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Anderson et al 1984, Anderson 1987). A dose-response study was recently performed by Davidson et al (1991) that indicated significant hypocholesterolemic effects with a daily intake of 7.2 g of β-glucan from either oatmeal or oat bran. In most studies, data on the contents of β-glucan or soluble fiber of the oatmeal or bran preparations used are incomplete. With the suggested AACC definition for oat bran (Anonymous 1989) taken as the minimum value and the β-glucan content of the richest commercial preparations as the maximum value in recalculations, most of the human studies indicate that a significant reduction of blood cholesterol can be achieved with a daily dose corresponding to 1.3–8 g of β-glucan. For most people, the amounts of oatmeal or oat bran needed to provide that dose of β-glucan are unrealistic on a continuous basis, even if the oats were introduced in various types of dishes.

Most of the animal experiments for reduction of blood cholesterol have been made using hypercholesterolemic diets containing added cholesterol and cholic acid. The lowest levels of oat fiber to significantly reduce cholesterol in hypercholesterolemic rats have been 4 or 10% of the feed dry weight, corresponding to 2 or 5% of β-glucan (Shinnick et al 1988, 1990). Relative to unprocessed oat fiber, the processed oat fiber used by those authors had a greater effect on total plasma cholesterol (Shinnick et al 1988) and a still more pronounced effect in normalizing the lipoprotein composition (Ney et al 1988). Comparing the effects of oat bran and an oat bran concentrate on the serum lipids of hypercholesterolemic and normocholesterolemic rats, Ranhotra et al (1990) found the effects of oat bran and oat bran concentrate to be equal in the hypercholesterolemic rats when the content of soluble fiber in the diet was similar (2.8%). However, in the normocholesterolemic rats, the oat bran diet with 2.8% soluble fiber did not reduce serum cholesterol relative to the cellulose control group, but the oat bran concentrate diet caused a 45% reduction in two weeks and 39% in four weeks.

The objective of our study was to concentrate the dietary fiber present in oat bran to reduce the bulk to be consumed to a realistic level, and simultaneously to preserve the integrity of the β-glucan as far as possible. To distinguish our preparations from commercial oat fiber preparations based on the insoluble fiber from oat hulls, we call our preparations oat bran concentrates (OBCs). Furthermore, with tests performed on rats, we investigated whether the effect of dietary OBC on the serum total cholesterol is dependent on the molecular size of β-glucan or the viscosity properties of the preparations.

MATERIALS AND METHODS

Commercial oat bran from Raisio Group Ltd. (Raisio, Finland), originating from a mixture of Finnish oat varieties, was heat-treated at 100°C for 90 min in Darre equipment (Bühler, Uzwill, Switzerland) before milling. Its gross composition is presented in Table I. In rheological and gel permeation studies this material is identified as OB 4.

OBCs were made in pilot and small industrial scale from oat bran by removing nonfiber components. One concentrate (OBC 5) was formed by wet milling in neutral cold-water (<14°C) suspensions in a Fryma colloid mill (Rheinfelden, Switzerland) and separating the coarse fraction on a vibrating screen with openings of 0.33 mm, with recirculation for 2 hr. To form OBC 6, the oat bran was wet milled as for OBC 5, but the suspension was maintained at pH 5 for 0.5 hr and subsequently neutralized to reduce the molecular weight of β-glucan. Two other concentrates were formed by wet milling and sieving in ethanol-water suspensions. OBC 13 was prepared from a commercial Swedish oat bran by wet milling in 90% (v/v) ethanol at 75°C, and OBC 14 was prepared from OB 4 by wet milling in 70% (v/v) ethanol at 20°C.

Gross composition of the concentrates is presented in Table I.

Isolation of β-Glucan

The OBC was alkaline-extracted (pH 9) at 70°C for 2 hr, and the pH was adjusted and maintained with sodium carbonate. The proteins were precipitated at pH 4.7 by the addition of hydrogen chloride solution at room temperature, and the solids were filtered out. The solution was neutralized to pH 7.0 and the viscosity was measured. β-Glucan was precipitated from the filtrate by adding at room temperature an equal volume of ethanol with continuous stirring. The isolates were separated by filtration and washed with ethanol. β-Glucan contents ranged from 60 to 75%. The protein contents varied between 4 and 6%. Other compositional details are published elsewhere (Autio et al 1992a).

Determination of β-Glucan

The content of β-glucan was determined enzymatically according to McCleary and Glennie-Holmes (1985).

Determination of Dietary Fiber

Total dietary fiber was determined using the procedure described by Prosky et al (1985), which was published in 1990 as an official method of the Association of Official Analytical Chemists.

