High-Fiber, Noncaloric Flour Substitute for Baked Foods. Alkaline Peroxide-Treated Lignocellulose in Chocolate Cake

BRIAN K. JASBERG, J. MICHAEL GOULD, and K. WARNER[1]

ABSTRACT

Cereal Chem. 66(3):209-213

Wheat straw was treated with hydrogen peroxide at pH 11.5, resulting in a partially delignified, highly water-absorbent and swellable fiber fraction that was used as partial replacement (2–50%) for flour in layer cakes. Volume of cakes prepared with less than 30% replacement of flour increased by 5 to 10% compared with controls. Taste panel flavor and texture scores indicated that cakes with as much as 40% of the flour removed were not significantly different from the control cake. The presence of alkaline peroxide-treated wheat straw allowed additional water to be added without reduction of cake volume. The data indicate that peroxide-treated lignocellulosics may be used as a noncaloric, high-fiber substitute for a portion of the flour in cakes without introducing undesirable sensory characteristics or causing deterioration of baking performance.

Numerous high-fiber additives have been introduced as ingredients in a variety of foods, especially baked products, to satisfy consumer demand for increased fiber content in foods, without sacrificing preferred sensory properties. These high-fiber additives range from minimally processed materials such as finely ground brans and seed hulls to extensively processed, purified cellulose fractions derived from wood pulp (e.g. microcrystalline cellulose, alpha-cellulose). Unfortunately, the intrinsic physical properties of these cellulosic materials limit the amount of fiber that can be incorporated into baked products without causing serious deterioration of baking performance and/or sensory properties. Incorporating high levels of cellulosic fiber in cakes as a substitute for flour can result in a significant decrease in cake volume accompanied by degradation of important sensory properties (Rajchel et al 1975, Springsteen et al 1977, Zabik et al 1977, DeFouw et al 1982). These problems are most likely related to the fact that these cellulosic fibers do not hydrate completely, and so behave as particulate inclusions rather than as an integral part of the gelatinized starch-gluten matrix.

Recently we discovered that the intrinsic physical properties of lignocellulosic materials such as brans, seed hulls, pulps, and straws are substantially altered by treatment with a dilute, alkaline solution of hydrogen peroxide (Gould 1984, 1985). This treatment removes about half of the lignin, leaving a cellulose-enriched fraction with greatly improved water absorption and swollen volume characteristics. These new properties enhance the interaction of the cellulosic fiber with flour in baked foods (Gould et al 1989, Jasberg et al 1989). In this paper we describe initial studies on the use of alkaline hydrogen peroxide treated wheat straw (AHP-WS) as a model system for the partial replacement of flour in layer cakes.

MATERIALS AND METHODS

AHP-WS was prepared using procedures developed by Gould (1985). The treated straw was washed with water and then dried in a forced air-oven (Proctor Schwartz) at 40°C for 24 hr. The dried

[1]Northern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Peoria, IL 61604.

The mention of firm names or trade products does not imply that they are engaged or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

straw was then ground in a Wiley mill (Thomas, model no. 3379-K05) fitted with a 0.5-mm screen. The final product was a fluffy, fibrous material that was off-white to pale yellow in color (Gould, 1984, 1985).

The chocolate cake formulation used in these studies is given in Table I. All dry ingredients were mixed for 5 min in a K45SS Hobart mixer using a stainless steel whip. Milk, eggs, oil, and vanilla (and additional water as needed) were added at 18°C, mixed at low speed for 30 sec, then at medium speed for 2 min. The bowl was scraped and boiling water was added and mixed at low speed for 30 sec. The bowl was scraped again, followed by an additional 30 sec mixing at low speed. Two 525-g portions of batter were measured into paper-lined, 20.3-cm diameter round aluminum pans and baked at 177°C for 35 min. AACC method 10-91 (AACC 1983) was used to determine volume index, shrinkage, symmetry, and uniformity of the cakes.

