

Lipidemic Response of Hamsters to Rice Bran, Uncooked or Processed White and Brown Rice, and Processed Corn Starch

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ABSTRACT

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This study was undertaken to evaluate the lipidemic response of rice bran and the possible enhancement of its healthful properties by using raw or processed white or brown rice in place of corn starch. All diets contained 10% total dietary fiber, 15% fat, and 0.5% cholesterol. Weanling male golden Syrian hamsters were fed cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), RB with white rice (RBWR), RB with processed white rice (RBPWR), RB with brown rice (RBBR), and RB with processed brown rice (RBPBR) diets. After three weeks, the PCS diet significantly lowered total plasma cholesterol (TC) compared with the CC, CPBR, RBWR, and RBPBR diets. RB and RBBR diets significantly lowered TC

and LDL-C compared with CPBR diet. All the RB-containing and PCS diets significantly lowered liver cholesterol and liver lipid content. Processing white rice increased TDF content 240% and insoluble dietary fiber (IDF) 360%, whereas soluble dietary fiber (SDF) decreased by 25%. Uncooked brown rice contained 7 times as much TDF as uncooked white rice. Processing brown rice decreased its TDF, IDF and SDF contents by 12, 6, and 42%, respectively. The data suggest that a possible mechanism for cholesterol-lowering by rice bran, with or without added raw or processed rice (white or brown), is by decreasing lipid digestibility and increasing neutral sterol excretion, whereas cholesterol-lowering by processed corn starch is mediated through other mechanisms.

Cereal brans are considered desirable for human consumption due to reported health benefits. Extensive research reviewed by Kahlon and Chow (1997) has shown that incorporating rice bran in the diet results in plasma and liver cholesterol reductions that lower the risk of cardiovascular disease. Resistant starch (RS) is defined as the sum of starch and starch degradation products that resist digestion in the small intestine (Asp 1992); RS analyzes as insoluble fiber. Ranhotra et al (1996, 1997) reported that hamsters fed a diet high in dietary fiber (20%) from RS (68% of diet) showed a significant lowering of blood cholesterol and triglyceride (TG) levels when compared with hamsters fed digestible starch. At such a high level of RS (a noncaloric ingredient), the growth response of the young animals was adversely affected (Ranhotra et al 1996). Cooking rice with low amylose (<20%) increased RS from 0.2 to 0.6% (Eggum et al 1993). Bjorck et al (1987) reported that RS in wheat starch was increased from 0.24 to 8% by heating and cooling in four autoclaving cycles. Repeated autoclaving and cooling of cooked rice (white or brown) could increase RS to a level higher than that obtained by cooking. This study was undertaken to determine the increase in RS in rice starch by processing (cooking and five autoclaving-cooling cycles). The lipidemic response of rice bran and the possible enhancement of healthful properties by using raw or processed, white or brown rice in place of corn starch was evaluated in hypercholesterolemic hamsters fed 10% total dietary fiber (TDF), 15% fat, and 0.5% cholesterol diets for three weeks. Stabilized rice bran, uncooked or processed rice (white or brown), and processed corn starch (40% RS) were evaluated. Raw white and brown rice were included for evaluating extent of lipidemic response by processing white and brown rice.

MATERIALS AND METHODS

Stabilized rice bran, brown rice, milled white rice (medium grain with amylose <20%) and processed corn starch were obtained from local mills. Raw white rice and brown rice were cooked in a steam-

heated pot (Lee Metal Products Co., Philadelphia, PA) with water-to-rice ratios of 2.5:1 and 3.0:1, for 45 and 75 min., respectively. Cooked rices were alternately autoclaved at 121°C for 15 min and stored at 4°C overnight for five cycles. After five autoclaving and cooling cycles, processed rice samples were dried at 100°C in a forced-air oven for 24 hr. Uncooked and processed rice samples were ground in a pin mill (Alpine Mill, Augsburg, Germany). Samples were analyzed for dry matter by method 934.01 (AOAC 1990), total dietary fiber (Prosky et al 1988), nitrogen by combustion method 46-30 (AACC 1995) using LECO FP-428 (Leco, St. Joseph, MI), and crude fat by method 920.39C (AOAC 1990). Compositions of uncooked and processed rice (white and brown), rice bran, and processed corn starch are given (Table I). Treatment diets (Table II) were: cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), rice bran with white rice (RBWR), rice bran with processed white rice, (RBPWR), rice bran with brown rice (RBBR), and rice bran with processed brown rice (RBPBR). All diets contained 10% TDF, 0.5% cholesterol, 15% fat (3% butter), 49.5% digestible starch, and 3.0% N. Digestible starch in all the rice diets was provided solely by the rice ingredients, with the exception of RB diet, to which 25.8% corn starch was added to provide a total of 49.5% digestible starch. Starch dry matter in rice bran, uncooked or processed white and brown rice was determined by difference (total – [fat + protein + total dietary fiber + ash]). To balance the crude fat level, peanut oil was used because its fatty acid composition is similar to that of rice bran oil (Kahlon et al 1996a).

