An unfermented gel component of psyllium seed husk promotes laxation as a lubricant in humans[1–3]

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ABSTRACT

Background: In addition to increasing stool weight, supplements of psyllium seed husk produce stools that are slick and gelatinous.

Objective: Our purpose was to test the hypothesis that a gel-forming fraction of psyllium escapes microbial fermentation and is responsible for the characteristics that enhance laxation.

Design: Fifteen healthy adults consumed controlled diets for two 7-d periods, one of which included 8.8 g dietary fiber provided by 15 g/d of a psyllium seed husk preparation. All stools were collected and evaluated and diet was monitored throughout.

Results: Psyllium significantly increased the apparent viscosity of an aqueous stool extract, stool moisture, and wet and dry stool weights. A very viscous fraction, not present in low-fiber stool and containing predominantly 2 sugars that are also found in abundance in psyllium husk, was isolated from psyllium stool.

Conclusions: In contrast with other viscous fibers that are fermented completely in the colon, a component of psyllium is not fermented. This gel provided lubrication that facilitated propulsion of colon contents and produced a stool that was bulkier and more moist than were stools resulting with use of comparable amounts of other bowel-regulating fiber sources. *Am J Clin Nutr* 2000;72:784–9.

KEY WORDS Psyllium seed husk, *Plantago ovata*, dietary fiber, laxation, colon function, constipation, fermentation

INTRODUCTION

Most dietary fiber sources promote laxation by increasing colonic contents, which stimulates propulsion. Unfermented or incompletely fermented fiber and the accompanying moisture it holds are 2 contributors to this increased stool mass (1). Slowly or incompletely fermented fibers also contribute to stool weight by providing substrate for microbial growth. The greater bacterial mass and accompanying water further increase stool weight (2, 3). In most studies, the additional stool mass produced by consumption of more dietary fiber contains the same proportion of moisture as do low-fiber stools (4).

Psyllium seed husk (PSH) is a partially fermented dietary fiber from *Plantago ovata* that increases stool weight and promotes laxation by its presence in stool and by increasing the moisture content of stool (5–8). Available evidence indicates that PSH does not increase fecal bacterial mass (8), although excretion of muramic acid, an amino sugar unique to bacteria, was increased when PSH was part of a rat diet (9).

In a preliminary human study, we observed that PSH consumption results in the passage of slick, gelatinous stools (Marlett and Fischer, unpublished observations, 1992), similar to those we observed in the rat study (9). The purposes of this experiment were to isolate the fraction in feces responsible for the gel characteristic of stool, to determine and relate the sugar composition of this fraction to the sugar composition of PSH, and to evaluate the laxative properties of PSH under controlled diet conditions. Our overall objective was to test the hypothesis that this gelatinous material represents unfermented PSH, which contributes to the laxation properties of PSH by acting as a lubricating emollient to facilitate the propulsion of colon contents.

SUBJECTS AND METHODS

Subjects

Twenty-one of 33 individuals who responded to local advertisements were enrolled in the screening phase. Criteria for exclusion from the screening phase were self-reported lactose intolerance, nonomnivorous diet, any perception of chronic bowel irregularity or constipation, and unwillingness to follow a specified diet. Subject compliance, reliability, availability, and attitude were evaluated during the screening phase and 15 subjects (8 men and 7 women) were selected to participate in the study. Fourteen subjects completed the study. Data from 1 subject who admitted to not providing all stools during the specified collection periods were deleted from the final analysis. Subjects ranged in age from 18 to 30 y ($\bar{x}$ ± SEM: 24 ± 1 y) and were of normal body weight for height, with a mean body mass index (in kg/m^2) of 24.2 ± 0.9.

