Effect of Dietary Cereal Brans on Body Weight and Blood Lipids in a Long-Term Rat Experiment[1]

ROGER MONGEAU,[2] RENÉ BRASSARD,[2] STEPHEN MALCOLM,[3] and BHAGWAN G. SHAH[2]

ABSTRACT

Cereal Chem. 68(5):448–453

Male and female Sprague-Dawley rats were fed diets containing purified cellulose, oat bran, hard wheat bran, soft wheat bran, corn bran, or rodent lab chow at 4 or 14% total dietary fiber, and their growth and blood lipids were examined after 8 and 29 weeks. Rats from each group were killed during weeks 8 or 29, and tissues were collected. Diets had only a transient effect on body weight gain, and differences were not significant at week 29. Females had higher serum lipid levels than males at week 29. Cholesterol levels were higher in males fed soft rather than hard wheat bran. The oat bran diet (4% fiber) mostly induced lower levels of high-density lipoprotein cholesterol than did the wheat bran diets (14% fiber). In conclusion, cereal brans had no long-term effect on body weight, but each influenced total serum lipid levels and intestinal weights differently.

Dietary fiber is resistant to the digestive secretions in the upper gastrointestinal tract. It has been proposed that amounts of dietary fiber in the diet be increased to decrease energy density for the purpose of controlling body weight (Heaton 1980). Dietary fiber has been associated with energy dilution of the diet, with less overweight, and, for soluble fiber, with lower blood lipids. However, 70–80% of dietary fiber from a mixed diet is fermented in the colon, and energy is absorbed as short-chain fatty acids (McNeil et al 1978, Van Soest 1978, Cummings 1986). The amount of energy absorbed may depend on several factors, including the duration of feeding. Some of the reported effects of dietary fiber on body weight and appetite may be transient. Weight reduction in the human is a long-term process, and little is known about the effects of dietary fiber used over a long time (Ryttig et al 1989). Long-term controlled clinical studies testing the effects of different sources of fiber have been recommended (Health and Welfare Canada 1985), but human studies involve several problems including long-term adherence to a well-controlled diet.

We reported previously on the long-term effects of wheat, corn, and oat bran on the metabolism of calcium, phosphorus, magnesium, phytate, iron, zinc, copper, and manganese in male and female rats (Shah et al 1990, 1991).

The present report compares the effect of fiber-adjusted bran (wheat, corn, or oat) diets on ad libitum food intake, body weight, organ weights, and blood lipids after 8 and 29 weeks. The effects on intestinal function and fecal characteristics will be reported later.

[1]Bureau of Nutritional Sciences No. 350.

[2]Nutrition Research Division, Bureau of Nutritional Sciences, Food Directorate, Health Protection Branch, Health and Welfare Canada, Ottawa, ON K1A 0L2.
[3]Food Statistics and Operational Planning Division, Food Directorate, Health Protection Branch, Health and Welfare Canada.

MATERIALS AND METHODS

Animals

Seventy female and 70 male Sprague-Dawley rats (Crl;Cd-(SD)BR; Charles River Canada Inc., St. Constant, PQ), weighing 50 ± 5 g, were housed individually in wire-bottom stainless steel cages. Distilled water was provided ad libitum. Lights were on from 7 a.m. to 7 p.m. Room temperature was controlled at 22 ± 1°C and humidity at 45–55%. Females and males were randomly divided into seven groups and fed one of the seven diets (10 males and 10 females on each diet). Animals were distributed randomly into individual cages.

Diets

One group was fed a rat chow diet with a measured mean dietary fiber content of 15.7 g/100 g. This diet was Rodent Laboratory Chow 5001 (Purina Mills Inc., Richmond, IN), with an apparent metabolizable energy (physiological fuel) value of 3.30 kcal/g. The sources of fiber in the chow diet included ground extruded corn, soybean meal, ground oats, dried beet pulp, and wheat germ meal. The six other diets were purified diets containing the same amount of basal diet calculated on an energy basis but with different sources of total dietary fiber at the 4 or 14% level (Table I). Corn starch was added at the expense of the fiber source, taking into account the energy density of the diet. The purified diets were not isocaloric but were adjusted for fiber content (NRC 1978) assuming 3.8, 2.5, 1.4, and 1.0 kcal/g for oat bran, wheat bran, corn bran, and wood cellulose (Alphacel) (Lockhart et al 1980). Calculations used 4.1 kcal/g for casein and starch, and 4.0, 9.2, 4.0, and 0.5 kcal/g for sucrose, corn oil, AIN 76 vitamin mixture (ICN Nutritional Biochemicals Ltd., Cleveland, OH) (99.3% sucrose), and AIN 76 mineral mixture (ICN Nutritional Biochemicals) (12% sucrose). These calculations were based on the assumption that the food intake of the animal was regulated by the energy content of the diet.

Each 100-kcal portion of the purified diets contained 45 kcal (8.76 g) of basal diet (Table I). More details of the diets are provided elsewhere (Shah et al 1990). The actual total dietary fiber content of the purified diets was measured during weeks

TABLE I
Composition and Energy Density of Purified Diets

Parameter	CEL-4[a]	OAT-4	H-WHT-4	H-WHT-14	WHT-14	CORN-14
Proportion of kcal per 100 kcal of diet						
Basal diet	45	45	45	45	45	45
Starch	54	35	51	39	37	48
Fiber source	1	20	4	16	18	7
Energy density, kcal/g of diet	4.39	4.44	4.39	4.06	4.01	3.96
Dietary fiber content						
TDF, g/396.4 kcal[b]	4.0	4.3	4.4	14.0	14.2	13.8
SDF, g/396.4 kcal	0.7	2.1	0.8	1.5	1.4	1.1
IDF, g/396.4 kcal	3.3	2.2	3.6	12.5	12.8	12.7

[a] CEL-4, purified wood cellulose; OAT-4, oat bran; H-WHT-4, hard red wheat bran (providing 4% dietary fiber); H-WHT-14, hard red wheat bran; WHT-14, soft white wheat bran; CORN-14, corn bran (providing 14% dietary fiber).
[b] TDF = total dietary fiber; 396.4 kcal corresponds to 89.4–100 g of diet. SDF = soluble dietary fiber. IDF = insoluble dietary fiber.

