# A novel source of wheat fiber and protein: effects on fecal bulk and serum lipids[1–3]

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**ABSTRACT**

**Background:** Wheat fiber is a laxative and wheat protein may affect blood lipids.

**Objective:** We therefore tested the effects on laxation and serum lipid metabolism of a novel source of wheat fiber and protein produced by the amylolytic digestion of starch from wheat.

**Design:** Twenty-four healthy men and women consumed 3 different test cereals in random order, each for 2 wk. The test supplement and the positive control, American Association of Cereal Chemists wheat bran supplement, both provided the same amount of fiber (21 g/d) and the negative control supplement provided 1.7 g fiber/d.

**Results:** The test supplement and the positive control supplement increased fecal bulk similarly (239.5 ± 19 and 216.7 ± 19 g/d, respectively) and significantly more than did the negative control supplement (165.6 ± 16 g/d, $P < 0.010$). Compared with the negative and positive control supplements, the week 2 value of the test supplement for the ratio of total to HDL cholesterol was significantly reduced ($P = 0.046$).

**Conclusion:** We conclude that the product of amylolytic digestion of starch from wheat flakes, which is high in wheat fiber and protein, has a fecal bulking effect similar to that of wheat bran and may have a beneficial effect on serum lipids. *Am J Clin Nutr* 1999;69:226–30.

**KEY WORDS** Wheat bran, wheat protein, fecal bulk, transit time, blood lipids, amylolysis, humans

## INTRODUCTION

There has been considerable interest in the development of alternative and renewable fuels and solvents that leave less residue and have less environmental impact than fossil fuels traditionally derived from the petrochemical industry. Recently, it has become possible to process wheat starch to produce large quantities of high-grade ethanol for solvent use and automobile fuel ("gasohol") to reduce exhaust emissions of carbon dioxide, benzene, and other hydrocarbons (1). Starch-reduced wheat flakes, produced by the initial amylolytic digestion of the milled wheat kernel to produce the sugars for fermentation to ethanol, are high in fiber (25.9% by wt) and protein (26.1% by wt). This product may have value in human nutrition because fiber has laxative properties (2–5) and vegetable proteins have been shown to reduce serum cholesterol concentrations (6–11). However, it has been suggested that a more processed wheat fiber increases fecal output less than does raw unprocessed wheat fiber (5). Furthermore, most studies noting a beneficial effect of protein in reducing serum cholesterol concentrations have studied soy protein (11). There have been no reports of a lipid-lowering effect of wheat protein (gluten) in human studies. However, in rabbit studies, wheat gluten was shown to be less atherogenic than lactalbumin in cholesterol-free diets and to result in lower serum cholesterol concentrations (8).

We therefore assessed the effect on fecal bulk and serum lipids of feeding healthy human subjects a high-fiber, high-protein test supplement resulting from the amylolytic digestion of wheat. These results were compared both with the effect of feeding an equal amount of fiber (21 g) as standard American Association of Cereal Chemists (AACC) wheat bran (positive control) and with a low-fiber breakfast cereal (negative control).

## SUBJECTS AND METHODS

### Subjects

Twenty-four healthy subjects (12 men and 12 women) aged 31 ± 2 y (range: 21–60 y) and 104 ± 3% of ideal body weight (range: 77–139%) made up the study group. The study was approved by the Ethics Committee of the University of Toronto and informed consent was obtained from each volunteer.

### Methods

The test and control supplements were taken in random order according to a 3-phase crossover design: three 2-wk periods with 2-wk washout periods between each phase. During one 2-wk period, 21 g fiber from the test supplement (Fibrotein; Mohawk

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Canada Ltd, Burnaby, Canada) was consumed daily in flake form with breakfast cereal or mixed with yogurt. These high-protein, high-fiber flakes were produced by amylolytic digestion of wheat in the manufacture of ethanol. The positive and negative control supplements were also eaten for 2-wk periods in the same manner. They were, respectively, standard AACC wheat bran (21g fiber/d) and a low-fiber control supplement consisting of crushed corn flakes (1.7 g fiber/d). Eight subjects (4 men and 4 women) received each treatment first.

