Evaluation of Selected Barley Cultivars and Their Fractions for β-Glucan Enrichment and Viscosity[1]

S. H. YOON[2], P. T. BERGLUND[2], and C. E. FASTNAUGHT[2]

ABSTRACT

Two waxy hull-less (Apollo and Wanubet) and one nonwaxy hulled (Robust) barley cultivars were milled on a hammer mill, using three screens to produce two grinds (coarse and fine) of whole grain barley flour (BF). Each grind of each BF was fractionated by means of sieves and combined into four fractions (A–D, largest to smallest particle size, respectively), based on similar particle sizes and extract viscosities. Percent distribution of weight in each fraction was similar among cultivars within the same grind but differed significantly between the coarse and the fine grinds. Apollo and Wanubet, both waxy hull-less cultivars, had higher β-glucan contents and extract viscosities than did the nonwaxy hulled cultivar for BF and all fractions. β-Glucan contents and extract viscosities of all fractions of the fine grind, except D, were higher than the original BF, in all cultivars. β-Glucan concentrations in fine-grind fractions were 1.38- to 1.88-fold greater than those of the original barley grains. Thus, milling with a hammer mill and fractionation produced fractions with higher β-glucan and extract viscosity when compared to the original BF.

Cereal Chem. 72(2):187–190

Waxy (up to 100% amylopectin) barley cultivars, particularly the hull-less type, are consistently higher in β-glucans (1.0–2.5%), extract viscosity, and soluble dietary fiber than are nonwaxy types (Ullrich et al 1986, Xue et al 1991). Waxy genotypes evaluated in our laboratory were 2.7–4.0% higher in β-glucan than were the normal starch genotypes.

The hypocholesterolemic effects of barley β-glucans have been demonstrated in animals (Fadel et al 1987, Newman et al 1987, Ranhotra et al 1991, Wang et al 1992, Kahlon et al 1993) and humans (Newman et al 1987, McIntosh et al 1991). The importance of fiber viscosity in plasma cholesterol reduction in animals has also been reported (Wang et al 1992, Gallaher et al 1993).

Twenty-nine studies summarized by Shinnick et al (1991) indicated that larger doses of oatmeal or oat bran were more effective in reducing cholesterol. Since large amounts seem unrealistic on a continual basis, more concentrated preparations of β-glucan would be desirable.

β-Glucan fractions can be prepared by extraction and precipitation, but these processes are expensive. Dry milling is a more economical way to obtain β-glucan-enriched fractions. Wood et al (1991) found that fractionating oat groats that had been milled in a falling number mill increased the β-glucan concentration in the oat bran by 150%. Knuckles et al (1992) reported that barley and oat fractions containing β-glucan concentrations 2.4- to 4.9-fold greater than the concentration in the original grain can be prepared by dry milling in a Udy mill and sieving. Bhatty (1992) reported that dry milling barley in an Allis-Chalmers mill produced, on average, a 1.36-fold enrichment of β-glucan in the bran.

The objective of this study was to mill and fractionate selected barley cultivars to produce fractions enriched in β-glucan content and of higher extract viscosity, using a mill with potential for larger-scale production.

MATERIALS AND METHODS

Barley Samples

Two waxy hull-less barley cultivars (Apollo and Wanubet) and one commercial nonwaxy hulled barley (Robust) were selected as representative cultivars with β-glucan contents of 7.8, 6.9, and 5.3%, respectively. Apollo was obtained from Ross Seed Co. (Fisher, MN) and Wanubet was obtained from Alexander-Peterson Inc. (Martin, ND). The covered barley of normal starch type, designated as the cultivar Robust, was dehulled by and obtained from Minnesota Pearling Co. (East Grand Forks, MN). Although this cultivar was not "identity preserved" during processing, Robust, a six-row malt barley, is the primary commercial cultivar grown and processed in the northwestern Minnesota region.

Barley Milling

The barley samples were hand-cleaned to remove foreign material and damaged kernels. Ten pounds of each cleaned barley

[1]Published with the approval of the director, North Dakota Agricultural Experiment Station as Journal series 2226.
[2]Graduate student, assistant professor, and food technologist, respectively, Department of Food and Nutrition, North Dakota State University, Fargo.

sample were milled with a hammer mill (model 66B, Jacobson Pulverator, Minneapolis, MN) using three screens (6/64 [2.38 mm], 3/64 [1.19 mm], 1.5/64 [0.59 mm]) to produce two grinds (coarse and fine) of whole grain barley flour (BF). For the coarse grind, whole grain barley flour was milled using 6/64 and 3/64 screens sequentially; for the fine grind, part of the sample obtained from the 3/64 screen was milled using a 1.5/64 screen.

