Mechanisms by which wheat bran and oat bran increase stool weight in humans

Hsiao-Ling Chen, Valerie S Haack, Corey W Janecky, Nicholas W Vollendorf, and Judith A Marlett

ABSTRACT Generally, stool weight is significantly increased by adding sources of insoluble fiber to the diet. Comparable amounts of fiber provided by wheat and oat brans have the same effect on daily stool output, even though > 90% of wheat bran fiber but only 50–60% of oat bran fiber is insoluble. To determine the bases for these increases in stool weight, stool samples collected from 5 men in 2 constant diet studies that determined the effects of wheat and oat brans on large-bowel physiology were fractionated by using a physicochemical procedure into plant, bacterial, and soluble fractions, which were weighed and analyzed for sugar content and composition. Nitrogen, crude fat, and ash outputs were also determined. Wheat bran increased the fecal concentration of sugars and mass of plant material more than did oat bran, whereas oat bran increased fecal bacterial mass more. Each fiber source increased nitrogen, ash, and fat excretion, but excretion of fat was greater with oat bran. The apparent digestibility of plant-derived neutral sugars decreased significantly when wheat but not oat bran was consumed. The apparent digestibility of neutral sugars provided by wheat bran was 56%; the apparent digestibility of those provided by oat bran was 96%. We conclude that bacteria and lipids are major contributors to the increase in stool weight with oat bran consumption, whereas undigested plant fiber is responsible for much of the increase in stool weight with wheat bran consumption. Results are consistent with the hypothesis that oat bran increases stool weight by providing rapidly fermented soluble fiber in the proximal colon for bacterial growth, which is sustained until excretion by fermentation of the insoluble fiber. Am J Clin Nutr 1998;68:711–9.

KEY WORDS Dietary fiber, wheat bran, oat bran, stool weight, dietary fiber digestibility, men

INTRODUCTION

Two of the primary physiologic functions of the large bowel, increasing stool weight and improving laxation, are major outcomes of consuming adequate dietary fiber. These responses are attributed to the insoluble fraction of fiber (1). Nearly all of the fiber in wheat bran (> 95%) is extracted as insoluble fiber (2), in contrast with the fiber in oat bran, which may be up to half soluble (2). Thus, it would be predicted from compositional data that, when consumed in comparable amounts, wheat bran fiber would produce larger stools than oat bran fiber. These predictions are supported by the findings of an exhaustive review indicating that products containing oats had about two-thirds (63%) of the ability of wheat products to increase stool weight (3). We reported recently that when dietary intake is strictly controlled, comparable amounts of fiber from wheat and oat brans have similar effects on stool weight increases in humans (4). Results of 2 rat studies that compared the stool-bulking effects of wheat and oats support our finding (5, 6).

Data from gravimetric fractionations of stool indicate that most of the increase in stool weight that occurs with wheat bran ingestion can be accounted for as undigested fiber (7), although subsequent research indicated that such gravimetric measures are relatively insensitive (8, 9). No data are available to explain the increase in stool weight we observed with the consumption of oat bran fiber. It could be hypothesized from available data that oat bran increases stool weight as effectively as wheat bran by providing rapidly fermented soluble fiber for bacterial growth, which is sustained until excretion, and by contributing to stool undigested insoluble fiber, although less than that contributed by wheat bran.

The overall aim of this research was to test this hypothesis by determining the output of specific sugars in fractions of stool. The specific objectives were to determine the effects of wheat and oat bran fibers on the yield and sugar composition of plant, small plant, and bacterial fractions isolated from stool; to determine the apparent digestibility of plant-derived sugars when wheat bran or oat bran was ingested; to compare the results of wheat bran with those of oat bran; and to evaluate the effectiveness of the fecal fractionation scheme by determining the distribution among the fecal fractions of the sugars derived primarily from the brans and of muramic acid, a sugar unique to bacteria (10).

1From the Department of Nutritional Sciences, University of Wisconsin–Madison.

2Supported by the National Cancer Institute (CA46339); the National Institute of Diabetes and Digestive and Kidney Diseases (DK21712); the College of Agriculture and Life Sciences, University of Wisconsin–Madison; and the Quaker Oats Company, Barrington, IL, which donated the oat products used in this study.

