Comparisons of β-Glucan Content of Barley and Oat

C. J. LEE,[1] R. D. HORSLEY,[2,3] F. A. MANTHEY,[2] and P. B. SCHWARZ[4]

Cereal Chem. 74(5):571–575

ABSTRACT

The cholesterol-lowering effect of cereal grains has been associated with the soluble fiber component of dietary fiber. β-Glucan is the major soluble fiber component of barley *(Hordeum vulgare* L.) and oat (*Avena sativa* L.). Much research has been conducted to determine the β-glucan content of barley and oat genotypes from many different countries. However, genotypes of both crops always were grown in separate experiments, making direct comparisons between the two crops difficult. This study compares in the same experiment the β-glucan content of nine barley and 10 oat genotypes grown at two locations in each of two years (i.e., four environments) in North Dakota. Averaged across genotypes, total β-glucan content of barley and oat groat was similar. Soluble β-glucan content of oat groat was greater than barley, and oat groat had a greater ratio of soluble-to-total β-glucan than barley. The soluble β-glucan content and ratio of soluble to total β-glucan content of the "best" barley genotypes were less than that of oat genotypes with the highest levels of these two traits.

Interest in β-glucan content of barley and oat has increased following a proposal from the Food and Drug Administration to allow health claims on foods that contain 13 g of oat bran or 20 g of oatmeal where the oat bran or oatmeal contain, without fortification, at least 1 g of β-glucan per serving. Oat and oat bran have been associated with the lowering of serum low density lipoprotein (LDL) cholesterol, a risk factor for heart disease. LDL cholesterol is involved in the development of atherosclerosis (Anderson and Chen 1986).

The soluble fiber component of cereal grains is believed to be responsible for the hypocholesterolemic effects (Newman and Newman 1992). The major soluble component of barley and oat fiber is β-glucan (Åman and Graham 1987, Åman et al 1989). β-Glucan is a collective term for high molecular weight polymers of glucose linked by β(1–3) and β(1–4) glycosidic bonds (Fincher and Stone 1986). β-Glucans are found in the cell walls of barley, oat, wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), sorghum (*Sorghum bicolor* L.), and millet (*Pennisetum americanum* L.) (Fincher and Stone 1986).

Compared to other cereals, barley and oat have relatively high levels of β-glucan. Barley contains between 20 and 100 g/kg (Bamforth 1982), and oat contains between 25 and 66 g/kg (Åman and Graham 1987, Welch and Lloyd 1989). Levels of β-glucan are influenced by both genetic and environmental effects, but genetic factors appear to be of greater importance (Stuart et al 1988, Peterson 1991, Miller et al 1993).

Barley cultivars expressing the hull-less or waxy traits generally have the greatest β-glucan content (Fox 1981). Hockett et al (1987) reported six-rowed barley to be consistently lower in β-glucan content than two-rowed genotypes. Horsley et al (1992) reported the two-rowed cultivar Bowman to be lower in β-glucan content than six-rowed barley genotypes grown in North Dakota.

Peterson et al (1995) evaluated the elite oat germplasm entered in three different oat uniform regional nurseries from 1988-1991. As part of this study, the correlations between β-glucan concentration and different agronomic traits were determined. In the Uniform Midseason and the Uniform Early Oat Nurseries, there were inconsistent or no correlations between β-glucan concentration and agronomic traits across years or nurseries. In the Uniform Northwestern States Oat Nursery, there were consistent significant positive correlations between β-glucan content and test weight, protein percentage, and groat percentage, and negative correlations between heading date and β-glucan content.

Based on values that appear in the literature (Åman and Graham 1987, Hockett et al 1987, Welch and Lloyd 1989, Peterson et al 1995), oat appears to have greater β-glucan content than barley. These comparisons have been between barley and oat genotypes grown in different experiments. To make direct comparisons of the β-glucan content of the two crops, they must be grown in the same experiment. This study provides a direct comparison of the β-glucan content between barley and oat in the same experiment. The total and soluble β-glucan content of nine barley and 10 oat genotypes grown at two locations in each of two years (i.e., four environments) in North Dakota was determined.

