High-Fiber, Noncaloric Flour Substitute for Baked Foods. Properties of Alkaline Peroxide-Treated Lignocellulose

J. MICHAEL GOULD,[1] BRIAN K. JASBERG,[1] LEE B. DEXTER,[1] J. T. HSU,[2] S. M. LEWIS,[2] and G. C. FAHEY, JR.[2]

Cereal Chem. 66(3):201-205

ABSTRACT

Treatment of lignocellulosic materials such as wheat straw, corn stalks, cereal brans, or vegetable and fruit pulps with an alkaline (pH 11.5) solution of hydrogen peroxide dramatically increased their ability to absorb water, soften, and swell when hydrated. Substitution of alkaline hydrogen peroxide treated lignocellulose for cornstarch-dextrose mixtures in the diets of nonruminant animals (rats, chicks) reduced the digestibility of the diets without increasing the amount of feed consumed. As a result, the rate and efficiency of weight gain were reduced for animals consuming the diets containing treated lignocellulose. The low digestibility of alkaline peroxide-treated lignocellulose by nonruminants, in conjunction with its enhanced physical properties compared with other cellulosic ingredients for baked foods, suggests that this material may be useful as an ingredient for reducing caloric density and/or increasing dietary fiber content of baked products.

There is increasing demand from consumers for baked products with lower caloric density and higher levels of dietary fiber (Leveille 1975). The acceptance of new products such as reduced calorie breads and cakes has been hindered by the fact that purified cellulosic additives such as alpha-cellulose, wood pulp cellulose, and microcrystalline cellulose, which are often substituted for a portion of the flour in reduced calorie formulations, tend to degrade sensory characteristics and baking performance of the product when used at high levels (Volpe and Lehmann 1977, Zabik et al 1977, Dubois 1978, Satin et al 1978, Shogren et al 1981, Titcomb and Juers 1986). Similar effects are observed when unprocessed lignocellulosic materials, such as cereal brans or vegetable pulps, are added to formulations for baked goods (Rajchel et al 1975, Lorenz 1976, Pomeranz et al 1976, Prentice and D'Appolonia 1977, Springsteen et al 1977, Finley and Hanamoto 1980, Nagai et al 1980, Tsen et al 1983). In both cases the loss of baked volume and the introduction of gritty textures can be traced to the fact that these materials do not hydrate extensively and so do not soften and integrate well with the dough or batter matrix.

Recently we reported that the properties of a wide range of lignocellulose materials could be altered substantially by treating them with a dilute, alkaline solution of hydrogen peroxide (Gould 1984, 1987, 1989; Gould et al 1989). Alkaline hydrogen peroxide (AHP) treatment solubilizes a portion of the lignin originally present in the cell wall, producing a highly water-absorbent material with a more open internal structure (Gould et al 1989). These properties apparently allow particles of AHP-treated lignocellulose to hydrate more extensively, causing the particles to swell and soften dramatically. We found that the unusual physical properties of AHP-treated lignocellulosics also allow them to be incorporated into dough and batter formulations at very high levels in lieu of flour without loss of baking performance or degradation of sensory qualities (Jasberg et al 1989a,b).

In separate studies, we also found that AHP treatment of lignocellulose greatly increased the rate and efficiency with which cellulolytic microorganisms can degrade the cell wall carbohydrate (Kerley et al 1985). In ruminants such as cattle and sheep, the total tract digestibility of AHP-treated wheat straw and corn stalks was increased to a level comparable to that of starch in feed grains. Although cellulose is generally regarded as essentially nondigestible by monogastric animals, cellulolytic bacteria are known to be present in the digestive tracts of many monogastrics, including humans (Betian et al 1977). Utilization of AHP-treated lignocellulosics as a calorie diluent or high-fiber ingredient in foods for human consumption requires knowledge of the fate of these materials in the nonruminant digestive system. In this paper we evaluated the digestibility of AHP-treated wheat straw, as a model for AHP-treated lignocellulose, in two different nonruminant animals, rats and chicks. In addition, we present data on the effects of AHP treatment on the physical properties of a variety of readily available, inexpensive "food-grade" lignocellulosic by-products more suitable for inclusion in commercial food products.