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Received July 8, 1997.

Accepted for publication March 25, 1998.
SUBJECTS AND METHODS

Human studies

The fecal samples used in these experiments were from two 56-d human metabolic studies of the effects of wheat bran and oat bran on small- and large-bowel function (4, 11). The studies were approved by the College of Agricultural and Life Sciences’ Committee on Research involving Human Beings, University of Wisconsin–Madison. Nine healthy young men participated in each study, and stools from the 5 men who participated in both studies were used to determine and compare the bases for stool weight. At the start of the studies, the mean (±SD) initial weight, height, and age of the subjects were 73.0 ± 7.9 kg, 176.2 ± 6.9 cm, and 23.4 ± 2.7 y, respectively (4).

The experimental design of each study was similar and has been described (4, 11). Briefly, each study consisted of two 28-d periods. Days 1–28 consisted of a constant, weighed, low-fiber diet in which subjects consumed a mixture of foods, typical of what is consumed by the US population. Days 29–56 were the high-fiber diet period, during which 30 g (“as is” weight) wheat bran (soft white wheat bran; American Association of Cereal Chemists, St Paul) or 100 g (“as is” weight) oat bran (Quaker Oats Co, Barrington, IL) was incorporated into the control diet by using specially developed recipes for bread, muffins, cookies, Salisbury steak, and meatballs, which were prepared in the metabolic unit from the same lots of ingredients for both diet periods of an experiment. Other grain-derived starch in the high-fiber period was reduced and gluten was added to the low-fiber period to keep the amounts of starch and vegetable protein in the low-and high-fiber periods comparable. The fat content of the oat bran diet was adjusted to account for the fat contributed by the oat bran. The control and high-fiber diets of each study contained (as a percentage of energy) 50% carbohydrate, 15% protein, and 35% fat. The calculated starch contents of the 12.55-MJ (3000-kcal) control and oat bran diets were 205 and 191 g/d, respectively, and those of the 12.55-MJ control and oat bran diets were 187 and 189 g/d, respectively (4). Intakes of all micronutrients met or exceeded recommended or safe and adequate intake levels. Preparation and service of the constant diets followed a metabolic diet protocol (4, 11).

The dietary fiber content and carbohydrate composition of the diets and fiber sources were measured by a modified version (12) of the method of Theander and Westerlund (13), in which the sugars were measured by HPLC instead of gas chromatography. Mixed-linkage β-glucans in the oat bran were measured by using the enzymatic-colorimetric method of McCleary and Glennie-Holmes (14). The mean (±SD) total dietary fiber intakes of the 5 subjects during the wheat bran study were 20.3 ± 1.3 g/d (15.1 g monosaccharides, 2.3 g uronic acids, and 2.9 g Klason lignin) and 31.1 ± 1.9 g/d (24.4 g monosaccharides, 2.7 g uronic acids, and 4.0 g Klason lignin) for the low-fiber and wheat bran periods, respectively. Mean intakes of the total analyzed fiber in the oat bran study were 15.5 ± 1.8 g/d (11.1 g monosaccharides, 2.1 g uronic acids, and 2.3 g Klason lignin) and 29.8 ± 1.8 g/d (21.7 g monosaccharides, 3.1 g uronic acids, and 5.0 g Klason lignin), for the low-fiber and oat bran periods, respectively.

Fecal samples

All stools were individually collected, weighed, and stored at −20°C within 8 h of defecation. Each stool was blended with sufficient water to produce a uniform homogenate and then lyophilized (Virtis Co, Gardiner, NY) for determination of dry weight and preparation of multiday composites for fractionation and analysis. We determined previously that blending had no effect on the effectiveness of the fecal fractionation (8). Ten-day composites of all stools excreted from days 18–27 and days 46–55 of each study were prepared by combining 25% of the dry weight of each stool.