MATERIALS AND METHODS

Grain Samples

The barley and oat genotypes evaluated are listed in Table I. Barley genotypes are cultivars adapted to the Northern Great Plains or backcross-derived genotypes produced from adapted cultivars. Oat genotypes are cultivars adapted to the Northern Great Plains or cultivars evaluated for production under contract in this region (M. McMullen, *personnel communication,* 1996). Agronomic performance of the barley and oat genotypes was evaluated in yield trial experiments conducted at Casselton and Prosper, ND, in 1991, and Prosper and Minot, ND, in 1992. The soil at Casselton is a Perella-Bearden silty clay loam complex. Perella is a fine-silty, mixed, frigid Typic Haplaquoll; Bearden is a fine-silty, frigid Aeric Calciaquoll. The soil at Prosper is a Bearden silty clay loam. The soil at Minot is a Williams loam, a fine-loamy, mixed Typic Argiboroll. The experimental design was a randomized complete block with three replicates per location. Experimental units consisted of three 3-m rows, with 30 cm between rows and 45 cm between plots. Seeding rate was 2.9 million kernels/ha.

At maturity, entire three-row plots were harvested with a plot combine. Grain samples were dried in a forced-air dryer to ≈100 g/kg moisture, then cleaned. Oat hulls were removed with a Quaker impact dehuller to determine oat groat proportion and to provide groats for chemical analyses. Before milling, hulls were removed from hull-less barley genotypes, but not from those genotypes with a hull (referred to as hulled). Removal of hulls by hand-dissection from enough grain to conduct β-glucan analyses is impractical because a consistent amount of hull cannot be removed.

[1]RR1 Box 170, Velva, ND 58790.
[2]Dept. of Plant Sciences, North Dakota State University, Fargo, ND 58105.
[3]Corresponding author. E-mail address: horsley@badlands.nodak.edu
[4]Dept. of Cereal Science, North Dakota State University, Fargo, ND 58105.

Publication no. C-1997-0818-05R.

β-Glucan Determination

Total and soluble β-glucan were determined on barley and oat groats milled in a centrifugal mill (Retsch model ZM-1, Brinkman Instruments, Westbury, NY) with a 0.5-mm screen. A β-glucan assay kit (Megazyme Ltd., Warriewood, Australia) was used to determine total and insoluble β-glucan. Total β-glucan was determined by the method of McCleary and Codd (1991). Insoluble β-glucan was determined by the method of Åman and Graham (1987). Soluble β-glucan was determined by subtracting insoluble from total β-glucan content. All β-glucan values are expressed on a dry weight basis.

Statistical Analysis

Data were analyzed using the Statistical Analysis System (SAS Institute, Cary NC). For each dependent variable, the error mean squares from each environment were tested for homogeneity of error variance to determine whether experiments could be combined across environments. In the combined analyses, environments were considered random effects and genotypes fixed effects. The genotype source of variation was partitioned into three orthogonal contrasts: among barley genotypes, among oat genotypes, and barley versus oat genotypes. The environment × genotype mean square interaction was used as the denominator of the *F*-test for each comparison. The environment × genotype source of variation also was partitioned into three orthogonal comparisons: environment × among barley genotypes, environment × among oat genotypes, and environment × barley versus oat genotypes. The error mean square was used as the denominator of the *F*-test to evaluate each comparison. *F*-tests were considered significant at $P \leq 0.05$. Mean separation between treatments was done using an *F*-protected least significant difference (LSD) at the $P = 0.05$ level.

RESULTS AND DISCUSSION

β-Glucan determinations were done on dehulled grains except for hulled barley genotypes (i.e., Azure, Waxy Azure, Bowman, and Waxy Bowman). Presence of the hull in milled hulled barley resulted in β-glucan values that were lower than they would have been if the hulls had been removed. Barley hulls contain no β-glucan and comprise 10–13% of the kernel (Bhatty et al 1975). Removal of hulls by pearling would increase experimental error because removal of a consistent amount of hull is difficult. β-Glucan values of hulled barley genotypes could be adjusted upward to compensate for the hull, but in this report, data are presented as they were determined.

