Effect of the Source of Fiber in Bread on Intestinal Responses and Nutrient Digestibilities[1]

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ABSTRACT

Young rats were fed one fiber-free and 12 isofibrous diets for three weeks. Fiber originated from 12 different types of breads. Five (white, oatmeal, corn, and two multigrain) of these contained one-fifth or more of the total fiber as soluble fiber. The following results were obtained: a) fiber caused a significant increase in stomach and colon weights; b) fiber increased the dry fecal weight three- to sixfold; c) insoluble fiber was positively correlated with fecal output ($r = 0.56$); d) cellulose added to bread was more resistant to colonic degradation than naturally occurring insoluble fiber; e) fecal density was lower on cellulose-containing, bran-containing, and wholewheat breads than on other breads; (f) fiber degradation averaged the highest (82.1%) on white bread and the least (15.9%) on cellulose-containing bread; g) apparent digestibility of nitrogen and fat was adversely affected by fiber; and h) fiber caused a significant reduction in fecal pH.

Cereal Chem. 65(1):9–12

Human epidemiological studies show a lower incidence of colorectal cancer in population groups consuming diets high in fiber (Trowell et al 1985). Fiber is postulated to protect against colorectal cancer by decreasing the transit time of contents, altering the bile acid metabolism, affecting the consequences of fermentation, providing a surface for adsorption and by physical dilution (bulking effect) of lumen contents (Burkitt et al 1972, Cummings 1985).

The fecal bulking capacity of fiber sources varies. Sources that are high in water-insoluble fiber fractions tend to provide more bulk. Whole wheat and other wheat-based variety breads are an important source of insoluble fiber in our diet. Several of these and related bread products, however, also contain flours and fractions from nonwheat cereals, noncereal grains, and vegetables. Some products also contain highly purified and/or modified fiber fractions. These various ingredients, usually carried through the use of added gluten, may contain a sizable portion of fiber as water-soluble fiber.

Soluble fiber is reported to be highly fermentable in the large intestine (Nyman and Asp 1982, Van Dokkum et al 1983, Nyman 1985, Cheng et al 1987) and thus may provide little bulk. This, and the understanding that food processing (baking, for example) may modify the physiological properties generally attributed to plant fibers (Nyman 1985, Eastwood et al 1986, Schneeman 1987), prompted these studies. Fiber in 12 types of widely consumed variety breads was examined for its behavior along the intestinal tract. Rats, which show a good correlation with man in fiber degradation and in bulking capacity (Nyman 1985), were used as the test model.

MATERIALS AND METHODS

Test Breads and Diets

Breads tested (Table I) were purchased locally but represent national brands. They were air-dried, finely ground, and then used to formulate diets (Table I). Diets were formulated to be equal in nitrogen, fat, and moisture (Table I). With the exception of the control (fiber-free) diet, all diets also contained the same, 4.1%, level of total dietary fiber (TDF) and about the same level of available carbohydrates. Diets were complete in all micronutrients required by the rat (NAS/NRC 1978).

Animals and Feeding

Male weanling rats (six rats per diet) of the Sprague-Dawley strain (Harlan Sprague-Dawley, Indianapolis, IN) were housed individually in mesh bottom stainless steel cages in a controlled environment. Sliding fecal collection trays were provided under each cage. Distilled water was offered to the animals ad libitum, but the amount of diet fed was restricted; each rat was fed the same amount, however, which was adequate and was gradually increased during the three-week test period. Rats were weighed at weekly intervals.

Intestinal Measurements

At the end of the test period, all animals were sacrificed and their intestinal tract was removed. Stomach, small intestine, and colon (cecum included) were separated, thoroughly cleaned of the lumen contents, blotted dry, and immediately weighed.

Fecal Measurements

Feces were collected quantitatively twice daily for the entire three-week period, pooled, air-dried, weighed, and stored under refrigeration. Density was calculated by dividing the fecal weight by volume. Fecal volume was determined in a long-stem graduated cylinder using fine sand as the embedding medium. Feces, recovered from the sand, were finely ground and analyzed for TDF, nitrogen, fat, ash, and pH.