Fractionation of fecal samples

The dual-screen procedure developed by Cabotaje et al (8, 15) to separate plant, small plant, bacterial, and soluble matter in feces was modified for this study as outlined in Figure 1. Briefly, to fractionate the high-fiber fecal composites, duplicate aliquots (1 g) were blended (Stomacher Lab Blender 400; Tekmar Co, Cincinnati) with an aqueous solution of 1% sodium lauryl sulfate (SLS; 60 mL) and filtered through a 150-μm screen. The residue on the screen was dispersed and rinsed with water while the screen was agitated by tapping the side of the screen ≈80 times/min until the foaming of the SLS in the sample disappeared. The volume of filtrate and rinse from the first blending, which was ≈250 mL, was centrifuged. Unless specified, all centrifugations were at 30000 × g for 30 min at 4°C.

The supernate obtained by centrifugation of the filtrate and rinse from the first blending was the soluble fraction (S fraction) and was recovered by lyophilization. The pellets obtained from

![FIGURE 1](https://academic.oup.com/ajcn/article-abstract/68/3/711/4648701/figure1)
the centrifugation of this filtrate and rinse were mixed with formylsaline and reserved for combination with the filtrates from the 3 additional blendings of the material on the 150-μm screen. These additional blendings used 1% SLS, but formylsaline (60 mL) instead of water. All subsequent rinsings of residue on the 150- and 35-μm screens were tapped. The final residue on the 150-μm screen was coarse plant material, the P fraction.

The combined filtrates and rinses from the 3 blendings and pellets from the centrifugation to obtain the S fraction were filtered through a 35-μm screen and the residue rinsed with formylsaline (≈500 mL) until the filtrate was clear. Twice more the residue retained on the 35-μm screen was blended (15 mL formylsaline, 0.45 mL SLS, 5 min), filtered, and rinsed through the 35-μm screen. The residue on the 35-μm screen was small plant material, the SP fraction.

The P and SP fractions of the stools from the wheat bran study were suspended in formylsaline, centrifuged, and resuspended in fresh formylsaline (9.9 mL) and SLS (0.1 mL) to obtain aliquots (0.1 mL) for microscopic bacterial counts. The formylsaline was removed from the fecal P and SP fractions from both studies by centrifugation followed by rinsing with water (20 mL) and recentrifugation.

The filtrates and rinses that passed through the 35-μm screen were mixed and a sample (5 mL) was taken from those from the wheat bran study for microscopic bacterial counts. The solution was then centrifuged (20000 × g for 30 min at 4°C) in 250-mL polypropylene bottles until all pellets and remaining supernate fit into one centrifuge tube (50 mL) for the final centrifugation. The supernate was discarded. The pellet, which was the bacterial fraction (B fraction) was rinsed (20 mL water), centrifuged, and lyophilized. The low-fiber fecal composites were fractionated with the same procedure except that 2.0 g feces was used and all fractionation reagents were increased accordingly.

**Fecal fat, protein, and ash analyses**

All analyses were done in duplicate with lyophilized fecal samples. Fecal fat was analyzed according to the method of the Association of Official Analytical Chemists, as modified for analysis of body tissue (16). Fecal nitrogen content was measured by a micro-Kjeldahl method. Fecal ash was the residue obtained by heating dry feces at 475°C for 24 h.

**Determination of microscopic counts**

Bacterial counts of fecal fractions from the wheat bran study were determined in a Petroff-Hauser bacterial counting chamber (Thomas Scientific, Horsham, PA) with a Laborlux D transmitted-light microscope (Ernst Leitz Wetzlar Inc, Wetzlar, Germany) at a magnification of ×400, as described previously (8).

**Neutral and amino sugar analysis**

The monosaccharide contents of the fecal composites and fecal fractions were determined by using a modification (17) of the method of Kraus et al (18). Briefly, duplicate samples (25 mg) were acid-hydrolyzed, neutralized, reduced to alditols, and derivatized to alditol acetate derivatives. The derivatized samples were analyzed by gas–liquid chromatography (model HP-5890; Hewlett-Packard, Palo Alto, CA) with a flame ionization detector and a fused silica column; response factors were determined from the analysis of a mixture of pure standard sugars and one standard sugar mixture was analyzed with each batch of biological samples, as described previously (19).

