A Poorly Fermented Gel from Psyllium Seed Husk Increases Excreta Moisture and Bile Acid Excretion in Rats

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ABSTRACT Psyllium seed husk (PSH) increases stool output and lowers blood cholesterol levels in humans. PSH and three fractions isolated from it were meal-fed to colectomized rats and fermented in vitro to test the hypothesis that viscous, gel-forming fraction B was responsible for these physiological actions. Control rats were fed 50 g/kg cellulose. The concentration of each PSH fraction in the test meals was equivalent to its concentration in PSH. Yields of the fractions were: A, 171; B, 575; and C, 129 g/kg of PSH. The wet weight and moisture content of ileal excreta (IE) from rats fed test meals containing PSH or fraction B were greater than those measured in excreta from rats fed meals containing cellulose or the other two PSH fractions. Total bile acids in IE did not differ between rats fed PSH or fraction B and were greater in these groups than in the other groups. Fraction A was not fermented during 3 d of incubation; fraction B was poorly fermented, with ~30% of the constituent sugars disappearing; and fraction C was rapidly and nearly completely fermented. These results indicate that the gel-forming fraction we isolated from PSH is the physiologically active component of the husks.


KEY WORDS: • dietary fiber • psyllium seed husk • laxation • hypercholesterolemia • rats

Psyllium seed husk (PSH)2 is well-known as a laxative (1). Like other fiber-based laxatives, PSH increases stool weight (1). In addition, when defecation frequency is < 1/d and gastrointestinal transit time is > 3 d, PSH normalizes these measures of large bowel physiology to ~1 bowel movement/d and a transit time of 2–3 d (2). Unlike most other fibers that affect large bowel physiology (3), PSH increases the concentration of water in stool and produces a “slick” stool that is easy to pass (4–8). PSH is also an atypical fiber laxative because it is largely a soluble fiber. Most soluble fibers are completely fermented in the colon (9) and have little effect on stool weight and laxation (1).

More recently, PSH has been shown to lower blood cholesterol concentrations (10). Several mechanisms have been proposed to explain how certain dietary fibers lower blood cholesterol concentrations (9,11). Many cholesterol-lowering fiber sources are viscous, and one proposed mechanism is that this viscosity interferes with bile acid absorption in the ileum (9,11). To replenish the pool, the liver draws LDL cholesterol this viscosity interferes with bile acid absorption in the ileum (9,11). To replenish the pool, the liver draws LDL cholesterol (10). Several mechanisms have been proposed to explain how certain dietary fibers lower blood cholesterol concentrations (9,11). Many cholesterol-lowering fiber sources are viscous, and one proposed mechanism is that this viscosity interferes with bile acid absorption in the ileum (9,11). To replenish the pool, the liver draws LDL cholesterol from the blood as the substrate for bile acid synthesis, thereby lowering blood cholesterol levels. PSH has been shown to increase bile acid excretion in human ileostomy output, which is consistent with this proposed mechanism of action (12).

We recently isolated a gel from the stool of humans who had consumed PSH (8). The majority of the stool collected during the PSH phase of this study was gelatinous, and subjects reported that output was slippery or slick. The gel fraction isolated from stool was 75% carbohydrate; most of this carbohydrate was xylose (64%) and arabinose (27%), the same two sugars that account for the majority (79%) of the carbohydrate in PSH. We proposed from this study that the gel isolated from stool was responsible for the emollient properties and greater water content of PSH-containing stools (8). No comparable fraction was isolated from stool when the subjects consumed the same controlled diet, but without the PSH supplement.

In a separate set of experiments, a fractionation scheme was developed that recovered three fractions from PSH (13). One fraction consisted of insoluble material that accounted for 15–20% of PSH; a second fraction was a gel-forming material that accounted for 55–60% of PSH, and the third fraction was a viscous, but not gel-forming component that accounted for 10–15% of PSH.