Male, 23-day-old weanling, golden Syrian hamsters (Charles River Laboratories, Kingston, NY) 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 basal diet (CC diet without added cholesterol) for four days. After equilibration, animals were weighed and assigned to one of eight diet groups by selective randomization (blocked by weight, one animal per diet group from each block), 10 animals per group. Hamsters were fed ad libitum, as paired or limit feeding ignores the influence of diet palatability, metabolizable energy, and individual animal growth potential and does not represent normal feed consumption. 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

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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).

After two weeks of feeding the treatment diets, total feces were collected for four days (days 16–19). Samples were analyzed for dry matter by method 934.01 (AOAC 1990), crude fat by method 920.39C (AOAC 1990), and total neutral sterols (same procedure as described later for liver cholesterol). At the end of the 21-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 × g for 30 min at 4°C to obtain plasma. Livers were excised, rinsed, blotted, weighed, and kept on dry ice. Liver and plasma aliquots were stored at –70°C until analysis.

Pooled samples of fresh plasma 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 μL/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 (TC) and lipoprotein cholesterol (VLDL-C, LDL-C, and HDL-C, respectively) and triglycerides were analyzed by an enzymatic colorimetric procedure for cholesterol (diagnostic kit no. 352, Sigma Chemicals, St. Louis, MO) and for triglycerides (Sigma diagnostic kit no. 405). Values were determined using standard curves obtained by running several concentrations of standards provided with the respective kits.

Each liver was individually thawed, minced, and thoroughly mixed to obtain a homogeneous 0.3-g 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.

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

Effect of Processing on Resistant Starch

Five cycles of autoclaving and cooling of cooked rice increased total dietary fiber (TDF) from 0.46 to 1.10%. This increase in TDF was a result of elevation in insoluble dietary fiber (IDF) by 360% and reduction in soluble dietary fiber by 25%. Because RS analyzes as IDF (Asp 1992), this shift in IDF could safely be considered to result from formation of RS by processing. Data suggest that cooking and repeated autoclaving and cooling milled rice more than doubled RS; however, this increase in RS was not similar to the elevation (20×) reported by processing wheat starch (Bjorck et al 1987). The elevation in RS by processing milled white rice was 57% more than could have resulted by cooking (Eggum et al 1993). In contrast to white rice, processing decreased TDF, IDF, and SDF (12, 6, and 42%, respectively) in brown rice. Brown rice IDF was degraded by processing, suggesting that some of the TDF components were made digestible by the autoclaving and cooling cycles.

Feed Intake and Weight Gain

Initial weights (57 ± 1 g, mean \pm standard error of the mean [SEM]) after four days of equilibration on the basal diet were similar in all treatment groups. After consuming treatment diets for 21 days, hamsters fed RB, RBWR, RBPWR, and RBPBR diets had significantly higher total feed intake than those fed the CC diet

TABLE I
Composition (%dry matter) of Rice Bran, Raw and Processed White and Brown Rice, and Processed Corn Starch

Ingredient	Total Dietary Fiber	Insoluble Dietary Fiber	Soluble Dietary Fiber	Fat	Nitrogen	Dry Matter
Rice bran	18.35	16.01	2.35	21.52	2.59	94.13
White rice	0.46	0.26	0.20	0.75	1.00	86.07
White rice, processed	1.10	0.94	0.15	0.42	0.93	98.36
Brown rice	3.31	2.78	0.53	3.32	1.12	86.33
Brown rice, processed	2.91	2.60	0.31	3.61	1.14	98.07
Processed corn starch	41.53	41.05	0.49	0.34	na	91.37