Fractionation

Before fractionation, samples were allowed to equilibrate at ambient temperature. Duplicate 400-g samples of each grind of each cultivar were fractionated using sieves (U.S. standard 60 [250 μm], 80 [178 μm], 100 [150 μm], 120 [125 μm], 140 [103 μm], and 200 [73 μm]) (W.S. Tyler Co., Cleveland, OH) in a Ro-Tap shaker (W.S. Tyler) for 30 min. The materials retained on and passed through each sieve were weighed (as-is basis), and the percent of total weight was calculated for each fraction.

Combining Fractions

Milled fractions of each grind of each BF were combined into four fractions (A–D) by similar extract viscosities, based on the results of viscosity determination from the fine grind of Apollo barley in preliminary fractionation. The combined fractions and the letter designations of the fractions are shown in Figure 1.

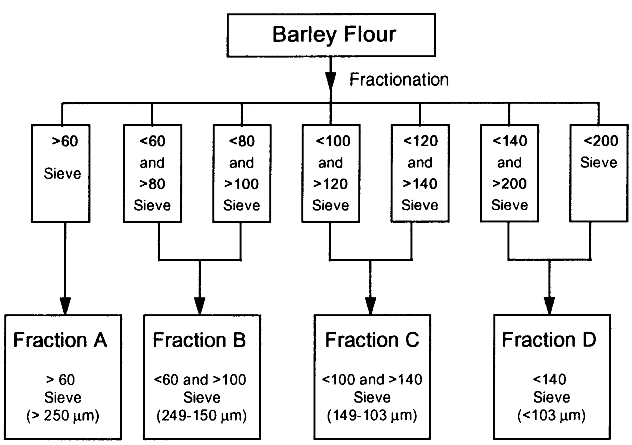

Fig. 1. Schematic diagram for combining fractions; > = material retained on the sieve, < = material passed through the sieve.

Analytical Methods

Total β-glucan content was determined according to AACC method 32-22 (AACC 1983), modified by using 13-mm × 100-mm screw cap tubes, 0.5 ml of 50% ethanol, 7.0 ml of sodium phosphate (20 mM, pH 6.5), and 10.0 ml of sodium acetate buffer (50 mM, pH 4.0). The analyses were conducted in duplicate and reported on a dry weight basis (db). The β-glucan yield was defined as the percent of total β-glucan found in each fraction and was calculated as:

$$\%\ \beta\text{-glucan yield} = \frac{\text{Weight (g) of fraction (db)} \times \%\ \beta\text{-glucan}}{\text{Weight (g) of total sample (db)} \times \%\ \beta\text{-glucan in unsieved flour}} \times 100$$

Alkaline extract viscosity was determined in duplicate according to Ullrich et al (1986), modified by using 0.5-g samples extracted with 10 ml of the sodium carbonate buffer (pH 10, 6.36 g of anhydrous sodium carbonate and 3.36 g of sodium bicarbonate in 1 L of double-distilled water). Samples were heated with stirring at 45°C for 50 min and centrifuged at 959 × g at 30°C using a JA-14 fixed-angle rotor centrifuge (Beckman J2 Centrifuges, Palo Alto, CA). Viscosity of the supernatant was measured on a Wells-Brookfield LVT cone-plate viscometer (Brookfield Engineering Laboratories, Stoughton, MA). The viscometer was held at a constant temperature of 30°C by a Lauda/Brinkman Rc-3T circulating bath (Westbury, NY). Apparent viscosities for all samples were obtained with the CP-40 cone at a shear rate of 22.5 sec^{-1}. Two fractions (B and C) from the fine grind of Apollo had a viscosity greater than 100 cP (the limit of the viscometer with this combination of cone and shear rate). It was necessary to reduce the shear rate to measure apparent viscosity of these two samples: for fraction B, CP-40 cone and 4.5 sec^{-1} shear rate; for fraction C, CP-52 cone and 1.2 sec^{-1} shear rate.

