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ABSTRACT

THE EFFECT OF MICROCRYSTALLINE CELLULOSE
ON SENSORY AND PHYSICAL CHARACTERISTICS
OF CAKES AND BISCUITS

By
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Three levels of microcrystalline cellulose (MCC) were substituted for flour in cakes and biscuits to lower the caloric density of these products. The physical properties and sensory characteristics of these products were compared with control products containing no MCC to determine the maximum level of MCC substitution which would produce an acceptable product. Functional properties of the flour-MCC mixtures were also tested using a farinograph and Visco-amyl-graph.

Farinograph studies showed that the mixing stability was drastically reduced for dough with more than 20% MCC substitution. Substitution of MCC for flour greatly decreased slurry viscosity, however, systems containing MCC and flour had greater viscosity than those with an equivalent amount of flour alone.

The lower mixing stability of the dough produced biscuits of lower quality: drier, tougher, and less flavorful. MCC substitution did not significantly change the pounds of force required to shear a gram of biscuit. However, greater force was required to compress the biscuits containing 50% MCC substitution than had been required for biscuits with 20 or 40% MCC substitution. Biscuits with increasing levels of MCC

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substitution had progressively lower volume measurements and crust brownness.

Sensory evaluation data was highest for cakes containing 20% MCC substitution. Cakes with 0 or 40% MCC substitution for flour were scored slightly lower than cakes with 20% MCC substitution. Cakes with 60% MCC substitution had scores significantly lower than all other cakes. Physical tests indicated that moistness, tenderness, and compactness of cakes increased with concurrent increase of MCC.

The cake system could tolerate a greater proportion of MCC substitution for flour than the biscuit system in this research to maximize caloric reduction. Substitution of 20% MCC for flour even improved the quality of the lean cake formula, since the water-binding capacity of MCC increased the moisture content. Substitution of 40% MCC for flour in the cakes and 20% MCC for flour in the biscuits produced products which were of good quality and had 20 and 10% fewer calories respectively. Higher substitution levels had fewer calories, but were less acceptable and of poorer quality.

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INTRODUCTION

Obesity is a major health problem in the United States. Using insurance statistics, Wagner (1970) estimated that 30% of the men and 40% of the women are 20% or more over their respective desired weights. In 1972, Finberg reported that 60% of the U. S. Adult population were overweight. Although half of these people were concerned with their weight, only 20% were guarding against further gain and 10% were actually dieting to reduce their weight. Dieting regimes can be found quite frequently in women's and other lay magazines. Group encouragement through organizations such as "Weight Watchers" and TOPS (Take Off Pounds Sensibly) may provide motivation to aid an individual's weight reduction program (Wagner, 1970).

Calorie restricted diets may not be successful as they do not have either the volume or the satiety value of a higher calorie diet (Lee et al., 1969). Pleasures associated with eating must be ignored if low calorie diets are to be effective (Wagner, 1970). The inclusion of micro-crystalline cellulose (MCC) may aid in producing more acceptable low-calorie foods by adding volume to food while reducing caloric density and by giving a feeling of fullness due to the water-binding capacity of MCC (Lee et al., 1969; Finberg, 1972). Diet foods reduce the caloric content of the diet. Diet soft drinks, sugar substitutes and foods which contain them, are regaining popularity (Engstrom, 1974). These diet foods are similar in quality characteristics to a standard product but lower in calories. The food industry is also increasing its use of cellulose

derivatives to serve as emulsifiers, stabilizers, thickeners, moisture retainers, and mechanical foamers in food systems and particularly in diet-type foods (Glicksman, 1969; Trauberman, 1961; Finberg, 1972).

Diverticulosis, ulcerative colitis, colonic cancer, gall bladder disorders, hiatus hernias, non-infective diseases of the bowel, atherosclerosis and other diseases have been linked to insufficient dietary fiber consumption in economically developed countries. (Painter and Burkitt, 1971; Harvey et al., 1973). Ingestion of diets low in dietary fiber is usually accompanied by over consumption of refined carbohydrates which when decomposed in the intestines by Escherichia coli and other organisms, can irritate the gut and result in non-specific diarrhea (Cleave, 1973; Harvey et al., 1973). Over consumption of refined carbohydrates and its resultant bacterial action decreases the time it takes the foods to pass through the intestine in diarrhea patients (Cleave, 1973; Harvey et al., 1973).

With constipation the transit time is increased which causes a drier feces due to more water absorption by the intestine. This results in a larger volume of feces which causes pressure and a wider diameter colon which segments less effectively. This colon is more susceptible to diverticulosis (Painter and Burkitt, 1971). Increased bulk in the diet is prescribed because of its laxative effect, therefore, reducing the transit time of food through the intestine. The reduced transit time reduces the time that water can be absorbed by the colon, making the feces softer and thus reducing the pressure (Painter and Burkitt, 1971; Harvey et al., 1973).

Sudaravalli and coworkers (1973) cited earlier studies which showed that the use of MCC caused a decrease in nutrient absorption and increased weight loss. Sudaravalli and coworkers (1973) studied the incorporation

of 25% MCC in restricted calorie diets of obese rats attempting to decrease the transit time. The low calorie diet with MCC caused greater weight loss than the calorie restricted diets without MCC. No deleterious effect on nitrogen balance accompanied this weight loss.

Incorporation of MCC in foods may be beneficial because it does not contribute calories but does add dietary fiber. Because of their high caloric content baked products are often excluded from reducing diets. Substitution of MCC for part of the flour may reduce the caloric density of cakes and biscuits so that they could be included for occasional consumption on reducing diets, thus increasing the satiety value of the diet. The more palatable the diet the more likely an individual will follow a reducing regime.

This study evaluated the effect of MCC substitution for part of the flour on the sensory and physical characteristics of cakes and biscuits. Taste panelists evaluated the products for tenderness, texture, moistness, color and flavor. Physical tests included shear press determination for tenderness and compressability, moisture content, color, and volume. MCC was substituted to reduce the caloric content of cakes and biscuits. The primary objective was to determine the level of MCC substitution which would provide a good quality product with maximum caloric reduction.

REVIEW OF LITERATURE

In order to understand the feasibility of incorporating MCC in baked products, the production, chemical properties, and food uses of MCC will be reviewed. Since MCC is being substituted for the flour in cakes and biscuits, the role of flour in cake and biscuit systems as well as the function of other ingredients in these systems will be reviewed.

Microcrystalline Cellulose

Cellulose is a polymer of glucose connected by β 1-4 glucosidic bonds. The polymers are laid down naturally in crystal line areas which vary in size and are held in lateral associations by hydrogen bonds, which are resistant to chemical re-agents. Between crystalline areas are non-crystalline areas which are hydrolyzable by acids and enzymes (Glicksman, 1969).

Alpha cellulose is obtained by acid hydrolysis of fibrous plant materials, such as cotton linters and wood pulp. Acid hydrolysis occurs at the amorphous area. Refining of the alpha cellulose removes any impurities and the remaining acid-insoluble, crystalline residue is designated microcrystalline cellulose (MCC). MCC is characterized by uniformity of lengths of the constituent chains of the aggregates, which have a normal range of degree of polymerization of 15 to 375 anhydroglucose units. MCC is a fine, white, odorless, crystalline powder, which is edible yet non-nutritive (Battista, 1962; Food Chemical Codex, 1971; Trauberman, 1961).

Microcrystalline cellulose has excellent water absorptive properties so that formulations containing MCC can form stable gels and firm gels with 20% and 35% cellulose solids respectively. The uses of cellulose concentrations lower than 20% solids yields creamy colloidal suspensions. Microscopic fissures and holes in the crystals of the dry particles contribute to MCC's absorptive properties. Trauberman (1962) stated that these absorptive abilities make the use of MCC excellent for converting oil-based foods and syrups into free-flowing granular powders.

The food industry uses MCC to improve the quality of a variety of food products. Incorporation of MCC in low-solids tomato sauce increases its coating ability and makes the sauce more resistant to serum separation. MCC can also stabilize and increase the body of other tomato products and foods containing these tomato products (Anon., 1970). Frozen desserts and ice milks use MCC to reduce the formation of ice crystals, to give superior dimensional stability and to aid in controlling the incorporation of air into these products. Other uses of MCC for stability are in salad dressings, canned salads, whipped toppings, and non-dairy cream substitutes (Glicksman, 1969).

MCC dispersed in a gel or in the dry form, which absorbs oil-based foods, can be incorporated into foods to reduce the caloric density of the foods without impairing a product's taste, texture, or appearance. MCC functions as a built-in calorie control mechanism when incorporated in foods (Anon., 1962). Many suggested uses for MCC are available, but actual uses in the reduced calorie foods have been limited. Lee and co-workers (1969) studied the effect of MCC incorporations in muffins, cookies, and mashed potatoes. Levels of MCC substitution for flour were 0, 24, 40, and 53% for muffins and 0, 45, 67, and 100% for cookies. As the MCC content increased, there was a decrease in appearance, texture and

flavor scores. The percentage moisture of the baked products increased, but sensory evaluation indicated these products were dry. All levels of substitution were considered edible by the taste panel. In a follow-up study, using both a normal-weight and an obese taste panel, testing the same types of cookies and mashed potatoes, but brownies instead of muffins (Pratt et al., 1971), the obese panelists scored the foods containing MCC similarly to the non-obese panelists.

Functional Properties of Flour

Wheat flour provides two major components for the structure of baked products, starch and protein. The principle protein which is responsible for structure in baked products is gluten, which is formed by the interaction of glutenin and gliadin, proteins of flour. Binding of glutenin and gliadin is affected by the amino acid side chains of the proteins; disulfide bonds of cystine, hydrophobic binding of leucine, hydrogen bonding contributed by the free amides of asparagine, glutamine, and salt bridges between lysine and glutamic acid residue. These protein interactions are responsible for the cohesive, elastic, three-dimensional gluten network (Paul and Palmer, 1972). The effects of gluten, water-soluble proteins, starch, and tailings on cake quality have been studied by fractionating and interchanging these components (Donelson and Wilson, 1960; Baldi et al., 1965).

Gluten and water-soluble proteins provide a network which retains air and carbon dioxide during early stages of baking. As the protein quantity and quality is increased, a stronger network is formed resulting in more cohesive, extensible doughs (Donelson and Wilson, 1960; Baldi et al., 1965). Protein staining has been used to show the distribution of proteins in the flour in relation to the total protein content (Baldi et

al., 1965). The protein was found to be distributed in very thin films which were continuous and intermeshed with denser areas of protein. As the protein content of the flour was increased the protein networks became larger, denser, and more numerous. The starch granules were enmeshed in the dense protein areas (Baldi et al., 1965).

Tailings are composed of water insoluble hemicelluloses, from the cell walls of the endosperm. These hemicelluloses are very hygroscopic and affect the quality of baked goods. Small amounts of tailings incorporated into doughs yielded soft dough which lacked elasticity (Baldi et al., 1965). Cake volume is largely dependent on the structural matrix of protein intermeshed with starch, but is also affected by the proportion and interaction of starch and tailings. Tailings interfere with starch-starch binding thus incorporation of tailings produces a cake with a finer texture (Baldi et al., 1965).

Starch present in granules absorbs available moisture. Intermolecular bonding between hydrophilic groups of the long chain starch molecules contribute to stability of the starch granules. As a starch suspension is heated the associative forces among the starch molecules in the intact granule are disrupted, the starch molecules hydrate and finally become gelatinized. The hydration of the starch molecules causes swelling of the granules which then allows them to aggregate and increase the viscosity of the suspension (Schoch, 1941; Jongh, 1961; Shellenberger et al., 1966).

Round starch granules electrostatically bonded to the gluten gel layer as a continuous phase, form the structural network for baked products. During baking the starch draws moisture from the gluten, providing a semi-rigid film surrounding the starch granules (Sandsted, 1961; Jongh, 1961; Baldi et al., 1965). Crumb properties are determined by the degree of starch gelatinization as well as by the quality and quantity of gluten,

water soluble proteins and tailings. The effect of starch gelatinization is independent of the other factors (Jongh, 1961; Donelson and Wilson, 1960; Baldi et al., 1965). Gas released into the air cells expands during baking and is entrapped by the protein network which expands and ruptures without collapsing. The adherence ability of the starch granule surface is also important (Sandsted, 1961).

Function of Cake Ingredients

Shortened cakes rely primarily on shortening for air incorporation. Carbon dioxide produced from baking powder or soda and acid reactions is used to expand these air cells and hence expand the volume. Other basic ingredients are sugar, milk, whole eggs or egg whites, and flavoring.

Aeration of a plastic shortening and the batter is important in the quality of layer cakes. The air cells formed during early mixing of the batter provide the cells for entrapping leavening gases and water vapor formed during baking. More numerous and smaller air cells in the batter yield a finer textured cake (Handleman et al., 1961; Carlin, 1941; Kim and De Ruiter, 1968). Emulsifiers added to plastic shortening improve air incorporation and emulsification of the batter. During the mixing and early baking period, the air cells which have been incorporated are stabilized by the emulsifiers (Wootton et al., 1967). Polysorbate 60 added with emulsifiers in bread yields a drier dough by functioning to bind water molecules and by competing with the flour for the moisture. Polysorbate 60 also combines with amylose to form insoluble complexes which increase viscosity of the batter (Langhans and Thalheimer, 1971).