Our overall objective was to determine whether one of these fractions was responsible for the physiologic responses observed when intact PSH is consumed. Thus, the experiments evaluated the amounts of the fractions that were present in the intact PSH. We tested two hypotheses that emphasized the gel-forming fraction. We proposed that the gel-forming fraction of PSH was not fermented and as the largest fraction of PSH, was responsible for the increased stool moisture when PSH is consumed. Second, we proposed that this gel-forming fraction of PSH increased ileal bile acid excretion.

MATERIALS AND METHODS

Experimental design. Interference by PSH and PSH fractions with bile acid absorption was evaluated by feeding groups of colectomized rats test meals of control diet or experimental diet containing PSH or one of the fractions of PSH. Ileal excreta (IE) were collected during 3 d of incubation; fraction B was poorly fermented, with ~30% of the constituent sugars disappearing; and fraction C was rapidly and nearly completely fermented. These results indicate that the gel-forming fraction we isolated from PSH is the physiologically active component of the husks.
from each rat and analyzed for moisture and total bile acid contents. Moisture in IE was the indicator of the effect of PSH and fractions on stool moisture. IE were analyzed instead of feces to avoid the microbial modification of bile acids that normally occurs in the intestinal lumen.

The gel-forming fraction would have to be either not or very poorly fermented for it to function as an emollient in the large intestine. Fermentation of PSH and its fractions was evaluated in vitro. Aliquots of psyllium husk, the 3 fractions, or a mixture of the fractions in proportion to their concentration in PSH were fermented for 0–72 h in the presence of veal infusion broth and yeast. Total short-chain fatty acids (SCFA) and disappearance of fiber-derived sugars were measured in terminated fermentations. Protocols for the animal experiments were approved by the College of Agricultural and Life Sciences Animal Care Committee, University of Wisconsin-Madison.

**Test materials.** PSH (donated by The Procter and Gamble Company, Cincinnati, OH) was fractionated as described (13). Briefly, dry, ethanol-extracted ground husk was treated with alkali. The insoluble material that was recovered by centrifugation at 23,500 × g was fraction A. The pH of the supernatant was adjusted to 4.5 with glacial acetic acid and centrifuged at 25,500 × g. The gel mass so recovered was fraction B. The supernatant produced during the previous step was poured into 95% ethanol to a final concentration of 70%. The precipitate that formed was recovered by centrifugation at 23,500 × g and was designated fraction C. Aliquots (n = 80; 4 g each) of PSH were fractionated, ground with mortar and pestle and combined for the in vivo and in vitro experiments.

**In vitro fermentation of psyllium husk and fractions.** The procedure for in vitro fermentation has been described (14). The carbohydrate substrate for fermentation consisted of 139.5 mg provided by veal infusion broth (providing 56.7 mg carbohydrate) (Difco Laboratories, Detroit, MI) and yeast (providing 82.8 mg) (Difco) in the broth. Carbohydrate, 261 mg of PSH, 280 mg fraction A, 244 mg fraction B, 256 mg fraction C and 258 mg of the recombined fractions were combined for fermentation of the sugars in the test materials. These corrected values were then subtracted from the amounts of the sugars in the test materials present at time zero and the result expressed as a percentage disappearance of each sugar.

Collectomized rat experiment. Male rats (n = 9; Harlan Sprague Dawley), mean initial body weight of 160.8 ± 1.9 g, were allowed free access to powdered purified diet and water. They were housed as described above, except that the room was dark from 800 to 2000 h. The diet was the AIN93G diet with cellulose as the dietary fiber and modified in fat and sucrose contents as described above. Approximately 2 wk later, the cecum and entire colon were surgically removed using the procedure of Lambert (16), as described (17). Mean body weight of food-deprived rats at surgery was 247.6 ± 4.1 g. Postoperative recovery and performance of the rats were similar to our previous experience (17,18). Ileal excreta was soft and formed by 4–5 d postoperative, and preoperative body weight was achieved 7–10 d after surgery. Postoperatively, rats had free access to an electrolyte solution (17) for 6 d and to a nutritionally complete liquid diet (Ensure with fiber, vanilla flavor, Ross Products Division, Abbott Laboratories, Columbus, OH) for 7 d. Rats also had access to powdered purified diet ad libitum from postoperative d 4. Mean body weight of the rats were 296.2 ± 5.8 g at the start of the test meals and 331.7 ± 6.3 g at the end of the test meals.