Measurement of Extractability and Viscosity

Suspensions and solutions for the viscosity measurements were prepared as follows.

In a modification of the method of Albertsson and Tönnerfors (1990), an amount of oat bran or concentrates containing 1 g of β-glucan was mixed with 100 ml of water and incubated at 40°C for 2 hr, with stirring at 15-min intervals. Solid particles were removed by centrifugation at 15,000 × *g*. Viscosity of this crude extract was determined, and its β-glucan content determined.

Thirty-five grams of OBC 13 and 50 g of oat bran or other concentrates, the difference caused by the viscosity properties, were mixed with 1,500 ml of sodium carbonate at 70°C for 2 hr. The pH was maintained at 9.0 by additions of sodium carbonate. Solids were removed by centrifugation as above, and the viscosity was measured.

Solutions of isolated β-glucan were made from preparations stored under 50% ethanol. Samples were dissolved in 0.1*M* β-morpholino-ethanesulfonic acid (MES) buffer (pH 6.6) while immersed in a boiling water bath and were then diluted to obtain 0.37% solutions of β-glucan.

For testing the effect of trypsin on the viscosity, alkaline extract of OBC 13 and a solution of β-glucan isolated from it were incubated at 36°C with trypsin (Merck, 1 mg/ml = 2 EU/ml) at pH 7.5. The absence of β-glucanase activity in trypsin was tested according to Nummi et al (1983) using barley β-glucan (Biocon, Cork, Ireland) as the substrate.

Viscosity properties were measured at 25°C with a Bohlin (Lund, Sweden) rheometer (VOR) using a C-25 concentric cylinder system (DIN 53019).

Determination of Molecular Weight Distribution

Gel permeation chromatography (GPC) of isolated β-glucan preparations was performed at 35°C on serially connected μHy-

TABLE I
Composition (dry basis) of Oat Bran and Concentrates[a]

	OB 4	OBC 5	OBC 6	OBC 13	OBC 14
Moisture	8.2	6.8	1.4	12.7	6.7
Protein	16.4	20.0	21.9	20.6	20.0
Fat	7.7	5.9	6.8	1.4	4.3
Ash	2.8	6.8	5.9	6.3	5.0
Total dietary fiber[b]	13.0	40.0	39.1	37.6	32.7
β-Glucan	6.0	14.7	15.5	18.9	16.3
Total carbohydrate (by difference)	64.9	60.5	64.0	59.0	64.0

[a] OB 4, untreated oat bran; OBC 5, cold-water wet-milled oat bran concentrate (OBC); OBC 6, hydrolyzed cold-water wet-milled OBC; OBC 13, hot ethanol-water wet-milled OBC; OBC 14, cold ethanol-water wet-milled OBC.

[b] According to Prosky et al (1985) and corresponding to a 1990 AOAC method.

drogel 2000 and 250 columns (Waters, Div. Millipore, Tokyo, Japan) and using a refraction index (RI) detector. The eluent was aqueous 0.1*M* MES buffer (pH 6.6) fed at a flow rate of 0.5 ml/min. Dextrans (Pharmacia, Uppsala, Sweden) were used as calibration standards. β-Glucans isolated from OBC 5, OBC 6, and OBC 14 were further characterized by determining molecular weights and hydrodynamic properties using GPC in 50 m*M* MES buffer (pH 6.5) at ambient temperature with both RI and multiangle laser-light scattering (MALLS; Dawn Inc., Santa Monica, CA) detectors.

Animal Experiments

Weanling male Mol:SPRD rats (Mollegaard ApS, Ejby, Denmark) were used in an experiment conducted between March 15 and April 18, 1990. The rats were adapted for four days before the start of the experiment. During the adaptation period and the experiment, the rats were housed in stainless steel cages, five per cage. The animals were divided into groups of 10, with approximately the same weight distribution (62–80 g) in each group. The animal room had 15–20 air changes per hour and a temperature of 20 ± 1°C. The relative humidity was 55 ± 10%, and a 14-hr light and 10-hr dark cycle was used. The test feeds, given in powder form ad libitum, were adjusted to contain oat bran or concentrates corresponding to 3.3% β-glucan, except in the control group. The composition of the feeds is given in Table II. The animals were allowed tap water ad libitum. During the experiment, the identity of the test feeds was unknown to the experimenters. Feed consumption was recorded for the groups of animals in each cage twice each week. The animals were weighed individually once each week. At the beginning of the experiment and after two, three, and four weeks, blood samples were drawn between 4 and 12 p.m. from the saphenal vein after 16–24 hr of fasting. Serum total cholesterol was analyzed by an enzymatic CHOD-PAP method using the test kit of Boehringer GmbH (237574, Mannheim, Germany). One day after the last blood sampling, the animals were weighed and then sacrificed by guillotine decapitation. Their livers were removed and weighed.