Cakes were evaluated for a number of sensory characteristics by a trained, fifteen-member in-house taste panel using standard methodology (Warner 1985). Parameters evaluated (and scoring ranges) were overall flavor quality (1–10, bad-excellent), presence of off-flavors (0–100, percent of panelists detecting), intensity of off-flavors (0–100, not detected-strong), mouthfeel (1–10, dry-soggy), and texture (1–10, smooth-gritty). Panelists were given an identified sample of the control cake (Table I) at the start of each evaluation session to use as the basis for rating the unidentified experimental cake samples.

Ingredients used in this study were purchased from commercial sources, and included all-purpose flour (Seal of Minnesota brand, International Multifoods), cocoa (Hershey Foods), alpha-cellulose (Alphacell, ICN Biochemicals), wood pulp cellulose (Solka Floc BW-40, James River Corp.), and finely ground oat hulls (ConAgra Inc.). Milk, eggs, soybean oil, and other ingredients were purchased at local markets.

RESULTS

The effect of water content in the cake formulation on the volume index of cakes containing up to 30% replacement of flour (dry weight basis) with AHP-WS is shown in Figure 1. In the absence of AHP-WS, the volume index increased slightly when the water content was decreased, and decreased rapidly when the water content was increased. The volume indexes for cakes containing 30% AHP-WS were essentially identical to the indexes of cakes prepared without AHP-WS. All of the cakes prepared with lower levels of AHP-WS in place of flour had 5–10% larger volume indexes than did cakes lacking AHP-WS. During baking, cakes containing AHP-WS appeared to shrink less (cake height) in the oven and while cooling, suggesting that a primary effect of AHP-WS was on the "setting" of cake structure. Replacement of more than about 20% of the flour in the formulation with AHP-WS caused a reduction in the height of the center peak, resulting in a slightly flatter cake profile (Table II). No significant differences in side-shrinkage or final cake weight (based on 525 g of batter) were observed as a function of either water or AHP-WS content in the formulation.

Cake formulations containing AHP-WS in place of 5–10% of the flour, even with extra water added, yielded cakes having the same or better volume indexes as cakes lacking AHP-WS. Thus, AHP-WS allowed the use of extra water in the formulation while retaining increased cake volume. It is important to point out that the cake volume indexes reported here are based on cakes derived from 525 g portions of the batter mix (Table I). In formulations containing extra water, the amount of dry ingredients contained in a 525-g portion was reduced, and the total batter volume (and the number of 525-g portions) was increased. As a result, the actual increase in cake volume realized for an entire batter formulation was larger than that represented by the volume index for a 525-g portion. The greatest relative increase in cake volume at any given water content was attained with a replacement level of 5% AHP-WS, with little additional increase in volume noted for replacement levels up to 20%.

Using the formulation in Table I, the volume index peaked when about 20% (55 g) of the flour was replaced with an equal amount of AHP-WS. Addition of extra water to the formulations, at the rate of 1 g of H_2O/g AHP-WS, reduced the volume index compared

TABLE I
Formulation for Chocolate Layer Cake

Ingredient	Amount (g)	Amount (%)[a]
All-purpose flour (Seal of Minnesota brand)	274.0[b]	100.0
Granulated sugar	390.0	142.3
Cocoa (Hershey's brand)	66.5	24.3
Baking soda	6.25	2.3
Baking powder	6.5	2.4
Salt	6.5	2.4
Milk, whole (3.5% butter fat)	250.0	91.2
Eggs, whole, fresh	104.0	38.0
Soybean oil	107.5	39.2
Water	220.0	80.3

[a] Based on flour = 100.
[b] Based on 14% moisture. All other ingredients on "as is" basis.

TABLE II
Volume, Symmetry, Uniformity, and Shrinkage of Chocolate Cakes Containing Alkaline Hydrogen Peroxide Treated Wheat Straw (AHP-WS)

Formulation[a]		Dimensional Indexes[b]			
% Flour Removed	% AHP-WS Added[c]	Volume (cm)	Symmetry (cm)	Uniformity (cm)	Shrinkage (cm)
0	0	12.0	1.0	0.1	0.4
0	4	13.2	1.7	0.1	0.5
10	10	12.6	1.5	0.1	0.5
20	20	12.8	1.0	0.1	0.5
30	30	12.0	0.4	0.1	0.3

[a] As in Table I.
[b] Based on 525 g of batter. Determined according to AACC method 10-91.
[c] Based on flour content of control formulation (Table I).

