Human Gastrointestinal Action on Wheat, Corn, and Soy Hull Bran—Preliminary Findings[1]

F. R. DINTZIS, L. M. LEGG, W. L. DEATHERAGE, F. L. BAKER, and G. E. INGLETT;[2,3] R. A. JACOB, S. J. RECK, J. M. MUNOZ, L. M. KLEVAY, and H. H. SANDSTEAD;[4] and W. C. SHUEY[5]

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ABSTRACT

Initial studies showed some changes in composition and morphology of brans of AACC wheat (a soft white wheat), dry milled corn, and soybean hull after passage through the human alimentary tract. These materials, incorporated in bread to provide the major food fiber component of a controlled diet, were retrieved as identifiable particles from lyophilized feces of five healthy human volunteers, analyzed for changes in major fiber components, and examined by scanning electron microscopy. The corn bran was recovered in yields of 90% and greater and seemed little affected by its journey. AACC wheat bran was recovered stripped of adhering endosperm and, frequently, of aleurone layer; its appearance changed greatly because remaining pericarp layers were folded or curled, and recovered material displayed losses of about 15% cellulose and 60% apparent hemicellulose. Soybean hulls could be greatly disrupted by the human alimentary system, with major losses of cellulose and apparent hemicellulose. Digestive effects on soy hulls may differ greatly between individuals, however; sometimes cellulose and lignin were almost fully recovered, whereas apparent hemicellulose was about 50% recovered.

In recent years questions about effects of a lack of dietary fiber complexes on human nutrition and health have become the subjects of many studies, and this research area continues to attract the attention of a variety of scientific disciplines. Reviews of efforts in this field indicate that many approaches are being used, and that although excellent work has been done, our understanding of the metabolic effects of fiber is still limited (Hegsted 1977, Spiller and Amen 1975).

The usual approach has been to study effects of ingesting dietary fiber complexes on human physiology. This paper examines the inverse question: What are the effects of human physiology on some sources of dietary fiber? We examined the composition and gross morphology of three sources of fiber before incorporation in bread dough and after elimination from the human body.

MATERIALS AND METHODS

Three dietary fiber sources were studied: a soft white winter wheat bran purchased from the American Association of Cereal Chemists (AACC) and designated by that organization as certified food grade wheat bran; a dry milled corn bran donated by the Lauhoff Grain Company of Danville, IL; and milled soybean hulls donated by the A. E. Staley Co. of Decatur, IL. The wheat and corn brans were sieved to pass a No. 18 U.S. standard sieve and to remain on a No. 30 U.S. standard sieve. Soy hulls were used as is: Ro-Tap® analysis showed that 85% of particles had a distribution of 25–40 mesh, and the remaining 15% were held on a 60-mesh U.S. standard sieve.

The three fiber sources were incorporated in a frozen bread dough recipe by replacing 25% of the flour with one of the three sources on an as-is basis. Appropriate portions of dough were frozen and stored until bread was fed to human volunteers.

The volunteers were housed in a controlled metabolic unit environment and fed constant diets designed to meet their individual needs according to guidelines of the U.S. National Research Council. The diet was similar in composition to diets consumed by many middle income U.S. males. Examples of menus have been reported (Munoz et al 1979). Composition in terms of calories was 16% protein (of which 70% was from animal protein), 40% fat (P/S = 0.31), and 44% carbohydrate with 9% of calories from sucrose. The crude fiber content of the basal diet was 1 g/1,000 kcal. A neutral detergent fiber (NDF) measurement of a basal diet yielded a value of about 1.8% NDF (Van Soest and Wine 1967). Dietary fiber was added by feeding 180 g of bread containing a dietary source so that each volunteer consumed daily about 25–26 g, on a dry weight basis, of AACC bran, dry milled corn bran, or soy hulls during the 30-day experimental periods. Fecal collections were done during the last 12 days. Collections of feces, usually six-day but infrequently five-day collections, were pooled, mixed with a blender, and freeze-dried for subsequent examination and analysis.

