

# Extrusion Conditions Modify Hypocholesterolemic Properties of Wheat Bran Fed to Hamsters

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## ABSTRACT

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Wheat bran was extruded in a twin-screw extruder at five specific mechanical energy (SME) levels (0.120, 0.177, 0.234, 0.291, and 0.358 kWh/kg, dwb) and the cholesterol-lowering effects were compared with those of unprocessed wheat bran when fed to four-week-old male golden Syrian hamsters ( $n = 10/\text{treatment}$ ) for three weeks. Diets contained 10% total dietary fiber, 10.3% fat, 3% nitrogen, and 0.4% cholesterol. Plasma total cholesterol and very-low-density lipoprotein cholesterol were significantly lower with 0.120 kWh/kg extruded wheat bran diet compared with the unextruded wheat bran control. Total triglycerides were significantly lower with 0.120 and 0.177 kWh/kg wheat bran diets compared with those fed 0.291 and 0.358 kWh/kg extruded wheat bran diets. Cholesterol digestibility, total liver cholesterol, and total liver lipids were significantly lower with all the extruded wheat bran diets compared

with the unextruded wheat bran control. Cholesterol digestibility for the 0.291 kWh/kg wheat bran diet was also significantly lower than all other extruded diets. Significantly more sterols were excreted with diets containing 0.291 and 0.358 kWh/kg extruded wheat bran compared with the unextruded wheat bran control. Wheat bran extruded with 0.291 kWh/kg diet resulted in a 13% reduction in plasma cholesterol and a 29% reduction in low-density lipoprotein cholesterol. Considering lowest cholesterol digestibility, significantly higher sterol excretion, desirable plasma lipoprotein cholesterol profile, significantly lower liver weight, total liver lipids, and liver cholesterol, the wheat bran extruded at 0.291 kWh/kg appeared to have the most desirable healthful potential. Data suggest that cholesterol-lowering potential of wheat bran could be enhanced by optimizing the energy input used in the extrusion process.

Many popular foods of cereal origin (ready-to-eat cereals, snacks, and pasta) are produced by extrusion processing. The extrudates have physical and chemical characteristics different from those of the original food (Harper 1979; Linko 1981). These differences depend on the extrusion parameters (energy input, residence time, type of extruder used) and the physical and chemical properties (moisture, fat, and fiber content) of the raw material. Extrusion alters the starch, protein, fat, and fiber components of cereals, forming complexes that may affect cholesterol-lowering properties. Extrusion processing could result in fragmentation of proteins, starches, and nonstarch polysaccharides, creating reactive molecules that may form new linkages that could result in enhancing health potential (Camire 1998). Wheat bran in general does not lower cholesterol. In many studies, wheat bran has been used as a control treatment to evaluate cholesterol-lowering effects of other cereals (Tredger et al 1991; Uusitupa et al 1992; Whyte et al 1992; Illman et al 1993; Jackson and Topping 1993; Rouanet et al 1993; Anderson et al 1994; Lewis et al 1996). Blood samples taken 7 hr after a test meal containing wheat fiber resulted in significantly lower serum triglycerides (Cara et al 1992). Extruded foods including wheat bran have lowered blood cholesterol in humans (Meshcheriakova et al 1995). Wheat bran when extruded at low specific mechanical energy (SME) of 0.221 kWh/kg has significantly lowered cholesterol in hamsters compared with unextruded wheat bran, whereas high SME of 0.442 kWh/kg resulted in cholesterol values similar to those of unextruded and low-SME extruded wheat bran (Kahlon et al 1998). These observations demonstrated that extrusion of wheat bran under the appropriate SME conditions could enhance its potential as a hypocholesterolemic food ingredient. The present study was conducted extruding wheat bran at five SME levels (0.120, 0.177, 0.234, 0.291, 0.358 kWh/kg, dwb) to optimize the extrusion energy input needed to maximize cholesterol-lowering effects.