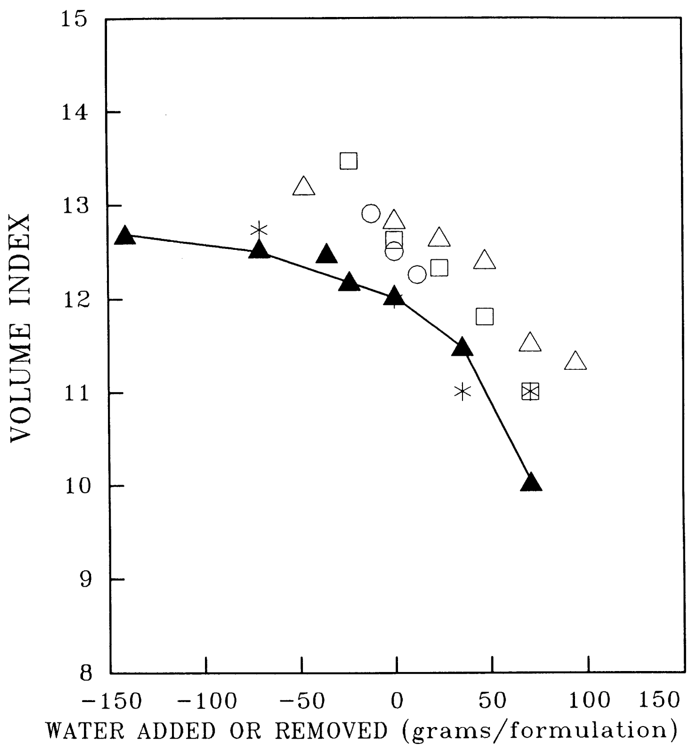

Fig. 1. Effect of water content and alkaline hydrogen peroxide treated wheat straw on baked volume of chocolate cakes. The basic cake formulation (Table I) was modified by replacing 0 (▲), 5 (○), 10 (□), 20 (△), or 30% (∗) of the flour with an equal weight of treated wheat straw. The water content of the formulation was varied as indicated.

with cakes formulated without extra water, regardless of AHP-WS content (Fig. 2). Conversely, removal of water from the basic formulation at the rate of 1 g H_2O/g AHP-WS increased the volume index. Removal of a small amount of water from the cake formulation caused a greater increase in the volume index of cakes containing a small amount of AHP-WS than did the removal of a similar level of water from cakes lacking AHP-WS (Fig. 1).

Gram-for-gram substitution of AHP-WS for flour in the formulations was associated with a decrease in cake volume when the amount of AHP-WS exceeded a certain level (Fig. 2). This negative effect could be partly overcome by substituting less than 1 g of AHP-WS for each gram of flour removed from the basic formulation (Table III). Under these conditions, it was possible to replace up to 40% of the flour and still attain cakes with volume indexes equal to or greater than the indexes observed in the absence of AHP-WS. These data indicate that, under certain conditions, AHP-WS contributes to cake volume more efficiently, on a per gram basis, than does flour, and suggests that AHP-WS, in small amounts, may also be useful as an additive to increase cake volume in formulations from which no flour has been removed.

When the basic formulation (Table I) was altered by the addition of extra flour, the volume index increased in a more or less linear fashion to a value of about 13.2 when 42 g (15%) of extra flour had been added. Similar results were observed when alpha-cellulose, wood pulp cellulose, or oat hulls were added to the formulation. In contrast, the volume index increased rapidly when small amounts of AHP-WS were added to the formulation, reaching a peak of about 13.2 when 11 g of AHP-WS (equivalent to 4% of the flour) was added. This effect is probably due to the much higher water absorbency and swollen volume of AHP-WS compared with flour or purified cellulose (Gould et al 1989) and to its gel-like properties when fully hydrated (Gould 1985).