Portions of lyophilized feces, about 10–15 g, were placed in a Soxhlet extraction thimble; fatty materials and bile acids were extracted with a solvent of chloroform/methanol/water in volume ratios 9:9:2. Extracted material was air-dried in a hood (after a minimum 24-hr extraction or until clear solvent drained from the thimble) and weighed. The defatted, air-dried feces were then hydrated overnight in distilled water at room temperature. Excreted bran was collected by sieving the particulate matter onto stainless-steel sieves of U.S. standard 40, 80, 120, and 200 meshes. Material on the sieves was rinsed in distilled water at room temperature, dipped in 95% ethanol to assist drying, air-dried in a hood overnight, weighed, and stored in glass jars. Moisture content of collected materials was determined by vacuum drying overnight at 95°C.

Cellulose and lignin in the raw and eliminated fiber sources were determined by the acid detergent fiber (ADF) method of Van Soest as modified by Holst (1973). Starch was measured independently (Wood et al 1977) by amyloglucosidase (Sigma Chemical Co., grade II, No. A-7255) attack upon a Micro Mill-ed® portion of bran substrate. After the substrate-enzyme mixture in pH 4.5 acetate buffer was stirred overnight at room temperature, the reaction mixture was analyzed for glucose by the Glucostat® special procedure (Washko and Rice 1961), and the amount of starch was calculated as 0.9 times the weight of glucose. Protein content was determined by amino acid analysis of substrate and was calculated in terms of protein on the basis of recovered amino acids. Ash and fat were determined by standard AOAC procedures. Apparent hemicellulose was obtained by difference of the sum of above six values from 100%. This apparent hemicellulose figure may contain contributions from materials such as pectins, water-soluble gums and hemicelluloses, and low-molecular-weight saccharides.

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[2]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.

[3]Northern Regional Research Center, Federal Research, Science and Education Administration, U.S. Department of Agriculture, Peoria, IL 61604.

[4]Human Nutrition Research Laboratory, Federal Research, SEA, USDA, Grand Forks, ND 58201.

[5]Spring and Durum Wheat Quality Laboratory, Federal Research, SEA, USDA, Fargo, ND 58102.

RESULTS AND DISCUSSION

Composition of starting materials is displayed in Table I. We assume "dietary fiber" to be the sum of "apparent hemicellulose," cellulose and lignin (Van Soest and Robertson, 1977). Lignin measurements include any cutin that may have been present. The corn bran and soy hulls have comparable high-dietary-fiber contents of 92 and 88%, respectively, whereas the AACC bran contents 52%. Total "dietary fiber" content measured for AACC bran was somewhat higher than values presented by Saunders and Hautala (1977).

A typical analysis of AACC bran retrieved from a portion of five-day, pooled, freeze-dried fecal collection is displayed in Table II. Comparison with starting material reveals that starch was removed along with major portions of minerals and protein. The protein value was estimated by using a nitrogen to protein conversion factor of 5.4, which was calculated from amino acid analysis on the 18–30 mesh starting material.

Balance calculations on composition of AACC bran recovered from feces of three persons are shown in Table III. The numbers shown in this table (and in Tables IV and V) represent the percent of ingested component that was recovered as identifiable fiber source remnant from feces collected during the indicated balance period. The amount of ingested component is calculated from the measured composition of raw material (Table I) and the known amount of whole fiber source material consumed in the high fiber bread. The amount of eliminated component is obtained from analysis of particles retrieved by sieving fecal aliquots. Two different balance periods were measured for volunteer A. The percent recovery of each component is similar among all three individuals. Our error estimates on all balance calculations in this article should be considered preliminary because of a limited sampling of volunteers. The lignin measurement is less precise than the other two, because it is obtained as a small difference between large numbers. Our measurements (Table III) suggest that approximately 40% hemicellulose, 70–85% cellulose, and all of the lignin is recovered from the AACC wheat bran after passage through the volunteer's alimentary tract. It is likely that some water soluble components such as pectins, hemicelluloses, and gums could be lost during the isolation procedure; however, we believe most of these components would have been extracted from the bran particles previously by contact with digestive fluids.

Composition of corn bran recovered from feces is listed for three volunteers in Table IV. Because the initial lignin content was low, meaningful measurements on recovered lignin were not feasible. Practically all of the ingested corn bran is recovered. Recovery for volunteer C during a six-day collection is significantly higher than recoveries for volunteers A and D during 12 days. This comparison emphasizes that although the volunteers ingest bran at a constant rate, they do not eliminate it at a constant rate. A 12-day fecal

TABLE I
Composition of Dietary Fiber Sources (Percent Dry Weight Basis)

	Apparent Hemicellulose[a]	Cellulose	Lignin	Starch	Protein	Oil	Ash
AACC wheat bran	40	8.81 ± 0.36	3.43 ± 0.64	23.0 ± 1.4[b]	15	4.0	5.7
Corn bran	70	22	1	<1	5.5	0.6	0.6
Soy hulls	33	53	2	<1	7	0.9	4.3

[a] Obtained by difference of the sum of remaining items from 100%.
[b] Our starch value of 23%, determined by enzyme attack on the bran and measurement of released glucose differs from an early figure of 19% that was determined by the $CaCl_2$ polarimetric method (AACC 1969). Polarimetric methods are not always suitable for determining starch in bran components of cereals (unpublished data).