**Apparent digestibility of fiber-derived sugars**

The daily intake of neutral sugars (glucose, arabinose, xylose, mannose, and galactose) from the fiber extracted from the diet composites was the measure of intake. The sum of the daily excrections of the same neutral sugars in the P and SP fractions isolated from stool was the measure of unfermented fiber-derived sugars. The apparent digestibility of fiber-derived sugars was calculated as the difference between intake and excretion, expressed as a percentage of intake. The apparent digestibility of the neutral sugars provided by the brans was calculated by using the differences between the respective control and experimental diet intakes and the control and experimental diet excretions.

The apparent digestibility of uronic acids was not determined because the origin of the very small amounts of uronic acids we measured previously in excreta was unclear and could represent endogenously produced glycoproteins (JA Marlett, unpublished observations, 1989). The apparent digestibility of Klason lignin was also not determined because analysis of feces for lignin likely includes several other materials besides Klason lignin (20).

**Statistics**

All data are expressed as means ± SDs. Statistical significance was set at P < 0.05. Three analyses were done by the paired t test method (21) on the following differences evaluated for each subject: 1) the effect of wheat bran consumption, namely the wheat bran response minus the corresponding basal response; 2) the effect of oat bran consumption, namely the oat bran response minus the corresponding basal response; and 3) the percentage change caused by oat bran minus the percentage change caused by wheat bran. These analyses were performed for all 32 responses.

**RESULTS**

**Gravimetric excretion**

Incorporation of wheat or oat bran into the constant diets significantly increased the gravimetric yield of all 4 fractions isolated from feces, although the effects of the 2 brans on the P and B fractions differed in magnitude (Table 1). The gravimetric yield of the P fraction from feces collected during the wheat bran diet was 580% larger than that of the P fraction from the control stool, whereas the gravimetric yield of the P fraction during the oat bran diet was 380% larger than that of the control feces P fraction. The increase in mass of the B fraction produced by incorporating wheat bran into the constant diet was 17%, compared with 36% for incorporation of oat bran into the diet.

Both fiber sources significantly increased stool output (Table 1). Fecal wet weight increased 67% when wheat bran was incorporated into the diet and 68% when oat bran was. Dry stool weight in the wheat bran study increased 61% compared with 57% in the oat bran study.

**Sugar excretion**

Wheat bran increased the concentration of total sugars in stool, but oat bran had no effect (Table 2). Furthermore, 1- to 7-fold increases in the 3 major sugars in wheat bran fiber—glucose, arabinose, and xylose (Table 3)—were observed when wheat bran was consumed. In contrast, although these same 3 sugars are the major sugars in oat bran fiber, the significant increases in arabinose and xylose with the added oat bran fiber.
were only 24% and 26%, respectively, and the fecal concentration of glucose was unchanged by oat bran consumption. Wheat bran consumption also decreased the concentrations of muramic acid, which is found only in bacteria (10), and of glucosamine and galactosamine, which are found in both bacteria and mucin (15, 17). Oat bran decreased only the fecal muramic acid concentration (Table 2).

Daily excretions of sugars in the P fractions from feces reflected these compositional differences (Table 4). The daily output of sugars in the P and SP fractions increased with bran incorporation, but the increase with wheat bran consumption was much greater than that with oat bran. Both brans increased the daily excretion of sugar in the B fraction, and the magnitude of this increase was comparable for both brans. Only oat bran significantly increased the excretion of sugars in the S fraction.

Fecal proximate composition

Both brans significantly increased excretions of ash, crude fat, and nitrogen (Table 5). These 3 components added 3.1 g to the wheat bran stool and 6.7 g to the oat bran stool, compared with the respective control excreta. However, only the increase in fat excretion produced by oat bran consumption was significantly greater than the increase generated by wheat bran consumption. Stool moisture did not change significantly with either bran.

