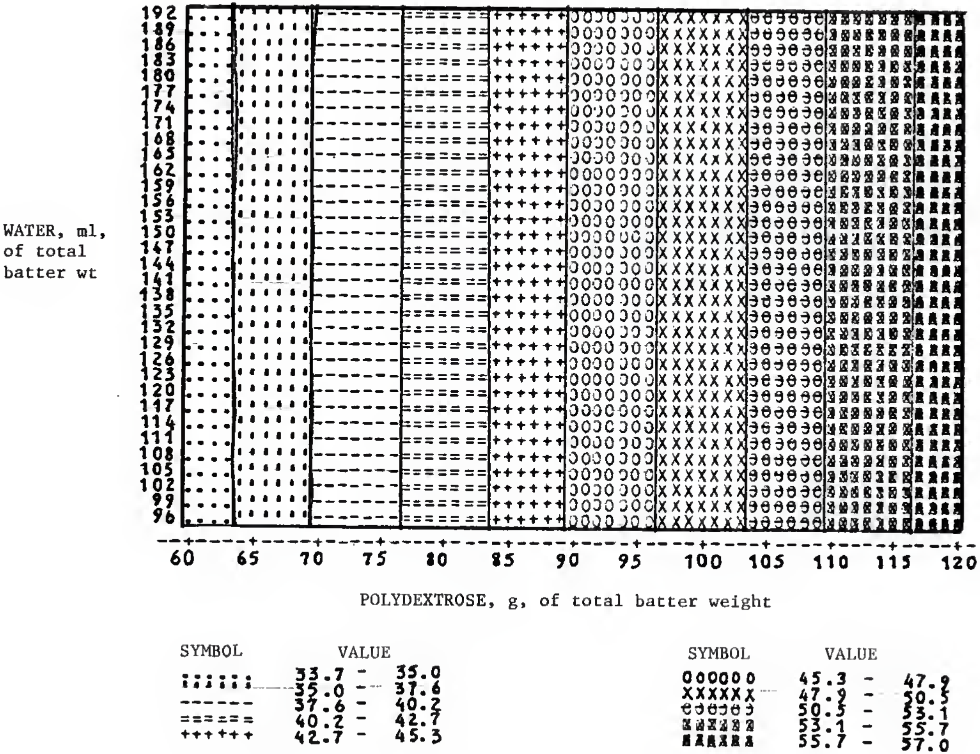
SYMBOL	VALUE		SYMBOL	VALUE	
::::::	128.1-	130.9	000000	152.9-	158.5
¡¡¡¡¡¡	130.9-	136.4	XXXXXX	158.5-	164.0
------	136.4-	141.9	ΘΘΘΘΘΘ	164.0-	169.5
======	141.9-	147.4	▨▨▨▨▨▨	169.5-	175.0
++++++	147.4-	152.9	■■■■■■	175.0-	177.8

A similar contour plot (Fig. 6) illustrates the striking effect of polydextrose on softness. The highest softness scores, represented by the dark band at the extreme right of the graph, are obtained with highest polydextrose levels. Water does not appear to influence this characteristic significantly.

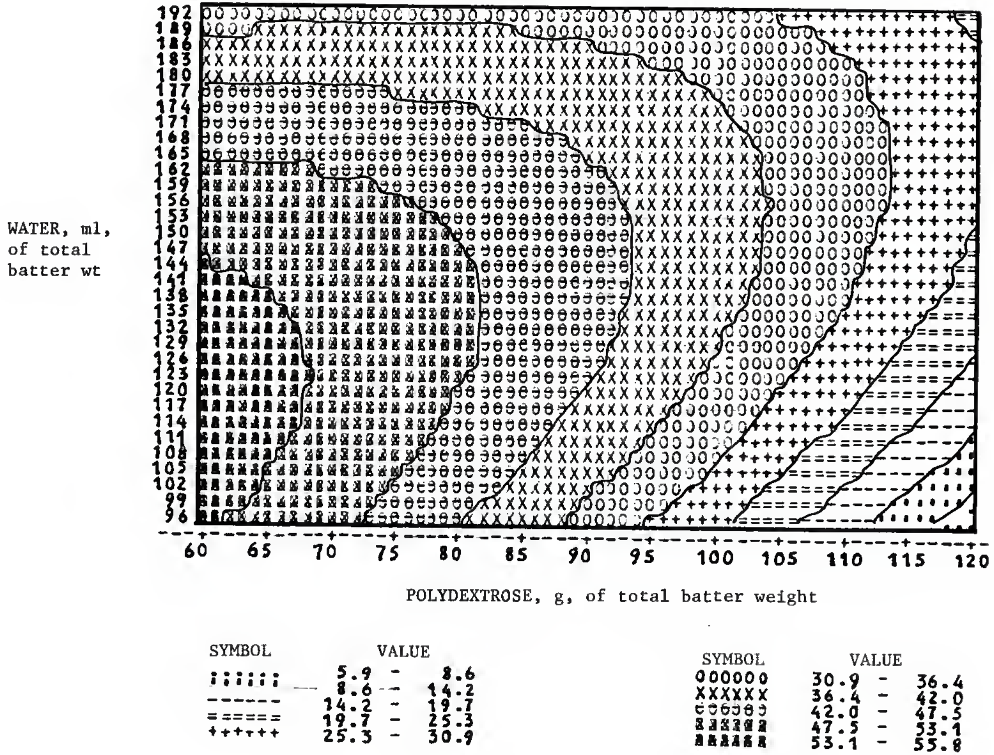
Figures 7, 8 and 9 are a series of contour plots for cake cell size using three levels of fructose (0, 28 and 42g, tbw, respectively). Polydextrose and water are varied, as in the previous graphs; leavening is constant at 12 g, tbw. As fructose level is increased, the dark region of optimum cell size expands. However, the actual cell size is larger, as indicated by the lower values, and is, therefore, not a goal to be attained. As fructose level is raised, the optimum range is shifted and partly inverted from the lowest levels of polydextrose and water to moderate levels of those ingredients. The absorptive properties of the sugar may cause the shift. Fructose competes with flour for water; as fructose is increased, additional water is required by starch for gelatinization. Since polydextrose behaves like sucrose in relation to gelatinization (Kim et al., 1986), increased sugars, including fructose, may permit decreases in polydextrose.

Areas of multiple optimum performance can be obtained by superimposing two or more contour plots for the quality attributes desired. The formula which optimizes several

Figure 6 - Contour plot for softness from response surface methodology optimization experiments; higher values represent greater softness, thus optimal area is band at far right.


WATER, ml, of total batter wt
192
189
186
183
180
177
174
171
168
165
162
159
156
153
150
147
144
141
138
135
132
129
126
123
120
117
114
111
108
105
102
99
96
60
65
70
75
80
85
90
95
100
105
110
115
120
POLYDEXTROSE, g, of total batter weight
SYMBOL
VALUE
:::::: 33.7 - 35.0
'''''' 35.0 - 37.6
------ 37.6 - 40.2
====== 40.2 - 42.7
++++++ 42.7 - 45.3
SYMBOL
VALUE
000000 45.3 - 47.9
XXXXXX 47.9 - 50.5
θθθθθθ 50.5 - 53.1
▨▨▨▨▨▨ 53.1 - 55.7
■■■■■■ 55.7 - 57.0

Figures 7, 8 and 9 - Series of contour plots for cell size from response surface methodology optimization experiments; higher values represent smaller cell size, thus optimal area is darkest section that shifts from left bottom to mid right throughout the series. Note decreasing values of optimum range as the optimum area expands.
Fructose values are 0, 28 and 42 g, respectively, based on total batter weight.


WATER, ml, of total batter wt
192
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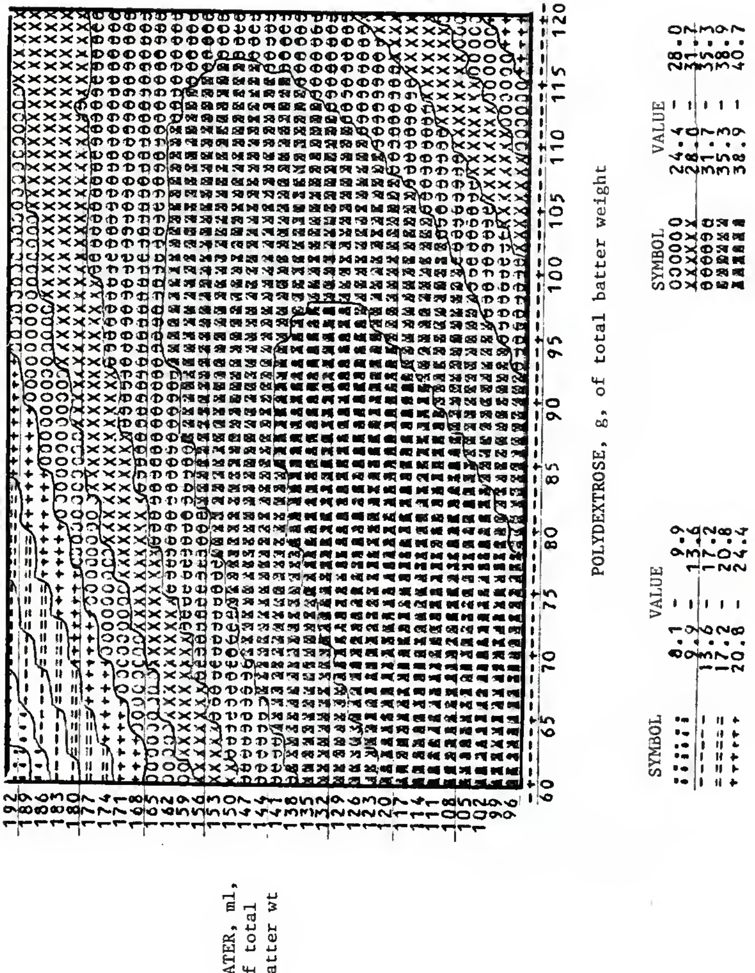
110
115
120
POLYDEXTROSE, g, of total batter weight
SYMBOL VALUE
:::::: 5.9 - 8.6
------ 8.6 - 14.2
====== 14.2 - 19.7
++++++ 19.7 - 25.3
25.3 - 30.9
SYMBOL VALUE
000000 30.9 - 36.4
XXXXXX 36.4 - 42.0
42.0 - 47.5
47.5 - 53.1
53.1 - 55.8