Purposes of sugar in baked products include sweetening and moisture retention. Tailings and sugar interact to affect batter and cake structure (Baldi et al., 1965). Baxter and Hester (1958) indicated that sugar has a

tenderizing effect by interfering with gluten development. This occurs primarily through competition of the gluten and sugar for water. Sugar also has an inhibitive effect on heat coagulation of gluten proteins. As the amount of sugar is increased more stress is placed on the protein structure.

Milk and eggs are the sources of liquid normally found in cake systems. The amount of these ingredients affects the cake contour and other quality characteristics. Liquid functions to dissolve sugar and provide moisture for starch gelatinization. The lean formula cake, developed by Kissell eliminating eggs and milk, has been used to study the function of ingredients (Wilson and Donelson, 1963; Miller and Trimbo, 1965).

The quantity of liquid required varies with the proportion of ingredients. Flours vary in tolerance to different liquid levels (Miller and Trimbo, 1965). The sorptive capacity of soft wheat flour decreases with increasing protein content (Gur-Arieh et al., 1967). The defects in cakes which occur because of improper moisture levels are sunken centers due to insufficient liquid or peaked cake due to excess liquid (Wilson and Donelson, 1963; Miller and Trimbo, 1965). Insufficient water with high concentrations of sugar depresses the gelatinization of the starch which produces a dry, coarse, granular crumb. However, if more liquid is provided than that required to satisfy the stronger hydrophilic ingredients, the remaining water is available for excessive starch gelatinization, which yields a crumb which has certain gel-like characteristics (Miller and Trimbo, 1965; Wilson and Donelson, 1963). Cake formulas which include milk and eggs have a higher liquid requirement than Kissell's lean cake formula due to the additional water-binding capacity of milk solids and egg albumin. A balanced cake formula must supply sufficient liquid to

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provide water for both starch gelatinization and water for hydrogen bonding of the hydrophilic ingredients such as sugar and protein.

Milk and egg proteins act as structural agents in the cell walls. They also aid in trapping gases generated in the leavening process, and act as buffers which limit and moderate the overall response of flour to liquid. These ingredients also minimize flour differences yielding a more uniform product with greater tolerance to errors (Wilson and Donelson, 1963; Berger, 1970).

Stabilization of the batter, which relies on several factors, is important during early stages of baking and thermal setting. Polyvalent cations aid in keeping the shortening and aqueous phases from separating; they also help to retain leavening gases. Foaming properties of soluble proteins stabilize the fluid batter during early baking. Emulsifiers function to aid in air incorporation and hold the air in by forming a plastic-like membrane at the shortening-water interface. Emulsifiers also prevent the shortening from inhibiting the foaming properties of soluble proteins during mixing (Howard et al., 1968).

During baking the emulsified batter thermally sets forming a rigid, porous expanded structure. As the temperature of the batter rises several changes take place. The fat melts releasing the air incorporated into the viscous emulsion thickened by starch gelatinization and protein coagulation. During baking the water is absorbed by starch, proteins, and sugar; however, starch absorbs the major portion of the water allowing the final porous structure to be formed (Howard, et al., 1968).

Function of Biscuit Ingredients

Biscuits are a simpler system which rely on flour, fat, and liquid for structure and quality. Desirable biscuits have a large volume and

flakey texture. Flakiness in biscuits is the result of sheets of gluten which have been separated by steam. The gluten layers are developed by manipulation of the dough after the liquid is added. Fat functions by competing for the surface of the flour with the liquid of the system. The water interacts with flour proteins to create a gluten network. Hydrogenated fats with beta prime crystals cover a large surface area and thus are good shortening agents. The coating of the flour particles with fat interrupts the gluten network which is more important in biscuit quality than starch gelatinization. As the fat content increases the biscuits become more tender. A fat with a low specific gravity is desirable for shortening biscuits, while a fat with a high specific gravity is better for other pastries (Matthews and Dawson, 1963; Berger, 1970; Griswold, 1962; Paul and Palmer, 1972).

Flour exhibits a strong affinity for fat. The oil finding capacity of the flour increases as the protein content increases. Aged and bleached soft wheat flours bind enough oil to form a gel-like protein-oil-water complex with a low specific gravity. Freshly milled and unbleached flours do not have this same oil binding capacity as aged or bleached flours (Shuey et al., 1963).

Fine, even crumb is desirable in biscuits, but volume development should not be at the expense of the evenness of the grain. Proper manipulation is necessary to develop the desired amount of gluten. Fat, by breaking up some of the continuity of the starch and gluten network, weakens the dough structure. The fat is spread into thin parallel layers. Moisture content is important in developing the flakiness which is produced during baking when the steam which is formed separates the layers along the natural lines of cleavage formed by the fat. A more tender pastry may be produced by using oil instead of plastic shortening, but the product may be crumbly

and greasy. In the dough of a pastry, the relatively dry gluten and starch compact during baking into a hard refractory mass (Mattil, 1964; Hirahara and Simpson, 1961; Griswold, 1961).

EXPERIMENTAL PROCEDURE

Cakes and biscuits were prepared containing microcrystalline cellulose which was substituted for flour on a volume basis. To determine the equivalent weight of MCC and an equal volume of flour, both were weighed 25 times during preliminary experimentation. Thus, it was determined that the volume of 10 gm of flour was equal to the volume of 6 gm of MCC. Extra water equivalent to 41% of the weight of MCC used was added to cakes and biscuits containing MCC, to compensate for the increased waterholding capacity of MCC (Lee et al., 1969).

The ingredients used for each system were from common lots and the dry ingredients were weighed for all five replications of each series before baking was started. The milk was reconstituted on the day it was used.

Cake Preparation

To maximize caloric reduction, a lean cake formula was **selected** and is presented in Table 1. This cake formula was then modified to contain 0, 20, 40, and 60% MCC substitution (volume basis). Cake batters were prepared using a Kitchen Aid mixer, model K5-A, with a rotary speed of 2.3 times the planar speed for which rpm is reported. The shortening and emulsifier were creamed for one minute at a speed setting of 8 (220 rpm). All the sugar was then added and creamed for 15 seconds at a speed setting of 2 (76 rpm) after which the speed setting increased to 8 and creaming continued for 4.75 minutes. The remaining dry ingredients were sifted

TABLE 1. Cake Formulas

Ingredient	Level of Flour Substituted with Microcrystalline Cellulose				Percentage of Flour Weight
	0%	20%	40%	60%	0% MCC
	grams				
Flour ¹	300	240	180	120	100
MCC ²	-	36.5	73.1	109.6	-
Shortening ³	75	75	75	75	25
Sugar	255	255	255	255	85
Egg ⁴	120	120	120	120	40
Milk ⁵	285	285	285	285	95
Baking Powder (SAS Double Acting)	12	12	12	12	4
Salt - Iodized	4.8	4.8	4.8	4.8	1.6
Vanilla - extract ⁶	5	5	5	5	1.7
Emulsifier ⁷	6	6	6	6	2.0
Distilled Water	-	15	30	45	-

¹All purpose, enriched, bleached and bromated.

²Avicel PH101, FMC, Marcus Hook, Pennsylvania.

³Hydrogenated vegetable oil, with methyl silicone.

⁴Purchased on each day of baking, Grade A medium.

⁵Reconstituted spray dried whole milk - 128 g dried milk + 946.4 g distilled water.

⁶Measured in milliliters.

⁷Panelmul 318, Panipulus Company, Kansas City, Missouri.

together and added along with the milk solution (milk, vanilla and extra water, when appropriate). Mixing was continued for 15 seconds at speed 1 (52 rpm) and then for 45 seconds at speed 4 (152rpm). The eggs were added last and the batter was beaten for 15 seconds at speed 2 followed by 45 seconds at speed 6 (184 rpm). The bowl was scraped before the addition of each new ingredient.

Approximately 400 ± 10 grams of batter was weighed to the nearest gram into tared 8-inch aluminum pans, that were pregreased and lined on the bottom with waxed paper. The pans were tapped on the counter 10 times to dislodge large air bubbles. Two cakes were made from one batch of batter per replication of each variable. The cakes were baked at $177^{\circ} \pm 6^{\circ}\text{C}$ (350°F) for 35 minutes in a 30-inch General Electric deck oven equipped with a Versatronik controller with the grid set on medium.

After the cakes had cooled for 30 minutes to room temperature they were weighed to the nearest gram in the pans to determine percentage of baking loss. They were then removed from the pans and cooled an additional 30 minutes before being placed in plastic bags on paper plates. The ends of the bags were twisted, folded over, secured with a rubber band and stored for testing on the following day.

Biscuit Preparation

Biscuits were prepared with four levels of flour substituted with MCC (0, 20, 40, 50%) using a modified AACC method 10-31A (1969), as outlined in Table 2. The dry ingredients were sifted together twice and then mixed for 30 seconds at speed setting of 1 (52 rpm) with a Kitchen Aid mixer model K5-A. The milk, oil, and extra water, when appropriate, were shaken vigorously in an up and down motion for 30 seconds in a stoppered 250 ml erlenmeyer flask. The liquid ingredients were added

TABLE 2. Biscuit Formulas

Ingredients	Level of Flour Substituted with Microcrystalline Cellulose				Percentage of Flour Weight
	0%	20%	40%	50%	0% MCC
	grams				
Flour ¹	228	182.4	136.8	114.0	100
MCC ²	-	27.4	55.6	69.5	-
Vegetable Oil	50.2	50.2	50.2	50.2	22
Milk ³	148.2	148.2	148.2	148.2	65
Monocalcium Phosphate ⁴	3.4	3.4	3.4	3.4	1.5
Baking Soda	3.0	3.0	3.0	3.0	1.3
Salt - Iodized	4.6	4.6	4.6	4.6	2.0
Distilled Water	-	11.3	22.8	28.5	-

¹All purpose, enriched, bleached and bromated.

²Avicel PH 101, FMC, Marcus Hook, Pennsylvania.

³Reconstituted Non Fat Dry Milk - 100 g NFDM + 900 g distilled water.

⁴CA(H₂PO₄)₂, Stauffer Chemical Co., Westport, Connecticut.

to the dry ingredients and mixed for 20 seconds using speed setting of 1.

The dough was placed onto a lightly floured board and flattened by hand to approximately 1 inch, then sheeted to 3/8 inch using a National Manufacture 1-pound (5-inch) teflon coated sheeting-roller. The biscuits were cut with a 5.1 cm (2-inch) diameter circular cutter, placed on an ungreased cookie sheet and baked in the 30-inch General Electric deck oven at $204^{\circ}\pm 2^{\circ}$ C (400° F) for 17 minutes. The biscuits were cooled for 20 minutes and stored in a plastic bag which had the end twisted, folded over and secured with a rubber band. Two batches of each substitution level were made to prevent loss of leavening gases which were found to occur during preliminary studies of the biscuits prepared in one large batch.

Objective Measurements of Cakes and Biscuits

Biscuits were evaluated on the day they were baked. All objective measurements of the cakes except specific gravity, batter viscosity, and baking losses were performed on the day after baking. Figure 1 illustrates the sampling procedure used to obtain cake pieces for color, shear and compression tests.

Specific Gravity

The cake batter was tested for specific gravity by averaging the weight of water determined 4 times in a metal cup of known weight. The water was poured into the cup and leveled by placing a piece of glass across the top of the cup. The batter was poured into the same cup and leveled with the straight edge of a metal spatula. The weights of the equal volumes of cake batter and water at room temperature (24° C) were compared.

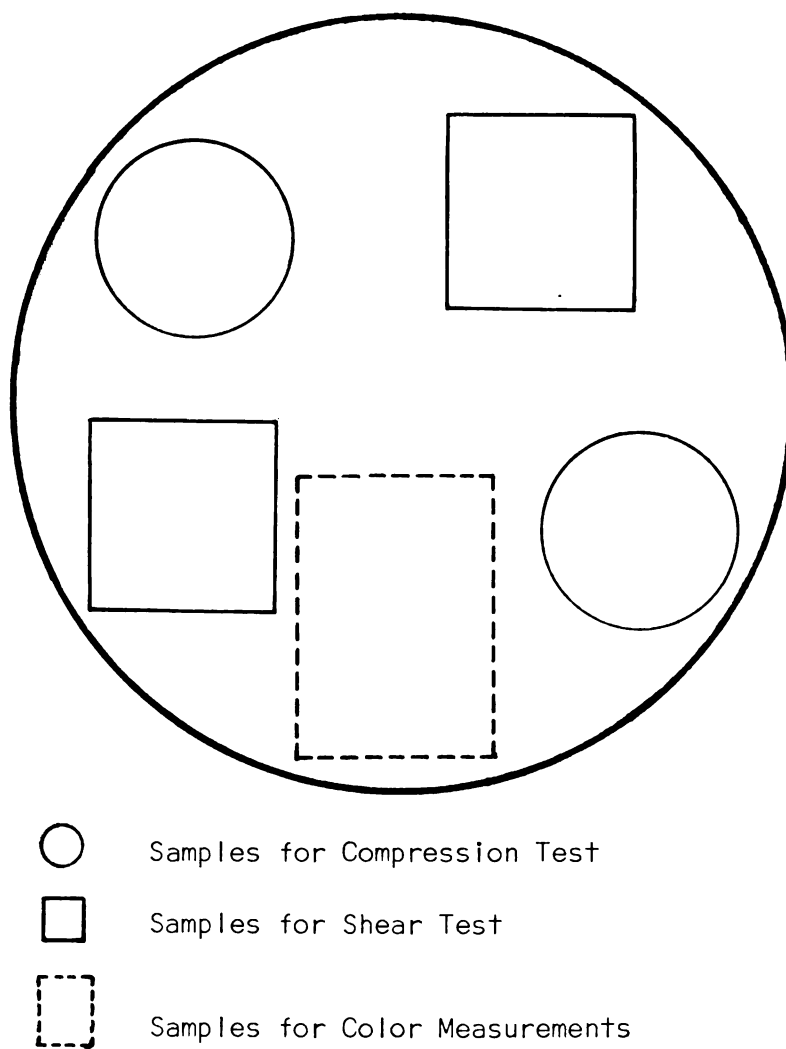


Figure 1. Scheme for Sampling Layer Cakes for Color, Compression, for Shear Tests

Viscosity

The viscosity of the cake batter was measured using a Brookfield Synchro-electric Viscometer, model RVT, on a helipath stand, model C. A B-spindle was used and the cross piece depth varied from approximately one to two inches. The helipath stand was allowed to run through its ascending and descending cycle once and then observed for one cycle. The most frequent reading was used as the value in calculation to convert the Brookfield reading to poise.