Statistical Analysis

Differences in percent distribution of weight, β-glucan, and extract viscosity attributable to barley cultivar, BF, mill grinds, and sieve fractions were determined using general linear model (GLM) with the statistical analysis system (SAS 1982). When significant differences were determined, the data were analyzed by Duncan's multiple range test. Because of unequal variances, extract viscosities were transformed to $\log_{10}$ viscosity to determine the significant differences among cultivars, mill grinds, and fractions. The Pearson correlation coefficients were calculated to determine the relationships between $\log_{10}$ viscosity and β-glucan content (Greenberg 1974).

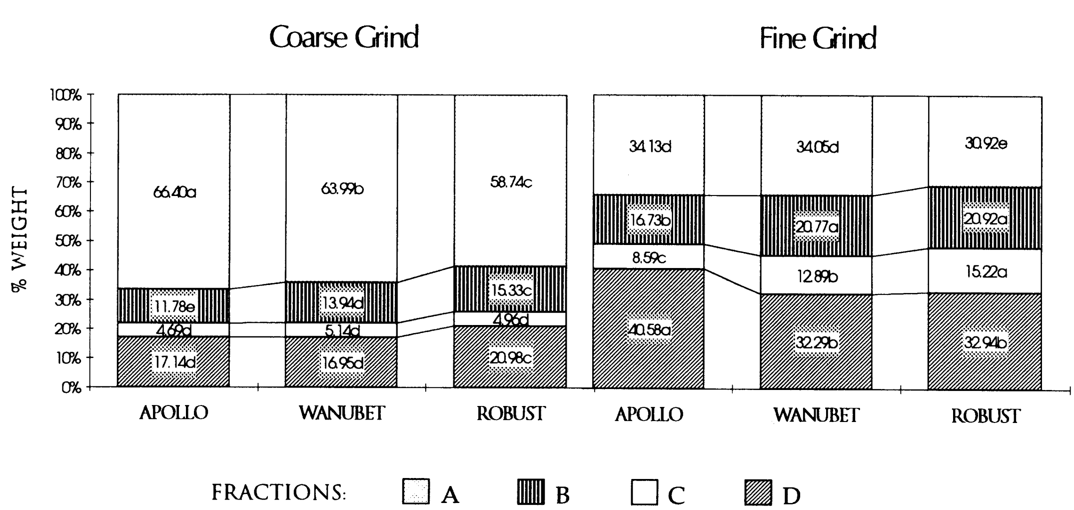

Fig. 2. Percent weight comparison of coarse and fine grinds of Apollo, Wanubet, and Robust cultivars. Sieve fractions: A = material retained on the 60 sieve; B = material passed through the 60 sieve and retained on the 100 sieve; C = material passed through the 100 sieve and retained on the 140 sieve; D = material passed through the 140 sieve. Means followed by different lower case letters in each row differ significantly (P = 0.05) according to Duncan's multiple range test (n = 2).

RESULTS AND DISCUSSION

Fractionation and Distribution of Weight

Similar trends in weight distribution of fractions were observed for all three cultivars within the same grind, but weight distribution differed between the two grinds (Fig. 2). Generally, the coarse grind produced the greatest percent weight for fraction A and the least percent weight for fraction C. For the fine grind, weights of fractions A and D were closer than those of the coarse grind, yielding 30–40% each of the total. Additional grinding to produce the fine grind increased the percent weight of fraction C as much as 300%.

When each fraction was compared across each grind of each cultivar, the percent weight differed significantly ($P < 0.001$). The coarse grind of Apollo had the greatest percent weight of fraction A and the fine grind of Robust had the least of fraction A. The fine grinds of Wanubet and Robust had the greatest percent weights for fractions B and C. The fine grind of Apollo had the greatest percent weight of fraction D, followed by the fine grinds of Wanubet and Robust, which did not differ significantly. The coarse grinds gave less of fractions B, C, and D than the fine grinds.

β-Glucan Content of the Fractions

The β-glucan contents of the waxy hull-less cultivars Apollo (7.8%) and Wanubet (6.9%) were higher than that of the nonwaxy hulled cultivar Robust (5.3%). The total β-glucan content was similar in both grinds of BF from each cultivar (Fig. 3). Fractions produced by the fine grind had higher β-glucan content than did similar fractions from the coarse grind within each cultivar, except for fraction D. Apollo had the highest β-glucan content in all fractions from the fine grind. β-Glucan content was similar in the coarse fractions of Apollo and Wanubet. Robust had the lowest β-glucan content in BF and all fractions, except fraction D. Fraction D had the lowest β-glucan content of all fractions for both grinds of all three cultivars.