## MATERIALS AND METHODS

Male, 24-day-old weanling golden Syrian hamsters (Siemonsen, Gilroy, CA) were housed individually in wire-bottomed cages in a controlled environment (20–22°C, 60% rh, 12-hr light and dark cycle) and fed ad libitum (rat laboratory chow 5001M, Purina, Richmond, IN) for one week. Animals were then weighed and assigned to one of six treatments by selective randomization (blocked by weight, one animal per treatment from each block, 10 animals per treatment). Total feed consumption was measured, fresh feed was provided twice weekly, and animals were weighed once a week during the 21-day feeding period. 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 specified by the Committee on Care and Use of Laboratory Animals (1985).

### Extrusion Cooking Conditions

Wheat bran of hard red winter wheat was obtained from a local mill. A twin-screw extruder (Continua 37, Werner and Pfleiderer, Ramsey, NJ) system with co-rotating and closely intermeshing screws was used to process wheat bran materials. The extruder system was controlled by a programmable controller (Series One Plus, General Electric, Charlottesville, VA). The extruder had eight barrel sections, each with a length of 160 mm. The screw diameter was 37 mm, and the total configured screw length was 1,324 mm, which gave an overall L/D ratio of 35.78. The screw configuration used for extrusion was a combination of right- and left-handed screw elements and kneading blocks: RHSE, 40 PD x 150; RHSE, 26 PD x 60; {RHKB x 40; Spacer (SP) x 1; LHKB x 40}; RHSE, 26 PD x 40; {RHKB x 40; SP x 1; LHKB x 40}; RHSE, 26 PD x 60; {LHKB x 40; SP x 1; RHKB x 40; SP x 1; LHKB x 40}; RHSE, 26 PD x 60; {RHKB x 40; SP x 1; LHKB x 20; SP x 1; LHKB x 20; SP x 1; RHKB x 20; SP x 1; LHKB x 20}; RHSE, 26 PD x 60; {RHSE, 40 PD x 10; SP x 1; LHSE, 40 PD x 10; SP x 1} x 5; RHSE, 26 PD x 100; {RHSE, 40 PD x 10; SP x 1; LHSE, 40 PD x 10; SP x 1} x 8; RHSE, 40 PD x 100. Screws were driven by a 11.2kW variable speed DC drive (model DC300, General Electric) operated at 400 rpm. The die plate contained two circular openings 2.5 mm in diameter. The temperature of each barrel section was controlled by a recirculating hot oil system (Mokon model MK4X06-TI, Protective Closures, Buffalo, NY). Temperature of the barrel sections was maintained within  $\pm 1^\circ\text{C}$  by a cool heat

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exchanger (packaged chiller model CD-5-A, Edwards Engineering, Pompton Plains, NJ). The heating profile used in this study was no heat, 80, 80, 100, 100, 115, 115, and 130°C corresponding to barrel sections 1–8, respectively. Feed was metered into the feed port by a twin-screw, loss-in-weight gravimetric feeder (model LWFD5-20, K-Tron, Pitman, NJ) at a rate of 15 kg/hr (dwb). Peanut oil (15% dwb) was injected 70 mm downstream from the center of the feed port using a variable stroke piston pump (model P5-120, Bran and Luebbe, Wheeling, IL). With a similar pump, variable amounts of water (19.6, 15.0, 11.0, 7.45, and 6.0 kg/hr) was injected to obtain final SME input of 0.120, 0.177, 0.234, 0.291, and 0.358 kWh/kg dwb, respectively. A computer collected extruder parameter data at 1-sec intervals for 5 min using a data acquisition system (LabView, v. 5.0 National Instruments, Austin, TX). Extruded wheat bran was collected ≈10 min after the operation conditions of torque and pressure were at steady state.

### Specific Mechanical Energy (SME)

SME was calculated in kWh/kg (dwb) from the total mechanic power consumption (calculated from the torque readings), feed rate, and moisture content (Erdemir et al 1992).

### Experimental Treatment and Sample Collection

Treatment diets (Table I) were formulated to contain 10% total dietary fiber (TDF), 10.3% fat, 3% nitrogen, and 0.4% cholesterol. The control diet contained unextruded wheat bran with the same level of TDF, fat, and cholesterol. Unextruded and extruded wheat bran were analyzed for insoluble and soluble dietary fiber (Prosky et al 1988); nitrogen by combustion (FP-428, Leco, St. Joseph, MI); ether-extracted crude fat by method 920.39C (AOAC 1990); and moisture by method 935.29 (AOAC 1990). Total dietary fiber composition of the unextruded and extruded wheat bran is given in Table II.