Blood lipid measurements were obtained for 23 subjects. Overnight, fasting blood samples were taken in the morning at the start and end of each study period. Diet histories and symptoms were recorded for the last week of each study period. Complete, 4-d fecal collections were obtained from the 24 subjects for all 3 phases of the study. Collections were made on an outpatient basis at the end of each treatment period. Participants were provided with underseat lavatory frames on which to attach plastic collecting bags. After use, the bags were sealed, labeled, and placed on frozen carbon dioxide in a polystyrene container. At the end of day 4, these containers were returned to the laboratory where samples were weighed and stored at −20°C. Pooled, 4-d collections were then partially thawed, were placed in a blender with 5-L capacity, 10% water by weight was added, and the mixture was homogenized. Aliquots of 300 g were then freeze-dried and weighed.

Symptom diaries used a 5-point scale and included flatus (1, no gas; 5, extreme flatulence), bloating (1, no bloating; 5, extreme bloating), ease of passing a bowel movement (1, easy; 5, difficult), and stool consistency (1, watery; 5, hard). To estimate transit time, a single capsule containing 20 radioopaque plastic rings was taken by subjects in the morning at the start of the 4-d fecal collection (12). Subjects were asked to maintain the same diet pattern across all study periods and to maintain their level of physical activity.

Nutrient values of diets were derived primarily from the US Department of Agriculture *Handbook* no. 8 (13). The particle size of the test supplement and AACC wheat bran was measured by the Ro-tap method as calculated by Mongeau and Bressard (14). The mean particle sizes of the test supplement and AACC wheat bran were estimated to be 0.6 and 1.0 mm, respectively.

Serum stored at −70°C was analyzed enzymatically at the end of the study for total cholesterol and triacylglycerol by using the Kodak Ektachem 700XR apparatus (Rochester, NY) and reagents (15). HDL-cholesterol concentration was determined after dextran sulfate and magnesium chloride precipitation (15). LDL-cholesterol concentration was derived by using the formula of Friedewald et al (16). Serum apolipoproteins (apos) A-I and B were measured by using a Behring nephelometer and reagents (17). Serum lipid results are presented for 23 subjects because 1 male subject did not comply with the blood sampling protocol.

Transit time was estimated after X-raying the frozen feces and counting the plastic radioopaque markers (12). The time of appearance of 80% of the markers was noted in relation to the time of marker administration (80% transit time) (18). Mean transit time was also calculated when all the markers passed (12). Two subjects were unwilling to take the markers and 4 subjects passed either none or one marker in one phase of the study, suggesting that they had not taken the markers. Two other subjects recovered <80% of their markers in the first and second phase of the study, respectively. Mean transit time data are presented for 18 subjects with complete data. Eighty percent transit time data are presented for 22 subjects.

### Statistical analyses

The results are expressed as means ± SEs. We performed an analysis of covariance with week 2 values as the response variable, and diet, sequence, sex, sequence-by-sex interaction, carryover (coded to reflect the previous diet), and random subject effects nested within sequence-by-sex interaction as categorical variables and baseline value as the covariate. We also used the Student-Neuman-Keuls test to assess mean treatment effects. For the 2 subjects for whom we did not achieve 80% marker recovery in 1 and 2 tests, respectively, predicted values were obtained by using PROC LIFEREG (19). These data were then run with the original data, including the 4 subjects with incomplete results, by using the LSMEANS option in SAS within a Tukey adjustment (19). In addition, we assessed the lipid and 80% transit time data using the CONTRAST statement in SAS PROC GLM that assigns weights of −0.5 to each of the combined treatments and 1 to the single treatment (19).

## RESULTS

Total energy intakes were not significantly different between study periods (**Table 1**). However, significantly more vegetable protein as a percentage of energy and correspondingly less carbohydrate was consumed during the test supplement period. The supplements were well tolerated and no differences were reported in symptoms apart from a mild increase in flatulence with the test supplement compared with the positive and negative control supplements (2.4 ± 0.2, 1.7 ± 0.2, and 1.6 ± 0.2, respectively, $P < 0.05$).

Both the test supplement and the positive control supplement increased fecal bulk (239.5 ± 19 and 216.7 ± 19 g/d, respectively) by comparison with the negative control supplement (165.6 ± 16 g/d, $P \leq 0.01$) (**Table 2**). The increase in weight was due to both fecal water and solids. There were no significant differences between the 2 high-fiber supplements. No significant difference was seen in mean transit time among the 3 supplements. The 80% transit times were as follows: negative control supplement, 50 ± 5 h; positive control supplement, 39 ± 5 h; and test supplement, 37 ± 5 h. Neither the positive control supplement nor the test supplement was significantly different from the negative control supplement on the basis of LSMEANS assessment. However, comparison of the 2 wheat-fiber supplements (positive control and test) with the negative control supplement showed a significant difference ($n = 18$, $P = 0.033$), indicating that the wheat-fiber supplements reduced 80% transit time. Both sexes responded similarly to the supplements. However, fecal weights were significantly greater for the men than for the women. According to subjects' records, all supplements were consumed and body weight remained constant across all study periods (**Table 3**).