Statistics

Statistical significance of the differences was analyzed using Statview 512+ (Brainpower, Inc., Calabasas, CA) on an Apple Macintosh computer. Data of the animal experiment were first analyzed by analysis of variance followed by the Scheffé multiple comparison test. Values of $P < 0.05$ were considered statistically significant.

RESULTS

Extractability and Viscosity

β-Glucan extractability at 40°C varied in the preparations studied. OBC 5, OBC 6, OBC 13, and OBC 14 had values of 48.0, 76.7, 40.4, and 44.0%, respectively. The highest extractability (90.8%) was found in the untreated oat bran (OB 4). In spite of that, the low shear rate viscosity of that extract was lower than that of the extract of one of the concentrates, OBC 14 (Table III). In addition, the aqueous extract of OB 4 showed less shear thinning than that of OBC 14, indicating that the viscous material solubilized from bran in 40°C water had a lower molecular weight and/or contained other viscosity elevating components than that solubilized from the concentrate. On the other hand, the viscosity

TABLE II
Percent Composition of Rat Diet

Component	Diet[a]					
	Control	OB 4	OBC 5	OBC 6	OBC 13	OBC 14
Oat bran or concentrate	0	55.00	22.45	21.29	17.46	20.25
Cellulose[b]	7.15	0	0	0	0	0
Vitamin mixture[c]	1.00	1.00	1.00	1.00	1.00	1.00
Mineral mixture[d]	3.94	3.94	3.94	3.94	3.94	3.94
Soya oil	5.00	0.77	3.68	3.55	4.76	4.13
Corn starch	59.86	31.09	52.25	53.55	54.74	53.33
Glucose	6.90	3.58	6.02	6.17	6.31	6.14
Casein	13.95	3.47	8.73	8.53	9.77	9.24
SiO_2	1.86	0.97	1.63	1.67	1.70	1.66
Mg-stearate	0.34	0.18	0.30	0.31	0.32	0.31
Protein	12.0	12.0	12.0	12.0	12.0	12.0
Carbohydrate						
Total (by difference)	69.03	64.38	64.80	66.99	66.85	67.82
Total dietary fiber[e]	7.15	7.15	8.98	8.32	6.57	6.62
β-Glucan	...	3.30	3.30	3.30	3.30	3.30
Fat	5.00	5.00	5.00	5.00	5.00	5.00

[a] OB 4, untreated oat bran; OBC 5, cold-water wet-milled oat bran concentrate (OBC); OBC 6, hydrolyzed cold-water wet-milled OBC; OBC 13, hot ethanol-water wet-milled OBC; OBC 14, cold ethanol-water wet-milled OBC.
[b] Emcocel 50*M* (Cultor Ltd., Helsinki, Finland).
[c] Prepared according to American Institute of Nutrition vitamin mixture 76.
[d] Prepared according to National Research Council requirement data.
[e] According to Prosky et al 1985 and corresponding to a 1990 AOAC method.

TABLE III
Viscosity[a] at 25°C of β-Glucan Solutions and Extracts from Bran and Concentrates[b]

	OB 4		OBC 5		OBC 6		OBC 13		OBC 14	
	SR[c] 19	SR 461	SR 19	SR 461	SR 19	SR 461	SR 19	SR 461	SR 19	SR 461
Aqueous extract[d]	141	55	ɔ	5	9	9	80	26	220	45
Alkaline extract[e]	29	12	240	50	12	11	164	43	179	35
β-Glucan[f]	367	49	196	42	15	14	177	47	229	41

[a] Measured in millipascal seconds.
[b] OB 4, untreated oat bran; OBC 5, cold-water wet-milled oat bran concentrate (OBC); OBC 6, hydrolyzed cold-water wet-milled OBC; OBC 13, hot ethanol-water wet-milled OBC; OBC 14, cold ethanol-water wet-milled OBC.
[c] Shear rate, per second.
[d] On equal initial β-glucan content (1%) basis.
[e] Except for OBC 13, on equal initial dry substance basis.
[f] 0.37% aqueous solutions of alkaline-extracted β-glucan.

of the β-glucan isolated from OB 4 was higher than that isolated from concentrates, and the shear thinning behavior was similar.

Alkaline extracts of the two ethanol-water wet-milled samples exhibited similar viscosities, although sample 13 was obtained from 35 g of OBC as opposed to 50 g of sample 14 (Table III). The viscosities of the alkaline extract of the cold-water wet-milled sample (OBC 5) were higher; however, the difference was within the limits of experimental variation. The viscosities of the alkaline extract of untreated oat bran (OB 4) reflect the lower level of β-glucan in the extract. As expected, the viscosities of the hydrolyzed concentrate (OBC 6) were low (Table III).

