Physical and Sensory Evaluation of Lean White Cakes Containing Substituted Fluffy Cellulose[1]

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ABSTRACT

A partly delignified, highly water-absorbent fiber fraction from oat straw (fluffy cellulose) was used as a partial replacement (10, 25, and 40%) for flour in a lean white cake. A comparison between fluffy cellulose and microcrystalline cellulose (MCC-Avicel) at the 40% level also was made. Sensory scores for cell size, crumbliness, grittiness, and cereal-like flavor increased, and moistness decreased as the amount of fluffy cellulose in the formulation increased. Sensory scores for the cake containing substituted MCC fell between scores for the cakes containing 10 and 25% substituted fluffy cellulose. No differences in sweetness or universal testing machine compression values could be attributed to treatments. As the percentage of fluffy cellulose increased, the color of the cake became lighter (lesser *L* values), less green (greater *a* values), and more yellow (greater *b* values). Cake volume decreased as the amount of fluffy cellulose increased, whereas the volume of the MCC cake was the same as that of the control.

The average daily intake of dietary fiber by people in the United States is about half the level recommended by the National Cancer Institute (Jasberg et al 1989). Dietary fiber intake could easily be increased by selecting foods naturally high in fiber. However, dietary patterns are difficult to change because consumer food selection patterns are dominated by sensory preferences for tastes and textures. Baked products with various high-fiber additives such as biscuits, cookies, cakes, and pancake mixes have been introduced to satisfy consumer demands for increased fiber content in foods without sacrificing sensory quality. High-fiber additives range from minimally processed materials such as finely ground bran and seed hulls to extensively processed, purified cellulose fractions derived from wood pulp (Jasberg et al 1989).

However, the amount of fiber that can be incorporated into cake products is limited. Cellulosic materials cause significant decreases in cake volume and reduction of important sensory properties (Rajchel et al 1975, Springsteen et al 1977, Zabik et al 1977, DeFouw et al 1982). Cellulosic fibers do not hydrate completely, and therefore behave as particulate inclusions rather than as an integral part of the gelatinized starch-gluten matrix (Dubois 1978).

Recently, a new treatment involving the addition of a dilute solution of hydrogen peroxide was shown to alter the physical intrinsic properties of lignocellulosic materials such as brans, seed hulls, pulps and straws (Gould 1984, 1985). Alkaline treatment removes approximately half of the lignin, leaving a cellulose-enriched fraction with greatly improved water absorption, which enhances the interaction of cellulosic fiber in baked foods (Gould et al 1989, Jasberg et al 1989). This study was designed to determine the effect of substituting oat fiber that had been treated with alkaline hydrogen peroxide (forming fluffy cellulose) for percentages of the flour in a lean white cake formula. Physical and sensory characteristics were evaluated and compared with a control cake and with a cake containing substituted microcrystalline cellulose (MCC).

MATERIALS AND METHODS

Preliminary studies were conducted to develop a lean white cake formula. The lean white cake formula of Brys and Zabik (1976) and the AACC mixing method 10-90 (AACC 1976) were adopted with minor alterations. Ingredient substitutions and alterations included dried egg whites for fresh eggs, cake flour for all-purpose flour, nonfat dry milk for reconstituted dried whole milk, and omitted added emulsifiers and flavorings (Table I). Method alterations included reducing mixing time by half and mixing on low speed for the second and third mixing periods. The decreased mixing time and speed helped to retain the tenderness of the lean white cake. In addition, many ingredient and method variations were investigated to improve the coarse texture, low volume, and cereal-like flavor that resulted upon substitution of fluffy cellulose for flour. Presoaking and premixing the cellulose with water or increasing the mixing time did not change the characteristics of the cakes containing substituted fluffy cellulose. Adjusting the batter pH by adding 1–5 g of cream of tartar produced a cake with an aftertaste and a hard crust. Toasting the fluffy cellulose in a 100°C oven for 1 hr and grinding it to a finer particle size resulted in a cake with an altered flavor, hard crust, and decreased volume. Finally, because fluffy cellulose is reported to have increased water absorption (Gould et al 1989) several water levels were tested in combination with each substitution level; however, the addition of any extra water (up to 1.5 ml per gram of fluffy cellulose) resulted in a cake with a low volume and rubberlike gel texture. Finally, for the purposes of this study, direct substitution of fluffy cellulose for flour was adopted, and no other ingredients were altered. Five treatments with a cellulose substitution of 0, 10, 25, or 40% fluffy cellulose or 40% MCC were investigated in a lean white layer cake. A randomized complete block design with five replications of each treatment was used.