After two weeks of feeding the treatment diets, total feces were collected for four consecutive days and analyzed for dry matter at 50°C under vacuum for 24 hr (method 934.01, AOAC 1990). Fecal samples were analyzed for crude fat (method 920.39C, AOAC 1990), and the lipid was redissolved in chloroform and methanol (86:14) for determination of total neutral sterols. Aliquots (50 µL) were dried under nitrogen, solubilized with a nonionic surfactant

(Triton X-100, Dow Chemical) as in Carlson and Goldfarb (1977), and analyzed for total neutral sterols by the same enzymatic colorimetric procedure as that used for plasma cholesterol (PC).

At the end of the 21-day feeding period, all animals were fasted for 16 hr and anesthetized with CO<sub>2</sub> for tissue sample collection. Blood was drawn by cardiac puncture into plastic tubes containing anticoagulant (ethylenediamine tetraacetic acid and 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. Plasma, liver, and feces samples were analyzed by an enzymatic colorimetric procedure for cholesterol and triglycerides (diagnostic kits 2350-500 and TR 22421, respectively; Thermo DMA, Cincinnati, OH). PC values were determined with standard curves obtained by running several concentrations of standards provided with the respective kits.

Fresh plasma samples were pooled (two animals per pool) by using an equal volume of plasma from each animal. A protease inhibitor, epsilon-amino caproic acid (ICN Biomedicals, Costa Mesa, CA), 1.3 mg/mL of plasma, and an antimicrobial agent, garamycin 50 mg/mL (Schering, Kenilworth, NJ), and 10 µL/mL of plasma were added to stabilize the plasma. Lipoproteins were fractionated by density gradient ultracentrifugation (Havel et al 1955). After the background density of 1 mL of plasma was adjusted to 1.019 g/mL with 5 mL of NaCl solution (1.0214 g/mL) plasma was centrifuged in an ultracentrifuge (model L8, Beckman, Palo Alto, CA) at 40K for 18 hr at 17°C in a rotor (model 50.3, Beckman). The top 1 mL (<1.019 g/mL) was removed as the very-low-density lipoprotein (VLDL) fraction and another 1 mL was removed as background. The supernatant density was adjusted to 1.067 g/mL and centrifuged similarly for 24 hr. The top 1 mL (1.019–1.063 g/mL) was removed as the low-density lipoprotein (LDL). The supernatant contained the high-density lipoprotein (HDL) fraction. With each ultracentrifugation, two salt solution tubes with similar density were run, and the densities of their fractions were monitored with a density meter (model DMA-48, Anton Paar, Richmond, VA). Lipoprotein fractions were analyzed for cholesterol by the procedure described for plasma.

Each liver was individually thawed, minced, and thoroughly mixed to obtain a homogeneous 0.5–0.8 g sample for extraction

**TABLE I**  
Composition of Diets (% dwb)<sup>a</sup>

Diet	Wheat Bran	Casein	Peanut Oil <sup>b</sup>	Corn Starch
WBU (unextruded)	19.5	17.0	9.5	54.3
WB-0.120 kWh/kg	19.1	17.7	6.6	51.1
WB-0.177 kWh/kg	19.4	17.7	6.6	50.8
WB-0.234 kWh/kg	19.7	17.6	6.4	50.9
WB-0.291 kWh/kg	19.6	17.6	6.4	51.0
WB-0.358 kWh/kg	19.9	17.6	6.3	50.8

<sup>a</sup> All diets contained 3.5% mineral mix, 1.0% vitamin mix, 0.3% DL-methionine, 0.2% choline bitartrate, 0.4% cholesterol. Diets were equal in total dietary fiber (10%), crude fat (10.3%), and protein (20%).