A comparison of the viscosities for 0.37% solutions of β-glucan isolated from the alkaline extracts showed that β-glucan extracted from the concentrates obtained by wet milling in cold water (OBC 5) or alcohol-water suspensions (OBCs 13 and 14) had similar viscosity properties, whereas β-glucan from the hydrolyzed concentrate (OBC 6) gave a very low viscosity (Table III). At the same concentration, β-glucan isolated from the untreated oat bran gave nearly twice the viscosity at the low shear rate as did β-glucan preparations from the nonhydrolyzed concentrates.

Trypsin treatment of the alkaline extract of OBC 13 (Table IV) reduced the viscosity, but the residual viscosity after incubation for 40 min was still above the level of the extracts with the lowest specific viscosities. Trypsin also had a similar effect on the viscosity of the β-glucan isolated from the alkaline extract of OBC 13 (Table IV).

Molecular Weight and Hydrodynamic Properties

In the gel permeation studies, β-glucan isolated from ethanol-water wet-milled concentrate (OBC 14) differed only slightly from β-glucan of the untreated oat bran (OB 4), but β-glucan from the hydrolyzed sample (OBC 6) was eluted later and was detected by RI detector as a broad peak (Fig. 1). Because of the difference in the shape of molecules, molecular weights cannot be estimated by comparing them to dextran standards. Under slightly different GPC conditions, more narrow peaks but similar retention volumes for the RI detection were obtained (Fig. 2). Peaks from laser light-scattering detection occurred earlier (Fig. 2); the greatest difference was for the hydrolyzed sample OBC 6 (Fig. 2c). Controls performed by dyeing the fractions with Calcofluor after the GPC separation and recording the color at 405 and 410 nm (not presented) confirmed that the material eluted before the RI peak was in fact β-glucan.

Using the MALLS data and the computer program of the equipment, molecular weights and gyration radii were calculated for β-glucans isolated from alkaline solutions of three concentrates. The results are presented in Table V and Figure 3. The highest molecular weight and the lowest polydispersity found was for β-glucan from the cold-water wet-milled concentrate. β-Glucan in this preparation also had the highest gyration radius and thus highest hydrodynamic volume.

In a comparison of the gyration radius with the molecular weight (Fig. 3), the root mean square radii of β-glucans from OBC 5 (Fig. 3a) and OBC 14 (Fig. 3b) were found to be distributed in a wide range, in contrast to the rather uniform root mean square radius pattern in hydrolyzed sample OBC 6 (Fig. 3c). For molecules of the same molecular weight, the gyration radius diminished from OBC 5 to OBC 6. This may indicate that during the hydrolysis under acidic conditions, the proportion of elongated

TABLE IV
Effect of Trypsin on the Viscosity[a] of Alkaline Extract of Oat Bran Concentrate (OBC 13[b]) and of Solutions of β-Glucan Isolated from the Extract

Sample	Trypsin (EU/ml)	Incubation at 36°C (min)	Viscosity (mPa·sec)
Alkaline extract	0	0	107
	0	40	85
	2	15	55
	2	40	33
1% β-glucan	0	60	750
	2	60	440

[a] Viscosity determined at 25°C and at a shear rate of 18.6 sec^{-1}.
[b] Hot ethanol-water wet-milled oat bran concentrate.

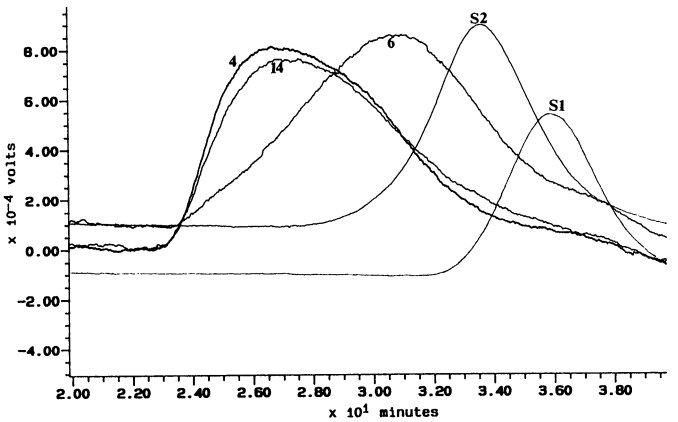

Fig. 1. Gel permeation chromatograms of β-glucans isolated from ethanol-water wet-milled oat bran concentrate (14), hydrolyzed cold-water wet-milled oat bran concentrate (6), and oat bran (4). Standards: Dextran MW 70,000 (S1) and 500,000 (S2).