TABLE II
Analysis of AACC Bran Retrieved from Feces[a]

Composition	% Dry Weight
Apparent hemicellulose	~56
Cellulose	29
Lignin	9.7
Protein	3.8[b]
Starch	<1
Ash	1.8

[a] Volunteer A, five-day collection.
[b] Estimated.

TABLE III
AACC Wheat Bran Component Recovery[a]

Volunteer	Collection Period (days)	Recovered Component (% Dry Wt) Apparent Hemicellulose	Cellulose	Lignin
A	12	37 ± 6[b]	85 ± 7[b]	87 ± 30[b]
A	12	38 ± 6	86 ± 7	90 ± 30
B	12	37 ± 6	76 ± 7	82 ± 30
C	12	40 ± 6	87 ± 7	106 ± 30

[a] Percent dry weight of ingested bran component recovered as identifiable bran particles from feces.
[b] Estimated standard deviation.

TABLE IV
Dry Milled Corn Bran Components[a]

Volunteer	Collection Period (days)	Apparent Hemicellulose	Cellulose
A	12	88 ± 5[b]	85 ± 5[b]
A	12	107 ± 5	101 ± 5
D	12	104 ± 5	100 ± 5
B	6	126 ± 5	117 ± 5

[a] Percent dry weight ingested bran components recovered as identifiable bran particles from feces.
[b] Estimated standard deviation.

TABLE V
Soybean Hull[a]

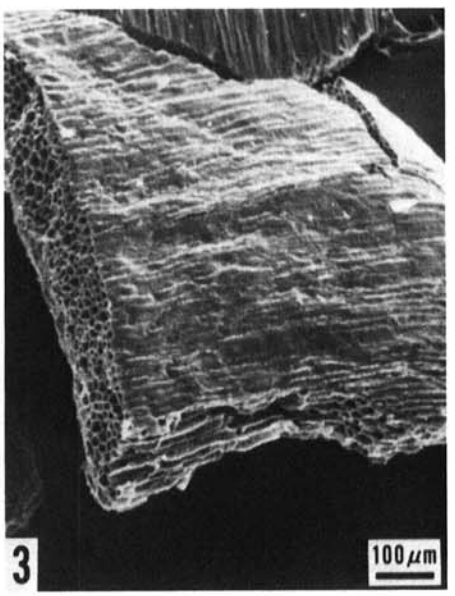
	Volunteer A (12 days)		Volunteer E (22 days)
Apparent hemicellulose	9[b]	15[c]	46 ± 5[d]
Cellulose	11[b]	19[c]	94 ± 5
Lignin	33[b]	59[c]	110 ± 30

[a] Percent dry weight ingested bran component recovered as identifiable bran remnants from feces.
[b] 40 and 80 mesh sieve collection.
[c] Total sieve collections with 120 and 200 mesh retained material calculated as having composition of 80 mesh retained material.
[d] Estimated standard deviation.

TABLE VI
Comparison of Stool Characteristics[a]

	Frequency[b]	Weight, Wet[c] (g)	Weight, Dry[c] (g)	Dry Wt/Wet Wt[d]
Volunteer A				
Basal diet	2.9	187, 310	74, 129	0.40, 0.42
AACC bran	3.8	615, 276	172, 109	0.28, 0.39
Dry milled corn bran	5.0	699, 590	268, 220	0.38, 0.37
Soy hulls	4.5	367, 246	164, 109	0.45, 0.44
Volunteer E				
Basal diet	5.3	697, 489	129, 84	0.19, 0.17
AACC bran	...	....	..., ...	..., ...
Dry milled corn bran	7.3	1,064, ...	257, ...	0.24, ...
Soy hulls	6.6	1,218, 1,319	255, 280	0.21, 0.21

[a]Source: Munoz et al (1979).
[b]Average number of stools per week.
[c]Each number represents a six-day collection.
[d]Ratios are given for six-day collections.