TABLE II
Diet Composition

Ingredients ^b	Diet (g/kg) ^a							
	CC	PCS	CPBR	RB	RBWR	RBPWR	RBBR	RBPBR
Cellulose	100	...	83	...	...	...	...	...
Processed corn starch	...	241	...	...	...	...	...	...
Corn starch	495	354	...	258	...	...	...	...
Casein	200	200	158	109	92	95	95	93
Peanut oil	120	120	100	3	2	5	5	2
Rice bran	...	...	...	545	538	528	485	494
White rice	...	...	...	...	283	...	...	...
Processed white rice	...	...	...	...	...	287	...	...
Brown rice	...	...	...	...	...	...	330	...
Processed brown rice	...	...	574	...	...	...	...	326

^a All diets contained butter fat, 3.0%; 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 (15%), total dietary fiber (10%), and N (3%). Diets: cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), RB with white rice (RBWR), RB with processed white rice (RBPWR), RB with brown rice (RBBR), and RB with processed brown rice (RBPBR).

^b Starch dry matter in rice bran, uncooked or processed white and brown rice was determined by difference (total – [fat + protein + total dietary fiber + ash]).

(Table III). Feed intake values for RBWR and RBPBR were also significantly higher than those for PCS, CPBR, and RBBR groups. There was significantly more feed required per unit gain in animals consuming RB and RBWR diets compared with those fed CPBR diet. Values for RBWR group were also significantly higher than PCS group. Feed efficiency (feed/gain) values for CC group were similar to all other treatments. Dry matter digestibility for diets containing rice bran (RB, RBWR, RBPWR, RBBR, and RBPBR) was significantly lower than with CC, PCS, and CPBR diets. Lower digestibility values suggest that diets containing rice bran promote fecal bulking which could improve regularity and prevent constipation.

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

After the 21-day feeding period, animals fed PCS diet had significantly lower total plasma cholesterol (TC) values compared with those fed CC, CPBR, RBWR, and RBPBR diets (Table IV). TC values for RB group were significantly lower than the values for CPBR and RBWR group. TC in RBPWR and RBBR groups was also significantly lower than TC in CPBR-fed animals. Higher TC

values observed with CPBR diet containing 8.3% cellulose and processed brown rice compared with CC (10% cellulose) diet is difficult to explain. A significant reduction in TC with 24% processed corn starch (10% TDF) diet without affecting weight gain suggests that processed corn starch at realistic dietary levels is hypocholesterolemic. Previously, Ranhotra et al (1996) reported a significant TC reduction with 68% resistant corn starch diet (20% TDF), although weight gains were also significantly lowered. In an earlier study, Kahlon et al (1990) reported TC values of 274 mg/dL with rice bran diet versus 402 mg/dL with cellulose control diet (a significant reduction) in hamsters fed 11% fat and 0.5% cholesterol diets for three weeks. TC values in the current study, after three weeks with 15% fat and 0.5% cholesterol diets, were 306 mg/dL for rice bran and 334 mg/dL for cellulose control. The 12% higher TC values with rice bran diet is expected due to the 4% higher fat (3% butter) in the current study; however, 17% lower TC values with cellulose diet with a higher fat content in the current study is unexpected and difficult to explain, although the direction of response in both studies is the same. The response in hamsters to atherogenic diets varies with the age, sex, source,

TABLE III

Effect of Rice Bran, Processed White or Brown Rice, and Processed Corn Starch on Feed Intake and Apparent Dry Matter Digestibility in Hamsters

Diet ^a	Fiber Source, % Starch Source, %	Feed Intake (g)	Feed Efficiency (feed/gain) ^b	Dry Matter Digestibility (%) ^c
CC	Cellulose, 10.0	164 ± 2c ^d	3.7 ± 0.1a-c	85.0 ± 0.2a
PCS	Processed corn starch, 24.1	174 ± 3bc	3.6 ± 0.1bc	85.4 ± 0.8a
CPBR	Cellulose, 8.3	168 ± 4bc	3.5 ± 0.1c	85.1 ± 0.3a
	Processed brown rice, 57.4			
RB	Rice bran, 54.5	179 ± 3ab	3.9 ± 0.1ab	82.3 ± 0.8b
RBWR	Rice bran, 53.8	188 ± 5a	4.0 ± 0.1a	83.1 ± 0.3b
	White rice flour, 28.3			
RBPWR	Rice bran, 52.8	179 ± 5ab	3.7 ± 0.1a-c	83.2 ± 0.5b
	Processed white rice, 28.7			
RBBR	Rice bran, 48.6	175 ± 3bc	3.7 ± 0.1a-c	82.7 ± 0.4b
	Brown rice, 33.0			
RBPBR	Rice bran, 49.3	188 ± 3a	3.7 ± 0.1a-c	82.5 ± 0.3b
	Processed brown rice, 32.6			

^a All diets contained butter fat, 3.0%; 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 (15%), total dietary fiber (10%), and N (3%). Diets: cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), RB with white rice (RBWR), RB with processed white rice (RBPWR), RB with brown rice (RBBR), and RB with processed brown rice (RBPBR).