Rats were deprived of food overnight before administration of the test meal at ~800 h. The test meals consisted of AIN93G diet, modified in fat and sugar contents as described above, but without cellulose; 6 g/kg of chromic oxide was added at the expense of starch. To this diet was added the test fiber. Meals of PSH, combined fractions and cellulose contained 50 g/kg of the fiber source. Meals of the individual fractions contained the proportion of the fraction that would have been provided by 50 g/kg of PSH. The meals consisted of ~5.0 g of diet and distilled water for a final slurry volume of 14–16 mL. Rats were randomly selected to be administered a different test meal 1–2 times/wk until 6 rats had received a particular test meal. They consumed the modified AIN93G diet containing cellulose ad libitum during the 3–7 d intervals between test meals.

Meals were administered to lightly anesthetized rats using an infant feeding tube (# 8 Fr, product #3641, Davol, Cranston, RI) connected to a 30-mL syringe containing the meal. The syringe and tube were weighed before and after meal administration to determine the amount of test meal given to each rat. Rats were placed in restraining cages, as described (17), to permit complete collection of IE, which was labeled day collection. Ileal output was collected hourly and frozen as collected during the day. Rats were returned to their regular cages after 12 h and allowed unrestricted access to the modified AIN93G diet containing cellulose. Any chromium-marked excreta were collected in the following morning and labeled overnight IE. Day and overnight collections were weighed and lyophilized to determine dry weight.

**Analyses.** Neutral and amino sugars in the fermentates, veal infusion broth, yeast, PSH and PSH fractions were measured by the method of Kraus et al. (19), as modified (20). Duplicate samples (10–25 mg) were acid-hydrolyzed, neutralized, reduced and derivatized to the alditol acetate forms. Derivatized samples were analyzed by gas-liquid chromatography (GLC) using a flame ionization detector and a fused silica column (20). Response factors were determined and applied to results to account for hydrolysis and derivatization losses. Sugars are expressed as their anhydrous forms (19). Total uronic acid content was determined using a colorimetric assay (21) with galacturonic acid as the standard. The crude protein contents were determined as Kjeldahl nitrogen multiplied by 6.25. The ash contents were determined by heating an aliquot at 450°C for 24 h. At each time point, the amounts of each sugar remaining in the control fermentate were subtracted from the amount of sugar in the experimental fermentate to provide the measure of fermentation of the sugars in the test materials. These corrected values were then subtracted from the amounts of the sugars in the test materials present at time zero and the result expressed as a percentage of the amount of test sugar in the flask at time zero to obtain disappearance of each sugar.

SCFA were measured by GLC as previously described (14). Samples were extracted by the method of Rémésy and Demigne (22). The amounts of the six fatty acids detected (acetate, propionate, i-butyrate, n-butyrate, i-valerate and n-valerate) were summed to give total SCFA.

Total bile acid content of IE was determined enzymatically (Sigma Co.)
Diagnostics, Procedure # 450, Sigma Chemical, St. Louis, MO) as modified (Story, J. A., Purdue University, West Lafayette, IN, personal communication, 1998). To extract bile acids, duplicate samples (15–25 mg) were refluxed (4 h) with chloroform:methanol (1:1) with stirring, centrifuged at 1500 × g and then washed 3 times with the solvent. The combined solvent extracts were evaporated under nitrogen (65 °C) and sonicated (10 min) with a known volume (10–15 mL) of solvent. Duplicate aliquots (1 mL) were taken for enzymatic treatment and dried under nitrogen; protein (0.2 mL of 25 g/L bovine serum albumin) was added to mimic protein in blood. Samples were reacted with enzyme, and bile acids were measured as outlined in assay kit directions.

