

Cholesterol Response and Foam Cell Formation in Hamsters Fed Rice Bran, Oat Bran, and Cellulose + Soy Protein Diets With or Without Added Vitamin E

T. S. Kahlon,^{1,2} F. I. Chow,¹ and D. F. Wood¹

ABSTRACT

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Four-week-old male golden Syrian hamsters were fed diets containing cellulose (control, CC), cellulose + soy protein (CS), CS + vitamin E, (CSE), rice bran (RB), RB + vitamin E (RBE), oat bran (OB), and OB + vitamin E (OBE) for six weeks ($n = 10/\text{treatment}$). Diets contained (by weight) 10% total dietary fiber, 3% N, 20% fat, 0.5% cholesterol, and some diets had an additional 0.1% vitamin E. After six weeks, RB and OB diets resulted in significantly higher weight gain than the CC diet. Plasma low-density lipoprotein cholesterol (LDL-C) values and the LDL-C/high-density lipoprotein cholesterol ratio in hamsters fed CSE, RBE, OB, and OBE diets were significantly lower than in those fed CC diet. There

were no significant differences in total plasma cholesterol values among the hamsters fed any of the diets. Liver cholesterol in animals fed OB and OBE diets was significantly lower than in all other groups. Foam cell areas in the inner bend of the aortic arch in animals fed all treatment diets were significantly reduced when compared with that in animals fed CC diet. The level of additional dietary vitamin E did not result in further significant reductions in foam cell area. The results of this study suggest that diets containing rice bran, oat bran, or soy protein significantly reduced the development of atherosclerosis in hypercholesterolemic hamsters.

Plasma cholesterol reductions with cereals such as oat bran and rice bran have been reported extensively and recently reviewed (Kahlon and Chow 1997). Soy protein has been shown to be hypocholesterolemic when compared with casein (Terpstra et al 1991). Cholesterol metabolism in hamsters closely resembles that of humans, in contrast to other rodent species, which has resulted in increased use of the hamster as a small animal model for atherosclerosis research (Spady and Dietschy 1985, Liu et al 1991, Kahlon et al 1993, Goulinet and Chapman 1993). Foam cells, fatty streaks, and plaque develop in the aortic arch of hamsters fed atherogenic diets, similar to the development of atherosclerotic lesions in humans (Nistor et al 1987, Takasu et al 1990, Sima et al 1990). Foam cell development was induced in hamsters fed 0.5% cholesterol (C) and 20% fat (65% saturated) diet for six weeks (Kahlon et al 1996c), establishing this model as appropriate for atherosclerosis progression and regression studies within a reasonable time frame.

Vitamin E is believed to lower the risk of atherosclerosis due to its antioxidant properties which may prevent oxidation of low-density lipoprotein (LDL) (Dieber-Rotheneder et al 1991, Wiklund et al 1991, Princen et al 1995). Oxidized LDL is implicated in the initiation and progression of atherosclerosis (Steinberg et al 1989, Witztum and Steinberg 1991). This study was undertaken to evaluate the foam cell reduction in the aortic arch by rice bran and oat bran diets in hamsters and the influence of enriched vitamin E diets to enhance the antiatherogenic properties of these brans. Soy protein was used as a source of plant protein to maintain a constant ratio of plant to animal protein in the treatment diets, and was also evaluated for antiatherogenic effects.

MATERIALS AND METHODS

Male, 28-day-old weanling golden Syrian hamsters (Simonsen Laboratories, Gilroy, CA) were housed individually in wire bottom cages in a controlled environment (20–22°C, 60% rh, 12-hr light

and dark cycle) and fed the control diet for seven days. After equilibration, animals were weighed and assigned to one of seven diet groups by selective randomization (blocked by weight, one animal/diet group from each block), 10 animals per group. Total feed consumption was measured, fresh feed was provided twice weekly, and animals were weighed once a week. Feed in the feeding cups was stirred daily to prevent caking of the high-fat diets. Hamsters were fed powdered diets that minimized the storage and fermentation of the food in the pregastric pouches. All the procedures described were approved by the Animal Care and Use Committee of the Western Regional Research Center, USDA, Albany, CA, and conformed to the principles in *Guide for the Care and Use of Laboratory Animals* (Committee on Care and Use of Laboratory Animals 1985).

