Availability of Dietary Fiber in Extruded Wheat Bran and Apparent Digestibility in Rats of Coexisting Nutrients

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ABSTRACT

Effects of extrusion cooking on availability of dietary fiber in wheat bran and the apparent digestibility in rats of coexisting nutrients (starch, protein, and fat) were studied. The content of soluble fiber was 3.3% in raw wheat bran, which increased in relation to the degree of extrusion to 4.2% after moderate extrusion and 5.1% after excessive extrusion. Scanning electron microscopic observations showed that the cell walls of extruded products were thinner and their surfaces rougher than those of the raw material. Apparent digestibility of starch, protein, and fat was not influenced by extrusion cooking, whereas that of the wheat bran dietary fiber was increased significantly in rats ($P < 0.05$). Even in the group fed a diet containing raw wheat bran, the honeycomb-like structure of fecal dietary fiber was disordered after passage through the rat alimentary tract. Dietary fiber in the rats fed the extruded products was also greatly disrupted; cell walls and inner surfaces were wrinkled, and the remaining pericarp layers were often greatly folded or curled. The present study suggests that extrusion cooking of wheat bran is effective in modifying its physicochemical form and the availability of dietary fiber in rats.

Wheat bran is an important source of dietary fiber; it is rich in insoluble fiber but also contains water-soluble fiber. Water-soluble fiber in wheat bran is mainly the hemicellulose fraction (D'Appolonia et al 1971, Saunders 1978). Unprocessed wheat bran is usually effective in accelerating intestinal transit (Wyman et al 1976). The fecal water content as well as fecal wet and dry weight increases with the addition of bran to the diet (Cummings et al 1976, Kay and Truswell 1977). Generally, water-soluble fiber improves glucose tolerance and lowers plasma lipids (Kies and Fox 1977, Vahouny and Krichevsky 1982), but such an effect has not been observed with wheat bran because most of its dietary fiber is insoluble.

In recent years, extrusion cooking has increasingly been used in the production of flat bread, pregelatinized foods, and weaning foods. This food-processing technology has been reported by various investigators (Harper 1981, Linko et al 1981). In the extruder, the raw material is subjected to mechanical processes (heating, compression, shear, and swelling) that completely disorganize the original structure of the raw material. Thus, extrusion cooking could be expected to affect both the physiological properties and content of dietary fiber (Björck et al 1984). However, limited information is available on the effect of different food processes on dietary fiber (Björck et al 1984, Fairweather-Tait et al 1987).

The objective of this research was to examine the effect of extrusion cooking on availability of dietary fiber in wheat bran. This study also examined the effect of extrusion cooking on apparent digestibility of the three coexisting nutrients (starch, protein, and fat) in rats.

MATERIALS AND METHODS

Materials

A number of products based on a hard red spring wheat bran (Nisshin Milling Co. Ltd., Japan), were processed in a twin-screw extruder (Suehiro Iron Works Co., Ltd., Japan, model α-50) under conditions described in Table I. Maximum temperature and pressure were measured with a thermocouple and pressure-gauge inserted. As shown in Table I, we considered the conditions of extrusion 1 as moderately processed and extrusion 2 as excessively processed. Both the extruded and raw products were ground to pass a 0.59-mm sieve.

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Analytic Methods

Dietary fiber. The dietary fiber content in the extruded and raw products was analyzed by the method of Asp et al (1983). After gelatinization and incubation with Termamyl 120L (Novo) for 15 min at 100°C, enzyme digestion was performed with pepsin NF (Merck) at pH 1.5 for 1 hr and with pancreatin 4 × NF (Sigma) at pH 6.8 for 1hr. Insoluble fiber was recovered by filtration (P-2 crucibles, Celite as filtering aid). Soluble fiber was precipitated with four volumes of 95% ethanol and recovered by another filtration. The dietary residues were corrected for remaining protein (assayed with the Kjeldahl procedure and calculated as N × 6.25) and ash. Neutral detergent fiber (NDF) in feces was measured to examine the availability of dietary fiber because it is difficult to recover soluble fiber precisely from feces. NDF in feces and diets was determined by the method of Van Soest and Wine (1967), and apparent digestibility of NDF was calculated.

