Mixed-linked $\beta$-glucan from breads of different cereals is partly degraded in the human ileostomy model$^1$–$^3$

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ABSTRACT The purpose of this investigation was to study the degradation of $\beta$-glucan in the small intestine and the molecular weight of $\beta$-glucan in the excreta of nine ileostomy subjects after consumption of different diets based on bread made with oat bran (oat bread), a fiber-rich barley fraction (barley bread), or wheat flour (wheat bread) as the main ingredients. Oat bread with enzymatically degraded $\beta$-glucan was also used (oat + enzyme bread). The $\beta$-glucan intake from the four diets was 12.5, 12.9, 1.1, and 4.0 g/d, respectively. On the basis of dry matter, the night effluents accounted for $\approx$15% of the total amount of the excreta, with the highest proportion (22%) being for the wheat-bread diet. A notable loss of $\beta$-glucan (0.7–2.4 g/d, or 13–64%) was found when intake was compared with excretion. In vitro, a higher viscosity development with time for dispensers of oat bread compared with barley bread was noted, which could be related to the higher molecular weight of the $\beta$-glucan in this bread. There seemed to be a depolymerization of the $\beta$-glucan both during bread making and transit through the upper gastrointestinal tract. Am J Clin Nutr 1996;64:878–85.

KEY WORDS Ileostomy, cereal-bread diets, mixed-linked $\beta$-glucan degradation, molecular weight

INTRODUCTION

A major constituent of dietary fibers in both oat and barley is the (1–$\rightarrow$3), (1–$\rightarrow$4)-$\beta$-D-glucan (subsequently referred to as $\beta$-glucan). The $\beta$-glucan from both cereals contains predominantly cellotriosyl and celloolitetraosyl units separated by single (1–$\rightarrow$3) linkages; a higher relative proportion of cellotriosyl units has been found in barley (1).

$\beta$-Glucan–rich oat and barley fractions have been shown to reduce serum cholesterol concentrations in both humans and animals (2–5). Recently, a purified $\beta$-glucan extract (80% $\beta$-glucan) was also shown to lower serum cholesterol concentrations in hypercholesterolemic subjects (6). The mechanism involved, however, is not clear. One explanation is the potential of soluble fibers to increase the fecal excretion of bile acids, which in turn leads to a reduced serum cholesterol concentration in blood (7).

When studying small bowel digestion in humans the ileostomy model is often used to investigate absorption and excretion of nutrients (4, 8–10). Recently, we found that ileostomy subjects had a higher bile acid excretion from the small intestine after consumption of oat-bran bread in comparison with oat-bran bread with degraded $\beta$-glucan and fiber-rich barley bread, although oat-bran bread and fiber-rich, barley-bread diets contained the same amount of $\beta$-glucan (11). The results from this part of the study indicate that the serum cholesterol-lowering capacity of $\beta$-glucan from oat and barley differ and consequently may not be related to the content and solubility of this dietary fiber component only. In animal studies, the cholesterol-lowering potential was related to the degradation rate and molecular size of $\beta$-glucan in the small intestine (12, 13).

The aim of this investigation was to study, on previously collected samples (11), the molecular weight and possible degradation of $\beta$-glucan in the ileostomy model after ingestion of different breads made of oat bran with or without enzymatically degraded $\beta$-glucan, fiber-rich barley fraction, and wheat flour as main ingredients.

SUBJECTS AND METHODS

Subjects

Nine subjects (six males and three females) with a median age of 57 years (range: 30–70 years) participated in this study. All subjects had undergone proctocolectomy because of ulcerative colitis without resection of the small intestine and had no signs of inflammation. Each subject gave their consent and the study protocol was approved by the Ethical Committee of Sahlgrenska Hospital in Gothenburg, Sweden. Further details of the clinical data are described by Lia et al (11).