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Experimental design

The study consisted of 4 phases: a screening phase, the PSH period, a washout phase, and the basal period. During the screening phase, subjects consumed 15 g/d of a fiber supplement containing PSH (5 g Smooth Texture Metamucil per meal; The Procter & Gamble Co, Cincinnati) along with their usual diet for 12 d; the supplement provided an additional 8.8 g dietary fiber/d. Subjects were asked to complete food intake records on days 9–12 so that we could evaluate compliance with the protocol and obtain more information on typical food intakes. Two stools were obtained from each subject on days 9–12 to evaluate compliance with the protocol. During the next 7 d (the PSH period; days 13–19 of the study), subjects consumed a defined, low-fiber diet, and with each meal, the PSH supplement and a nonabsorbable marker (chromic sesquioxide, 200 mg/meal). During the following 2-wk washout phase (days 20–33 of the study), subjects consumed their usual diets to allow all of the PSH to be excreted. For the 7 d of the basal period (days 34–40 of the study), the same controlled, low-fiber diet and nonabsorbable marker as in the PSH period, but no PSH supplement, were consumed.

This experimental design was based on results of a preliminary study of 7 healthy subjects in which we observed that 7–10 d of ingestion of the maximum supplement dose recommended on the label were necessary to achieve high PSH excretion and to facilitate recovery of the gel from stool (Marlett and Fischer, unpublished observations, 1992). Therefore, the PSH period for data collection followed the 12 d of PSH consumption that constituted the screening phase and a crossover experimental design was not used. A 2-wk washout phase was included because the preliminary observations also showed that it took 7–10 d from ingestion of the last test dose for all of the PSH to be excreted.

Stools and qualitative bowel responses, food intake, and activity data were collected daily during both weeks of controlled diet. The study was approved by the College of Agricultural and Life Sciences Human Subjects Committee, University of Wisconsin–Madison.

Diet

All subjects consumed fixed diets during the PSH and basal periods that consisted of foods provided to them as part of the study. Foods were portioned with use of household measures. Breakfast was consumed at home and consisted of rice cereal, skim milk, orange juice, white bread, margarine or butter, and jelly. Lunch consisted of a sandwich, fresh fruit, and milk. The evening meal consisted of a meat, a starch source (potatoes, rice, or pasta), salad, and dessert. Subjects consumed prescribed amounts of the menu foods. The amounts of bread and milk varied with daily energy needs. Limited amounts of fiber-free snacks and alcohol were also permitted. Coffee was allowed ad libitum. Subjects were supervised at the evening meal. Consumption of the supplement and nonabsorbable marker was verified daily when empty packets were exchanged for the next day's allotment of supplement.

Data and sample collection

All stools excreted during the PSH and basal periods of the study were individually collected, refrigerated promptly, and weighed and frozen within 8 h of collection. In addition, stools were collected after the 7-d PSH and basal periods until the green chromic oxide was no longer visible (days 8–10 of each experimental period, because it takes 1–4 d for the chromium oxide to be excreted) and processed similarly. Subjects evaluated each stool by using a 9-point rating scale in which they agreed or disagreed with simple declarative statements, as follows: −4, disagree the most; −3, disagree extremely; −2, disagree very much; −1, disagree; 0, neutral; +1, agree; +2, agree very much; +3, agree extremely; and +4, agree the most possible. The statements are summarized in **Table 1**. Subjects also completed daily food intake records to verify consumption of the items in the controlled diet. Activity questionnaires were completed daily to identify any major changes in daily routine or physical activity. Daily routines and physical activity for each participant remained consistent throughout the 2 wk of sample collection.

TABLE 1
Large-bowel response to ingestion of psyllium seed husk (PSH)[1]

	Basal period	PSH period	P^2
Did not cause gas	1.7 ± 0.5	0.1 ± 0.5	0.0439
Did not cause bloating	3.0 ± 0.2	1.1 ± 0.6	0.0048
Did not cause abdominal cramping	2.9 ± 0.3	2.3 ± 0.4	0.2989
Caused a strong signal to go	1.4 ± 0.3	2.0 ± 0.3	0.2013
Made BM easier to pass	−0.4 ± 0.4	2.4 ± 0.2	0.0001
Did not cause diarrhea	2.2 ± 0.4	2.3 ± 0.4	0.9000
Did not cause repeat BM	1.7 ± 0.4	2.2 ± 0.4	0.2944
Resulted in gentle BM	0.2 ± 0.3	2.4 ± 0.2	0.0001
Resulted in softer stools	−0.3 ± 0.4	2.5 ± 0.3	0.0001
Provided increased bulking	−1.0 ± 0.2	1.4 ± 0.4	0.0001
Provided ease of wiping	−1.6 ± 0.4	2.2 ± 0.4	0.0001
Provided a feeling of complete relief	0.3 ± 0.3	1.6 ± 0.3	0.0045

[1] $\bar{x}$ ± SEM; n = 14. The rating scale ranged from −4 to 4; increasingly negative scores indicated increasing disagreement and increasingly positive scores indicated increasing agreement with the declarative statement. BM, bowel movements.
[2] One-way ANOVA between treatments.