7 and 24 (total of eight determinations), and the mean is indicated in Table I (dietary fiber content per 396.4 kcal; 396.4 is equivalent to 89.4–100.0 g of diet); these values include small amounts of dietary fiber from other diet ingredients such as starch. The purified cellulose was Alphacel (Teklad, Madison, WI). Mothers Oat Bran, Creamy High-Fiber Cereal, was obtained from the Quaker Oats Company, Barrington, IL. Hard red and soft white wheat brans were purchased locally, and the corn bran was obtained from Kellogg Salada Canada Inc., Rexdale, ON.

Protocol

The animals were fed their respective diets for up to 29 weeks. During week 7, half of the males and females (total 70) in each group were placed in Nalgene (Nalgene Co., Rochester, NY) metabolic cages for a five-day collection of feces and urine for a mineral balance trial (Shah et al 1990, 1991).

During week 8, the animals were killed by exsanguination while under anesthesia with pentobarbital (Somnotol, MTZ Pharmaceuticals, Mississauga, ON), intraperitoneal administration of 30 mg/kg body weight. The hearts, spleens, livers, muscles, and kidneys were excised, cleaned of obvious fat, weighed, and stored for mineral analysis. Blood was collected from the abdominal aorta and centrifuged; the resulting serum was stored at −70°C for lipid analysis. The entire gastrointestinal tract was removed and placed in ice-cold Ringer's solution. The stomach was opened with scissors, washed, patted dry, and weighed. The cecum was separated from the intestine and weighed with its contents. Small and large intestines were perfused with ice-cold Ringer's solution until all apparent food material (digesta) was removed. The intestine was patted dry and weighed. In some animals, the digesta from the distal ileum and pellets from the distal large intestine were collected and stored at −70°C for microscopic examination. The results of microscopic analysis will be reported elsewhere (Mongeau et al, *unpublished*). All nonintestinal tissues (i.e., diffused pancreatic tissue, fat) were carefully removed.

One animal died during week 17 following blood loss due to extensive epistaxis, and another was discarded during week 19 due to an ulcerative skin lesion. During week 24, the animals were placed in large metabolic cages for a second mineral balance trial. The 68 animals were sacrificed during week 29 as described for week 8.

Methods

Dietary fiber was analyzed by the method of Mongeau and Brassard (1986). Total lipid was measured by the method of Amenta (1970). Total cholesterol and HDL (high-density lipoprotein) cholesterol were measured using an Abbott bichromatic analyzer with A-Gent cholesterol and HDL test kits (Abbott Laboratories Ltd., Mississauga, ON).

Statistics

Data were analyzed separately for each variable using analysis of variance procedures, with the factors being time (weeks 1–6 and weeks 7–28), sex, and diet. Analysis of variance residuals were screened for outliers and for normality using the Shapiro-Wilk test (Shapiro and Wilk 1965). Data were analyzed on the original or logarithmic scale, or they were ranked, ignoring time, sex, and diet, and the ranks were analyzed, as deemed appropriate after screening analysis of variance residuals. Ranking was done to transform the data into numbers that more nearly fit the assumptions of the parametric model for the analysis of variance and to retain all of the ordinal information in the data (Conover and Iman 1976). Data were then tested for homogeneity of variance using Barlett's test (Snedecor and Cochran 1967). Pairwise comparisons for significant effects were made using t tests on least means in the Statistical Analysis System (SAS Institute 1987). Differences were not considered significant if the P values exceeded 0.01. Where several comparisons are summarized together and a single P value is reported, the P value is the maximum for all significant comparisons.

TABLE II
Food Consumption (g/day) Measured at Different Periods[a]

Diet[b]	Males[c] Weeks 1–6	Males[c] Weeks 7–28	Females Weeks 1–6	Females Weeks 7–28
CEL-4	17.5 (0.7)	22.0 (1.2)	13.1 (0.9)	14.4 (1.0)
OAT-4	17.3 (1.7)	21.0 (2.1)	12.9 (1.9)	14.2 (1.7)
H-WHT-4	17.2 (1.4)	19.9 (2.2)	13.5 (1.3)	15.7 (2.2)
H-WHT-14	17.3 (1.2)	21.9 (2.7)	13.0 (1.4)	16.2 (2.2)
WHT-14	17.5 (1.3)	23.0 (2.1)	12.3 (1.2)	14.4 (1.5)
CORN-14	18.5 (1.0)	21.6 (1.9)	14.2[d] (0.9)	15.9 (1.8)
CHOW[e]	21.9 (2.3)	27.0 (3.7)	15.3 (1.6)	18.0 (1.6)

[a] Mean (standard deviation) per rat; n = 10 for first period and n = 5 for second period.
[b] Described in Table I.
[c] Male higher than female, $P < 0.0001$.
[d] CORN-14 higher than WHT-14 in females during weeks 1–6, $P < 0.004$.
[e] CHOW higher than all diets in both sexes except CORN-14 in females during weeks 1–6, $P < 0.005$.

RESULTS AND DISCUSSION

The rats ate more CHOW than any other diet except for females fed CORN-14 (14% corn bran fiber) during weeks 1–6 ($P < 0.005$; Table II). Females on the CORN-14 diet ate more than those on the WHT-14 diet during weeks 1–6 ($P < 0.004$), but the difference was not significant during weeks 7–28.