Digestibility of fiber-derived neutral sugars

Glucose, arabinose, and xylose were the major fiber-derived sugars in both brans (Table 3), which is consistent with other analyses (2). The apparent digestibility of all fiber-derived sugars extracted into the P and SP fractions exceeded 90% during both low-fiber diet periods (Table 6). Incorporation of wheat bran into the constant diet significantly decreased the digestibility of all fiber-derived neutral sugars. The apparent digestibility of all of the major neutral sugars in wheat bran was 56%, with glucose the least extensively fermented (Table 6). Incorporation of oat bran into the diet had no effect on the digestibility of mannose, glucose, galactose, and rhamnose, and the significant decreases in the digestibility of arabinose and xylose were much
more modest than those when wheat bran was part of the diet. The neutral sugars in oat bran were more extensively fermented than those in wheat bran (Table 6). The amount of glucose contributed by mixed-linkage β-glucans was so substantial that when it was included in the total neutral sugars, oat bran-derived neutral sugars were as completely fermented as those in the low-fiber control diets. No β-glucans were detected in feces.

**Effectiveness of the fecal fractionation**

The mean gravimetric recoveries of the starting samples, the sum of the 4 fractions isolated from feces during the 4 diet periods, ranged from 86% to 92%. Recoveries of total fecal sugars in the 4 fractions were 98% and 92% for samples from the wheat bran and oat bran control periods, respectively, and 94% for the fractionations of the samples from both experimental periods.

The effectiveness of the fractionation of stools from both studies was evaluated by tracking the distribution of 3 key sugars. Muramic acid, a sugar found only in bacteria, was used to monitor the ability of the fractionation scheme to recover bacteria in the B fraction. Arabinose and xylose, found primarily but not exclusively in plant material (15), were the indicator sugars for plant material.

Of the arabinose and xylose in excreta, 50–65% was in the P fraction and 0.03–0.05% was in the SP fraction. The distribution of bacteria was similar among the fecal fractions of the stools containing wheat bran, although significantly fewer bacteria (<0.004) were detected in the wheat bran B fraction (42.18 ± 9.9 × 10⁹) than in the B fraction from the low-fiber stool. Because essentially all bacteria were located in the B fractions of stools from the wheat bran study, bacterial counts of fecal fractions from the oat bran study were not done.

**DISCUSSION**

Our results indicate that fiber from oat bran can increase stool weight as effectively as fiber from wheat bran, but that it does so by a different mechanism. In the wheat bran study the analyzed increase in mean dietary fiber intake of 10.8 g/d was accompanied by a mean increase in wet stool weight of 52.4 g/d, resulting in an increase in daily wet stool weight of 4.85 g for each additional gram of fiber consumed. During the oat bran study the increase in analyzed dietary fiber intake was 14.3 g/d, the increase in mean wet stool weight was 64.9 g/d, and each additional gram of dietary fiber consumed daily increased stool weight 4.54 g. These findings contrast with those reported previously of a 5.4-g increase in stool weight for each gram of wheat products consumed and 3.4-g increase in stool weight for each gram of oat bran consumed.

**TABLE 4**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Wheat bran</th>
<th>Oat bran</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control diet</td>
<td>Experimental diet</td>
</tr>
<tr>
<td>Plant</td>
<td>175 ± 39</td>
<td>3481 ± 278</td>
</tr>
<tr>
<td>Small plant</td>
<td>336 ± 88</td>
<td>1207 ± 173</td>
</tr>
<tr>
<td>Bacterial</td>
<td>925 ± 148</td>
<td>1358 ± 210</td>
</tr>
<tr>
<td>Soluble</td>
<td>434 ± 206</td>
<td>726 ± 628</td>
</tr>
</tbody>
</table>

1x ± SD; n = 5 men. Control data were collected during constant low-fiber diets and experimental data during the same diet into which wheat or oat bran was incorporated.

2Effects of wheat bran were compared with those of oat bran by statistical analysis of the differences between the results obtained during the control and experimental periods of each study.
### TABLE 5
Fecal composition of excreta of humans consuming diets with and without wheat and oat brans