TABLE III
Effect of Alkaline Hydrogen Peroxide Treated Wheat Straw (AHP-WS) for Flour Replacement Ratio[a] on Volume Indexes of Chocolate Cakes

Formulation[b]				
% Flour Removed	% AHP-WS Added[c]	H_2O (g) Added (+) or Removed (−)	Replacement Ratio[a]	Volume Index[d] (cm)
30	30	0	1.0	12.0
30	30	−71	1.0	12.7
30	20	−59	0.67	12.9
30	15	−59	0.5	12.3
40	40	0	1.0	10.8
40	20	−59	0.5	12.2
50	25	0	0.5	10.6
50	25	−59	0.5	11.1
50	25	−118	0.5	10.9

[a] Replacement ratio = g of AHP-WS added/g flour removed.
[b] As in Table I.
[c] Based on flour content of control formulation (Table I).
[d] Based on 525 g of batter.

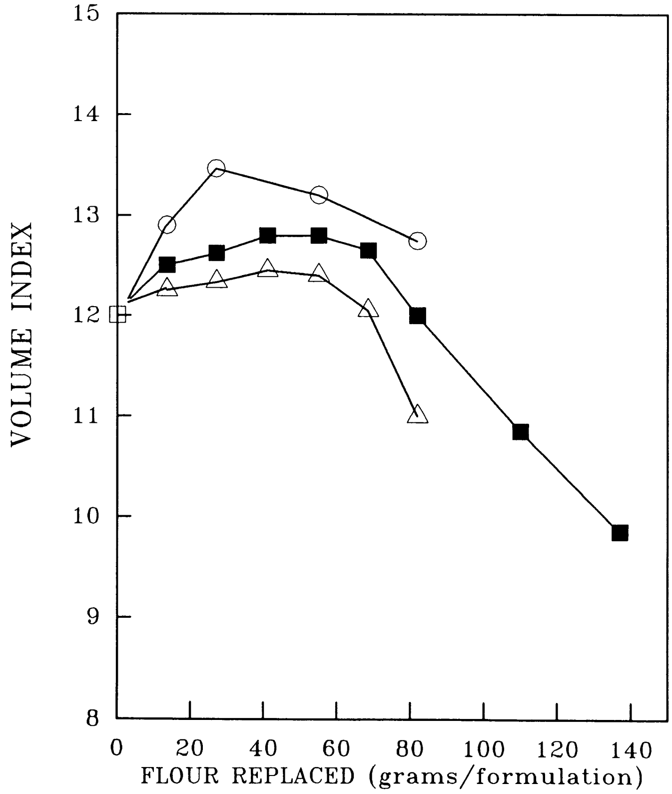

Fig. 2. Effect of alkaline hydrogen peroxide treated wheat straw (AHP-WS) and water on baked volume of chocolate cake. The basic cake formulation (Table I) was modified by replacing the indicated weight of flour with an equal weight of AHP-WS. Water content varied from the basic formulation (□) as follows: no change (■), 1 g of water added for each gram of AHP-WS added (△), or 1 g of water removed for each gram of AHP-WS added (○).

TABLE IV
Sensory Panel Evaluations and Volume Indexes of Cake Formulations Containing Alkaline Hydrogen Peroxide Treated Wheat Straw (AHP-WS)

	Formulation[a]				Sensory Parameter[b]				
Cake Sample	% Flour Removed	% AHP-WS Added[c]	H_2O (g) Added (+) or Removed (−)	Volume Index[d] (cm)	Overall Flavor Quality	Off-Flavor (Presence	Off-Flavor (Intensity)	Mouthfeel	Texture
Control[a]	0	0	0	12.0	8.0	0	0	5.7	2.6
A	0	4	0	13.2	7.1	0	0	5.4	3.0
B	0	4	+19	13.1	7.1	0	0	5.2	2.9
C	0	4	+57	12.0	7.5	0	0	6.1	2.5
D	5	5	−12	12.9	7.0	10	0.4	5.4	3.2
E	10	10	−24	13.5	6.8	10	0.5	5.3	3.3
F	20	20	−71	12.9	5.9	75	1.8	4.5	4.2
G	30	20	−58	12.9	6.4	10	0.9	4.1	3.8
H	40	20	−58	12.2	7.3	10	0.7	5.5	2.8
I	20	20	−47	13.2	6.6	55	1.5	4.8	4.0
J	20	20	0	12.8	6.1	60	1.4	4.3	4.1
K	20	20	+47	12.4	6.8	50	1.1	5.0	3.7
L	20	20	+71	11.5	6.5	40	1.3	4.6	3.8
M	30	30	−71	12.7	4.6	82	3.8	3.1	5.1
N	30	30	0	12.0	5.2	79	3.2	4.1	4.7
O	30	30	+71	11.0	5.9	63	3.3	5.4	3.6
P	40	40	0	10.8	4.0	100	3.6	3.3	5.9