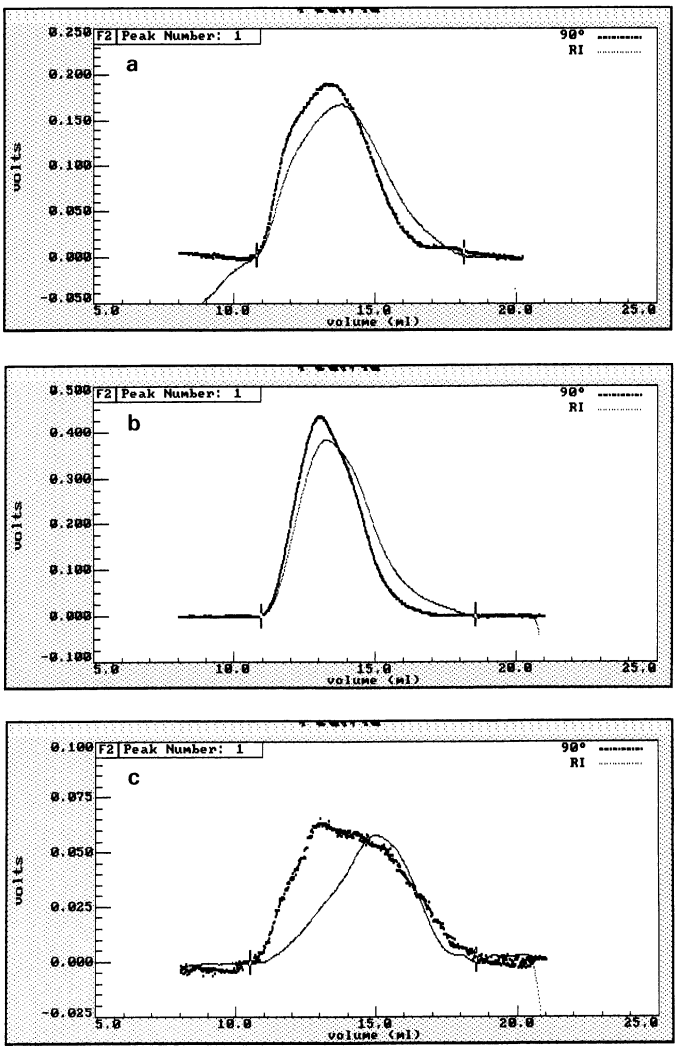

Fig. 2. Gel permeation chromatograms of β-glucan isolated from oat bran concentrates (OBCs). **a**, Cold-water wet-milled OBC (OBC 5); **b**, ethanol-water wet-milled OBC (OBC 14); **c**, hydrolyzed cold-water wet-milled OBC (OBC 6). RI = refractive index detection, 90° = light scattering at 90° angle.

shapes of molecules diminished in favor of more globular shapes. A similar but less obvious difference is between OBC 5 (Fig. 3a) and OBC 14 (Fig. 3b).

Effects on Rat Growth and Serum Cholesterol Level

Rat body and liver weights and serum cholesterol values of the experimental groups are presented in Table VI. No significant differences between the groups were observed in either food consumption or growth. Some barbering (mutual nibbling of hairs) was observed in the control and OBC 14 groups. At the end of the experiment the condition of all animals appeared normal. In group OBC 6, one animal was accidentally lost.

In groups OBC 13 and OBC 14, the liver absolute and relative weights were both 10–15% higher than in the control (cellulose) group.

No significant reduction in serum total cholesterol concentration was observed in the rats receiving oat bran (OB 4) relative to their starting level and to the control group. The different OBCs had various effects. As compared with the start levels, all concentrates significantly reduced cholesterol at one or more of the sampling periods. As compared with the control group, OBC 14 caused significant reductions of cholesterol from 28 to 33%.

DISCUSSION

Differences in the viscosity of water extracts from the different oat brans (Table III) could be due to solubility and hence β-glucan concentration. In addition, differences in β-glucan molecular weight, enzymatic breakdown, or hydrodynamic properties may affect extract viscosity. The neutral aqueous extracts tested simulate (in respect to the temperature and time of extraction) the residence time in stomach. Hydrolysis by residual β-glucanases could occur both in the extraction procedure and in the stomach.