Food intakes were generally reflected in the body weight gains (Table III). During weeks 1–6, males and females fed the OAT-4 (4% oat bran fiber) diet gained more weight than those fed the H-WHT-14 (14% hard wheat bran fiber), WHT-14 (14% soft wheat bran fiber), or CHOW diets ($P \leq 0.0004$). Animals fed the H-WHT-4 diet gained more weight than those on WHT-14 diet ($P < 0.008$). Thus, during weeks 1–6, rats fed the 4% fiber diets gained more weight than those on other diets, except CORN-

14. However, during weeks 7–28, the differences due to diet were not significant, probably because with age the rate of growth slowed. This is in agreement with the assumption that animals eat a sufficient amount of diet to satisfy their energy needs. If an adaptation occurred, it was not attributable to an increase in the extent of fiber fermentation, because the fermentability of bran fiber at the 14% fiber level in the diet did not increase and even tended to decrease from week 10 to week 27 (Mongeau et al, *unpublished*). The adaptation could be due to a better absorption and utilization of short-chain fatty acids produced by the intestinal microflora. The purified diets used here contained 10% fat. It is possible that the transient limiting effect of dietary fiber on weight gain would be more evident with diets containing less fat. It is noteworthy that the CHOW containing 4.5% fat tended to cause a lower body weight gain, particularly in females during weeks 7–28. The lower energy density of rat chow was largely compensated for by the increased food intake (Table II), in agreement with the general thought that rodents adjust their food intake so that the number of calories consumed remains constant. However, this may be true only within certain ranges of fat and/or fiber contents. Sprague-Dawley rats fed 20%-fat diets consumed more energy than animals fed 5%-fat diets (Nauss et al 1987). The present results (Table III) showed that the long-term feeding of different sources and levels of bran fiber in Sprague-Dawley rats resulted in similar growth rates.

Dietary fiber has the ability to reduce the energy density of food, but the effect on body weight in human adults appears to be dependent, among other things, on the degree of restriction. Nevertheless, eating ad libitum food supplemented with psyllium gum may result in sustained small decreases in energy intake (Stevens et al 1987). Madar and Odes (1990) summarized the possible mechanisms by which dietary fiber may influence body weight.

The partial digestible energy value is the change in energy value of the diet per gram of increase in unavailable carbohydrate intake. Using published data, Livesey (1990) calculated a negative value of −3.8 kcal/g of fiber for oat bran diets in human subjects, a positive value of 1.4 kcal/g of fiber for wheat bran diets (species not indicated), and 0 kcal/g of wood cellulose for cellulose diets fed to human subjects or to rats. These values suggest that, with the same fiber level in the diet, the OAT-4 diet should have provided less energy than the H-WHT-4 diet. The partial digestible energy values of the diets were not calculated in the present study. However, the body weight gain and food efficiency ratio of the animals fed the OAT-4 diet were not significantly different from those of the animals fed the H-WHT-4 diet (Tables III and IV). In males, a trend to a larger body weight gain with the OAT-4 diet than with the H-WHT-4 diet was rather contradictory to the view (Livesey 1990) that an oat bran diet has a lower energy value than a hard wheat bran diet.

Food conversion efficiency (FCE) (g of food intake/g of weight gain) was obviously better for males than for females (Table IV). The lower the FCE, the less the amount of food needed to obtain a given body weight. In other words, a low FCE value means a diet with high efficiency. FCE for males and females on CHOW was higher than that on all other diets except for females on WHT-14 during weeks 7–28 ($P < 0.009$). For the purified diets, FCE was generally lower for diets with 4% fiber than for those at the 14% level. For both sexes during weeks 1–6, FCE for OAT-4 was lower than that for all the bran diets at the 14% fiber level ($P < 0.0001$). In males, the FCE for OAT-4 was also lower than that for H-WHT-4 ($P < 0.003$) and CEL-4 ($P < 0.0001$) diets. During weeks 7–28, FCE was the same for all purified diets, but males fed OAT-4 had lower FCE than those fed WHT-14 ($P < 0.01$). The weight gains during weeks 7–28 indicate that higher fiber intakes did not necessarily increase FCE in the long term. For example, during weeks 1–6 FCE of the CEL-4 group was slightly but significantly ($P < 0.008$) lower than that of H-WHT-14 and CORN-14 groups, but it tended to be higher during weeks 7–28. Another example is the two H-WHT groups, which showed similar FCE at the 4 and 14% levels of fiber in the diet (Table IV). The sustained lower FCE for the OAT-4 diet may be due to the high fermentability of oat bran fiber (>70%; Mongeau et al, *unpublished*).

The males and females killed at week 29 had higher total serum lipid levels than those killed at week 8 for CEL-4, OAT-4, WHT-14 and CHOW diets ($P < 0.001$) (Table V). Results for males and females did not differ at week 8, but females had higher

TABLE III
Body Weight Gain (g) Measured at Different Periods[a]

Diet[b]	Males[c] Weeks 1–6	Males[c] Weeks 7–28	Females Weeks 1–6	Females Weeks 7–28
CEL-4	315 (17)	334 (97)	171 (16)	125 (14)
OAT-4[d]	339 (29)	370 (49)	183 (38)	148 (41)
H-WHT-4[e]	318 (31)	308 (66)	179 (25)	155 (64)
H-WHT-14	298 (24)	329 (59)	158 (23)	150 (54)
WHT-14	305 (25)	333 (61)	149 (22)	131 (49)
CORN-14	314 (18)	317 (48)	173 (12)	140 (55)
CHOW	309 (33)	292 (75)	154 (26)	107 (27)

[a] Mean (standard deviation); $n = 10$ for weeks 1–6 and $n = 5$ for weeks 7–28.
[b] Described in Table I.
[c] Male higher than female, $P < 0.0001$.
[d] OAT-4 higher than H-WHT-14, WHT-14, and CHOW during weeks 1–6, $P \leq 0.0004$.
[e] H-WHT-4 higher than WHT-14 in both sexes during weeks 1–6, $P < 0.008$.