<sup>b</sup> Wheat bran endogenous crude fat (4.1%), injected peanut oil during wheat bran extrusion (15%), and added peanut oil resulted in total of 10.3% crude fat in diets.

**TABLE II**  
Dietary Fiber Composition of Unextruded and Extruded Wheat Bran (% dwb)<sup>a,b</sup>

Diet	Total Dietary Fiber (TDF, %)	Insoluble Dietary Fiber (IDF, %)	Soluble Dietary Fiber (SDF, %)	SDF/IDF Ratio
WBU (unextruded)	48.21c	46.16c	2.05bc	0.044bc
WB-0.120 kWh/kg	51.35b	49.82a	1.54c	0.031c
WB-0.177 kWh/kg	51.22b	49.70ab	1.51c	0.030c
WB-0.234 kWh/kg	52.30ab	49.19b	3.11a	0.063a
WB-0.291 kWh/kg	52.56a	49.74ab	2.82a	0.057ab
WB-0.358 kWh/kg	52.26ab	49.72ab	2.53ab	0.051ab

<sup>a</sup> Triplicate analysis. Water was injected during extrusion to obtain the required % torque.

<sup>b</sup> Values followed by different letters within a column differ significantly ( $P \leq 0.05$ ).

**TABLE III**  
**Effect on Hamster Cholesterol and Triglycerides from Diets Containing Extruded Wheat Bran for 21 Days<sup>a,b</sup>**

Diet	PC (mg/dL)	VLDL-C (mg/dL)	LDL-C (mg/dL)	HDL-C (mg/dL)	TG (mg/dL)
WBU (unextruded)	455 ± 30a	258 ± 29a	52 ± 8a	145 ± 15a	744 ± 73ab
WB-0.120 kWh/kg	355 ± 30b	175 ± 29b	44 ± 8a	136 ± 15a	630 ± 73b
WB-0.177 kWh/kg	419 ± 30a	220 ± 29ab	52 ± 8a	147 ± 15a	564 ± 73b
WB-0.234 kWh/kg	422 ± 30a	234 ± 29ab	50 ± 8a	138 ± 15a	767 ± 73ab
WB-0.291 kWh/kg	398 ± 30a	214 ± 29ab	37 ± 8a	147 ± 15a	892 ± 73a
WB-0.358 kWh/kg	415 ± 30a	224 ± 29ab	46 ± 8a	145 ± 15a	863 ± 73a

<sup>a</sup> Plasma cholesterol (PC), very-low-density lipoprotein cholesterol (VLDL-C), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and triglycerides (TG).

<sup>b</sup> Mean ± standard error of the mean; *n* = 5, except for TG, where *n* = 10. Values followed by different letters within a column differ significantly (*P* ≤ 0.05).

of total lipids by a supercritical fluid extraction procedure (Kahlon et al 1996b). Briefly, liver aliquots were mixed with pelletized diatomaceous earth adsorbent (Hydromatrix, Varian, Harbor City, CA) in 10-mL crystalline polymer cartridges (Isco, Lincoln, NE) and extracted at 7,000 psi for 46 min, which included 6 min of static extraction steps, with a combination of supercritical CO<sub>2</sub> and ethanol (70:30, v/v) at a combined flow rate of 2.0 mL/min in a chamber maintained at 80°C. Ethanol was evaporated in a 55°C oven under vacuum (33 mm Hg). Lipid extract was stored at -17°C until dissolved in 10 mL of chloroform and methanol (86:14) for cholesterol analysis. Liver total cholesterol was determined in aliquots (30 µL) of extract after evaporation under nitrogen and solubilization with Triton X-100 surfactant (Carlson and Goldfarb 1977). The enzymatic kit used was the same as that used for plasma. Values were determined from standard curves obtained by running National Bureau of Standards reference material for cholesterol (SRM 911 b) through the procedure as described for the samples.

#### Statistical Analyses

Values were determined in triplicate, and analysis of variance and Duncan's new multiple range test (Steel and Torrie 1960) were conducted. A value of *P* ≤ 0.05 was considered the criterion of significance.