Diets

Each subject was served four different diets in random order. The diets differed only in the type of bread served. The main

REFERENCES

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ILEAL DEGRADATION OF MIXED-LINKED β-GLUCAN

ingredient in each different bread was as follows: oat bran from Kungström AB, Stockholm; a roller-dried and drum-dried, fiber-rich, barley fraction denoted M2 described by Sundberg et al (5); and a wheat flour from Kungström AB. A fourth bread was also made of the oat bran, to which 2 g β-glucanase/kg (GP 5000; Grindsted Products A/S, Braband, Denmark) was added to the bread dough. The breads are referred to as oat bread, oat + enzyme bread, barley bread, and wheat bread.

Energy requirements were determined from body weight and a 24-h recall of dietary intake. The food was prepared in a metabolic-ward kitchen and kept frozen at −20 °C until consumed. On the experimental days the subjects attended the metabolic ward and were served breakfast at 0800. The rest of the meals were eaten by the subjects at work or in their homes at fixed times: 1000 (breakfast and coffee), 1230 (fish dish, creamed potatoes, and bread), 1700 (chicken dish, creamed potatoes, and bread), and 2000 (peach slices and cream). Double portions from the diets were freeze-dried and analyzed. The four kinds of breads were prepared in advance and immediately frozen at −20 °C. The different breads were made of the following ingredients:

1) Oat bread (30 rolls): 675 g oat bran, 450 g wheat flour, 100 g wheat gluten, 30 g dry yeast, 20 g sugar, 15 g syrup, 12 g salt, and 1000 g water; oat + enzyme bread—same as the oat-bran bread except that 4 g β-glucanase was added.

2) Barley bread (30 rolls): 830 g barley fraction M2, 450 g wheat flour, 100 g wheat gluten, 30 g dry yeast, 34 g margarine, 20 g sugar, 15 g syrup, 12 g salt, and 1720 g water.

3) Wheat bread (30 rolls): 1400 g wheat flour, 24 g dry yeast, 30 g margarine, 20 g sugar, 12 g salt, and 800 g water.

The subjects were served either six rolls of oat bread, oat + enzyme bread, or barley bread, or four rolls of wheat bread per day. Each diet was eaten 2 d in a row with 5 d in between. The β-glucan content on a dry matter basis was 9% in oat bran, 7% in barley fraction M2, and 0.3% in wheat flour. Further information regarding the mixed diets is described by Lia et al (11).

Collection of effluents

The sampling of ileostomy effluents started at 0800 and the bags were changed every second hour. During the night, from 2300 to 0800, one or two bags were used. The samples were immediately frozen on solid carbon dioxide in a Dewar vessel, which the subjects kept at home. The participants delivered the frozen ileostomy bags to the hospital in the morning, where they were stored at −20 °C and thereafter weighed and freeze-dried. Ileostomy effluents from each 24-h period were weighed, ground, mixed, and stored at −20 °C until analyzed. The day and night bags were analyzed separately for dry matter content and excretion and molecular weight of β-glucan.

Chemical analyses

The dry matter content was determined by oven drying at 105 °C for 16 h. The content of total and insoluble β-glucan was analyzed according to Åman and Graham (14). Oligosaccharides from β-glucan, which do not precipitate in 80% aqueous ethanol, are excluded in this analysis. The soluble β-glucan was calculated as total β-glucan minus insoluble β-glucan.

Viscosity measurements

Viscosity development of slurries of ground oat bran (1 g), barley fraction M2 (1 g), or wheat flour (1 g) with or without the addition of 10 mg pancreatin (P-7545; Sigma Chemical) to the oat-bran and barley-fraction samples was continuously monitored in a Bohlin Viscometer (Bohlin Visco 88, DIN 53019; Bohlin Reolog i AB, Lund, Sweden). The samples were suspended in 0.2 mol sodium phosphate buffer/L, pH 6.0 (20 mL), and viscosity was measured for 60 min at 37 °C at a shear rate of 1200 s⁻¹ (M Luhaloo, A-C Tilly, R Andresson, P Åman, unpublished observations, 1995).