WATER, ml, of total batter wt
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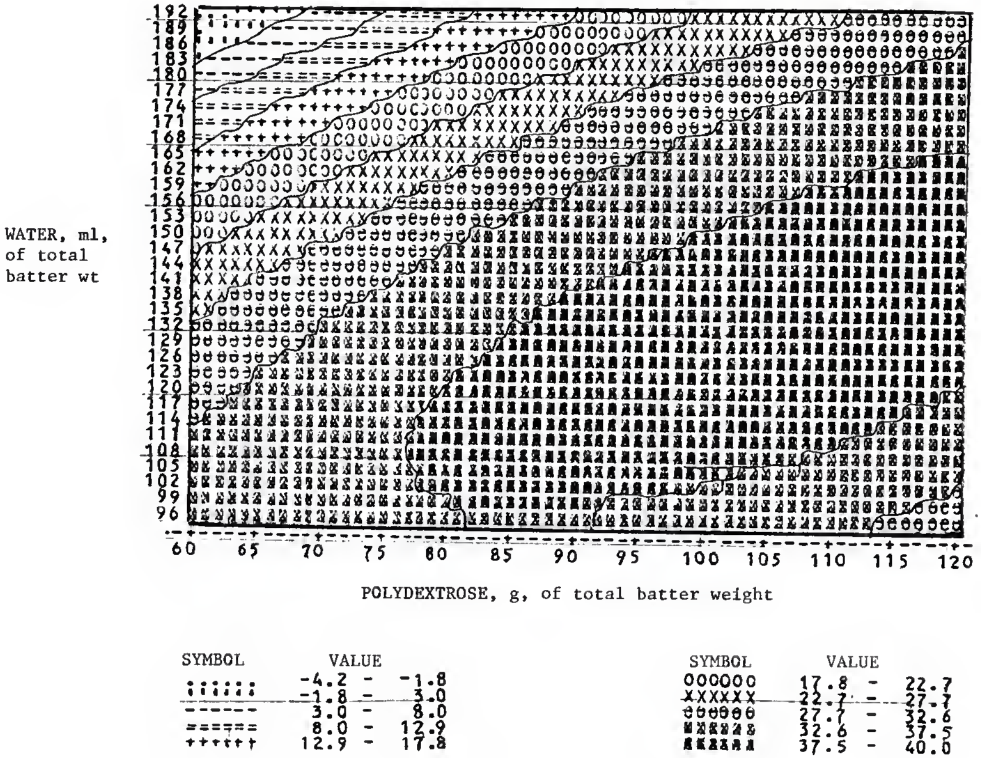
POLYDEXTROSE, g, of total batter weight
SYMBOL
VALUE
..... 8.1 - 9.9
''''' 9.9 - 13.6
----- 13.6 - 17.2
===== 17.2 - 20.8
+++++ 20.8 - 24.4
SYMBOL
VALUE
00000 24.4 - 28.0
XXXXX 28.0 - 31.7
00000 31.7 - 35.3
▨▨▨▨▨ 35.3 - 38.9
█████ 38.9 - 40.7


WATER, ml, of total batter wt
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111
108
105
102
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96
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95
100
105
110
115
120
POLYDEXTROSE, g, of total batter weight
SYMBOL
VALUE
:::::: -4.2 - -1.8
------ -1.8 - 3.0
====== 3.0 - 8.0
++++++ 8.0 - 12.9
000000 12.9 - 17.8
SYMBOL
VALUE
XXXXXX 17.8 - 22.7
θθθθθθ 22.7 - 27.7
▨▨▨▨▨▨ 27.7 - 32.6
■■■■■■ 32.6 - 37.5
■■■■■■ 37.5 - 40.0

dependent variables is found in the region where the optimum values of the different plots overlap. For example, to optimize both volume and cell size at 0 level of fructose, a batter would be prepared with low levels of polydextrose and water. Areas which optimize multiple factors are generally small. Often, not all characteristics may be optimized simultaneously and the researcher must determine which quality goals are important. Optimization involves compromising to obtain the best possible value for each variable within the experimental constraints. In this study, the two attributes selected for optimization were volume and cell size or uniformity.

Validation: analysis of variance

Physical Data

Polydextrose

The F-values and probabilities from ANOV for the physical parameters of batters and cakes are presented in Table 10. No polydextrose by leavening, water by leavening, or polydextrose by water by leavening agent interactions were significant. Highly significant differences ($p < 0.0001$) existed among polydextrose treatments for specific gravity and volume. Polydextrose's influence on structure is evidenced by the ingredient's significant ($p < 0.01$) effects on symmetry and shrinkage. Polydextrose was related

Table 10- F-values and probabilities[a] from analysis of variance for physical measurements[b] of batters and cakes

Source of variation	Degrees of freedom	Physical parameters					
		Specific gravity	Viscosity	Volume	Symmetry	Uniformity	Shrinkage
Replication (R)	2	0.71 NS	8.23 (.0009)	3.77 (.0311)	0.45 NS	1.22 NS	2.39 NS
Polydextrose (P)	2	14.65 (.0001)	1.69 NS	15.70 (.0001)	6.91 (.0026)	0.53 NS	5.39 (.0082)
Water (W)	3	4.63 (.0065)	281.47 (.0001)	3.79 (.0171)	9.07 (.0001)	1.61 NS	7.27 (.0005)
P × W	6	1.08 NS	1.40 NS	1.02 NS	0.77 NS	0.91 NS	2.44 (.0409)
Leaven (L)	1	1.20 NS	0.79 NS	17.37 (.0002)	2.33 NS	0.03 NS	4.01 NS
P × L	2	0.21 NS	2.64 NS	0.50 NS	0.19 NS	0.58 NS	0.19 NS
W × L	3	0.75 NS	1.02 NS	0.55 NS	0.61 NS	0.91 NS	2.51 NS
P × W × L	6	0.39 NS	0.53 NS	1.40 NS	0.13 NS	0.68 NS	0.57 NS
Error	25						

---

[a] Probabilities are given in parentheses; NS = not significant.

[b] Procedures are given in Appendix, Table A-5.

inversely to specific gravity, volume, symmetry and shrinkage; higher levels of the bulking agent resulted in lower values for the dependent variables (Table 11).

Water

Water (Table 10) significantly influenced specific gravity ($p < 0.01$), viscosity and symmetry ($p < 0.0001$), shrinkage (0.001) and volume ($p < 0.05$). Highest water level (125 ml, tbw) increased specific gravity (Table 12), indicating reduced air incorporation. The decrease in air cells resulted in significantly lower volume for the 125-ml treatments. Viscosity decreased with increasing water level. Ellinger and Shappeck (1963) reported specific gravity affected grain, tenderness and texture. Lee and Hoseney (1982) found specific gravity and viscosity were correlated highly and both affected grain quality. Funk and co-workers (1969) stated that low values for specific gravity, which indicate presence of a large amount of air, are associated with "good volume and other desirable properties of cakes".

Cook (1963) said that desirable specific gravities for layer cakes were in the range of 0.65 - 0.75, and specific gravity for sponge cake should be near 0.50. Ellinger and Shappeck (1963) found optimum specific gravity for a cake containing plastic shortening to be 0.80 - 0.85. The average specific gravity in this study was near 0.60, a low to normal value for high ratio cake.

Table 11 - Influence of polydextrose on physical characteristics[a] of yellow cakes.

Polydextrose		Physical parameters					
%, fwb[b]	Total g[b]	Specific gravity (x 100)	Viscosity (cps, x 10^4)	Volume (cc)	Symmetry	Uniformity	Shrinkage
62.5	75.0	60.3 a	8.8 a	176.5 a	16.8 a	-1.9 a	7.3 a
70.8	85.0	58.3 b	9.0 a	174.8 a	16.5 a	-1.5 a	7.0 ab
79.2	95.0	57.9 b	8.7 a	170.3 b	14.4 b	-1.3 a	6.7 b

[a] Mean values for 24 observations (3 replications, pooled for all water and leavening levels); means in the same column with same letter are not significantly different (p _ 0.05). Procedures for physical measurements are given in Appendix, Table A-5.

[b] Flour weight basis; gram amount based on total batter weight.

Table 12 - Influence of water on physical characteristics[a] of yellow cakes

Water		Physical parameters					
%, fwb[b]	Total ml[b]	Specific gravity (x 100)	Viscosity (cps, x 10^4)	Volume (cc)	Symmetry	Uniformity	Shrinkage
66.7	80.0	58.3 a	12.1 a	174.5 a	14.2 a	-1.7 a	6.6 a
79.2	95.0	58.1 a	9.8 b	175.7 a	15.0 ab	-1.7 a	7.1 b
91.7	110.0	58.9 a	7.5 c	173.9 a	16.4 b	-2.0 a	6.8 ab
104.2	125.0	59.9 b	6.0 c	171.3 b	18.1 c	-0.8 a	7.5 c

[a] Mean values for 18 observations (3 replications, pooled for all polydextrose and leavening levels); means in the same column with same letter are not significantly different ($p \leq 0.05$). Procedures for physical measurements are given in Appendix, Table A-5.

[b] Flour weight basis; ml amount is based on total batter weight.

