Cholesterol-lowering effect of β-glucan from oat bran in mildly hypercholesterolemic subjects may decrease when β-glucan is incorporated into bread and cookies[1–3]

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ABSTRACT

Background: Findings about the effects of β-glucan on serum lipoproteins are conflicting.

Objective: The study investigated the effects of β-glucan from oat bran in bread and cookies (study 1) and in orange juice (study 2) on serum lipoproteins in mildly hypercholesterolemic subjects.

Design: In study 1, 48 subjects (21 men, 27 women) received for 3 wk control bread and cookies rich in wheat fiber. For the next 4 wk, by random assignment, 23 subjects continued to consume the control products, and 25 received bread and cookies rich in β-glucan. Mean daily intake of β-glucan was 5.9 g. Total dietary fiber intake did not differ significantly between the groups. In study 2, the same sources of control fiber and β-glucan (5 g/d) as in study 1 were provided. For 2 wk, 25 of the original 48 subjects (10 men, 15 women) were randomly assigned to consume orange juice containing either wheat fiber (n = 13) or β-glucan from oat bran (n = 12). After a washout period of 1 wk, dietary regimens were crossed over.

Results: In study 1, the change in LDL cholesterol did not differ significantly (−0.12 mmol/L; P = 0.173) between the 2 groups. In study 2, the drink rich in β-glucan decreased LDL cholesterol by 0.26 ± 0.07 mmol/L (6.7 ± 1.8%; P = 0.001) and the ratio of total to HDL cholesterol by 0.26 ± 0.11 (5.4 ± 2.1%; P = 0.029) compared with the other drink. HDL-cholesterol and triacylglycerol concentrations did not change significantly.

Conclusions: The food matrix or the food processing, or both, could have adverse effects on the hypocholesterolemic properties of oat β-glucan. *Am J Clin Nutr* 2003;78:221–7.

KEY WORDS β-glucan, oat bran, oat bran concentrate, wheat fiber, food matrix, food processing, LDL cholesterol, HDL cholesterol, triacylglycerol, mildly hypercholesterolemic humans

INTRODUCTION

Oats, an important source of water-soluble fibers, have long been recognized as a potential cholesterol-lowering dietary component (1). Indeed, Ripsin et al (2) concluded from a meta-analysis of 12 trials that soluble fiber from oat products had a significant effect on total cholesterol concentrations. It was estimated that a daily consumption of ≈3 g soluble fiber lowered total cholesterol by 0.13 mmol/L in normocholesterolemic persons and by 0.41 mmol/L in hypercholesterolemic persons.

The beneficial effects of oat products on the lipoprotein profile are ascribed to their soluble fiber compound, β-glucan (3). β-glucan from oats is a nonstarch polysaccharide that is composed of β-(1→4)–linked glucose units, which are separated every 2–3 units by a single β-(1→3)–linked glucose unit (4). β-glucan from barley (5, 6) or yeast (7) has also been shown to be hypocholesterolemic.

On 21 January 1997, the US Food and Drug Administration (FDA) approved the printing on food-product packages of a health claim that "a diet high in soluble fiber from whole oats (oat bran, oatmeal and oat flour) and low in saturated fat and cholesterol may reduce the risk of heart disease" (8, 9). In its proposal (8), the FDA reviewed 37 studies in which oats were consumed as hot and cold cereals or used in a variety of other foods, eg, muffins, breads, shakes, and entrées. It was concluded that ≥3 g of β-glucan from oats should be consumed daily to achieve a clinically relevant decrease in serum total cholesterol concentrations. Such an amount of β-glucan is provided by ≤40 g oat bran or ≤60 g oatmeal (8). Compliance with this dietary guideline would be greatly improved if common food products rich in oats were available. We therefore decided to investigate in mildly hypercholesterolemic subjects the effects on serum lipids and lipoproteins of a daily consumption of ≥5 g β-glucan from oat bran that was incorporated into bread and cookies (study 1). To examine in more detail the effects of food processing and the food matrix, we also examined in a second study (study 2) whether the same source and amount of oat bran as in study 1 would lower serum LDL-cholesterol concentrations when given with a drink.