TABLE I
Origin of Barley and Oat Genotypes

Genotype	Origin[a]
Barley	
Azure	NDAES
Waxy Azure[b]	NDAES
Waxy Hull-less Azure[b]	NDAES
Bowman[c]	NDAES
Hull-less Bowman[b,c]	NDAES
Waxy Bowman[b,c]	NDAES
Waxy Hull-less Bowman[b,c]	NDAES
Waxy Hull-less Short Awn Bowman[b,c]	NDAES
Wanubet[c]	MTAES
Oat	
Dumont	ACRSM
Kelsey	ACRSM
Marion	ACRSQ
Moore	MNAES
Newdak	NDAES
Otana	MTAES
Porter	INAES
Premier	MNAES
Robert	ACRSM
Valley	NDAES

[a] NDAES = North Dakota Agricultural Experiment Station; MTAES = Montana Agricultural Experiment Station; ACRSM = Agriculture Canada Research Station, Manitoba; ACRSQ = Agriculture Canada Research Station, Quebec; MNAES = Minnesota Agricultural Experiment Station; INAES = Indiana Agricultural Experiment Station.
[b] Unreleased germplasm.
[c] Two-rowed barley.

Total β-Glucan

Significant interactions of environment × barley versus oat genotypes, and environment × among barley genotypes were observed (Table II). Peterson (1991) reported a significant interaction of genotype × environment for total β-glucan content of oat. We did not observe such an interaction in this study. The interaction of environment × barley versus oat genotypes was due to differences in magnitude of treatment means among the four environments, thus, means combined across environments are discussed. The source of variation between barley and oat genotypes was not significant. Mean total β-glucan content averaged across genotypes and environments was 52.3 g/kg for barley and 51.0 g/kg for oat groat.

At all environments, Bowman, Azure, and Hull-less Bowman tended to have the lowest total β-glucan content (Table III). At all locations, Azure had a lower total β-glucan content than Waxy Azure, and Waxy Azure had a lower total β-glucan content than Waxy Hull-less Azure. The difference in total β-glucan content between Waxy Azure and Waxy Hull-less Azure ranged from 14–16%. Much of this difference may be explained by the presence of the hull in Waxy Azure.

Differences in total β-glucan content between Bowman and Hull-less Bowman were observed only at Prosper in 1992 (Table III). Waxy Hull-less Bowman tended to have greater total β-glucan than Bowman. At Minot and Prosper in 1992, the differences were significant. Waxy Hull-less Short Awn Bowman generally had the greatest total β-glucan content of the Bowman backcross-derived genotypes. Differences in total β-glucan content between hulled and hull-less Bowman backcross-derived genotypes could not be explained due to the presence of the hull.

Wanubet had the greatest total β-glucan content at both locations in 1991 and had high total β-glucan content at both locations in 1992 (Table III). Wanubet was grown under contract on limited acreage in North Dakota in the late 1980's and early 1990's because of its high β-glucan content. However, this cultivar was not widely accepted by producers because of its susceptibility to several barley diseases and its weak straw.

Hockett et al (1987) reported that two-rowed barley cultivars generally had greater β-glucan content than six-rowed barley cultivars. In this study, the two-rowed cultivar Bowman and its backcross-derived genotypes had lower β-glucan content than the six-rowed cultivar Azure and its backcross-derived genotypes, and

TABLE II
Pertinent Sources of Variation[a]

		Mean Square		
Sources of Variation	df	Total β-Glucan	Soluble β-Glucan	Soluble to Total β-Glucan
Among barley genotypes	8	88.2**[b]	54.9**	2,079**
Among oat genotypes	9	33.7**	28.7**	358
Barley versus oat genotypes	1	6.1	351.5**	160,000**
Environment × differences				
Among barleys	24	2.9**	1.9**	437*
Among oats	27	1.0	2.0**	309
Barley versus oat	3	11.1**	1.6	1,477**
Coefficient of variation (%)		5.1	8.1	6.7

[a] Degrees of freedom (df), mean squares, results of *F*-tests, and coefficients of variation from the combined analysis of variance across environments.
[b] *,** = Significant at the $P < 0.05$ and $P < 0.01$ levels of probability, respectively.

these genotypes had lower β-glucan content than the two-rowed cultivar Wanubet.