MATERIALS AND METHODS

Treated Lignocellulosics

Lignocellulosic materials were treated with alkaline hydrogen peroxide (AHP) as described in detail elsewhere (Gould 1984, 1987). The dry lignocellulosic residues were suspended in water (20–40 g/L) containing 10 g/L of hydrogen peroxide, and the slurry was adjusted to pH 11.5 with NaOH. The mixture was stirred gently for about 18 hr. The slurry was then neutralized to pH 6–7 with HCl, and the insoluble fraction was collected by filtration through a fine-meshed wire screen. The treated materials were washed thoroughly with water and then dried in a forced air-oven (Proctor Schwartz) at 40° C for 24 hr. For evaluation of water absorbency and swollen volume, dried samples were ground in a Wiley mill (Arthur Thomas Co., Philadelphia, PA) using a 1-mm screen. Alternatively, samples were ground in a pin mill (14,000 rpm, Alpine model 160Z, Augsburg, Germany). A portion of the pin-milled material was further ground using a ball mill (U.S. Stoneware Co., 19-L jar, 54 rpm, 25-mm granite balls, 40% charge, 1:1 material/void volume ratio) for 7 hr. For some experiments, treated wheat straw was partially dewatered after the washing step using a hydraulic press (Williams-White, Moline, IL) with a total force of 600 tons (approximately 100 kg/cm^2). The pressed material (approximately 50% solids) was then dried and ground as described above. Samples of never-dried material were also taken immediately after the washing step, and stored at 4° C until use. Commercially available food-grade cellulosics were obtained from James River Corp. (ground wood pulp, Solka Floc BW-40), ICN Biochemicals (alpha-cellulose), and FMC Corp. (microcrystalline cellulose, Avicel).

Determination of Water Absorbency and Swollen Volume

The relative ability of lignocellulosic materials to absorb water was estimated by mixing several grams of the dry sample with an excess of distilled, deionized water and allowing the sample to hydrate for several hours. The excess water was then removed by allowing the wet sample to drain on a fine-meshed wire screen until no more water separated (approximately 15 min). A portion of the wet sample on the screen was removed, weighed, and then dried to

[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 endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

[2]Department of Animal Sciences, University of Illinois, Urbana, 61801.

constant weight in a forced-air oven (110°C). The water absorbency (grams of water absorbed/gram dry weight) for each sample was defined as (wet weight − dry weight)/dry weight. The volume occupied by the fully hydrated lignocellulosic samples (swollen volume) was estimated by mixing 1 g of fiber with a large excess of distilled, deionized water in a graduated cylinder. The suspension was mixed intermittently for several hours to ensure complete hydration of the sample, and the particles were allowed to settle overnight. The volume in the cylinder occupied by the swollen particles was taken as the swollen volume in milliliters per gram of dry material.

Animal Feeding Studies

Feeding trials were conducted to determine performance responses and nutrient digestibilities when rats and chicks were fed diets containing AHP-treated wheat straw (AHP-WS). The AHP-WS used in these studies was prepared to yield two types of treated products differing mainly in their relative content of hemicellulose. AHP-WS from which much of the hemicellulose was removed during the treatment process (type I), and AHP-WS containing the bulk of the hemicellulose originally present in the straw (type II) were prepared as described by Gould (1985). Each diet was thoroughly mixed in a vertical mixer.

TABLE I
Composition of Basal Diet Fed to Chicks

Diet Constituent	%
Cornstarch/dextrose (2:1)	Variable (to 100%)[a]
Casein	23.4
DL-Methionine	0.35
Arginine	1.5
Glycine	1.0
Corn oil	5.0
Mineral mix[b]	5.4
Vitamin mix[c]	0.2
Choline chloride	0.2
Ethoxyquin	125 mg/kg
Sodium bicarbonate	1.5