Stabilized rice bran and oat bran were obtained from local mills and were used as-is; all other diet ingredients were obtained from Dyets, Inc., Bethlehem, PA. All diets contained 10% total dietary fiber, 0.5% cholesterol, 20% fat (10% butter), and were isonitrogenous (3.0% N). To balance the crude fat level, peanut oil was used because its fatty acid composition is similar to that of the rice bran oil (Kahlon et al 1996a). The level of dietary fat, cholesterol, necessary butter fat, and duration of this study were based on the foam cell formation in the atherosclerosis hamster model (Kahlon et al 1996c). All diet treatments contained 8.8% casein and the remaining protein was provided by the cereal bran or soy protein, while the cellulose control diet (CC) contained 20% casein as the sole source of protein. To keep the plant-to-animal protein ratio (11.7:8.8) constant among the six treatment diets, soy protein was added to the cellulose and rice bran diets (diets CS and RB, respectively); plant protein in the oat bran diet (OB) was provided entirely by oat bran. All diets contained a minimum of 50 IU of vitamin E/kg of diet, which was provided in the diet mix. To formulate vitamin-E enriched diets, α -tocopheryl acetate was added to one-half of each of the CS, RB, and OB diets to provide an additional 1,000 IU of vitamin E/kg of diet (CSE, RBE and OBE, respectively) for a total of 1,050 IU/kg of diet. Composition of the diets is given in Table I.

After five weeks of feeding the treatment diets, total feces were collected for 72 hr (days 37–39). Samples were analyzed for dry matter by Method 934.01 (AOAC 1990), total dietary fiber (Prosky et al 1988), nitrogen (Kjeldahl method), crude fat by Method 920.39C (AOAC 1990), and total neutral sterols. At the end of the 42-day feeding period, all animals were fasted for 16 hr and anesthetized with CO₂ for tissue sample collection. Blood was drawn by cardiac puncture into plastic tubes containing anticoagulant (ethylenediamine tetraacetic acid, dipotassium salt, 0.8 mg/mL of blood) and centrifuged at 1,500 \times g for 30 min at 4°C to obtain plasma.

¹ Western Regional Research Center, USDA-ARS, 800 Buchanan St, Albany, CA 94710. Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

² Corresponding author. E-mail: tsk@pw.usda.gov Phone: 510/559-5665. Fax: 510/559-5777.

Livers were excised, rinsed, blotted, weighed, and kept on dry ice. Liver and plasma aliquots were stored at -70°C until analysis. Following blood and liver removal, the intact aorta was first perfused with phosphate-buffered saline for 5 min, then with 10% formaldehyde for 10 min to preserve the internal elastic lamina (IEL). The heart was removed with the aorta intact and refrigerated in formaldehyde until dissection and staining by procedures described previously (Kahlon et al 1996c).

Fresh plasma pooled samples were prepared (two animals per pool) using an equal volume of plasma from each animal because lipoprotein fractionation by density gradient ultracentrifugation requires 1 mL of plasma for each sample, which is more than half that obtained from each animal by heart puncture. A protease inhibitor, epsilon-amino caproic acid, (ICN Biomedicals, Inc., Costa Mesa, CA), 1.3 mg/mL of plasma, and an antimicrobial agent, garamycin 50 mg/mL (Schering Corp., Kenilworth, NJ), 10 $\mu\text{L}/\text{mL}$ of plasma, were added to stabilize the plasma. Lipoproteins were fractionated using density gradient ultracentrifugation (Havel et al 1955) by a procedure described previously (Kahlon et al 1998). Plasma cholesterol (PC) and very low, low, and high density lipoprotein cholesterol (VLDL-C, LDL-C, and HDL-C, respectively) were analyzed by an enzymatic colorimetric procedure for cholesterol (kit 352, Sigma Chemicals, St. Louis, MO). Values were determined using standard curves obtained by running several concentrations of standards provided with the kit. Plasma total antioxidant status was evaluated with a commercial kit (Randox Laboratories, CA). Using the kit, a total antioxidant assay, ABTS (2,2'-azino-di-[3-athylbenzthiazolin sulfonate]) is incubated with a peroxidase (metmyoglobin) and H_2O_2 to produce the radical cation ABTS. The antioxidants in the sample cause suppression of color development proportional to their concentrations. Blue-green color developed is measured at 600 nm.