SUBJECTS AND METHODS

Subjects

Study 1: effects of oat β-glucan in bread and cookies

Volunteers were recruited from Maastricht and the surrounding area by advertisements in local newspapers. In addition, subjects who had participated in earlier studies at our department were approached. Before they entered the screening procedure, all subjects were given a detailed written description of the study, which

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consisted of measurements of body weight, height, and blood pressure; the drawing of 2 fasting blood samples for analysis of serum lipids and lipoproteins; and assessment of the absence of glucose in a morning specimen of urine. In addition, all subjects had to complete a medical questionnaire. Fifty-one participants were selected for the study according to the following inclusion criteria: age 18–65 y, stable body weight (weight gain or loss < 3 kg in the previous 3 mo), body mass index (BMI; in kg/m^2) < 30, diastolic blood pressure < 95 mm Hg, systolic blood pressure < 160 mm Hg, concentrations of serum total cholesterol < 8.0 mmol/L and of triacylglycerol < 4.0 mmol/L, no indication for treatment with cholesterol-lowering drugs according to the Dutch Cholesterol Consensus (10), no use of medication known to affect serum lipids, no glucosuria, no pregnancy or breastfeeding, and no history of coronary heart disease. None of the subjects had participated in another biomedical trial or donated blood 30 d before the study, nor were subjects allowed to donate blood during the study. The study protocol was approved by the Ethics Committee of Maastricht University, and all subjects gave written informed consent.

During the 3-wk run-in period, one female subject dropped out of the study in the first week for personal reasons, and another female subject withdrew in the second week because of illness. In the first week of the treatment period, one male subject withdrew because of the constraints of the study. The remaining 48 volunteers, 21 men and 27 women, completed the study. The mean (± SEM) age of the men was 53 ± 2 y and their mean BMI was 25.6 ± 0.6. For the women, these values were 50 ± 2 y and 24.4 ± 0.5, respectively. In the men, mean fasting concentrations of serum total, LDL, and HDL cholesterol and triacylglycerol were 6.36 ± 0.17, 4.39 ± 0.16, 1.26 ± 0.06, and 1.54 ± 0.15 mmol/L, respectively; in the women, the respective values were 5.96 ± 0.15, 3.82 ± 0.14, 1.64 ± 0.08, and 1.09 ± 0.09 mmol/L. Four men and 2 women were smokers, 4 women used oral contraceptives, and 9 women were postmenopausal.

Study 2: effects of oat β-glucan in orange juice

Twenty-six volunteers from the first study agreed to participate in the second study. Inclusion criteria were identical to those for study 1. All subjects received a detailed written description of the study before they gave written informed consent. The study protocol was approved by the Ethics Committee of Maastricht University.

One female subject withdrew in the first week of the study because of influenza. Thus, 25 volunteers, 10 men and 15 women, completed the trial. The mean age of the men was 54 ± 2 y, and the mean BMI was 24.9 ± 0.7. For the women, these values were 53 ± 3 y and 24.6 ± 0.8, respectively. In the men, mean fasting concentrations of serum total, LDL, and HDL cholesterol and triacylglycerol were 6.09 ± 0.23, 4.22 ± 0.22, 1.23 ± 0.09, and 1.39 ± 0.17 mmol/L, respectively; the respective values in the women were 5.94 ± 0.23, 3.83 ± 0.22, 1.67 ± 0.09, and 0.96 ± 0.08 mmol/L. One man and 1 woman smoked, 1 woman used oral contraceptives, and 6 women were postmenopausal.

Experimental design

Study 1

Study 1 was a parallel, randomized controlled experiment. During the first 3 wk of the trial (run-in period), all volunteers were provided with control bread and cookies rich in wheat fiber. After the run-in period, the subjects were randomly divided into 2 treatment groups, stratified by age and sex. For the last 4 wk of the study, the first group continued consuming control bread and cookies, and the second group received experimental bread and cookies rich in β-glucan from oat bran. At least 5 slices of control or experimental bread had to be consumed daily throughout the study. The subjects were instructed to spread the consumption of the bread over ≥ 2 of 3 daily eating sessions (ie, breakfast, lunch, and dinner). No explicit instructions were given to consume beverages with these meals, although subjects in general did do so. The subjects were free to consume cookies whenever they liked. One 30-g slice of the experimental bread contained 1 g β-glucan, and one 12-g cookie contained 0.5 g β-glucan from oat bran (**Table 1**). The subjects were free to replace one slice of bread with 2 cookies. The target daily intake of β-glucan from oat bran was therefore ≥ 5 g.