Baking Losses

The percentage of baking losses of both the cakes and biscuits were calculated by determining the weight of the batter or dough, and the weight lost during the baking and cooling periods. The following formula was used to calculate percentage baking losses:

Percent Baking Loss =

$$\frac{(\text{weight of batter or dough before baking}) - (\text{weight of cake or biscuit after baking})}{\text{weight of original batter or dough}} \times 100$$

Volume

The cakes were cut in half and measured using a template according to the AACC method 10-91 (1969), to obtain shrinkage value and indices for volume, symmetry, and uniformity.

The volume of the biscuits was determined in duplicate by rape seed displacement. The volume of a small loaf pan was determined by filling the pan with rape seed, leveling the seeds with a spatula and transferring the seed to a graduated cylinder. This procedure was repeated with a biscuit in the pan and the difference of the volumes obtained was used as the volume of the biscuit.

Shear and Compression Determinations

An Allo-Kramer shear-press attached to a model E2EZ-recorder was used for both shear and compression tests. A 3000 pound ring with a range of 5 for the cake samples and 20 for biscuits, with a down stroke time of 43.3 seconds were used for both tests. The tests were run in duplicate. A whole biscuit of a 5.1 cm square piece of cake weighed to the nearest 0.1 grams was sheared using the standard shear compression cell. The force needed to shear the sample was calculated as follows:

$$\text{Force (lb/gm)} = \frac{\text{ring} \times \text{range} \times \text{reading}}{\text{sample weight} \times 10^4}$$

The top portion of the succulometer cell, 5.6 cm in diameter was used to compress the samples to 0.93 cm. The heights of whole biscuits or cake samples cut with a 5.1 cm diameter circular cutter were measured to the nearest 0.01 cm with a caliper. Because of varying heights of the samples the force was calculated per centimeters compressed, using the formula:

$$\text{Force (lb/gm compressed)} = \frac{\text{ring} \times \text{range} \times \text{reading}}{\text{cm of sample compressed} \times 10^4}$$

Color Determination

The color of both the crust and interior of the cake sample and whole biscuits were measured using a Hunterlab Color Difference Meter, model D25. For cake samples the instrument was standardized with the yellow tile ($L = 83.0$, $a_L = -3.5$, $b_L = +26.5$); while the white tile ($L = 94.8$, $a_L = -0.7$, $b_L = +2.7$) was used to standardize the instrument for biscuit color determination. A piece of cake approximately 2 x 3 inches was cut from each layer cake as illustrated in Figure 1. This piece of cake was sliced

horizontally to obtain an even surface for the interior color measurement. The samples were placed in a glass dish over the 3-inch diameter opening and the sample and dish were covered with a black can while the measurement was made. The biscuits were split in two to obtain a smooth surface for the crumb color measurement.

Moisture Determinations

To obtain a homogeneous sample for moisture determination, a center piece of cake or a whole biscuit was ground in a blender for approximately 20 seconds, until thoroughly ground. Duplicate samples of approximately two grams were dried under vacuum according to AACC method 44-40 (1969). The dried samples were allowed to cool in a desiccator until weighed.

Sensory Evaluation

Cakes

One of the two cakes of each level of MCC substitution was used for an 11-member taste panel evaluation. Preliminary evaluations were run to familiarize the taste panelists with the score card. On each evaluation day the taste panel members were served a piece of cake from each level of substitution, cut $5/8 \times 2$ inches and labeled with random numbers. Panel members were asked to evaluate each sample of cake for color, tenderness, texture, moisture, flavor, and general acceptability. A 7 point scale was used with 7 being excellent, 4 fair, and 1 unacceptable. A score card (see appendix) with the characteristics described at each of the three levels of acceptability was given each taste panel member.

Biscuits

An eleven member taste panel was served half of a biscuit of each substitution level of MCC used. Biscuits were labeled with random numbers and heated for 15 seconds in a microwave oven (Linton Industries, model 500 015). Panelists were trained to evaluate biscuits for appearance, texture, tenderness, moisture, flavor, and general acceptability using a 7 point scale with 7 as excellent, 4 fair, and 1 unacceptable. Quality descriptions which were given for each characteristic at the three levels of acceptability are in the Appendix.

Slurry Viscosity Studies

The effect of the MCC on the viscosity of a flour slurry was determined using a Brabender Visco-amylo-graph, model VAV 1, with the bowl rotating at 75 rpm. The slurries were prepared at room temperature and run for a 45 minute heating cycle, with the temperature rising from 25°C to 92.5°C at the rate of 1.5°C per minute after which the 92.5°C temperature was maintained for 15 minutes. Then a controlled cooling cycle was run with the temperature decreasing 1.5°C per minute for 45 minutes.

A 25% slurry was prepared using 100 grams of flour as the control. The substitution levels of 20, 40, and 60% MCC were prepared having the same ratio of flour:MCC:water as the cake systems, but were calculated so the total weight was 100 grams, (Table 3). A constant 400 grams of water were added to all MCC substitution levels to make the slurry. Slurries were also prepared using the same amount of flour and water as in the previous series, but without the MCC, to study the viscosity of the flour per se, in order to determine the effect of MCC on viscosity. Both series were run in duplicate.

TABLE 3. Composition of Slurries for Visco-amylo-Graph Tests

Ingredient	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	60%
Flour (grams)	100	82.3	63.6	43.7
MCC (grams)	-	12.6	25.8	39.9
Extra Distilled Water (ml)	-	5.1	10.6	16.4
Distilled Water (ml)	400	400	400	400

Dough Consistency

The study of the consistency of the dough as affected by MCC was run using a Brabender Farinograph with a measuring head model 3-S-300 and a dynamo-meter type PL211 as outlined by Shuey (1972). The slow speed was used with the blades rotating at 63 and 31.5 rpms. A constant 300 grams of flour mixture (flour and MCC) were used and MCC substitution levels of 0, 20, and 30% were used to give similar ratios of flour:MCC as had been used in the biscuit system, (Table 4). Use of MCC substitution levels higher than 30% were not possible since insufficient flour remained to give a consistency reading. The optimum flour absorption levels were determined by trial runs.

The flour-MCC mixture was mixed for one minute before the water was added as rapidly as possible from the buret attached to the instrument. When all the water was added the sides of the bowl were scraped with a plastic spatula and the cover placed on the bowl. All farinograms were run for 15 minutes. The bowl was thoroughly cleaned and dried before the next run. Each substitution level was run in triplicate.

TABLE 4. Composition of Dough for Farinograph Tests

Ingredients	Level of Flour Substituted with Microcrystalline Cellulose		
	0%	20%	30%
Flour (grams)	300	260.4	236.9
MCC (grams)	-	39.6	62.1
Distilled Water (ml)	184.8	202.2	207.0
Percent Absorption	61.1	67.4	69.0

Statistical Analysis

Mean values, standard deviations, and analysis of variance were computed. Duncan's Multiple range test was used to sort out significant differences revealed by analysis of variance (Duncan, 1957; Rohlf and Sokal, 1969; Sokal and Rohlf, 1969).

RESULTS AND DISCUSSION

Slurry Viscosity Studies

The Visco-amylo-Graph was used to determine the effect of MCC substitution on the viscosity of flour slurries. Starch gelatinization is primarily responsible for the increase in viscosity that occurs as a flour-water mixture is heated (Figure 2). Although all unmodified starch slurries are susceptible to shear effects causing a decrease in viscosity once maximum gelatinization has been reached, flour contains amylase which rapidly degrades the highly swollen amylose molecules resulting in the formation of numerous shorter chain fragments (Brown and Harrel, 1944; Magurs et al., 1957). These shorter chain fragments have smaller spheric water attractions and thus do not contribute significantly to increasing the system's viscosity as did the parent molecules. Therefore, the thinning of a gelatinized flour system is much greater than that of a wheat starch system alone. As the starch slurry cools, the viscosity is increased due to the hydrogen bonding in gelation (Magurs et al., 1957).

A comparison of the amylograph curves in Figures 3, 4, and 5 with that in Figure 2, shows that the maximum viscosity of the systems decrease substantially as the amount of MCC substitution for flour increased. MCC substitution has a much smaller effect on the final viscosity of the slurry. Nevertheless, the data in Figures 3, 4, and 5 indicate that the slurries containing MCC are more viscous than the corresponding slurries with only an equivalent proportion of flour. The initial rise in viscosity for the systems with MCC and flour also occurred at a slightly lower

Figure 2. Visco-amylo-Graph of a Control Flour and Water Slurry
(25% Flour)

Figure 3. Visco-amylo-Graph for Slurries Modified to Contain 80% of the
Flour in the Control Slurry and with 20% MCC Substitution

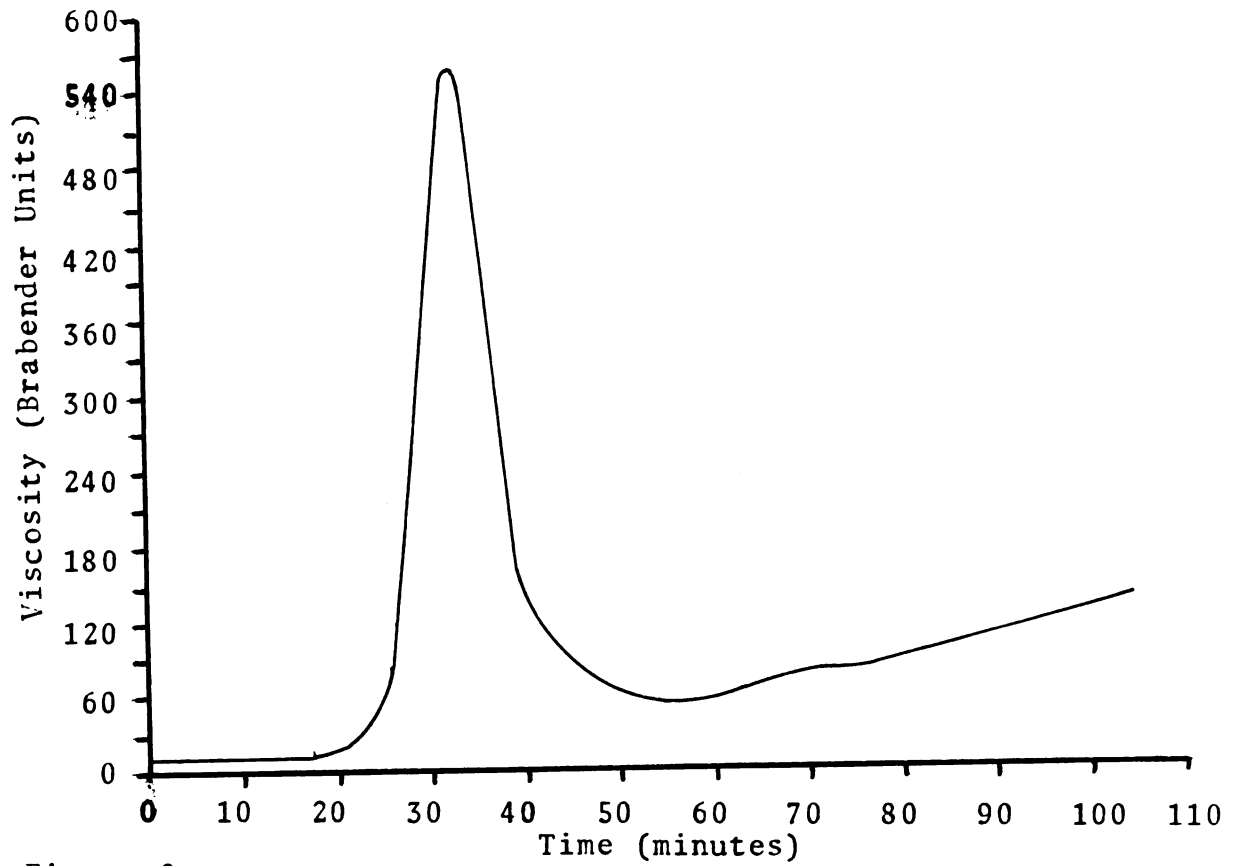


Figure 2.