Each liver was individually thawed, minced, and thoroughly mixed to obtain a homogeneous 0.3 g of sample for extraction of lipids by supercritical carbon dioxide (Kahlon et al 1996b). Extracted lipids were dissolved in 10 mL of chloroform and methanol (86:14) and liver cholesterol was determined in aliquots (30 μL)

of extract after evaporation under nitrogen and solubilizing with Triton X-100 (Carlson and Goldfarb 1977), using the same enzymatic kit as with plasma. Liver cholesterol values were determined from standard curves obtained by running National Bureau of Standards reference material for cholesterol (SRM 911b) through the procedure as described for the samples.

Aortas were cleaned of adventitia, stained in Oil Red O (Nunari et al 1989), cut transversely into two segments (from cardiac origin to innominate artery and from innominate artery to the left subclavian artery), and mounted on glass slides for image analysis (Kahlon et al 1996c). The percent of the total surface area of IEL stained with Oil Red O was measured to determine the extent of foam cell formation.

All analyses were conducted in triplicate. Data were statistically analyzed using analysis of variance and Duncan's new multiple range test (Steel and Torrie 1960). A value of $P \leq 0.05$ was considered the criterion of significance.

RESULTS AND DISCUSSION

Feed Intake and Weight Gain

Initial weights (102 ± 1 g, mean \pm SEM) were similar for all treatment groups after one week of equilibration on the CC diet. At the end of the six-week experimental treatment period, hamsters fed RB and OB diets had significantly higher weight gains and final weights than those fed the CC diet (Table II). The feed intake of groups RB, RBE, and OB was significantly greater than that of group CC. Feed to gain values were similar (4.4 ± 0.4 g feed/g of weight gain) in all groups.

Plasma Total, VLDL-C, LDL-C, and HDL-C

At the end of the six-week feeding period, there were no significant differences in total PC values among hamsters fed any of the diets (value range 322–439 mg/dL) (Table III). Previously, Kahlon et al (1990) reported significant PC reductions with RB and OB diets in growing hamsters fed 10% fat and 0.5% cholesterol diets for three weeks. The lack of PC reduction with RB

TABLE I
Composition of Diets (% dry matter)

Diet ^a	Fiber	Cellulose	Bran ^b	Casein	Soy Protein ^b	Corn Starch	Peanut Oil	Vitamin E (500 IU/g)
CC	Cellulose	10	...	20	...	44.9	10.1	...
CS	Cellulose	10	...	8.8	11.7	44.3	10.2	...
CSE	Cellulose	10	...	8.8	11.7	44.1	10.2	0.2
RB	Rice bran	...	44.4	8.8	5.8	26.0
RBE	Rice bran	...	44.4	8.8	5.8	25.8	...	0.2
OB	Oat bran	...	64.1	8.8	...	6.1	6.0	...
OBE	Oat bran	...	64.1	8.8	...	5.9	6.0	0.2

^a Cellulose control diet (CC); soy protein added to the cellulose and rice bran diets (diets CS and RB, respectively); oat bran diet (OB). All diets contained butter fat (9.5%); mineral mix (3.5%); vitamin mix (1%); cholesterol (0.5%); DL-methionine (0.3%); choline bitartrate (0.2%); and were equal in total crude fat (20%), total dietary fiber (10%), and N (3%). Vitamin E supplement provided an additional 1,000 IU/kg of diet for CSE, RBE, and OBE.

^b Rice bran, oat bran, and soy protein contained 22.5, 15.6, and 0.1% total dietary fiber; 2.0, 2.7, and 14.8% N; 23.1, 6.8, and 0.3% crude fat, respectively.

TABLE II
Effect of Rice Bran, Oat Bran and Cellulose + Soy Diets on Weight Gain, Final Body Weight, and Feed Intake in Hamsters

Diet ^a	Fiber Source	Weight Gain/42 Days (g) ^b	Final Weight (g)	Feed/Day (g)
CC	Cellulose	83 \pm 6b ^c	185 \pm 6b	9.1 \pm 0.3c
CS	Cellulose	92 \pm 4ab	192 \pm 3ab	9.3 \pm 0.2bc
CSE	Cellulose	96 \pm 9ab	197 \pm 10ab	9.7 \pm 0.4a-c
RB	Rice bran	107 \pm 5a	209 \pm 6a	10.4 \pm 0.2a
RBE	Rice bran	100 \pm 9ab	203 \pm 10ab	10.1 \pm 0.3ab
OB	Oat bran	113 \pm 6a	216 \pm 6a	10.1 \pm 0.2ab
OBE	Oat bran	98 \pm 9ab	202 \pm 10ab	9.6 \pm 0.4a-c