Stool and diet analyses

Stools excreted during days 16–20 and days 37–41 (days 4–8 of each experimental period) of the study were thawed, pooled for each subject by hand mixing with a rubber spatula in a large shallow glass container, and refrozen until used or processed as outlined below. Stools were pooled by hand mixing because the gel disintegrates during mechanical blending (Marlett and Fischer, unpublished observations, 1992). Duplicate portions (3 g) were dried (for 16 h at 70 °C) to determine moisture content (10). Stool chromium content was determined with a modification (11) of the method of Guncaga et al (12). The modification involved the use of less sulfuric acid, which interfered with the spectrophotometric measurements. Portions of pooled stool were lyophilized for duplicate (25 mg) determinations of neutral and amino sugar content. Samples were acid hydrolyzed and reduced before formation of the alditol acetate derivatives for separation by gas chromatography (13, 14). Sugars were quantitated on a Chemstation (HP3368; Hewlett-Packard, Palo Alto, CA) with response factors to account for hydrolysis and derivatization losses and were expressed as their anhydrous forms (14). Galacturonic acid was used as the standard for uronic acid analysis with a colorimetric assay (15).

Duplicate measurements of the relative viscosity of stool (Ostwald dropping pipet viscometer, catalog no. 13-695; Fisher Scientific, Pittsburgh) were made on an aqueous extract of thawed, pooled stool. Aqueous fractions were obtained by vortex mixing

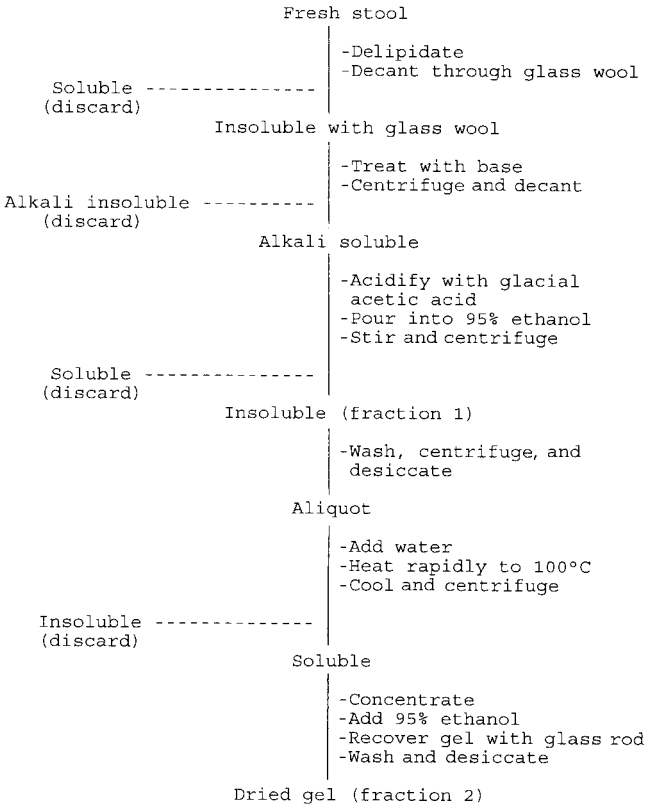

FIGURE 1. Procedure used to isolate gel from stools of humans consuming psyllium seed husk.

aliquots (2 g) with water (10 mL) and centrifuging (30 000 × *g*, 30 min, 4 °C) to recover the aqueous fraction. The aqueous fraction was centrifuged again to remove any particulate matter.