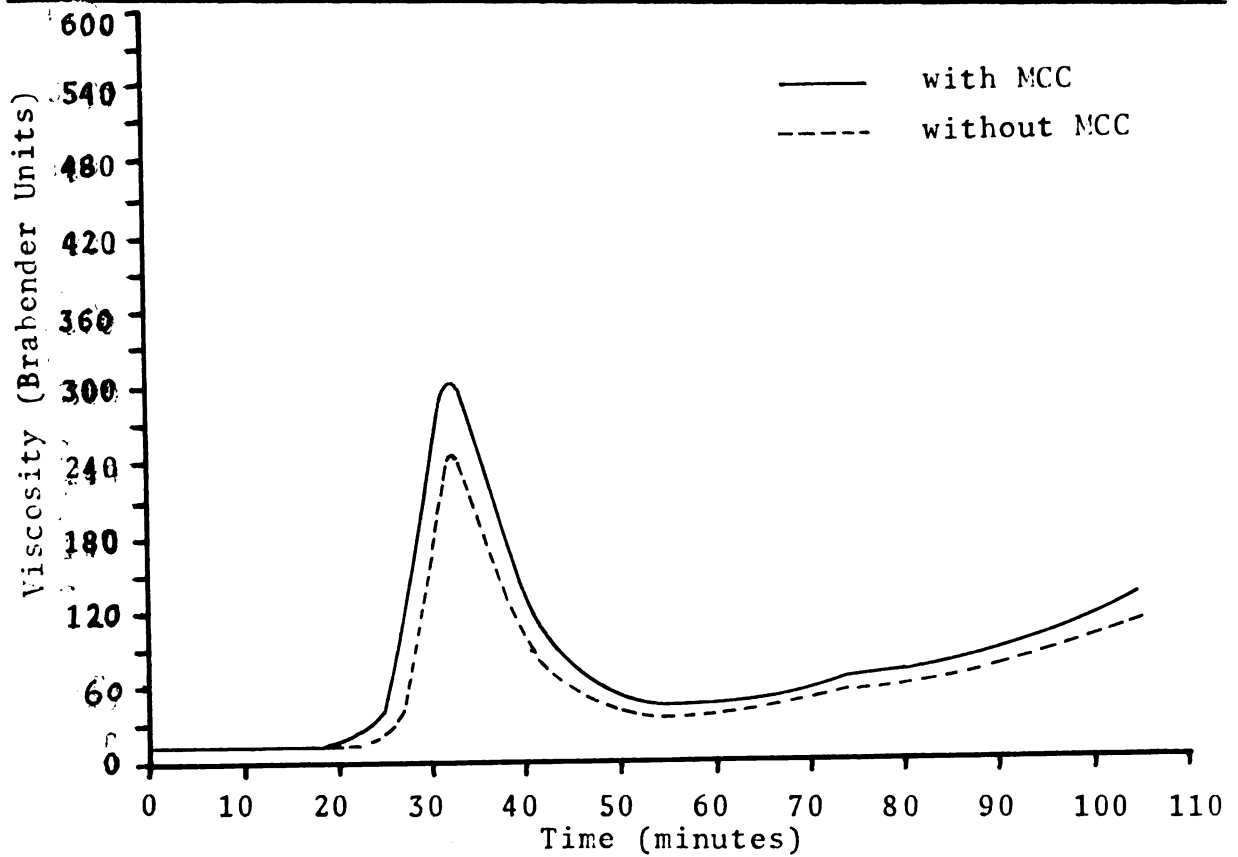


Figure 3.

Figure 4. Visco-amylo-Graphs for Slurries modified to Contain 60% of the Flour in the Control Slurry and with 40% MCC Substitution

Figure 5. Visco-amylo-Graphs for Slurries modified to Contain 40% of the Flour in the Control Slurry and with 60% MCC Substitution

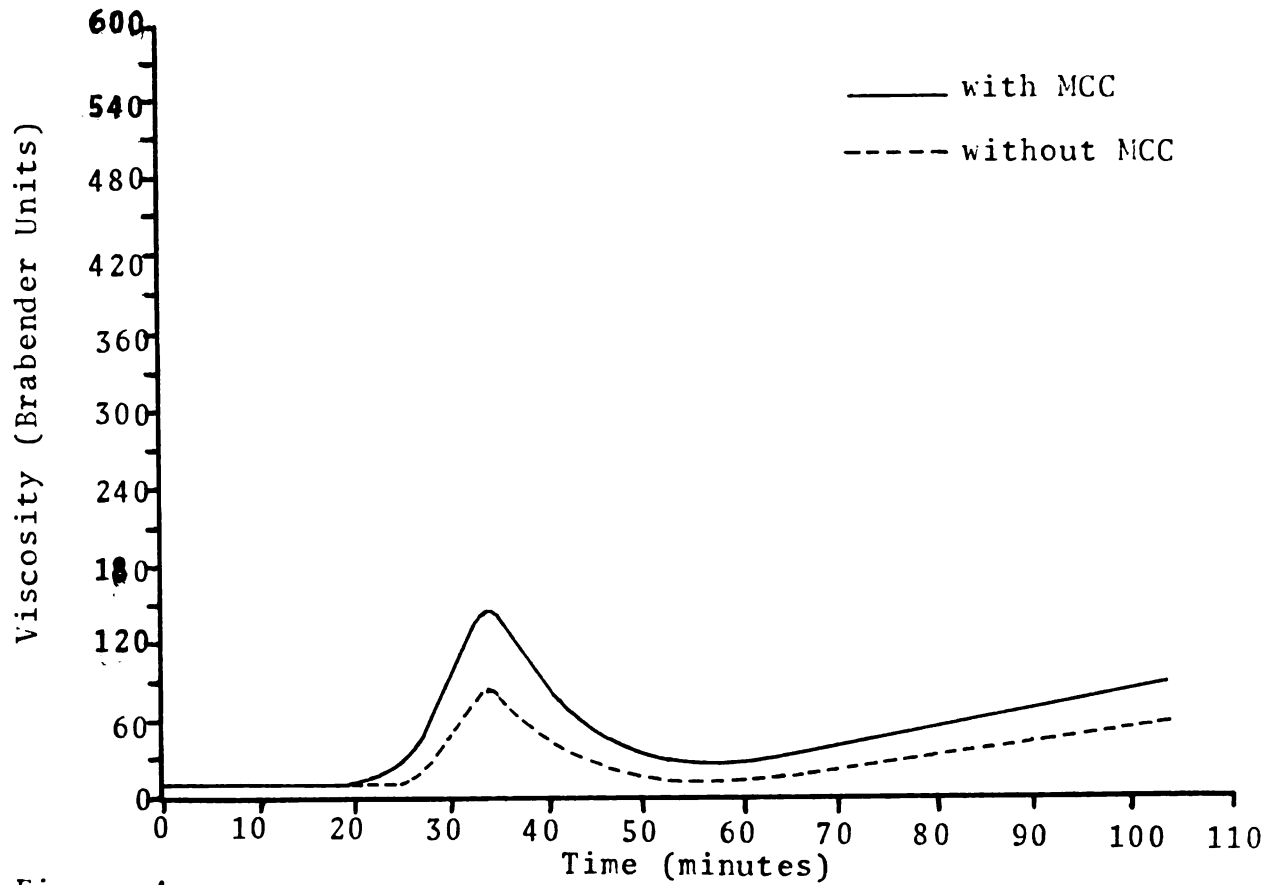


Figure 4.

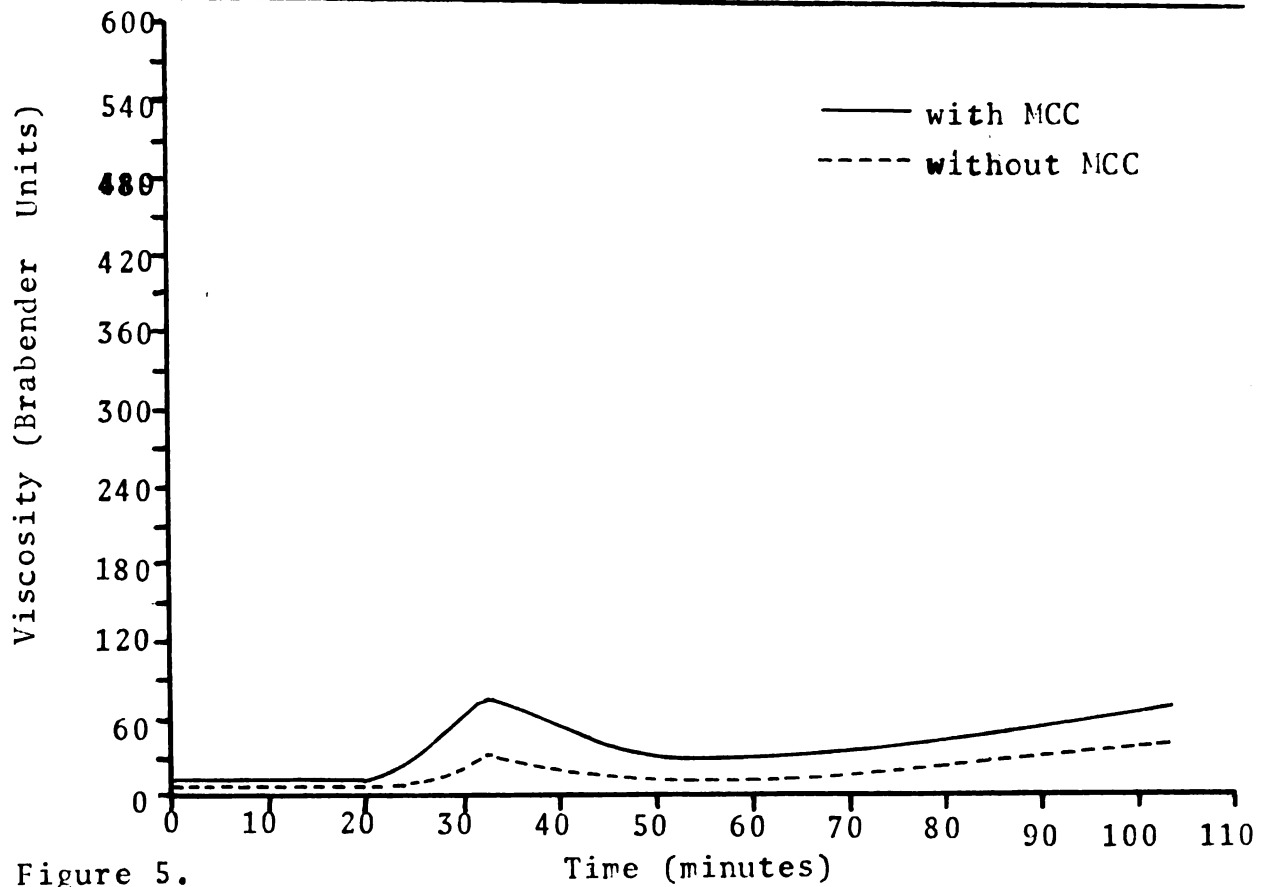


Figure 5.

Figure 4. Visco-amylo-Graphs for Slurries modified to Contain 60% of the Flour in the Control Slurry and with 40% MCC Substitution

Figure 5. Visco-amylo-Graphs for Slurries modified to Contain 40% of the Flour in the Control Slurry and with 60% MCC Substitution

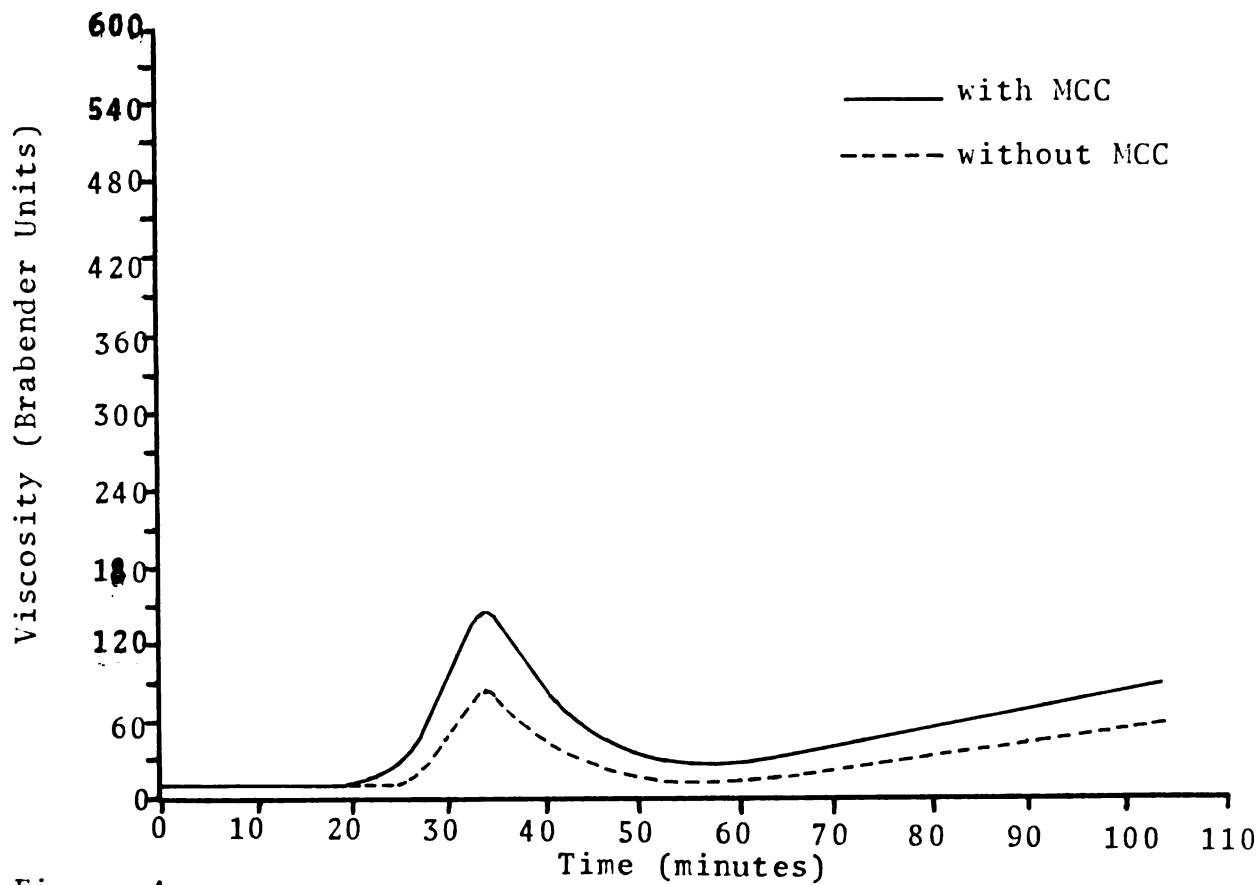


Figure 4.