Differences between the β-glucan content of the original BF and fractions A–C were small for the coarse grind. The enrichment ranged from 1.09 to 1.38. However, the fine grind produced fractions (A, B, and C) with significantly higher β-glucan contents than the BF; enrichment was 1.38–1.88 for all cultivars. Fraction C of the fine grind of Apollo had the highest β-glucan content (14.6%; enrichment 1.88). The β-glucan enrichment of the fine grind was somewhat higher than the 1.1- to 1.6-fold reported by Bhatty (1992) and the 1.35- to 1.59-fold reported by Ranhotra et al (1991).

The β-glucan yield of fractions B, C, and D from the fine grinds was higher than yield from the coarse grinds for all three cultivars (Table I). Fraction A had the highest β-glucan yield for both fine and coarse grinds of all three cultivars, whereas fraction C had the highest β-glucan content. Greater enrichment of β-glucan may be possible with additional processing of fractions A and B.

Alkaline Extract Viscosity of Fractions

Both grinds of Apollo and Wanubet BF had significantly higher extract viscosity than either grind of Robust BF (Fig. 4). The fine grind of Apollo and Wanubet BF had a significantly higher extract viscosity than the coarse grind, suggesting that the higher proportion of small particles in the fine grind might allow better extraction of the compounds that contribute to viscosity. However, this difference was not observed with the sample of Robust. This might reflect a difference in cell-wall attrition during milling.

Milling produced several fractions that were significantly different from the BF in extract viscosity. For the coarse grind, fractions B and C of Apollo and Wanubet had higher extract viscosity than the BF, and fraction D had lower extract viscosity than the BF. For the fine grind, fractions A, B, and C of both Apollo and Wanubet were significantly higher in extract viscosity ($P < 0.001$) than the BF. The fine grind of fraction D of all three cultivars had extract viscosity lower than that of the BF. All fractions of the fine grind of Apollo and Wanubet had significantly higher extract viscosity than the same fractions of the coarse grind.

Fraction C of the fine grind of Apollo had the highest extract viscosity of all fractions. It also had the highest β-glucan content. The considerably greater viscosity (2,745 cP) in the extract from the fine grind of fraction C of Apollo may relate, in part, to the lower shear rate used for the viscosity determination. However, extracts from this sample were clearly more viscous than all other

TABLE I
Distribution of β-Glucan Yield (%)[a] of Sieve Fractions of Coarse and Fine Grinds of Apollo, Wanubet, and Robust Barley Cultivars

Sieve Fractions[b]	Apollo		Wanubet		Robust	
	Coarse[c]	Fine[d]	Coarse	Fine	Coarse	Fine
A	77.9	46.0	74.1	46.4	66.0	38.8
B	14.2	24.3	15.7	28.3	18.8	28.1
C	5.1	16.2	5.8	17.1	6.9	22.9
D	2.8	13.5	4.4	8.2	8.3	10.2

[a] Percent of total β-glucan found in each fraction (dry basis).
[b] A = material retained on the 60 sieve; B = material passed through the 60 sieve and retained on the 100 sieve; C = material passed through the 100 sieve and retained on the 140 sieve; D = material passed through the 140 sieve.
[c] Through a 6/64 screen and a 3/64 screen, sequentially.
[d] Part of the coarse grind through a 1.5/64 screen.