TABLE I
Cake Formulation

Ingredient	Quantity (g)	Percent (flour weight basis)
Cake flour[a]	180–300	60–100
Sugar[b]	336	112
Shortening[c]	84	28
Nonfat dry milk[d]	24	12
Dried egg whites[e]	18	6
Salt	6	2
Baking powder[f] (sodium aluminum sulfate-phosphate)	12	4
Fluffy cellulose[g]	0–120	0–40
Microcrystalline cellulose[h]	0–120	0–40
Distilled water	390	130

[a]Softasilk, General Mills, Minneapolis, MN.
[b]Crystal Sugar, American Crystal Sugar Co., Moorhead, MN.
[c]Crisco, Procter & Gamble, Cincinnati, OH.
[d]Chefs Helper Instant NFDM, AMPI, Mason City, IA.
[e]Type P-11, Henningsen Foods, White Plains, NY.
[f]Calumet, General Foods Corp., White Plains, NY.
[g]Fibre-Oat, Conagra, Omaha, NE.
[h]Avicel pH101, FMC Corp., Newark, DE.

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Cake Preparation

Dry ingredients were preweighed, sifted three times, and stored in an air-tight container at room temperature until used. Dry ingredients, shortening, and 60% of the water (234 ml) were mixed at low speed (61 rpm) for 30 sec with a wire whip in a 4.7-L bowl of an electric mixer (KitchenAid, Hobart, model K5SS, Troy, OH). After the bowl was scraped, mixing was continued on medium speed (109 rpm) for 4 min. Half of the remaining water (78 ml) was added, and the batter was mixed for 20 sec on low speed. The bowl was again scraped, and the batter was mixed 30 sec on low speed. The remaining water (78 ml) was added, the batter was mixed for 20 sec on low speed, the bowl was scraped, and mixing was continued for 30 sec on low speed. Cake batter (425 g) was weighed into two lightly greased 4xxxx sheet-steel round cake pans (20.3-cm diam, 3.8-cm deep). The cake pans containing batter were tapped on the table four times and turned 90° between taps. The cakes were baked at 180°C for 30 min in an electric rotary oven (Despatch Oven Co., model VU5 33, Minneapolis, MN). Upon removal from the oven, the cakes were cooled to room temperature on wire racks for 15 min, turned out of the pan onto a paper plate, and sealed in a plastic bag for 1.5 hr until sensory and physical evaluations were made.

pH Measurements

Batter and crumb pHs were measured with an analog pH meter (model 301, Orion, Cambridge, MA). The cake batter (25 g) and the cake crumbs (20 g) were diluted with 15 and 40 ml of distilled water, respectively (Griswold 1962).

Volume Index

Volume, symmetry, uniformity, and shrinkage indexes were calculated by using measurements from a template according to AACC method 10-91 (AACC 1976). The cakes were tested 2 hr after baking.

Sensory Analysis

A 12-member sensory panel was trained during two preliminary sessions using samples representing extreme characteristics. Control samples and samples substituted with 40% fluffy cellulose were used to train for visual cell size, crumbliness, grittiness, and cereal-like flavor. Fresh and dried-out control samples were used to train for moistness, and sweetness was demonstrated with control and high-ratio white cakes. The panelists were experienced in sensory evaluation procedures and in evaluating baked products. One cake from each treatment was used for sensory analysis. Each panel member received two (2 × 2 × 3 cm) cubes in styrofoam cups with lids (7-cm diam, 5-cm height) coded with three-digit random numbers. Samples were evaluated for visual cell size, crumbliness, moistness, grittiness, sweetness, and cereal-like flavor. A 15-cm line scale was used, with low degree of the characteristics scored at 0 and high degree of the characteristics scored at 15. Panelists were seated in individual booths under red lights and provided with room-temperature water and unsalted crackers. The red lights sufficiently masked the color so that the samples could not be distinguished by color alone.