^b Mean values ± standard error of the mean (SEM) = 57 ± 1, 48 ± 2, and 105 ± 2 g, respectively, for initial body weights, weight gain, and final weight (similar among all treatments).

^c Apparent digestibility = (intake - excretion)/intake. Based on feed intake and fecal excretion data for four days (days 16-19).

^d Values followed by the same letter in the same column are not significantly different (P < 0.05); n = 10 per treatment.

TABLE IV

Effect of Rice Bran, Processed White or Brown Rice, and Processed Corn Starch Diets on Plasma Total Cholesterol (TC) and Very Low Density, Low Density, and High Density Lipoprotein Cholesterol (VLDL-C, LDL-C, and HDL-C) in Hamsters^a

Diet ^b	Fiber Source %, Starch Source %	TC (mg/dL)	VLDL-C (mg/dL)	LDL-C (mg/dL)	HDL-C (mg/dL)	HDL-C to TC Ratio, %	Triglycerides (mg/dL)
CC	Cellulose, 10.0	334 ± 17a-c ^c	73 ± 7b	66 ± 2ab	195 ± 8ab	58.3 ± 1.5a	276 ± 64b
PCS	Processed corn starch, 24.1	289 ± 10d	70 ± 6b	54 ± 3b	165 ± 4cd	57.3 ± 1.1ab	274 ± 38b
CPBR	Cellulose, 8.3	362 ± 9a	95 ± 12ab	70 ± 6a	197 ± 4a	54.7 ± 2.0ab	527 ± 71a
	Processed brown rice, 57.4						
RB	Rice bran, 54.5	306 ± 6cd	80 ± 9ab	53 ± 9b	173 ± 10cd	56.5 ± 3.0ab	250 ± 30b
RBWR	Rice bran, 53.8	341 ± 8ab	107 ± 5a	58 ± 3ab	176 ± 2cd	51.7 ± 0.9b	536 ± 89a
	White rice flour, 28.3						
RBPWR	Rice Bran, 52.8	318 ± 11b-d	83 ± 11ab	57 ± 3ab	179 ± 2bc	56.4 ± 1.7ab	364 ± 77ab
	Processed white rice, 28.7						
RBBR	Rice bran, 48.6	312 ± 11b-d	97 ± 11ab	54 ± 4b	161 ± 6d	51.8 ± 1.8b	410 ± 90ab
	Brown rice, 33.0						
RBPBR	Rice bran, 49.3	332 ± 12a-c	90 ± 10ab	59 ± 3ab	183 ± 4a-c	55.3 ± 1.3ab	395 ± 62ab
	Processed brown rice, 32.6						

^a n = 5 per treatment, except TC, where n = 10; lipoprotein cholesterol values were normalized to TC values, assuming a proportional loss for each class of lipoprotein.

^b All diets contained butter fat, 3.0%; 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 (15%), total dietary fiber (10%), and N (3%). Diets: cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), RB with white rice (RBWR), RB with processed white rice (RBPWR), RB with brown rice (RBBR), and RB with processed brown rice (RBPBR).

^c Mean values ± standard error of the mean (SEM) followed by the same letter in the same column are not significantly different (P < 0.05).

and strain of the animals (Ayyad et al 1993, Trautwein et al 1993, Robins et al 1995).

VLDL-C values for CC and PCS diets were significantly lower than those fed RBWR diet (Table IV). The highest VLDL-C value (107 mg/dL observed with RBWR diet) may be due in part to highest feed (lipid) consumption by this group for the duration of the study (Table III). VLDL-C may be considered an atherogenic risk factor because it is a precursor for the atherogenic LDL-C (Marzetta et al 1990). The negative effect of raising VLDL-C by raw rice was ameliorated by processing rice, as VLDL-C values for RBPWR (83 mg/dL) were similar to those with CC and PCS diets, the treatments with the lowest VLDL-C values (73 and 70 mg/dL, respectively).