[a] As in Table I.
[b] Scoring details in Materials and Methods. LSD = 1.0 at 95% confidence level (except for off-flavor [presence] data).
[c] Based on flour content of control formulation (Table I).
[d] Based on 525 g of batter.

Addition to up to 40 g of extra water to cake formulations containing AHP-WS (10 g/formulation) did not reduce the enhancement of cake volume caused by the AHP-WS. Similar results were obtained when 42 g of flour were added to the basic formulation. In each case, up to 60 g of extra water could be added per formulation before the volume index was reduced to the level obtained in the absence of added flour or AHP-WS. From these data it is evident that AHP-WS has the same effect on volume index as about four times its weight in flour.

Several cake formulations containing AHP-WS were rated for overall flavor quality, the presence and intensity of off flavors, mouthfeel, and texture by a trained sensory evaluation panel (Table IV). This evaluation was designed not to optimize cake flavor and texture, but rather to investigate the interactive effects of AHP-WS and water on cake sensory parameters. Four of the AHP-WS cakes evaluated were found to be not significantly different from the control cake (Table I) in all categories, including three cakes with 4% extra AHP-WS (containing 0, 19, and 57 g of extra water) and a cake in which 40% of flour (110 g) was replaced with 55 g of AHP-WS. The importance of water content in formulations containing AHP-WS was apparent in the score patterns. In general, scores in all five sensory categories improved with increasing water content in the formulation. For example, the overall flavor scores for cakes in which AHP-WS replaced 30% of the flour (gram for gram) increased from 4.6 to 5.9 as the formulation water content increased. This relationship is probably a result of the very high water absorbency of AHP-WS compared with flour (Gould et al 1989). In some formulations, sufficient water may not be present to allow complete softening and swelling of the AHP-WS fibers, resulting in cakes with drier mouthfeel and grittier texture. Competition for water between AHP-WS and other ingredients such as flour, sugar, and chocolate may also be a significant factor in changing the contribution of these ingredients to overall cake flavor in some formulations, and may be responsible for the general increase in off-flavor detectability associated with decreasing water content. The data suggest that the off-flavors detected by the panel may have been a measure of altered (reduced) flavors of other ingredients, rather than a direct measure of AHP-WS flavor, which is bland. The intensity of off-flavor detected was generally weak.

The interrelationships between water, AHP-WS, and flour content are apparent from a comparison of the sensory scores for two cakes (samples G and H, Table IV) in which the same amount of AHP-WS (equal to 20% of the flour content of the control formulation) was incorporated into formulations in which 30 or 40% of the flour was removed. Both cakes had 58 g less water per formulation than the control, and competition for water by AHP-WS and the other dry ingredients would be expected. The cake with 40% flour removal had scores for overall flavor quality, mouthfeel, and texture that were close to the control's scores. The cake with 30% flour removal had much poorer scores. This indicates that increased competition for water by AHP-WS and the additional flour in cake "G" was sufficient to seriously degrade sensory performance.

DISCUSSION

Our data indicate that alkaline peroxide-treated lignocellulose may offer significant potential as a high-fiber, noncaloric additive for layer cakes. AHP-WS can be used to replace a large portion of the flour normally present in cake formulations, reducing calories and increasing dietary fiber content. Alternatively, the addition of low levels of AHP-WS to cake formulations can increase cake volume and allow the use of extra water. In both cases, it is possible to produce highly acceptable cakes with regard to overall flavor quality, mouthfeel, texture, and the absence of off-flavors.