No significant differences were seen in baseline serum lipid or lipoprotein values between supplements. According to results of the Student-Neuman-Keuls assessment, the changes across supplements in the ratios of total to HDL cholesterol and LDL to HDL cholesterol showed greater reductions with the test supplement than with both the negative and positive control supplements ($P < 0.05$; Table 3), although these differences were not significant in analysis of covariance. Comparison of the test supplement with the 2 control supplements also showed a lower ratio of total to HDL cholesterol in week 2 ($F = 4.26$, $P = 0.046$).

**TABLE 1**
Daily intakes during the 3 phases of the study[1]

| Nutrient | Negative control ($n$ = 22) | Positive control ($n$ = 23) | Test ($n$ = 24) |
|---|---|---|---|
| Energy (kJ)[2] | 9008 ± 364 | 8281 ± 418 | 8878 ± 389 |
| Total protein | | | |
| (g) | 81.8 ± 4.5$^{a}$ | 81.6 ± 4.2$^{a}$ | 101.4 ± 5.6$^{b}$ |
| (% of energy) | 15.2 ± 0.5$^{x}$ | 16.8 ± 0.6$^{y}$ | 19.3 ± 0.7$^{z}$ |
| Vegetable protein | | | |
| (g) | 27.9 ± 2.5 | 30.9 ± 2.6 | 39.7 ± 2.4 |
| (% of energy) | 5.1 ± 0.4$^{x}$ | 6.2 ± 0.4$^{y}$ | 7.7 ± 0.5$^{z}$ |
| Animal protein | | | |
| (g) | 53.5 ± 4.2$^{a,b}$ | 50.7 ± 4.2$^{a}$ | 61.7 ± 6.2$^{b}$ |
| (% of energy) | 10.0 ± 0.7$^{x}$ | 10.5 ± 0.8$^{x,y}$ | 11.6 ± 0.9$^{y}$ |
| Available carbohydrate | | | |
| (g) | 310 ± 14$^{a}$ | 265 ± 18$^{b}$ | 269 ± 12$^{b}$ |
| (% of energy) | 57.7 ± 1.7$^{x}$ | 53.4 ± 1.7$^{y}$ | 50.7 ± 1.2$^{y}$ |
| Total fat | | | |
| (g) | 66.1 ± 5.1 | 66.5 ± 5.3 | 72.5 ± 4.9 |
| (% of energy) | 27.5 ± 1.5 | 30.2 ± 1.6 | 30.4 ± 1.1 |
| Saturated fat | | | |
| (g) | 23.7 ± 1.6 | 23.2 ± 1.3 | 24.5 ± 1.9 |
| (% of energy) | 10.0 ± 0.6 | 10.6 ± 0.5 | 10.2 ± 0.5 |
| Monounsaturated fat | | | |
| (g) | 25.1 ± 2.6 | 26.0 ± 3.1 | 26.4 ± 2.4 |
| (% of energy) | 10.4 ± 0.7 | 11.7 ± 1.0 | 11.0 ± 0.7 |
| Polyunsaturated fat | | | |
| (g) | 11.4 ± 1.2 | 10.5 ± 1.0 | 13.1 ± 1.6 |
| (% of energy) | 4.7 ± 0.4 | 4.8 ± 0.3 | 5.6 ± 0.6 |
| Total fiber | | | |
| (g) | 16.3 ± 1.7$^{a}$ | 33.1 ± 1.8$^{b}$ | 33.3 ± 1.6$^{b}$ |
| (g/MJ) | 1.8 ± 0.2$^{x}$ | 4.1 ± 0.2$^{y}$ | 3.8 ± 0.2$^{y}$ |
| Insoluble fiber | | | |
| (g) | 11.2 ± 1.2$^{a}$ | 26.7 ± 1.5$^{b}$ | 27.0 ± 1.4$^{b}$ |
| (g/MJ) | 1.2 ± 0.1$^{x}$ | 3.3 ± 0.2$^{y}$ | 3.1 ± 0.2$^{y}$ |
| Soluble fiber | | | |
| (g) | 5.1 ± 0.6$^{a}$ | 6.4 ± 0.5$^{b}$ | 6.3 ± 0.4$^{b}$ |
| (g/MJ) | 0.6 ± 0.1$^{x}$ | 0.8 ± 0.1$^{y}$ | 0.7 ± 0.1$^{y}$ |
| Dietary cholesterol | | | |
| (mg) | 224 ± 18 | 200 ± 17 | 229 ± 20 |
| (mg/MJ) | 25 ± 2 | 24 ± 2 | 26 ± 8 |

[1] $\bar{x}$ ± SEM. Values in the same row with different superscript letters are significantly different, $P < 0.05$ (Student-Neuman-Keuls test when there was a main effect of diet by ANOVA).
[2] Significant effect of sex, $P = 0.014$.