Apparent digestibility of three nutrients. Protein in feces and diets was assayed with the Kjeldahl procedure and calculated as N × 6.25. Fat was extracted with a Soxhlet extractor and determined gravimetrically. Starch was determined as follows: 0.5 g of sample was suspended in 35 ml of distilled water, and 10 ml of 0.2*M* sodium-acetate buffer (pH 4.8) and 5 ml of glucoamylase solution (Nagase Biochemicals Ltd., centrifuged supernatant of 1.2 mg/ml) were added. The suspension was incubated at 37°C for 24 hr. After filtration of the suspension, the released glucose was determined by Somogyi's method (Somogyi 1952). Starch content was expressed as glucose × 0.9. Using these determinations, apparent digestibility of starch, fat, and protein were calculated.

Scanning Electron Microscopy (SEM)

After washing four times in distilled water with mixer, the raw wheat bran was incubated in NDF solution (Van Soest and Wine 1967) at 100°C for 1 hr. Residues were recovered by filtration (17G-3, glass filter). These residues were washed three times in boiling water, recovered by another filtration, and dehydrated

TABLE I
Processing Conditions During Extrusion Cooking[a] of Wheat Bran

Condition	Extrusion 1	Extrusion 2
Mass feed rate, kg/hr	14	14
Feed moisture content, %	11	11
Screw speed, rpm	100	100
Maximum temperature, °C	136	160
Maximum pressure, MPa	2.4	3.4

[a]Twin-screw extruder, Model α-50, Suehiro Iron Works, Japan. Screw combination: BRBBB-BBBB-BBBRR-BBTT-BBB-feed, where B = ball-type screw element, R = reverse screw element, and T = trapezoid-type screw element.

with acetone. The extruded products were digested with pancreatin at 40°C for 24 hr before undergoing the same treatment. They were mounted on aluminum stubs with colloidal graphite (Ted Pella Inc.) and coated with 15 nm of gold/palladium in a IB-5 spattering device (Eiko Engeneering, Japan). Microscopy was performed in an S-800 scanning electron microscope (Hitachi, Japan) at 1–5 kV accelerating voltage.

Animal Experiments

Animals and diets. Male albino rats (approximately 57 g each) of the Wistar strain were purchased from Clea Japan, Inc. They were divided into groups of three, placed individually in stainless steel cages and fed CE-2 chow (Clea Japan) for three days before being fed the experimental diets. Diets and tap water were provided ad libitum. After 11 days, feed residues and feces were collected for 16 days. Feces were collected every day and frozen at −20°C, lyophilized, weighed, and milled to pass a 0.59-mm sieve, and stored at −20°C until analysis. Composition of the experimental diets is given in Table II. The extruded and raw wheat brans were added at 10.75% on a dry matter basis (corresponding to 5% of NDF). Casein as a protein source was added to adjust N at 3% in all experimental diets. Sucrose was added to adjust dry matter content.

Observation of fecal dietary fiber by SEM. After washing several times in 95% ethanol and distilled water, dietary fiber residues in feces were recovered by filtration (17G-3 glass filter), washed with ethyl ether, and dried at 30°C. Dietary fiber residues were observed by SEM, as described above.

Statistical analysis. Statistical analysis was made by analysis of variance and Tukey's multiple range test.

RESULTS AND DISCUSSION

Solubilization of Dietary Fiber Through the Extrusion Process

Components of the raw and extruded wheat brans are shown in Table III. The content of soluble fiber in raw wheat bran was 3.3%, which increased to 4.2 and 5.1% with the degree of extrusion processing (moderately extruded and excessively extruded, respectively). In contrast, the insoluble fiber decreased in all the extruded products. Crude protein, fat, and ash were almost the same. The increase in soluble fiber content in the extruded wheat bran indicates solubilization of dietary fiber during the processing. This might be also accounted for by release of the soluble hemicellulose fraction from the dietary fiber in wheat bran. This is consistent with previous work (Björck et al 1984) on extruded whole grain wheat flour.