Viscosity development was also measured in samples from ground oat and barley bread containing equal total amounts of β-glucan as in the slurries of the cereal fractions. Sample weights were 1.7 and 1.3 g for the oat and barley breads, respectively (corresponding to a total β-glucan content of 9% in oat bran and 7% in fiber-rich barley fraction on a dry matter basis). Sample weights of oat + enzyme bread and wheat bread were 1.7 and 1.0 g, respectively. The viscosity development of oat and barley breads with 50 mg added pancreatin was also monitored.

Molecular weight of β-glucan

The molecular weight of β-glucan in the effluents was measured on pooled samples with an equal amount added from each subject. The samples were refluxed with 70% aqueous ethanol in a boiling water bath for 2 h. The mixture was centrifuged at 14 500 × g for 10 min at room temperature and the solvent discarded; this procedure was done twice. The pellets were washed with 95% ethanol and then air-dried with gentle warming on a hot plate and finally in a vacuum oven. Triplicate samples (duplicate, when there was limited amount of material) of ethanol-treated samples were extracted by stirring with carbonate buffer (pH 10 and an ionic strength of 0.2) at 60 °C for 2 h. Mixtures were then centrifuged at 14 500 × g for 10 min at room temperature and the supernates were filtered through 1.2-µm membranes before fractionation by high-performance size exclusion chromatography (HPSEC), essentially as described by Wood et al (15). PL aquagel-OH60 (Polymer Laboratories Inc, Amherst, MA), Shodex OH pak KB 806 (Shodex, Showa Denko America Inc, New York), and Bio-Rad TSK-20, TSK-40, and TSK-60 XL gels (Bio-Rad, Mississauga, Canada) were used. Because different column systems were used, different retention volumes were obtained for the different samples. Postcolumn detection was determined by measuring the increase in fluorescence of bound fluorescent whitener 28 (Cyannamid Co, Bound Brook, NJ). Peak molecular weight was determined from a calibration curve made from β-glucan molecular weight standards and retention volume from the fluorescence detector (15). With this system only high-molecular-weight (> 10 000) β-glucan fragments are detected (16).

Statistics

The results are given as mean values. The intake and excretion of total β-glucan were compared between the 2 d as well as between days and nights, respectively, by the Wilcoxon matched-pairs, signed-rank test (17). Differences were considered significant at P < 0.01. Statistical analyses of intake and excretion of β-glucans were performed with the general linear

RESULTS

Intake and excretion of β-glucan

Each roll of oat bread and barley bread contained 2 g β-glucan (Table 1). The β-glucan content in the oat + enzyme bread was reduced to about one-third compared with the content in the oat bread. Only small amounts of β-glucan (0.17 g) were found in one roll of wheat bread. About 50% of the total β-glucan was in the soluble form in the oat, oat + enzyme, and barley breads; but only ~10% in the wheat bread.

Neither intake nor excretion of β-glucan differed significantly between either the 2 days or the 2 nights. The statistical evaluation was therefore performed on mean values from the 2 days and 2 nights, respectively. After consumption of oat and barley breads, a higher total ileal excretion of β-glucan was noted: 87% and 81% of intake, respectively, compared with the oat + enzyme and wheat breads, which had an excretion of 58% and 36% of intake, respectively (Table 2). Excretion of insoluble β-glucan was essentially quantitative after consumption of the oat-bread and barley-bread diets, but a significant proportion of the insoluble β-glucan in the oat + enzyme and wheat-bread diets was lost or solubilized during transit through the upper gut.

A small proportion of the total excretion of β-glucan was observed in the night bags. Night excretion of β-glucan after the oat- and barley-bread periods was ~7% of total excretion and ~9% after the oat + enzyme–bread period, whereas excretion after the wheat-bread period was ~15%.

Weight of the effluents

The dry matter yields of ileal effluents did not differ significantly between the 2 d or the two nights of collection, during each dietary period. The highest excretion of dry matter was noted after consumption of the oat-bread and barley-bread diets, whereas the lowest excretion was found during the wheat-period (Table 3). During the nights, 15–17% of the total amounts of effluents were collected after consumption of the oat-, oat + enzyme–, and barley-bread diets, whereas after consumption of the wheat-bread diet a higher proportion (22%) was collected.