**TABLE 2**
Wet and dry weight, moisture of feces, transit time, and marker recovery[1]

| | Negative control | Positive control | Test |
|---|---|---|---|
| Wet weight (g/d)[2] | 165.6 ± 16[3] | 216.7 ± 19 | 239.5 ± 19 |
| Dry weight (g/d)[4,5] | 32.3 ± 2.4[3] | 41.5 ± 3.2 | 45.5 ± 2.9 |
| Moisture (%) | 79.3 ± 0.9 | 80.2 ± 0.6 | 80.3 ± 0.5 |
| Mean transit time (h)[6] | 30.7 ± 3.4 | 32.3 ± 3.3 | 28.7 ± 2.4 |
| Marker recovery (%)[6] | 92 ± 2 | 92 ± 1.2 | 90 ± 3 |

[1] $\bar{x}$ ± SEM; $n$ = 24 unless otherwise indicated.
[2,4] Significant sex effect: [2] $P < 0.007$, [4] $P < 0.001$.
[3] Significantly different from positive control and test, $P < 0.05$ (Student-Neuman-Keuls test after ANOVA for diet).
[5] After freeze-drying.
[6] $n$ = 18.

## DISCUSSION

The present study indicates that processed wheat fiber produces an increase in fecal bulk at least as large as that with wheat bran, despite a somewhat smaller particle size. At the same time, feeding the processed high-fiber, high-protein wheat product resulted in a reduction in the ratio of total to HDL cholesterol that was not seen with the AACC wheat bran or the low-fiber control.

Cereal fiber has long attracted attention in relation to the prevention of chronic disease (20). Previous studies have indicated that wheat fiber increases fecal bulk by 3–6 g for each additional gram of wheat fiber consumed (21–24). This places wheat fiber amongst the most effective fibers for increasing fecal bulk. In the present study, AACC wheat bran increased daily fecal bulk by 2.9 ± 0.7 g for each additional gram of fiber, whereas the respective figure for the test supplement was somewhat higher at 3.8 ± 0.6 g.

Several other factors may influence the laxative effects of wheat bran. The potential advantages of unprocessed and especially uncooked wheat bran as a laxative have been debated (5, 25–27). In this context, the effect of fiber-associated substances, such as phytate, in enhancing the laxative effect of fiber have been considered (28). In the present study, it is likely that the amount of water-soluble materials in the test supplement, such as phytate, would have been greatly reduced in the amylolytic digestion process. A slightly reduced rather than increased laxative effect would have been predicted (28). Particle size has also been shown to be important for the laxative effect of wheat bran, with a particle size ≥0.5 mm having a greater effect than a small particle size (14, 29, 30). The mean particle sizes of our test and positive control materials were 0.6 and 1.0 mm, respectively. If anything, a slightly reduced laxative effect might have been predicted (14, 29).

Studies have shown that transit time tends to decrease as daily fecal weight increases, but tends to change much less at fecal outputs >160–180 g/d (20). Beyond that point, no further significant decrease in transit time has been found (20, 23, 31, 32). In the present study, no differences were seen in transit time despite differences in daily fecal weight between the supplements, although a distinct trend was seen, suggesting a reduced transit time with the test supplement. This might have related to the relatively high mean fecal weights of our subjects (165 g/d) after consumption of the negative control supplement.

The present study suggests a significant tendency for the test supplement to lower the ratio of total to HDL cholesterol. In general, studies of wheat bran in the 1970s concluded that there was little or no effect on serum lipids (33, 34) and it was acceptable to use wheat bran as a lipid-neutral control fiber in studies aimed at determining the hypocholesterolemic effect of soluble-fiber diets. Nevertheless, one controlled metabolic study showed that hard red spring wheat bran may reduce serum cholesterol (35) and several other studies reported decreases in total or LDL cholesterol when wheat bran was fed (36–38).