[a] The addition of fibers was at the expense of cornstarch/dextrose.
[b] Composed of each of the following (percentage of total diet): $CaCO_3$, 0.3; $Ca_3(PO_4)_2$, 2.8; K_2HPO_4, 0.9; NaCl, 0.9; $MgSO_4 \cdot 7H_2O$, 0.4; $MnSO_4 \cdot H_2O$, 0.07; Fe citrate, 0.05; $ZnCO_3$, 0.01; $CuSO_4 \cdot 5H_2O$, 0.002; H_3BO_3, 0.0009; $Na_2MoO_4 \cdot H_2O$, 0.0009; KI, 0.004; $CoSO_4 \cdot 7H_2O$, 0.0001; Na_2SeO_3, 0.00002.
[c] Composed of each of the following (mg/kg total diet): vitamin A palmitate (250,000 IU/g), 40.0; cholecalciferol (400,000 IU/g), 1.5; DL-alpha-tocopherol acid succinate, 20.0; menadione, 5.0; riboflavin, 16.0; calcium pantothenate, 20.0; niacin, 100.0; vitamin B-12 triturate, 0.02; folic acid, 4.0; biotin, 0.6; ascorbic acid, 250.0; pyridoxine HCl, 6.0; thiamine HCl, 100.0; powdered starch, 1,334.9.

TABLE II
Fiber Content of Diets (dry matter basis)

Diet	% NDF[a]	% ADF[b]	% ADL[c]
Control (0% added fiber)	2.6	2.3	0.4
Type I AHP-WS[d]			
10%	15.5	10.1	1.4
20%	21.8	17.8	2.0
30%	31.7	25.4	2.8
Type II AHP-WS			
10%	13.7	8.8	1.1
20%	19.5	15.3	1.9
30%	30.0	23.1	2.7
Wood pulp cellulose[e]			
10%	14.8	12.0	0.5
20%	25.7	21.4	0.6
30%	34.3	30.3	1.7
Alpha-cellulose[f]			
10%	15.0	1.05	0.4
20%	25.8	18.6	0.7
30%	34.0	27.2	0.8

[a] NDF = Neutral detergent fiber.
[b] ADF = Acid detergent fiber.
[c] ADL = Acid detergent lignin.
[d] AHP-WS = Alkaline hydrogen peroxide treated wheat straw.
[e] Solka floc BW-40.
[f] Alphacel.

Chick Trials

Eight-day-old New Hampshire × Columbian female chicks were allotted in a completely randomized design with three pens of five chicks for each diet. Chicks were housed in electrically heated brooders (33° C) that were placed in a temperature-controlled room (23° C). All chicks received ad libitum feed and water for 14 days, and the amount of feed intake and rate of weight gain were recorded for each pen.

The ingredient composition of the basal chick diet is presented in Table I. Three levels (10, 20, and 30%) of type I AHP-WS, type II AHP-WS, wood pulp cellulose (Solka-Floc, James River Corp.), and alpha-cellulose (ICN Biochemicals) were tested. AHP-WS was ground in a Wiley mill to pass a 1-mm screen. Neutral detergent fiber (NDF) was measured using the modified method of Robertson and Van Soest (1977). Acid detergent fiber (ADF) and acid detergent lignin (ADL) levels in each diet were also determined (Goering and Van Soest 1970) and are reported in Table II. Type III analysis of variance and weighted least squares means obtained using the SAS linear model (SAS 1982) were used to compare the effects of diet composition on weight gain, feed intake, and gain/feed ratios.

Rat Trials

Thirty-five weanling male Sprague-Dawley rats (Harlan Industries, Inc.) weighing 45 ± 5 g initially were randomly assigned to seven experimental groups with five rats per group. Animals were housed individually in metabolism cages with wire mesh floors designed for the quantitative collection of urine and feces. Temperature, humidity, and light cycle were held constant. The experiment consisted of a 14-day preliminary period and an eight-day excreta collection period. Water was provided ad libitum.

The ingredient composition of the basal diet is presented in Table III. Type II AHP-WS or arenaceous flour were substituted for 10, 20, or 30% of the cornstarch-dextrose component of the experimental diets. During the first 10 days of the experiment, feed was provided ad libitum daily at 9:00 a.m. Feed refusals from the previous day were weighed and discarded before feeding. For the last four days of the 14-day preliminary period (days 11–14), the quantity of feed offered per day to each rat in the experimental group was reduced to 90% of the amount eaten by the animal with the lowest consumption during the ad libitum feeding period. This four-day period allowed the rats to become accustomed to the 90% level of intake. After this, the eight-day collection period began. During the collection period, feed refusals (orts), and feces were

TABLE III
Composition of Basal Diet Fed to Rats

Diet Constituent	%
Cornstarch/dextrose (2:1)	Variable (to 100%)[a]
Casein	15.1
DL-Methionine	0.2
Corn oil	6.0
Mineral mix[b]	5.37
Vitamin mix[c]	0.2
Choline chloride	0.1
$MgSO_4$	0.03