Macronutrient and energy contents of the planned menus and of the daily intakes of each subject were calculated by using nutrient composition tables (16–18). Dietary fiber intakes were calculated from food intake records by using a detailed database of the fiber content and composition of US foods (19–24). Intakes calculated from this database are usually within 10% of intakes determined by analysis of daily food composites with use of the same analytic method (11, 25); therefore, composites of foods consumed, which were portioned with use of household measures, were not analyzed. The sums of the daily intakes on days 2–6 of each controlled diet period (days 14–18 and days 35–39 of the study) were used as the 5-d intakes of uronic acids and neutral sugars (glucose, arabinose, xylose, mannose, and galactose) for the determination of apparent digestibility of fiber-derived sugars. The sugar composition of the PSH supplement also was measured by gas chromatography after acid hydrolysis, as outlined above. Fecal excretion of sugars was adjusted to reflect excretion of 5 d of intake by using the content of chromium in the pooled stool (3). Apparent digestibilities of fiber-derived sugars were calculated as the difference between 5 d of intake and excretion and were expressed as a percentage of intake (3).

Isolation of gel from stool

To isolate the component responsible for the gel characteristic, a fractionation procedure was applied to thawed aliquots of pooled fresh stool from each subject from both diet periods (26; **Figure 1**). Aliquots (≈25 g fresh weight) were delipidated twice with chloroform:methanol:water (500:250:52; 250 mL, 30 min, ambient temperature) in a shaking water bath and decanted through glass wool. The insoluble material and glass wool were stirred with base (0.18 mol KOH/L) containing sodium borohydride (0.026 mol/L; 10 mL/g original sample, 15 min) under nitrogen to solubilize the polysaccharide under conditions that were not destructive to the complex carbohydrate. The material insoluble in alkali was removed by centrifugation (15 min, 23 500 × *g*, ambient temperature) and the supernate was acidified to pH 4.5 with glacial acetic acid to restore the polysaccharide to its native state. A residue (fraction 1) was recovered by adding this mixture to 95% ethanol (3.4 times the volume of alkali solution). An aliquot (300–400 mg) of fraction 1 was suspended in water (250 mL), heated to boiling, cooled to 30 °C, and centrifuged (15 min, 23 500 × *g*, ambient temperature) to remove protein that also had been solubilized by the alkali. The supernate was recovered and reduced in volume by rotoevaporation (40 °C). The concentrate was added to ethanol to give a final alcohol concentration of 70%.

The fibrous mass that formed by addition of the concentrated supernate to ethanol was washed with 95% ethanol and ether and was vacuum-dried (40 °C over P_2O_5). This material represented the gelatinous component of PSH stools (fraction 2). No precipitate formed at this point during the analysis of the control stool samples. Neutral and amino sugar and uronic acid concentrations were determined on aliquots of fraction 2, as outlined above.

Statistical analyses

Data are reported as means ± SEMs. Data collected during the PSH and basal periods of the study were compared by one-way analysis of variance with use of SAS computer software (release 6.12; SAS Institute Inc, Cary, NC). Significant differences were identified by the least-significant-difference means separation test.

RESULTS

The alkali-soluble fraction (fraction 1) isolated from stools collected during the PSH period was significantly larger than that extracted from stools collected during the basal period (**Table 2**). An ethanol-precipitable fraction (fraction 2) that was extracted by hot aqueous treatment of the alkali fraction of stools from all subjects consuming PSH was gelatinous. No gelatinous fraction was extracted from stools collected during the basal, low-fiber study period.

The major component of fraction 2 was a polysaccharide that contained 763 ± 18 mg sugar/g fraction 2, most of which was xylose (64 ± 1%) and arabinose (27 ± 0%); the remaining sugars were 2% glucose, 3% galactose, and 3% other sugars (fucose, ribose, mannose, myoinositol, muramic acid, glucosamine, and

TABLE 2
Fractionation of control and psyllium-containing stool[1]

Fraction	Basal period	PSH period
	mg/g dry wt	
Fraction 1 (alkali soluble)	87.2 ± 1.2	142.3 ± 1.4[2]
Fraction 2 (alkali soluble, water soluble)	ND	74.9 ± 1.2

[1] $\bar{x}$ ± SEM; *n* = 14. Stools quantitatively collected on days 4–8 from each subject during each phase of controlled diet were combined for analysis. PSH, psyllium seed husk; ND, none detected.