TABLE 1
The amount of β-glucan, total dietary fiber, and fat content of one slice of bread and one cookie in study 1 and of one sachet of fiber in study 2[1]

	Study 1		Study 2:
	Slice of bread	Cookie	sachet of fiber
Control products			
Wheat fiber (g)	2.0	1.0	6.0
Wheat flour (g)	13.0	2.0	0.0
Total dietary fiber (g)	2.3	1.0	5.6
Fat (g)	1.3	3.0	0.0
Experimental products			
Oat bran (g)	5.6	2.8	14.0
Oat bran concentrate (g)	2.4	1.2	6.0
Wheat flour (g)	6.6	0.0	0.0
β-Glucan (g)	1.0	0.5	2.5
Total dietary fiber (g)	2.3	1.1	5.3
Fat (g)	1.3	3.0	1.3

[1] In study 1, ≥ 5 slices of control or experimental bread had to be consumed daily. The participants were free to replace 1 slice of bread with 2 cookies. The target daily intake of β-glucan from oat bran was therefore ≥ 5 g. In study 2, the subjects consumed daily 2 sachets of wheat fiber or a mixture of oat bran and oat bran concentrate, which did not differ significantly in total dietary fiber content (≈5 g), after mixing each sachet with 200 mL orange juice.

The total dietary fiber content of the control and the experimental breads and of the control and experimental cookies did not differ significantly (one slice of bread, 2 g; one cookie, 1 g; Table 1). In addition, the fat content of the control and experimental products did not differ significantly (one slice of bread, 1 g; one cookie, 3 g; Table 1), but the color and taste differed because of the use of different sources of fiber.

The wheat fiber (VITACEL Wheat Fibre WF 200; J. Rettenmaier & Söhne GmbH+Co, Rosenberg, Germany) contained 93.3% total dietary fiber, of which 98.8% was water-insoluble fiber, mainly cellulose and hemicellulose. For the bread and cookies rich in β-glucan, a mixture consisting of 23 parts (by wt) of oat bran (Melia Oy, Raisio, Finland) and 10 parts of oat bran concentrate (Swedish Oat Fiber AB, Väröbacka, Sweden) was used. Oat bran was prepared by steaming oat grain for 45–60 min at 100 °C, during which the moisture content of the grains increased from ≈12% to 16%. After steaming, the grains cooled very slowly for ≈3 h until they regained their original moisture content (12%). After inactivation of enzymes, the grains were cut into 2–3 pieces, and the oat bran was separated with the use of rollers.

The oat bran contained 20.6% total dietary fiber, of which 41% was β-glucan, whereas the oat bran concentrate contained 40.3% total dietary fiber, of which 53% was β-glucan. The compositions of wheat fiber, oat bran, and oat bran concentrate are shown in **Table 2**. Before being baked, the oat bran was soaked in 30 °C

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TABLE 2
Composition (per 100 g product weight) of wheat fiber, oat bran, and oat bran concentrate in study 1 and study 2[1]

	Wheat fiber	Oat bran	Oat bran concentrate
Total dietary fiber (g)	93.3	20.6	40.3
β-Glucan (g)[2]	0.1	8.4	21.2
Fat (g)	0.3	7.1	4.9
Protein (g)	0.3	20.2	22.8
Moisture (g)	5.3	10.6	5.3
Ash (g)	0.7	3.1	3.9
Carbohydrate (g)	0.1	38.4	22.8
Energy (kJ)	17	1247	950

[1] Composition was based on chemical analyses (11–15), except for carbohydrates, which were calculated by difference. In study 1, wheat fiber, oat bran, and oat bran concentrate were incorporated into bread and cookies, whereas in study 2, these products were given with orange juice. For experimental details, *see* Table 1.

[2] Content was determined by using a specific enzymatic kit (Megazyme, Wicklow, Ireland).

water for 1 h in a 36 °C chamber to promote rising. During the soaking phase, oat bran absorbed water, and the mixture formed a light gel. Thereafter, the other ingredients for the final product were added. Nearly each week, new batches of bread and cookies were prepared by a local bakery and deep-frozen at −18 °C. The subjects received bread and cookies at their request once a week.