LDL-C values in hamsters fed the various treatment diets were similar to those with the CC diet. LDL-C values with PCS, RB and RBBR diets were significantly lower than those with CPBR diet. The proportion of LDL-C with all diets containing rice bran was 17–18% of TC compared with 20% for CC diet. The normal lipoprotein profile of hamster plasma by sequential density gradient ultracentrifugation contains VLDL (20%), LDL (25%), and HDL (55%) cholesterol (Goulinet and Chapman 1993, Kahlon et al 1993). HDL-C values for animals fed PCS, RB, RBWR, and RBBR diets were significantly lower than in those fed CC and CPBR diets. The reduction in TC with PCS and RB diets compared with CPBR diet appears to be due to the reduction in

both atherogenic and nonatherogenic fractions. HDL-C as a percent of TC remained in the normal range (54–58% of TC) in all the treatments except RBWR and RBBR, where it was 52%. The negative effect of RBWR and RBBR diets on HDL-C may in part be due to a higher lipid intake in these groups toward the end of the study (Table V).

CPBR and RBWR diet-fed animals had significantly higher plasma triglycerides (TG) compared with those fed CC, PCS, and RB diets (Table IV). High TG is suggested to be an atherogenic risk factor. In this study, CPBR diet (cellulose with processed brown rice) appears to be the most atherogenic, with significantly high TC, LDL-C, and TG levels. Rice bran with raw white rice (RBWR) diet also appears to be atherogenic with significantly higher VLDL-C and TG levels compared with control group. The higher atherogenic risk observed with the RBWR diet may be due, in part, to higher feed (fat and cholesterol) consumption by this group (Table III), but such atherogenic effects could be ameliorated by repeated autoclaving-cooling cycles.

Lipid and cholesterol intake during the four-day fecal collection period (days 16–19) in groups fed RBWR and RBBR diets was significantly higher than in those fed CC and CPBR diets (Table V). Lipid excretion with CPBR and all RB-containing diets was significantly higher than with CC diet. Lipid excretion values for all RB-containing diets were also significantly higher than for PCS

TABLE V
Effect of Rice Bran, Processed White or Brown Rice, and Processed Corn Starch Diets on Lipid Digestibility and Sterol Excretion in Hamsters

Diet ^a	Fiber Source, %, Starch Source, %	Lipid			Cholesterol Intake (mg)	Neutral Sterol Excretion (mg)
		Intake (g)	Excretion (g)	Digestibility ^b (%)		
CC	Cellulose, 10.0	4.5 ± 0.1b ^c	0.10 ± 0.01c	97.7 ± 0.1a	150.2 ± 4.5b	44.8 ± 1.9c
PCS	Processed corn starch, 24.1	4.8 ± 0.1ab	0.12 ± 0.01bc	97.5 ± 0.1a	158.5 ± 3.4ab	57.1 ± 2.5c
CPBR	Cellulose, 8.3	4.6 ± 0.1b				
	Processed brown rice, 57.4		0.16 ± 0.01b	96.6 ± 0.1b	152.9 ± 4.2b	45.9 ± 2.6c
RB	Rice bran, 54.5	4.8 ± 0.1ab	0.42 ± 0.02a	91.3 ± 0.3c	160.7 ± 3.7ab	107.3 ± 7.6ab
RBWR	Rice bran, 53.8	5.0 ± 0.2a				
	White rice flour, 28.3		0.43 ± 0.01a	91.4 ± 0.1c	167.6 ± 5.2a	104.7 ± 6.0ab
RBPWR	Rice bran, 52.8	4.9 ± 0.1ab				
	Processed white rice, 28.7		0.42 ± 0.02a	91.3 ± 0.2c	162.2 ± 4.6ab	102.1 ± 10.4ab
RBBR	Rice bran, 48.6	5.1 ± 0.1a				
	Brown rice, 33.0		0.45 ± 0.01a	91.2 ± 0.1c	169.1 ± 4.3a	114.8 ± 4.9a
RBPBR	Rice bran, 49.3	4.8 ± 0.2ab				
	Processed brown rice, 32.6		0.42 ± 0.01a	91.2 ± 0.2c	159.1 ± 5.5ab	89.7 ± 4.9b

^a All diets contained 10% total dietary fiber, 15% crude fat, 0.5% cholesterol, and 3% N. Diets: cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), RB with white rice (RBWR), RB with processed white rice (RBPWR), RB with brown rice (RBBR), and RB with processed brown rice (RBPBR).

^b Apparent digestibility = ([intake - excretion]/intake). Based on feed intake and fecal excretion data for four days (days 16–19).

^c Mean values ± standard error of the mean (SEM) followed by the same letter in the same column are not significantly different ($P < 0.05$); $n = 10$ per treatment.