[2] Significantly different from basal period, *P* = 0.0005 (one-way ANOVA).

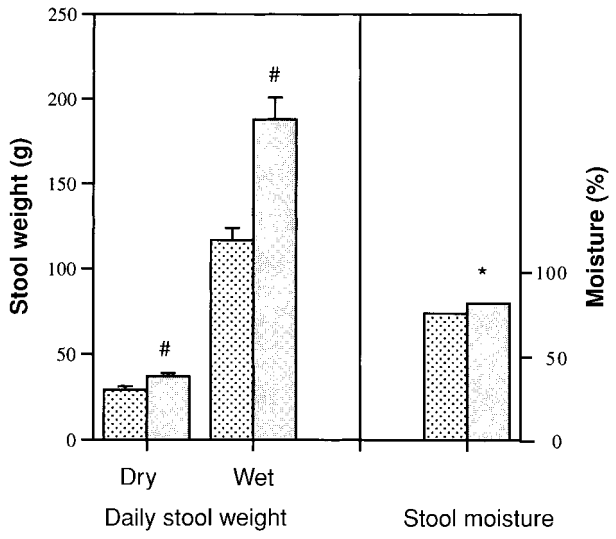

FIGURE 2. Mean (±SEM) characteristics of stools collected during the basal (left bar) and psyllium seed husk (right bar) periods of the study. n = 14. Error bars not visible were <1. $^{*,\#}$Significantly different from basal period (one-way ANOVA): $^{*}P < 0.05$, $^{\#}P < 0.0001$.

galactosamine). The xylose and arabinose in this gel fraction accounted for 53.9 ± 2.1% and 31.1 ± 1.4% of the respective sugar in feces.

Because no fraction comparable to the gel isolated from the PSH-containing stool was obtained from basal excreta, aqueous extracts of stool were prepared to compare the relative viscosity of stools collected during the 2 study periods. The apparent viscosity of the aqueous extract of the PSH-containing stool was significantly greater than that of the basal, low-fiber stool (238 ± 38 compared with 128 ± 7 s; $P < 0.01$).

Compared with consumption of the low-fiber diet, consumption of the PSH supplement increased mean daily wet output, mean daily dry output, and stool moisture (**Figure 2**); stool moisture was 74.4 ± 0.9% during the basal period compared with 80.2 ± 1.0% during the PSH period. Other measures of large-bowel function also were significantly different. The mean wet weight of each stool (121 ± 6 compared with 173 ± 14 g; $P < 0.005$), mean dry weight of each stool (30 ± 2 compared with 34 ± 3 g; $P < 0.0001$), and defecation frequency (1.0 ± 0.1 compared with 1.1 ± 0.1/d; $P < 0.05$) all increased when the PSH supplement was consumed.

The mixed-food controlled diet contained a mixture of fiber-derived sugars and the apparent digestibility of the fiber-derived total neutral sugars was 67 ± 4% during the low-fiber basal period (**Figure 3**). The composition of the PSH preparation was as follows (mg/g): 21 rhamnose, 127 arabinose, 325 xylose, 8 mannose, 25 galactose, 44 glucose, 35 uronic acids, 19 ash, 18 crude protein, and 346 coating. Apparent digestibilities of the fiber-derived xylose and arabinose decreased, whereas uronic acid digestibility increased, when the supplement was ingested (Figure 3). Subtracting xylose and arabinose excreted during the basal diet period from the amounts of these sugars in the PSH-containing stool provided a means of estimating the apparent digestibility of the 2 major sugars in PSH. The apparent digestibilities of the xylose, arabinose, and total neutral sugars provided by PSH were 59 ± 5%, 28 ± 7%, and 54 ± 9%, respectively, and were variable (**Figure 4**). The daily output of muramic acid, which is found only in bacterial cell wall (27), was 45 ± 4 mg during the low-fiber basal period and 46 ± 4 mg during the PSH period.