TABLE II
Batter and Cake pH Values, and Shrinkage, Volume, Symmetry, and Uniformity Indexes of Cellulose Substituted Cakes[a]

		Fluffy Cellulose			
Variables	Control	10%	25%	40%	40% MCC[b]
Batter pH	6.66 b	6.66 b	6.62 b	6.66 b	6.76 a
Cake pH	7.10 b	7.00 b	6.82 c	6.76 c	7.30 a
Shrinkage[c]	1.14 ab	1.28 a	1.30 a	1.04 b	1.04 b
Volume	11.26 a	10.18 b	9.68 c	8.66 d	9.96 bc
Symmetry[c]	0.62 a	0.26 b	0.22 b	0.10 b	0.22 b
Uniformity[c]	0.22 a	0.18 a	0.10 a	0.06 a	0.10 a

[a] Data are means of five replications. Means within a row with different letters differ significantly (P <0.05 for shrinkage, symmetry; P <0.01 for batter pH; P <0.001 for volume and cake pH).
[b] Microcrystalline cellulose.
[c] Determined by the template AACC method 10-91.

Color

Cake crumb color (L, a, and b values) was measured across a 2.5-cm-thick center slice with a HunterLab colorimeter (model LS5100, Reston, VA) that was standardized with a white color tile ($X = 81.6$, $Y = 86.68$, $Z = 91.18$). Values for each replication were reported as an average of six readings from each sample.

Universal Testing Machine Measurements

Five, 2-cm crustless cake cubes were used from the center of the cake. A two-cycle, 80% compression was done on each cube 27 hr after baking with a 3.6-cm diameter compression anvil mounted on an Instron universal testing machine (UTM; model 1122, Canton, MA). Peak heights of the two compressions were measured in kilograms. UTM cross-head and chart speeds were 200 mm/min and 500 mm/min, respectively.

Water-Holding Capacity

The water-holding capacities of cake flour, fluffy cellulose, and MCC were determined according to AACC method 88-04 (AACC 1976). The samples were dried in a Brabender semiautomatic moisture oven (model 951, Rochelle Park, NJ) for 3 hr at 100°C. Average values from four replications were reported.

Statistical Analysis

Analysis of variance (PROC ANOVA) (SAS Institute 1982) was used to test for replication (5) and treatment (5) differences for all parameters. A split-plot design was used for the sensory data to test for panelist × treatment interactions. When F values were significant, least significant differences (LSD) were calculated. Correlation coefficients were determined for selected variables (PROC CORR, $n = 25$).

RESULTS AND DISCUSSION

Studies have reported that high-fiber, noncaloric celluloses, such as MCC (Brys and Zabik 1977) and fluffy cellulose (Jasberg et al 1989), can be successfully substituted for the flour in cake formulas with regard to overall flavor, mouthfeel, and texture. In the current study, the fluffy cellulose substitutions for flour in cakes produced different sensory and color attributes compared with the control cake.

The addition of fluffy cellulose did not affect the pH of the cake batter, but as the amount of fluffy cellulose was increased, the cake crumb became more acidic (Table II). Microcrystalline cellulose substitution increased the pH in the cake crumb. Why the pH changed in the cake crumb but not in the batter with the cellulose addition is not fully understood.

Each increasing increment of fluffy cellulose resulted in a volume index reduction (Table II), with the volume of the cake containing MCC falling between that of the cakes with 10 and 25% fluffy cellulose substitutions. Cake contour, measured by symmetry, was only slightly affected, but reflected the trend of decreasing contour as the amount of fluffy cellulose was increased. Uniformity index, which also reflects cake symmetry, was not affected by cellulose substitutions. The shrinkage index indicated that cakes with 40% fluffy cellulose shrank less than the other treatments including the control, which supports the results of studies done by Jasberg et al (1989) and Brys and Zabik (1976). This suggests that the major effect of the fluffy cellulose substituted at high levels (40%) is primarily on the "setting" of the cake structure (Jasberg et al 1989). In this study, cakes containing the fluffy cellulose did not appear to rise any higher during baking than cakes without the cellulose, but did shrink less (cake height) while cooling. Volume is affected by the air incorporated into the batter and ability of the batter to entrap leavening gases released from the baking powder system (Brys and Zabik 1976). Increased replacement of the flour with the cellulose should weaken the gluten matrix responsible for retaining the leavening gases.