The subjects recorded in diaries any signs of illness, medication used, menstrual phase, alcohol and fruit consumption, and any deviations from the protocol. In addition, the daily amounts of bread and cookies consumed were recorded. Subjects were urged not to change their habitual diets, smoking and drinking habits, level of physical activity, or use of oral contraceptives during the study. Body weight without shoes or heavy clothes was recorded once a week. In the last week of the run-in period and at the end of the treatment period, subjects recorded their food intake for the previous 4 wk by completing food-frequency questionnaires to estimate their intake of energy and nutrients throughout the study. Food-frequency questionnaires were checked by a registered dietitian in the presence of the subjects.

Study 2

The follow-up study was a randomized, controlled crossover trial consisting of 2 periods of 2 wk each with an intermediate washout period of 1 wk. In this study, the same sources and daily amounts of wheat fiber, oat bran, and oat bran concentrate as in study 1 were used and were given in orange juice. Wheat fiber, oat bran, and oat bran concentrate were from the same batches as in study 1.

Before the start of study 2, the subjects were randomly allocated to 1 of the 2 groups, stratified by age and sex. During the first 2-wk period, one group consumed orange juice with wheat fiber (control drink), and the other group consumed orange juice with β-glucan from oats (β-glucan drink). After the washout period, subjects who consumed the control drink in the first period crossed over to consume the β-glucan drink in the second period, and vice versa.

During the 2 periods of study 2, subjects consumed on 2 separate daily occasions 1 glass of orange juice rich in control fiber from wheat or in β-glucan from oat bran. The subjects were free to choose the 2 times at which they consumed the servings of orange juice mixture, with the stipulation that the consumption occasions be separated by ≥3 h. Fifteen sachets filled with wheat fiber or oat bran were provided weekly: 2 sachets for each day plus one extra sachet as a reserve. Each sachet contained wheat fiber (6 g) or oat bran (a mixture of 14 g oat bran and 6 g oat bran concentrate, in a similar proportion as in study 1) that was to be mixed with 200 mL orange juice, which was also provided. This mixture had to be consumed immediately because palatability decreased with time. One sachet of oat bran provided 2.5 g β-glucan (Table 1). Thus, the target daily intake of β-glucan from oat bran was 5 g. Sachets of wheat fiber and oat bran did not differ in total dietary fiber content but did differ in color, taste, and fat content. Sachets that were left over at the end of each period were collected and counted. Other experimental procedures were the same as those in study 1.

Blood sampling

The participants in study 1 and study 2 fasted overnight, did not consume alcohol the day before, and did not smoke on the morning before blood sampling. All venipunctures were generally done by the same person, in the same room, and mostly at the same time of the day (between 0800 and 1100). Blood was sampled from a forearm vein by using evacuated tubes under minimal stasis with the participant in a supine position for ≥5 min. The evacuated tubes were kept at room temperature before and after blood sampling. For analysis of serum lipids and lipoproteins, 10 mL blood was collected in a serum tube (CORVAC; Sherwood Medical, St Louis). At least 1 h after venipuncture, serum was obtained by centrifugation at 2000 × *g* for 30 min at 4 °C, and this serum was stored at −80 °C.

In study 1, blood samples were taken at the start of the study (day 0), in the latter part of the run-in period (weeks 2 and 3), and in the latter part of the treatment period (weeks 6 and 7). In study 2, blood was sampled at the beginning of the study (day 0), at the end of the first dietary period (days 12 and 14), at the end of the washout period (day 21), and at the end of the second period of the trial (days 33 and 35).

Analyses

Concentrations of total cholesterol (CHOD-PAP method with the Monotest cholesterol kit; Boehringer Mannheim GmbH, Mannheim, Germany), HDL cholesterol (precipitation method by the addition of a mixture of phosphotungstic acid and magnesium ions to the sample and CHOD-PAP method), and triacylglycerol with correction for free glycerol (GPO Trinder; Sigma Diagnostics, St Louis) were analyzed enzymatically in serum. LDL-cholesterol concentrations were calculated by using the Friedewald equation (16). The within-run CVs for concentrations of serum total and HDL cholesterol and triacylglycerol in study 1 were 1.2%, 3.9%, and 2.3%, respectively, and those in study 2 were 1.1%, 5.0% and 1.8%, respectively. All samples from one subject were analyzed within one run at the end of each part of the trial.

The molecular weight (MW) distribution of β-glucan was determined by high-performance size-exclusion chromatography (17) in oat bran and oat bran concentrate after the baking of bread and cookies and after deep-freezing at −18 °C.