Kamel and Washnuik (1983) similarly reported specific gravities near 0.60 for their shortening-free cakes, and even attained values near 0.44. Smith (1984) replaced shortening with N-Flate^{TM}, as in the current study, and reported batter densities of 0.64. Hess and Setser (1983) substituted aspartame and/or fructose for sucrose and obtained specific gravity values of 0.73-0.77. Redlinger (1986) found that specifc gravity of shortening creams fluctuated among treatments with no consistent pattern. She attributed variations to sweetener weight and bulk density rather than amount of air incorporated, and cautioned that comparisons of specific gravities of nutritive sweetener systems to those with intense sweeteners may not be appropriate.

Leavening

As anticipated, level of leavening affected volume significantly (Table 10). The higher level of leavening used (9g, tbw) produced cakes with higher volumes than 8g leavening agent. Mean volume for the former was 175.8 cc compared to 171.9 cc for the latter. Though leavening did not influence shrinkage significantly, cakes with the higher leavening level tended to shrink more. Miller and Trimbo (1965) found that decreased leavening had only small effects on batter consistency but did improve the final cake. They concluded that the leavening agent did not affect starch gelatinization but decreased cake internal pressure, resulting in less strain on the structure during baking.

Only one ingredient interaction was noted; polydextrose by water caused variations in shrinkage significant at the 0.05% level. The LSM for shrinkage according to treatments are given in Table 13.

Sensory

Polydextrose

F-values and probabilities from ANOV for sensory characteristics of cakes are shown in Table 14. As shown in Table 15, increased levels of polydextrose increased gumminess and density ($p < 0.001$), maximum and residual sweetness ($p < 0.01$), and maximum bitterness ($p < 0.05$). Polydextrose had no effect on residual bitterness or cell uniformity.

Sweetener level was not varied in this study, but perceived maximum and residual sweetness tended to be greatest at the highest level of polydextrose. Maximum sweetness scores of the reduced-calorie cakes were similar to those for the standard layer and pound cakes.

Sensory density was significantly higher (Table 15) and similar to the density of pound cake with 75g (tbw) polydextrose; 85 and 95g polydextrose levels produced cakes with lower ($p < 0.05$) densities which were comparable to standard layer cake. All cakes were evaluated as more gummy than standard layer and pound

Table 13-Least squares means[a] for shrinkage[b] of cakes with varied levels of polydextrose and water

Least squares mean	Levels[c] Polydextrose	Water
6.17 a	85	80
6.33 a	95	80
6.50 ab	95	110
6.67 ab	75	110
6.67 ab	95	95
7.17 b	75	80
7.17 b	75	95
7.17 b	95	125
7.25 c	85	125
7.33 cd	85	95
7.33 cd	85	110
8.0 d	75	125

[a] Three replications; means in the same column with same letter are not significantly different ($p \leq 0.05$).

[b] Determined by AACC Method 10-91.

[c] Gram amount of total batter weight.

Table 14–F-values and probabilities[a] from analysis of variance for sensory measurements[b] of yellow cakes

Source of variation	Degrees of freedom	Sensory parameters						
		Cell uniformity	Density	Gumminess	Maximum bitterness	Residual bitterness	Maximum sweetness	Residual sweetness
Polydextrose (P)	2	0.15 NS	11.95 (.0001)	10.61 (.0002)	4.95 (.0113)	1.78 NS	6.71 (.0028)	6.66 (.0029)
Water (W)	3	5.57 (.0024)	1.54 NS	6.69 (.0008)	1.49 NS	0.67 NS	0.56 NS	0.22 NS
P × W	6	0.31 NS	0.13 NS	0.63 NS	0.40 NS	0.64 NS	2.44 (.0395)	2.32 (.0487)
Leavening agent (L)	1	0.26 NS	1.55 NS	4.92 (.0315)	2.39 NS	0.58 NS	1.93 NS	1.31 NS
P × L	2	0.68 NS	2.23 NS	0.15 NS	0.07 NS	0.11 NS	0.93 NS	2.51 NS
W × L	3	1.38 NS	2.20 NS	0.49 NS	0.50 NS	0.11 NS	0.13 NS	0.25 NS
P × W × L	6	1.22 NS	0.27 NS	1.39 NS	0.62 NS	0.46 NS	0.56 NS	0.63 NS
Error	23							

---

[a] Probabilities are given in parentheses; NS = not significant.

[b] Based on descriptive, computerized, unstructured linear scaling.

Table 15-Influence of polydextrose on sensory characteristics[a] of yellow cakes

Polydextrose		Sensory parameters				
%, fwb[b]	total g[b]	Cell uniformity	Density	Gumminess	Maximum bitterness	Residual bitterness
62.5	75	39.0 a	49.5 a	18.9 a	30.8 a	20.0 a
70.8	85	39.7 a	46.4 b	20.7 a	32.0 a	20.4 a
79.0	95	39.6 a	44.8 b	23.9 b	34.4 b	22.0 a
Standard cake scores[c]						
Layer		47.0	41.0	5.0	4.0	3.0
Pound		49.0	56.0	11.0	3.0	3.0

[a] Mean values for 24 observations (3 replications, pooled for all water and leavening agent levels); means in the same column with same letter are not significantly different ($p \leq 0.05$). Sixty-point computer scale with 60 highest or most intense and 0 lowest or least intense.

[b] Flour weight basis; g based on total batter weight.

[c] Consensus values assigned during the training period for cake mixes (Betty Crocker, General Mills) prepared according to package directions.

cakes, but gumminess was highest ($p < 0.05$) with 95g polydextrose. The highest level of polydextrose also resulted in greatest maximum bitterness. Though the trends were not significant, intensities of both bitterness and sweetness were enhanced with 95g polydextrose.

Gumminess

Water influenced gumminess and cell uniformity at the 0.001 and 0.01% levels, respectively (Table 14). Leavening likewise had a significant effect on gumminess ($p < 0.05$).

Gumminess was a defect of the experimental cakes. Miller and co-workers (1967) found that cakes tended to form gummy layers when greater than normal amounts of water were used. Both these authors and Mizukoshi (1983a) attributed gumminess to foam instability and drainage of liquid. Moisture may transfer from one section of cake to another because of temperature gradients in the batter during baking (Miller et al., 1967). In the current study, cakes did not form discrete gummy layers, but had an overall gummy mouthfeel, and were easily compressed or sticky. Szczesniak (1963) defined gumminess as "the energy required to disintegrate a semi-solid food product to a state ready for swallowing" and related the characteristic to the primary parameters of hardness and cohesiveness. Gumminess may have resulted from the hygroscopic nature of the polydextrose. Informal observations indicated that cakes absorbed moisture from the atmosphere and became increasingly gummy upon storage, particularly when sealed in plastic wrap.

Tunnelling, another defect of the cakes, may have been due to the rapid setting of the crust which prevented escape of large air bubbles. Cake crusts were very firm, almost hard, upon removal from the oven but became softer upon storage.

Interactions

No significant differences were noted for polydextrose by leavening, water by leavening, or polydextrose by water by leavening agent interactions. However, variations in polydextrose by water were responsible for intensities of maximum and residual sweetness. The LSM for these attributes are shown in Tables 16 and 17.

Water

Water's influence on sensory attributes is presented in Table 18. The ANOV results verified the RSM experiments where water affected cell size; water's influence here was indicated by cell uniformity. The lower water level (80 ml,tbw) produced more uniform cells than 110 or 125 ml water treatments. The highest level of water used, 125 ml, resulted in the gummiest cakes. Water did not significantly influence density or maximum or residual

Table 16-Least squares means[a] for maximum sweetness[b] of cakes with varied levels of polydextrose and water

Least squares mean	Levels[c]	
	Polydextrose	Water
31.57 a	75	80
32.83 ab	75	125
33.60 abc	85	110
34.90 bcd	85	95
35.60 bcd	85	80
35.60 bcd	85	125
35.73 bcd	75	110
35.77 bcd	95	110
36.03 cd	75	95
36.77 d	95	95
37.10 d	95	125
37.37 d	95	80

---

[a] Three replications; means in the same column with same letter are not significantly different ($p \leq 0.05$).

[b] Sixty-point computer scale with 60 highest or most intense and 0 lowest or least intense.

[c] Gram amount based on total batter weight.

Table 17-Leastsquares means[a] for residual sweetness[b] of cakes with varied levels of polydextrose and water

	Levels[c]	
Least squares mean	Polydextrose	Water
18.67 a	75	80
19.27 ab	75	125
20.17 abc	85	110
21.70 abcd	85	95
22.33 bcd	85	80
22.53 bcd	75	95
22.77 cd	85	125
22.93 cd	75	110
23.20 cd	95	95
23.33 cd	95	110
24.17 d	95	80
24.30 d	95	125

---

[a] Three replications; means in the same column with same letter are not significantly different ($p \leq 0.05$).

[b] Sixty-point computer scale with 60 highest or most intense and 0 lowest or least intense.

[c] Gram amount, based on total batter weight.

Table 18-Influence of water on sensory characteristics[a] of yellow cakes

Water		Sensory parameters				
% fwb[b]	total g[b]	Cell uniformity	Density	Gumminess	Maximum bitterness	Residual bitterness
66.7	80	42.4 a	47.8 a	18.6 a	33.0 a	21.1 a
79.2	95	40.6 ab	46.7 a	20.7 a	33.5 a	21.4 a
91.7	110	37.8 bc	45.6 a	21.0 a	32.4 a	21.0 a
104.2	125	36.9 c	47.5 a	24.3 b	30.8 a	19.7 a
Standard cake scores[c]						
Layer		47.0	41.0	6.0	4.0	3.0
Pound		49.0	56.0	11.0	3.0	3.0

[a] Mean values for 18 observations (3 replications, pooled for all polydextrose and leavening levels); means in the same column with same letter are not significantly different ($p \leq 0.05$). Sixty-point computer scale with 60 highest or most intense and 0 lowest or least intense.

[b] Flour weight basis; g based on total batter weight.

[c] Consensus valuea assigned during the training period for cake mixes (Betty Crocker, General Mills) prepared according to package directions.

bitterness.

Leavening

Table 19 compares the effects of 8 and 9g (tbw) leavening agent. The higher level resulted in less gumminess than 8g leavening; other sensory factors were unaffected by this variable.