A modification (23) of the method of Guncaga et al. (24) involving less sulfuric acid that interfered with spectrophotometry was used to determine the chromium content of IE.

Data are reported as the mean ± SEM. Differences among experimental groups were determined by one-way ANOVA using SAS computer software (release 6.12; SAS Institute Inc, Cary, NC). Significant differences were identified by the least significant difference means separation test. Differences were significant at P < 0.05.

RESULTS

Fraction B was the major fraction isolated from PSH (Table 1). Yields of fractions A and C were < 20% of the husk. Recoveries of PSH and fractions as the sums of carbohydrate, protein and ash ranged from 97 to 103%. Carbohydrate accounted for 0.902 of PSH, 0.839 of fraction A, 0.963 of fraction B, 0.917 of fraction C and 0.910 of the combined fractions.

Xylose and arabinose, the major sugars in PSH, were the major sugars in fraction B; the primary sugar in fraction A was arabinose and in fraction C, it was xylose. Most of the mannose, galactose and glucose in PSH was recovered in fraction A. Fraction C contained most of the rhamnose and uronic acid in PSH.

The experimental fermentation flasks at time zero contained ~2000 μmol carbohydrate, and the composition of the carbohydrate reflected the composition of the test materials (Table 2).

The gel-forming fraction, fraction B, was poorly fermented throughout the 3 d of fermentation (Fig. 1). Of fraction B sugars, 22% disappeared by 48 h and 29% by 72 h. Most of fraction C sugars (86%) disappeared by 24 h of fermentation. Alkali-insoluble fraction A remained essentially unfermented throughout the 48-h test period. The PSH and combined fractions were fermented to similar extents. By 24 h, 28–33%

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**TABLE 1**

Carbohydrate composition of psyllium seed husk and fractions

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Psh</th>
<th>Fr A</th>
<th>Fr B</th>
<th>Fr C</th>
<th>Combined fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravimetric yield</td>
<td>—</td>
<td>171.3 ± 4.3</td>
<td>574.6 ± 15.7</td>
<td>128.7 ± 6.0</td>
<td>—</td>
</tr>
<tr>
<td>Protein</td>
<td>35.0</td>
<td>74.4</td>
<td>9.1</td>
<td>2.0</td>
<td>—</td>
</tr>
<tr>
<td>Ash</td>
<td>33.5</td>
<td>52.8</td>
<td>30.1</td>
<td>113.8</td>
<td>—</td>
</tr>
<tr>
<td>Total sugars</td>
<td>902.4</td>
<td>838.7</td>
<td>962.9</td>
<td>916.8</td>
<td>910.4</td>
</tr>
<tr>
<td>Recovery</td>
<td>970.9</td>
<td>965.9</td>
<td>1002.0</td>
<td>1031.0</td>
<td>—</td>
</tr>
<tr>
<td>Rhamnose</td>
<td>28.7</td>
<td>4.7</td>
<td>9.1</td>
<td>143.0</td>
<td>27.6</td>
</tr>
<tr>
<td>Fucose</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>—</td>
</tr>
<tr>
<td>Ribose</td>
<td>1.2</td>
<td>2.5</td>
<td>tr</td>
<td>tr</td>
<td>1.0</td>
</tr>
<tr>
<td>Arabinose</td>
<td>203.2</td>
<td>342.9</td>
<td>203.4</td>
<td>84.2</td>
<td>203.8</td>
</tr>
<tr>
<td>Xylose</td>
<td>503.1</td>
<td>33.0</td>
<td>711.7</td>
<td>421.0</td>
<td>541.3</td>
</tr>
<tr>
<td>Mannose</td>
<td>22.3</td>
<td>99.8</td>
<td>tr</td>
<td>tr</td>
<td>14.8</td>
</tr>
<tr>
<td>Galactose</td>
<td>41.2</td>
<td>129.0</td>
<td>15.7</td>
<td>17.4</td>
<td>33.7</td>
</tr>
<tr>
<td>Glucose</td>
<td>45.9</td>
<td>191.0</td>
<td>1.4</td>
<td>4.9</td>
<td>32.1</td>
</tr>
<tr>
<td>Uronic acids</td>
<td>54.1</td>
<td>34.8</td>
<td>20.0</td>
<td>244.8</td>
<td>55.7</td>
</tr>
</tbody>
</table>