Statistical analysis

The power of both study 1 and study 2 to detect a difference of 8% (0.32 mmol/L) in serum LDL-cholesterol concentrations between 2 treatments with an α of 0.05 was 80%. Data for the 3 subjects in study 1 and the 1 subject in study 2 who dropped out during the studies were not included in the analysis. Thus, in the per-protocol analysis performed, the results for 48 subjects from study 1 and for 25 subjects from study 2 were included.

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TABLE 3
Molecular weight (MW) distribution of β-glucan in the oat bran products[1]

	MW		
	>1 000 000	250 000–1 000 000	<250 000
	%		
Oat bran	20	50	30
Concentrate	30	50	25[2]
Mix	23	49	28
Oat bread			
Fresh	10	30	60
Frozen	15	30	55
Frozen oat cookie	40	45	15

[1] During study 1, subjects consumed only bread and cookies that had been frozen.
[2] Total exceeds 100% because of rounding of the results.

In study 1, the responses to treatment were calculated for each subject as the change between lipid and lipoprotein values obtained at the end of the treatment period (means of values from weeks 6 and 7) and at the end of the run-in period (means of values from weeks 2 and 3). Differences in changes between the 2 treatment groups in study 1 were examined by using the unpaired *t* test. At the end of the run-in period, none of the measured variables differed significantly between the 2 groups in study 1 (unpaired *t* test).

For study 2, lipid and lipoprotein values from days 12 and 14 (period 1) and from days 33 and 35 (period 2) were first averaged for each subject. Responses to treatment, which were calculated as the difference between values obtained at the end of the β-glucan drink period and those obtained at the end of the control drink period were analyzed by the one-sample *t* test. Carryover effects on these responses, which were not significant for all variables, were analyzed as described (18).

In both studies, $P < 0.05$ was considered significant. Responses to the treatments did not differ significantly between the men and the women. For study 1, this lack of difference in responses was examined by analysis of variance (ANOVA) with diet, sex, and diet × sex as factors. For study 2, an unpaired *t* test was used with sex as the factor. Variables are presented as means ± SEMs. All statistical analyses were performed with STATVIEW software (version 5.0; Abacus Concepts, Berkeley, CA).

RESULTS

Molecular weight distribution of β-glucan in the oat products

The MW distribution of β-glucan in oat bran and that in oat bran concentrate were similar (**Table 3**). Bread production decreased the MW of β-glucan, but freezing the bread did not affect the MW. For bread, the MW was lower than for oat bran or oat bran concentrate. The β-glucan in the frozen cookie had the largest MW.

Dietary intake and body weight

Study 1

As calculated from the diaries, the mean daily consumption of β-glucan from oat bran during the treatment period was 5.9 ± 0.2 g (range: 4.3–8.6 g), of which 5.1 ± 0.2 g (range: 3.7–7.5 g) came from bread and only 0.8 ± 0.1 g (range: 0.0–1.9 g) came from cookies (**Table 4**). Changes in the intakes of energy and nutrients did not differ significantly between the 2 groups, except for the percentage of energy from protein and alcohol. Body weights changed slightly, by 0.2 ± 0.2 kg (range: −1.2 to −2.1 kg) in the control group and by 0.0 ± 0.1 kg (range: −1.2 to −1.5 kg) in the β-glucan group. These changes did not differ significantly ($P = 0.350$).

TABLE 4
Mean daily intakes of β-glucan (from oat bran in bread and cookies), energy, and nutrients during study 1[1]