[a] The addition of arenaceous flour or type II alkaline hydrogen peroxide-treated wheat straw was at the expense of cornstarch/dextrose.
[b] Composed of each of the following (percentage of total diet): $CaCO_3$, 0.3; $Ca_3(PO_4)_2$, 2.8; K_2HPO_4, 0.9; NaCl, 0.9; $MgSO_4 \cdot 7H_2O$, 0.4; $MnSO_4 \cdot H_2O$, 0.07; Fe citrate, 0.05; $ZnCO_3$, 0.01; $CuSO_4 \cdot 5H_2O$, 0.002; H_3BO_3, 0.0009; $Na_2MoO_4 \cdot H_2O$, 0.0009; KI, 0.004; $CoSO_4 \cdot 7H_2O$, 0.0001; Na_2SeO_3, 0.00002.
[c] Composed of each of the following (mg/kg total diet): vitamin A palmitate (250,000 IU/g), 40.0; cholecalciferol (400,000 IU/g), 1.5; DL-alpha-tocopherol acid succinate, 20.0; menadione, 5.0; riboflavin, 16.0; calcium pantothenate, 20.0; niacin, 100.0; vitamin B-12 triturate, 0.02; folic acid, 4.0; biotin, 0.6; ascorbic acid, 250.0; pyridoxine HCl, 6.0; thiamine HCl, 100.0; powdered starch, 1,334.9.

measured daily before feeding. All feed and excreta samples were composited daily. Feces were dried at 55°C in a forced-air oven and ground to pass a 1-mm screen. Dry matter and organic matter content of feed, orts, and fecal samples were determined according to AOAC (1975) methods. Cellulose content of feed and fecal samples was determined by the method of Crampton and Maynard (1938). Data were analyzed as a completely randomized design with seven experimental diets. Comparisons among means were made by the least significant difference method (Carmer and Swanson 1973) for criteria exhibiting a significant analysis of variance ($P < 0.05$). Computations were conducted on the SAS (1982) linear model.

RESULTS AND DISCUSSION

Physical Properties

The ability of an added cellulosic filler to absorb water, soften, and swell when it is incorporated into a baked food affects a number of important performance and sensory characteristics of the product. Poorly hydrated particles do not soften completely, and so may not become fully integrated into the starch/gluten matrix (Dubois 1978). This contributes to a reduction in baked volume and the introduction of gritty textures. The data presented in Table IV compare the relative abilities of a variety of natural lignocellulosic materials, highly purified cellulose fractions, and AHP-treated lignocellulosic materials to absorb water and swell when hydrated. Highly processed, purified cellulose preparations such as wood pulp cellulose, alpha-cellulose, and microcrystalline cellulose generally absorbed less than 10 g of water per gram dry weight and did not swell appreciably when hydrated with an excess of water. Similar results were obtained with unprocessed cell wall materials from wheat straw, corn stalks, cereal brans, and fruit and vegetable pulps.

Treatment of lignocellulosic materials with an alkaline (pH 11.5) hydrogen peroxide solution has been shown to solubilize a portion of the lignin present in the cell walls, resulting in disruption of the substrate's morphological integrity and a dramatic increase in its susceptibility to hydrolysis by cellulolytic organisms and enzymes (Gould 1984, Kerley et al 1985). AHP treatment also significantly increased the ability of native cell wall materials to absorb water and swell when hydrated (Table IV). For example, AHP treatment increased the absorbency of wheat straw threefold, from 6.8 to 21.9 g of water per gram of straw. Drying and grinding the straw after AHP treatment reduced the water absorbency somewhat, but the absorbency of AHP-treated straw remained twice the absorbency of untreated straw. These higher absorbencies are consistent with the idea that AHP-treated cell walls have a more open or sponge-like internal structure that provides greater access of water to cell wall carbohydrates (Gould et al 1989). When AHP-treated wheat straw was partially dewatered by pressing in a hydraulic press prior to drying, the water absorbency of the final ground particles was reduced. A similar, apparently additive reduction in water absorbency was observed when the treated straw was ball milled, as observed previously for milled wheat bran (Mongeau and Brassard 1982). Similar effects were also seen with AHP-treated corn stalks.