Differences in total β-glucan content were observed among oat genotypes (Table II). Mean total β-glucan content of oat genotypes ranged from 44.4 to 60.5 g/kg (Table IV). The range in total β-glucan content of oat groat was similar to that observed by Peterson (1991). Premier and Marion generally had greater total β-glucan content than the other oat genotypes. Total β-glucan content of barley and oat genotypes with the greatest β-glucan content were similar (Table IV).

Soluble β-Glucan

Significant interactions of environment × among barley genotypes, and environment × among oat genotypes were observed for soluble β-glucan content (Table II). However, the significance of both interactions was due to differences in magnitude of genotype means among the four environments. Thus, means combined across environments are discussed.

The contrasts between barley and oat genotypes, differences among barley genotypes, and differences among oat genotypes were significant (Table II). Mean soluble β-glucan content of oat groat averaged across genotypes and environments was 41.9 g/kg compared to 34.0 g/kg for barley. Mean soluble β-glucan content ranged from 25.1 to 44.3 g/kg for barley genotypes and from 36.5 to 50.1 g/kg for oat genotypes (Table IV).

Bowman backcross-derived genotypes with the waxy and hull-less character generally had greater soluble β-glucan content than their hulled, normal endosperm counterpart. Some of the difference in soluble β-glucan between hulled and hull-less genotypes may be explained by the presence of the hull. For example, the difference in soluble β-glucan content between Waxy Bowman and the two Waxy Hull-less Bowman genotypes ranged from 9.8 to 16.5%. The soluble β-glucan content of Bowman and Hull-less Bowman was not different. However, after compensating for the presence of the hull, Bowman appears to have a greater soluble β-glucan content than Hull-less Bowman.

Soluble β-glucan content of Waxy Azure and Azure was similar and significantly less than that of Waxy Hull-less Azure. The difference in soluble β-glucan content of the Hulled Azure genotypes and Waxy Hull-less Azure was ≈40%. This difference is much more than can be explained by the presence of the hull in β-glucan assays.

Premier and Marion had the greatest oat groat soluble β-glucan content and Wanubet and Waxy Hull-less Azure had the greatest barley soluble β-glucan content. Soluble β-glucan content of Premier and Marion was significantly greater than that of Wanubet, Waxy Hull-less Azure, and the other oat genotypes.

TABLE III
Mean Total β-Glucan Content (g/kg) of Barley Genotypes Averaged Across Environments, 1991-1992

	Environment			
Genotype	Casselton 1991	Prosper 1991	Minot 1992	Prosper 1992
Azure	46.9	45.1	43.7	47.7
Waxy Azure	54.2	52.6	52.3	52.3
Waxy Hull-less Azure	64.7	61.9	61.0	61.7
Bowman	43.2	43.7	40.3	40.0
Hull-less Bowman	44.3	44.5	44.0	46.3
Waxy Bowman	57.2	52.5	53.7	49.0
Waxy Hull-less Bowman	48.2	48.4	53.7	52.7
Waxy Hull-less Short Awn Bowman	51.5	57.0	63.3	65.0
Wanubet	65.2	64.8	63.3	63.0

Least significant difference at $P = 0.05$ level of probability = 4.3 for all environments.

TABLE IV
Mean Total β-Glucan, Soluble β-Glucan, and the Ratio of Soluble to Total β-Glucan Content (g/kg) of Oat and Barley Genotypes Averaged Across Environments, 1991-1992

Genotype	Total β-Glucan	Soluble β-Glucan	Ratio of Soluble to Total β-Glucan
Barley			
Azure	45.8	31.6	68.9
Waxy Azure	52.9	31.5	59.6
Waxy Hull-less Azure	62.3	44.3	71.0
Bowman	38.9	25.1	64.6
Hull-less Bowman	43.8	26.5	60.5
Waxy Bowman	50.2	31.6	62.8
Waxy Hull-less Bowman BB	50.7	34.7	68.8
Waxy Hull-less Short Awn Bowman	59.2	36.8	62.6
Wanubet	64.1	44.0	68.6
LSD[a]	4.0	3.6	5.4
Oat			
Dumont	51.3	41.8	81.4
Kelsey	44.4	36.5	82.2
Marion	58.7	48.4	83.9
Moore	51.7	43.7	84.6
Newdak	46.1	36.7	79.5
Otana	50.3	40.5	80.4
Porter	47.0	39.0	82.9
Premier	60.5	50.1	82.9
Robert	47.3	37.6	79.6
Valley	52.2	43.3	82.9
LSD[a]	ns	ns	ns

[a] Least significant difference at $P = 0.05$ level of probability. ns = Not significant.