Fiber Fermentation and Nutrient Digestibilities

Fiber fermentation and the apparent digestibility of nitrogen, fat, and ash were estimated by the difference between amounts ingested and excreted over the three-week test period.

Analytical

Finely ground breads and casein were analyzed for moisture, protein (Kjeldahl), fat (acid hydrolysis), and ash using standard AACC methods (1983). TDF in breads was determined by the recently approved method of Prosky et al (1985); the incorporation of additional steps (filtration and precipitation) in the method allowed the determination of insoluble and soluble fiber components. The same methods (AACC 1983, Prosky et al 1985) were used to determine TDF, nitrogen, fat, and ash in feces. Fecal pH was also determined by the standard AACC method (1983).

Statistical

Averages, as are listed in Tables II and III, were compared by Duncan's (1955) multiple range test.

RESULTS AND DISCUSSION

Twelve different types of breads were tested (Table I). Whole wheat bread, corn tortillas, and rye bread represent three different grains used almost in totality. Two of the four mixed grain/multi-

[1]This paper was presented at the AACC 72nd Annual Meeting, Nashville, TN, November 1987.

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grain breads (breads K and L) also contained powdered vegetables and a high level of calcium. Four other bread types contained a purified (cellulose) or a natural (wheat bran, cracked wheat, oats) fiber source. Only white bread was a refined product (made entirely with low-extraction wheat flour).

Fiber in Breads and Diets

On an as-purchased basis, TDF in test breads ranged between 3.0 and 9.9%. In five test breads, over 20% of the TDF was soluble fiber (Table I). For white bread, this may reflect the compositional makeup of the fiber fractions or the contribution of resistant starch formed during baking (Berry 1986).

White bread was lowest (4.4%, dry basis) in TDF content and permitted only 4.1% TDF in the diet (diet A) with a nitrogen content of 1.88%. Other bread-based diets (diets B–L) were formulated to also contain only 4.1% TDF. Casein, corn oil, and sucrose were used to equalize the content of nitrogen, fat, available carbohydrates, and energy among diets.

Growth Response of Animals

Rats were fed the same amount of the test diets (159 g) during the three-week period. The growth response of animals (Table II), however, differed significantly ($P < 0.01$) among groups, primarily because the amount of casein (Table I) and, thus, the quality of protein in diets varied. The effect of fiber on energy utilization (discussed later) was likely not a significant factor affecting growth.

Intestinal Measurements

The weight of the gastrointestinal tract (GIT) of rats fed the test diets averaged between 1.65 and 3.07 g, being significantly higher in animals fed the fiber-free diet than the fiber-containing diets except for diet B (Table II). GIT weights were only weakly correlated ($r = 0.53$) with body weight gains.

As a percentage of the GIT weight, colon weight was significantly higher in rats fed the fiber-containing diets than the fiber-free diet. This agrees with results reported by Jacobs and Schneeman (1981), who attribute this effect to proliferation of colonic mucosa and possible increase in colonic muscle mass. The health consequences of this observation remain uncertain, however. Stomach weights also tended to be significantly higher on several, but not all, of the fiber-containing diets. In contrast, weight of the small intestine (as percent of GIT weight) was consistently and significantly higher in rats fed the fiber-free diet than diets A–L. Thus two anatomical segments of the GIT, separated by the small intestine, responded to fiber in a morphologically similar manner.

Fecal Measurements

Unless feces are collected immediately as expelled (this was not done), fecal moisture loss may vary between groups. For this reason, fecal measurements (based on three-week collections) are expressed on dry basis only (Table II). This, no doubt, distracts from a more realistic assessment of physiological effects where measurements are based on wet feces.

Although a low fecal weight is not necessarily cancer promoting, a high fecal weight may protect against colon cancer (Cummings 1985). Compared to the fiber-free diet, fecal weights increased three- to sixfold as breads were included in the diet. This increase represents primarily the bacterial mass, the undegraded fiber, and, in some cases, the excreted mineral matter.

