GASTROINTESTINAL RESPONSE TO OAT AND WHEAT MILLING FRACTIONS IN OLDER WOMEN[1]

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ABSTRACT

Several indexes of gastrointestinal function were measured in aged women fed a control formula diet and test meals containing wheat bran, oat bran, oat gum, and the nondigestible sugar, raffinose. Test substances were fed for three successive days, separated by two days of formula diet. The wet weight of feces was significantly increased over baseline levels with all four test meals. The dry weight of feces was not increased with raffinose; with the brans, fecal dry matter was increased several-fold beyond the weight of crude fiber fed, but not as much as the total weight of bran fed (25 and 50 g). Intestinal hydrogen production increased markedly as a result of fermentation of raffinose and wheat bran by enteric flora. Gas production was increased only moderately with oat bran, and very little with oat gum. The relation of these effects to the probable composition of the dietary fiber is discussed.

Cereal Chem. 54(1): 110-119

Carbohydrates that are resistant to digestion by the secretions of the human gastrointestinal tract have been termed "dietary fiber" (1). This is a loosely defined and heterogeneous category. The extent to which certain food carbohydrates such as the hemicelluloses are actually digested by humans is not known. The various analytical schemes available for isolation of fibrous components of food do not accurately identify the nondigestible fractions, and *in vivo* studies show a wide range of apparent digestibility.

It is well known that dietary fiber increases fecal mass. This occurs through a variety of possible mechanisms, including the hydrophilic nature of the fiber itself, its physical bulk, or chemical products present in fiber or produced by bacteria which directly affect gut motility and secretion.

Previous studies have indicated that analysis of certain trace constituents of breath can be used to detect nondigestible food fractions (2,3). Breath hydrogen (H_2) and methane (CH_4) concentrations have been found to be proportional to H_2 and CH_4 concentrations in the intestinal tract. Since mammalian cells do not produce H_2 or CH_4, bacterial fermentation is the sole source of these gases in the breath. The production of H_2 characteristically increases after delivery of fermentable substrate to enteric bacteria in the small intestine and colon. Breath concentrations of CH_4 are characteristic for individuals and in general have not been found to change in response to test foods. In healthy people, CH_4 production is confined to the colon.

In the present study, we compared the effects of four sources of nondigestible carbohydrates on several indirect measures of gastrointestinal function. Older adults were selected as the metabolic study population because they frequently experience bowel irregularities for which stimulatory foods are advised.

[1]Supported in part by grants from the National Institutes of Health (AM 10202) and the Quaker Oats Company.

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MATERIALS AND METHODS

Voluntary participants in this study were six women, aged 65–73 years. All were ambulatory and in relatively good health. All had normal absorptive capacity as measured by the 5-g xylose absorption test, and normal hematologic indexes. During the 30-day study, the women were confined to a metabolic unit.

The basal diet consisted of a bland formula, based on dried egg white, sucrose, maltodextrins, and corn starch, and a few low-residue food items. Vitamin and trace mineral supplements were given separately. This basal diet was adequate in all known essential nutrients, and provided 1600 kcal (6694 kJ) per day. A nonprotein, caloric supplement composed of simple carbohydrates and vegetable oil was added to the basal diet as necessary to keep body weights constant during the study. Meals were served at 8:30 a.m., 12:30 p.m., 4:30 p.m., and 8:30 p.m., and were completed within 30 min.

Food substances tested were wheat bran, oat bran, oat gum, and the nondigestible trisaccharide raffinose (see Table I). All subjects received the control formula diet initially and carbohydrate absorption tests were conducted during the first 10 days. Then, cereal fractions were fed for 3 successive days at the breakfast meal, and test periods were separated by at least 2 days of control formula diet. The test substances were given to subjects in different sequences.

Test cereal dosages were calculated to provide 2 and 4 g of crude fiber[3]. Since most of the carbohydrate content in oat gum is thought to be nondigestible, levels of gum roughly equivalent in carbohydrate content to 5- and 10-g reference doses of raffinose were fed. After levels of test foods were determined, the test breakfast meals were made isocaloric and equal in protein to the control breakfast by

[3]Analytical data on crude fiber (AOAC) courteously provided by the Quaker Oats Company.