Although β-glucan in the untreated oat bran had the highest molecular weight, the viscosity of its aqueous extract was lower than that of OBC 14. Since the extractability of β-glucan was high (>90%), the viscosity is low in regard to β-glucan concentration. Also, the low shear thin indicates a breakdown of the macromolecules of β-glucan. The viscosity of the aqueous extract was highest in one of the ethanol-water wet-milled concentrates (OBC 14). Since the raw material for the two ethanol-water wet-milled preparations (OBCs 13 and 14) was different, it is not possible to explain the difference in the viscosity properties and hypocholesterolemic effect of these two preparations.

Viscosities of the alkaline extracts reflect both concentrations and molecular weights of β-glucan in the preparations. Since the extractions (at pH 9.0) were performed far outside the pH range of the β-glucanases (mostly around pH 5), there is less possibility of residual enzyme activity than in neutral extracts.

TABLE V
Molecular Weights and Gyration Radii of β-Glucan from Three Oat Bran Concentrates[a]

	OBC 5	OBC 14	OBC 6
Mean molecular weight by number (M_n)	1.1×10^6	3.7×10^5	2.1×10^5
Mean molecular weight by weight (M_w)	1.5×10^6	1.1×10^6	3.7×10^5
Z-average[b] (M_z)	1.9×10^6	1.5×10^6	1.0×10^6
Polydispersity			
M_w/M_n	1.4	3.1	1.7
M_z/M_n	1.8	4.0	4.7
RMS[c] radius, number average, nm	114	89	32
RMS radius weight average, nm	117	88	34

[a] OBC 5, OBC 14, and OBC 6 = cold-water wet-milled, cold ethanol-water wet-milled, and hydrolyzed cold-water wet-milled oat bran concentrates, respectively.
[b] $(\Sigma c_i M_i^2)/(\Sigma c_i M_i)$, where c = concentration and M = molecular weight.
[c] Root mean square.

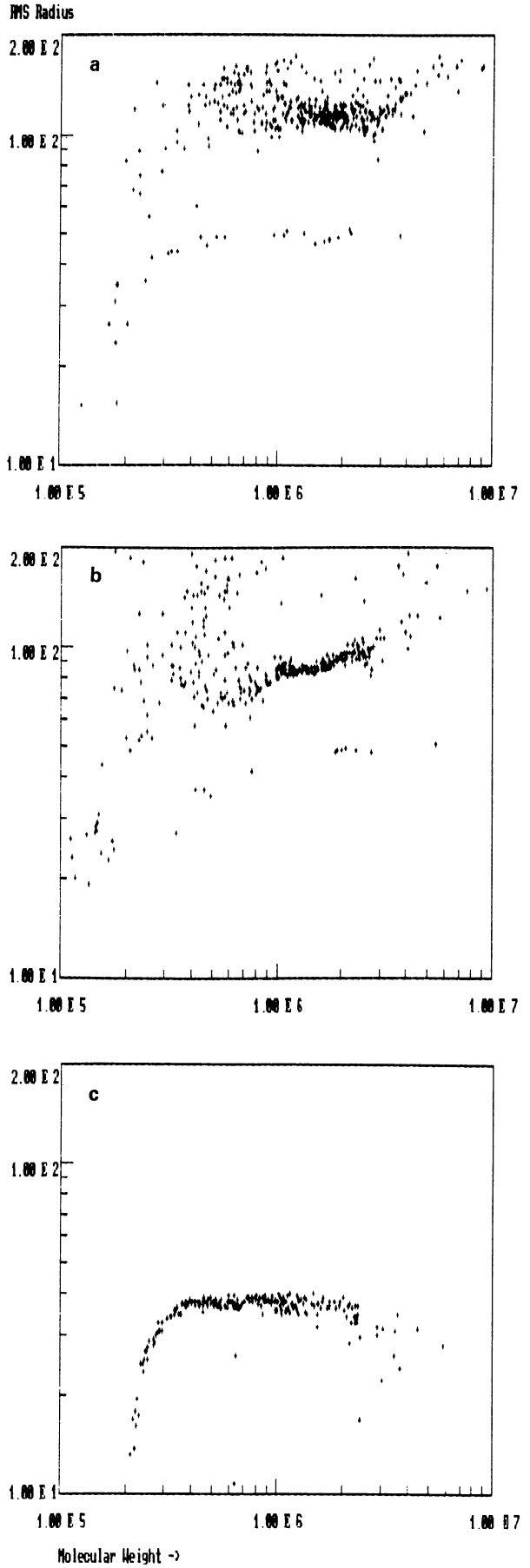

Fig. 3. Gyration radius as a function of molecular weight in β-glucans isolated from oat bran concentrates (OBCs). **a,** Cold-water wet-milled OBC (OBC 5); **b,** ethanol-water wet-milled OBC (OBC 14); **c,** hydrolyzed cold-water wet-milled OBC (OBC 6).