The increase in bacterial mass due to colonic degradation of fiber may be sufficient to increase the fecal weight. This is evident when fiber-free diet M is compared with diet A, which contained a highly degradable fiber source (Table III). Where fiber is resistant to bacterial degradation (diet B, for example), the increase in fecal weight is primarily due to undegraded fiber. Exceptions to this are noted for diets D, K, and L. Rats fed these diets also excreted a substantial amount of mineral matter that originated from lime-treated tortillas (diet D) or super-fortified (with calcium) breads K and L.

Soluble fiber components are readily degraded by the colonic bacteria (Nyman 1985, McLean Ross et al 1983). For white bread, oatmeal bread, and corn tortillas, this is apparent when relevant data in Tables I and III are examined. Breads K and L, probably because of the high ash content (Table I), defy this trend, however.

Disregarding the error introduced by the high ash content on diets K and L, fecal output was the highest on cellulose-containing bread (bread B). Breads F–J, which like bread B were also high in insoluble fiber (Table I), yielded significantly lower fecal outputs. Thus, although dietary insoluble fiber (diets D, K, and L not considered) appears to be correlated with fecal weight ($r = 0.56$), the source of insoluble fiber may be another determining factor of bacterial degradation and, therefore, fecal output. Eastwood et al (1986), however, suggest there is no correlation between chemical composition and structure of the fibers and their physiological effects.

Fecal volumes, which highly correlated with fecal weights, well exceeded the fecal weights in some cases. This is particularly true in animals fed diets made with breads containing cellulose (bread B),

TABLE I
Composition of Test Breads and Diets

		Bread Composition[a] (%)					Diet Composition[b] (g/100 g)			
Diet	Bread	Moisture	Protein (N × 5.7)	Fat	Ash	Total Fiber[c]	Bread	Casein	Corn Oil	Sucrose
A	White	36.7	7.8	2.8	1.8	3.0 (34.1)	93.8	···	1.84	0.1
B	Cellulose-containing	41.5	8.2	3.4	2.1	9.9 (11.4)	26.3	9.45	4.22	51.0
C	Oatmeal	36.3	9.1	5.1	2.3	3.7 (32.6)	75.0	1.02	···	17.8
D	Tortillas, corn	43.8	5.0	3.7	1.4	4.3 (21.7)	58.1	7.64	2.13	25.9
E	Rye, German	36.8	10.2	3.8	2.2	8.3 (17.9)	33.6	7.27	3.76	46.5
F	Cracked wheat	35.2	10.0	3.6	2.1	6.7 (14.1)	42.3	5.96	3.43	40.0
G	Bran-containing	39.1	9.2	3.6	2.1	5.4 (15.1)	49.7	4.87	2.88	34.8
H	Whole wheat, 100%	39.7	10.5	5.3	2.1	8.1 (13.6)	32.7	6.98	2.97	48.4
I	Mixed grain	40.3	9.9	3.3	1.9	5.6 (10.7)	46.6	4.58	3.20	37.6
J	Multigrain	39.5	10.6	3.5	2.4	9.6 (13.1)	27.8	8.00	4.12	50.9
K	Multigrain + DPV-I[d]	38.3	7.4	3.1	4.6	3.4 (40.6)	81.4	2.25	1.87	9.7
L	Multigrain + DPV-II[d]	38.8	9.0	3.4	4.5	4.9 (24.4)	55.2	4.22	2.81	31.0
M	None (control)	···	···	···	···	···	···	13.75	5.43	70.5