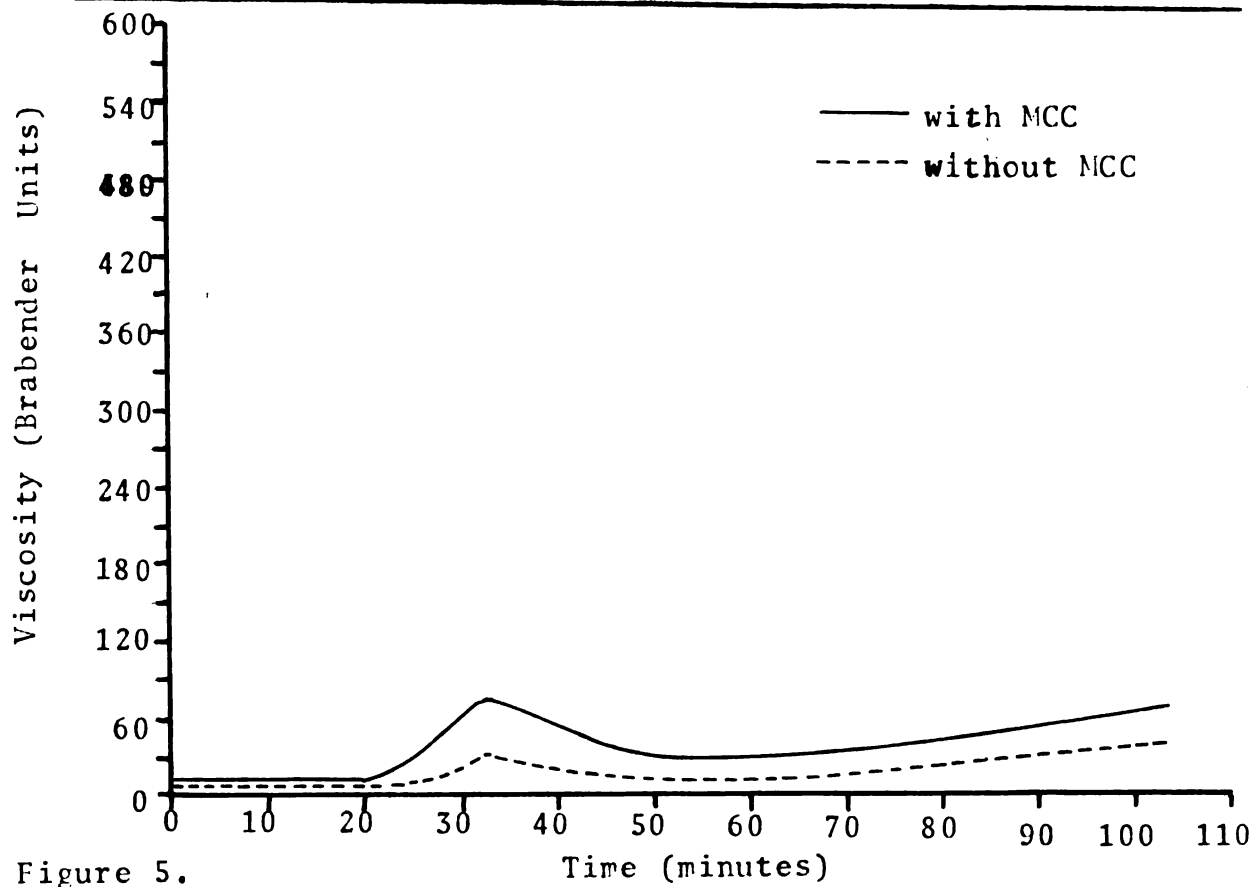


Figure 5.

Figure 4. Visco-amylo-Graphs for Slurries modified to Contain 60% of the Flour in the Control Slurry and with 40% MCC Substitution

Figure 5. Visco-amylo-Graphs for Slurries modified to Contain 40% of the Flour in the Control Slurry and with 60% MCC Substitution

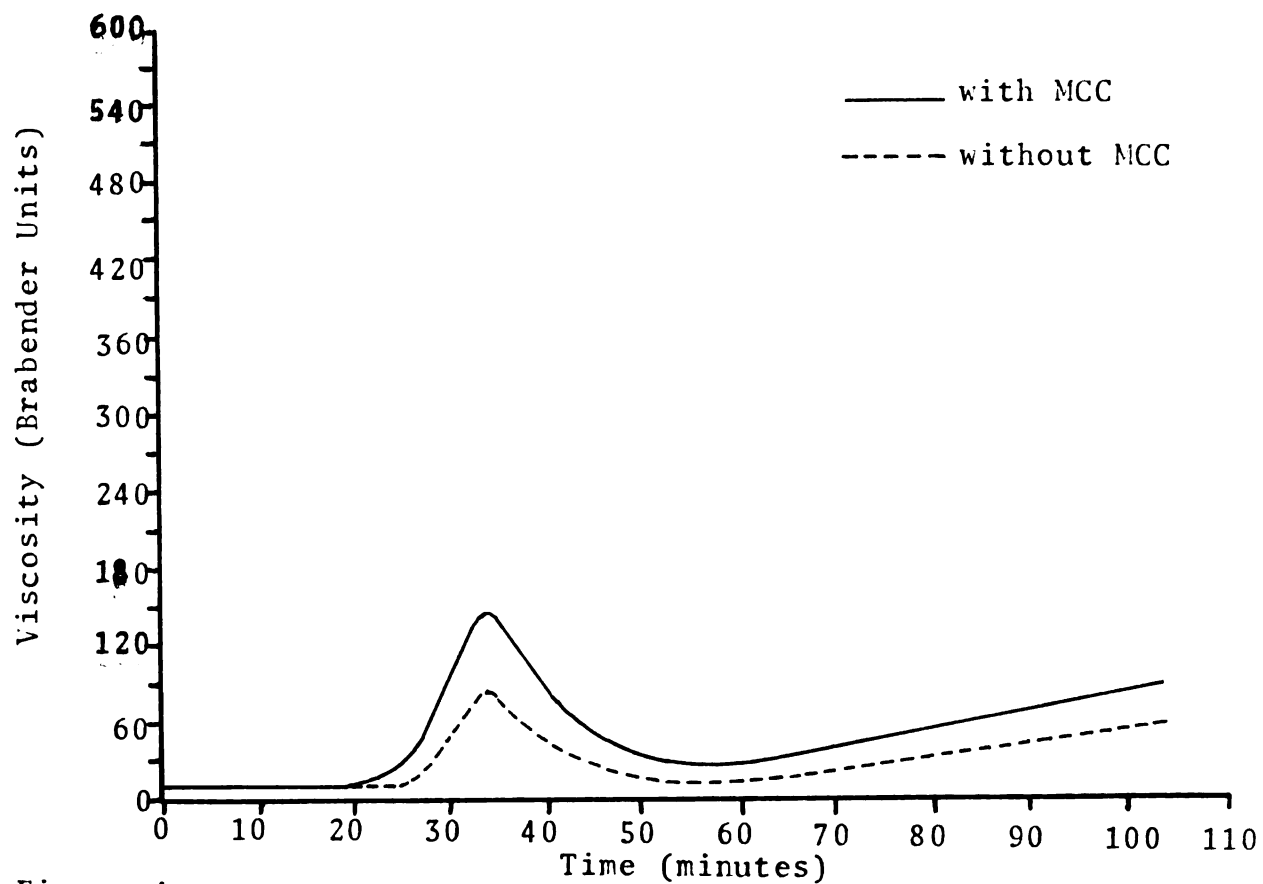


Figure 4.

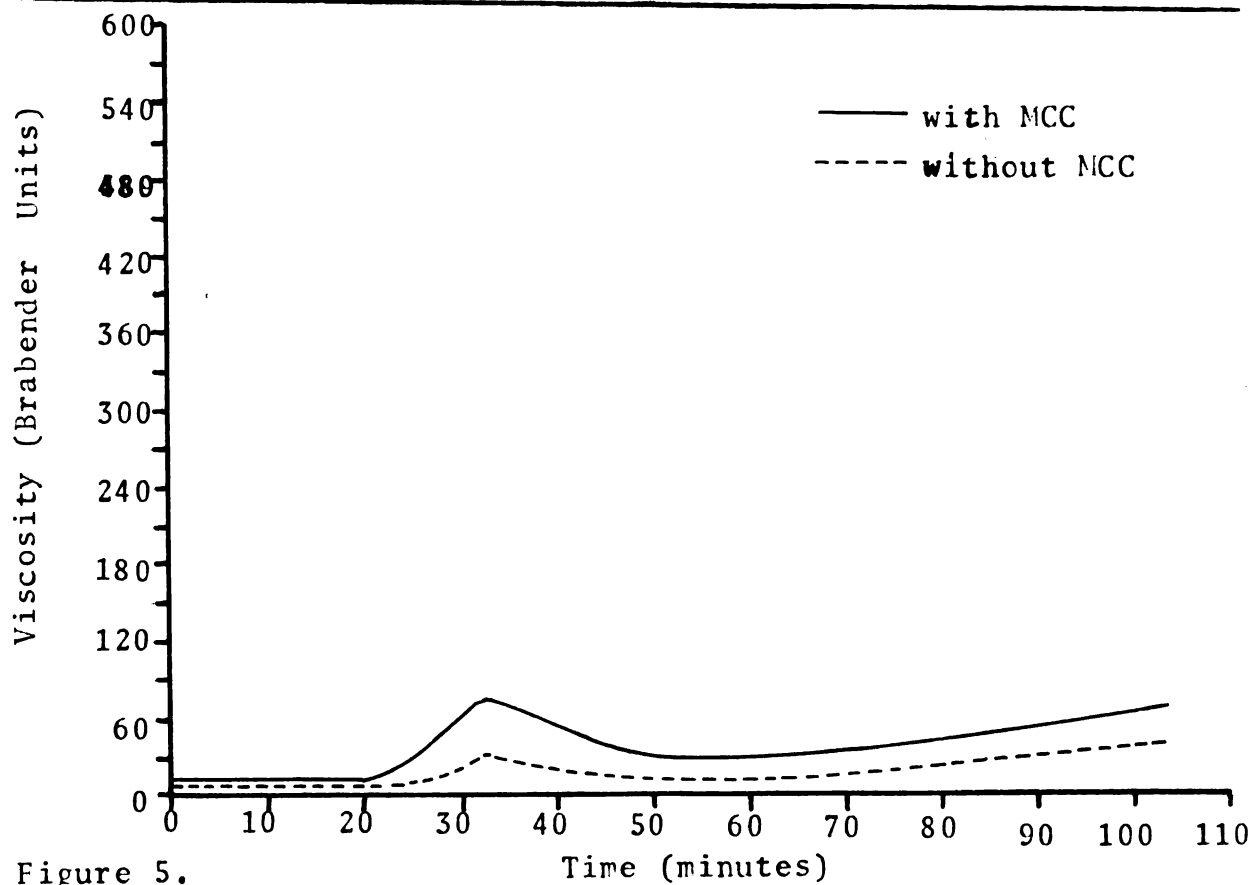


Figure 5.

temperature than that for flour slurries alone. The water absorption capabilities of MCC have been previously reported (Trauberman, 1962). Although the initial rise in viscosity in systems containing MCC occurred at a slightly lower temperature, heat appeared to have little effect on the swelling properties of MCC. Increasing the substitution level of MCC brought about slightly greater differences in Brabender units between the flour and MCC curves and the flour curves, per se. However, the water absorption properties of MCC exerted much less effect on the viscosity of the system than did those of gelatinized flour which the MCC replaced.

Dough Consistency

The farinograph is used to determine the mixing characteristics and mixing tolerance of flour in dough systems. The characteristics measured are related to the protein quantity and quality. The arrival time, which is when the curve crosses the 500 BU line, measures the rate at which water is taken up. As the protein content increases the arrival time increases. The peak time is the time it takes for the dough to reach maximum consistency and minimum mobility. Stability is the time the curve remains on the 500 BU line. It indicates maximum mixing time of the flour in a dough (Shuey, 1972).

Originally it was planned to study dough consistency at 20, 40, and 50% MCC substitution levels; however, it was not possible to study 40 or 50% substitution levels. As shown in Table 5, when MCC was substituted for 20% of the flour, peak time and stability were increased. Even though the MCC diluted the flour protein content it did not appear to have a detrimental influence on dough stability. Substitution with 30% MCC for flour slightly decreased the peak time but greatly reduced dough stability. The arrival

time decreased progressively indicating that the water was taken up progressively quicker as the amount of MCC was increased. A 30% dilution of flour protein content with MCC may have contributed to the drastic reduction in mixing tolerance and loss of cohesive and adhesive properties of dough. The latter two characteristics are vital to obtaining good farinograms.