The test dose of PSH was well tolerated by all subjects. Compared with large-bowel function during the basal period, PSH resulted in gentler bowel movements, softer stools that were easier to pass, greater ease of wiping, a feeling a complete relief, and increased bulk (Table 1). The PSH supplement had no significant effect on abdominal cramping, urge to defecate, or experience of a repeat bowel evacuation, nor did it cause diarrhea, although subjects perceived more flatulence and bloating. Although soft and formed, most stools were visibly gelatinous and the defecated stool vibrated when agitated. The macronutrient and dietary fiber intakes provided by the foods in the diet did not change significantly when the PSH supplement was consumed (**Table 3**).

DISCUSSION

We propose that by functioning as an emollient and a lubricant, the unfermented gel we isolated from PSH-containing stool represents a new mechanism of laxation for a dietary fiber. The greater ease of passage, gentleness, and softness reported by the subjects during the PSH period of the study and the isolation of a very viscous fraction from the PSH-containing stools support this hypothesis. The lubricity was evident as a glossy appearance and a sensation of slipperiness during defecation. Yet, stools containing PSH were defecated as a cohesive mass, even when they were so soft that they did not retain a typical shape after defecation.

The analyses reported here establish the identity of the stool-lubricating component of PSH. Our compositional analysis of the supplement agrees with earlier structural work of Kennedy et al (28), who isolated a polysaccharide from PSH that contained xylose and arabinose as the principal constituents. These data also indicate that the supplement was the source of the additional xylose and arabinose that appeared in the PSH stool in both our

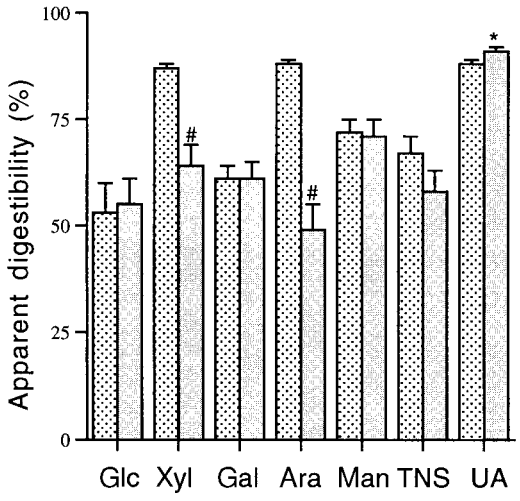

FIGURE 3. Mean (±SEM) apparent digestibilities in humans of individual (Glc, glucose; Xyl, xylose; Gal, galactose; Ara, arabinose; Man, mannose) and total neutral sugars (TNS) and uronic acids (UA) extracted as dietary fiber during the basal (left bar) and psyllium seed husk (right bar) periods of the study. n = 14. $^{*,\#}$Significantly different from basal period (one-way ANOVA): $^{*}P < 0.03$, $^{\#}P < 0.0001$.

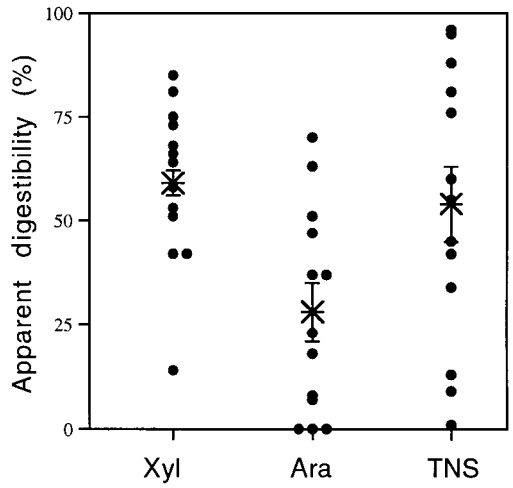

FIGURE 4. Apparent digestibilities of individual (Xyl, xylose; Ara, arabinose) and total neutral sugars (TNS) derived from psyllium seed husk in 14 subjects. The bars with an X and the error bars are the group means ± SEMs.

study and that of Marteau et al (8). The report by Kennedy et al (28) that the polysaccharide isolated from whole PSH was viscous further supports our contention that the gel isolated from stool represents partially unfermented PSH.