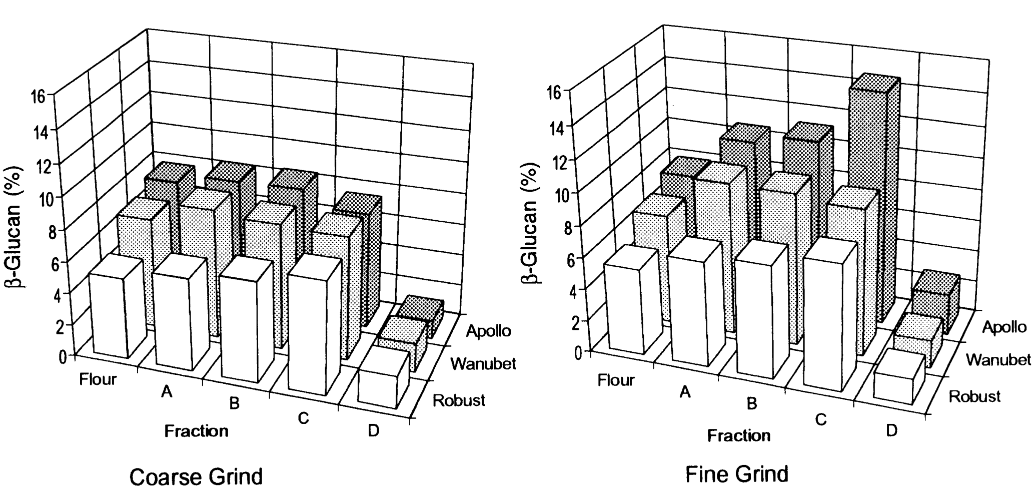

Fig. 3. β-Glucan content of coarse and fine grinds of Apollo, Wanubet, and Robust barley cultivars. Sieve fractions: A = material retained on the 60 sieve; B = material passed through the 60 sieve and retained on the 100 sieve; C = material passed through the 100 sieve and retained on the 140 sieve; D = material passed through the 140 sieve.

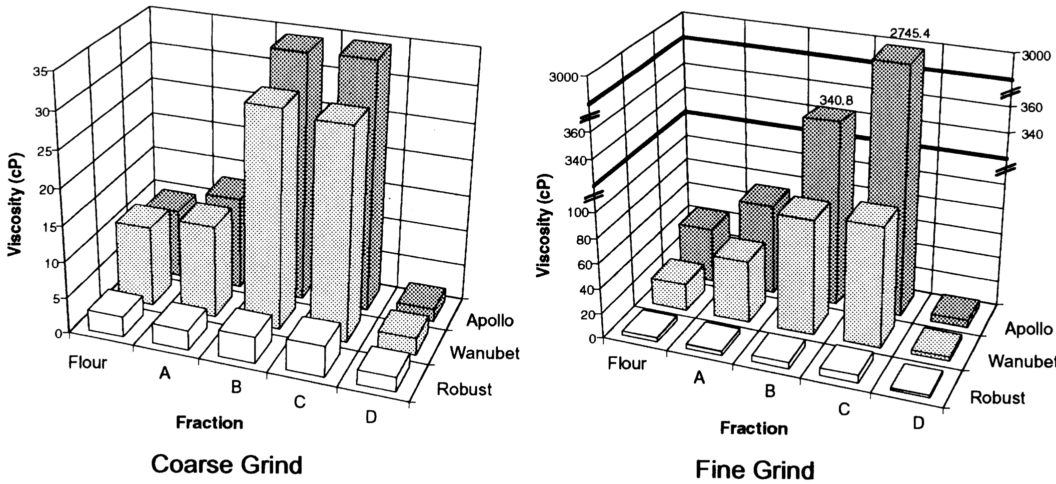

Fig. 4. Viscosity of extracts from coarse and fine grinds of Apollo, Wanubet, and Robust barley cultivars. Sieve fractions: A = material retained on the 60 sieve; B = material passed through the 60 sieve and retained on the 100 sieve; C = material passed through the 100 sieve and retained on the 140 sieve; D = material passed through the 140 sieve.

samples. Presumably, this fraction contained higher amounts of extractable β-glucan than all other fractions, although it is possible that the extract contains β-glucan of higher molecular weight.

Hesselman and Åman (1985) reported a high correlation between β-glucan content and viscosity. In this study, the correlation coefficients for β-glucan content and $\log_{10}$ viscosity for Apollo, Wanubet, and Robust were 0.92, 0.93, and 0.94, respectively ($P < 0.001$). The overall correlation coefficient for all samples was 0.87 ($P < 0.001$).

CONCLUSIONS

Similar trends in distribution of percent weight were observed for all three cultivars within each grind. Generally, the coarse grind produced the greatest percent weight for fraction A and the least percent weight for fraction C. Yields of fractions A and D were more similar in the fine grind than the coarse grind.

Coarse grinding produced fractions with considerably higher extract viscosity than BF, despite relatively small increases in β-glucan. Fine grinding produced fractions that were higher in both β-glucan content and extract viscosity than the original BF in all cultivars. Fraction C of the fine grind of Apollo had the highest β-glucan content and extract viscosity among fractions from both grinds of all three barley cultivars. Apollo and Wanubet, both waxy hull-less cultivars, had higher β-glucan contents and extract viscosities than Robust for BF and all fractions. Higher β-glucan content and extract viscosity for waxy hull-less barley cultivars has been previously reported. The basis for the additional differences in milling behavior reported here probably have a similar genetic origin but may also relate to sample history.