TABLE IV
Food Conversion Efficiency Measured at Different Periods[a]
(g food intake/g weight gain)

Diet[b]	Males Weeks 1–6	Males Weeks 7–28	Females Weeks 1–6	Females Weeks 7–28
CEL-4	2.3[c] (0.1)	11.0 (3.7)	3.1[d] (0.2)	17.9 (1.3)
OAT-4	2.1[e] (0.1)	8.8[f] (0.5)	2.9[g] (0.2)	15.4 (2.9)
H-WHT-4	2.2 (0.1)	10.2 (1.3)	3.1 (0.2)	17.1 (4.5)
H-WHT-14	2.4 (0.1)	10.4 (0.9)	3.4 (0.2)	18.4 (6.6)
WHT-14	2.4 (0.1)	10.8 (1.4)	3.4 (0.2)	18.5 (5.7)
CORN-14	2.4 (0.1)	10.5 (0.7)	3.4 (0.2)	21.4 (12.5)
CHOW[h]	2.9 (0.1)	14.6 (1.7)	4.1 (0.4)	27.2 (7.5)

[a] Mean (standard deviation); $n = 10$ for weeks 1–6 and $n = 5$ for weeks 7–28.
[b] Described in Table I.
[c] CEL-4 lower than all diets, $P < 0.007$.
[d] CEL-4 lower than WHT-14 and CHOW in female, $P < 0.009$.
[e] OAT-4 lower than all diets in male, $P < 0.003$.
[f] OAT-4 lower than WHT-14 in male, $P < 0.01$.
[g] OAT-4 lower than all diets in female except CEL-4 and H-WHT-4, $P < 0.0001$.
[h] CHOW higher than all diets in both sexes except WHT-14 in females for weeks 7–28, $P < 0.009$.

TABLE V
Total Serum Lipids Measured at Different Periods[a]
(mg/100 ml)

Diet[b]	Males[c] Week 8	Males[c] Week 29	Females Week 8	Females Week 29
CEL-4[d,e]	499 (62)	746 (144)	425 (114)	870 (93)
OAT-4[d]	444 (77)	623 (116)	645 (341)	945 (244)
H-WHT-4[b]	551 (48)	630 (125)	652 (164)	900 (331)
H-WHT-14[f]	565 (146)	522 (67)	518 (117)	817 (306)
WHT-14[d]	527 (163)	632 (94)	437 (110)	887 (505)
CORN-14	471 (93)	572 (40)	517 (119)	588 (176)
CHOW[d,g]	352 (79)	438 (95)	353 (101)	801 (183)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Male lower than female for week 29, $P < 0.0001$.
[d] Week 29 higher than week 8, $P < 0.001$.
[e] CEL-4 higher than CORN-14 and CHOW in week 29, $P < 0.003$.
[f] H-WHT-4 higher than CEL-4 and WHT-14 in week 8, $P < 0.008$.
[g] CHOW lower than OAT-4, H-WHT-4, H-WHT-14, and CORN-14 in week 8, $P < 0.009$.

serum lipid levels than males at week 29 ($P < 0.0001$). In week 8, the CHOW group had lower serum lipid levels than the OAT-4, H-WHT-4, H-WHT-14, and CORN-14 groups ($P < 0.009$), and the H-WHT-4 group had higher serum lipid levels than the CEL-4 and WHT-14 groups ($P < 0.008$). In week 29, the CEL-4 group had higher serum lipid levels than the CORN-14 and CHOW groups ($P < 0.003$). Cellulose was reported to increase triglyceride levels in rats (Mueller et al 1983). The serum lipid levels were among the lowest in OAT-4 fed males during week 8 but were among the highest in females in both weeks 8 and 29 (Table V). The effect of CHOW diet on serum lipids was not as persistent in females as in males but the level remained significantly lower than in the CEL-4 group in week 29 for males and females ($P < 0.003$).

The data analyzed on the logarithmic scale showed that the total cholesterol level was higher at 29 weeks than at 8 weeks ($P = 0.007$) (Table VI). In males fed the soft wheat bran diet (WHT-14), the total serum cholesterol level was higher than that in those fed OAT-4, H-WHT-14, and CORN-14 diets ($P < 0.008$). Thus the soft wheat bran diet was associated with higher cholesterol levels than the hard wheat bran diet in males for weeks 8 and 29. In human subjects, only the hard red spring wheat bran has been reported to lower serum cholesterol (Munoz et al 1979). The OAT-4 diet was associated with a lower cholesterol level than the CEL-4 ($P = 0.009$) and the WHT-14 ($P < 0.0001$) diets in male rats (Table VI), in agreement with the recognized cholesterol-lowering effect of dietary oat bran in human subjects. The CHOW diet was associated with a clearly lower cholesterol level than all other diets except WHT-14 in females ($P < 0.008$). The CHOW diet was not a purified diet, and its energy density was lower than for the six purified diets. Its lower total fat content may explain the lower blood lipid levels. On the other hand, the highest fecal fat excretion of CHOW-fed rats (Mongeau et al, *unpublished*) suggested that the nature of diet components (e.g. fat, carbohydrate, protein, and dietary fiber) and the complexity of the mixture in which they are eaten are as important as their dietary level.

CHOW-fed rats had lower serum levels than all other groups for the HDL fraction ($P = 0.007$; Table VII). For both sexes, the OAT-4 diet was associated with lower HDL levels than several diets ($P < 0.007$) including the 4% fiber hard wheat bran diet (H-WHT-4) for males ($P = 0.0002$). The metabolism of cholesterol in Sprague-Dawley rats is more closely controlled than in humans, and results may not apply to the human situation. Nevertheless, a 20% decrease in HDL cholesterol was reported in human subjects fed oat bran (Anderson et al 1984). In males, the CORN-14 diet was associated with lower HDL levels than the H-WHT-4 and the WHT-14 diets ($P < 0.008$).