1 Values are the means of two analyses, except for gravimetric yield, n = 80; tr (trace) was <1.0 mg/g.
2 Abbreviations: PSH, psyllium seed husk; Fr, fraction.

**TABLE 2**

Sugars in fermentation flasks at time zero

<table>
<thead>
<tr>
<th>Sugar</th>
<th>PSH</th>
<th>Combined fractions</th>
<th>Fr A</th>
<th>Fr B</th>
<th>Fr C</th>
<th>Veal infusion broth and yeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhamnose</td>
<td>54.3</td>
<td>51.6</td>
<td>17.8</td>
<td>23.8</td>
<td>223.3</td>
<td>13.0</td>
</tr>
<tr>
<td>Arabinose</td>
<td>365.7</td>
<td>374.5</td>
<td>659.0</td>
<td>358.4</td>
<td>141.6</td>
<td>18.7</td>
</tr>
<tr>
<td>Xylose</td>
<td>821.8</td>
<td>866.0</td>
<td>72.3</td>
<td>1133.0</td>
<td>591.8</td>
<td>15.2</td>
</tr>
<tr>
<td>Mannose</td>
<td>178.1</td>
<td>171.7</td>
<td>340.4</td>
<td>143.9</td>
<td>143.1</td>
<td>152.1</td>
</tr>
<tr>
<td>Galactose</td>
<td>95.4</td>
<td>89.5</td>
<td>238.2</td>
<td>59.8</td>
<td>59.5</td>
<td>41.0</td>
</tr>
<tr>
<td>Glucose</td>
<td>373.8</td>
<td>363.7</td>
<td>610.7</td>
<td>310.8</td>
<td>312.7</td>
<td>326.9</td>
</tr>
<tr>
<td>Mannose</td>
<td>95.6</td>
<td>89.6</td>
<td>80.6</td>
<td>48.0</td>
<td>338.9</td>
<td>26.5</td>
</tr>
<tr>
<td>Other sugars</td>
<td>177.3</td>
<td>183.7</td>
<td>178.6</td>
<td>182.7</td>
<td>170.1</td>
<td>193.3</td>
</tr>
<tr>
<td>Total</td>
<td>2162.0</td>
<td>2190.3</td>
<td>2197.7</td>
<td>2260.4</td>
<td>1980.9</td>
<td>786.5</td>
</tr>
</tbody>
</table>

1 Values are means of two flasks.
2 Abbreviations: PSH, psyllium seed husk; Fr, fraction.
3 Other sugars are fucose, ribose, myoinositol, muramic acid, glucosamine and galactosamine.
of the sugars in these two fractions had disappeared; disappearance of the carbohydrate in these two substrates gradually increased to 38–43% by 72 h.

Disappearance of arabinose, one of the two main sugars in PSH, reflected total sugar disappearance, although its disappearance from fraction B fermentations was less than what was observed for total sugars (Fig. 2). Of the arabinose in fraction B, 8–11% was fermented during the first 48 h, which increased to 19% by 72 h of fermentation. Of the arabinose in fraction C, ~75% disappeared by 48 h, and none of the arabinose in fraction A was apparently fermented; 15–20% of the arabinose in PSH and the combined fractions disappeared by 48 h and no further fermentation of this sugar occurred during the final 24 h fermentation of PSH and combined fractions.