Viscosity measurements

An increase in viscosity with time was noted for slurries of the finely ground samples in sodium phosphate buffer, except for the non-heat-treated wheat flour, which did not develop any notable viscosity (Figure 1). The sample from the barley fraction M2 developed viscosity more rapidly than did the oat-bran sample. Addition of pancreatin, with protease and amylase activity but no β-glucanase activity, to the dispersions with oat-bran and barley fraction M2, respectively, had little effect on the viscosity development.

Dispersions of oat bread developed the highest viscosity followed by that of barley bread whereas that of oat + enzyme bread and that of wheat bread had low viscosity (Figure 2). Addition of pancreatin to the dispersion of oat bread reduced the viscosity, and both oat samples showed a decrease in viscosity with time after ~10 min. No notable difference in development of viscosity was shown between the dispersions of barley bread with or without pancreatin.

Molecular weight

The molecular-weight distributions were studied by HPSEC and the average peak molecular weights were determined from a calibration curve by using retention volume. The β-glucan with the highest peak molecular weight was that extracted from oat bran (2.7 × 10⁶) whereas that from the barley fraction M2

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### Table 1

<table>
<thead>
<tr>
<th>Bread</th>
<th>Total β-glucan</th>
<th>Soluble β-glucan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat</td>
<td>2.03 ± 0.08 (5.4)</td>
<td>0.95 ± 0.04 (2.5)</td>
</tr>
<tr>
<td>Oat + enzyme</td>
<td>0.63 ± 0.38 (1.6)</td>
<td>0.30 ± 0.12 (0.8)</td>
</tr>
<tr>
<td>Barley</td>
<td>2.03 ± 0.08 (4.7)</td>
<td>0.95 ± 0.15 (2.2)</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.17 ± 0.02 (0.4)</td>
<td>0.004 ± 0.0 (0.01)</td>
</tr>
</tbody>
</table>

* x ± SD of three batches; percentage of dry matter in parentheses.

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>Oat bread</th>
<th>Oat + enzyme bread</th>
<th>Barley bread</th>
<th>Wheat bread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12.5 ± 0.6*</td>
<td>4.0 ± 0.6*</td>
<td>12.9 ± 0.4*</td>
<td>1.1 ± 0.1*</td>
</tr>
<tr>
<td>Insoluble</td>
<td>6.7 ± 0.6*</td>
<td>2.6 ± 0.1*</td>
<td>6.9 ± 0.6*</td>
<td>1.1 ± 0.1*</td>
</tr>
<tr>
<td>Soluble</td>
<td>5.7 ± 0.2*</td>
<td>1.4 ± 0.5*</td>
<td>6.0 ± 1.0*</td>
<td>0.02 ± 0.0*</td>
</tr>
<tr>
<td>Excretion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total day + night</td>
<td>10.9 ± 0.6*</td>
<td>2.3 ± 0.4*</td>
<td>10.5 ± 0.8*</td>
<td>0.4 ± 0.08*</td>
</tr>
<tr>
<td>Insoluble</td>
<td>6.6 ± 0.9*</td>
<td>0.9 ± 0.2*</td>
<td>6.9 ± 2.8*</td>
<td>0.2 ± 0.8*</td>
</tr>
<tr>
<td>Soluble</td>
<td>4.3 ± 1.0*</td>
<td>1.4 ± 0.3*</td>
<td>3.6 ± 2.6*</td>
<td>0.1 ± 0.08*</td>
</tr>
<tr>
<td>Total day</td>
<td>10.1 ± 0.6*</td>
<td>2.1 ± 0.5*</td>
<td>9.8 ± 0.7*</td>
<td>0.3 ± 0.07*</td>
</tr>
<tr>
<td>Insoluble</td>
<td>6.3 ± 1.0*</td>
<td>0.8 ± 0.2*</td>
<td>6.6 ± 2.7*</td>
<td>0.2 ± 0.07*</td>
</tr>
<tr>
<td>Soluble</td>
<td>3.8 ± 0.1*</td>
<td>1.3 ± 0.4*</td>
<td>3.2 ± 2.5*</td>
<td>0.1 ± 0.08*</td>
</tr>
<tr>
<td>Total night</td>
<td>0.8 ± 0.5*</td>
<td>0.2 ± 0.1*</td>
<td>0.7 ± 0.6*</td>
<td>0.06 ± 0.03*</td>
</tr>
<tr>
<td>Insoluble</td>
<td>0.3 ± 0.2*</td>
<td>0.1 ± 0.07*</td>
<td>0.3 ± 0.2*</td>
<td>0.05 ± 0.02*</td>
</tr>
<tr>
<td>Soluble</td>
<td>0.5 ± 0.4*</td>
<td>0.1 ± 0.1*</td>
<td>0.4 ± 0.4*</td>
<td>0.01 ± 0.03*</td>
</tr>
</tbody>
</table>