TABLE 5. The Effect of MCC Substitution on Farinogram Parameters

Measurement	Level of Flour Substituted with Microcrystalline Cellulose		
	0%	20%	30%
Arrival Time (min)	1.0	0.8	0.5
Peak Time (min)	2.0	2.5	1.5
Stability (min)	7.5	11.5	3.8

Muller (1968) coated a farinograph bowl and blades with parafin, emphasizing the need for adhesion to the bowl and paddles, to obtain a good farinogram. Attempts to use 40 and 50% level of MCC substitution gave curves which were erratic and non-readable. This supports the theory that adhesion to the bowl and paddles is necessary for farinograms. It also appears that cohesion within the dough is essential.

Cake System

To maximize caloric reduction a lean cake formula (low in sugar and fat) was selected as the control cake. These cakes were then prepared with 0, 20, 40, and 60% MCC substitution for the flour. In order to measure the effect of this MCC substitution, physical characteristics of

TABLE 6. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour
on the Sensory Evaluation of Cakes

Source of Variance	Degree of Freedom	Mean Square				
		Color	Texture	Tenderness	Moisture	Flavor General Acceptability
Total	19					
Variable:MCC Substitution Level	4	.277*	3.384*	2.023*	1.749*	.5830* 2.370*
Replication	3	.076	.251	.324	.037	.0630 .129
Error	12	.037	.072	.169	.180	.0710 .133

*Significant at the 1 percent level of probability

the batters and cakes were evaluated. Sensory characteristics of the cakes were evaluated by a taste panel.

Sensory Evaluation of Cakes

Analysis of variance of taste panel data established significant difference ($p \leq 0.01$) among the parameters due to the level of MCC substitution (Table 6). Use of Duncan's Multiple Range Test (1957) showed that only the taste panel scores for all characteristics of cake with 60% MCC substitution for flour were significantly lower ($p \leq 0.01$) than the scores for all characteristics of cakes with the other substitution levels. Table 7 summarizes the sensory evaluation of the cakes prepared with 0 to

TABLE 7. The Effect of MCC Substitution for Flour on Sensory Evaluation of Cakes¹

Characteristic	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	60%
Color	6.4 $\pm$ 0.05 ^a	6.4 $\pm$ 0.16 ^a	6.5 $\pm$ 0.08 ^a	5.9 $\pm$ 0.40 ^b
Texture	5.5 $\pm$ 0.48 ^a	5.7 $\pm$ 0.18 ^a	5.1 $\pm$ 0.31 ^a	3.6 $\pm$ 0.22 ^b
Tenderness	5.6 $\pm$ 0.34 ^a	5.9 $\pm$ 0.20 ^a	5.8 $\pm$ 0.26 ^a	4.3 $\pm$ 0.73 ^b
Moisture	4.9 $\pm$ 0.27 ^a	5.6 $\pm$ 0.26 ^a	5.3 $\pm$ 0.37 ^a	4.0 $\pm$ 0.55 ^b
Flavor	5.4 $\pm$ 0.26 ^a	5.6 $\pm$ 0.22 ^a	5.6 $\pm$ 0.10 ^a	4.8 $\pm$ 0.37 ^b
General Acceptability	5.3 $\pm$ 0.25 ^a	5.8 $\pm$ 0.19 ^a	5.5 $\pm$ 0.37 ^a	4.0 $\pm$ 0.45 ^b

¹Mean and Standard deviation for 5 replications; 7 point scale, 7 optimum
Values marked with the same superscription are not significantly different
($p \leq 0.01$) (Duncan, 1957)

60% MCC substitution for flour. The cakes prepared with 20% of the flour substituted with MCC received the highest sensory evaluation scores for all characteristics; the cakes prepared with the 40% substitution level were rated slightly higher for all characteristics except for texture than were the control cakes. However, none of these differences were significantly different (Table 7). Lee and coworkers (1969) previously reported that as the amount of MCC increased in cookies the sensory evaluation data showed that the product became drier and possessed a chalk-like texture. This did not occur in this study, however, some taste panelists commented that the cakes prepared with 60% MCC substituted for flour were too moist and gummy.

Batter Characteristics

Analysis of variance for batter characteristics are summarized in Table 8. Substitution of 20% MCC for flour had little effect on cake

TABLE 8. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on the Batter Viscosity and Specific Gravity of Cakes

Source of Variance	Degree of Freedom	Mean Square	
		Batter Viscosity	Specific Gravity
Total	19		
Variable:MCC Substitution Level	4	7967960*	.001525*
Replication	3	37707	.001861*
Error	12	4828	.000258

*Significant at 1.0 percent level of probability

batter viscosity (Table 9). Nevertheless, substitution of 40 and 60% MCC for flour resulted in progressively higher viscosity values as shown in Table 9. The increase in batter viscosity does not agree with the results of the Visco-amylo-Graph study. Since cake batter contains other solid ingredients, the total solids content of the batter was considerably higher than that in the 25% flour-MCC slurry used in the Visco-amylo-Graph study. The 40 and 60% levels of substitution had a ratio of cellulose solids and liquid which

TABLE 9. The Effect of Substituting MCC for Flour on Batter Viscosity and Specific Gravity of Cakes¹

Test	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	60%
Batter Viscosity (poise)	299 ± 25 ^a	292 ± 25 ^a	488 ± 3 ^b	588 ± 22 ^c
Specific Gravity	.88 ± .029	.89 ± .022 ^a	.90 ± .014 ^{ab}	.92 ± .026 ^b

¹Mean and standard deviation for 5 replications.
Values marked with the same superscript are not significantly different
($p \leq 0.01$) (Duncan, 1957)

were 20 and 29% respectively. Because of the different solid-liquid ratio, the MCC may be acting to form a gel as described by Trauberman (1962). The other ingredients such as sugar, egg, and milk proteins can form hydrogen bonds with water. Therefore, there is actually less available water which would increase the possibility of forming a MCC gel.

Specific gravity which is an indication of the amount of air incorporated in a batter was lowest for the control cake batter and increased slightly as the amount of MCC increased in the batter (Table 9). Since

the amount of air incorporated during creaming of the shortening should be the same for all variables, the MCC either decreased the amount of air incorporated in the batter after its addition, and/or caused a loss of the air which had been already incorporated in the batter during the creaming process. Since the flour was diluted with MCC, the amount of flour soluble proteins were also reduced. Howard et al., (1968) indicated that soluble proteins in flour contribute to the foaming function of the batter and hence air incorporation. The greater the proportion of MCC incorporated, the greater the reduction in amount of soluble albumins and globulins in flour. This may explain the progressively higher specific gravity of cake batters with MCC.

Volume Indices

Analysis of variance (Table 10) and use of Duncan's Multiple Range Test (1957) showed that the cake volume index decreased significantly ($p \leq 0.01$) with each progressive increment of MCC substitution (Table 11). Cake contour which is measured by the symmetry index was only slightly affected by MCC incorporation. The only significant differences occurred between symmetry values for the control cake and the cake with 60% of the flour substituted. Moreover, there were no significant differences (Table 11) among the uniformity indices which measure the symmetry of the cakes, for the four cake variables. Substitution of 60% MCC for flour significantly reduced the cake shrinkage as compared to that of the control cake and cakes containing 20 and 40% MCC substitution.

Decreased air incorporation as shown by the specific gravity of batters contributed to lower cake volume. The ability of the cakes batter to entrap leavening gases as they are released from the chemical reactions of the baking powder system is also important in producing a high volume

TABLE 10. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on Cake Volume, Symmetry, Uniformity, and Shrinkage Indices

Source of Variance	Degree of Freedom	Mean Square			
		Volume Index	Symmetry Index	Uniformity Index	Shrinkage Index
Total	39				
Variable:MCC Substitution Level	9	6.101*	0.074	0.0023	0.049*
Replication	3	.326	0.023	0.0751*	0.018
Error	27	.089	0.027	0.0155	0.011

*Significant at the 1 percent level of probability

TABLE 11. The Effect of MCC Substitution on Cake Volume, Symmetry, Uniformity, and Shrinkage Indices¹

Index	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	60%
Volume (cm)	11.4 ± .32 ^a	10.9 ± .34 ^b	9.6 ± .33 ^c	8.3 ± .23 ^d
Symmetry (cm)	0.4 ± .17 ^a	0.3 ± .14 ^{ab}	0.3 ± .20 ^{ab}	0.2 ± .21 ^b
Uniformity (cm)	0.2 ± .13 ^a	0.2 ± .15 ^a	0.2 ± .14 ^a	0.2 ± .09 ^a
Shrinkage (cm)	1.4 ± .12 ^a	1.4 ± .05 ^a	1.4 ± .12 ^a	1.2 ± .09 ^b

¹Mean and standard deviation for 5 replications.
Values marked with same superscript are not significantly different.
($p \leq 0.01$) (Duncan, 1957)

cake. As the protein content of the flour decreases, less of a gluten matrix was formed to hold in these leavening gases. Even though higher MCC substitution levels produced more viscous batters, the resultant cake systems may have lacked the gluten network essential for gas retention (Howard *et al.*, 1968). The highly viscous batters of cakes with MCC substitution may have also reduced air cell mobility and normal batter dynamics during baking, thus contributing to a decreased volume. Cakes with 60% of flour substituted with MCC had collapsed cells and were compact in appearance substantiating the theory that the gluten matrix was not strong enough to hold the released leavening gases.

Moisture and Tenderness of Cakes

Analysis of variance established significant differences ($p \leq 0.01$) among all parameters (Table 12). Moistness of cakes was evaluated as a

TABLE 12. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on Baking Losses, Moisture and Tenderness of Cakes

Source of Variance	Degree of Freedom	Mean Square			
		Baking Losses	Moisture Content	Shear Press	Compression
Total	39				
Variable:MCC Substitution Level	9	1.570*	5.69*	.652	1.60*
Replication	3	4.870	8.70*	.152	9.74
Error	27	.53	1.11	.008	.64

*Significant at the 1.0 percent level of probability

sensory characteristic (Table 7), from baking loss data, and by the moisture content determined by drying cake samples under vacuum (Table 13). During baking, cakes containing the highest MCC substitution levels lost significantly more moisture than did the other cakes (Table 13). The percentage moisture content of the cakes increased as the degree of MCC substitution increased from 0 to 60%. The cakes with 60% MCC substituted for

TABLE 13. The Effect of MCC Substitution on Baking Losses, Moisture and Tenderness of Cakes¹

Test	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	60%
Baking Losses (%)	11.5 ± .56 ^a	11.8 ± .66 ^a	12.0 ± .33 ^a	13.2 ± 1.5 ^b
Moisture Content (%)	26.8 ± .78 ^a	28.1 ± .78 ^{ab}	29.4 ± .72 ^c	29.5 ± 2.1 ^{bc}
Shear Press (lb/gm)	2.11 ± .15 ^a	1.66 ± .11 ^b	1.35 ± .16 ^c	1.08 ± .18 ^d
Compression (lb/cm)	6.52 ± .99 ^a	6.15 ± .76 ^a	7.16 ± .14 ^{ab}	7.72 ± 1.3 ^b

¹Mean and standard deviation for 5 replications.
Values marked with same superscript are not significantly different.
($p \leq 0.01$) (Duncan, 1957)

flour lost significantly ($p \leq 0.01$) more moisture during baking than did any of the other cakes yet had the highest moisture content; this is possible since the batter contained more liquid to allow for the increased water-binding capacity of MCC. The taste panel scored the cakes with the highest level of MCC significantly lower (Table 7) indicating that the cakes were overly moist and gummy. The taste panelists felt the control

cakes were slightly dry, probably due to the low sugar content. The water-binding capacity of MCC, as demonstrated here, improves the quality of the cakes with 20% MCC substituted for flour. However, when greater than 40% MCC was substituted for flour, the cakes contained excess moisture resulting in a gummy texture which was considered undesirable.

As the amount of MCC increased significantly less force was required to shear the samples of cake (Table 13). This indicated that the samples became more tender as the proportion of MCC in the cakes increased. This is probably due to the progressively lower amounts of flour proteins available to create a structure and resist shearing. The taste panel results agree in that some members felt that the control showed some resistance to tearing, while the cake with 60% MCC substitution for flour was regarded as crumbly. All cakes in this study were prepared with all purpose flour which forms both a stronger gluten and a greater amount of gluten than cake flour. Use of all purpose flour would generally cause a tougher product for the control. This was also augmented by the reduction of normal tenderizing agents, i.e. sugar and shortening, to produce a low calorie control cake. Use of MCC diluted the protein which produced more tender cakes, however, at the 60% substitution level the cakes were too tender and were found to be crumbly.

The amount of force required to compress a centimeter of cake gradually increased as the degree of MCC substituted for flour increased (Table 9). An increase in force required to compress the cake is indicative of a decrease in the open texture of an angel cake study (Funk et al., 1969). Compressability values indicates that as the MCC increased the openness of the cell structure decreased slightly. The taste panel's comments showed a similar trend for the texture evaluation of the cakes. The control cake and cake with 20% MCC substitution were scored as having good

texture with only occasional scores of irregular or large air cells. The cakes with 40% MCC substitution were evaluated as sometimes slightly compact whereas the cakes with 60% MCC substituted for flour were usually evaluated as compact. This increase in compactness shows the impaired ability of the diluted gluten network to provide structure.

Cake Color

Analysis of variance (Table 14) showed no significant differences in crust and crumb color of cakes containing 0 to 60% MCC substitution (Table 15). Use of the Hunter Color Difference Meter to measure the color of the flour and MCC, per se, showed that the flour was less white and slightly more yellow and green. These slight color differences were probably offset by the yellow of eggs and the brown of the vanilla in the cake batter as well as pigments produced by caramelization and the Maillard reaction during baking.