## RESULTS AND DISCUSSION

Extrusion of wheat bran at various SME levels (0.120, 0.177, 0.234, 0.291, and 0.358 kWh/kg, dwb) resulted in a significant increase in total dietary fiber (TDF) and insoluble dietary fiber (IDF) compared with the unextruded wheat bran (Table II). Increase in TDF with 0.291 kWh/kg was significant over 0.120 and 0.177 kWh/kg SME input, whereas increase in IDF with 0.120 kWh/kg was significant compared with 0.234 kWh/kg SME input. Extruding wheat bran at 0.234 and 0.291 kWh/kg SME input resulted in significant elevation in SDF compared with unextruded wheat bran and extruded wheat bran at 0.120 and 0.177 kWh/kg SME input. There was an improvement in the ratio of soluble to insoluble dietary fiber with extrusion at 0.234, 0.291, and 0.358 kWh/kg compared with wheat bran extruded at 0.120 and 0.177 kWh/kg SME input. Water was injected during extrusion at the rate of 6, 7.45, 11.0, 15.0, and 19.6 kg/hr to obtain the desired SME input of 0.358, 0.291, 0.234, 0.177, and 0.120 kWh/kg. Injection of water at 11 kg/hr to obtain 0.234 kWh/kg SME input exhibited the most desirable chemical changes as it resulted in a significant increase in SDF, IDF, TDF, and SDF/TDF ratio compared with unextruded wheat bran. Wang and Klopfenstein (1993) found great variability in extrusion effects on dietary fiber in oat bran with hulls, barley with hulls, and whole wheat. Other investigators reported increases in soluble dietary fiber (SDF) when a variety of cereal grains and fractions were extruded (Bjorck et al 1984; Siljestrom et al 1986; Shinnick et al 1988; Aoe et al 1989; Oda et al 1988; Ralet et al 1990; Wang et al 1993). Differences in results could be related to differences in extrusion conditions and the nature of raw materials.

#### Weight Gain and Feed-to-Gain Ratio

Weights on arrival for 21-day-old male hamsters were 65.6 ± 1.2 g (mean ± standard error of the mean). After feeding the basal diet for one week, selectively randomized initial weights were similar for all treatments (88.3 ± 1.4 g). For the 21-day feeding period feed intake (11.7 ± 0.3 g/day), weight gain (4.3 ± 0.2 g/day), feed/gain ratio (2.7 ± 0.1), and final weight (156 ± 5 g) were similar among all treatment groups. Apparent dry matter digestibility evaluated during days 14–17 was also similar among all treatments (85.9 ± 0.6%). These observations agree with the previous reported observations with diets containing unextruded wheat bran and low torque extrusion (0.221 kWh/kg, dwb) and high torque extrusion (0.442 kWh/kg, dwb) wheat bran diets (Kahlon et al 1998).

#### Total PC, VLDL-C, LDL-C, HDL-C, and TG

Total plasma cholesterol (PC) in hamsters fed the diet containing wheat bran extruded at SME of 0.120 kWh/kg was significantly lower (-22%) than unextruded control and all the other extruded wheat bran diets (Table III). PC values for the 0.291 kWh/kg extruded wheat bran diet were 13% lower than those fed the unextruded control diet; however, this difference was not significant due to high variability in animals within each treatment. Animals consuming the 0.120 kWh/kg diet had significantly lower (-32%) total very-low-density lipoprotein cholesterol (VLDL-C) compared with those fed the control diet. Values for all the other extruded diets (0.177, 0.234, 0.291, and 0.358 kWh/kg, dwb) were similar to those of the control and the 0.120 kWh/kg diet. Total low-density lipoprotein cholesterol (LDL-C) in the hamsters fed the control diet was 52 mg/dL, and values for the hamsters fed the diets containing extruded wheat bran ranged from 37 to 52 mg/dL. The lowest mean value 37 ± 8 mg/dL for LDL-C for the 0.291 kWh/kg wheat bran diet was 29% lower than those for control and the 0.177 kWh/kg diet. However, these differences were not significant due to high animal variability within each treatment. Total high-density lipoprotein cholesterol (HDL-C) for all the treatments were similar (values of 136–147 mg/dL). Wheat bran extruded with 0.291 kWh/kg appeared to have the most desirable effect with 13% reduction in PC and 29% reduction in LDL-C. Highest elevation in TDF and second highest increase in SDF (both significant effects) with 7.45kg/hr addition of water with 0.291 kWh/kg SME input resulted in most enhancement of health potential of wheat bran. Data suggest that cholesterol-lowering potential of wheat bran could be enhanced by appropriate extrusion process technologies. Specific chemical changes under these extrusion conditions need to be explored. Total triglycerides (TG) for the animals fed 0.120 kWh/kg (630 mg/dL) and 0.177 kWh/kg (564 mg/dL) extruded diets were significantly lower than those fed 0.291 kWh/kg (892 mg/dL) and 0.358 kWh/kg (863 mg/dL) diets. TG values for the unextruded wheat bran (744 mg/dL) and 0.234 kWh/kg (767 mg/dL) treatment diets were similar to those of 0.120, 0.177, 0.291, and 0.358 kWh/kg diets. We observed very high (564–892 mg/dL) TG values in cholesterol-fed hamsters