* x ± SD for the 2 d and nights of collection; n = 9. Values within a row with different superscript letters are significantly different, P < 0.01.
TABLE 3
Ileal excretion of dry matter in ileostomy bags after consumption of diets with the different breads

<table>
<thead>
<tr>
<th></th>
<th>Oat bread</th>
<th>Oat + enzyme bread</th>
<th>Barley bread</th>
<th>Wheat bread</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total day + night</td>
<td>92.6 ± 9.6 *</td>
<td>82.0 ± 10.1 *</td>
<td>94.1 ± 9.5 *</td>
<td>47.7 ± 9.3 *</td>
</tr>
<tr>
<td>Day</td>
<td>78.8 ± 10.9 (85.1)</td>
<td>68.0 ± 10.3 (82.9)</td>
<td>78.4 ± 10.7 (83.3)</td>
<td>37.4 ± 8.9 (78.4)</td>
</tr>
<tr>
<td>Night</td>
<td>13.8 ± 3.8 (14.9)</td>
<td>14.0 ± 4.0 (17.1)</td>
<td>15.7 ± 5.1 (16.7)</td>
<td>10.3 ± 3.2 (21.7)</td>
</tr>
</tbody>
</table>

*± SD for the 2 d and nights of collection; \( n = 9 \). Percentages of dry matter in parentheses. Values within a row with different superscript letters are significantly different, \( P < 0.01 \).

showed a bimodal molecular-weight distribution (peaks at \( 1.9 \times 10^5 \) and \( 0.2 \times 10^6 \)) and that from the wheat flour had a low peak molecular weight (\( 0.3 \times 10^5 \)) (Figure 3 and Table 4). Low amounts in wheat bread and oat + enzyme bread make estimates of peak molecular weight difficult. Compared with the cereal fractions, \( \beta \)-glucans extracted from the corresponding bread had lower peak molecular weights. That from oat bread again had the highest peak molecular weight and that from oat + enzyme bread the lowest (Figure 4 and Table 4).

The peak molecular weight of the \( \beta \)-glucan in day effluents after oat-bread consumption was notably lower than that of the \( \beta \)-glucans in oat bread. No corresponding peak molecular weight reduction was seen for the lower molecular weight \( \beta \)-glucans in the other three diets (Figure 5 and Table 4). The peak molecular weight of the \( \beta \)-glucans in the night excreta was low in all samples, and generally lower than that of the \( \beta \)-glucans in the day excreta (Figure 6 and Table 4).

**DISCUSSION**

The oat and barley breads were calculated to contain the same amount of \( \beta \)-glucan, which was corroborated by chemical analysis. The decrease in \( \beta \)-glucan content in the oat + enzyme bread illustrates a high activity of the added \( \beta \)-glucanase during the baking process leading to low-molecular-weight products not detected in the assay used.