Cake Formulas and Caloric Values

Mean values for physical and sensory characteristics of all cakes are listed in the Appendix, Tables A-9 and A-10. Cakes with characteristics most comparable to the standard layer cake were attained by several combinations: 75 or 85g polydextrose with 80 or 95g water and 9g leavening agent were rated similarly.

Caloric contents of the experimental cakes are given in Table 20. Most of the caloric reduction was due to the removal of shortening and sugar. Part of the decrease was due to the high volume of air incorporated with N-Flate^{TM}. According to the manufacturer, batter required to produce a standard-sized cake can be reduced by 10%. High specific volumes result in fewer calories per volume of cake. In addition, the high levels of water incorporated decreased calories. Further caloric reduction resulted from use of polydextrose. Polydextrose contributed only 1 kcal/g, compared to 9 kcal/g for fat and 4 kcal from sugar. The final cakes, which contained about half the calories of sucrose control cakes, can be classified as

Table 19- Influence of leavening agent on sensory[a] characteristics of yellow cake

Leavening		Sensory parameters				
% fwb[b]	total g[b]	Cell uniformity	Density	Gumminess	Maximum bitterness	Residual bitterness
6.7	8	39.2 a	47.4 a	22.2 a	31.7 a	20.5 a
7.5	9	39.7 a	46.4 a	20.1 b	33.2 a	21.1 a
Standard cake scores[c]						
Layer		47.0	41.0	6.0	4.0	3.0
Pound		49.0	56.0	11.0	3.0	3.0

[a] Mean values for 36 observations (3 replications, pooled for all water and polydextrose levels); means in the same column with same letter are not significantly different ($p \leq 0.05$). Sixty-point computer scale with 60 highest or most intense and 0 lowest or least intense.

[b] Flour weight basis ; g based on total batter weight.

[c] Consensus values assigned during the training period for cake mixes (Betty Crocker, General Mills) prepared according to package directions.

Table 20 - Caloric content[a] of experimental yellow cake

Ingredient	Kcal/g	x	g	=	Kcal in cake
N-Flate™	5.1		27.0		137.7
Polydextrose	1.0		85.0		85.0
Eggs, whole	1.6		100.0		160.0
Flour	3.7		120.0		444.0
Egg white, dried	3.5		1.5		5.3
Leavening, water, sweetener, flavor	0.0		105.5		0.0
	TOTALS:		439.0 g		832.0 kcal

Weight of batter per cake = 300 g = 568.6 kcal = 189.5 kcal/100g

Weight of cake after baking = 276 g = 206.0 kcal/100g

Caloric content of unfrosted sucrose control cake = 366 kcal/100g[b]

Caloric content = $\frac{206.0}{366.0}$ x 100 = 56.3% = 43.7% caloric reduction

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[a] FDA defines low-calorie and reduced-calorie as follows:
Low-calorie: product contains 40 calories or less per serving and 0.4 cal or less per gram.

Reduced-calorie: product must have caloric reduction of 33 1/3% and at least 25 fewer calories per serving than the food it replaces, while maintaining equivalent nutritional value.

[b] From USDA Handbook No. 8.

"reduced-calorie". Other investigators (Freeman, 1982; Koser and Andres, 1983; Smith, 1984; Osberger and Olinger, 1985) have reported caloric reductions of 33% in shortening-free cakes.

Proposed Mechanisms of Cake Functionality

Sucrose and shortening functionality were replaced in this study by bulking agents, emulsifiers, modified starch, gums and intense sweeteners. Therefore, not all of the mechanisms and ingredient interactions involved in classical cake baking would apply here. The following principles are proposed as explanations for the successful development of reduced-calorie layer cakes:

1) Batter was viscous and trapped air bubbles in the foam, producing high volume (Handleman et al., 1961; Pyler, 1979; Mizukoshi, 1983b). The guar gum in the N-Flate TM may have increased viscosity and helped form interfacial films with proteins to allow a greater degree of aeration (Glicksman, 1969; Friberg, 1976; Sharma, 1981; Lee and Hoseney, 1982). Gum interacts with milk protein, flour gluten, and particularly with egg albumen to increase structural strength (Morris, 1981; Kelco, undated). Emulsifiers increase viscosity and limit the number of bubbles which reach critically buoyant size and escape, and could have enhanced air retention. Gums retain water to counteract the viscosity decrease with

increasing temperature, thus retaining gas until the cakes set.

3) Starch gelatinization was delayed by cake ingredients. Gums lowered the temperature of the initial increase in batter viscosity and reduced starch gelatinization (Watson and Johnson, 1965). Emulsifiers can delay starch gelatinization by complexing with the amylose portion of the starch (Moncrieff, 1970; Longley and Miller, 1971; Osman, 1975; Krog, 1977). Hydroxyl groups on the emulsifiers bind water so insufficient water is available for complete starch gelatinization to occur (Ebeler and Walker, 1984). Polydextrose could have behaved like sugar in delaying gelatinization of the starch (Kim et al., 1986). N-Flate™ contained pregelatinized starch, which might have affected final cake setting temperature.

4) Emulsifiers in N-Flate™ adsorbed at interfacial boundaries to stabilize the foam (Friberg, 1976). The N-Flate™ contained a "well-balanced emulsifier blend" (National Starch and Chemical Co., 1982) but the specific emulsifiers used in the matrix remain unknown. The improved efficiency of a multiple-emulsifier system was described by Buddemeyer et al., (1962); Wootton et al., 1967; MacDonald, 1968; Krog, 1977 and Knightly, 1981; such synergy could have improved cake texture in the current study. The emulsifiers in N-Flate™ were probably α -tending, possibly PGMS and polysorbate 60 or SSL. If

they were α-tending, instead of decreasing interfacial tension to allow emulsion formation, they would have increased tension and formed thick, strong barriers or films (Wootton et al., 1967) and functioned as an anti-antifoaming agent (MacDonald, 1968; Krog, 1977)

5) The gum probably improved appearance, texture and eating qualities of the cakes. Gums have been shown to decrease cracking, enhance symmetry and volume, produce uniform texture and grain, reduce cell size, create a silky crumb and increase moistness (Young and Bayfield, 1963; Lee and Hoseney, 1982; Kelco, undated).

6) Polyvalent ions from flour, leavening, milk and salt might have interacted with acidic lipids in the emulsifiers to stabilize interfaces (Howard, 1972).

7) Lipids in egg yolk and flour would have enhanced cake emulsification and stability (Howard, 1972; Yamazaki and Kissell, 1978; Chung and Pomeranz, 1981).

8) The soluble proteins, particularly from eggs, denatured to form interfacial membranes that stabilized cake foam (Phillips, 1981; Townsend and Nakai, 1983; Poole, 1984). Proteins from egg, milk and flour coagulated upon heating to set the cake structure.

Future Studies

Though this study did not include flavor optimization, such information is needed. Two currently allowed intense sweeteners, saccharin and aspartame, were used in the cakes. Panelists noted, as expected, the bitter aftertaste of saccharin. Stein (1966) attributed bitter aftertaste to imbalances in the total flavor system. Such factors as sweetness-acid ratios, salt additives, type of buffer salts, flavor potentiation, and composition of flavor all should be considered in the development of the total flavor sensation for a product containing non-caloric sweeteners. Stein emphasized that when all flavor components are in balance, the flavor of such products should be equally acceptable as those sweetened with carbohydrates.

Aspartame, which decomposes upon heating, does not produce bitter or off-flavors, but a loss of sweetness. Homler (1984) stated that simply adding extra aspartame to the batter will compensate for that which breaks down during baking.

Further investigations are needed to optimize the sweetener levels and develop flavor systems for the reduced-calorie cakes to make them marketable. Several ingredients, developed specifically for use with reduced-calorie products, may facilitate flavor optimization. Globe Extracts Company has designed a line of flavoring systems for use with polydextrose and aspartame. To offset the sweetness loss when sugar is replaced, the flavors have a sweeter flavor profile then conventional flavors (LaBell, 1985). A flavor potentiator, marketed by

Ottens Flavors, enhances sweetness at reduced sugar levels (Hannigan, 1979). Aspartame itself has been shown to enhance, or be enhanced by, fruit flavors (Baldwin and Korschgen, 1979; Hess and Setser, 1983).

Follow-up studies should evaluate the tolerance of the optimized cake formulas to variations in formulation and preparation. According to Miller and co-workers (1967), most commercial yellow cake mixes specify use of two fresh eggs and 1 1/3 cups (315 ml) water, and mixing 2-4 min on medium speed. When excess water is added, gummy layers form (Miller et al., 1967) and over- or undermixing results in cakes with poor volume and texture. Some testing indicates the experimental cake formulations from this study will tolerate alterations in water level, mixing speed and time, batter temperature, pan type and size, and baking time.

A final possibility for further investigation is grinding or finishing of the cake mix. Lee and Hoseney (1982) found grinding the shortening-emulsifier system of a cake mix with the dry ingredients resulted in decreased specific gravity and increased volume. The grinding could, likewise, enhance the reduced-calorie cake mix prepared in this study.

SUMMARY AND CONCLUSIONS

Polydextrose was the most influential factor affecting cake quality, followed by water. In RSM analysis, all significant ingredient effects were linear. During ANOV validation, polydextrose level was related inversely to specific gravity, volume, symmetry and shrinkage. The highest level of polydextrose (95g, tbw) resulted in highest gumminess, lowest density, and greatest maximum sweetness, residual sweetness and maximum bitterness of all cakes.

Water increased specific gravity; high water levels (125 ml, tbw) increased gumminess and reduced cell uniformity. The higher (9 g, tbw) leavening level increased volume and decreased gumminess more than 8g leavening treatments. The only ingredient interaction was polydextrose by water, which influenced shrinkage and the intensity of maximum and residual sweetness.