Functionality of MCC in Cake Systems

The function of flour starch may be equally or more important than that of the flour proteins in the overall characteristics of the cake system, especially when the cake system contains an ingredient such as an emulsifier which aids in suspending the starch granules. The polar moieties of the monoglycerides in emulsifier systems interact with the polar groups of the starch molecules, therefore, physically separating the starch granules and preventing their interactions (Handleman et al., 1961). The granular swelling which occurs after gelatinization temperature is reached is irreversible (Schoch, 1965), and the amount of this swelling affects both the final volume and the textural characteristics of the cake.

Microcrystalline cellulose may function similarly to starch in its ability to bind water. Both MCC and starch are polymers of glucose and,

TABLE 14. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on Crumb and Crust Color Measurements of Cake

Source of Variance	Degree of Freedom	Mean Square					
		Crumb			Crust		
		L	a _L	b _L	L	a _L	b _L
Total	19						
Variable:MCC							
Substitution Level	4	5.060	1.214	3.68	1.57	0.37	0.94
Replication	3	98.64*	5.161	21.75*	34.53*	4.12	7.98
Error	12	7.77	2.533	1.77	5.37	1.65	1.56

*Significant at the 1.0 percent level of probability

TABLE 15. Color Measurements of Cakes prepared with MCC Substitution for Flour¹

Scale ²	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	60%
<u>Crumb</u>				
L	61.86 ± 5.75	60.59 ± 5.64	61.36 ± 3.84	63.34 ± 4.20
a _L	- 2.35 ± 1.48	- 2.30 ± 1.45	- 3.28 ± 1.81	- 3.34 ± 1.76
b _L	+16.56 ± 2.76	+16.25 ± 2.41	+16.80 ± 1.94	+18.30 ± 2.00
<u>Crust</u>				
L	34.80 ± 3.09	35.40 ± 3.26	34.84 ± 1.44	33.84 ± 4.44
a _L	+ 8.35 ± 0.50	7.79 ± 1.07	+ 8.36 ± 1.28	+ 8.49 ± 2.23
b _L	+15.52 ± 1.72	+15.95 ± 1.64	+16.07 ± 0.95	+14.96 ± 2.02

¹Mean and standard deviation of 5 replications.²L= lightness, a_L = greenness and redness, b_L = yellowness

therefore, contributed similar numbers of hydroxyl group which can interact with emulsifiers. If MCC can function similarly to starch and starch exerts the major influence on textural characteristics of the cake system, the substitution of MCC for flour should not have a detrimental affect on cake quality. Cakes prepared with 20 and 40% MCC substitution were quite similar in quality characteristics to those of the control. However, MCC substitution does dilute the protein content of the flour, which provides the protein matrix structure of the cake. When the protein content is decreased so that there is an insufficient amount of gluten to provide a continuous network, the structure collapses and the cake is compact, as was seen in cakes with 60% substitution of flour with MCC (Donelson and Wilson, 1960; Baldi et al., 1965).

Differences in taste panel scores were minimal among the cakes prepared with 0, 20, and 40% flour substituted with MCC. The volume index and tenderness were the only objective tests that showed any significant differences between cakes containing 0 and 20% MCC substitution for flour. Cakes with 40% substitution for flour showed some significantly lower measurements for objective tests, but these cakes were not scored significantly lower by the taste panelsits. Cakes with 60% MCC substituted for flour was found to be inferior by both methods of testing.

Calorie Content of Cakes

Caloric density of 100 grams of baked cake was calculated using compositional data in Handbook No. 8 (Watt and Merrill, 1963), and this information is summarized in Table 16. Since the proportion of sugar and fat were reduced in the control formula, the caloric value is also compared to a standard yellow cake which had sugar and fat ratios of 116 and 42% respectively of the weight of the flour (Betty Crocker, 1973).

TABLE 16. Caloric Density of Cakes

Sample	Calories per 100 grams of Cake	Percent Calories reduced from higher Ration Cake	Percent Calories reduced from 0% MCC Cake
0% MCC Substitution for flour	337.2	8.9	- -
20% MCC Substitution for flour	317.5	14.0	5.8
40% MCC Substitution for flour	297.0	19.7	11.9
60% MCC Substitution for flour	279.4	24.6	17.1
Higher Ratio Cake ¹	370.0	- -	- -

¹Crocker, 1973, p. 96

Compared to the caloric content of the Betty Crocker cake the caloric reduction with increasing MCC substitution is even more encouraging. Moreover, cakes differ in the ratio of ingredients. The standard white cake formula adapted by the American Association of Cereal Chemists (AACC, 1969) uses sugar and shortening ratios of 140 and 50% respectively, as compared to a flour weight of 100; and chocolate cakes may use as much as 170 and 60% sugar and shortening respectively, thus having considerable higher caloric content per 100 grams of cake. The caloric reduction of cakes with MCC substitution is not enough to classify these cakes as a dietetic food since this classification requires a 50% caloric reduction. Nevertheless, 20 and 14% fewer calories for the cakes with 40 and 20% MCC substitution levels respectively, would help in reducing caloric consumption.

The cellulose content for the cakes is 3.5, 7, and 10.5% for the 20,

40, and 60% substitution of flour with MCC, respectively. This amount may be less dietary fiber than is recommended, but would help by adding to the fiber already present in the diet. Ingestion of this additional cellulose would probably speed-up the transit time in the intestine, and might cause less nutrients from the cake to be absorbed, therefore providing fewer calories.

Biscuit System

Substitution of MCC for flour was also evaluated in biscuits. Biscuits were chosen since they are a simpler system, containing only flour, shortening, baking powder, salt and liquid. Since they are an example of a dough, they depend more on the development of the gluten matrix for desired quality characteristics.

Sensory Evaluation of Biscuits

Analysis of variance (Table 17) established significant differences ($p < 0.01$) among the biscuits with 0, 20, 40, and 50% MCC substitution for flour, for all sensory characteristics evaluated. Duncan's multiple Range Test (1957) was used to pinpoint the significant difference among levels of MCC incorporation.

Sensory evaluation scores rated the biscuits with 20% MCC substituted for flour significantly lower for appearance, texture and general acceptability than the control biscuits (Table 18). These biscuits however all received ratings of 5 or above on a 7 point scale and were, therefore, still rated as good. With 40% substitution of the flour with MCC all the characteristics of the biscuits evaluated had significantly lower scores ranging from 3.9 to 4.7 on a 7 point scale. Moisture and tenderness were the only scores of the biscuits containing 50% MCC substitution for flour which were not significantly lower than those of the biscuits with 40% of

TABLE 17. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on Sensory Evaluation of Biscuits

Source of Variance	Degree of Freedom	Mean Square				
		Appearance	Texture	Tenderness	Moisture	Flavor
Total	19					General Acceptability
Variable:MCC						
Substitution Level	4	4.00*	4.91*	4.02*	2.03*	2.34*
Replication	3	0.181	0.12	0.21	0.06	0.16
Error	12	0.078	0.048	0.068	0.044	0.075

*Significant at the 1.0 percent level of probability

TABLE 18. The Effect of MCC Substitution on Sensory Evaluation of Biscuits¹

Characteristic	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	50%
Appearance	5.9 ± .26 ^a	5.1 ± .36 ^b	3.9 ± .25 ^c	3.2 ± .32 ^d
Texture	5.9 ± .19 ^a	5.3 ± .37 ^b	3.9 ± .18 ^c	3.3 ± .15 ^d
Tenderness	5.7 ± .16 ^a	5.3 ± .34 ^a	3.9 ± .23 ^b	3.5 ± .40 ^b
Moisture	5.5 ± .31 ^a	5.1 ± .19 ^a	4.3 ± .11 ^b	3.9 ± .18 ^b
Flavor	5.9 ± .23 ^a	5.4 ± .31 ^a	4.7 ± .25 ^b	4.1 ± .35 ^c
General Acceptability	5.7 ± .17 ^a	5.1 ± .38 ^b	3.9 ± .28 ^c	3.3 ± .19 ^d

¹Mean and standard deviation of 5 replications; 7 point scale, 7 optimum. Values marked with same superscript are not significantly different ($p \leq 0.01$) (Duncan, 1957)

the flour substituted with MCC. Panelists' comments were that the biscuits with 40 and 50% MCC substitution were tough, dry, and lacked flavor. The taste panel results did not show any biscuit characteristic improved by the substitution of MCC for flour, whereas improvement had occurred with 20 and 40% MCC substitution for flour in the cake system.

Volume, Moisture and Tenderness of Biscuits

Analysis of variance established significant differences ($p < 0.01$) among all parameters (Table 19). Moisture for the biscuits was also assessed by three methods: baking loss, moisture content, and sensory evaluation. Baking losses of the biscuits significantly ($p < 0.01$) increased up to the 40% MCC substitution level, as shown in Table 13. The moisture content increased with the additional MCC substitution, but this increase was not significant, except in the biscuits containing 50% MCC substitution level. Taste panelists rated the moistness of biscuits containing 40 and 50% MCC substitution for flour significantly lower than that of those containing 0 and 20% MCC substitution for flour. The panelists indicated that biscuits with higher levels of MCC substitution for flour were drier, especially the crust, substantiating the work of Lee and coworkers (1969). Occasionally a panelist commented that the biscuits containing higher levels of MCC substitution were too moist or gummy, particularly toward the center. Since the biscuits with the higher levels of MCC actually had higher moisture contents (Table 20) a moist or gummy product might be expected.

Biscuit size was evaluated using two measurements: height in centimeters and volume as determined by rape seed displacement. Substituting 50% of the flour with MCC produced biscuits which were significantly smaller than the 0 and 20% substitution levels (Table 13). Although biscuits

TABLE 19. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on Baking Losses, Moisture Content, Volume, and Tenderness of Biscuits.

Source of Variance	Degree of Freedom	Mean Square				
		Baking Losses	Moisture Content	Volume	Height	Shear Press Compression
Total	39					
Variable:MCC Substitution Level	9	14.50*	9.04*	156*	18.7*	11.26
Replication	3	6.79	33.59*	109*	45.3	57.06*
Error	27	1.14	1.56	43	4.3	10.78
						154

*Significant at the 1.0 percent level of probability

TABLE 20. The Effect of MCC Substitution on Baking Losses, Moisture Content, Volume and Tenderness of Biscuits¹

Tests	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	50%
Baking Losses (percent)	17.6 ± 0.81 ^a	18.9 ± 0.94 ^b	21.7 ± 1.6 ^c	21.5 ± 1.3 ^c
Moisture Content (percent)	20.7 ± 1.6 ^a	22.1 ± 2.0 ^a	22.2 ± 2.7 ^a	24.7 ± 1.5 ^b
Volume (cc)	62 ± 11.1 ^a	62 ± 6.7 ^a	56 ± 12.7 ^{ab}	48 ± 12.1 ^b
Height (cm)	3.0 ± .19 ^a	2.9 ± .14 ^a	2.5 ± .12 ^b	2.2 ± .20 ^c
Shear Press (lb/gm)	16.8 ± 1.7 ^a	18.7 ± 3.0 ^a	21.1 ± 3.5 ^a	20.1 ± 5.3 ^a
Compression (lb/cm)	52.6 ± 8.8 ^{ab}	48.0 ± 11.4 ^a	44.9 ± 8.1 ^a	65.5 ± 23.1 ^b

¹Mean and standard deviation for 5 replications.

Values marked with the same superscript are not significantly different ($p \leq 0.01$) (Duncan, 1957)

containing 40% MCC substitution were smaller than those containing lower levels of MCC substitution the differences were not significant. The biscuit height decreased as the proportion of MCC increased with biscuits containing 40 and 50% MCC substitution for flour being significantly lower than those with lower levels of MCC.

Differences in height account for most of the differences in volume, nevertheless the biscuits with a higher level of MCC substitution appeared to have a slightly larger diameter, but this was not measured. Volume and height of biscuits is attributed to steam and leavening gases released during baking. This separates the layers of dough created by the gluten networks coated with fat. Early release of leavening gases and insufficient gluten networks to retain the gases would decrease the volume. The dilution of the flours protein by addition of MCC reduces the amount of gluten present to form networks. The starch component of wheat flour and starch-like MCC which lack the functional properties of flour gluten protein. Consequently increasing the proportion of MCC resulted in loss of volume and flakiness in biscuits.

The results of the farinograph studies also showed that as the proportion of MCC substitution for flour increased a less cohesive dough was formed. Gluten which is necessary to provide cohesiveness and elasticity to the dough is diluted by MCC. The quality characteristic of biscuits are adversely affected when a less elastic and cohesive dough is formed. The volume may be decreased because the dough is not elastic and cohesive enough to expand, and consequently, the steam, carbon dioxide, and air are allowed to escape without functioning to separate the dough layers.

The amount of force required to compress each centimeter of the biscuit did not follow the expected pattern of increasing compressibility values as the biscuit volumes were lowered which resulted from the

increasing level of MCC substitution for flour (Table 13). The biscuits were expected to be more compact as the volume decreased, but the force required to compress the biscuits dropped insignificantly up to the 40% MCC substitution level then rose significantly for biscuits with 50% MCC substituted for flour. Biscuits with 50% MCC substitution were definitely more compact than those containing lower amounts of MCC. Reasons for decreased force required to compress biscuits with 20 and 40% MCC substitution for flour is not clearly understood. An increase in compactness was expected because of the lower volume but data did not support this assumption. The taste panelists indicated that the biscuits containing 20 and 40% MCC substitution lacked flakiness, where as at the highest substitution level the biscuits were scored as being compact. The ability of MCC to absorb oil may have interfered with the functional property of oil to shorten and separate the gluten strands.