**TABLE IV**  
**Effect on Hamster Liver Weight, Lipids, and Cholesterol from Diets Containing Extruded Wheat Bran for 21 Days<sup>a,b</sup>**

Diet	Liver Wt (g)	Total Liver Lipid (g)	Liver Lipid (%)	Total Liver Cholesterol (mg)	Liver Cholesterol (mg/g)
WBU (unextruded)	9.2 ± 0.3a	1.05 ± 0.05a	11.5 ± 0.4a	403 ± 20a	43.8 ± 1.9a
WB-0.120 kWh/kg	7.7 ± 0.3b	0.68 ± 0.05b	9.2 ± 0.4b	284 ± 20b	38.5 ± 1.9ab
WB-0.177 kWh/kg	8.4 ± 0.3ab	0.81 ± 0.05b	9.7 ± 0.4ab	315 ± 20b	37.6 ± 1.9ab
WB-0.234 kWh/kg	8.7 ± 0.3ab	0.69 ± 0.05b	8.7 ± 0.4b	292 ± 20b	33.3 ± 1.9b
WB-0.291 kWh/kg	7.8 ± 0.3b	0.75 ± 0.05b	9.6 ± 0.4ab	277 ± 20b	35.9 ± 1.9ab
WB-0.358 kWh/kg	8.7 ± 0.3ab	0.80 ± 0.05b	9.2 ± 0.4b	312 ± 20b	36.0 ± 1.9ab

<sup>a</sup> Mean standard error of the mean; *n* = 10.

<sup>b</sup> Values followed by different letters within a column differ significantly (*P* ≤ 0.05).

**TABLE V**  
**Effect on Hamster Digestibility from Diets Containing Extruded Wheat Bran for 21 Days<sup>a,b</sup>**

Diet	Fat Digestibility (%)	Cholesterol Digestibility (%)	Sterol Excretion (mg/4 days)
WBU (Unextruded)	95.0 ± 0.5a	75.3 ± 0.4a	46 ± 20b
WB-0.120 kWh/kg	94.2 ± 0.5ab	71.7 ± 0.4b	50 ± 20ab
WB-0.177 kWh/kg	94.4 ± 0.5ab	71.8 ± 0.4b	52 ± 20ab
WB-0.234 kWh/kg	94.1 ± 0.5ab	72.0 ± 0.4b	55 ± 20ab
WB-0.291 kWh/kg	94.6 ± 0.5ab	66.0 ± 0.4c	61 ± 20a
WB-0.358 kWh/kg	93.8 ± 0.5b	70.1 ± 0.4b	56 ± 20a

<sup>a</sup> Mean ± standard error of the mean; *n* = 10.