<table>
<thead>
<tr>
<th></th>
<th>Wheat bran</th>
<th>Oat bran</th>
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<tbody>
<tr>
<td></td>
<td>Control diet</td>
<td>Experimental diet</td>
<td>Control diet</td>
<td>Experimental diet</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>69.3 ± 5.0</td>
<td>71.7 ± 2.2</td>
<td>71.2 ± 2.7</td>
<td>73.3 ± 2.0</td>
</tr>
<tr>
<td>Crude fat (g/d)</td>
<td>4.1 ± 0.7</td>
<td>5.2 ± 0.6</td>
<td>4.1 ± 1.3</td>
<td>7.5 ± 1.0</td>
</tr>
<tr>
<td>Nitrogen (g/d)</td>
<td>1.4 ± 0.3</td>
<td>1.9 ± 0.4</td>
<td>1.8 ± 0.5</td>
<td>2.7 ± 0.5</td>
</tr>
<tr>
<td>Ash (g/d)</td>
<td>4.5 ± 0.5</td>
<td>6.0 ± 0.4</td>
<td>4.9 ± 0.6</td>
<td>7.3 ± 0.6</td>
</tr>
<tr>
<td>PP (g/d)</td>
<td>1.4</td>
<td>0.5</td>
<td>0.21</td>
<td>0.20</td>
</tr>
<tr>
<td>Glc (g/d)</td>
<td></td>
<td>2.0</td>
<td>0.07</td>
<td>1.33</td>
</tr>
<tr>
<td>Total</td>
<td>11.4</td>
<td>3.1</td>
<td>3.3</td>
<td>4.5</td>
</tr>
</tbody>
</table>

1 ± SD; n = 5 men. Control data were collected during constant low-fiber diets and experimental data during the same diet into which wheat or oat bran was incorporated.

2 Effects of wheat bran were compared with those of oat bran by statistical analysis of the differences between the results obtained during the control and experimental periods of each study.

### TABLE 6
Intake, excretion, and apparent digestibility of neutral sugars from dietary fiber in humans consuming diets with and without wheat and oat brans

<p>| | | | | |</p>
<table>
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<tr>
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<tbody>
<tr>
<td></td>
<td>Ara</td>
<td>Xyl</td>
<td>Man</td>
<td>Gal + Rha</td>
</tr>
<tr>
<td>Wheat bran study</td>
<td></td>
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<tr>
<td>Control diet</td>
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</tr>
<tr>
<td>Intake (g/d)</td>
<td>0.16 ± 0.19</td>
<td>1.77 ± 0.20</td>
<td>0.99 ± 0.10</td>
<td>0.42 ± 0.21</td>
</tr>
<tr>
<td>Excretion (g/d)</td>
<td>0.07 ± 0.01</td>
<td>0.10 ± 0.02</td>
<td>0.02 ± 0.01</td>
<td>0.03 ± 0.01</td>
</tr>
<tr>
<td>Apparent digestibility (%)</td>
<td>95.8 ± 0.5</td>
<td>94.3 ± 1.0</td>
<td>97.6 ± 1.1</td>
<td>98.0 ± 1.8</td>
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<tr>
<td>Experimental diet</td>
<td></td>
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</tr>
<tr>
<td>Intake (g/d)</td>
<td>2.11 ± 0.20</td>
<td>2.53 ± 0.20</td>
<td>1.10 ± 0.10</td>
<td>1.62 ± 0.21</td>
</tr>
<tr>
<td>Excretion (g/d)</td>
<td>0.16 ± 0.02</td>
<td>0.21 ± 0.05</td>
<td>0.03 ± 0.02</td>
<td>0.06 ± 0.03</td>
</tr>
<tr>
<td>Apparent digestibility (%)</td>
<td>92.3 ± 1.4</td>
<td>91.7 ± 2.2</td>
<td>97.3 ± 1.4</td>
<td>96.2 ± 1.9</td>
</tr>
<tr>
<td>Oat bran study</td>
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<tr>
<td>Control diet</td>
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<tr>
<td>Intake (g/d)</td>
<td>1.46 ± 0.19</td>
<td>1.77 ± 0.20</td>
<td>0.99 ± 0.10</td>
<td>0.42 ± 0.21</td>
</tr>
<tr>
<td>Excretion (g/d)</td>
<td>0.07 ± 0.01</td>
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</tr>
</tbody>
</table>

1 ± SD; n = 5 men. Control data were collected during constant low-fiber diets and experimental data during the same diet into which wheat or oat bran was incorporated. Ara, arabinose; Xyl, xylose; Man, mannose; Gal+Rha, galactose plus rhamnose (which coeluted during HPLC separation of sugars in food fiber); Glc, glucose.