[a] Available carbohydrate values (not listed) equal the remainder of the sum of components listed subtracted from 100.
[b] All diets contained 1.888% nitrogen, 5.6% fat, 4.1% total dietary fiber (diet M was a fiber-free control), and 7.0% moisture. Water added to equalize the moisture content among diets varied from 0 to 6.11%. Diet components not listed included: vitamin mix (AIN mix 76 from U.S. Biochemicals, Cleveland, OH), 1 g; and mineral mix (in sucrose base), 3.2 g. Mineral mix contained (mg): Ca, 500; P, 400; Fe, 3.5; Cu, 0.5; I, 0.015; Mg, 40; Mn, 5; Se, 0.01; Zn, 1.2; and K, 360.
[c] Total dietary fiber. Values within parentheses are soluble fiber contents expressed as percentage of total fiber.
[d] DPV = Dried powdered vegetable. DPV-I is a light and DPV-II is a dark product.

bran (bread G), and whole wheat (bread H). Consequently, fecal density was lower (Table II, Figure 1), and fecal bulking capacity was higher on these three breads. This observation is important because density, rather than mass, reflects the carcinogen-diluting potential of fiber (Lupton and Ferrell 1986).

Extension of these observations to wet feces or to colonic contents may or may not be valid but, according to Lupton and Ferrell (1980), stools from rats consuming wheat bran became less and less dense as it travelled distally whereas fiber-free, pectin, and guar diets produced the opposite effect.

Transit time was not measured, but several studies show an inverse relationship between transit time of GIT contents and fecal weight and density.

Fiber Fermentation

Fiber fermentation fell from 82.1% on white bread to 52.0% on bran-containing bread and to 15.9% on cellulose-containing bread (Table III). In studies with humans, Stephen et al (1986) reported the digestibility of nonstarch polysaccharides to fall from 77.6% on the white bread diet to 65.6% with the bran added.

Water solubility of a fiber fraction does not appear to be the sole criterion determining fiber degradation. However, noncellulosic (usually water-soluble) fractions are often extensively degraded in the colon. In contrast, cellulose is relatively resistant (Nyman and Asp 1982), and lignin passes through the colon virtually unaltered (Van Dokkum et al 1983, Cheng et al 1987).

Nutrient Digestibility

Lowering of nutrient digestibility is associated with the consumption of fiber (Schneeman 1987, Reiser 1987). Data in Table III show this for nitrogen and fat. Apparent digestibility of

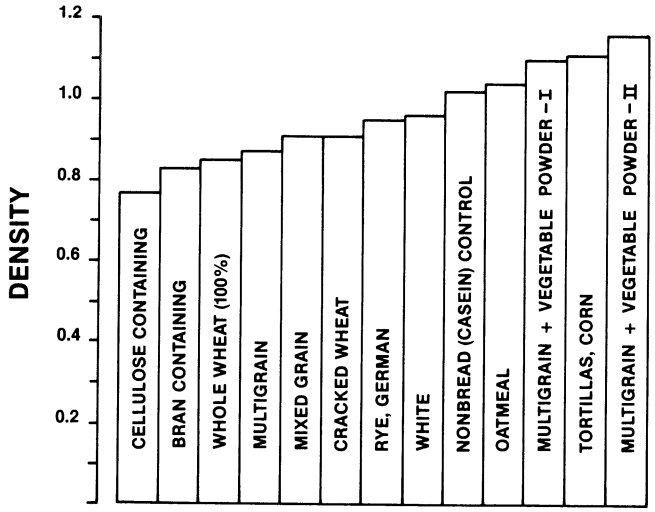

Fig. 1. Effect of the source of fiber in bread on fecal density (g/cm^3).

TABLE II
Intestinal Measurements and Fecal Characteristics[a] (three-week experiment)