The bran and concentrates studied differ from each other in too many physical properties to conclude which of them bears the primary responsibility for the hypocholesterolemic effect. The β-glucan in the most effective preparation (OBC 14) had a 44% solubility in neutral water extraction. Viscosity of this extract was the highest; the hydrodynamic gyration radius was intermediate. On the other hand, the hydrolyzed concentrate (OBC 6), which had highly soluble (77%) β-glucan, exerted only a weak hypocholesterolemic effect, probably because of the the lower mean molecular weight of the β-glucan, lower hydrodynamic volume, and lower viscosity.

The weaker hypocholesterolemic effect of the cold-water wet-milled preparation (OBC 5) was probably because of hydrolytic breakdown of β-glucan before it passed to the small intestine, as indicated by the low viscosity of its neutral extract, despite its moderate solubility (48%). It is unclear what role in cholesterol reduction should be attributed to the hydrodynamic volumes and steric properties.

The hydrodynamic properties of β-glucans (Fig. 3) indicate that the gyration radii can be very different for a certain molecular weight. Isolated β-glucan is known to contain small amounts (1.1 to 8.4%) of protein or peptides (Forrest and Wainwright 1977, Vårum and Smidsrød 1988, Autio et al 1992a,b), either firmly linked or as an impurity. Part of the differences in the gyration radii could be because of linkages with proteins or peptides to form structures or agglomerates with different spherical shapes than those obtained from structural studies of β-glucans. The effect of trypsin on β-glucan extracts (Table IV) can be explained by such linkages. Reduced hypocholesterolemic effect may be in proportion to the decrease in viscosity. Whether the proteins and trypsin have other effects on the hypocholesterolemic properties of β-glucan remains to be studied.

With all the test diets except the control diet, similar amounts of β-glucan were fed. Since only a minor amount is digested in the small intestine (Bach Knudsen and Nygaard Johansen 1991), similar amounts of β-glucan must have ended up in the large bowel of animals in all experimental groups. A preparation with low molecular weight and high solubility, like sample OBC 6, would be expected to be most effectively converted to volatile fatty acids. However, among the OBCs, OBC 6 had the weakest effect on serum cholesterol, suggesting that volatile fatty acid formation probably does not play a major role in the cholesterol reduction by oat soluble fiber. The role of viscosity within the small intestine as the primary mechanism for hypocholesterolemic effect recently has been shown in rat and in vitro studies by Lund et al (1989) and in chicken studies with barley by Bengtsson et al (1990).

The enhanced effect of fiber from concentrates over oat bran has been described by Ney et al (1988), who fed rats hypercholesterolemic diets, one of which contained a processed oat flour product with 40% more β-glucan than oat bran. An even more pronounced difference was found with normocholesterolemic rats by Ranhotra et al (1990). In their experiments, animals fed OBC had far lower total cholesterol and higher HDL-cholesterol than animals fed oat bran with similar amounts of soluble fiber.

In human studies reported by van Horn et al (1986), oatmeal had a nonsignificantly greater cholesterol-lowering effect than oat bran, despite its lower β-glucan content. Since the β-glucan-containing cell walls in the endosperm are thinner than in the subaleurone layers, perhaps the β-glucan of the whole groat was more soluble than that of oat bran. The critical roles of molecular weight and solubility observed here might also explain why Mongkolsirikieat et al (1989) found that 5–6 g per day of pectin obtained by eating rambutan fruit lowered cholesterol levels, whereas a dose of 15 g per day of isolated pectin was needed for the same effect (Vargo et al 1985).

No significant differences in food intakes and weight gains were found among the experimental groups. These data agree with reports for oat bran (Chen et al 1981), oat gum (Jennings et al 1988), and several processed high fiber oat products (Shinnick et al 1988, Ranhotra et al 1990). Contrary to these findings, lower food intake or weight gain has been observed in rats fed oat β-glucan than in rats fed cellulose (Chen et al 1981, Vachon et al 1988, Bégin et al 1989). Greater weight gains have been reported for oat bran-fed rats than for cellulose-fed rats (Kritchevsky et al 1984, Ranhotra et al 1990).

At the end of the test period, the livers of the rats receiving concentrates that had significant hypocholesterolemic effects (OBCs 13 and 14) were slightly larger than the livers of the control group rats. Changes in liver weights for normocholesterolemic rats have not been reported in earlier studies. When hypercholesterolemia was induced with cholesterol and cholic acid, relative liver weights were significantly increased, and fat was found to be infiltrated into liver cells (Shinnick et al 1990). When hypercholesterolemic rats were fed diets containing oat bran (Kritchevsky et al 1984), oat gum (Chen et al 1981, Jennings et al 1988), or processed high-fiber oat products (Shinnick et al 1988), relative liver weights were similar or lower than those in cellulose-fed groups.