Asp et al (1983) reported that wheat bran fiber at 5 and 10% in the diet gradually increased total and HDL cholesterol in male Sprague-Dawley rats fed a diet containing 20% fat for six months. This was not supported by the present results for hard wheat bran groups, where serum total and HDL cholesterol were no higher in the H-WHT-14 group than in the H-WHT-4 group after 8 or 28 weeks on diets containing 10% corn oil (Tables VI and VII). In females, there was a trend toward higher HDL values at the 14% wheat bran fiber level, but the difference was not significant. In males, however, the WHT-14 diet was associated with higher total and HDL cholesterol levels than the OAT-4 and CORN-14 diets ($P < 0.008$). The H-WHT-4 and H-WHT-14 diets were also associated with higher HDL levels than the OAT-4 diet ($P < 0.004$). Thus, the present results provide evidence of increased total and HDL cholesterol in rats fed soft wheat bran fiber compared with those fed the oat or corn bran fiber diets, but the effect of hard wheat bran appeared to be specific to the HDL fraction. A fiber-free diet was not included in the present study because there may be more difference between the 0 and the 2% wheat bran fiber diets than between the 2 and 10% wheat bran fiber diets in regard to some physiological parameters (Mongeau et al 1986). The effects of dietary fiber on blood lipid levels are generally associated with its water-soluble fraction. In the present work, the OAT-4 diet with 49% of its fiber present as soluble fiber, was the only purified diet with soluble fiber representing more than 18% of total dietary fiber. Except for the oat bran group, the effects of dietary fiber should be largely attributable to the insoluble fraction (Table I).

The heart and femur represented a larger proportion of body weight in females than in males over the 29 weeks (61 vs. 48, and 142 vs. 117 mg dry weight/100 g of body weight, respectively; $P < 0.001$). These tissues had a higher concentration of iron (heart and femur), zinc (femur), and copper (heart) in females than in males (Shah et al 1991). No diet effect was found on the weight of these tissues.

The gastrointestinal tract sections represented a larger portion of the body weight in females than males ($P < 0.0001$) (Tables VIII–XI). The H-WHT-4 diet was associated with a significantly higher fresh weight of washed stomach compared with OAT-4 ($P = 0.0001$), indicating that these sources of cereal fiber had different effects on the stomach even at the 4% level in the diet (Table VIII). The weight of the stomach was generally higher at the 14% fiber level than at the 4% level (Table VIII). It is not known if an increased stomach weight is related to the delaying effect of dietary fiber on gastric emptying (Dubois 1985).

There was no diet effect on the weight of the small intestine at week 8 (Table IX). At week 29, the small intestine weight of animals fed the H-WHT-4, H-WHT-14, and WHT-14 diets was higher than for those fed the CEL-4 diet ($P < 0.008$). Those fed the WHT-14 diet also had a higher small intestine weight than those fed the CORN-14 diet ($P < 0.002$). CHOW-fed rats had a higher small intestine weight than those fed the CEL-4,

TABLE VI
Serum Cholesterol Measured at Different Periods[a] (mg/100 ml)

Diet[b]	Males Week 8	Males Week 29[c]	Females Week 8	Females Week 29[c]
CEL-4	146 (35)	197 (61)	135 (61)	190 (45)
OAT-4[d]	114 (17)	149 (16)	149 (52)	174 (55)
H-WHT-4	152 (12)	167 (28)	153 (34)	215 (65)
H-WHT-14	149 (28)	152 (24)	154 (33)	185 (53)
WHT-14[e]	206 (95)	197 (50)	128 (22)	183 (58)
CORN-14	130 (20)	139 (14)	171 (83)	164 (11)
CHOW[f]	66 (6)	83 (5)	101 (45)	120 (14)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Week 29 higher than week 8, $P = 0.007$.
[d] OAT-4 lower than CEL-4, $P = 0.009$, and than WHT-14, $P < 0.0001$, in males.
[e] WHT-14 higher than all other diets in males except CEL-4 and H-WHT-4, $P < 0.008$.
[f] CHOW lower than all other diets in males, $P < 0.0001$, and in females except WHT-14, $P < 0.008$.

TABLE VII
Serum High-Density Lipoprotein Cholesterol Measured at Different Periods[a] (mg/100 ml)

Diet[b]	Males Week 8	Males Week 29[c]	Females Week 8	Females Week 29[c]
CEL-4	69.5 (9.0)	67.2 (28.4)	57.0 (12.2)	66.0 (6.2)
OAT-4[d]	54.7 (9.0)	64.1 (6.7)	57.3 (11.3)	54.3 (8.6)
H-WHT-4	73.4 (10.6)	80.5 (8.8)	59.5 (3.8)	71.5 (13.1)
H-WHT-14	68.5 (10.0)	76.8 (8.2)	68.2 (14.2)	78.0 (20.5)
WHT-14	72.6 (12.9)	80.8 (13.5)	58.8 (9.9)	79.2 (15.1)
CORN-14[e]	51.4 (6.6)	75.1 (16.3)	56.9 (7.0)	69.8 (9.4)
CHOW[f]	28.6 (7.5)	36.4 (3.4)	42.3 (5.6)	43.7 (4.5)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Week 29 higher than week 8, $P = 0.001$.
[d] OAT-4 lower than CEL-4, H-WHT-4, H-WHT-14, and WHT-14 in males, $P < 0.004$, and than H-WHT-14 and WHT-14 in females, $P < 0.007$.
[e] CORN-14 lower than H-WHT-4 and WHT-14 in males, $P < 0.008$.
[f] CHOW-14 lower than all diets, $P < 0.007$.

OAT-4, and CORN-14 diets ($P < 0.002$). In rats, viscous polysaccharides increase intestinal weight (Brown et al 1979, Jacobs 1983), but insoluble fiber is reported to have little effect on intestinal weight (Fisher 1957, Jacobs and White 1983). The similarity in small intestine weights of the H-WHT-4 and H-WHT-14 groups (Table IX) is in agreement with this observation. The higher small intestine weight of wheat bran-fed animals compared with those fed the wood cellulose diet after 29 weeks indicated a different effect of wheat bran even at the 4% fiber level. The effect of corn bran at the 14% fiber level was not different from that of cellulose. Further work is needed to identify more specific changes in the small intestine, such as distal versus proximal sections, the turnover and length of the villus, and/or the number of the mucus-secreting goblet cells in different sections (Edwards and Read 1989). Intestinal length is also an interesting measure of absorption surface, but a concomitant change in the intestinal resistance to stretch may confuse this measurement.