^a Cellulose control diet (CC); soy protein added to the cellulose and rice bran diets (diets CS and RB, respectively); oat bran diet (OB). All diets contained butter fat (9.5%); mineral mix (3.5%); vitamin mix (1%); cholesterol (0.5%); DL-methionine (0.3%); choline bitartrate (0.2%); and were equal in total crude fat (20%), total dietary fiber (10%), and N (3%). Vitamin E supplement provided an additional 1,000 IU/kg of diet for CSE, RBE, and OBE.

^b Initial body weights and feed efficiency were similar among all treatments (102 ± 1 g and 4.4 ± 0.4 g of feed/g of weight gain, respectively).

^c Values within a column with different letters differ significantly ($P \leq 0.05$); $n = 10$ per treatment; means \pm standard error.

and OB diets in this study may be related to the use of a hypercholesterolemic diet for the equilibration period, the much higher fat level (20%) of the diets, and the longer feeding period, which extended into the adult age of the animals. Animals in groups RB, RBE, and OB also consumed significantly more feed (including fat and cholesterol) than control group animals. In addition, the hamsters in this study consumed 28% more feed and gained 69% more weight than hamsters of a similar age fed a similar diet for the same duration in a previous study (Kahlon et al 1996c). The response in hamsters to atherogenic diets varies with the age, sex, source, and strain of the animals (Ayyad et al 1993, Trautwein et al 1993, Robins et al 1995). Substituting soy protein for part of the casein in cellulose diets had no significant effect on plasma total cholesterol levels (diets CS and CSE vs. CC). Hypocholesterolemic effects of soy protein versus casein in hamsters have been reported (Beynen and Schouten 1983, Terpstra et al 1991). In those studies, the protein in the diets was either casein or soy protein, whereas in the current study, the soy protein diet also contained 8.8% casein.

LDL-C values in hamsters fed CSE, RBE, OB, and OBE diets were significantly lower than in those fed the CC diet, resulting in reduced atherogenic risk in those animals. VLDL-C and HDL-C values in all groups were similar to those of the CC group. HDL-C values in animals fed CSE and RBE diets were significantly higher than in those fed CS diet. The LDL-C to HDL-C ratio with CSE, RBE, OB, and OBE diets was significantly lower than that in the control animals, suggesting a reduction in atherogenic risk with OB diet and with vitamin E added to CS, RB, and OB diets.

Total plasma antioxidant levels for all treatments were similar to those of the CC diet. Significantly higher antioxidant levels were observed with the CSE diet compared with CS and OB diets. Vitamin E supplementation did not significantly elevate total plasma antioxidant levels in RBE or OBE diets, suggesting that the plasma in these animals contained a substantial antioxidant pool, or that the additional dietary vitamin E was not efficiently absorbed.

Liver Lipid and Cholesterol

Liver weight per 100 g of fasting body weight in hamsters fed CS and OBE diets was significantly lower than in those fed CC diet (Table IV). Liver weight differences as percent of body weight may be due to increased feed intake or fatty infiltration resulting from impaired lipid metabolism that occurs with high fat and cholesterol diets (Ayyad et al 1993). With the exception of those fed RB diet, animals fed all other treatment diets resulted in significantly lower liver lipid percentage (g of lipid/100 g of liver) compared with those fed CC diet. These results agree with our previous studies in which we observed significant liver lipid reductions in hamsters fed RB diets (Kahlon et al 1992b, 1996a) or OB diets (Kahlon et al 1993). Liver lipid values for the RB group were 9% lower than the CC group, but the difference was not significant. Significantly higher feed and fat intake by the animals fed RB diet may, in part, be responsible for higher liver lipid values. The substitution of soy protein for casein in the C diets also resulted in prevention of liver lipid infiltration. These data suggest that CS, CSE, RBE, OB, and OBE diets significantly reduced the fatty infiltration of liver which would otherwise occur with a high-fat and high-cholesterol diet (Chanutin and Ludewig 1933, Beynen et al 1986).