TABLE VI
Effects of Four-Week Feeding of Young Male Mol:SPRD Rats with Diets Containing Oat β-Glucan Preparations on Growth, Liver Weight, and Serum Cholesterol Concentrations[a]

	Experimental Group[b]					
Measurement	**Control**	**OB 4**	**OBC 5**	**OBC 6**	**OBC 13**	**OBC 14**
Average feed consumption, g/animal	526	558	548	522	521	539
Initial body weight, g	70.8 ± 5.6	70.7 ± 4.3	70.0 ± 3.6	69.8 ± 2.7	68.0 ± 3.7	68.7 ± 4.3
Body weight,[c] g	222.3 ± 19.5	243.5 ± 12.0	239.6 ± 11.6	238.7 ± 9.1	225.1 ± 18.0	237.3 ± 23.0
Final body weight,[d] g	244.1 ± 22.0	266.7 ± 15.3	261.2 ± 11.3	259.1 ± 11.0	248.6 ± 19.7	257.3 ± 25.2
Liver weight, g	11.1 ± 1.3	12.6 ± 1.6	12.2 ± 0.6	12.4 ± 1.2	13.1 ± 1.3[f]	13.4 ± 1.5[f]
Relative liver weight[e]	4.6 ± 0.3	4.7 ± 0.5	4.7 ± 0.2	4.8 ± 0.4	5.3 ± 0.4[f]	5.2 ± 0.6[f]
Serum cholesterol, mmol/L						
Start	2.98 ± 0.27	3.06 ± 0.28	2.83 ± 0.30	2.92 ± 0.27	2.90 ± 0.21	2.94 ± 0.20
Two weeks	2.86 ± 0.31	2.86 ± 0.76	2.60 ± 0.28	2.47 ± 0.54[g]	2.37 ± 0.51[h]	1.96 ± 0.58[f,i]
Three weeks	2.81 ± 0.32	3.04 ± 0.77	2.62 ± 0.21	2.86 ± 0.71	2.23 ± 0.61[i]	1.87 ± 0.69[f,i]
Four weeks	2.84 ± 0.33	2.82 ± 0.56	2.56 ± 0.27[g]	2.55 ± 0.46	2.38 ± 0.54[h]	2.04 ± 0.48[f,i]

[a] Numbers in table represent means ± SD; $n = 10$, except $n = 9$ for group OBC 6.
[b] OB 4, untreated oat bran; OBC 5, cold-water wet-milled oat bran concentrate (OBC); OBC 6, hydrolyzed cold-water wet-milled OBC; OBC 13, hot ethanol-water wet-milled OBC; OBC 14, cold ethanol-water wet-milled OBC. Total composition of the diets given in Table II.
[c] Body weight at the time of the last blood sample.
[d] Body weight at the time of killing.
[e] Grams of liver per 100 g of body weight.
[f] $P < 0.05$ as compared with the control group.
[g] $P < 0.05$ as compared with the initial cholesterol concentrations in each group.
[h] $P < 0.01$ as compared with the initial cholesterol concentrations in each group.
[i] $P < 0.001$ as compared with the initial cholesterol concentrations in each group.

When livers from control and OBC 14 groups were subjected to pathological examination, considerable accumulation of fat in the liver was observed in the OBC 14 group but not in the control group. This effect needs to be more thoroughly explored.

CONCLUSIONS

A serum cholesterol-reducing effect was achieved in rats receiving OBCs at about 20% concentration of the feed, an amount corresponding to 3.3% β-glucan in the feed.

The integrity of the β-glucan molecules and possibly also the association of β-glucan with protein or peptides, as well as good solubility in the intestinal tract, seem to be essential for their hypocholesterolemic effect. Those properties were achieved in OBCs using an ethanol-water wet-milling concentration process, in which the molecular weight of β-glucan was only slightly reduced and the enzymatic breakdown in water was minimal.

Preparations that had a significant hypocholesterolemic effect had high or medium-high viscosities and pseudoplastic properties in aqueous extraction. Preparations that were ineffective or less effective yielded aqueous extracts of lower viscosity. The association of the hypocholesterolemic effect of oat β-glucan with good extractability in an aqueous solution and a fairly high molecular weight supports the hypothesis that the mechanism of action is based on the ability of the gum to increase the viscosity of the contents of the gastrointestinal tract, which results in a reduction of the diffusion rate leading to a reduction of the absorption of cholesterol and bile acids.

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