The effects of AHP treatment on the aqueous swollen volume of a variety of cell wall materials paralleled the effects on water absorbency (Table IV). The effects were particularly dramatic for a number of "food-grade" lignocellulosic materials such as wheat, corn and rice bran, sugar beet pulp, and orange pulp, where AHP treatment increased the swollen volumes by four- to 20-fold. The AHP-treated materials formed stable, gel-like dispersions in water at solids levels of approximately 3–6%. As with water absorbency, the increase in swollen volume of AHP-treated materials was reduced by drying and essentially eliminated by pressing and ball milling. The swollen volumes of the AHP-treated materials were also higher than the swollen volumes of wood pulp cellulose, alpha-cellulose, and microcrystalline cellulose. AHP treatment of these already delignified cellulosics had no effect upon either their water absorbency or swollen volume (not shown).

TABLE IV
Water Absorbency and Aqueous Swollen Volume of Various Cellulosic Materials

Sample	Water Absorbency (g H_2O/g)	Swollen Volume (ml/g)
Alpha-cellulose	3.8	5.0
Microcrystalline cellulose	1.7	4.3
Wood pulp cellulose		
SW-40	5.2	···
BW-40	5.3	7.9
Wheat straw, Wiley milled	6.8	13.0
Wheat straw		
Type I AHP-treated[a]		
never dried	21.9	39.0
Wiley milled	14.0	22.0
pin milled	14.0	···
ball milled	9.3	12.0
pressed, pin milled	11.4	···
pressed, ball milled	5.9	8.5
Type II AHP-treated		
Wiley milled	10.3	16.5
Corn stalks, Wiley milled	7.5	···
Type I AHP-treated		
pin milled	10.3	···
ball milled	7.5	···
Wheat bran	···	6.5
Type I AHP-treated	···	22.0
Corn bran	···	7.0
Type I AHP-treated	···	25.0
Rice bran	···	5.5
Type I AHP-treated	···	34.0
Sugar beet pulp	···	11.0
Type I AHP-treated	···	58.0
Orange pulp	···	6.0
Type I AHP-treated	···	137.0

[a] AHP = Alkaline hydrogen peroxide.

Animal Feeding Studies

Animal performance and nutrient digestibilities of diets containing AHP-WS in nonruminant animals were evaluated using growing chicks and rats in which up to 30% of the energy component of the basal feed was replaced with AHP-WS, wood pulp cellulose, alpha-cellulose, or arenaceous (silica) flour (Tables

TABLE V
Weight Gain, Feed Intake, and Gain to Feed Efficiency for Chicks Fed Fiber-Amended Diets

Dietary Replacement for Cornstarch/Dextrose	Weight Gain (g/day)	Feed Intake (g/day)	Gain/Feed
None	14.8 bcd[a]	18.8 f	0.79 a
Wood pulp cellulose			
10%	16.1 a	22.0 cde	0.74 abc
20%	15.1 abc	23.2 bcd	0.66 de
30%	13.5 e	25.8 a	0.55 g
Alpha-cellulose			
10%	15.7 ab	21.3 de	0.74 abc
20%	16.1 ab	23.3 bc	0.70 cd
30%	13.8 de	24.2 ab	0.59 fg
Wheat straw			
Type I AHP-treated[b]			
10%	15.7 ab	20.7 ef	0.77 a
20%	14.2 cde	21.5 cde	0.68 de
30%	14.1 cde	24.3 ab	0.60 fg
Type II AHP-treated			
10%	16.2 a	21.5 cde	0.76 ab
20%	16.2 a	23.2 bcd	0.71 bcd
30%	14.8 bcd	24.5 ab	0.63 ef
SEM[c]	0.78	1.18	0.031

[a] Means in the same column followed by different letters differ ($P < 0.05$).
[b] AHP = Alkaline hydrogen peroxide.
[c] Standard error of the means.