TABLE VI
Effect of Rice Bran, Processed White or Brown Rice, and Processed Corn Starch Diets on Liver Weight, Lipid, and Cholesterol in Hamsters

Diet ^a	Fiber Source, %, Starch Source, %	Liver wt	Lipid	Liver Cholesterol
		(g/100 g of fasting body wt)	(g/100 g of liver)	(mg/g of liver)
CC	Cellulose, 10.0	5.9 ± 0.1a ^b	21.7 ± 1.0a	82.6 ± 1.9a
PCS	Processed corn starch, 24.1	5.4 ± 0.1cd	17.9 ± 1.0bc	72.6 ± 2.1b
CPBR	Cellulose, 8.3	5.7 ± 0.1ab	19.6 ± 0.4b	84.7 ± 2.0a
	Processed brown rice, 57.4			
RB	Rice bran, 54.5	5.2 ± 0.1d	16.6 ± 0.6cd	59.4 ± 2.5c
RBWR	Rice bran, 53.8	5.5 ± 0.1b-d	15.4 ± 0.3de	59.8 ± 1.5c
	White rice flour, 28.3			
RBPWR	Rice bran, 52.8	5.6 ± 0.1bc	14.7 ± 0.5e	59.5 ± 2.0c
	Processed white rice, 28.7			
RBBR	Rice bran, 48.6	5.2 ± 0.1d	14.3 ± 0.4e	57.4 ± 1.7c
	Brown rice, 33.0			
RBPBR	Rice bran, 49.3	5.5 ± 0.1b-d	14.9 ± 0.2de	62.9 ± 1.5c
	Processed brown rice, 32.6			

^a All diets contained 10% total dietary fiber, 15% crude fat, 0.5% cholesterol, and 3% N. Diets: cellulose control (CC), processed corn starch (PCS), cellulose with processed brown rice (CPBR), rice bran (RB), RB with white rice (RBWR), RB with processed white rice (RBPWR), RB with brown rice (RBBR), and RB with processed brown rice (RBPBR).

^b Mean values ± standard error of the mean (SEM) followed by the same letter in the same column are not significantly different ($P < 0.05$); $n = 10$ per treatment.

and CPBR diets. Lipid apparent digestibility for animals fed CPBR and all RB-containing diets was significantly lower than in those fed CC and PCS diets. Lipid digestibility with RB-containing diets was also significantly lower than with CPBR diet. The data suggest that a possible mechanism for lower accumulation of liver lipid and cholesterol in animals fed rice bran with or without added raw or processed rice (white or brown) is diminished digestibility of lipid in these diets. The endogenous lipid in rice bran appears to be less available than lipid added to the diets. Neutral sterol excretion with all RB-containing diets was significantly higher than with CC, PCS, and CPBR diets. Neutral sterol excretion values with RBBR diet were significantly higher than those with RBPBR diet. These data suggest that a possible mechanism for cholesterol lowering by rice bran with or without added raw or processed rice (white or brown) is by increasing sterol excretion. The data further suggest that processing brown rice could lower its sterol excretion potential, a reflection of the reduced TDF, IDF, and SDF content of brown rice resulting from processing (Table I).

Liver Lipid and Cholesterol

Liver weight/100 g of fasting body weight in hamsters fed PCS and any of the diets containing rice bran was significantly lower than in those fed CC diet (Table VI). Liver weights were lowest for animals fed RB or RBBR diets; these values were also significantly lower than those for animals fed CPBR and RBPWR diets. Liver weight differences may be due to fatty infiltration resulting from impaired lipid metabolism which occurs with high-fat and cholesterol diets (Ayyad et al 1993). There was significantly lower liver lipid in hamsters fed all treatment diets compared with those fed the CC control diet. Lowest liver lipid values observed were with RBPWR and RBBR diets; these values were significantly lower than diets with PCS, CPBR, and RB diets. Liver lipid values for animals fed RB, RBWR, and RBPBR were also lower than those fed CPBR diet. All diets containing rice bran in this study reduced liver lipid accumulation by 24–34% (significant effect). These results agree with our previous studies in which we observed significant liver lipid reductions in hamsters fed rice bran diets (Kahlon et al 1992b, 1996a). These data suggest that diets containing processed corn starch, rice bran with or without white or brown rice, or processed (white or brown) rice significantly reduced the fatty infiltration of liver that would otherwise occur with a high-fat and high-cholesterol diet (Chanutin and Ludewig 1933, Beynen et al 1986).