Ratio of Soluble to Total β-Glucan

The ratio of soluble to total β-glucan content has been used to compare differences in relative solubility of β-glucan among crop species (Åman and Graham 1987). Significant interactions of environment × barley versus oat genotypes, and environment × among barley genotypes were observed for the ratio of soluble to total β-glucan (Table II). The significance of the contrast of environment × barley versus oat genotypes was due to differences in magnitude of genotype means among the four environments. Thus, means combined across environments are discussed. Mean ratio of soluble to total β-glucan averaged across genotypes and environments was 65.3% for barley and 82.0% for oat groats.

In general, Azure and Bowman had a higher ratio of soluble to total β-glucan than the waxy hulled genotypes (Table IV). Also, not all waxy hull-less genotypes had a higher ratio of soluble to total β-glucan as compared to the recurrent parent (i.e., Azure or Bowman). Waxy Hull-less Azure and Waxy Hull-less Bowman had a higher ratio of soluble to total β-glucan as compared to Azure and Bowman, respectively, but Waxy Hull-less Short Awn Bowman had a lower ratio of soluble to total β-glucan compared to Bowman. These data indicate that even though the hull-less and waxy traits often were associated with increased total and soluble β-glucan contents, these traits did not necessarily result in an increased ratio of soluble to total β-glucan. The increase in the insoluble β-glucan fraction in waxy and hull-less waxy genotypes often was greater than the increase in the soluble β-glucan fraction, thus, resulting in a lower ratio of soluble to total β-glucan.

The ratio of soluble to total β-glucan content among barley genotypes at the different environments was inconsistent (Table V). Azure had an intermediate ratio of soluble to total β-glucans at all environments but Prosper in 1992. Waxy Hull-less Azure had a greater ratio of soluble to total β-glucan content than Waxy Azure. The ratio of soluble to total β-glucan content of Bowman was low in 1991 but intermediate in 1992, as compared to the other barley genotypes. Waxy Hull-less Short Awn Bowman had the lowest ratio of soluble to total β-glucans in 1992 but nearly the highest in 1991. Waxy Hull-less Bowman had a significantly greater ratio of soluble to total β-glucan content than Bowman at all environments but Minot in 1992. The ratios of soluble to total β-glucan content of Waxy Hull-less Short Awn Bowman and Waxy Hull-less Bowman were similar at all environments but Prosper in 1992.

The ratio of soluble to total β-glucan content of oat groat was not significantly influenced by the environment. The ratio of soluble to total β-glucan content ranged from 79.5 to 84.6% for oat genotypes (Table IV). Åman and Graham (1987) also found a consistent ratio of soluble to total β-glucan for oat over environments and a lower ratio for barley than oat. Moore and Marion generally had the greatest ratio of soluble to total β-glucan content of oat genotypes, 84.6 and 83.9%, respectively (Table IV). The ratio of soluble to total β-glucan of the oat genotype with the greatest ratio, Moore, was significantly greater than that of the barley genotype with the greatest ratio, Waxy Hull-less Azure.

SUMMARY AND CONCLUSIONS

The barley and oat genotypes evaluated in this study had similar total β-glucan content. However, soluble β-glucan content was greater for oat than for barley genotypes. Oat genotypes evaluated in this study also had a greater ratio of soluble to total β-glucan than barley. To compete with these characteristics of oat grown in the Northern Great Plains, barley genotypes need to be developed that have levels of soluble β-glucans comparable to the "best" oat genotypes. Also, barley breeders should strive to increase the ratio of soluble to total β-glucan in the new cultivars. Such high soluble β-glucan barley genotypes would most likely have the waxy and hull-less characters. However, barley cultivars with these traits have had limited grower acceptance in the Northern Great Plains because they yield ≈20% less than hulled, normal endosperm cultivars. Waxy hull-less cultivars also have more problems with plant emergence from the soil following seeding. To be widely accepted by the grower, the new barley cultivars will need to have a soluble β-glucan content similar to the "best" oat cultivar available and equivalent agronomic characteristics to hulled barley cultivars.