TABLE VI
Feed Intake and Nutrient Digestibility for Rats Fed Either Arenaceous Flour or Alkaline Hydrogen Peroxide (AHP)-Treated Wheat Straw

Item	Control	Arenaceous Flour			AHP-Treated Wheat Straw			SEM[a]
		10%	20%	30%	10%	20%	30%	
Apparent digestibility, %								
Dry matter	96.2 a[c]	86.0 b	75.6 d	63.9 f	86.4 b	78.4 c	69.5 e	0.61
Organic matter	98.4 a	98.1 ab	97.7 ab	97.1 b	88.8 c	80.4 d	71.3 e	0.39
Cellulose	...	...	...	...	28.5	24.7	20.1	2.45
Weight gain, g/day	5.50 ab	5.58 ab	5.76 a	5.58 ab	5.46 ab	4.86 bc	4.54 c	0.26
Dry matter intake, g/day	8.7 g	9.1 g	11.1 a	10.9 b	9.7 d	9.5 e	10.0 c	0.009

[a] Standard error of the mean.
[b] There was no cellulose in the control diet or in diets containing arenaceous flour.
[c] Means in the same row followed by different letters are different ($P < 0.05$).

I–III). Initial trials were conducted with chicks because they are very sensitive to changes in the level of metabolizable energy in their diet. As shown in Table V, the efficiency with which chicks gained weight when consuming diets containing the same level of fiber varied little regardless of the type of fiber (alpha-cellulose, wood pulp cellulose, type I AHP-WS, or type II AHP-WS). Chicks consuming a high level of type II AHP-WS appeared to gain weight slightly more efficiently than chicks consuming a high level of the other cellulosics, perhaps because of the higher hemicellulose content of the type II AHP-WS. The differences were very small, however, and with each diet the efficiency of weight gain per gram of feed eaten declined significantly as the level of cellulose in the diet increased.

The apparent digestibility of type II AHP-WS was further evaluated in a rat feeding trial in comparison with arenaceous flour, a totally nondigestible, inorganic filler, and the results are presented in Table VI. When AHP-WS was substituted for a portion of the cornstarch-dextrose mixture, the apparent digestibility of dry matter and organic matter declined by an amount roughly equal to the level of AHP-WS in the diet. Arenaceous flour also reduced the apparent digestibility of the total diet dry matter but did not affect the digestibility of the organic matter components of the diet. The apparent digestibility of cellulose in the diets containing AHP-WS tended to decline slightly as the level of AHP-WS increased.

Rats consuming diets containing increasing levels of arenaceous flour consumed more feed per day than the control group. As a result, the rate of weight gain remained constant regardless of the level of arenaceous flour in the diet (up to 30%) or the apparent dry matter digestibility of the diet. In contrast, rats consuming diets containing increasing levels of AHP-WS consumed only slightly more feed per day than the control group. Consequently, the rate of weight gain for rats consuming the AHP-WS containing diets decreased as the level of AHP-WS in the diet increased.

These data indicate that AHP-WS was an efficient calorie diluent when used in place of easily digestible carbohydrate components in diets fed to nonruminant animals. Feed formulations containing up to 30% AHP-WS were significantly less digestible than formulations containing cornstarch and dextrose alone. Furthermore, by virtue of its enhanced ability to absorb water and swell in size when fully hydrated, AHP-WS may have contributed to physical fullness that limited feed intake. As a result, the total calorie intake per day, and hence the rate of weight gain per day, tended to decrease when AHP-WS was included in the diet, especially at the 30% level. The enhanced physical properties introduced into a wide range of lignocellulosic materials by AHP treatment also greatly improved the interactions of AHP-treated lignocellulosics within the starch matrix of baked foods, as compared to untreated lignocellulosics and purified cellulose preparations (Jasberg et al 1989a,b). Together, these properties should allow the use of high levels of AHP-treated lignocellulose as a replacement for a portion of the flour in baked foods, for the purpose of reducing caloric density and/or increasing dietary fiber content. The effects of incorporating AHP-treated lignocellulose into dough and batter-based food formulations are presented in detail elsewhere (Jasberg et al 1989a,b).

ACKNOWLEDGMENTS

The authors thank Ninette Fandel for expert technical assistance during the course of this work, and L. L. Berger and M. S. Kerley for helpful comments during preparation of the manuscript.

LITERATURE CITED

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1975. Official Methods of Analysis, 12th ed. The Association: Washington, DC.

BETIAN, H. G., LINEHAN, B. A., BRYANT, M. P., and HOLDEMAN, L. V. 1977. Isolation of a cellulolytic *Bacteriodes* sp. from human feces. Appl. Environ. Microbiol. 33:1009-1010.