2 Non-mixed-linkage β-glucans; digestibility was 97.9 ± 1.2% if β-glucans were included.

3 Includes 6.39 g mixed-linkage β-glucans/24 h.

4 Effects of wheat bran (WB) were compared with those of oat bran (OB) by statistical analysis of the differences between the results obtained during the control and experimental periods of each study.

5 Calculated by using the differences between the respective control and experimental diet intakes and the control and experimental diet excretions.

6 Not calculated.

Overestimating the fiber content of a diet also affects the calculation. Two of the oat studies reviewed by Cummings reported that the concentration of dietary fiber in the oat bran used was 26–28% (23, 24). Available data indicate that oat bran contains 15–18% fiber (2). Early methods of fiber analysis did not always remove the starch that is normally assimilated in the small bowel and it is likely that the concentration of fiber in oat bran reported as 26–28% included digestible starch. A later report from the same laboratory in which the analyzed fiber content of oat bran was 15.7% (25) agrees with the results of others (2).
Analytic errors such as these would have less of an effect when results from many studies, such as the 41 studies available to Cummings (3) for calculating the effect of wheat products on stool output, are averaged. For oats, the mean calculated by Cummings (3) is skewed to a lower effect of oat fiber on stool output by the inflated fiber data from these 2 studies, which represented half of the 4 studies from which Cummings could determine a mean effect.

The increase in stool weight with oat bran consumption was not the result of the presence of dietary fiber in stool, as was the case when wheat bran was ingested. Extraction of more of the increase in the mass of the fractions into the B fraction (42%) and less into the plant fractions (P and SP, 21%) from oat bran stool than from wheat bran stool (17% and 53%, respectively) supports the more extensive fermentation of the oat bran fiber we measured as apparent digestibility. Both results are consistent with greater bacterial growth during oat bran consumption than during wheat bran consumption.

The extensive fermentation of the glucose in the form of mixed-linkage β-glucans is consistent with other data indicating that soluble dietary fiber is highly available to microflora and is fermented before the insoluble fiber fraction (19). Apparent digestibility data also indicate that the cellulose and arabininoxylans extracted from oat bran, primarily as insoluble fiber components, were more completely degraded than those in wheat bran. It is not possible to distinguish the relative importance of 2 possible bases for the more extensive fermentation of the cellulose and arabininoxylans polysaccharides when they were consumed as oat (compared with wheat) bran. This difference could reflect the fermentative activity of a larger bacterial population in the large bowel during oat bran ingestion or differences in plant cellular or intercellular structure.

These findings support our original hypothesis that soluble fiber in oat bran stimulates bacterial growth and that the insoluble fiber then provides more slowly fermentable polysaccharides to maintain the microbial population during transit through the large bowel. In contrast, if a test fiber consists of only soluble fiber, it has a negligible effect on stool weight (3). It is likely that although rapid bacterial growth occurs in the proximal large bowel because of the availability of isolated soluble fiber, there is negligible other exogenous carbohydrate to sustain the microflora and autolysis consumes most of the microbial population by the time excretion occurs ≈2 d later.

Our fractionations of stool containing wheat bran fiber confirm and extend the earlier observations of Stephen and Cummings (7). Data from both laboratories suggest that plant residue is responsible for a major portion (50–60%) and bacteria for only a small fraction (12–17%) of the increase in stool weight when wheat bran is added to a low-fiber diet. The gravimetric yields of B fractions from the wheat bran–containing feces obtained by the 2 laboratories were also similar, 44% in the present study compared with 38% in the study by Stephen and Cummings. The yields of fecal plant material by the 2 laboratories were moderately different, 26% compared with 35%, respectively. Both laboratories reported that bacteria accounted for a high proportion of stool dry weight (55–60%) during low-fiber diets. The success of this fecal fractionation scheme is dependent on careful quantitative techniques and the use of samples of appropriate particle sizes. It is likely that the differences between the results of fractionation of wheat bran stool from the 2 laboratories are a result of different analysts and different sources of wheat bran.