The cecum had thinner walls than the other parts of the intestine, and it was weighed with its contents to better take into account the difference in size observed between groups (Table X). The CHOW diet was associated with large cecums with higher weights than all other diets ($P < 0.0001$). The CEL-4 and H-WHT-4 diets had lower cecal weights than the H-WHT-14 and WHT-14 diets. The amount of total dietary fiber fermented was correlated ($P < 0.05$) with cecal weight ($r = 0.83$ for males and 0.82 for females, $n =$ seven diets). It is noteworthy that the highly fermentable oat bran fiber at the 4% level induced higher cecal weight than the H-WHT-4 diet ($P < 0.002$) and that the unfermentable corn bran fiber at 14% induced lower cecal weight than the H-WHT-14 diet ($P < 0.01$, Table X). Wheat bran fiber has a moderate fermentability (Mongeau et al, *unpublished*). The fermentability of dietary fiber in CHOW was also moderate, but the higher food intake of this group (Table II) resulted in larger amounts of fermentable fiber in the cecum. In addition, their limited weight gain (Table III) enhanced the cecum weight relative to total body weight.

The weight of the large intestine was recorded only during week 8. Table XI shows that the fresh weight of the large intestine was lower in the diets supplied at the 4% dietary fiber level than in the other diets. These other diets were associated with larger fecal volumes and luminal diameters that affected intestinal weights (Mongeau et al 1990, and *unpublished*).

The effect of energy dilution by cereal bran fiber was most evident in the weight gain after 8 weeks, but this effect was transient and was no more significant after 29 weeks. This indicates that the purified diets were adequately adjusted for the long-term maintenance of body weight (Table III). The changes observed in stomach and lower gut of animals fed the 14% bran fiber diets suggest that a morphological adaptation occurred for absorbing more energy and nutrients, but the weight and specific changes (e.g., mucus production) of gastrointestinal organs have not been related in the literature.

In summary, the effects of the CHOW diet on food efficiency, blood lipids including HDL cholesterol, size of cecum, and weight of large intestine were not comparable to those of purified diets containing low or high bran fiber levels. During the 7–28 week period, bran fibers at 4 or 14% total dietary fiber in the purified diets did not affect growth negatively compared with the 4% cellulose diet. In males, the soft wheat bran diet was associated with the highest serum total cholesterol level, which was significantly higher than that of the oat, hard wheat (14% fiber), and corn bran groups. However, the soft and hard wheat bran diets were associated with the highest HDL values, which were generally higher than those of the oat bran group. The weight

TABLE VIII
Weight of Washed Stomach Measured at Different Periods[a] (g/100 g of body weight)

Diet[b]	Males		Females[c]	
	Week 8[d]	Week 29	Week 8	Week 29
CEL-4	0.40 (0.02)	0.32 (0.05)	0.48 (0.02)	0.46 (0.04)
OAT-4	0.37 (0.03)	0.29 (0.02)	0.46 (0.04)	0.43 (0.04)
H-WHT-4[e]	0.39 (0.04)	0.34 (0.03)	0.53 (0.04)	0.50 (0.07)
H-WHT-14[f]	0.47 (0.04)	0.36 (0.03)	0.56 (0.03)	0.53 (0.06)
WHT-14[f]	0.45 (0.04)	0.36 (0.04)	0.59 (0.05)	0.55 (0.05)
CORN-14[f]	0.43 (0.05)	0.34 (0.02)	0.54 (0.02)	0.50 (0.09)
CHOW[f]	0.43 (0.04)	0.40 (0.03)	0.58 (0.06)	0.57 (0.10)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Female higher than male, $P < 0.0001$.
[d] Week 8 higher than week 29 in males, $P < 0.0001$.
[e] H-WHT-4 higher than OAT-4, $P = 0.0001$.
[f] Higher than CEL-4, OAT-4 and H-WHT-4 diets ($P < 0.005$) except that CORN-14 and H-WHT-4 were not different.

TABLE IX
Weight of Washed Small Intestine Measured at Different Periods[a] (g/100 g of body weight)

Diet[b]	Males		Females[c]	
	Week 8[d]	Week 29	Week 8[d]	Week 29
CEL-4	2.43 (0.27)	1.26 (0.17)	2.76 (0.27)	1.86 (0.31)
OAT-4	2.40 (0.16)	1.52 (0.24)	3.19 (0.48)	1.92 (0.19)
H-WHT-4[e]	2.26 (0.32)	1.62 (0.24)	2.85 (0.38)	2.03 (0.31)
H-WHT-14[e]	2.37 (0.17)	1.45 (0.18)	2.91 (0.21)	2.18 (0.19)
WHT-14[e,f]	2.34 (0.22)	1.67 (0.26)	2.93 (0.23)	2.15 (0.37)
CORN-14	2.37 (0.14)	1.30 (0.32)	2.98 (0.49)	1.87 (0.34)
CHOW[g]	2.65 (0.20)	1.66 (0.26)	3.16 (0.37)	2.52 (0.14)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Female higher than male, $P < 0.0001$.
[d] Week 8 higher than week 29, $P < 0.0001$.
[e] H-WHT-4, H-WHT-14, and WHT-14 higher than CEL-4 in week 29, $P < 0.008$.
[f] WHT-14 higher than CORN-14 in week 29, $P < 0.002$.
[g] CHOW higher than CEL-4, OAT-4, and CORN-14 in week 29, $P < 0.002$.