	Control products	β-Glucan products
Total β-glucan (g)[2]	—	5.9 ± 0.2
From bread (g)	—	5.1 ± 0.2
From cookies (g)	—	0.8 ± 0.1
Energy (MJ/d)		
Run-in	9.1 ± 0.3	8.8 ± 0.3
Treatment	9.3 ± 0.4	8.6 ± 0.3
Change	0.2 ± 0.3	−0.3 ± 0.2
Protein (% of energy)		
Run-in	15.9 ± 0.4	16.3 ± 0.5
Treatment	15.4 ± 0.4	18.4 ± 0.7
Change	−0.5 ± 0.3	2.1 ± 0.4[3]
Fat (% of energy)		
Run-in	39.2 ± 1.2	40.4 ± 1.1
Treatment	39.9 ± 1.2	41.6 ± 1.1
Change	0.8 ± 0.7	1.2 ± 0.8
SFAs (% of energy)		
Run-in	14.4 ± 0.5	15.2 ± 0.5
Treatment	15.0 ± 0.4	15.6 ± 0.5
Change	0.6 ± 0.3	0.5 ± 0.3
MUFAs (% of energy)		
Run-in	13.4 ± 0.5	13.8 ± 0.4
Treatment	13.7 ± 0.5	14.9 ± 0.4
Change	0.2 ± 0.3	1.1 ± 0.4
PUFAs (% of energy)		
Run-in	8.5 ± 0.3	8.5 ± 0.3
Treatment	8.6 ± 0.4	8.4 ± 0.3
Change	0.1 ± 0.3	−0.1 ± 0.2
Carbohydrates (% of energy)		
Run-in	51.8 ± 1.4	49.0 ± 1.0
Treatment	50.3 ± 1.3	45.6 ± 1.2
Change	−1.5 ± 0.7	−3.5 ± 0.7
Alcohol (% of energy)		
Run-in	1.7 ± 0.5	2.1 ± 0.5
Treatment	1.8 ± 0.6	1.6 ± 0.5
Change	0.1 ± 0.1	−0.5 ± 0.2[4]
Cholesterol (mg/d)		
Run-in	210.6 ± 13.4	220.3 ± 12.8
Treatment	210.5 ± 12.4	240.9 ± 12.1
Change	−0.1 ± 12.3	20.6 ± 12.7
Dietary fiber (g/MJ)		
Run-in	3.7 ± 0.1	3.6 ± 0.1
Treatment	3.7 ± 0.1	3.6 ± 0.1
Change	−0.1 ± 0.1	0.0 ± 0.1

[1] $\bar{x}$ ± SEM. Forty-eight participants consumed control bread and cookies for 3 wk (run-in period). For the next 4 wk (treatment period), one group ($n = 23$) continued consuming their control products, and the other group ($n = 25$) consumed bread and cookies rich in β-glucan (5.9 g/d) from oat bran. Nutrient intake was calculated from a food-frequency questionnaire completed at the end of each period. SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids.
[2] The amount of β-glucan in the control products was not analyzed, but it was insignificant, as indicated by the analysis of the raw material (wheat fiber; *see* Table 2).
[3,4] Significantly different from the control group (unpaired *t* test): [3] $P < 0.001$, [4] $P < 0.05$.

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TABLE 5
Effects of β-glucan from oat bran in bread and cookies on serum lipid and lipoprotein concentrations in study 1[1]

	Control products	β-Glucan products
Total cholesterol (mmol/L)		
Run-in	6.00 ± 0.16	5.98 ± 0.16
Treatment	6.04 ± 0.15	5.85 ± 0.18
Change	0.03 ± 0.06	−0.13 ± 0.07
LDL cholesterol (mmol/L)		
Run-in	4.09 ± 0.17	3.96 ± 0.16
Treatment	4.11 ± 0.16	3.86 ± 0.17
Change	0.02 ± 0.06	−0.10 ± 0.06
HDL cholesterol (mmol/L)		
Run-in	1.38 ± 0.09	1.50 ± 0.09
Treatment	1.41 ± 0.09	1.47 ± 0.08
Change	0.03 ± 0.03	−0.03 ± 0.03
Triacylglycerol (mmol/L)		
Run-in	1.15 ± 0.09	1.13 ± 0.12
Treatment	1.12 ± 0.10	1.13 ± 0.14
Change	−0.03 ± 0.05	−0.01 ± 0.07
Total:HDL		
Run-in	4.70 ± 0.28	4.35 ± 0.29
Treatment	4.62 ± 0.27	4.29 ± 0.28
Change	−0.08 ± 0.08	−0.06 ± 0.07

[1] $\bar{x}$ ± SEM. Twenty-three subjects consumed the control products, and 25 subjects consumed the β-glucan products. The changes did not differ significantly between the treatments (unpaired *t* test). For experimental details, *see* Table 1.

Study 2

As calculated from the returned sachets, the mean daily intake of β-glucan from oat bran was 5.00 ± 0.01 g (range: 4.87–5.07 g). The difference in body weight of 0.0 ± 0.2 kg between the control and β-glucan drink periods was not significant ($P = 0.902$).