TABLE I
Composition of Test Foods

Test Food	Code	Amount Fed g	Fat	Protein	Ash	Moisture	Crude Fiber	Carbohydrate (by diff.)
Oat bran[a]	OB	28.6	1.10	6.30	1.40	1.20	2.0	16.4
	OBB	57.1	2.30	12.60	2.90	2.40	4.0	32.9
Wheat bran[a]	WB	25.0	0.88	3.60	0.40	2.80	2.0	15.4
	WBB	50.0	1.80	7.20	0.80	5.70	4.0	30.7
Oat gum[a]	OG	6.2	0.06	0.12	0.01	0.01	0.006	6.0
	OGG	12.4	0.12	0.25	0.02	0.02	0.012	12.0
Raffinose[b]	R	5.0	...	...	...	...	...	5.0
	RR	10.0	...	...	...	...	...	10.0

[a]Both brans and gum were supplied courteously by the Quaker Oats Company. Oat bran and wheat bran represented approximately 11 and 14%, respectively, of the weight of the native grain, and the avena oat gum, about 5%.
[b]MC/B Chemical Company.

addition of basic formula and/or extra caloric formula and sucrose. For serving, the brans were heated with deionized water for 30–60 sec in a microwave oven. Oat gum and raffinose were mixed directly into the basic formula.

All feces were collected on a daily 24-hr basis. Feces were weighed as passed, refrigerated in covered plastic tubs, and then homogenized in a colloid mill. Dry solids content was determined by drying in a vacuum oven. Group means for daily fecal weights with each treatment were evaluated using Student's t-test. Fecal weights for individuals were compared to their own control data by using the t-distribution. The level accepted as significant was $p \leqslant 0.05$.

Breath gases were collected hourly from 8:00 a.m. until 6:00 p.m. and at 8:00 p.m. and 10:00 p.m. on the third day of each test feeding. On all other days of the study, samples were collected at 8 a.m. and 10 p.m. Breath gases were collected and analyzed chromatographically for concentrations of H_2 and CH_4 as published previously (4). Ventilation volume was measured for each woman by using Douglas bags and a gasometer. Criteria of intestinal gas formation were the time of occurrence and the magnitude of peak H_2 production, the average of the five highest H_2 values, area under breath H_2 curve, and total H_2 production. Area was determined by cubic splining technique and resting ventilation volume was used to estimate total H_2 production. Group averages were compared for gas production with test foods and control diet using the paired t-test. The production of CH_4 was examined for treatment effects and for cyclic variation.

RESULTS

Subjective Signs and Symptoms

The control diet caused no noticeable intestinal discomfort for any of the women. On the whole, wheat bran was the least well tolerated test food. The wheat bran had a sharp, metallic taste which the women found objectionable. Five of the six women complained of dyspepsia, abdominal cramping, intestinal gas pains, and loose stools. Lowering the dose of bran from 50 to 25 g generally relieved the most acute symptoms. Raffinose also caused marked intestinal

TABLE II
Fecal Output with Test Foods

Food	Fecal Weight[a] Wet	Fecal Weight[a] Dry	Feces, % Dry Solids	No. Bowel Movements/Day
Control diet	57.0 ± 16.6	13.7 ± 3.0	27.2 ± 2.1	1.4 ± 0.3
Day after oat bran[b]	62.8 ± 40.0	13.7 ± 8.0	21.7 ± 7.2	1.7 ± 0.5
Day after wheat bran[b]	130.5 ± 80.4	27.7 ± 14.7	23.4 ± 5.6	2.3 ± 0.4
Oat bran	124.6 ± 43.2	31.1 ± 8.5	26.6 ± 6.9	1.8 ± 0.4
Wheat bran	205.4 ± 127.0	38.3 ± 10.4	22.4 ± 8.2	3.4 ± 1.1
Oat gum	73.1 ± 27.7	22.0 ± 7.4	29.1 ± 8.2	1.8 ± 0.4
Raffinose	73.9 ± 45.0	14.3 ± 6.8	22.5 ± 7.4	3.0 ± 0.9

[a]In grams $\overline{X} \pm$ S.E.
[b]Control diet fed the day after bran treatments; these values are not included in the control mean.