Even though the force required to shear the biscuits increased as the amount of MCC increased, these tenderness values were not significantly different (Table 13). The taste panel indicated a gradual decrease in biscuit tenderness as levels of MCC substitution increased. However, comments indicated that the crusts tended to be tough, especially for the biscuits with 40 and 50% MCC substitution. The discrepancy between the two evaluations may be because whole biscuits were sheared. The crusts toughness may have been more similar among variables than the crumb tenderness, and the taste panel could differentiate between the parts of the biscuits' tenderness, whereas, the shear press based on maximum peak height could not.

Tenderness is usually associated with the amount of gluten development. As the protein was diluted with higher substitution of MCC for flour, the biscuits should have become more tender. Since the biscuits became tougher

as the amount of MCC increased, this indicates that other factors may cause the increased toughness. The compactness and dryness or factors which also influenced them may have had an affect on the taste panelists perception of tenderness. Mutual starch-starch binding if in excess would also have an effect (Baldi et al., 1965).

Color of Biscuits

Analysis of variance established significant difference ($p \leq 0.01$) among some of the crumb and crust color measurements (Table 21). The crust color of the control biscuit was significantly darker than the biscuits with MCC (Table 22). The control biscuit had a slight degree of redness ($+a_L$) while the biscuits containing MCC had a small amount of greenness ($-a_L$), however, these values were very low and the difference was not significant. The yellowness of the biscuit crust decreased with increasing amounts of MCC substitution for flour. Neither lightness (L) nor greenness ($-a_L$) of the biscuit's crumb showed any significant differences among variables. The crumb yellowness ($+b_L$) was significantly lower for the biscuits with 40 and 50% MCC substitution than those with 0 and 20% of the flour substituted with MCC. MCC does not impart the color that flour does. It lacks the pigments in flour and does not contribute the proteins or carbonyl compounds which interact during baking to cause browning. Whether MCC interacts with other ingredients or components to produce browning reaction is not known, but it does not appear to contribute significantly to crust browning in baked products since the biscuits containing higher levels of MCC substitution were paler than the control biscuits.

Calorie Content of Biscuits

Caloric density of the biscuits was calculated on the basis of a 25 gram biscuit from composition data in Handbook 8 (Watt and Merrill, 1963).

TABLE 21. Analysis of Variance for Determining the Effect of MCC Substitution for part of the Flour on Crumb and Crust Color Measurements of Biscuits.

Source of Variance	Degree of Freedom	Crumb			Crust		
		L	a _L	b _L	L	a _L	b _L
Total	19						
Variable:MCC							
Substitution level	3	3.98	.64	2.80*	36.85*	1.48	16.85*
Replication	4	14.48	2.81	.78	20.36	8.06	.79
Error	12	2.45	1.22	.29	2.54	1.99	1.81

*Significant at the 1.0 percent level of probability

TABLE 22. Color Measurements of Biscuits prepared with MCC Substitution for Flour¹

Color Measurement ²	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	50%
<u>Crumb</u>				
L	45.73 ± 3.21 ^a	47.91 ± 1.49 ^a	46.34 ± 1.38 ^a	47.60 ± 1.90 ^a
a _L	-1.29 ± 1.08 ^a	-1.70 ± 1.18 ^a	-0.79 ± 1.30 ^a	-1.62 ± .12 ^a
b _L	10.62 ± .79 ^a	10.35 ± .57 ^a	8.93 ± .48 ^b	9.07 ± .46 ^b
<u>Crust</u>				
L	39.06 ± 2.07 ^a	42.28 ± 2.66 ^b	45.08 ± 1.37 ^b	46.02 ± 3.11 ^b
a _L	-0.68 ± 0.72 ^a	-0.05 ± 1.47 ^a	-0.23 ± 1.61 ^a	-0.85 ± 2.6 ^a
b _L	15.87 ± 1.02 ^a	14.98 ± 1.67 ^a	11.47 ± 0.14 ^b	12.22 ± 1.27 ^b

¹Mean and standard deviation for 5 replications.

Values marked with the same superscript are not significantly different (p≤0.01) (Duncan, 1957)

²L = lightness, a_L = redness and greenness, b_L = yellowness

Since the average weights of the 5.1 cm (2 in.) diameter biscuits varied, the caloric values were also calculated for the average weight biscuit at each substitution level and are summarized in Table 23. The weight of the biscuits decreased as the amount of MCC in the formulation was increased. The average biscuit weights were 27.5, 27.4, 24.2, and 22.5 grams for the 0, 20, 40, and 50% of the flour substituted with MCC, respectively.

TABLE 23. Caloric Density of Biscuits

Caloric Evaluation	Level of Flour Substituted with Microcrystalline Cellulose			
	0%	20%	40%	50%
25 Gram Biscuit	91.8	83.1	74.8	68.9
Averaged weight Biscuit	100.7	90.0	72.4	62.0
Percent calories reduced from 0%				
for averaged weight Biscuits	- -	9.9	28.2	38.5
for 25 gram biscuit	- -	9.5	18.5	24.9

The caloric reduction of the biscuits for 20 and 40% substitution levels is not quite as high as for the cakes compared to the standard yellow cake on a weight comparison. The caloric content of an average weight biscuit exhibited greater reduction than the 25 gram biscuits of the same MCC substitution level because the biscuits weighed less with increasing MCC substitution.

The cellulose content was higher than in the cake system because the biscuits have a higher proportion of flour in the basic formula. In the biscuits with 20, 40, and 50% MCC substitution for flour, the MCC content

is 6.4, 13.1, and 16.5%, respectively. If two biscuits of the average weight for the 20, 40, and 50% substitution levels were eaten 3.5, 6.2, and 7.4 grams of cellulose would be added to the diet, respectively.

SUMMARY AND CONCLUSIONS

Microcrystalline cellulose was substituted on an equal volume basis for a portion of the flour in cake and biscuit systems. Substitution levels of 0, 20, 40, and 60% MCC for flour in a lean formula cake system and 0, 20, 40, and 50% MCC for flour in a biscuit system were evaluated by sensory and objective methods. The taste panel scored the cakes with 20% MCC substituted for flour highest for all characteristics, whereas, the control cakes and cakes with 40% MCC substituted for flour were scored slightly lower but the differences were not significant. The cakes of the 60% MCC substitution level were scored significantly lower for all characteristics evaluated. Objective tests of the cake batter showed an increase in batter viscosity and specific gravity as the proportion of MCC increased. Cooking losses and moisture content both increased with higher substitution levels of MCC. The cakes were more tender, compact, and had less volume with increased amounts of MCC. The crumb and crust color was not affected by the addition of MCC. Caloric density was decreased approximately 14, 20, and 25% for cakes with 20, 40, and 60% MCC substituted for flour, respectively, when compared with a standard yellow cake.

Taste panelists scored all characteristics of the biscuits progressively lower as the amount of MCC substituted for flour was increased. The biscuits generally became tougher, drier and had less flavor. The shear press showed no significant differences in the tenderness. Progressively less force was required to compress a centimeter of biscuit as the

amount of MCC substitution level increased up to the 40% level, after which the required force increased. As in the cake system the baking losses and moisture both increased with increased substitution of MCC for flour. The volume also decreased with additional MCC incorporation as it did in the cake system. Substitution of MCC for part of the flour resulted in significant color difference, the crust color values for lightness increased and for yellowness decreased, as did the crumb yellowness values. Biscuit caloric density was reduced about 10, 28, and 39% for 20, 40, and 50% MCC substitution for flour respectively, when biscuits of average weight for the substitution levels were compared to the control.

Dough consistency was studied using a farinograph and MCC substitution for flour of 0, 20, and 30%. The arrival time decreased with increased MCC substitution, while the peak time and stability increased for the 20% substitution level and decreased for the 30% substitution level. The Visco-amylo-Graph was used to study viscosity of 25% flour in water slurries. Substitution of 0, 20, 40, and 60% MCC for flour were tested, showing a decreased viscosity with increased amounts of MCC. Slurries with equivalent reduction of flour without substitution of MCC showed that the presence of MCC added to the viscosity of the slurries containing it.

Micro-crystalline cellulose may be successfully substituted for part of the flour to reduce the caloric density of baked products. The amount which may be incorporated and still provide an acceptable product is dependent on the system used.

The cake system was capable of carrying a higher percentage of MCC substituted for flour and still produce good quality products. Biscuit quality decreased rapidly with increased substitution of MCC for flour.

The maximum caloric reduction for products in which good quality was maintained was 20% less calories for the cake system using a cake with 40% of the flour substituted with MCC and 10% less calories for biscuits containing 20% MCC substituted for flour. Corresponding amounts of cellulose which could be added to the diet by ingesting these foods is 7 grams per 100 grams of cake containing 40% MCC substitution and 3.5 grams per 2 biscuits of average weight made with 20% MCC substituted for flour.

The caloric density reduction may be considered small, but would be beneficial in that eating small amounts of baked products occasionally may make a diet more tolerable than it would be when omitting these foods. Yet the calories consumed would be less than from ingestion of a similar quantity of the foods without MCC incorporated. Consumption of baked products with MCC rather than higher caloric normal biscuits and cakes, would probably be beneficial to the general public as well. Their consumption would increase the dietary fiber component of the diet which would be beneficial in light of the increasing incidence of diverticular disease, colonic cancer and other related diseases.

The amount of MCC which can be successfully used is dependent on the system and the component of flour which is most important for the quality characteristics of that baked product. The products in which the gluten matrix plays a vital role, the incorporation of MCC is limited as substitution dilutes the flour protein producing products of lower acceptability as was seen in the biscuit system. The proportion of flour to other functional ingredients is also an important factor. If the gelatinization of the flour-starch contributes significantly to the quality of the product and if other ingredients such as milk and eggs are also present in the product as they are in batter systems, the MCC may take over some of

the functionality of the starch and higher levels of MCC substitution may be incorporated.

SUGGESTIONS FOR FURTHER RESEARCH

Research into the functionality of MCC and its interaction with other ingredients would be beneficial since little information in this area is available.

Since dilution of the protein resulted in biscuits of lower quality; studies should be conducted evaluating incorporation of gluten with MCC or other ingredient supplementation which might function to form a rigid three-dimensional structure. This would provide a greater variety of usable products with MCC substitution and/or allow for greater MCC incorporation and hence greater caloric reduction in products already studied.

Different methods of mixing the ingredients can affect the product quality; the study of different mixing methods for products containing MCC may lead to improved product quality characteristics.

In addition use of other lower calorie counterparts for other ingredients as sugar and possibly fat would lower the caloric content, if an acceptable product were produced.

APPENDIX

SCORE SHEET FOR SHORTENED CAKES

Characteristic	Excellent	Fair	Unacceptable
Color	pale yellow interior, brown crust, even color	slightly too pale or dark, very slightly marbled, uneven color	very pale or dark marbled, uneven color (interior and exterior)
Texture	numerous, fine uniform air cells, thin cell walls	small air cells with some large cells, thick and thick cell walls	large irregular air cells, thick cell wall compact or tunneled
Tenderness	tears easily, cuts evenly without tearing	tears with slight resistance, cuts with a little crumbling	tough, resists tearing, crumbles when sliced
Moisture	soft and moist, velvety	slightly dry or moist	dry, gummy soggy
Flavor	rich, slightly vanilla, slightly sweet	slightly too bland or sweet, or not sweet enough, very slight off flavor	too bland, too sweet, not sweet enough, off flavors, caramelization

Seven Point Scale 1 - unacceptable 4 - fair 7 - excellent

Sample	Color	Texture	Tenderness	Moisture	Flavor	General Acceptability
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐

Please indicate defect for scores of 4 or lower.

Figure 6: Score Sheet Used to Evaluate the Effect of MCC Substitution on Shortened Cakes

SCORE SHEET FOR BISCUITS

Characteristic	Excellent	Fair	Unacceptable
Appearance	Top crust--pale, golden brown, slightly rough, sides--straight slightly spotted	Crust--slightly too dark or pale, smooth or rough surface, spotted	Crust--too pale or too dark, too rough or smooth surface, sides not straight, excessively spotted
Texture	Uniform small gas holes, relatively thin cell walls, crumb--peel off in sheets of layers, i.e. flaky	Irregular gas holes, some large cells, slightly thick cell walls, only slightly flaky crumb	Large and/or irregular gas holes, thick cell walls, not flaky, crumb doesn't peel
Tenderness	Outer crust--crisp yet tender, little resistance when bitten. Interior--tender very little resistance when bitten	Exterior--slightly too crisp, some resistance when bitten. Interior--slightly tough, some resistance when bitten	Outer crust--too crisp, brittle, tough resistance when bitten. Interior--tough resistance when bitten, crumbly
Moisture	Soft and moist	slightly too dry, slightly too moist	Very dry, very moist or gummy
Flavor	Mild flavor, slight baking powder flavor	Bland, moderate off flavor	Too bland, pronounced off flavor, soapy, bitter

Seven Point Scale 1 - unacceptable 4 - fair 7 - excellent

Sample	Appearance	Texture	Tenderness	Moisture	Flavor	General Acceptability
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐

Please indicate defect for scores of 4 or lower.

Figure 7: Score Sheet Used to Evaluate the Effect of MCC Substitution on Biscuits

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