From other studies it is known that about one-third of the \( \beta \)-glucan in oat bran is soluble in water (M Luhala et al., unpublished observations, 1995) and 36% is soluble in the roller-dried barley fraction M2 (5). After the baking process the content of soluble \( \beta \)-glucan was \( \approx 50\% \) in all breads, except in wheat bread, which had a low \( \beta \)-glucan solubility. It is known from previous investigations that a redistribution of insoluble to soluble fiber components takes place during thermal processes (5, 18, 19).

Except for the intake of \( \beta \)-glucan from breads, a small amount (0.2–0.7 g) of the intake originated from the other foods in the diets. When intake was compared with excretion of \( \beta \)-glucan from the oat and barley breads, a small loss of \( \beta \)-glucan was observed (13% and 19%, respectively). However, when intake was compared with excretion of \( \beta \)-glucan from oat + enzyme and wheat breads, there was a high loss (42% and 64%, respectively). In another study, there was a high degradation of \( \beta \)-glucans from wheat bread (80%), which

![FIGURE 1](https://example.com/figure1.jpg)

**FIGURE 1.** Development of viscosity (at \( 1200 \text{s}^{-1} \)), with time, of 1 g oat bran with (OB+) and without (OB) 10 mg pancreatin, 1 g fiber-rich barley fraction with (B+) and without (B) 10 mg pancreatin, and 1 g wheat flour (W), suspended in 20 mL sodium phosphate buffer (pH 6, 37 °C, 0.2 mol/L).

![FIGURE 2](https://example.com/figure2.jpg)

**FIGURE 2.** Development of viscosity (at \( 1200 \text{s}^{-1} \)), with time, of 1.7 g ground oat bread with (OB+) and without (OB) 50 mg pancreatin, 1.3 g barley bread with (B+) and without (B) 50 mg pancreatin, 1.7 g oat + enzyme bread (OBE), and 1 g wheat bread (W) suspended in 20 mL sodium phosphate buffer (pH 6, 37 °C, 0.2 mol/L).
indicates that the capacity to degrade β-glucans in the upper gut could be limited when the amount is high (10). A low recovery of β-glucan may be explained by bacterial or enzymatic degradation in the ileostomy subjects and/or the ileostomy bags. In a recent study by Livesey et al. (20), it was shown that the degradation of nonstarch polysaccharides in a barley diet almost exclusively took place in the night bags, but results from the present study showed that a degradation in the day bags had also taken place. Also, in an ileostomy study with oats by Englyst and Cummings (21), nonstarch polysaccharides were almost completely recovered in the effluent, although a 16% loss of soluble glucans (mainly β-glucan) was found. Our study supports the results of the latter study, with a pronounced degradation of β-glucan in cereal-based diets in the small intestine of humans, but also to a certain degree in the day and night bags.

More of the insoluble β-glucan fraction from the oat + enzyme– and wheat-bread diets was also lost during the transit through the upper gut compared with the insoluble β-glucan of the other two diets. The apparently low loss of soluble β-glucan from the oat + enzyme bread and an actual increase from the wheat bread could be due to a redistribution of the β-glucan from insoluble to soluble. An alternative explanation for this loss could be that when the soluble β-glucan content is low the permanently present microbes or enzymes are more likely to attack the insoluble ones (9, 22).

When the ileostomists consumed the wheat-bread diet, a higher relative proportion of digesta and β-glucan was found in the night bags compared with the other diets. This could have been due to an increased transit time, which has been observed in humans not consuming a high-fiber diet (23), or it could simply be explained by an increased relative proportion of a basal intestinal secretion.

Longer time to freezing and consequent microbial fermentation could be one reason for the higher degradation of β-glucan, as measured by loss and increased solubility of the β-glucans in the night bags. However, because the night effluents only account for ~15% of the total amount of the excreta, the possible fermentation in the night bags cannot fully explain the ileal degradation of the β-glucans from the diets. Also, the time for fermentation in the day bags is probably too short to fully explain the exclusive degradation that was found, especially in the low-β-glucan diets.