SEM

The structural characterization revealed by SEM is shown in Figure 1. SEM of NDF preparations after extrusion (1B and C) showed that the original honeycomb-like structure (1A) did not change noticeably. However, the cell walls of the extruded

TABLE II
Composition of Diets (%)

Component	Type of Wheat Bran in Diet		
	Raw	Extrusion 1	Extrusion 2
Test bran[a]	12.13[b]	11.27	11.40
Corn starch	45	45	45
Casein	19.85	19.93	20.00
Lard	9	9	9
Corn oil[c]	1	1	1
Salt mixture[d]	4	4	4
Vitamin mixture[d]	0.85	0.85	0.85
Choline chloride	0.15	0.15	0.15
Sucrose	8.02	8.80	8.60

[a]10.75%, dry matter basis.
[b]Corresponding to 5% neutral detergent fiber.
[c]One gram of corn oil contains 300 I.U. of vitamin A, 30 I.U. of vitamin D_2 and 10 mg of DL-α-tocopherol.
[d]Prepared according to Harper (1959).

TABLE III
Components of Raw and Extruded Wheat Brans (%)[a]

Component	Wheat Bran		
	Raw	Extrusion 1	Extrusion 2
Moisture	11.40	4.6	5.7
Crude protein[b]	15.8	15.2	14.8
Fat[c]	7.1	7.0	7.2
Ash	5.6	5.3	5.6
Carbohydrate	16.0	19.9	20.8
Dietary fiber[d]			
Insoluble	52.2	48.4	46.5
Soluble	3.3	4.2	5.1

[a]All data except moisture on a dry matter basis.
[b]Calculated by N ×6.25.
[c]AOAC method 14.019 (1984).
[d]Method of Asp et al (1983).

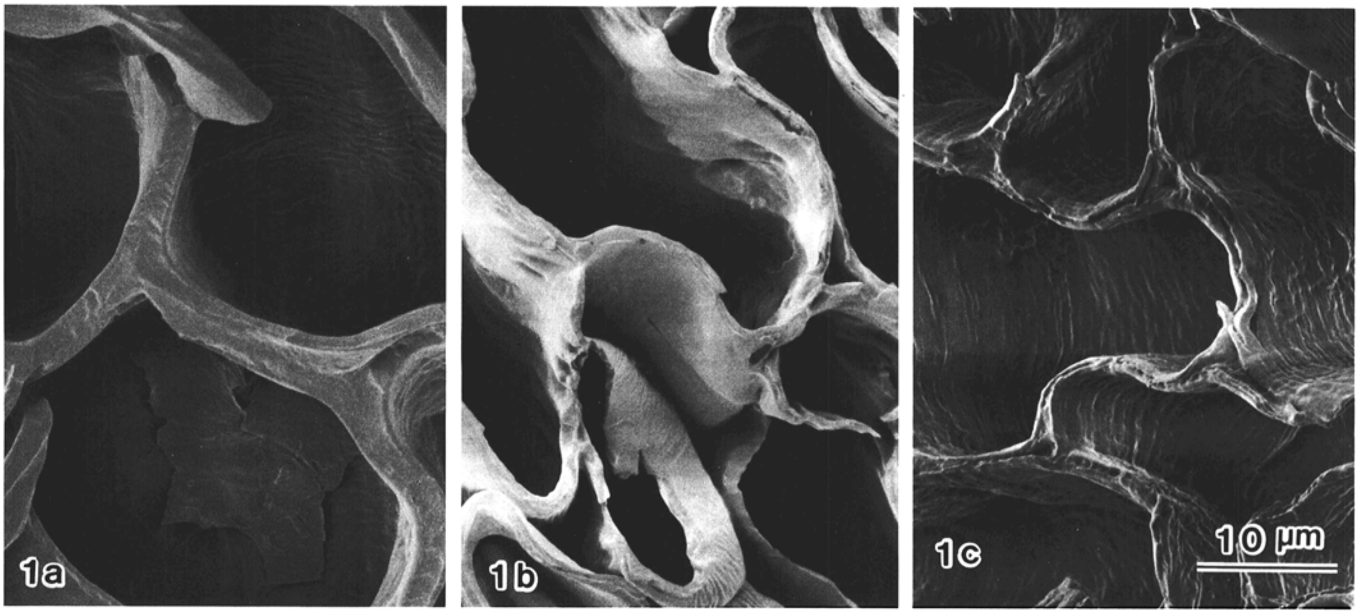

Fig. 1. Neutral detergent fiber preparation showing the aleurone cell walls of raw wheat bran (**a**), the moderately extruded wheat bran (**b**), and the excessively extruded wheat bran (**c**) (×2,000).