Animals fed processed corn starch or any of the diets containing rice bran had significantly lower liver cholesterol (mg/g of liver) compared with CC and CPBR groups. The groups fed RB-containing diets resulted in significantly lower liver cholesterol compared with the processed corn starch-fed animals. The liver data suggest that processed corn starch and rice bran with or without raw or processed rice (white or brown) diets result in lower liver cholesterol accumulation as well as reduced fatty infiltration of the liver. A mechanism postulated for cholesterol reduction with cereal bran diets is increased excretion of bile acid (de Schrijver et al 1992), which in turn stimulates the liver to utilize available cholesterol to produce more bile acid. Our previous work has shown liver cholesterol reductions with rice bran (Kahlon et al 1990; 1992a,b; 1993; 1996a). Significant liver lipid and cholesterol reduction with RS from corn starch diet (10% TDF) is very encouraging. Previously, Ranhotra et al (1996) reported significant elevations in liver lipid and liver cholesterol with RS from corn starch diet (21% TDF). The liver is the principle organ for lipid, cholesterol, and bile acid metabolism. While plasma cholesterol values are considered as indicators of atherosclerotic risk, they are influenced by cholesterol and fat intake, duration of fasting, and are subject to homeostatic mechanisms; therefore, liver response for dietary lipidemic evaluation is critical. In human studies, liver cholesterol data are

normally not available. However, in animal studies, liver cholesterol response may be considered a more reliable indicator of cholesterol status than plasma data in evaluating the lipidemic effects of diets.

In conclusion, processing white rice increased TDF content 240% and insoluble dietary fiber (IDF) 360%, whereas soluble dietary fiber (SDF) decreased by 25%. Uncooked brown rice contained 7× as much TDF as uncooked white rice. Processing brown rice decreased its TDF, IDF, and SDF content by 12, 6, and 42%, respectively. Processing white or brown rice did not significantly influence lipidemic response as it lowered SDF, one of the components associated with cholesterol lowering, and the magnitude of TDF change was also small. The results of this study show that processed corn starch diet (10% TDF diet) significantly lowered plasma and liver cholesterol. All the RB-containing (RB, RBWR, RBPWR, RBBR, RBPBR) diets significantly lowered liver cholesterol. RB and RBBR diets significantly lowered TC and LDL-C compared with CPBR diet. The data suggest that a possible mechanism for cholesterol-lowering by rice bran, with or without added raw or processed rice (white or brown), is decreased lipid digestibility and increased neutral sterol excretion; cholesterol-lowering by processed corn starch is through other unidentified mechanisms.

LITERATURE CITED

- American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. The Association: St. Paul, MN.
- AOAC. 1990. Official Methods of Analysis of the Association of Official Analytical Chemists, 15th ed. The Association: Arlington, VA.
- Asp, N.-G. 1992. Resistant starch. *Eur. J. Clin. Nutr.* 46 (suppl. 2): S1-2.
- Ayyad, N., Cohen, B. I., Mosbach, E. J., Miki, S., Mikami, T., Mikami, Y., and Stenger, R. J. 1993. Age, sex and source of hamster affect experimental cholesterol cholelithiasis. *Lipids* 28:981-986.
- Beynen, A. C., Danse, L. H. J. C., Van Leeuwen, F. X. R., and Speijers, G. J. A. 1986. Cholesterol metabolism and liver pathology in inbred strains of rats fed a high-cholesterol, high-cholelate diet. *Nutr. Rep. Int.* 34:1079-1087.
- Bjorck, I., Nyman, M., Pedersen, B., Siljestrom, M., Asp, N.-G., and Eggum, B. O. 1987. Formation of enzyme resistant starch during autoclaving of wheat starch: Studies in vitro and in vivo. *J. Cereal Sci.* 6:159-172.
- Carlson, S. E., and Goldfarb, S. 1977. A sensitive enzymatic method for the determination of free and esterified tissue cholesterol. *Clin. Chim. Acta* 79: 575-582.
- Chanutin, A., and Ludewig, S. 1933. The effect of cholesterol ingestion on tissue lipids of rats. *J. Biol. Chem.* 102:57-65.
- Committee on Care and Use of Laboratory Animals. 1985. Guide for the care and use of laboratory animals. Institute of Laboratory Animal Resources Commission of Life Sciences, National Research Council. Publ. 85-23 (rev.) National Institutes of Health: Washington, DC.
- De Schrijver, R., Fremaut, D., and Verheyen, A. 1992. Cholesterol-lowering effects and utilization of protein, lipid, fiber and energy in rats fed unprocessed and baked oat bran. *J. Nutr.* 122:1318-1324.
- Eggum, B. O., Juliano, B. O., Perez, C. M., and Acedo, E. F. 1993. The resistant starch, undigestible energy and undigestible protein contents of raw and cooked milled rice. *J. Cereal Sci.* 18:159-170.
- Goulinet, S., and Chapman, J. M. 1993. Plasma lipoproteins in the golden syrian hamster (*Mesocricetus auratus*): Heterogeneity of apoB- and apoA-1-containing particles. *J. Lipid Res.* 34:943-959.
- Havel, R. J., Eder, H. A., and Bragdon, J. H. 1955. The distribution and chemical composition of ultracentrifugally separated lipoproteins in human serum. *J. Clin. Invest.* 34:1345-1353.
- Kahlon, T. S., Saunders, R. M., Chow, F. I., Chiu, M. M., and Betschart, A. A. 1990. Influence of rice bran, oat bran, and wheat bran on cholesterol and triglycerides in hamsters. *Cereal Chem.* 67:439-443.
- Kahlon, T. S., Chow, F. I., Sayre, R. N., and Betschart, A. A. 1992a. Cholesterol-lowering in hamsters fed rice bran at various levels, defatted rice bran and rice bran oil. *J. Nutr.* 122:513-519.
- Kahlon, T. S., Saunders, R. M., Sayre, R. N., Chow, F. I., Chiu, M. M., and Betschart, A. A. 1992b. Cholesterol-lowering effects of rice bran and rice bran oil fractions in hypercholesterolemic hamsters. *Cereal Chem.* 69:485-489.
- Kahlon, T. S., Chow, F. I., Knuckles, B. E., and Chiu, M. M. 1993. Choles-