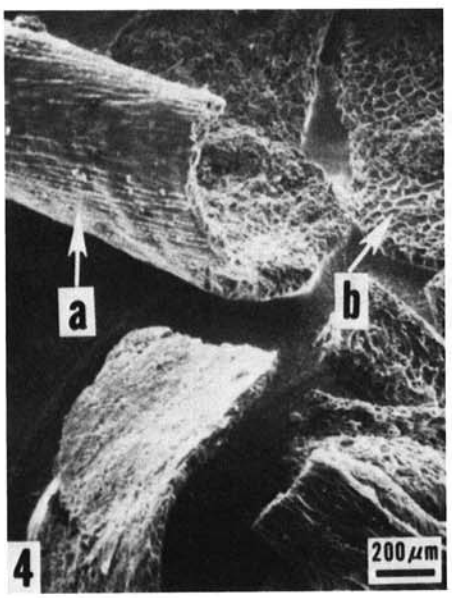


Fig. 1. Raw dry milled corn bran, 18–30 mesh, as sieved (×50). **Fig. 2.** Dry milled corn bran retrieved from feces on 40-mesh sieve (×50). **Fig. 3.** Dry milled corn bran particle, somewhat atypical, retrieved from feces on 40-mesh sieve (×100). **Fig. 4.** AACC wheat bran, 18–30 mesh, "almost" baked in bread (×50). **a,** outside surface; **b,** adhering endosperm, showing aleurone cell walls. **Fig. 5.** AACC wheat bran retrieved from feces on 40-mesh sieve (×50).

collection appears to be superior to shorter collection periods for estimation of balance.

Marked differences in composition changes that occurred when soy hulls were exposed to the human alimentary tract are contrasted in Table V. Digestion by volunteer A was much greater than that by volunteer E. Significant weights of particulate matter were collected on the 120 and 200 mesh sieves from portions of hydrated stool containing soy hull from volunteer A; this did not happen with similar stool from volunteer E. Microscope observation of matter on the 120 and 200 mesh screens revealed collection of nonsoy hull residues from the stool of volunteer A. Therefore, two balance estimates were made: The first one considered material collected only on the 40 and 80 mesh sieve. The second estimate was calculated, assuming that material on the 120 and 200 mesh sieves had the same composition as material collected on the 80 mesh sieve. Both estimates are given in Table V. Soy hull recovery measured for volunteer A is the lowest so far noted. Results for volunteer E are strikingly different. Cellulose and lignin were approximately completely recovered and hemicellulose recovery was similar to that of AACC bran. These findings