TABLE X
Weight of Cecum Measured at Different Periods[a] (g/100 g of body weight)

Diet[b]	Male		Females[c]	
	Week 8[d]	Week 29	Week 8[d]	Week 29
CEL-4[e]	0.84 (0.09)	0.54 (0.09)	1.02 (0.23)	0.86 (0.17)
OAT-4	0.92 (0.14)	0.62 (0.16)	1.22 (0.09)	0.87 (0.20)
H-WHT-4[f]	0.74 (0.16)	0.52 (0.10)	0.92 (0.15)	0.79 (0.26)
H-WHT-14	1.05 (0.16)	0.75 (0.18)	1.27 (0.31)	1.16 (0.25)
WHT-14	1.06 (0.21)	0.72 (0.07)	1.35 (0.33)	0.98 (0.22)
CORN-14[g]	0.85 (0.18)	0.69 (0.09)	1.00 (0.12)	0.97 (0.19)
CHOW[h]	2.00 (0.09)	1.37 (0.34)	2.29 (0.44)	1.88 (0.34)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Female higher than male in the same period, $P < 0.0001$.
[d] Week 8 higher than week 29, $P < 0.0001$.
[e] CEL-4 lower than WHT-14 and H-WHT-14, $P < 0.0005$.
[f] H-WHT-4 lower than all other diets except CEL-4, $P < 0.005$.
[g] CORN-14 lower than H-WHT-14, $P < 0.01$.
[h] CHOW higher than all other diets, $P < 0.0001$.

TABLE XI
Weight of Washed Large Intestine Measured at Week 8[a] (g/100 g of body weight)

Diet[b]	Males	Females[c]
CEL-4[d]	0.37 (0.03)	0.47 (0.05)
OAT-4[d]	0.39 (0.06)	0.51 (0.06)
H-WHT-4[d]	0.39 (0.13)	0.47 (0.10)
H-WHT-14	0.48 (0.09)	0.60 (0.09)
WHT-14	0.52 (0.05)	0.63 (0.07)
CORN-14	0.50 (0.03)	0.61 (0.03)
CHOW[e]	0.66 (0.03)	0.87 (0.06)

[a] Mean (standard deviation); $n = 5$.
[b] Described in Table I.
[c] Female higher than male, $P < 0.0001$.
[d] CEL-4, OAT-4, and H-WHT-4 lower than all other diets, $P < 0.003$.
[e] CHOW higher than all other diets, $P < 0.0001$.

of the stomach of animals fed the 4% and 14% hard wheat bran fiber diets was higher than that of the oat bran group. The weight of the small intestine of animals fed the wheat bran diets was higher than that of the cellulose group in week 29. The weight of the large intestine was proportional to the level of fiber in the diet.

These results substantiate that cereal brans produce different effects because they contain different levels of dietary fiber and because of the different nature of their fiber. Swain et al (1990) concluded from the results of a human study that "oat bran has little cholesterol-lowering effect and that high-fiber and low-fiber dietary grain (wheat) supplements reduce serum cholesterol levels about equally, probably because they replace dietary fats." Another recent human study by Anderson et al (1990) concluded that an oat bran cereal diet lowered serum total and low-density lipoprotein cholesterol in hypercholesterolemic men (vs. a corn flakes control diet). Keeping in mind that the Sprague-Dawley rat is not a good model for studying cholesterol metabolism in man, it is worth mentioning that, in the present study, the serum total cholesterol was significantly lower in the male rats fed the oat bran diet (23% bran and 4% fiber) than in those fed the soft wheat bran diet (28% bran and 14% fiber), whereas the mean daily intakes for corn oil and bran fat during weeks 7–28 were 2.35 g and 0.31 g, and 2.33 g and 0.08 g, respectively. These results indicate that, compared to soft wheat bran, oat bran has a cholesterol-lowering effect that is independent of the nature and amount of the fat ingested by male rats.

ACKNOWLEDGMENTS

The competent technical assistance of C. Desloges of the Animal Resources Division is gratefully acknowledged. We also thank Andrew Armstrong from the Food Statistics and Operational Planning Division for help in conducting the statistical analysis of the data.

LITERATURE CITED

AMENTA, J. S. 1970. A rapid extraction and quantification of total lipids and lipid fractions in blood and feces. Clin. Chem. 16:339-346.

ANDERSON, J. W., STORY, L., SIELING, B., and CHEN, W. J. L. 1984. Hypocholesterolemic effects of high-fibre diets rich in water-soluble plant fibres J. Can. Diet. Assoc. 45:140-149.

ANDERSON, J. W., SPENCER, D. B., HAMILTON, C. C., SMITH, S. F., TIETYEN, J., BRYANT, C. A., and OELTGEN, P. 1990. Oat-bran cereal lowers serum total and LDL cholesterol in hypercholesterolemic men. Am. J. Clin. Nutr. 52:495-499.

ASP, N.-G., BAUER, H. G., NILSSON-EHLE, P., and ÖSTE, R. 1983. Pectins and guar gum; effect on plasma lipoproteins and lipoprotein lipase activity in rats. Pages 93-104 in: Unconventional Sources of Dietary Fiber. I. Furda, ed. American Chemical Society: Washington, D.C.

BROWN, R. C., KELLEHER, J., and LOSOWSKY, M. S. 1979. The effect of pectin on the structure and function of the rat small intestine. Br. J. Nutr. 42:357-365.

CONOVER, W. J., and IMAN, R. L. 1976. On some alternative procedures using ranks for the analysis of experimental designs. Communications in Statistics—Theory and Methods. A5:1349.

CUMMINGS, J. H. 1986. The effect of dietary fiber on fecal weight and composition. Pages 211-280 in: Handbook of Dietary Fiber in Human Nutrition. G. A. Spiller, ed. CRC Press: Boca Raton, FL.

DUBOIS, A. 1985. Diet and gastric digestion. Am. J. Clin. Nutr. 42:1003-1005.

EDWARDS, C. A., and READ, N. W. 1989. Fibre and small intestinal function. Pages 52-75 in: Dietary Fibre Perspectives, Reviews and Bibliography 2. A. R. Leeds, ed. John Libbey: London.