Recovery from stool of a viscous dietary fiber that survives microbial action in the large intestine has not been described previously. Common gelatinous fiber sources, eg, concentrated citrus pectins or (1→3), (1→4)-linked β-glucan present in oats and barley, are completely fermented in the colon (3, 29). The polysaccharide species we isolated was very effective. In this study, it represented only 1.5% of wet stool. We used the largest recommended daily dose of the supplement to optimize isolation of the polysaccharide from stool and it is likely that a lower dose would provide effective laxation, in part through action as an emollient.

The features of this gel-forming polysaccharide that limit its fermentation are not well defined. The earlier structural studies of all the polysaccharides isolated from the husk suggest that the polymers have relatively low molecular weights ($5–40 \times 10^3$) and are highly branched (28). The three-dimensional arrangement around the branch sites may sterically hinder microbial enzymatic accessibility.

TABLE 3
Daily macronutrient and dietary fiber intakes from food[1]

Component	Basal period	PSH period
Energy (MJ)	10.5 ± 0.5	10.3 ± 0.5
Carbohydrate (% of energy)	51 ± 1	51 ± 1
Protein (% of energy)	17 ± 1	18 ± 1
Fat (% of energy)	31 ± 1	32 ± 1
Dietary fiber		
(g/d)	12.1 ± 0.4	12.5 ± 0.5[2]
(g/MJ)	1.17 ± 0.0	1.22 ± 0.0
(g/1000 kcal)	4.9 ± 0.1	5.1 ± 0.1
(% insoluble)	80 ± 0	79 ± 0

[1] $\bar{x}$ ± SEM; n = 14. There were no significant differences between experimental periods. PSH, psyllium seed husk.

[2] Does not include 8.8 g dietary fiber/d from PSH supplement.

PSH is a well-established laxative with a long clinical history. Previous studies of this dietary fiber examined more typical bases for its laxative effect, ie, stool weight, gastrointestinal transit time, stool moisture, fecal bacterial mass, and the apparent digestibility of psyllium during transit through the gut. Our study confirmed most of the previous findings, including the increase in stool moisture concentration (5–8). Typical moisture concentrations of human stool are 70–75% (4) and most stool-bulking fiber sources do not increase the moisture content of stool (4). The additional hydration of stool by psyllium is an uncommon mechanism of laxation for a dietary fiber source, a feature that has been used to treat loose stools (30).

All studies involving a psyllium supplement reported increases in wet and dry stool weights both in healthy subjects (5–8, 31–33) and in subjects with gastrointestinal disease (34–39). PSH appears to increase stool mass more effectively than do other common laxative fiber sources. In our study, each gram of PSH increased stool weight an average of 5.9 g [6.1 g in the study by Marteau et al (8)]; both sets of results are greater than the increases of 4.9–5.4 g and 3.4–4.5 g observed for each gram of wheat bran fiber or oat bran fiber, respectively, consumed (1, 3).

The relatively small increase we observed in stool frequency agrees with reports by others (7, 8). Fiber sources used as laxatives typically have modest effects on defecation frequency when defecation frequency without the additional fiber is about once daily in healthy adults. Gastrointestinal transit time was not measured in the present study because several other studies showed no change in transit time with psyllium consumption (6, 8, 31, 34, 35), and only one (7) of the studies reporting a decrease in whole-gut transit time (7, 35–39) evaluated a healthy population. Most studies evaluating insoluble fiber sources support the hypothesis put forth by Harvey et al (40) in the 1970s that dietary fiber normalizes whole-gut transit time to 2–4 d.

Subjective evaluations indicated that psyllium was well tolerated, with few adverse effects, as reported previously (5, 7, 8). Although our study population perceived that the supplement caused more flatulence, others did not detect changes in rectal gas volume after ingestion of psyllium (8, 40).

Our method of calculating the digestibility of the PSH-derived sugars assumed that the digestibility of the sugars constituting the fiber in the diet does not change when PSH is consumed. However, most of the polysaccharides in psyllium consist of xylose and arabinose, and these were the only sugars whose digestibility was substantially decreased when the PSH was ingested. The highly variable PSH digestibility among subjects in our study was unexpected but was observed previously (5).

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