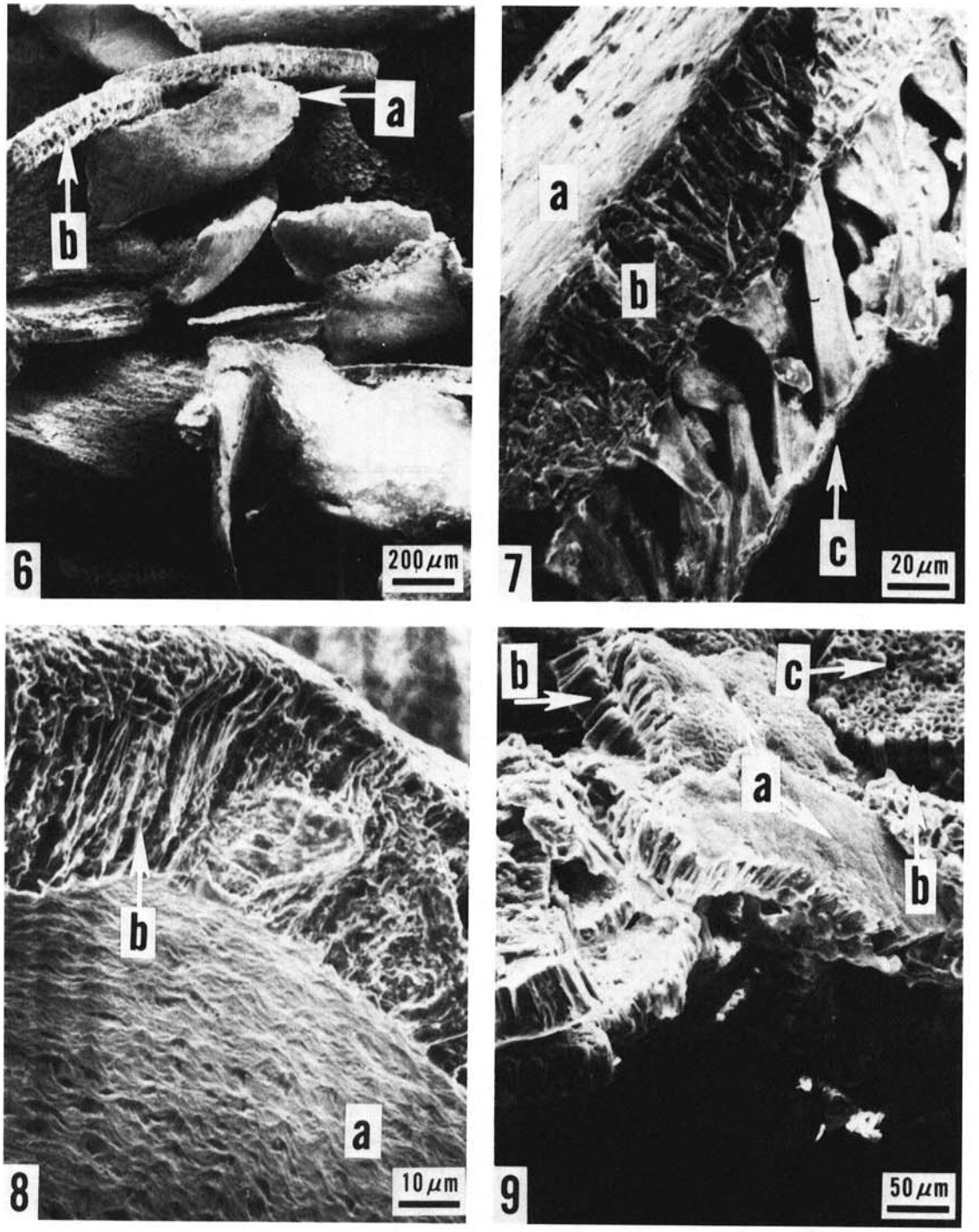


Fig. 6. Raw soy hulls, as is (×50). **a,** outside surface; **b,** double layer at edge of fracture. **Fig. 7.** Raw soy hulls, as is; detail of edge (b) in Fig. 6 (×500). **a,** outside surface; **b,** epidermis, containing palisade cells that are obscured by cell wall fragmentation; **c,** hourglass cells of the adhering hypodermis with intercellular spaces visible. **Fig. 8.** Soy hulls retrieved from feces on a 40-mesh sieve (×1,000). **a,** bottom of epidermis showing removal of hourglass cells and underneath of palisade cells; **b,** edge fracture showing palisade cells. **Fig. 9.** Soy hulls retrieved from feces on 80-mesh sieve (×200). Figures 8 and 9 are material from the same individual, obtained during sieving a common aliquot of freeze-dried stool. **a,** top surfaces of hull. Hollows appear in upper surface as palisade cells start to fall away from the cuticle layer near the surface; **b,** edges showing cylindrical bodies of palisade cell remnants separating from hull; **c,** underneath surface showing "holes" or exposed lumens of palisade cells with bottoms removed by digestion.

demonstrate that effects on soy hulls were very much a function of the individual volunteer. It probably is relevant to comment that volunteer A was constipated, compared with the other volunteers. This condition is confirmed by examination of stool frequency and weight records shown in Table VI. In addition, stools of volunteer A contained a higher solids content, as shown in the column on the right, and therefore were harder. Consequently, soy hulls were exposed to intestinal microflora of volunteer A for a longer time than for other volunteers. Because degradation of cellulosic plant tissues is thought to result from microfloral digestion, the constipation of volunteer A might explain the extreme breakdown of soy hulls. This constipation did not, however, significantly affect recovery values of AACC bran or dry milled corn bran.

Since we have not found human digestibility studies of corn bran and soy hulls in the literature, comparison of our findings with those of others is feasible only for wheat bran. Even then, only qualitative comparisons can be made because of differences in types of wheat brans, condition of ingested materials, and differences in the diet regimens. The classic studies of Williams and Olmsted proved that cellulose and hemicellulose in various plant tissues including wheat bran were degraded in the human alimentary tract (1936a). They fed medical students about 40 g daily of a relatively coarse wheat bran (it did not pass through a 20-mesh wire gauze when washed). This bran was washed in water, air-dried, extracted twice with ethyl alcohol, again air-dried, and then fed as a dry cereal with cream and sugar (Williams and Olmsted 1936b). Analysis of feces by methods then available indicated loss of about 35% hemicellulose, 30% cellulose, and 10% lignin (Williams and Olmsted 1936a).