CARMER, S. G., and SWANSON, M. R. 1973. An evaluation of ten pair-wise multiple comparison procedures by Monte Carlo methods. J. Am. Stat. Assoc. 68:66-74.

CRAMPTON, E. W., and MAYNARD, L. A. 1938. The relation of cellulose and lignin content to the nutritive value of animal feeds. J. Nutr. 15:383-395.

DUBOIS, C. 1978. The practical application of fiber materials in bread production. Baker's Dig. 52(2):30-33.

FINLEY, J. W., and HANAMOTO, M. M. 1980. Milling and baking properties of dried brewer's spent grains. Cereal Chem. 57:166-168.

GOERING, H. K., and VAN SOEST, P. J. 1970. Pages 8-9 in: Forage Fiber Analysis. U.S. Dep. Agric. Agric. Handb. 379. U.S. Government Printing Office: Washington, DC.

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

GOULD, J. M. 1985. Enhanced polysaccharide recovery from agricultural residues and perennial grasses treated with alkaline hydrogen peroxide. Biotechnol. Bioeng. 27:893-896.

GOULD, J. M. 1987. Alkaline peroxide treatment of nonwoody lignocellulose. U.S. patent no. 4,649,113. Patented March 10.

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., and COTE, G. C. 1989. Structure-function relationships of alkaline peroxide-treated lignocellulose. Cereal Chem. 66:213-217.

JASBERG, B. K., GOULD, J. M., WARNER, K., and NAVICKIS, L. L. 1987a. High-fiber, noncaloric flour substitute for use in baked foods. Effects of alkaline peroxide-treated lignocellulose on dough properties. Cereal Chem. 66:205-209.

JASBERG, B. K., GOULD, J. M., and WARNER, K. 1987b. High-fiber, noncaloric flour substitute for use in baked foods. Alkaline peroxide-treated lignocellulose in chocolate cake. Cereal Chem. 66:209-213.

KERLEY, M. S., FAHEY, G. C., JR., BERGER, L. L., GOULD, J. M., and BAKER, F. L. 1985. Alkaline hydrogen peroxide treatment unlocks energy in agricultural by-products. Science 230:820-822.

LEVEILLE, G. A. 1975. The importance of dietary fiber in food. Baker's Dig. 49(2):34-39.

LORENZ, K. 1976. Triticale bran in fiber breads. Baker's Dig. 50(6):27-31.

MONGEAU, R., and BRASSARD, R. 1982. Insoluble dietary fiber from breakfast cereals and brans: Bile salt binding and water holding capacity in relation to particle size. Cereal Chem. 59:413-417.

NAGAI, T., IMAMURA, H., and KIRIYAMA, S. 1980. Dietary fiber breads containing gobo residue, gobo holocellulose, and konjac powder. Cereal Chem. 57:307-310.

POMERANZ, Y., SHOGREN M. D., and FINNEY, K. F. 1976. White wheat bran and brewer's spent grains in high-fiber bread. Baker's Dig.

50:35-38.
PRENTICE, N., and D'APPOLONIA, B. L. 1977. High-fiber bread containing brewer's spent grain. Cereal Chem. 54:1084-1095.
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.
ROBERTSON, J. B., and VAN SOEST, P. J. 1977. Dietary fiber estimation in concentrate feedstuffs. J. Anim. Sci. 45(Suppl. 1):254.
SAS. 1982. SAS User's Guide. Statistical Analysis Systems Institute: Cary, NC.
SATIN, M., McKEOWN, B., and FINDLAY, C. 1978. Design of a commercial natural fiber white bread. Cereal Foods World 23:676-681.
SHOGREN, M. D., POMERANZ, Y., and FINNEY, K. F. 1981. Counteracting the deleterious effects of fiber in breadmaking. Cereal Chem. 58:142-144.
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.
TITCOMB, S. T., and JUERS, A. A. 1986. Reduced calorie, high fiber content breads and methods of making same. U.S. patent no. 4,590,076. Patented May 20.
TSEN, C. C., WEBER, J. L., and EYESTONE, W. 1983. Evaluation of distiller's dried grain flour as a bread ingredient. Cereal Chem. 60:295-297.
VOLPE, T., and LEHMANN, T. 1977. Production and evaluation of a high-fiber bread. Baker's Dig. 51(2):24-26.
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. 42:1428-1431.

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