A major factor that must be considered in any formulation including AHP-WS is the relationship between AHP-WS and the amount of water used in the formulation. AHP-WS is highly water absorbent, and must be sufficiently hydrated in the formulation for optimal sensory characteristics. Since the inclusion of too much extra water in cake formulations can result in reduced baked volume, care must be taken to optimize water and AHP-WS content together. When properly hydrated, AHP-WS swells to form a soft, gel-like material that is difficult to detect in baked products. These soft structures occurred even at an AHP-WS

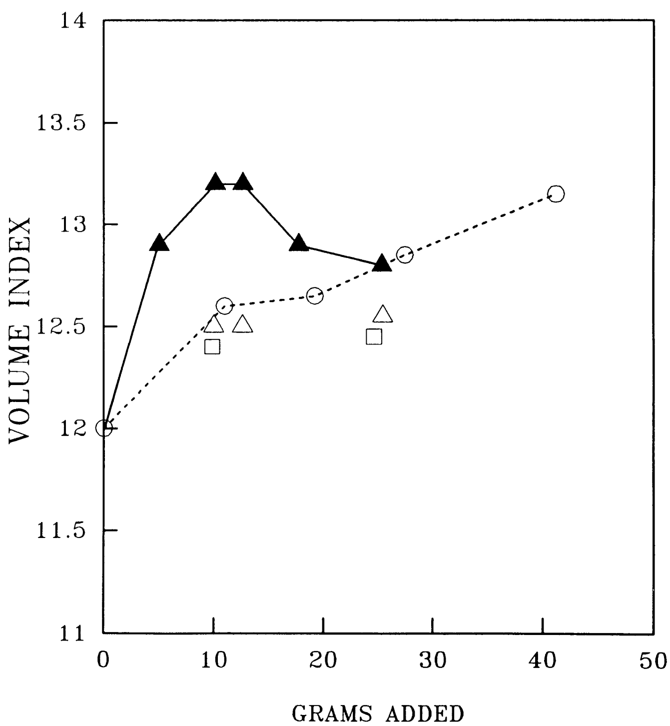

Fig. 3. Effect of low levels of alkaline hydrogen peroxide treated wheat straw, flour, and some other cellulosics on the baked volume of chocolate cake. The indicated amounts of flour (O), treated wheat straw (▲), ground oat hulls (□), or alpha-cellulose (△) were added to the basic formulation. Flour and water contents were as shown in Table I.

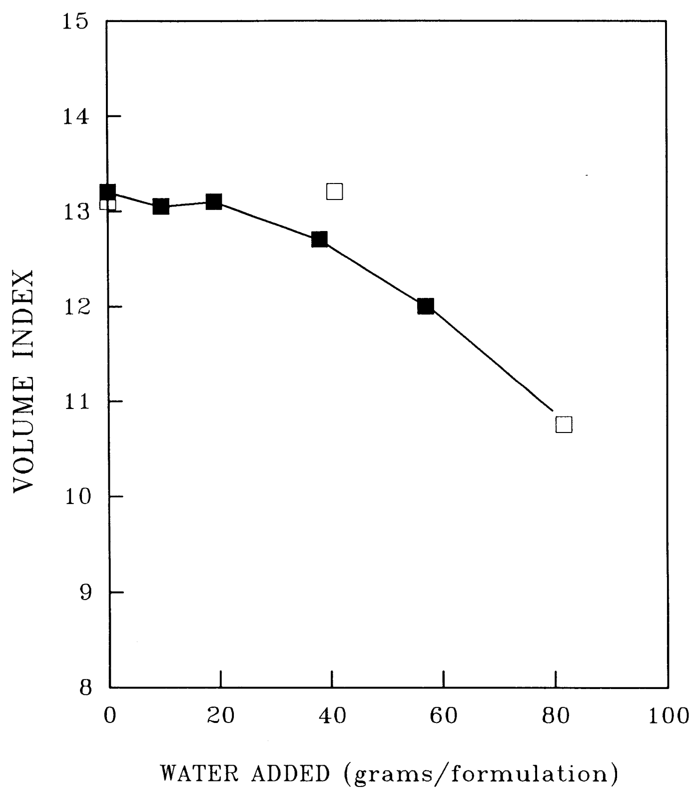

Fig. 4. Effect of water content on baked volume of chocolate cake containing alkaline hydrogen peroxide treated wheat straw. The basic formulation (Table I) was altered by the addition of 42 g of flour (□) or 10 g of treated wheat straw (■). Water content was varied as indicated.

average particle size of 0.5–1.0 mm.