Lipids and lipoproteins

Study 1

Serum total cholesterol concentrations increased by 0.03 ± 0.06 mmol/L in the control group and decreased by 0.13 ± 0.07 mmol/L in the β-glucan group (**Table 5**). Changes in total cholesterol concentrations did not differ significantly between the control and β-glucan groups (95% CI for the difference of −0.16 mmol/L between the 2 groups: −0.36, 0.03 mmol/L; $P = 0.098$). Moreover, changes in concentrations of serum LDL cholesterol (95% CI for the difference: −0.29, 0.05 mmol/L; $P = 0.173$), HDL cholesterol (95% CI for the difference: −0.14, 0.02 mmol/L; $P = 0.154$), and triacylglycerol (95% CI for the difference: −0.16, 0.21 mmol/L; $P = 0.792$) and in the ratio of total to HDL cholesterol (95% CI for the difference: −0.19, 0.23; $P = 0.835$) did not differ significantly between the 2 groups.

Study 2

Consumption of β-glucan with orange juice lowered serum total cholesterol concentrations by 0.22 ± 0.07 mmol/L (3.8 ± 1.3%) compared with consumption of the control drink (**Table 6**; 95% CI for the difference: −0.37, −0.07 mmol/L; $P = 0.006$). Serum LDL-cholesterol concentrations also decreased after consumption of the β-glucan drink by 0.26 ± 0.07 mmol/L, or 6.7 ± 1.8% (95% CI for the difference: −0.41, −0.12 mmol/L; $P = 0.001$), and the ratio of total to HDL cholesterol decreased by 0.26 ± 0.11, or 5.4 ± 2.1% (95% CI for the difference: −0.48, −0.03; $P = 0.029$), compared with that after consumption of the control drink. HDL-cholesterol (95% CI for the difference: −0.02, 0.08 mmol/L; $P = 0.222$) and triacylglycerol (95% CI for the difference: −0.11, 0.16 mmol/L; $P = 0.714$) concentrations did not change significantly.

TABLE 6
Effects of β-glucan from oat bran in orange juice on serum lipid and lipoprotein concentrations in study 2[1]

	Control drink	β-Glucan drink	Difference
Total cholesterol (mmol/L)	5.58 ± 0.13	5.36 ± 0.13	−0.22 ± 0.07[2]
LDL cholesterol (mmol/L)	3.77 ± 0.14	3.50 ± 0.14	−0.26 ± 0.07[2]
HDL cholesterol (mmol/L)	1.25 ± 0.07	1.28 ± 0.08	0.03 ± 0.03
Triacylglycerol (mmol/L)	1.22 ± 0.09	1.24 ± 0.12	0.02 ± 0.07
Total:HDL	4.84 ± 0.31	4.58 ± 0.32	−0.26 ± 0.11[3]

[1] $\bar{x}$ ± SEM. During the first period of the trial, one group ($n = 13$) consumed wheat fiber with control orange juice, and the other group ($n = 12$) consumed β-glucan (5 g/d) from oat bran with orange juice. After a washout period of 1 wk, dietary regimens were crossed over.

[2,3] Significantly different from the control drink (one-sample *t* test): [2] $P < 0.01$, [3] $P < 0.05$.

DISCUSSION

The present studies showed that a mean daily 4-wk intake of 5.9 g β-glucan from oat bran administered in bread and cookies had no favorable effects on the serum lipoprotein profile (study 1). Slight decreases of 0.16 mmol/L in total cholesterol and of 0.12 mmol/L in LDL-cholesterol concentrations were observed, but these changes were not statistically significant. On the basis of the meta-analysis of Ripsin et al (2), we expected that a daily intake of ≥3 g β-glucan from oat bran would lower serum cholesterol concentrations in our mildly hypercholesterolemic subjects by >0.41 mmol/L. When a smaller amount of oat β-glucan (0.5 g) was consumed for 2 wk with a drink, serum total cholesterol concentrations decreased by 0.22 mmol/L (study 2). This change, which was mainly due to an effect on LDL cholesterol, was still less than that predicted. Whether a larger decrease would have been observed after a longer treatment period remains to be established.

Previous studies with oat β-glucan showed both beneficial effects and no effect on the serum lipid profile (3, 19–26). It has been suggested that discrepancies between studies could be attributed to the cultivar of the oat used, growing conditions, or to processing—factors known to influence the amount and properties of β-glucan in oats (27, 28). The source of β-glucan and the method of processing the oat bran or oat bran concentrate in both our studies were similar, however, and therefore those variables cannot explain why the drink with oat β-glucan appeared to be somewhat more effective than were the bread and cookies enriched with oat β-glucan.