The two defects of the cakes were overall gumminess and tunnelling. The former was enhanced by high water levels and the latter was enhanced by low levels of water. Several combinations of ingredient levels produced cakes comparable to the standard layer cake control. The formulas optimized in this study are free of sucrose, fructose and shortening and are low in cholesterol and sodium. The reduced-calorie cakes compare favorably with dietetic cakes currently on the market. Faculty, staff and students have expressed great interest in the reduced-calorie cakes; informal comments and evaluations indicate the cakes are of acceptable quality. Formal follow-up consumer acceptance testing would reveal the marketability of the optimized cakes.

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"TETELESTAI!"

APPENDIX

Table A-1- Preliminary Investigations

Cakes, prepared according to AACC method 10-90 (AACC, 1984), were modified for use with 6" (15.2 cm) pans. Mixing procedures, pan batter amounts and baking times were varied.

Mixing Methods

Creaming, alternate addition of dry and liquid ingredients and prewhipping egg whites were steps added to the original 2-stage AACC plan. However, the additional steps had minimal effect on volume or texture. Since the product was intended for consumer home use, development of a one-stage process similar to that for commercial boxed mixes seemed appropriate. The conventional method finally selected involved blending of dry ingredients, addition of eggs and water and beating at high speed. Several speed settings were evaluated, but with these ingredients, the recommended (Anon., 1983) high speeds seemed more effective than low speeds for incorporating air and developing the batter structure.

Baking

Shiny pans produced higher volume, finer textured, less browned cakes than the dark pans and were selected for use in this study. The quantity of batter to be placed in 6" pans was calculated volumetrically from the amount designated for 8" pans in AACC method 10-90.

8 x 1 1/3 " = 20.3 x 3.4 cm
6 x 2 " = 15.2 x 5.1 cm

	8"	6"
$\frac{\text{diameter}}{2}$ = radius =	$\frac{20.3}{2}$ = 10.2 cm	$\frac{15.2}{2}$ = 7.6 cm
radius ^{2} = r^2 =	104.0 cm^2	57.8 cm^2
r^2h = volume =	1110.3 cm^3	925.6 cm^3

$$\text{Ratio } \frac{6''}{8''} = \frac{925.6}{1110.3} \text{ cm}^3 \times 100 = 83.3\%$$

Therefore, since 425 g was recommended for an 8" pan, 83.3% of that amount, or 354.3 g, should be suitable for a 6" pan.

As cakes containing gums, bulking agents and emulsifiers were baked, gummy layers formed under the top crust and at the bottom, or cakes dipped in the center. A non-ingredient cause of gumminess may be excess batter for size of pan: in this investigation, the calculated batter amount might have been inaccurate. Several other batter levels were tested: 263 g, 300 g, 320 g, and 339 g approximately 75, 85, 90 and 95%, respectively, of the calculated amount. Based on textural and volumetric evaluations, 320 g batter was selected as the level for cakes.

Baking times

Baking times were altered as the cake formula developed. Preliminary baking times ranging from 16-38 minutes were assessed before a time of 30 minutes was selected for the RSM phase.

Ingredient variables

A large number of ingredients were incorporated at varying levels and combinations to determine which might be effective in producing reduced-calorie cakes. Ingredients evaluated included:

Emulsifiers

Sodium stearoyl lactylate (SSL); Emplex, PATCO, Inc.
Top-Scor (sodium and calcium stearoyl-2-lactylate, lactylic stearate); Breddo, Inc.
Mono- and diglycerides; Batter-lite, Inc.
Cake Short (polysorbate 60, propylene glycol, glyceryl monostearate, lactic and citric acids, cream of tartar, CMC, methyl and propyl paraben; Davis Flavor Corp.
Polysorbate 60 (Durfax); Durkee Corp.

Matrix system

N-Flate TM; National Starch and Chemical Co.

Bulking agents

Crystallline cellulose (Solka-floc BW-200 and BW-300); James River Corp.
Methylcellulose powder (Methocel A15); Dow Chemical Co.
Polydextrose (powder); Pfizer Chemical Co.
Maltodextrin (Maltrin M-040, M-100, M-150, M-500); Grain Processing Corp.
Corn syrup solids (Maltrin M-200); Grain Processing Corp.
Modified food starches (H-50, Baka Snak); National Starch and Chemical Co.
Tapioca Dextrin (K4484); National Starch and Chemical Co.

Leavening agents

Sodium aluminum phosphate (Levair); Stauffer Chemical Co.
Sodium aluminum pyrophosphate; Stauffer Chemical Co.
Monocalcium phosphate; Stauffer Chemical Co.
Sodium aluminum sulfate and calcium acid phosphate

(Calumet); General Foods Corp.
Sodium bicarbonate; Arm and Hammer.

Sweeteners

Sucrose (crystalline, granulated); C & H.
Fructose (liquid); Batterlite-Whitlock.
Fructose (crystalline); Sigma Chemical Co.
Sodium saccharin; Alberto-Culver.
Aspartame; NutraSweet Co.
Acesulfam K; Hoechst.
Calcium cyclamate; Abbott Laboratories.

Egg white, dried

Plain; Milton G. Waldbaum Co.
1% Sodium lauryl sulfate (SLS) added; Milton G. Waldbaum.

Miscellaneous ingredients
Nonfat dry milk; Carnation Co.
Shortening; Crisco

Specific combinations of these ingredients are shown in the Appendix, Table A-2.

As a result of these preliminary investigations, a basic cake formula was created as a starting point for the RSM optimization:

Ingredient	%, flour weight	g, total weight
Cake flour	100.0	120.0
Egg white, dried	1.3	1.5
Vanilla, powdered	0.8	1.0
Salt	1.7	2.0
Sodium saccharin	0.4	0.5
Whole eggs, fresh	83.3	100.0
Polydextrose	75.0	90.0
N-Flate matrix	20.0	24.0
Baking powder, dbl. actg.	7.5	9.0
Water, distilled	120.0	144.0
Fructose, crystalline	17.5	21.0

The last five ingredients were selected as those most influential on texture and were optimized by RSM.

Table A- 2 - Qualitative ingredient combinations evaluated in preliminary phase of study

	Ingredient																															
Ingredient	Sodium stearoyl lactlt.	Mono-diglycerides	Batterlite™	Cake Short™	Polysorbate 60	N-Flate™	Crystalline cellulose	Methycellulose	Polydextrose	Maltodextrins	H-50 starch	Baka Snak™ starch	Tapioca dextrin	Corn syrup solids	Guar gum	Xanthan gum	Sodium alum. phosphate	Sodium alum. pyrophos.	Monocalcium phosphate	Dbl-actg baking pwdr	Sodium bicarbonate	Sucrose	Fructose, liquid	Fructose, crystalline	Sodium saccharin	Aspartame	Acesulfame K	Calcium cyclamate	Egg white, dried	Egg white, dry, SLS	Dry milk, nonfat	Shortening, emulsified
Sodium stearoyl lactylate								X												X		X							X		X	X
Mono-diglycerides							X		X							X	X				X										X	X
Batterlite™				X			X		X								X				X								X		X	X
Cake Short™							X		X								X				X								X		X	X
Polysorbate 60		X					X		X								X				X								X		X	X
N-Flate™							X		X											X									X			
Crystalline cellulose						X			X											X									X			
Methylcellulose																				X		X							X		X	X
Polydextrose						X														X									X			
Maltodextrins						X														X									X			
H-50 starch						X														X									X			
Baka Snak™ starch						X														X									X			
Tapioca dextrin						X														X									X			
Corn syrup solids						X														X									X			
Guar gum	X																			X		X							X		X	X
Xanthan gum																																
Sodium aluminum phosphate						X			X												X								X			
Sodium alum. pyrophosphate						X			X												X								X			
Monocalcium phosphate						X			X									X											X			
Double-acting baking pwdr						X			X	X													X						X			
Sodium bicarbonate						X			X								X		X										X			
Sucrose									X											X									X		X	X
Fructose, liquid						X														X									X			
Fructose, crystalline						X			X											X		X										
Sodium saccharin						X			X											X							X			X		
Aspartame						X			X											X							X			X		
Acesulfame K						X			X											X								X	X			
Calcium cyclamate						X			X											X					X				X			
Egg white, dried					X	X			X											X												
Egg white, dry, SLS added						X			X											X												
Dry milk, nonfat					X				X											X												X
Shortening, emulsified						X	X		X																							

Table A-3 - List of ingredients, suppliers and lot numbers.

<u>Cake flour</u>

SnoSheen high-ratio cake flour
10.2% protein (N x 5.7), 1.9% fat, 14.3% moisture, 1.9% ash
Lot # F5125 Pillsbury Minneapolis, MN

<u>Polydextrose bulking agent</u>

Polydextrose powder
1 kcal/g
Lot # G56130-S6810 (RSM optimization phase)
V5X 290 (ANOV validation phase)
Pfizer Chemical Co. New York, NY

<u>N-Flate matrix system</u>

Matrix system containing pregelatinized waxy maize starch, emulsifiers, and guar gum in a skim milk powder base
5.1 kcal/g
Lot # 163202 KD6733 (RSM optimization phase)
183218 KD6732 (ANOV validation phase)
National Starch and Chemical Co. Bridgewater, NJ

<u>Fructose</u>

Pure crystalline, anhydrous β-D fructose # F-0127
Lot# 14F-0396
Sigma Chemical Co. St. Louis, MO

<u>Vanilla powder</u>

Vanilla N/A SD Flavor #3451
no lot # given
Warner Jenkinson St. Louis, MO

<u>Sodium saccharin</u>

#2223
no lot # given
Alberto-Culver Co. Melrose Park, IL

Baking powder

Calumet
Commercial double-acting, sodium aluminum sulfate and calcium acid phosphate
Lot # 4-275 (RSM optimization phase)
5-297 (ANOV validation phase)
General Foods Corp. White Plains, NY

Dried egg whites

Plain, spray-dried standard albumen
total egg solids: 92.0% min
moisture: 8.0% max
fat: 0.1% max
protein: 80.0% min
pH: 7.0 + 5
granulation: #60 US Sieve
reducing sugars: 0.15% max