Alkaline hydrogen peroxide treatment has been found to be effective on a wide range of lignocellulosic materials, including straws, brans, pulps, seed hulls, and the like. Although the studies reported here were conducted using peroxide-treated wheat straw, similar results should also be obtained with a number of more conventional, food-grade cellulosic residues, which exhibit the same enhancement of water absorption and swelling properties after alkaline peroxide treatment (Gould 1985, 1989; Gould et al 1989). In addition to their improved physical properties, alkaline peroxide-treated materials are efficiently sterilized by the treatment process, reducing the possibility that the fiber could introduce viable bacterial and/or mold spores into food formulations.

Our studies illustrate the application of AHP-WS in a representative cake formulation. Additional work must be completed to determine the optimum conditions for inclusion of alkaline peroxide-treated materials in a wider range of cake products. For instance, the effect of many conditioning additives (e.g., gums) needs to be assessed, as does the performance of alkaline peroxide-treated materials in formulations containing cake flour. Preliminary studies in our laboratory indicate that peroxide-treated cellulosics can be successfully incorporated into a variety of baked products, including batter-based foods such as pancakes and donuts, as well as dough-based, yeast-leavened foods such as breads and rolls.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 10-91, approved April 1968. The Association: St. Paul, MN.

DeFOUW, D. F., ZABIK, M. E., UEBERSAX, M. A., AGUILERA, J. M., and LUSAS, E. 1982. Use of unheated and heat-treated navy bean hulls as a source of dietary fiber in spice-flavored layer cakes. Cereal Chem. 59:229-230.

GOULD, J. M. 1984. Alkaline peroxide delignification of agricultural residues to enhance enzymatic saccharification. Biotechnol. Bioeng. 26:46-52.

GOULD, J. M. 1985. Studies on the mechanism of alkaline peroxide delignification of agricultural residues. Biotechnol. Bioeng. 27:225-231.

GOULD, J. M. 1989. Alkaline peroxide treatment of agricultural byproducts. U. S. patent no. 4,806,475. Patented February 21.

GOULD, J. M., JASBERG, B. K., DEXTER, L., HSU, J. T., LEWIS, S. M., and FAHEY, G. C., JR. 1989. High-fiber, noncaloric flour substitute for use in baked foods. Properties of alkaline peroxide-treated lignocellulose. Cereal Chem. 66:201-205.

JASBERG, B. K., GOULD, J. M., WARNER, K., and NAVICKIS, L. L. 1989. High-fiber, noncaloric flour substitute for baked foods. Effects of alkaline peroxide-treated lignocellulose on dough properties. Cereal Chem. 66:205-209.

RAJCHEL, C. L., ZABIK, M. E., and EVERSON, E. 1975. Wheat bran and middlings: A source of dietary fiber in banana, chocolate, nut, and spice cakes. Baker's Dig. 49(3):27-30.

SPRINGSTEEN, E., ZABIK, M. E., and SHAFER, M. A. 1977. Note on layer cakes containing 30 to 70% wheat bran. Cereal Chem. 54:193-198.

WARNER, K. 1985. Sensory evaluation of flavor quality of oils. Page 207 in: Flavor Chemistry of Fats and Oils, ed. D. B. Min and T. H. Smouse. American Oil Chemists, Society, Champaign, IL.

ZABIK, M. E., SHAFER, A. M., and KUKOROWSKI, B. W. 1977. Dietary fiber sources for baked products. Comparison of cellulose types and coated cellulose products in layer cakes. J. Food Sci. 42(6):1428-1431.

[Received December 3, 1987. Revision received December 19, 1988. Accepted December 21, 1988.]