Animals fed OB and OBE diets had significantly lower liver cholesterol concentrations when compared with all other groups, suggesting that oat bran diets resulted in lower liver cholesterol accumulation as well as reduced fatty infiltration of the liver. A mechanism for cholesterol reduction with OB diets could include an increased excretion of bile acid (de Schrijver et al 1992), which would in turn stimulate the liver to utilize available cholesterol to produce more bile acid. Our previous work has shown liver cholesterol reductions with RB (Kahlon et al 1990; 1992a,b; 1993) and OB diets (Kahlon et al 1990, 1993). The lack of effect of RB on liver cholesterol in this study may be related to the differences in fat sources and level of fat in the diet. The high level of the dietary

TABLE III
Effect of Rice Bran, Oat Bran, and Cellulose + Soy Diets on Plasma Cholesterol (PC), Very Low Density, Low Density, and High Density Lipoprotein Cholesterol (VLDL-C, LDL-C, and HDL-C, respectively) and Total Antioxidants in Hamsters

Diet ^a	Fiber Source	Cholesterol (mg/dL) ^b					Total Antioxidants (mmol/L)
		PC	VLDL-C	LDL-C	HDL-C	LDL-C/HDL-C	
CC	Cellulose	408 ± 33a ^c	159 ± 22a	71 ± 13a	178 ± 13ab	0.40 ± 0.13a	1.60 ± 0.03ab
CS	Cellulose	322 ± 20a	114 ± 10a	46 ± 5ab	162 ± 8b	0.28 ± 0.03ab	1.48 ± 0.03b
CSE	Cellulose	398 ± 59a	151 ± 28a	41 ± 11b	206 ± 11a	0.20 ± 0.04b	1.65 ± 0.05a
RB	Rice bran	439 ± 37a	189 ± 32a	63 ± 14ab	187 ± 6ab	0.32 ± 0.07ab	1.55 ± 0.04ab
RBE	Rice bran	389 ± 27a	146 ± 28a	37 ± 11b	206 ± 11a	0.19 ± 0.04b	1.55 ± 0.03ab
OB	Oat bran	390 ± 41a	179 ± 21a	35 ± 6b	176 ± 8ab	0.20 ± 0.04b	1.48 ± 0.04b
OBE	Oat bran	377 ± 42a	165 ± 14a	36 ± 10b	177 ± 13ab	0.19 ± 0.05b	1.54 ± 0.05ab

^a Cellulose control diet (CC); soy protein added to the cellulose and rice bran diets (diets CS and RB, respectively); oat bran diet (OB). All diets contained butter fat (9.5%); mineral mix (3.5%); vitamin mix (1%); cholesterol (0.5%); DL-methionine (0.3%); choline bitartrate (0.2%); and were equal in total crude fat (20%), total dietary fiber (10%), and N (3%). Vitamin E supplement provided an additional 1,000 IU/kg of diet for CSE, RBE, and OBE.

^b *n* = 5 per treatment, except PC where *n* = 10. Lipoprotein cholesterol values were normalized to total plasma cholesterol values assuming a proportional loss for each class of lipoprotein.

^c Values within a column with different letters differ significantly (*P* ≤ 0.05); means ± standard error.

TABLE IV
Effect of Rice Bran, Oat Bran, and Cellulose + Soy Diets on Liver Weight, Lipid, and Cholesterol in Hamsters

Diet ^a	Fiber Source	Liver Weight (g)	Liver Weight/100 g of		Liver Cholesterol (mg/g of liver)
			Fasting Body Wt (g)	Lipid/100 g of Liver (g)	
CC	Cellulose	11.7 ± 0.5ab ^b	6.66 ± 0.25a	16.1 ± 0.6a	59.4 ± 3.2a
CS	Cellulose	10.8 ± 0.3b	5.90 ± 0.09c	12.7 ± 0.7cd	59.2 ± 2.4a
CSE	Cellulose	11.7 ± 0.9ab	6.15 ± 0.23a-c	12.8 ± 0.4cd	65.7 ± 2.2a
RB	Rice bran	13.0 ± 0.6a	6.54 ± 0.17ab	14.8 ± 0.4ab	59.2 ± 2.4a
RBE	Rice bran	12.9 ± 0.8ab	6.66 ± 0.13a	14.3 ± 0.6bc	64.5 ± 3.4a
OB	Oat bran	12.8 ± 0.6ab	6.18 ± 0.17a-c	12.0 ± 0.5d	47.0 ± 2.2b
OBE	Oat bran	11.8 ± 0.8ab	6.06 ± 0.14bc	12.1 ± 0.6d	49.5 ± 3.4b

^a Cellulose control diet (CC); soy protein added to the cellulose and rice bran diets (diets CS and RB, respectively); oat bran diet (OB). All diets contained butter fat (9.5%); mineral mix (3.5%); vitamin mix (1%); cholesterol (0.5%); DL-methionine (0.3%); choline bitartrate (0.2%); and were equal in total crude fat (20%), total dietary fiber (10%), and N (3%). Vitamin E supplement provided an additional 1,000 IU/kg of diet for CSE, RBE, and OBE.