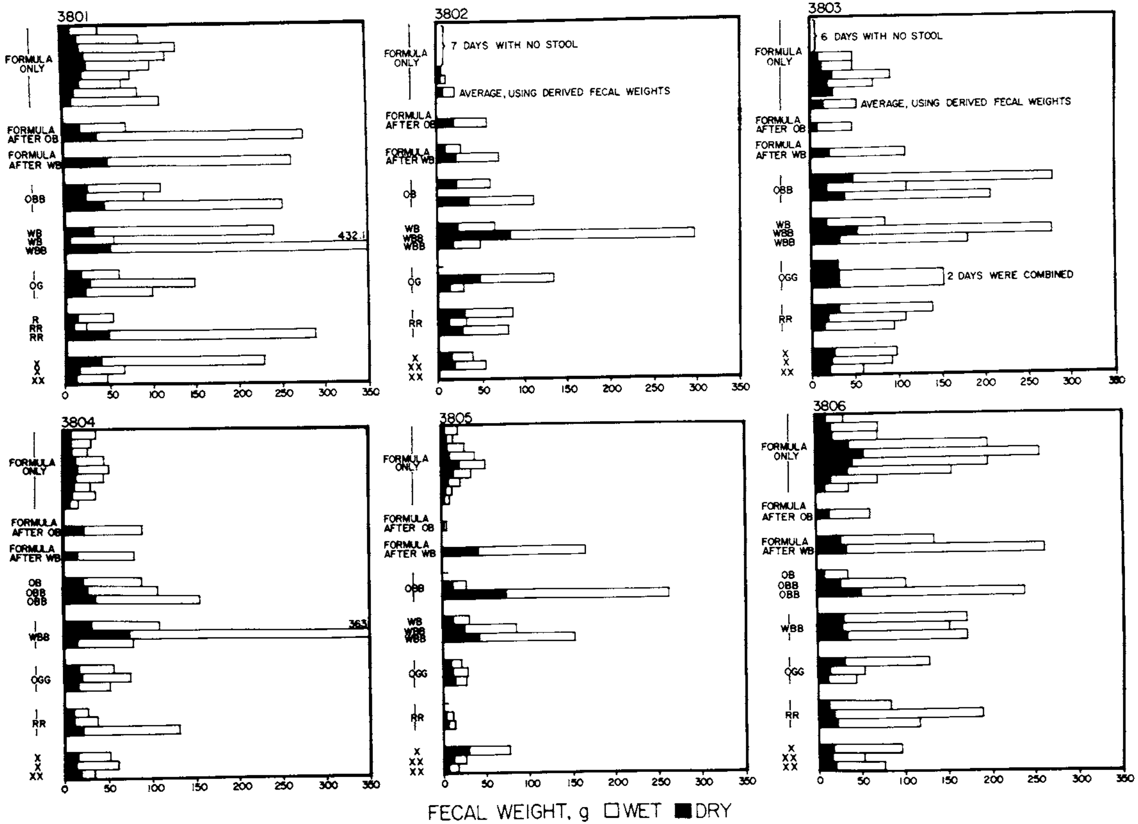

Fig. 1. Daily fecal weights, by treatment. Treatment codes are listed in Table I, with the exception of X and XX which stand for the administration of xylose for measurement of absorption.

discomfort and gaseousness. Symptoms included a sensation of lower abdominal pressure, foul-smelling gas, "explosive" liquid bowel movements, and varying degrees of cramping.

For most of the women, the oat bran caused little or no discomfort. Three of the women had cramping and noticeable changes in flatus gas. A fourth participant felt "more regular" with the oat bran. None of the women felt that their bowel function was abnormal with the oat gum.

Fecal Output

One indicator of changes in bowel function is the average number of bowel movements per day (Table II). Frequency was highest with wheat bran and raffinose. With oat bran and oat gum, frequency of bowel movements was only slightly elevated over the control value. The day following the wheat bran test period, two of the six women continued to have more frequent bowel movements, but there was no carry-over effect on frequency from oat bran.

Daily wet and dry fecal weights, and percentage dry solids for the group are presented in Table II. Since the level of test foods varied for each individual, the values compared are daily fecal weights for the days when equal amounts were fed. Daily fecal weights for each subject, according to test food, are shown graphically in Fig. 1.

There was a great deal of day-to-day variation in fecal wet and dry weight and percentage dry solids, which is characteristic of normal bowel function (Fig. 1). Wheat bran clearly increased both wet and dry fecal weights, when compared to the other test foods, as well as to control diet. Fecal output with wheat bran feeding was higher than with oat bran but the difference was not significant. Oat bran and oat gum feeding resulted in significantly increased fecal output when compared to control diet and the increase with oat bran was larger than with oat gum. During periods of oat gum feeding, feces were significantly drier than with wheat bran, oat bran, or raffinose for five of the six women. Both wet and dry fecal weights for the day after wheat bran feeding were significantly higher than for other control diet days. Fecal output for the control diet day after oat bran was significantly higher for only three of the women.