Lot # 291-4-4 (RSM optimization phase)
340-5-4 (ANOV validation phase)
Milton G. Waldbaum Co. Wakefield, NE

Color

Orange lake blend #9815
includes FD&C Yellow #5 and 6 lake, FD&C Yellow #5
Lot # 4018-C
Warner Jenkinson St. Louis, MO

Whole eggs

Fresh, Grade A
obtained weekly from local market

Table A-4 - Response surface methodology cake formulas

Sample number	N-Flate™		Water		Polydextrose		Leavening agent		Fructose	
	gms	fwb[a]	gms	fwb	gms	fwb	gms	fwb	gms	fwb
1	21	17.5	120	100.0	75	62.5	7.5	6.25	31.5	26.25
2	27	22.5	120	100.0	75	62.5	7.5	6.25	10.5	8.75
3	21	17.5	168	140.0	75	62.5	7.5	6.25	10.5	8.75
4	27	22.5	168	140.0	75	62.5	7.5	6.25	31.5	26.25
5	21	17.5	120	100.0	105	87.5	7.5	6.25	10.5	8.75
6	27	22.5	120	100.0	105	87.5	7.5	6.25	31.5	26.25
7	21	17.5	168	140.0	105	87.5	7.5	6.25	31.5	26.25
8	27	22.5	168	140.0	105	87.5	7.5	6.25	10.5	8.75
9	21	17.5	120	100.0	75	62.5	10.5	8.75	10.5	8.75
10	27	22.5	120	100.0	75	62.5	10.5	8.75	31.5	26.25
11	21	17.5	168	140.0	75	62.5	10.5	8.75	31.5	26.25
12	27	22.5	168	140.0	75	62.5	10.5	8.75	10.5	8.75
13	21	17.5	120	100.0	105	87.5	10.5	8.75	31.5	26.25
14	27	22.5	120	100.0	105	87.5	10.5	8.75	10.5	8.75
15	21	17.5	168	140.0	105	87.5	10.5	8.75	10.5	8.75
16	27	22.5	168	140.0	105	87.5	10.5	8.75	31.5	26.25
17	18	15.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
18	30	25.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
19	24	20.0	96	80.0	90	75.0	9.0	7.5	21.0	17.5
20	24	20.0	192	160.0	90	75.0	9.0	7.5	21.0	17.5
21	24	20.0	144	120.0	60	50.0	9.0	7.5	21.0	17.5
22	24	20.0	144	120.0	120	100.0	9.0	7.5	21.0	17.5
23	24	20.0	144	120.0	90	75.0	6.0	5.0	21.0	17.5
24	24	20.0	144	120.0	90	75.0	12.0	10.0	21.0	17.5
25	24	20.0	144	120.0	90	75.0	9.0	7.5	0.0	0.0
26	24	20.0	144	120.0	90	75.0	9.0	7.5	42.0	35.0
27	24	20.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
28	24	20.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
29[b]	24	20.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
30[b]	24	20.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
31[b]	24	20.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5
32[b]	24	20.0	144	120.0	90	75.0	9.0	7.5	21.0	17.5

[a] Flour weight basis.

[b] Omitted since identical to 27 and 28.

Table A-5 - Procedures for physical measurements of cakes

Specific Gravity

Specific gravity was used to assess the amount of air incorporated into and held by the batter. The greater the amount of air, the lower the specific gravity. The method of Campbell et al. (1979) was followed. Specifc gravity was obtained gravimetrically by dividing the weight of the batter by the weight of an equal volume of water:

$$\text{Specific Gravity} = \frac{(\text{wt of cup + batter}) - \text{wt of cup}}{(\text{wt of cup + water}) - \text{wt of cup}}$$

Batter pH

Twenty five g batter were mixed with 50 ml distilled water in a 100 ml glass beaker. The beaker contents were stirred with a glass rod. Two readings were obtained on the Corning model 140 pH meter and an average of the readings recorded.

Cake pH

Twelve and a half g crust-free crumb were mixed with 50 ml distilled water in a 100 ml glass beaker. The beaker conntents were stirred with a glass rod. Two readings were obtained on the Corning model 140 pH meter and an average of the readings recorded.

Batter Water Activity (Aw)

For products with an aw below .95, saturated solutions are used as standards; those with Aw above .95 are compared to molal solutions. The batters and cakes in this study were determined to have Aw's ranging from .93 to .97 so the molal scale was selected as most appropriate. Four standards were used: 0.1, 0.5, 1.0 and 2.0 molal NaCl.

One-half ml standard solution or approximately 1 ml batter was placed in each sample cup of the Decagon NT-3 Nanovoltmeter Thermometer water activity meter. Microvolt readings were taken on the standards and duplicate samples. A standard curve was drawn, microvolt readings plotted, and Aw of samples were obtained from the graph. An example of an Aw graph is included at the end of this section.

Cake Water Activity

Sample cups were packed approximately 2/3 full with a metal spatula and tamped to leave a "V"-shaped indentation in the center. This was to allow the meter's thermocouple to take readings without actually contacting the cake. Standard solutions and duplicate samples were read as for the batter. A standard curve was prepared, microvolt readings plotted and Aw of samples obtained from the graph.

Volume, Symmetry, Uniformity and Percentage Shrink

Volume, symmetry, uniformity and shrinkage were determined by AACC method 10-91 (AACC, 1984) adapted for 6"cakes (Appendix, A-1).

Batter Viscosity

Hundred ml beakers were filled with batter; care was taken to avoid large pockets of air. Viscosity was measured on a Viscometers UK Ltd. viscometer, model RV-8-0 with a #6 spindle rotating at 5 rpm. Readings for four replications of each treatment were recorded as centipoises (cps) and averaged.

CAKES: 21 27 DATE: 1-22-86

PLOT	AW	mV
0.1	.9966	17.2
0.5	.9835	22.6
1.0	.9668	29.8
2.0	.9318	45.0

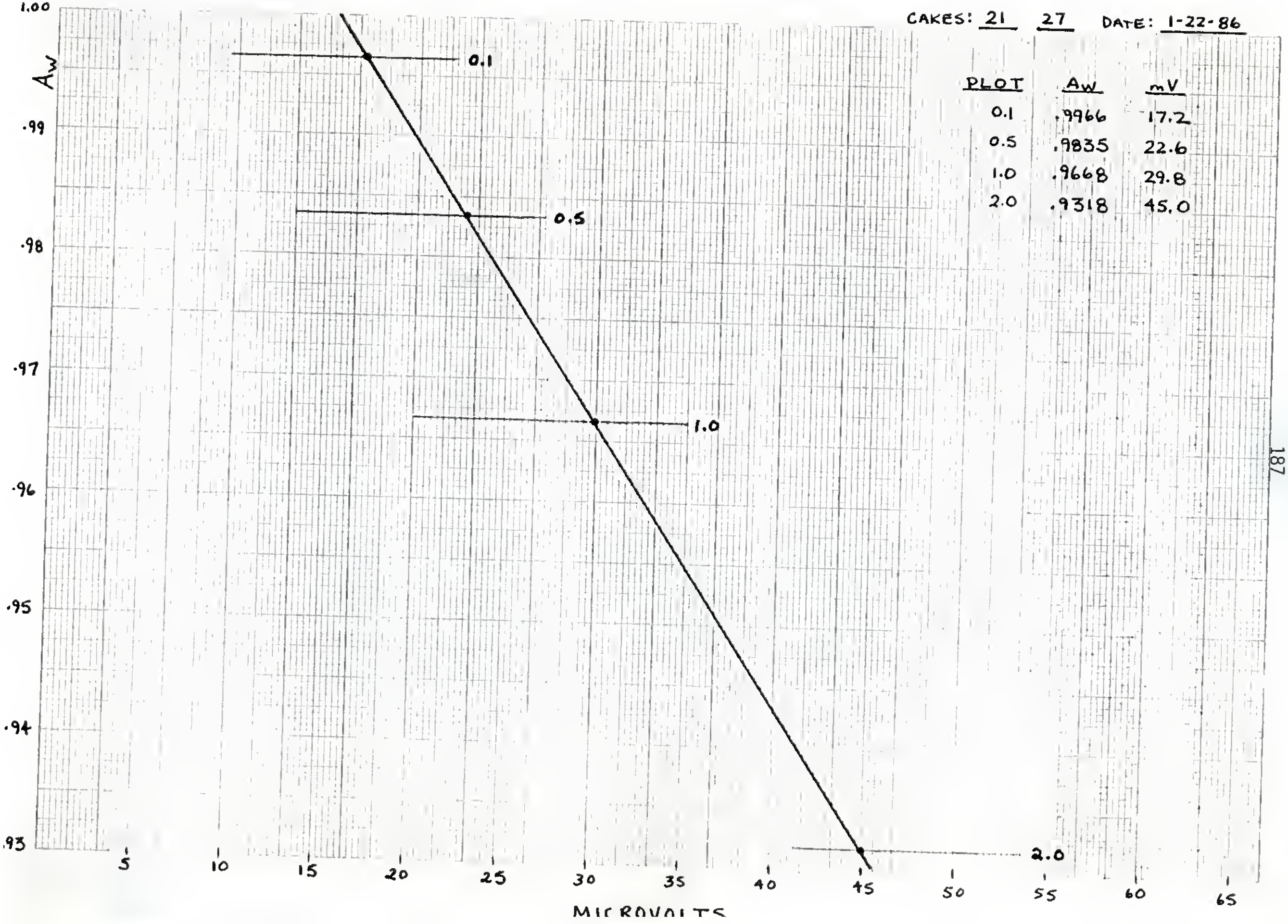

Table A-6 - Training of sensory panel for validation phase

OBJECTIVES of panel training were to insure that panelists

* understood the basic goals of the study
* understood the characteristics being evaluated and the terms used to describe them
* understood the method of scoring
* were comfortable with the computerized scoring system
* were familiar with the experimental and control cakes and could evaluate them consistently

Day 1

1. Discussed scope of experiment, including objectives, sweetener safety and market potential of the cakes. Emphasized importance of panelists' role in success of the study.
2. Examined sample cakes.
3. Demonstrated use of computer and acquainted panelists with scoring system.