More xylose in fraction B was apparently fermented than arabinose; 23% of the xylose disappeared by 48 h and 29% by 72 h (Fig. 3). More than three fourths (78%) of the xylose in fraction C disappeared by 24 h, which increased to 82% by 48 h. Of the xylose in fraction A, 25% was apparently fermented, although xylose was a very small proportion of the total sugars (3.3%) in the fraction A fermentations. Apparent fermentation of xylose in PSH and the combined fractions reached 46–48% after 48 h of fermentation and did not increase during the last 24 h of fermentation.

Total SCFA production was greater initially in the combined fractions and fractions A and C, compared with the other test materials, although by 48 h, the amount of SCFA was greater in the fraction C fermentates than in all of the other materials fermented (Fig. 4). At 48 and 72 h, SCFA production in the PSH, combined fractions and fraction B was not different from what was produced by fermentation of the veal infusion broth and yeast alone.

The output of IE was significantly greater from rats fed test meals containing 5% PSH or 3.5% fraction B than from those fed meals containing 5% cellulose, 1.6% fraction A or 1.3% fraction C (Table 3). Rats fed the 3.5% fraction B test meal had less output than those fed 5% PSH. Differences in dry output of IE among the groups were not as large and not always significant. The moisture contents of IE of rats fed test meals containing 5% PSH or 3.5% fraction B were greater than those of the other 3 groups and were not different from one another. The concentrations of bile acids in IE of rats fed the PSH or fraction B test meals were not different from one another, and both were significantly greater than the concentration of bile acids in IE from rats fed meals containing cellulose or fractions A or C.

**DISCUSSION**

The results of these experiments strongly suggest that viscous fraction B is the primary active component of PSH that interferes with bile acid absorption and holds water in colon contents; the gel-forming fraction B fed at 3.5% of the test meal was as effective as the unfractionated PSH fed as 5% of the test meal. Bile acid excretion during the PSH or fraction

![FIGURE 1](https://academic.oup.com/jn/article-abstract/132/9/2638/4687853/12069238/4687853/12069238.png)

**FIGURE 1** Disappearance of total sugars in psyllium seed husk (PSH), PSH fractions (Fr) or Fr combined in proportion to their concentration in PSH (Combo) during in vitro fermentation. Each point is the mean of two fermentations. Data points at a time without common letters are significantly different. The average of the pooled SEM of 12-, 24-, 48- and 72-h time points was 6.1.

![FIGURE 2](https://academic.oup.com/jn/article-abstract/132/9/2638/4687853/12069238/4687853/12069238.png)

**FIGURE 2** Disappearance of arabinose in psyllium seed husk (PSH), PSH fractions (Fr) or Fr combined in proportion to their concentration in PSH (Combo) during in vitro fermentation. Each point is the mean of two fermentations. Data points at a time without common letters are significantly different. The average of the pooled SEM of 12-, 24-, 48- and 72-h time points was 8.7.

![FIGURE 3](https://academic.oup.com/jn/article-abstract/132/9/2638/4687853/12069238/4687853/12069238.png)

**FIGURE 3** Disappearance of xylose in psyllium seed husk (PSH), PSH fractions (Fr) or Fr combined in proportion to their concentration in PSH (Combo) during in vitro fermentation. Each point is the mean of two fermentations. Data points at a time without common letters are significantly different. The average of the pooled SEM of 12-, 24-, 48- and 72-h time points was 6.0.
protein in fraction B. These two findings suggest that a particular protein or amino acid, or lipid-soluble constituents are unlikely to be responsible for the cholesterol-lowering ability of PSH.

We measured bile acid excretion because it is a direct outcome of consuming a viscous fiber source (9,11). Stable isotope-labeled bile acids have been used to demonstrate that interference with ileal bile acid absorption is a primary mechanism by which oatmeal and bran (25) and psyllium (26) alter sterol balance and effect lower LDL cholesterol levels in the blood. Oat bran (27) and PSH (12) also increased bile acid excretion in human ileostomy output. Excreta from colectomized rats, in which the cecum and entire colon were removed surgically, were used to measure the extent of bile acid excretion because increased amounts of bile acids exiting the ileum may or may not be reflected in stool; up to half of the steroids entering the colon may be metabolized to compounds not measured during fecal sterol analysis (28,29). We showed previously that the bacterial population of IE from colectomized rats is low, -20% of what is detected in rat feces (18). Our findings are consistent with the hypothesis that gel-forming fraction B in the amounts in which it is normally present in PSH is responsible for the increased bile acid excretion. Fraction C, because it is viscous, may increase ileal bile acid loss, but we found no effect when an amount equivalent to that in PSH was tested.