TABLE III
Sensory Analysis of Cellulose Substituted Cakes[a]

Variables	Control	Fluffy Cellulose 10%	25%	40%	40% MCC[b]
Cell size	2.6 d	3.6 d	8.1 b	11.3 a	5.2 c
Crumbliness	2.1 e	4.0 d	8.6 b	11.3 a	5.7 c
Moistness	8.7 a	8.9 a	6.7 b	6.2 b	8.1 a
Grittiness	2.0 d	4.3 c	9.3 b	11.2 a	2.9 d
Sweetness	6.4 a	6.8 a	7.2 a	7.7 a	7.6 a
Cereal-like flavor	3.0 d	4.9 c	8.6 b	10.2 a	4.9 c

[a]Sensory scores: 0 = fine cell size, low degree of crumbliness, dry, no grittiness, low degree of sweetness, or no cereal-like flavor. 15 = coarse cell size, high degree of crumbliness, high degree of moistness, high degree of grittiness, high degree of sweetness, or high degree of cereal-like flavor. Data are means of five replications. Means within a row with different letters differ significantly ($P < 0.001$).
[b]Microcrystalline cellulose.

TABLE IV
Universal Testing Machine (UTM) and Color Measurements of Cellulose Substituted Cakes[a]

Variable	Control	Fluffy Cellulose 10%	25%	40%	40% MCC[b]
Color					
L (lightness)	86.7 a	84.5 b	82.7 c	79.8 d	86.0 a
a (greenness)	−1.2 ab	−1.3 a	−1.2 ab	−0.9 c	−1.1 b
b (yellowness)	9.7 d	13.1 c	15.5 b	17.4 a	9.2 d
UTM (kg)					
Peak 1	6.3 a	6.8 a	7.2 a	7.4 a	6.8 a
Peak 2	4.3 a	4.4 a	4.7 a	4.9 a	4.8 a

[a]Means of five replications. Means within a row with different letters differ significantly ($P < 0.001$ for L value, a value. b value; no significant difference for UTM).
[b]Microcrystalline cellulose.

Although the visual cell size of the cake at the 10% substitution level did not differ from the control, a difference was noted at the 25 and 40% levels (Table III). The cell size of the cake containing 40% MCC was judged to be smaller than that of the 25% substitution level but a larger cell size than that of the 10% substitution level of fluffy cellulose. As moistness decreased, crumbliness increased ($r = -0.75$, $P < 0.001$), indicating that, as the cake became drier, it became more crumbly. The panelists observations seem contradictory to the fact that MCC and fluffy cellulose have water-holding capacities of 2.05 and 2.65 respectively, whereas cake flour has a water-holding capacity of 0.69. The ability of the fluffy cellulose to hold water may have redistributed the water in the cakes. Water redistribution may have reduced the interaction of water with the starch and proteins of flour, thus preventing starch gelatinization and formation of gluten matrix. Other researchers have mentioned the importance of water distribution as well as total water on sensory qualities such as dryness (Cloke et al 1984). Also, the fiber may bind the water so tightly that the water is not available as free moisture; thus, the cake may seem dry in the mouth. Added cellulose tended to increase the sweetness scores. The presence of the fluffy cellulose altered the product by leaving a gritty mouthfeel and a cereal-like flavor after being swallowed.

Generally, as the amount of cellulose was increased in the formulation, the cake became firmer as measured by the UTM (Table IV). Differences, however, were not significant.

Color values (L, a, and b) did not vary between the control and the MCC sample (Table IV). However, as the amount of fluffy cellulose was increased, the cake crumb became darker (lower L values), more yellow (higher b values), and less green (lower negative a values) when compared with the control. The a values were only slightly affected.

Generally, as the amount of fluffy cellulose was increased from zero to 40% of the flour weight in a lean white cake, sensory and physical characteristics were altered. Sensory results indicated that cell size of the cakes increased and that the cakes became more crumbly, dry, gritty, and had an intense cereal-like flavor as the amount of substituted fluffy cellulose increased. Physical characteristics indicated a reduction in cake volume and increased yellowness of the cake crumb.

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