ENGLYST, H., WIGGINS, H. S., and CUMMINGS, J. H. 1982. Determination of the non-starch polysaccharides in plant foods by gas-liquid chromatography of constituent sugars as alditol acetates. Analyst 107: 307-318.

FISHER, J. E. 1957. Effects of feeding diets containing lactose, agar, cellulose, raw potato starch, or arabinose on the dry weight of cleaned gastrointestinal tract organs in the rat. Am. J. Physiol. 188:550-555.

HEALTH AND WELFARE CANADA. 1985. Report of the Expert Advisory Committee on Dietary Fibre. Health and Welfare Canada: Ottawa.

HEATON, K. W. 1980. Food intake regulation and fiber. Pages 223-238 in: Medical Aspects of Dietary Fiber. G.A. Spiller and R.M. Kay, eds. Plenum Medical: New York.

JACOBS, L. R. 1983. Effects of dietary fiber on mucosal growth and cell proliferation in the small intestine of the rat: A comparison of oat bran, pectin and guar with total fiber deprivation. Am. J. Clin. Nutr. 37:954-960.

JACOBS, L. R., and WHITE, F. A. 1983. Modulation of mucosal cell proliferation in the intestine of rats fed a wheat bran diet. Am. J. Clin. Nutr. 37:945-953.

LIVESEY, G. 1990. The effects of α-amylase-resistant carbohydrates on energy utilization and deposition in man and rat. Pages 207-218 in: Dietary Fiber: Chemistry, Physiology, and Health Effects. D. Kritchevsky, C. Bonfield, and J. W. Anderson, eds. Plenum Press: New York.

LOCKHART, H. B., LEE, H. S., O'MAHONY, S. P., HENSLEY, G. W., and HOULIHAN, E. J. 1980. Caloric value of fiber-containing cereal fractions and breakfast cereals. J. Food Sci. 45: 372-374.

MADAR, Z., and ODES, H. S. 1990. Dietary fiber in metabolic diseases. In: Dietary Fiber Research. R. Paoletti, ed. Karger: Basel.

McNEIL, N. I., CUMMINGS, J. H., and JAMES, W. P. 1978. Short-chain fatty acid absorption by the human large intestine. Gut 19:819-822.

MONGEAU, R., and BRASSARD, R. 1986. A rapid method for the determination of soluble and insoluble dietary fiber: comparison with AOAC total dietary fiber procedure and Englyst's method. J. Food Sci. 51: 1333-1336.

MONGEAU, R., BEHRENS, W. A., MADERE, R., and BRASSARD, R. 1986. Effect of dietary fiber on vitamin E status in rats: Dose-response to wheat bran. Nutr. Res. 6:215-224.

MONGEAU, R., SIDDIQUI, I. R., EMERY, J., and BRASSARD, R. 1990. Effect of dietary fiber concentrated from celery, parsnip, and rutabaga on intestinal function, serum cholesterol, and blood glucose response in rats. J. Agric. Food Chem. 38: 195-200.

MUELLER, M. A., CLEARY, M. P., and KRITCHEVSKY, D. 1983. Influence of dietary fiber on lipid metabolism in meal-fed rats. J. Nutr. 113:2229-2238.

MUNOZ, J. M., SANDSTEAD, H. H., JACOB, R. A., LOGAN, G.M., JR., RECK, S. J., KLEVAY, L. M., DINTZIS, F. R., INGLETT, G. E., SHUEY, W. C. 1979. Effects of some cereal brans and textured vegetable protein on plasma lipids. Am. J. Clin. Nutr. 32:580-592.

NATIONAL RESEARCH COUNCIL. 1978. Control of Diets in Laboratory Animal Experimentation. A Report of the Committee on Laboratory Animal Diets. Institute of Laboratory Animal Resources, Assembly of Life Sciences: Washington, DC.

NAUSS, K. M., JACOBS, L. R., and NEWBERNE, P. M. 1987. Dietary fat and fiber: Relationship to caloric intake, body growth, and colon tumorigenesis. Am. J. Clin. Nutr. 45: 243-251.

RYTTIG, K. R., LEEDS, A. R., and RÖSSNER, S. 1989. Dietary fiber in the management of overweight—An update. Pages 87-99 in: Dietary Fibre Perspectives, Review and Bibliography, 2. A. R. Leeds, ed. John Libbey: London.

SAS INSTITUTE. 1987. SAS/STAT Guide for Personal Computers, Version 6 Edition. The Institute: Cary, NC.

SHAH, B. G., BELONJE, B., MALCOLM, S., TRICK, K. D., BRASSARD, R., and MONGEAU, R. 1990. Effect of dietary cereal brans on the metabolism of calcium, phosphorus and magnesium in a long term rat study. Nutr. Res. 10:1015-1028.

SHAH, B. G., MALCOLM, S., BELONJE, B., TRICK, K. D., BRASSARD, R., and MONGEAU, R. 1991. Effect of dietary cereal brans on the metabolism of trace elements in a long-term rat study. Cereal Chem. 68:190-194.

SHAPIRO, S. S., and WILK, M. B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52: 591.

SNEDECOR, G. W., and COCHRAN, W. G. 1967. Page 153 in: Statistical Methods, 6th ed. Iowa State University Press: Ames, IA.

STEVENS, J., LEVITSKY, D. A., VAN SOEST, P. J., ROBERTSON, J. B., KALKWORF, H. J., ROE, D. A. 1987. Effect of psyllium gum and wheat bran on spontaneous energy intake. Am. J. Clin. Nutr. 46:812-817.

SWAIN, J. R., ROUSE, I. L., CURLEY, C. B., SACKS, F. M. 1990. Comparison of the effects of oat bran and low-fiber wheat on serum lipoprotein levels and blood pressure. N. Engl. J. Med. 322:147-152.

VAN SOEST, P. J. 1978. Dietary fibers: Their definition and nutritional properties. Am. J. Clin. Nutr. 31: S12-S20.

[Received October 15, 1990. Accepted April 8, 1991.]