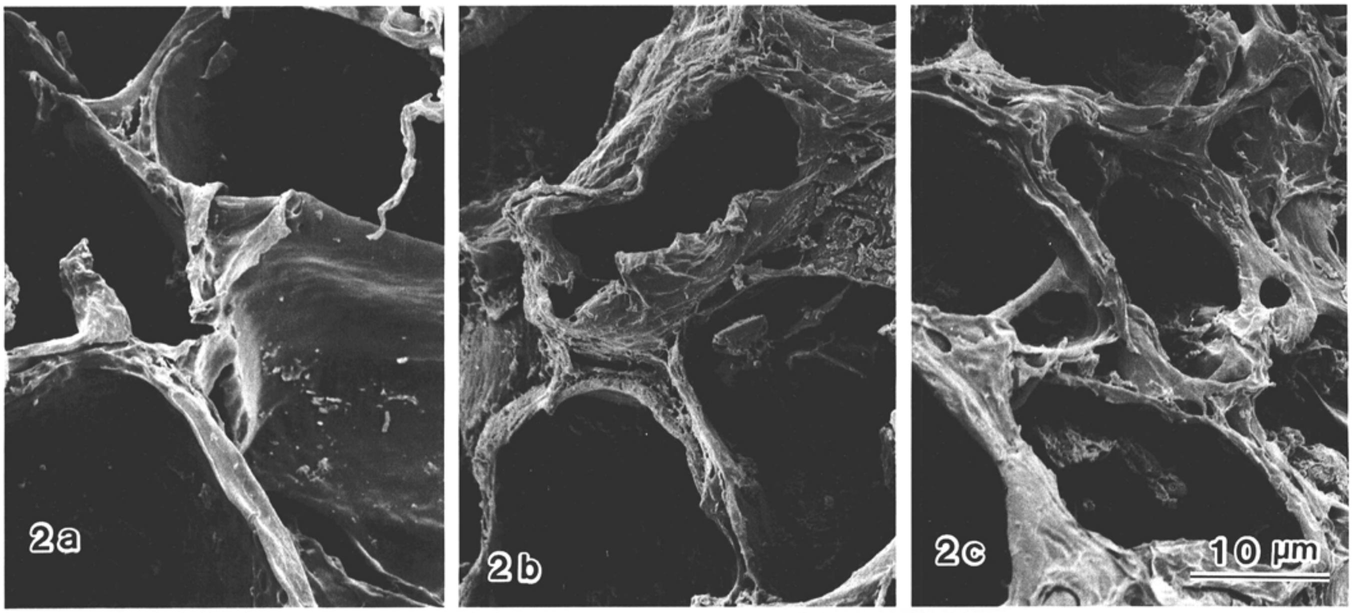

Fig. 2. Dietary fiber preparation showing aleurone cell walls of of the raw wheat bran (**a**), the moderately extruded wheat bran (**b**), and the excessively extruded wheat bran (**c**) recovered from rat feces (×2,000).

TABLE IV
Effect of Raw and Extruded Wheat Bran Diets on Body Weight, Feed Intake, and Feed Efficiency in Rats[a]

	Type of Wheat Bran in Diet		
Parameter	Raw	Extrusion 1	Extrusion 2
Initial weight, g	57.2 ± 0.7	57.4 ± 0.7	57.4 ± 0.7
Weight gain, g	159.7 ± 2.5	160.2 ± 1.7	161.1 ± 2.3
Feed intake, g	372.3 ± 3.1	377.0 ± 3.7	389.7 ± 5.1[b]
Feed efficiency	0.42 ± 0.01	0.42 ± 0.01	0.41 ± 0.01

[a]Data given are means ± SEM ($n = 7$).
[b]Significantly different from the raw wheat bran group ($P < 0.05$).