It may be that higher plant protein and possibly lower fat intakes are required to allow the effect to be seen. In this regard, it appears that animal proteins tend to sustain or increase serum cholesterol whereas several plant proteins, including soy, wheat gluten (6–11), rice, and microbiological protein tend to decrease serum cholesterol (39, 40). The latest meta-analysis of studies in humans involving soy protein showed a 9.3% lowering of serum cholesterol for an average intake of 47 g soy protein or soy isolate (11). Although there are few human studies of vegetable protein

**TABLE 3**
Fasting serum concentrations of lipids and apolipoproteins (apo) and body weight at baseline and week 2 of supplement consumption[1]

| Lipid and other body variables | Negative control | | Positive control | | Test | |
|---|---|---|---|---|---|---|
| | Week 0 | Week 2 | Week 0 | Week 2 | Week 0 | Week 2 |
| Cholesterol (mmol/L) | | | | | | |
| Total | 4.78 ± 0.17 | 4.71 ± 0.17 | 4.71 ± 0.16 | 4.78 ± 0.19 | 4.86 ± 0.18 | 4.69 ± 0.18[2] |
| LDL | 3.29 ± 0.17 | 3.23 ± 0.17 | 3.22 ± 0.17 | 3.25 ± 0.19 | 3.37 ± 0.18 | 3.18 ± 0.19[2] |
| HDL | 1.23 ± 0.06 | 1.20 ± 0.06 | 1.21 ± 0.06 | 1.20 ± 0.06 | 1.21 ± 0.05 | 1.22 ± 0.05 |
| Triacylglycerols (mmol/L) | 1.32 ± 0.19 | 1.43 ± 0.23 | 1.41 ± 0.22 | 1.65 ± 0.26 | 1.43 ± 0.25 | 1.42 ± 0.26 |
| Apolipoproteins (g/L) | | | | | | |
| A-I | 1.57 ± 0.05 | 1.54 ± 0.04 | 1.54 ± 0.05 | 1.57 ± 0.04 | 1.57 ± 0.05 | 1.54 ± 0.04 |
| B | 1.05 ± 0.05 | 1.05 ± 0.06 | 1.02 ± 0.05 | 1.04 ± 0.06 | 1.06 ± 0.06 | 1.05 ± 0.06 |
| Ratios | | | | | | |
| Total to HDL cholesterol | 4.11 ± 0.25 | 4.17 ± 0.27 | 4.16 ± 0.29 | 4.24 ± 0.29 | 4.24 ± 0.28 | 4.04 ± 0.26[3] |
| LDL to HDL cholesterol | 2.86 ± 0.21 | 2.88 ± 0.23 | 2.88 ± 0.24 | 2.91 ± 0.23 | 2.96 ± 0.24 | 2.76 ± 0.23[3] |
| Apo B to Apo A-I | 0.69 ± 0.04 | 0.69 ± 0.04 | 0.68 ± 0.05 | 0.68 ± 0.04 | 0.69 ± 0.04 | 0.69 ± 0.05 |
| Body weight (kg) | 69.2 ± 3.0 | 69.2 ± 3.0 | 69.2 ± 3.0 | 69.5 ± 2.9 | 69.3 ± 2.9 | 69.3 ± 3.0 |

[1] $\bar{x}$ ± SEM; $n$ = 23.
[2] Change significantly different from that for the positive control, $P < 0.05$ (Student-Neuman-Keuls test). No significant effect of diet by ANCOVA.
[3] Change significantly different from that for the negative and positive controls, $P < 0.05$ (Student-Neuman-Keuls test).

sources other than soy, studies in rabbits have suggested that vegetable proteins in general (including gluten) produce less of an increase in serum cholesterol than do animal proteins (9) and are less atherogenic (8). Note, too, that when studies have shown a protective association of dietary fiber and cardiovascular disease it has been in those individuals eating diets higher in insoluble fiber that the strongest relations were found (41–43). However, even here the case has been argued that it is with soluble fiber that the strongest association would be expected and that additional diet and lifestyle habits may have contributed to the effect (43, 44).

We conclude that the test supplement, a new source of wheat fiber and protein for human consumption, has a laxative effect that is equivalent to or greater than that seen with standard wheat bran. In addition, it may have a favorable effect on serum lipids that requires confirmation by further studies. Other effects on colonic function of the fiber and protein in the test supplement, including changes in microflora and short-chain fatty acid production, may provide useful data about the metabolism of fiber in influencing fecal bulk and serum lipids (45).

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