- terol-lowering effects in hamsters of β -glucan-enriched barley fraction, dehulled whole barley, rice bran, and oat bran and their combinations. *Cereal Chem.* 70:435-440.
- Kahlon, T. S., Chow, F. I., Chiu, M. M., Hudson, C. A., and Sayre, R. N. 1996a. Cholesterol-lowering by rice bran and rice bran oil unsaponifiable matter in hamsters. *Cereal Chem.* 73:69-74.
- Kahlon, T. S., Chow, F. I., and Sayre, R. N. 1996b. Quantitative extraction of hamster liver lipid and cholesterol with supercritical carbon dioxide. *J. Am. Oil Chem. Soc.* 73:1341-1342.
- Kahlon, T. S., and Chow, F. I. 1997. Hypocholesterolemic effects of oat, rice, and barley dietary fibers and fractions. *Cereal Foods World* 42:86-92.
- Kahlon, T. S., Edwards, R. H., and Chow, F. I. 1998. Effect of extrusion on hypocholesterolemic properties of rice, oat, corn, and wheat bran diets in hamsters. *Cereal Chem.* 75:897-903.
- Marzetta, C. A., Foster, D. M., and Brunzell, J. D. 1990. Conversion of plasma VLDL and IDL precursors into various LDL subpopulations using density gradient ultracentrifugation. *J. Lipid Res.* 31:975-984.
- Prosky, L., Asp, N.-G., Schweizer, T. F., De Vries, J. W., and Furda, I. 1988. Determination of insoluble, soluble and total dietary fiber in foods and food products: Collaborative study. *J. Assoc. Off. Anal. Chem.* 71:1017.
- Ranhotra, G. S., Gelroth, J. A., and Glaser, B. K. 1996. Effect of resistant starch on blood and liver lipids in hamsters. *Cereal Chem.* 73:176-178.
- Ranhotra, G. S., Gelroth, J. A., and Leinen, S. D. 1997. Hypolipidemic effect of resistant starch in hamsters is not dose dependent. *Nutr. Res.* 17:317-323.
- Robins, S. J., Fasulo, J. M., Patton, G. M., Schaefer, E. J., Smith, D. E., and Ordovas, J. M. 1995. Gender differences in the development of hyperlipemia and atherosclerosis in hybrid hamsters. *Metabolism* 44:1326-1331.
- Steel, R. G. D., and Torrie, J. H. 1960. *Principles and Procedures of Statistics*. McGraw-Hill: New York.
- Trautwein, E. A., Liang, J., and Hayes, K. C. 1993. Cholesterol gallstone induction in hamsters reflects strain differences in plasma lipoproteins and bile acid profiles. *Lipids* 28:305-312.

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