The magnitude of increases in fecal weights over control values is listed in Table III. With all of the treatments, wet weight increased more than the weight of the test food administered. With the bran treatments, the increase in fecal dry weight is less than the dry weight of the test food, but greater than the amount of crude fiber fed. The increase in total fecal weight with raffinose is mostly water, while with oat gum there was also a definite increase in solids excreted. Again,

TABLE III
Increase[a] of Wet and Dry Weight of Daily Feces Over Control Periods

	Oat Bran	Wheat Bran	Oat Gum	Raffinose
Wet	67.6 ± 45.2	148.4 ± 113.1	18.3 ± 40.4	17.0 ± 39.1
Dry	17.4 ± 9.6	24.6 ± 11.0	6.4 ± 10.2	0.6 ± 8.6

[a]In grams. $\bar{X} \pm$ S.D.

this was greater than the crude fiber content of the oat gum fed.

Breath Hydrogen

The average H_2 production figures given in Table IV are for all women, irrespective of doses of test food received. The data have been consolidated because breath H_2 excretion was not significantly different for those women receiving higher and lower doses. This may be due to the fact that women for whom the test dose of foods had to be reduced due to initial adverse reactions were among the higher H_2 producers in the group.

The time at which H_2 production begins to increase is an indication of transit time to the lower ileum, where H_2 production begins (5). With wheat bran and raffinose, the elevation began 2–3 hr after the test meal (*post cibum*), significantly earlier than with control diet (5 hr *post cibum*). Oat bran and oat gum were like the control diet in that the increase did not begin until 4 and 5 hr after the meal.

Paired data show that some parameters of H_2 production were increased with all of the test foods when compared with formula. The average of the five highest hourly values ($\overline{X}_5$) was significantly increased for all of the treatments except oat gum. Total breath H_2 excretion increased somewhat with all of the test foods but was significantly increased only for raffinose.

The H_2 parameters were consistently highest with raffinose, and most of the women reported gaseousness with the raffinose feeding. However, for individuals these complaints did not always correlate with the time or magnitude of increases in H_2 in the breath. Total H_2 excretion with raffinose was significantly greater than with the other treatments, with the exception of wheat bran.

Peak H_2 excretion and $\overline{X}_5$ after wheat bran also were quite high, although the variation was large. For several of the women, H_2 excretion remained elevated up

TABLE IV
Hydrogen (H_2) Production

	Control	Oat Bran	Wheat Bran	Oat Gum	Raffinose
Increase began (hr *p.c.*[a])	5 ± 3	5 ± 2	2 ± 3	5 ± 2	2 ± 1
Peak (ppm)	30 ± 18	39 ± 18	47 ± 38	34 ± 20	78 ± 18
Time (hr *p.c.*)	10 ± 4	10 ± 2	7 ± 5	10 ± 4	5 ± 1
X_5[b]	27 ± 13	17 ± 12	34 ± 12	28 ± 17	54 ± 6
ml/hr		Total H_2 Excretion			
ml/hr	4.9 ± 3.1	6.6 ± 5.3	9.0 ± 7.7	7.4 ± 6.5	9.0 ± 3.1
Area[c]	396 ± 174	533 ± 369	770 ± 656	568 ± 233	748 ± 77

[a]*p.c.* = *post cibum*, after the test meal.
[b]Average of five highest hourly values.
[c]Area under 24-hr breath H_2 curve.

to 14 hr after wheat bran feeding. These women also had cramping and large bowel movements in the late evening.

With oat bran and oat gum, H_2 production was lower than with the other test foods, which corresponds with the more moderate increases in fecal weight and milder subjective symptoms reported during these feeding periods.