^b Values within a column with different letters differ significantly (*P* ≤ 0.05); *n* = 10 per treatment; means ± standard error.

cholesterol and fat, combined with long duration of the study would explain, in part, the failure of blood cholesterol to drop and the inability to see a clear response in liver cholesterol. Substitution of soy protein for casein in the cellulose diets had no significant effect on liver cholesterol levels.

Aortic Foam Cell Formation

The percent of foam cell area in the aortic arch was significantly lower in all treatment groups compared with the control group (Fig. 1). The reduction in the percent of foam cell area was 45–54% with CS diets, 49–65% with RB diets, and 59–63% with OB diets. With CS and RB diets, additional dietary vitamin E resulted in 9 and 16% further reductions in foam cell formation, respectively; however, the differences were not significant. The vitamin E supplemented diets in this study contained an additional 1,000 IU of α -tocopheryl acetate/kg of diet (0.1% of diet), which provided approximately an additional 60 IU/kg of body weight per day. This is similar to the amount used by other investigators (Parker et al 1995) in hamsters fed 0.2, 0.4, or 0.8% cholesterol and 10% corn oil, antioxidant-free diets for 10 weeks. Those authors found significant reductions in foam cell area with this level of vitamin E supplementation to each of the diets, but as dietary cholesterol and plasma cholesterol levels increased, the efficacy of the vitamin E diminished. Others (Rein et al 1998) found significant reductions in foam cell area in the aortic arch of hamsters fed 15% fat, 0.2% cholesterol, and 30 IU of vitamin E/kg of diet versus 3 IU of vitamin E/kg of diet in a 30-week study. In those studies, moderate or high levels of vitamin E supplemented diets were compared against an antioxidant-deficient diet or a diet with minimum vitamin E (3 IU/kg of diet). In the present study, the CC diet contained more than adequate vitamin E (50 IU/kg of diet) to maintain growth, so that the extent of foam cell formation may not have been great enough to be significantly reduced by additional vitamin E. It appears that in the current study, the primary effect of these diets was the lowering of LDL-C and the LDL-C/HDL-C ratio, resulting in diminished LDL substrate for foam cell formation and an increase in the protective effect of HDL. Thus, although total plasma cholesterol levels were not significantly lowered by any of the treatments, the potential for plaque formation in the aortic arch by a 20% fat/0.5% cholesterol diet was significantly reduced by these diets.

Fecal Lipid and Neutral Sterol Excretion:

Lipid excretion was significantly greater and apparent lipid percent digestibility ($\frac{\text{intake} - \text{excretion}}{\text{intake}} \times 100$) was significantly lower with all treatment diets during the three-day collection period than lipid excretion and digestibility with the control diet (Table V). Lipid excretion was also significantly different among each of the dietary fiber sources with rice bran > oat bran > cellulose. Apparent lipid digestibility with RB diets was significantly lower than that with all other treatments, and that with OB diets was significantly

lower than that with CS diets. However, the reduced availability of dietary lipid with RB diets had no significant effect on plasma or liver cholesterol levels in this study in contrast to previous work (Kahlon et al 1996a), possibly due in part to the much higher fat content of the diets in this study or to feeding a 0.5% cholesterol diet rather than a cholesterol-free diet during the equilibration period of one week.

Neutral sterol excretion during the three-day fecal collection period was significantly greater with RB diet compared with CC. RB contains more phytosterols when compared with other cereal grains (Saunders 1990), which may account for some of the additional sterol excretion. Plant sterols, especially β -sitosterol, have been shown to interfere with cholesterol absorption (Mattson et al 1982). Neutral sterol excretion with OB and OBE diets was significantly lower than that with CC. This is surprising, in that OB treatments resulted in significantly lower liver lipid and cholesterol when compared with CC. These results suggest that additional mechanisms other than fecal excretion of lipid and neutral sterols may have influenced plasma and liver cholesterol levels in these animals.