TABLE V
Digestibilities of Starch, Protein, and Fat in Rats Fed Diets Containing Raw and Extruded Wheat Brans[a]

	Type of Wheat Bran in Diet		
Parameter	Raw	Extrusion 1	Extrusion 2
Weight of feces,[b] g	1.03 ± 0.02	1.02 ± 0.02	1.05 ± 0.01
Starch			
Daily intake, g	6.76 ± 0.08	6.85 ± 0.07	7.09 ± 0.09[c]
Daily excretion, mg	18.21 ± 1.33	12.81 ± 0.77[c]	11.69 ± 0.47[c]
Apparent digestibility, %	99.7 ± 0.1	99.8 ± 0.1[c]	99.8 ± 0.1[c]
Protein			
Daily intake, g	2.97 ± 0.03	3.04 ± 0.03	3.17 ± 0.04[c,d]
Daily excretion, mg	172.1 ± 4.4	199.3 ± 6.9[c]	205.8 ± 3.3[c]
Apparent digestibility, %	93.9 ± 0.1	93.3 ± 0.2	93.4 ± 0.1[c]
Fat			
Daily intake, g	1.69 ± 0.02	1.69 ± 0.01	1.76 ± 0.02[d]
Daily excretion, mg	53.1 ± 2.6	45.1 ± 1.8[c]	45.0 ± 1.0[c]
Apparent digestibility, %	96.8 ± 0.1	97.2 ± 0.1[c]	97.3 ± 0.1[c]

[a]For the last 16 days of a 27-day period. Data are means ± SEM ($n = 7$).
[b]Daily per rat.
[c]Significantly different from the raw wheat bran group ($P < 0.05$).
[d]Significantly different from the extruded wheat bran (extrusion 1) group ($P < 0.05$).

TABLE VI
Digestibilities of Neutral Detergent Fiber (NDF) in Rats Fed Diets Containing Raw and Extruded Wheat Brans[a]

	Type of Wheat Bran in Diet		
Parameter	Raw	Extrusion 1	Extrusion 2
NDF intake, g/day	0.91 ± 0.01	0.91 ± 0.01	0.91 ± 0.01
NDF in feces, g/day	0.53 ± 0.01	0.52 ± 0.01	0.53 ± 0.01
Apparent digestibility, %	40.7 ± 0.8	42.4 ± 1.1	43.0 ± 0.4[b]

[a]For the last 16 days of a 27-day period. Data are means ± SEM ($n = 7$).
[b]Significantly different from the raw wheat bran group ($P < 0.05$).

products were thinner and their surfaces rougher than those of the raw material. These changes are more obvious in the excessively extruded wheat bran (1C) than in the moderately extruded (1B). These changes may be caused by releasing the soluble hemicellulose fraction from dietary fiber. Thus, extrusion cooking of wheat bran was effective in modifying the availability of dietary fiber.

Animal Experiments

There was no significant difference in mean body weight gain, feed intake, and feed efficiency between groups fed raw and extruded wheat bran (Table IV). It has been reported that diarrhea was observed in rats given severely processed wheat flour (Björck et al 1984), but this was not observed in the present study. Thus, extrusion cooking of wheat bran might not affect rat growth.

After the 27-day feeding period, the rats were sacrificed, and each organ was observed and weighed. No typical difference between dietary groups was observed. Apparent digestibility of starch, protein, and fat is given in Table V. Fecal weight and apparent digestibility of protein, starch, and fat were very similar between the before and after extrusion diets. Apparent digestibility of the three nutrients was not influenced by extrusion cooking.

Mean ingested and fecal dietary fiber data are given in Table VI. NDF data are expressed in terms of grams of NDF per rat per day. When data were compared with percentage of digestibility, the extruded products had a higher digestibility than the raw material. The extrusion 2 group was significantly different from the raw wheat bran group ($P < 0.05$). This increase in apparent digestibility of NDF means an increase in availability of dietary fiber. The extrusion cooking of wheat bran that increased the release of hemicellulose could be expected to increase the availability of dietary fiber in rats. Some hemicelluloses are reported to be easily fermented (Hellendoorn 1978, Salyers et al 1979).

SEM of Fecal Dietary Fiber

The structural changes of fecal dietary fiber shown by SEM are given in Figure 2. Compared with the honeycomb-like structure before passage through the rat alimentary tract (Fig. 1), the dietary fiber structure was slightly disrupted even in the group that ate raw wheat bran (2A). Dietary fiber of the rats fed the extruded products was greatly disrupted (2B and C); cell wall and inner surface were wrinkled, and the remaining pericarp layers were often greatly folded or curled. Changes in the extruded material were more typical under excessive conditions (2C) than under moderate conditions (2B). These changes may be related to digestion in the alimentary tract and bacterial fermentation.

The present study suggests that extrusion cooking of wheat bran is effective in increasing the availability of dietary fiber in rats.

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