The viscosity profiles for oat-bran and barley fraction M2 suspended in phosphate buffer indicated that only a small endogenous enzymatic activity may remain in these samples. The more rapid viscosity development for the drum-dried bar-

### TABLE 4

Peak molecular weight (MWₚ) of β-glucan extracted with carbonate buffer (pH 10. 60 °C) from the different cereal fractions, breads, and pooled ileal excreta from the different diets

<table>
<thead>
<tr>
<th>Sample</th>
<th>MWₚ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat bran</td>
<td>2669 ± 187</td>
</tr>
<tr>
<td>Barley fraction M2</td>
<td>165 ± 7</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>1893 ± 141 (shoulder)</td>
</tr>
<tr>
<td>Oat bread</td>
<td>308 ± 65</td>
</tr>
<tr>
<td>Oat + enzyme bread</td>
<td>1270 ± 64</td>
</tr>
<tr>
<td>Barley bread</td>
<td>49 ± 2</td>
</tr>
<tr>
<td>Wheat bread</td>
<td>285 ± 28</td>
</tr>
<tr>
<td>Excreta (day)</td>
<td>82 ± 15</td>
</tr>
<tr>
<td>Oat bread</td>
<td>706 ± 122</td>
</tr>
<tr>
<td>Oat + enzyme bread</td>
<td>50</td>
</tr>
<tr>
<td>Barley bread</td>
<td>261</td>
</tr>
<tr>
<td>Wheat bread</td>
<td>63</td>
</tr>
<tr>
<td>Excreta (night)</td>
<td>120</td>
</tr>
<tr>
<td>Oat bread</td>
<td>109</td>
</tr>
<tr>
<td>Oat + enzyme bread</td>
<td>33</td>
</tr>
<tr>
<td>Barley bread</td>
<td>33</td>
</tr>
</tbody>
</table>

* ± SD when three samples were analyzed; other samples were analyzed in duplicate; n = 9.
ley fraction M2 was probably due to a faster solubilization of the β-glucan in this sample.

It is evident that neither starch nor protein contributed notably to the developed viscosity in the cereal fractions because the addition of pancreatin did not give any marked effect on the viscosity profiles of the slurries of oat bran or barley fraction M2. In another study (M Luhaloo et al., unpublished observations, 1995) with oat bran, under the same conditions as in the present study, addition of β-glucanase rapidly reduced viscosity, indicating that the β-glucans were mainly responsible for the development of viscosity. The viscosity that develops in the intestine after ingestion of partly soluble β-glucan may change the transit time, the absorption rate of nutrients, and the reabsorption of bile acids in the ileum, which in turn increases the hepatic synthesis of bile acids from serum cholesterol. The reason for the decreased viscosity for the slurries of oat-bran bread when pancreatin was added is not known.

The higher viscosity of the suspension of oat bread compared with barley bread was probably due to the higher molecular weight of the β-glucan in the oat bread because both the content and solubility of the β-glucan are very similar. The low viscosity developed from the oat + enzyme and wheat breads could be explained by the low amount of soluble β-glucan and low molecular weight of the β-glucan in these breads. However, a comparison between results from the viscosity measurement and the molecular-weight analyses is tentative because different extraction methods were used. The viscosity method was developed to simulate physiologic conditions (37 °C and

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**FIGURE 4.** Size-exclusion chromatography of carbonate buffer extracts from oat bread (OB), oat + enzyme bread (OBE), barley bread (B), and wheat bread (W); detection by fluorescence intensity of fluorescent whitener 28 (Cyanamid Co) complex.

**FIGURE 5.** Size-exclusion chromatography of carbonate buffer extracts from ileal excreta (daytime) after the oat-bread diet (OB), the oat + enzyme–bread diet (OBE), barley-bread diet (B), and wheat-bread diet (W); detection by fluorescence intensity of fluorescent whitener 28 (Cyanamid Co) complex.
REFERENCES

ILEAL DEGRADATION OF MIXED-LINKED $\beta$-GLUCAN