We extended earlier observations by Stephen and Cummings (7) of the fractions from stool containing wheat bran in 2 ways. First, our determination of the apparent digestibility of wheat bran fiber was more specific because we analyzed both diet and excreta for the specific sugars in fiber. In contrast, Stephen and Cummings (7) used a relatively insensitive gravimetric measure of fecal fiber, the neutral detergent fiber method. Thus, they reported that only 36% of the wheat bran fiber was fermented, which is different from the apparent digestibility of 56% we determined. We contend that our measure of fermentation of wheat bran fiber is more accurate because specific sugars in fiber intake and excretion were analyzed. In our experience, the neutral detergent fraction of feces from humans consuming wheat bran is only 60–65% neutral sugars (20) and contains protein (26); both of these observations would constrict the fiber digestibility results.

Second, we extended their efforts to validate the effectiveness of fecal fractionation by monitoring the location of muramic acid, an amino sugar found only in bacteria (10). Stephen and Cummings (7) evaluated the effectiveness of the fractionation scheme by conducting numerous bacterial counts, using stains
specific for plant material, and measuring neutral sugars in wheat bran fiber. If the recovery of ≈10% muramic acid in the S fraction reflects intact bacteria, then a gravimetric measure of bacteria as the B fraction would underestimate the amount of bacteria in excreta. It is more likely, however, that the muramic acid and a portion of the other sugars in the S fraction, e.g., glucosamine and galactosamine, reflect bacterial exopolysaccharides removed from the exterior of the bacteria by the solvents used in the fractionation and not remnants of bacterial cell walls (15). Some of the glucosamine and galactosamine, along with the fucose in the S fraction of stool, probably reflect mucin (15, 17). Our findings also suggest that even though arabinose and xylose are used as markers for plant material, they appear to be present in bacteria (15).

Stephen and Cummings (27) did not use an aqueous extraction because exposure of feces to an aqueous extraction might result in rupture of bacterial cell walls. We found similar amounts of muramic acid in the S fraction of feces extracted with isotonic formylsaline as we did when water containing 1% SLS was the extractor (15), indicating that there were no additional bacterial components in the S fraction when water was used. It is possible that when water and SLS are added to dried excreta, the ionic composition and buffering capacity of the sample in combination with the additions results in an extracting fluid that is not hypotonic.

Neither fiber source increased the proportion of water in stool. This result agrees with almost all other findings when healthy, nonconstipated adults ingest fiber supplements (3).

Although the increases in sugar excretion were significant with the incorporation of both wheat and oat brans into the diets, they represented only 36% and 8%, respectively, of the observed increases in stool weight. The remainder of the change in stool weight would have to have been other constituents of bacteria because the B fractions we isolated contained only ≈8–9% carbohydrate, or undigested dietary fat or protein, both of which increase in stool when some fibers are consumed (28). If the fecal nitrogen we measured is converted to crude protein (X 6.25), the protein, fat, and ash, combined with the carbohydrate determined by gas chromatography analysis of sugars extracted from stool, accounted for 80% and 82%, respectively, of the increase in stool weight that occurred with the additional wheat or oat bran. However, a nitrogen conversion factor of 6.25 may be inappropriate for fecal nitrogen (26). When fecal nitrogenous material is estimated to contain 11% nitrogen (26, 29), proximate and sugar analysis accounted for most of the increase in dry stool weight, 90% of that observed when wheat bran was incorporated into the diet and 99% when oat bran was incorporated. Regardless of the factor used to convert nitrogen into nitrogen-containing compounds, no factor is likely to be accurate because there are many sources of nitrogen in stool (26).

We did not attempt to analyze any of the isolated fecal fractions for fat and nitrogen content. Data from the literature suggest that bacteria are 6–10% nitrogen (27, 30) and 10–20% fat (31). If the larger value for each of these components is used, ≈90% of the mean bacterial mass isolated from each of the 4 series of stools that we fractionated is accounted for: ≈63% as crude protein, 20% as fat, and 8–9% as carbohydrate. These estimates of bacterial lipid accounted for about one-half to three-fourths of the total fat measured in stool, whereas bacterial protein contents were 75–90% of the crude protein measured in feces. Mucosal cell debris and secretions and remnants of incompletely digested food would likely contribute fat, protein, sugar, and ash.

REFERENCES

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