Diet[b]	Body Weight Gain[c] (g)	Gastrointestinal Tract: Total Weight[d] (g)	Gastrointestinal Tract: % of Total Weight: Stomach	Small Intestine	Colon[e]	Fecal Characteristics: Dry Weight (g)	Dry Volume (ml)	Density (g/cm^3)
A	38 ± 2	2.49 ± 0.14 cd	18.9 ± 1.9 ef	64.5 ± 2.7 b	16.6 ± 1.4 c	5.37 ± 0.21 h	5.6 ± 0.2 g	0.96 ± 0.04 d
B	55 ± 2	2.93 ± 0.16 ab	19.3 ± 0.5 def	63.8 ± 0.8 b	16.9 ± 0.5 bc	8.53 ± 0.15 c	11.1 ± 0.3 a	0.77 ± 0.02 h
C	37 ± 1	1.65 ± 0.03 f	23.1 ± 1.8 bc	60.0 ± 2.7 def	16.9 ± 1.9 bc	5.96 ± 0.20 fg	5.7 ± 0.3 g	1.04 ± 0.04 c
D	54 ± 2	2.60 ± 0.28 cd	22.7 ± 1.7 bc	57.9 ± 2.6 f	19.4 ± 1.0 a	7.49 ± 0.21 d	6.8 ± 0.2 ef	1.11 ± 0.03 b
E	56 ± 2	2.72 ± 0.17 bc	19.3 ± 1.3 def	63.5 ± 1.5 bc	17.2 ± 0.6 bc	5.37 ± 0.21 h	5.6 ± 0.3 g	0.95 ± 0.02 d
F	54 ± 3	1.96 ± 0.10 e	27.5 ± 1.9 a	55.2 ± 2.1 g	17.3 ± 0.7 bc	5.82 ± 0.43 g	6.4 ± 0.5 f	0.91 ± 0.02 ef
G	52 ± 2	2.49 ± 0.12 cd	20.2 ± 0.9 def	62.7 ± 1.8 bcd	17.1 ± 1.3 bc	6.82 ± 0.20 e	8.2 ± 0.3 c	0.83 ± 0.02 g
H	56 ± 2	2.46 ± 0.30 d	20.6 ± 1.8 def	61.7 ± 1.9 bcde	17.7 ± 1.5 abc	7.35 ± 0.36 d	8.7 ± 0.6 c	0.85 ± 0.02 g
I	51 ± 2	2.50 ± 0.22 cd	20.7 ± 2.2 de	60.8 ± 3.7 cdef	18.6 ± 1.7 ab	6.79 ± 0.34 e	7.5 ± 0.6 d	0.91 ± 0.04 e
J	57 ± 1	2.13 ± 0.21 e	24.4 ± 2.0 b	58.4 ± 1.7 f	17.3 ± 0.9 bc	6.27 ± 0.30 f	7.2 ± 0.6 de	0.87 ± 0.05 fg
K	40 ± 1	1.99 ± 0.15 e	23.9 ± 1.8 b	58.2 ± 2.5 f	17.9 ± 1.5 abc	12.57 ± 0.63 a	10.9 ± 0.6 a	1.16 ± 0.02 a
L	47 ± 2	2.43 ± 0.13 d	21.1 ± 1.3 cd	59.9 ± 2.0 ef	19.1 ± 1.4 a	11.01 ± 0.16 b	10.1 ± 0.3 b	1.10 ± 0.03 b
M	55 ± 1	3.07 ± 0.31 a	18.4 ± 1.7 f	69.2 ± 1.3 a	12.4 ± 1.6 d	1.95 ± 0.11 i	1.9 ± 0.1 h	1.02 ± 0.04 c

[a] Values are averages (6 rats/diet) ± SD. Averages in a column followed by the same letter are not significantly different ($P > 0.05$).
[b] Diets are the same as listed in Table I.
[c] Initial body weight averaged 35 g on all diets.
[d] Residue-free.
[e] Cecum included.