β-Glucan enrichment in fractions of the coarse grind and fine grind were 1.09- to 1.38-fold and 1.38- to 1.88-fold greater, respectively, than the original BF. Extract viscosity also increased, particularly in the waxy cultivars. The basis for viscosity increase is only partly explained by increased total β-glucan content.

ACKNOWLEDGMENTS

We wish to thank the USDA Hard Red Spring and Durum Wheat Quality Laboratory, North Dakota State University, Fargo, for the use of their hammer mill.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC Method 32-22, approved October 1989. The Association: St. Paul, MN.

BHATTY, R. S. 1992. β-Glucan content and viscosities of barleys and their roller-milled flour and bran products. Cereal Chem. 69:469-471.

FADEL, J. G., NEWMAN, R. K., NEWMAN, C. W., and BARNES, A. E. 1987. Hypocholesterolemic effects of β-glucans in different barley diets fed to broiler chicks. Nutr. Rep. Int. 35:1049-1058.

GALLAHER, D. D., HASSEL, C. A., LEE, K. J., and GALLAHER, C. A. 1993. Viscosity and fermentability as attributes of dietary fiber responsible for the hypocholesterolemic effect in hamsters. J. Nutr. 123:244-253.

GREENBERG, D. C. 1974. Correspondence. J. Inst. Brew. 80:435.

HESSELMAN, K., and ÅMAN, P. 1985. Pages 363-372 in: New Approaches to Research on Cereal Carbohydrates. R. D. Hill and L. Munck, eds. Elsevier Science: Amsterdam.

KAHLON, T. S., CHOW, F. I., KNUCKLES, B. E., and CHIU, M. M. 1993. Cholesterol-lowering effects in hamsters of β-glucan-enriched barley fraction, dehulled whole barley, rice bran, and oat bran and their combinations. Cereal Chem. 70:435-440.

KNUCKLES, B. E., CHIU, M. M., and BETSCHART, A. A. 1992. β-Glucan-enriched fractions by laboratory scale dry milling and sieving of barley and oats. Cereal Chem. 69:198-202.

MÄLKKI, Y., MYLLYMÄKI, O., AUTIO, K., and SUORTTI, T. 1992. Preparation and properties of oat bran concentrates. Cereal Foods World 37:693-700.

McINTOSH, G. H., WHYTE, J., McARTHUR, R., and NESTEL, P. J. 1991. Barley and wheat foods: Influences on plasma cholesterol concentrations in hypercholesterolemic men. Am. J. Clin. Nutr. 53:1205-1209.

NEWMAN, R. K., NEWMAN, C. W., FADEL, J., and GRAHAM, H. 1987. Nutritional implication of β-glucans in barley. Barley Genet. Proc. Int. Symp., 5th: 773-780.

RANHOTRA, G. S., GELROTH, J. A., ASTROTH, K., and BHATTY, R. S. 1991. Relative lipidemic responses in rats fed barley and oat flours and their fractions. Cereal Chem. 68:548-551.

SAS. 1982. SAS User's Guide: Statistics. The Institute, Cary, NC.

SHINNICK, F. L., MATHEWS, R., and INK, S. 1991. Serum cholesterol reduction by oats and other fiber sources. Cereal Foods World 36:815-821.

ULLRICH, S. E., CLANCY, J. A., ESLICK, R. F., and LANCE, R. C. M. 1986. β-Glucan content and viscosity of extracts from waxy barley. J. Cereal Sci. 4:279-285.

WANG, L., NEWMAN, R. K., NEWMAN, C. W., and HOFER, P. 1992. Barley β-glucans alter intestinal viscosity and reduce plasma cholesterol concentrations in chicks. J. Nutr. 122:2292-2297.

WOOD, P. J., WEISZ, J., and FEDEC, P. 1991. Potential for β-glucan enrichment in brans derived from oat (*Avena sativa* L.) cultivars of different $(1\rightarrow3),(1\rightarrow4)$-$\beta$-D-glucan concentrations. Cereal Chem. 68:48-51.

XUE, Q., NEWMAN, R. K., NEWMAN, C. W., and McGUIRE, C. F. 1991. Waxy gene effects on dietary fiber content and viscosity of barleys. Cereal Res. Comm. 19:399-404.

[Received May 11, 1994. Accepted December 15, 1994.]