Breath Methane

Initially, five of the women had relatively high concentrations of CH_4 (15–55 ppm) in the breath. Patterns of CH_4 excretion over the course of the study are shown in Fig. 2. For two of the women (3801 and 3804) CH_4 excretion dropped dramatically after the oat bran and wheat bran feedings. These women also experienced large increases in fecal output and complained subjectively of gastrointestinal discomfort. By the end of the study, their CH_4 production had

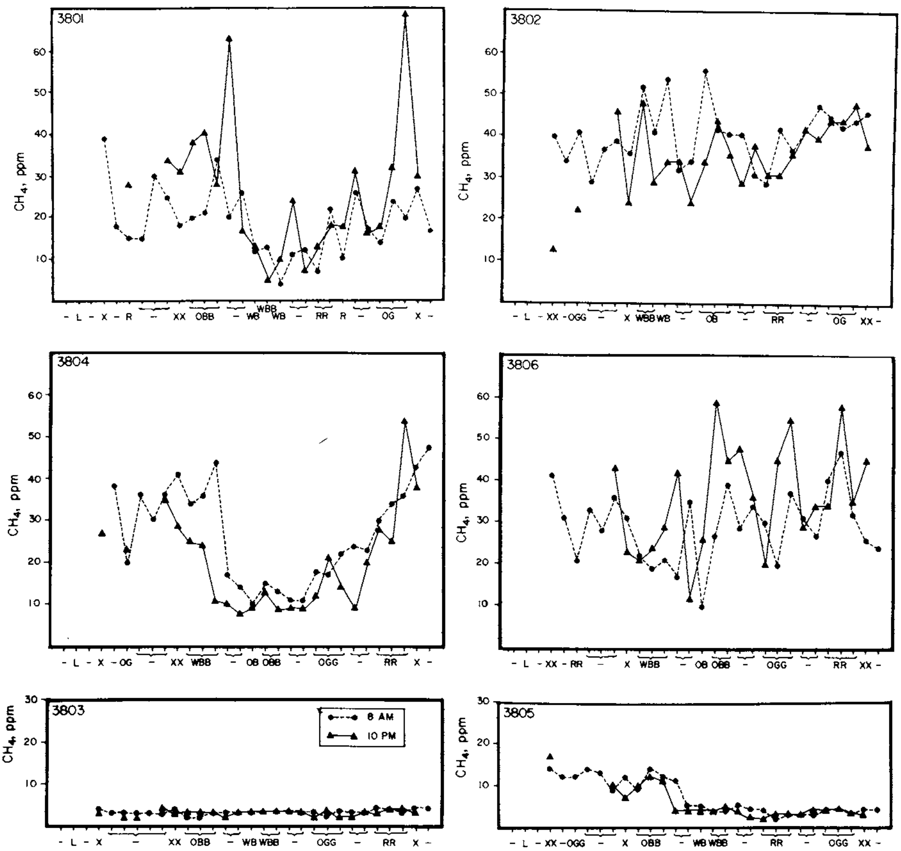

Fig. 2. Methane concentration in the breath each morning and evening of the study. Treatment codes are the same as in Fig. 1.

increased again and approached prebran levels. For a third woman (3805), CH_4 production also fell with the wheat bran treatment and was not recovered for the remainder of the study.

Each woman had a unique pattern of daily CH_4 excretion. Two of the women (3802, 3806) had cyclic production of CH_4. Both the morning and night concentrations peaked every 3–6 days (averages 4.6 and 4.5 days for 8 a.m. and 10 p.m. values, respectively). For two of the women (3801, 3806), CH_4 concentration was consistently higher at night than at 8 a.m. the following day, whereas for the others, the reverse was generally true.

DISCUSSION

In this study, several measures of gastrointestinal response were used in order to establish major differences between the cereal components tested, if any, and as a guide to future research on the nutritional significance of various substances crudely grouped as dietary fiber. In general, changes in fecal output reflect the digestibility of the foods and their water-holding capacity and/or their breakdown into osmotically or physiologically active components. Changes in breath H_2 directly reflect bacterial fermentation and, less directly, the time pattern of flow of digesta through the gastrointestinal tract. Depending on the particular subject and the type and amount of food taken, elevations in breath H_2 may be the only evidence of increased bacterial action (6), or breath H_2 can be correlated with other symptoms such as increased flatus, cramping, and distension. Patterns of breath H_2 excretion thus provide useful information about the physiological activity of test foods.

The largest increases in wet and dry weight of feces occurred with wheat bran. The average increase in fecal solids was approximately equal to the estimated dose of dietary fiber (7,8). The oat bran moved both less water and less solids from the gut than an equivalent weight of wheat bran. Percentage dry solids was higher with oat bran, indicating either that wheat bran had a greater water-holding capacity than oat bran or that wheat bran feeding increased motility sufficiently so that water was less effectively recovered from the intestinal contents.