Gel-forming fraction B would have to remain largely unaltered by the microflora to function as an emollient in the large intestine. The relatively low and similar levels of sugar disappearance when PSH, the combined fractions or fraction B were fermented contrasts with the high level of disappearance of the sugars in fraction C. The observation that gel-forming fraction B was poorly fermented by microflora adapted to PSH as a substrate is consistent with its proposed role in the colon and with our previous isolation of a gel from the stool of humans consuming PSH (8). In that study, stool containing PSH was largely a gelatinous mass. The rapid and relatively complete fermentation of fraction C indicates that fraction C would not be present for any substantial period of time to modify colon contents. Fraction A was essentially not fermented. This fraction is isolated as an insoluble material that does not solubilize in an aqueous medium and thus is not viscous (13). Carbohydrate disappearance during fermentation of the combined fractions and intact PSH was similar to what was observed when fraction B was fermented because they contain only small amounts (<13%) of the fermentable component of PSH, i.e., fraction C.

We observed few differences in total SCFA production

B test meals was about twice the amounts produced by test meals containing fractions A or C, and ~3.5-4 times bile acid excretion when cellulose was the test fiber.

The cholesterol-lowering feature of some dietary fibers has been related to SCFA produced by fermentation of the fiber in the large intestine, certain amino acids found in protein that may be present in the fiber source, lipid-soluble components, e.g., tocotrienols, which have been shown to inhibit cholesterol synthesis and are present in the lipid fraction of some fiber sources, and viscosity of some fiber sources that has been proposed to interference with bile acid absorption, cholesterol absorption and/or composition of the bile acid pool (9,11).

The results of our study, which largely eliminated any effects of SCFA by using a model in which the major sites of SCFA production, i.e., cecum and colon, were removed, indicate that significant changes in bile acid excretion can occur in the absence of increased SCFA. Further, we found no measurable fat in PSH (13) and only minor amounts of crude

![FIGURE 4](https://example.com/figure4.png)

**Production of total short-chain fatty acids (SCFA) during in vitro fermentation of psyllium seed husk (PSH), PSH fractions (Fr), Fr combined in proportion to their concentration in PSH (Combo) or a mixture of veal infusion broth and yeast (VIB&Y). Each point is the mean of two fermentations. Data points at a time without common letters are significantly different. The average of the pooled SEM of 12-, 24-, 48- and 72-h time points was 20.6.**

### TABLE 3

<table>
<thead>
<tr>
<th>Test component</th>
<th>Wet g/24 h</th>
<th>Dry g/100 g</th>
<th>Moisture g/100 g</th>
<th>Total bile acids μ mol/g test meal recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>2.5 ± 0.1c</td>
<td>0.9 ± 0.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>62.6 ± 4.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.6 ± 1.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Psyllium seed husk</td>
<td>8.7 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.8 ± 0.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>90.2 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.2 ± 2.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fraction A</td>
<td>2.0 ± 0.1&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.7 ± 0.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>65.9 ± 1.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.6 ± 1.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fraction B</td>
<td>6.9 ± 0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.0 ± 0.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>85.6 ± 0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.5 ± 2.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fraction C</td>
<td>2.0 ± 0.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.7 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>64.1 ± 1.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.7 ± 2.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Values are means ± SEM, n = 6. Means in a column without a common letter differ, P < 0.05.
among PSH and its fractions. The greater SCFA production during fermentation of fraction C is consistent with its rapid degradation in the gut of healthy humans. Gut 35: 177–182.