Day 2

1. Panelists read and signed consent forms.
2. Discussed panel schedule and established time table.
3. Gave preliminary score card and discussed meaning of terms.
4. Panelists tasted a series of saccharin (0.01, 0.02, 0.03 and 0.05 w/v) and aspartame (0.02, 0.03, 0.05 and 0.10 w/v) solutions to determine which level of sweetener was considered high.
5. Panelists evaluated control angel, layer and pound cakes (Betty Crocker, General Mills). Selected pound and layer cakes as anchors for comparison and assigned standard values to these references, given on score card in Appendix, Form C.
6. Panelists evaluated experimental cakes.
7. Panelists assessed sweetness and bitterness:
   "Maximum" was defined as the most intense level perceived during oral manipulation.
   "Residual" was defined as the quality lingering 30 sec after swallowing.
8. Panelists evaluated two experimental cakes and standard layer and pound cakes with score cards and on the computer.

Day 3

1. Panelists discussed sample size and determined portion necessary for evaluation.

2. Panelists discussed and refined methods for tasting, rinsing and cleansing. Discussed fatiguing and rest time needed between samples to eliminate cumulative effect or carry over.
3. Panelists discussed positioning of standard layer and pound cakes on the scales. Determined that standard references should be available for comparison each session.
4. Panelists evaluated four experimental cakes with score cards and on the computer. After further group discussion and clarification of terms, test cakes were reevaluated.
5. Analyzed data to review consistency among panel members and determine panelists' ability to duplicate results.

Day 4

1. Method for tasting and cleansing and basic protocol were reestablished.
2. Standard layer and pound cakes were evaluated as a memory refresher for panelists.
3. Panelists evaluated four experimental cakes with score cards and on the computer.

Table A-6a - Characteristics and scale anchors used to evaluate sensory quality of cake

Characteristic	Scale anchor and score
Cell uniformity [a]	0 = uneven; 60 = even
Overall density [b]	0 = not dense; 60 = very dense
Gumminess	0 = very gummy; 60 = not gummy, crumbly
Maximum bitterness	0 = not bitter; 60 = very bitter
Residual bitterness	0 = not bitter; 60 = very bitter
Maximum sweetness	0 = not sweet; 60 = very sweet
Residual sweetness	0 = not sweet; 60 = very sweet

[a] Cell uniformity is the overall appearance; how many of the cells are the same size. This scale is concerned with consistency, not how large or small the cells are.

[b] Overall density is weight per unit volume; left/low end of the scale is large and open like angel cake; right/high end is the tighter, compact poundcake texture.

Table A-7 - Response surface regression coefficients for physical characteristics of cake

	Characteristics								
Parameter	Specific gravity	Batter pH	Cake pH	Aw batter	Aw cake	Volume	Symmetry	Uniformity	Shrinkage
Intercept	1.19	12.7	4.52	1.24	.952	-29.7	-67.2	-.896	1.37
N-Flate (N)	-.0504	-.129	.0531	-.00744	.00288	12.6	4.81	-1.36	-.072
Water (W)	.000832	-.021	.00359	.0000122	.000999	-.496	.175	.165	-.00295
Polydextrose (P)	-.00291	-.0541	-.00264	-.000669	-.0000569	1.74	.664	.0917	-.00583
Leavening agent (L)	.0601	.0407	.192	-.0350	-.0206	-2.93	-5.36	.0278	.131
Fructose (F)	-.00936	.0291	.0173	-.000813	-.000720	2.76	1.09	.0357	-.00198
N × N	.00132	.00186	-.000521	-.000142	-.000116	-.196	-.0174	.00347	.00313
N × W	-.00005903	.000321	.0000174	.0000365	.00000260	.00608	-.00347	-.00347	-.000174
W × W	.00000798	.0000377	-.0000125	-4.88	-.00000290	-.000461	.000380	-.000597	.0000271
N × P	.0000194	-.0000417	-.000444	.0000278	.00000694	-.0486	-.0306	.00278	4.28
W × P	-.00000660	.0000330	-4.82	-.00000347	-.00000434	-.00226	-.000347	.00104	.0000347
P × P	.0000271	.000147	-.0000431	.00000153	9.03	-.00174	-.000139	-.000417	.0000139
N × L	-.0012	-.000139	.00139	.000611	.000236	.181	-.0556	.167	-.00556
W × L	-.000132	-.0002604	.0000347	-.0000208	.0000399	.0610	-.0139	-1.50	-.000347
P × L	-.000417	.00147	.000889	.00000556	-.00000833	-.00833	.0167	-.0278	-1.62
L × L	.00126	-.00201	-.00875	.00132	.000535	-.396	.375	-.0972	.00139
N × F	-.000167	.000179	.0000397	.0000119	-.0000575	-.0417	-.0238	3.29	-1.11
W × F	.0000228	.00000744	-.0000546	4.96	.00000620	-.00967	-.00298	-2.83	.0000496
P × F	.0000833	.000171	-.0000635	-.00000635	.00000437	-.00675	-.00397	.000794	2.56
L × F	.000111	-.000278	-.000714	-.0000476	-.00000397	-.00397	-.0317	.0159	1.35
F × F	.0000258	.000254	-.0000198	.0000213	.00000638	.00326	.00652	-.00539	-.0000850

Table A-8- Response surface regression coefficients for sensory characteristics of cake

Parameter	Characteristic							
	Cell uniformity	Cell size	Cell thickness	Density	Moistness	Gumminess	Crust stickiness	Softness
Intercept	-60.6	-99.2	-345.6	106.5	414.5	-474.8	-407.0	575.6
N-Flate (N)	7.50	11.4	10.4	1.24	-12.2	16.8	19.7	-21.1
Water (W)	.447	1.02	1.47	-.0959	-.312	.208	.250	-2.22
Polydextrose (P)	1.22	.213	1.86	1.46	-2.78	1.42	2.58	-.606
Leavening agent (L)	-18.3	-11.5	9.60	-29.2	-21.8	57.8	17.7	-31.3
Fructose (F)	-.0456	-.118	3.20	.779	-1.27	-.607	.544	.854
N × N	.116	-.128	-.0686	.122	.0677	1.49	-.267	.209
N × W	-.041	-.0291	-.0525	-.017	.0339	-.037	.00174	.023003
W × W	.00117	-.00460	-.000529	-.00167	-.000678	.000326	-.000380	.00218
N × P	-.0722	-.0229	-.00764	-.0507	-5.30	-.0181	-.00278	.00903
W × P	-.00260	.00668	-.00130	.00755	-.000868	.00451	-.00278	.00408
P × P	-.00340	-.00733	-.00413	-.0112	.0102	-.00722	-.00875	.00476
N × L	.153	.174	.188	.0347	.403	-1.14	-.472	.799
W × L	.0347	.0443	.013	.0356	-.00694	.00174	-.0278	.0703
P × L	.131	.0236	-.0764	.0542	.114	-.0472	-.0722	-.0486
L × L	-.146	-.177	-.413	.906	.299	-1.61	.125	.476
N × F	-.103	-.051	-.0466	-.0565	.0615	-.048	-.0813	-.0129
W × F	-.00124	-.00459	-.00682	-.00310	-.000992	-.00273	.00769	-.000372
P × F	.0246	.0177	-.00893	.00655	.00913	-.00595	-.00357	-.0109
L × F	.060	.0377	-.0298	.0615	-.127	.206	.0754	-.0456
F × F	-.00468	-.00248	.00233	-.00871	.0118	.0187	.00198	.00517

Table A-9- Analysis of variance means[a] for physical measurements[b] of cakes

Treatments[c]								
Polydextrose	Water	Leavening agent	Specific gravity	Viscosity, cps (X 10^4)	Volume, cc	Symmetry	Uniformity	Shrinkage
75	80	8	59.7	12.9	176.7	16.3	-1.7	7.0
75	80	9	58.7	12.1	180.7	15.3	-2.7	7.3
75	95	8	59.0	9.9	174.0	16.0	-1.3	7.3
75	95	9	59.0	10.2	185.2	16.0	-2.0	7.0
75	110	8	60.3	7.5	175.0	18.0	-2.3	7.3
75	110	9	62.0	6.9	177.7	16.0	-4.0	6.0
75	125	8	61.3	5.8	170.7	19.3	-0.67	8.0
75	125	9	62.0	5.8	172.3	17.7	0.33	8.0
85	80	8	58.0	11.9	170.0	13.0	-1.0	6.0
85	80	9	58.7	12.5	179.7	14.3	-2.3	6.3
85	95	8	57.7	9.6	175.0	16.0	-2.0	7.7
85	95	9	58.3	10.3	176.0	16.0	-0.67	7.0
85	110	8	58.0	7.4	173.0	17.0	-1.0	7.7
85	110	9	58.3	7.9	176.7	16.3	-2.3	7.0
85	125	8	59.3	6.0	172.7	21.0	-2.0	7.5
85	125	9	58.3	6.4	175.3	18.7	-0.67	7.0
95	80	8	57.3	11.3	168.7	13.3	-1.3	6.3
95	80	9	57.7	11.7	171.3	12.7	-1.3	6.3
95	95	8	57.0	9.4	171.2	13.5	-1.0	7.0
95	95	9	57.7	9.7	173.0	13.0	-2.3	6.3
95	110	8	56.3	7.8	170.0	16.0	-2.0	6.7
95	110	9	58.3	7.1	171.0	15.0	-0.33	6.3
95	125	8	59.3	5.8	166.0	17.0	-1.0	7.0
95	125	9	59.3	6.4	171.0	15.0	-0.33	7.3

[a] Three replications.