Data on bowel movements recorded for a large group of subjects led Connell *et al.* (9) to conclude that less than three movements per week or more than three movements per day was outside of the normal range. Even with the low-residue control diet used in our study, frequency of bowel movements of all the women fell within these limits. With wheat bran and raffinose, however, the frequency increased beyond the normal range, indicating marked effect on gastrointestinal motility.

Based on the early rise in H_2 production with the wheat bran, and the fact that evening and overnight production were still high, it seems that wheat bran might have at least two nondigestible fermentable components—one that moved through the gut and was fermented at the same rate as raffinose, and another fraction that reached the bacteria later or that was fermented to gaseous products at a slower rate. Oat bran and oat gum apparently lacked the short-term fermentable component and resulted in elevated H_2 only later in the day.

The largest increases in H_2 excretion were found with the 10-g dose of raffinose. There are no known mammalian enzymes which hydrolyze the galacto-sucrose bond in raffinose (10) but it appears to be readily fermentable by the enteric flora. Based on analytical data of Saunders *et al.* (11) 50 g of wheat bran would have about 1.3 g of raffinose. Intestinal gas excreted in the breath with the wheat bran was somewhat less than with the raffinose, but not as low as one-seventh the amount, suggesting that other components in wheat bran are good substrates for bacterial fermentation. It is possible, however, that H_2 production with raffinose exceeded the limits of pulmonary ventilation of this gas and that the excess was expelled as flatus (6).

Wheat bran contains about 22% cellulose and lignin, 25% hemicellulose (7,8) and 6% total sugars, of which about half are oligosaccharides such as raffinose, stachyose, verbascose, and neokestose (10). No carbohydrate analysis is available for oat bran. However, when dehulled oats were analyzed for fibrous components, their lignin content was found to be 3.1%, compared with 1.6% in whole spring wheat. Also, the oats had a hemicellulose content of 4.8%, compared with 8.5% in whole spring wheat (12). It is probable that milled oat bran has a higher content of lignin and less hemicellulose than milled wheat bran.

In the studies of Williams and Olmsted (13), when hemicellulose content of the test food was high, the food was 'apt to be laxative.' When lignin content was high, fecal weights were increased above basal levels, but only to the extent of the material fed. Lignins are much less hygroscopic than the polysaccharides (14) and are not fermented by enteric flora. Hemicellulose is more soluble and probably is more completely used by bacteria even than cellulose (15). Some of the differences in fecal weights between oat and wheat bran treatments could be explained on the basis of their differing fiber components.

The samples of oat and wheat bran fed in this study were analyzed for activity of α-amylase inhibitor (unpublished data, Dr. John Lang, University of California, Berkeley). The inhibitor was 23 times more active in the wheat bran than oat bran. This difference in inhibitor content may also relate to the larger increase in fecal weights and intestinal gas production with wheat bran. In rats, the inhibitor has been shown to decrease the digestibility of starch-containing diets; the inhibitor might have a similar effect in man but this has not been demonstrated directly.

The cell walls of the endosperm and the germ are chiefly composed of hemicellulosic material, both water-soluble and water-insoluble. The water-soluble substances are known as cereal gums. They are composed of hemicelluloses (chiefly arabosylans), glucosans, and protein, and yield viscous solutions in water (12). At the levels tested, the response to oat gum was moderate. The H_2 in the breath was only slightly elevated over control values with the oat gum. Oat gum increased fecal output over the control value but did not cause larger increases in fecal wet weight than raffinose. The dry solids excretion was higher with the gum than raffinose, which does not have water-binding properties, so it is likely that the basis of the raffinose effect is increased motility.

This study shows that changes in the numbers or activity of the methane-producing enteric flora can be studied indirectly. The sharp drop in CH_4 excretion after the bran treatments indicates a temporary shift in the flora due to altered transit time or composition of residues in the colon or to overgrowth of competitive bacteria, sufficient to suppress CH_4 production.

Under the conditions of this study, 50 g of wheat bran and 10 g of raffinose were not well tolerated, but this study was not long enough to allow the women to adapt to the test materials. Painter *et al.* (16) reported that 3 to 8 weeks are needed to relieve the initial gastrointestinal symptoms found with a 'high fiber' diet (15–35 g wheat bran per day, raw or processed), and even after this time, not all of their patients tolerate the increased fiber well.

Acknowledgments

We wish to thank the women participants and the many staff members of the human nutrition research group for their support, and particularly Del Brown for his excellent technical assistance.

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[Received March 19, 1976. Accepted May 11, 1976]