It can be argued that the mode of administration is important. In our first trial, 5.1 g oat β-glucan was provided by bread, and only 0.8 g was provided by the cookies. It is therefore possible that the incorporation of the oat bran and oat bran concentrate into the bread may be responsible for the lack of effect. Although consumption of oat β-glucan from a variety of foods (cereal, muffins, and bread) efficiently lowered LDL cholesterol (29), the effects of oats administered only in bread are controversial. De Groot et al (1) showed that the consumption of bread that provided 140 g

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rolled oats/d led to an 11% reduction in serum total cholesterol concentrations. In contrast, other studies found no hypocholesterolemic effect of incorporating oats into bread (22, 30–32). Moreover, studies that provided oat β-glucan in a drinkable preparation yielded conflicting results. Lovegrove et al (26) found that LDL-cholesterol concentrations were not affected by the minimum FDA-recommended daily dose of 3 g oat β-glucan when it was consumed with low-fat yogurt or low-fat milk. In contrast, Beer et al (23) found no hypocholesterolemic effect after a daily intake of 9 g β-glucan from oat gum, which was mixed in an instant whip. Other groups, however, observed significant reductions in serum LDL-cholesterol concentrations when the β-glucan preparation from oat bran was given with a drink (3, 25). Therefore, the mode of administration appears not to be a decisive factor.

A possible mechanism of action for the cholesterol-lowering effect of β-glucan is decreased bile acid reabsorption caused by fiber binding or by an increased viscosity of intestinal contents (23, 33). The viscosity in the intestine may depend, among other things, on the solubility and MW of β-glucan. It is doubtful, however, whether the inconsistent effects of β-glucan in the oat products on the lipoprotein profile are solely due to variations in the MW of β-glucan. The authors of 2 studies (22, 23) attributed their negative results to the poor solubility and low-to-moderate MW of β-glucan in their oat products, which, in turn, may lead to a low viscosity in the intestine. In the study of Törrönen et al (22), the MW of the β-glucan was low (370 000). The MW of β-glucan used in the study of Beer et al (23) was substantially higher (1 000 000), but it still did not show any beneficial effects on the lipoprotein profile. However, in the study of Braaten et al (3), consumption of β-glucan with an MW of 1 200 000 resulted in decreased LDL-cholesterol concentrations. From the results of these 3 studies (3, 22, 23), it could be inferred that a hypocholesterolemic effect can be expected when the MW of β-glucan from oats is ≥ 1 200 000. But a comparison of these data with our results makes us doubtful that a high MW of β-glucan per se is a strong predictor of β-glucan's cholesterol-lowering effect. Only 20–30% of our β-glucan had an MW > 1 000 000. In fact, most (≈75%) of the β-glucan had an MW < 1 000 000. Our findings indicate that, although the MW of β-glucan is < 1 200 000, it still has cholesterol-lowering properties when given with a drink. Furthermore, no clear dose-response relations between the height of the MW of β-glucan and its cholesterol-lowering effect has been shown in rats (34). Thus, there is no convincing evidence that the MW of β-glucan alone predicts β-glucan's cholesterol-lowering potency.

The results of our first study were not confounded by other factors that may influence the serum lipid concentrations, such as body weight or nutrient intake. In our second study, however, the energy content and nutrient composition were not identical when wheat fiber or oat bran was given with a drink. The daily energy intake from 12 g wheat fiber was 2 kJ, whereas that from the oat bran mixture was 464 kJ, of which only 96, 226, and 142 kJ came from fat, carbohydrate, and protein, respectively. Even if subjects did not compensate for the small differences in energy and fat intakes during the 2 wk of supplementation, it is not very likely that these differences have confounded the results (35).

In conclusion, the β-glucan preparation from oat bran consumed with orange juice is more effective in lowering total and LDL-cholesterol concentrations and the ratio of total to HDL cholesterol than is the same preparation administered in bread and cookies. This indicates that the food matrix or the food processing, or both, could have detrimental effects on the cholesterol-lowering properties of β-glucan from oat bran. There is no clear, unequivocal explanation for this difference in effect, which raises the question of whether foods that are rich in β-glucan by definition lower LDL cholesterol.

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