<sup>b</sup> Values followed by different letters within a column differ significantly (*P* ≤ 0.05).

which were consistent with previously reported hamster TG values (539–1,309 mg/dL) under similar conditions (Kahlon et al 1992). TG is considered a risk factor for atherosclerosis and its reduction with 0.120 kWh/kg and 0.177 kWh/kg extruded diets could be viewed as health-promoting. Elevated PC values with unextruded wheat bran have been reported (Tredger et al 1991; Uusitupa et al 1992; Whyte et al 1992; Illman et al 1993; Jackson and Topping 1993; Rouanet et al 1993; Anderson et al 1994; Lewis et al 1996). In this study, hamsters fed extruded wheat bran diets had 8–22% lower PC compared with those fed unextruded wheat bran diet. Wang and Klopfenstein (1993) reported significant PC reductions in rats fed extruded wheat bran compared with their unextruded products. Kahlon et al (1998) reported significantly lower PC values (–12%) with low SME (0.221 kWh/kg) extruded wheat bran diet. However, similar lower values (–13%) with the 0.291 kWh/kg wheat bran diet observed in this study were not significant reductions. This discrepancy was due to high animal variability within each treatment. The data suggest that the hypercholesterolemic activity of wheat bran can be reduced or eliminated by appropriate extrusion energy input conditions.

### Liver Weight, Lipids, and Cholesterol

Liver weights in hamsters fed diets containing 0.120 kWh/kg and 0.291 kWh/kg extruded wheat bran were significantly lower (–16% and –15%, respectively) compared with those fed the control unextruded wheat bran diet (Table IV). Total liver lipids were significantly (23–35%) lower in animals fed all the diets containing extruded wheat bran compared with those fed the control diet. Percent liver lipid was significantly lower for the 0.120, 0.234, and 0.291 kWh/kg wheat bran treatments compared with the control treatment. Data suggest that inclusion of extruded wheat bran in the diets prevents fatty infiltration of the liver. Fatty liver has been associated with increased risk heart disease in men and women (Takeda et al 2000; Akahoshi et al 2001). Total liver cholesterol was significantly lower (28–31%) in hamsters fed all the extruded wheat bran diets compared with those fed the control diet. Liver cholesterol (mg/g of liver) was significantly lower in the animals fed 0.234 kWh/kg extruded wheat bran compared with the control diet. In rat studies, extruded grain diets (oats with hulls, wheat, and barley with hulls) reportedly resulted in significantly lower liver cholesterol compared with their respective raw grains (Wang and Klopfenstein 1993), while no consistent effect of extrusion

was found by others (Shinnick et al 1988). Liver is the main cholesterol-synthesizing and cholesterol-storing organ, and significant liver cholesterol reductions with diets containing extruded wheat bran is very encouraging. Data suggest that cholesterol-lowering potential of wheat bran could be enhanced by appropriate extrusion processing, which could lead to the development of wheat products with more health-promoting properties.

### Lipid and Sterol Excretion

During the four-day fecal-collection period (days 14–17), hamsters fed a diet containing 0.358 kWh/kg extruded wheat bran had significantly lower apparent lipid digestibility (digestibility = [intake – excretion]/intake) than those fed the control diet (Table V). Cholesterol digestibility was significantly lower with all diets containing extruded wheat bran compared with the unextruded control. Cholesterol digestibility for the 0.291 kWh/kg diet was significantly lower than all other extruded wheat bran diets (0.120, 0.177, 0.234, and 0.358 kWh/kg). Neutral sterol excretion for the four-day collection period was significantly higher for the hamsters fed diets containing 0.291 kWh/kg (+33%) and 0.358 kWh/kg (+12%) compared with those fed diets containing unextruded wheat bran (control diet). Because the liver is the main cholesterol-synthesizing and cholesterol-catabolizing organ, significant liver cholesterol reductions, liver lipid reductions, and significantly higher sterol excretions with the extruded wheat bran diets suggest that incorporating appropriately extruded wheat bran into the diet would have great potential for alleviating or moderating hypercholesterolemia.

In conclusion, considering lowest cholesterol digestibility, significantly higher sterol excretion, desirable plasma lipoprotein cholesterol profile, significantly lower liver weight, total liver lipids, and liver cholesterol, wheat bran extruded at 0.291 kWh/kg (dwb) appears to have the most desirable potential for improved health. Data suggest that cholesterol-lowering potential of wheat bran could be enhanced by optimizing the energy input used in the extrusion process.

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