[b] Procedures given in Appendix, Table A-5.

[c] Grams, based on total batter weight.

Table A-10- Analysis of variance means[a] for all panelists for sensory measurements[b] of cake

Treatments[c]									
Polydextrose	Water	Leavening agent	Cell uniformity	Density	Gumminess	Maximum bitterness	Residual bitterness	Maximum sweetness	Residual sweetness
75	80	8	42.4	50.3	15.1	29.7	18.7	31.9	19.3
75	80	9	43.9	50.7	16.5	33.3	21.8	31.3	18.1
75	95	8	40.2	50.0	18.5	29.9	19.9	34.7	21.0
75	95	9	38.3	47.9	17.3	32.3	20.6	37.3	24.1
75	110	8	40.5	49.6	20.1	32.1	22.1	35.7	21.7
75	110	9	35.5	47.9	17.6	32.4	21.2	35.8	24.2
75	125	8	34.8	52.9	24.5	27.7	17.6	33.3	18.9
75	125	9	36.5	46.5	21.3	29.2	18.2	32.4	19.7
85	80	8	40.1	46.0	21.3	33.5	20.2	37.4	23.8
85	80	9	44.3	47.9	13.3	30.4	19.5	33.8	20.9
85	95	8	39.4	45.6	21.9	32.0	21.3	35.8	22.1
85	95	9	41.9	47.5	18.1	34.6	23.3	34.0	21.3
85	110	8	38.3	44.3	22.8	31.6	20.2	33.7	21.1
85	110	9	38.7	46.1	21.3	32.3	19.7	33.5	19.2
85	125	8	36.7	47.1	21.1	28.5	17.7	36.0	22.8
85	125	9	38.0	46.9	25.7	33.3	21.3	35.2	22.7
95	80	8	39.7	45.1	23.5	36.5	23.1	37.5	24.2
95	80	9	44.0	46.9	21.8	34.7	23.1	37.3	24.1
95	95	8	39.1	44.7	25.9	34.7	21.0	37.7	24.1
95	95	9	44.5	44.3	22.5	37.3	22.5	35.8	22.3
95	110	8	36.7	44.5	23.9	31.2	20.7	36.9	24.7
95	110	9	37.3	41.5	20.5	34.8	21.9	34.6	21.9
95	125	8	41.9	48.8	27.6	32.9	23.0	37.4	26.3
95	125	9	33.3	42.9	25.7	33.3	20.7	36.8	22.3

[a] Three replications.

[b] Based on 60-point linear, computer scale, with 60 highest or most intense and 0 lowest or least intense.

[c] Grams, based on total batter weight.

NAME________________

FORM A-1

DATE________________

SAMPLE #s________________

CELL UNIFORMITY

uneven — even

CELL SIZE

very large — very tiny

CELL THICKNESS

very thick — very thin

DENSITY

not dense; open — very dense; close

MOISTNESS

very dry — very moist

GUMMINESS

very gummy — not gummy; crumbly

CRUST STICKINESS

very sticky — not sticky

SOFTNESS

very firm — very soft

Form B-1

September 24, 1985

Dr. Robert Raeves, Chairman,
Subcommittee on Research Involving Human Subjects
Department of Foods and Nutrition
Justin Hall

Dear Dr. Raeves:

I wish to request permission to use human subjects on taste panels in the proposed research project. The proposal and the statement of informed consent with a rating scale such as we will be using are included.

Procedures for informing the taste panel volunteers would include:

1. A brief written statement regarding the research and the samples to be analyzed would be sent along with a short questionnaire to determine interest in serving on the panel and times of availability.
2. Those persons volunteering for panels will be asked to attend an introductory session when the purpose, benefits and objectives of the research, time schedule, and analysis procedures are explained by the project director and graduate student.
3. The project director or researcher would answer questions (and be available throughout the study). Only those who volunteer participate after the introductory session and receive further training.

This is a continuation of the project for which permission was received May, 1984 to use human subjects.

All materials used are food grade and have been or are pending FDA approval or on the GRAS list. I'd appreciate your earliest possible consideration of this request. Thank you.

Sincerely,

Carole Setser
Associate Professor

Form B-2

KANSAS STATE UNIVERSITY

Graduate School

Research and Sponsored Programs
Fairchild Hall
Manhattan, Kansas 66506
913-532-6195

TO: Dr. Carole Setser
Foods and Nutrition
Justin Hall

Proposal Number: 489

FROM: Robert P. Lowman, Chair
Committee on Research Involving Human Subjects

DATE: November 8, 1985

RE: Committee Review of Your Proposal Titled Mechanisms of Sucrose Interaction with Starch and Protein in Chemically Baked Products: Comparisons with Alternative Sweetening/Bulking Systems

The Committee on Research Involving Human Subjects has reviewed the modifications which you made in your proposal in response to stipulations placed on its approval by the Committee. The Committee has accepted these modifications as fulfilling its stipulations and therefore grants full approval to your proposal, as modified. In granting this approval, the Committee has determined that:

☒ There is no more than minimal risk to subjects.

☐ There is greater than minimal risk to subjects.

This approval applies to this project only and only under the conditions and procedures described in the application, as revised. Any change in the protocol or conditions described in the proposal, as revised, will require separate approval. This approval may be followed by a periodic review of the project and examination of records related to the project. Individual identification of human subjects in any publication is an "invasion of privacy" and requires a separately executed "informed consent."

Prior to involving human subjects, properly executed informed consent must be obtained from each subject or an authorized representative, and such forms must be retained on file for a minimum of three years after termination of the project. Each research subject must be furnished with a copy of the informed consent document for his or her personal records. Your informed consent statement, as approved by the Committee, is attached to this memorandum.

Any unanticipated problems involving risk to human subjects or others must be reported immediately to the Director of the Student Health Center and the Chairperson of the Committee on Research Involving Human Subjects.

Form B-3

Statement of Informed Consent

1. I have volunteered to be a member of a taste panel to test sweetening agents in model systems and in food products. The research will be conducted by personnel in the Department of Foods and Nutrition at Kansas State University.

2. The purpose of this research is to find the most acceptable, safe sweetening systems for low calorie products. This requires taste-testing of the products to determine which are most acceptable. Food-grade materials will be used. Standard methods of preparation of food samples will be followed. We anticipate no risk involved in tasting samples.

3. I have had the opportunity to discuss the procedures with the investigator and to ask questions.

4. I understand this testing involves multiple panel sessions and will require my participation from one to six months.

5. I understand that my performance as an individual will be treated as research data and will in no way be associated with me for other than identification purposes, thereby assuring confidentiality of my performance and responses.

6. I understand that I do not have to participate in this research, and that if I choose not to participate there will be no penalty or loss of benefits to which I am otherwise entitled.

7. I further understand that I may withdraw my consent and end my participation in the panel at any time without penalty or loss of benefits to which I am otherwise entitled.

8. If I have any questions concerning my rights as a research subject, injuries or emergencies resulting from my participation or any questions concerning this study, I understand that I can contact Carole Setser in Justin 143A.

I have read the above and signed this informed consent statement on ______________________ 19 ______.

Signature ______________________________

Form C-1

NAME____________________

DATE____________________

PANEL____________________

Please taste the samples in the order presented by the computer and evaluate each characteristic in the order listed. Rinse your mouth with water, then cleanse with milk and carrots in between samples.
Use the smaller cake sample in each set to evaluate gumminess and use the larger piece to evaluate the other attributes.

THANK YOU VERY MUCH FOR YOUR HELP!!

CELL UNIFORMITY

low high

OVERALL DENSITY

low high

GUMMINESS

low high

MAXIMUM
BITTERNESS

low high

RESIDUAL
BITTERNESS

low high

MAXIMUM
SWEETNESS

low high

RESIDUAL
SWEETNESS

low high

COMPUTER CORRECTIONS/COMMENTS:

TEXTURAL OPTIMIZATION OF REDUCED-CALORIE LAYER CAKES USING POLYDEXTROSE AND A GUM-EMULSIFIER BLEND

by

NANCY ELIZABETH NEVILLE

B.S., University of Missouri, 1984

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

The objective of this study was to develop a high quality cake that contained no sugar or shortening. Twenty-eight sucrose- and shortening-free cakes were prepared and evaluated using response surface methodology (RSM) in which polydextrose, N-Flate™ matrix system, leavening, water and fructose levels were varied while other ingredients were held constant. Cakes were evaluated by physical and sensory means.

The RSM analysis revealed that all significant ingredient effects were linear. Polydextrose was the most influential factor affecting cake quality, followed by water. Contour plots of these two variables were generated to project optimum volume and cell size. Fructose was replaced by a saccharin-aspartame blend, the N-Flate level was held constant, and additional cakes with varying levels of polydextrose, leavening and water were prepared. Specific gravity, viscosity, volume, symmetry, uniformity, and percentage shrink were measured. Sensory evaluation included cell uniformity, gumminess, overall density, maximum and residual bitterness, and maximum and residual sweetness. Data were analyzed by analysis of variance (ANOV); when F-values for effects were significant, least significant differences were calculated.

Polydextrose level inversely affected specific gravity, volume, symmetry and shrinkage. Highest

polydextrose level (95 g, based on total batter weight, or tbw) resulted in highest gumminess, density, maximum and residual sweetness, and maximum bitterness of all formulations. Polydextrose did not influence cell uniformity or residual bitterness.

Water increased specific gravity; the high water level (125 ml, tbw) increased gumminess and reduced cell uniformity. Water did not affect density or maximum and residual bitterness. The higher (9g, tbw) leavening level increased volume and decreased gumminess more than 8g leavening.

The only ingredient interaction shown by ANOV was polydextrose by water, which influenced shrinkage and the intensity of maximum and residual sweetness. Two defects of the cakes were overall gumminess upon mastication and occasional tunnelling.

Several combinations of ingredient levels produced cakes comparable to the standard layer cake controls. Optimized cakes contained only about one-half the calories of traditional sucrose cake.