In summary, diets containing RB, OB, or CS significantly diminished the atherogenicity of 20% fat, 0.5% cholesterol diets in hamsters as manifested by a 45–65% reduction in foam cell formation in the aortic arch of these animals. This effect was apparently influenced by reductions in the plasma LDL-C level and LDL-C/HDL-C ratios. The level of additional dietary vitamin E did not significantly enhance the protective effect of the diets, suggesting that these diets provided adequate antioxidants or other factors that resulted in reduced foam cell formation. The amount of vitamin E

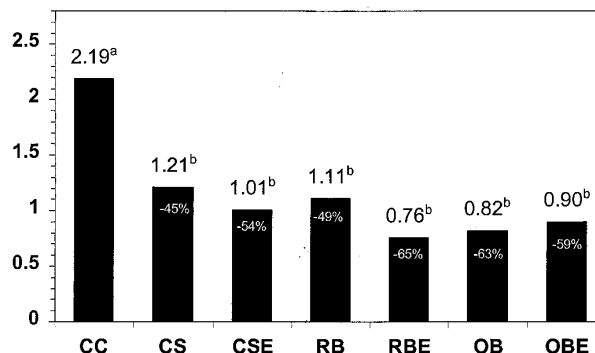


Fig. 1. Relative plaque area (mm²) in the inner bend of the aortic arch in hamsters fed cellulose control (CC), cellulose + soy (CS), CS + vitamin E (CSE), rice bran (RB), RB + vitamin E (RBE), oat bran (OB), and OB + vitamin E (OBE) diets for six weeks. The percent reduction with each treatment compared with the control is indicated on the bars. Mean values followed by different letters are significantly different ($P \leq 0.05$).

TABLE V
Effect of Rice Bran, Oat Bran, and Cellulose + Soy Diets on Lipid Digestibility and Sterol Excretion in Hamsters

Diet ^a	Fiber Source	Lipid Intake (g/3 days)	Lipid Excretion (g/3 days)	Lipid Digestibility (%) ^b	Cholesterol Intake (mg)	Neutral Sterol Excretion (mg)
CC	Cellulose	5.05 ± 0.25ab ^c	0.11 ± 0.01d	97.7 ± 0.1a	126 ± 6ab	33 ± 4bc
CS	Cellulose	5.24 ± 0.19ab	0.16 ± 0.01c	96.9 ± 0.1b	131 ± 5ab	26 ± 3cd
CSE	Cellulose	4.91 ± 0.53b	0.15 ± 0.01c	96.8 ± 0.2b	123 ± 13b	23 ± 3cd
RB	Rice bran	5.89 ± 0.12a	0.38 ± 0.01a	93.5 ± 0.1e	147 ± 3a	55 ± 6a
RBE	Rice bran	5.78 ± 0.11ab	0.39 ± 0.01a	93.2 ± 0.2e	144 ± 3ab	43 ± 5b
OB	Oat bran	5.53 ± 0.11ab	0.25 ± 0.01b	95.4 ± 0.2c	138 ± 3ab	15 ± 1d
OBE	Oat bran	5.28 ± 0.34ab	0.27 ± 0.03b	95.0 ± 0.2d	132 ± 8ab	16 ± 2d

^a Cellulose control diet (CC); soy protein added to the cellulose and rice bran diets (diets CS and RB, respectively); oat bran diet (OB). All diets contained butter fat (9.5%); mineral mix (3.5%); vitamin mix (1%); cholesterol (0.5%); DL-methionine (0.3%); choline bitartrate (0.2%); and were equal in total crude fat (20%), total dietary fiber (10%), and N (3%). Vitamin E supplement provided an additional 1,000 IU/kg of diet for CSE, RBE, and OBE. Three-day feed intake and total fecal collection data (days 37–39).

^b Apparent digestibility, % = $\frac{\text{intake} - \text{excretion}}{\text{intake}} \times 100$.

^c Values within a column with different letters differ significantly ($P \leq 0.05$); $n = 10$ per treatment; means ± standard error.

required to be effective in significantly reducing foam cell formation in hypercholesterolemic animals still needs to be defined. The results of this study suggest that consumption of RB, OB, or soy protein could significantly reduce the development of atherosclerotic plaque formation in at-risk populations.

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