Recently, Thomas and Elchazly measured digestibility of whole meal bread and raw whole wheat flakes when about 50% of the energy intake was from wheat products (1976). They found an apparent disappearance of: $29.5 \pm 9.7\%$ hemicellulose, $18.5 \pm 9.5\%$ cellulose, and $1.1 \pm 0.43\%$ lignin for whole meal bread and $19.4 \pm 7.7\%$ hemicellulose, $10.2 \pm 5.5\%$ cellulose, and $0.2 \pm 0.1\%$ lignin for raw whole wheat flakes. They concluded that apparent digestibility of dietary fiber is inversely proportional to fiber particle size and directly proportional to intestinal transit time. Their findings and our observations indicate that effects of passage through the human alimentary tract on "dietary fiber" depend on a variety of ill-defined factors.

Of the materials we examined, dry milled corn bran displayed high resistance to digestion in the small intestine and colon. The relationship of this resistance to possible physiologic effects is unknown. Likewise, the physiologic effects of the other two more digestible fiber sources is unknown. Presumably, some of the products of digestion of the fiber sources were absorbed by the volunteers and utilized for energy. If other metabolic effects occurred, they are unknown.

Scanning electron micrographs (SEM) of bran tissue as it appeared before and after excretion show that the corn bran (Fig. 1) did not noticeably change its gross shape or overall dimensions after passage through a human alimentary tract (Fig. 2). The single particle (Fig. 3) very much maintained its integrity.

The SEM of AACC bran before ingestion (Fig. 4) was taken of particles that were exposed to simulated baking conditions by placing them in a trough of a standard yeast bread dough (1 lb), folding the other half of the dough over the bran, and baking. The bran did not become an integral part of the bread crumb and was easily removed. AACC bran so treated produced SEM images that could not be distinguished from those of untreated 10–30 mesh bran. Changes in appearance of excreted wheat bran (Fig. 5) are obvious: Adhering endosperm and aleurone were removed and remaining pericarp material was often greatly folded or curled. The imaged changes are typical.

The micrograph (Fig. 6) of as-is soy hull shows particles consisting predominantly of two layers of cells: the palisade cells in the epidermis and adhering hourglass cells beneath (Wolf and Baker 1972). A magnified view (Fig. 7) displays structured detail of a fractured edge. A particle excreted and collected on a 40-mesh sieve is shown in Fig. 8. The hourglass cells have been completely removed to expose the underneath side of the palisade cells. Note that the appearance of the fractured edge of these cells (Fig. 8) seems little changed from that of fractured palisade cells of noningested bran (Fig. 7). However, the view (Fig. 9) of a soy hull particle excreted by the same person and collected on an 80-mesh screen provides a dramatic contrast. The palisade cells were strongly attacked and the particle in the upper right (Fig. 9, c) shows some palisade cells with bottoms removed and exposed lumens. The fiberlike material at the fractured edges is gone, and disrupted cells appear as cylindrical bodies beginning to separate from each other. The top surfaces show hollows, as remnants of palisade cells begin to pull away from the cuticle layer. Figures 8 and 9 were obtained from a fecal aliquot of a volunteer whose alimentary tract treated the hulls about the same as that of volunteer E. The last two micrographs show that effects of alimentary passage on soy hulls were not uniform. The epidermis layer of particles on the 40-mesh sieve appears almost unchanged, but particles on the 80-mesh screen were in various stages of disintegration. Three possible explanations for these findings are that larger soy hull particles may be more resistant to attack, that particles collected on the 80-mesh screen may have been in the colon longer and therefore had greater exposure to microflora digestion, or that contact between soy hull particles and microflora colonies may be sufficiently nonuniform that some particles received little effective exposure to microflora digestion.

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ADDENDUM

Measurement by gas chromatography of glucose released by glucoamylase attack on AACC bran yields a calculated starch value of about 23% rather than 31% obtained with use of the glucostat special reagent. We accept 23% starch as valid and use this value in our calculations.

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