TABLE III
Fiber Fermentation, Nutrient Digestibility, and Fecal pH[a]

Diet[b]	Total Dietary Fiber (% fermented)	Apparent Digestibility[c] (%): Nitrogen	Fat	Ash	Fecal pH
A	82.1 ± 1.1 a	90.7 ± 0.8 e	90.1 ± 1.1 cd	87.6 ± 0.9 cd	6.51 ± 0.26 fg
B	15.9 ± 1.7 h	94.8 ± 0.4 b	91.9 ± 1.0 b	87.5 ± 1.1 cd	6.98 ± 0.08 c
C	78.5 ± 1.5 b	91.3 ± 0.7 e	87.5 ± 2.3 e	84.3 ± 0.7 e	6.68 ± 0.10 e
D	78.2 ± 0.9 b	88.6 ± 0.6 f	89.6 ± 1.6 d	67.1 ± 1.4 f	7.30 ± 0.11 b
E	69.6 ± 1.3 c	92.5 ± 0.4 d	90.7 ± 0.4 bcd	89.9 ± 1.4 a	6.40 ± 0.06 g
F	63.6 ± 2.6 d	92.9 ± 0.8 d	90.2 ± 0.4 cd	89.4 ± 1.2 ab	6.47 ± 0.08 fg
G	52.0 ± 1.6 e	92.7 ± 0.3 d	91.2 ± 0.9 bc	88.7 ± 0.9 abc	6.53 ± 0.05 fg
H	43.9 ± 2.2 g	92.8 ± 0.5 d	89.3 ± 0.8 d	86.7 ± 1.2 d	6.60 ± 0.06 ef
I	52.3 ± 2.8 e	92.4 ± 0.6 d	91.9 ± 0.6 b	88.1 ± 1.0 bcd	6.58 ± 0.08 ef
J	53.8 ± 1.9 e	93.9 ± 0.5 c	91.7 ± 0.4 b	89.1 ± 1.3 ab	6.57 ± 0.08 ef
K	63.1 ± 2.0 d	88.7 ± 1.1 f	86.9 ± 1.9 e	57.7 ± 1.1 g	7.48 ± 0.08 a
L	48.8 ± 4.6 f	89.2 ± 0.4 f	87.8 ± 1.5 e	67.0 ± 1.2 f	7.40 ± 0.09 ab
M	···	96.9 ± 0.3 a	94.8 ± 0.3 a	90.1 ± 1.6 a	6.84 ± 0.11 d

[a] Values are averages (6 rats/diet) ± SD. Averages in a column followed by the same letter are not significantly ($P > 0.05$) different.
[b] Diets are the same as listed in Table I.
[c] Each rat consumed a total of 6.52 g of fiber, 3.0 g of N, and 8.9 g of fat during the three-week collection period. Ash content among diets was not equalized, hence ash intake varied between 4.63 g (diet M) and 13.40 g (diet K).

nitrogen and fat decreased irrespective, as reported also by Nyman and Asp (1982), of the source of fiber used (bread, in this study). The apparent digestibility of available carbohydrates (not calculated) was perhaps not adversely affected as studies earlier reported (Ranhotra et al 1982) seem to suggest. This also appears to be the case for mineral matter; the poor mineral balance observed on diets D, K, and L seems to be unrelated to fiber.

Fecal pH

Several metabolic events occurring in the GIT, including the degradation of fiber, affect fecal pH. The production of fiber degradation products, primarily the short-chain fatty acids, was not studied, but the pHs listed in Table III provide some indication of it. Compared to the fiber-free diet, fecal pH tended to be lower on the fiber-containing diets; patients with bowel cancer usually have a higher fecal pH (MacDonald et al 1978). Exception was noted on diets B, D, K, and L. For diet B, this may be the consequence of insignificant cellulose degradation, as results in Table III and those reported by Cheng et al (1987) suggest. For diets D, K, and L, it may reflect the buffering capacity of calcium in the fecal matter.

CONCLUSION

Several studies show that soluble fiber components may be effective in normalizing elevated blood lipid and sugar levels. However, where intestinal dysfunctions, related to low fecal bulk, are of health concern, insoluble fiber may prove a valuable adjunct in remedying these dysfunctions. The present studies showed that insoluble fiber in wheat, especially the cellulose component, may be most effective in this regard. The slight adverse effect the fiber may have on nutrient digestibilities carries a limited physiological significance.

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[Received March 25, 1987. Revision received July 17, 1987. Accepted July 20, 1987.]