ACKNOWLEDGMENTS

We would like to express our gratitude to Michael McMullen for supplying seed of the oat cultivars evaluated, Jerome Franckowiak for supplying seed of Bowman and Bowman-derived genotypes evaluated, and American Crystal Sugar Company for their donation of seed of Waxy Azure and Waxy Hull-less Azure to the North Dakota Agricultural Experiment Station.

LITERATURE CITED

Åman, P., and Graham, H. 1987. Analysis of total and insoluble mixed-linked (1–3),(1–4)-β-D-glucans in barley and oats. J. Inst. Food Chem. 35:706-709.

Åman, P., Graham, H., and Tilley, A. 1989. Content and solubility of mixed-linked (1–3),(1–4)-β-D-glucan in barley and oats during kernel development and storage. J. Cereal Sci. 10:45-50.

Anderson, J. W., and Chen, W. J. L. 1986. Cholesterol-lowering properties of oat products. Pages 309-333 in: Oats: Chemistry and Technology. F. H. Webster, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Bhatty, R. S., Berdahl, J. D., and Christison, G. I. 1975. Chemical composition and digestible energy of barley. Can. J. Anim. Sci. 55:759-764.

Bamforth, C. W. 1982. Barley β-glucans. Their role in malting and brewing. Brew. Dig. 57:22-35.

Fincher, G. B., and Stone, B. A. 1986. Cell walls and their components in cereal grain technology. Pages 278-295 in: Advances in Cereal Technology, Vol. VIII. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Fox, G. J. 1981. The effect of the waxy endosperm, short awn and hull-less seed genes upon biochemical and physiological seed characteristics important in barley (*Hordeum vulgare* L.) utilization. PhD dissertation, Abstract No. DE082-14646. Montana State Univ.: Bozeman, MT.

Hockett, E. A., McGuire, C. F., Newman, C. W., and Prentice, N. 1987. The relationship of barley β-glucan content to agronomic and quality

TABLE V
Mean Ratio of Soluble to Total β-Glucan Content (%) of Barley Genotypes at Four Environments, 1991-1992

Genotype	Environment			
	Casselton 1991	Prosper 1991	Minot 1992	Prosper 1992
Azure	68.7	65.3	64.1	70.6
Waxy Azure	58.6	62.3	58.1	59.2
Waxy Hull-less Azure	70.2	70.7	73.9	69.2
Bowman	56.9	52.5	62.1	60.8
Hull-less Bowman	56.8	56.0	65.0	58.9
Waxy Bowman	63.9	50.9	61.4	61.2
Waxy Hull-less Bowman	77.4	67.7	60.5	69.4
Waxy Hull-less Short Awn Bowman	70.0	66.4	57.0	57.1
Wanubet	77.2	70.7	63.3	63.2

Least significant difference at $P = 0.05$ level of probability = 7.9 for all environments.

characteristics. Pages 851-860 in: Barley Genetics, V. Proc. 5th Int. Barley Genet. Symp. S. Yasuda and T. Konishi, eds. Sanyo Press: Okayama, Japan.
Horsley, R. D., Schwarz, P. B., Faue, A. C., and Manthey, F. A. 1992. Survey of β-glucan content of barley cultivars adapted to North Dakota. North Dakota Farm Res. 49(5):4-26.
McCleary, B. V., and Codd, R. 1991. Measurement of (1–3),(1–4)–β–D–glucan in barley and oats: streamlined enzymic procedure. J. Sci. Food. Agric. 55:303-312.
Miller, S. S., Vincent, D. J., Weisz, J., and Fulcher, R. G. 1993. Oat β-glucans: An evaluation of eastern Canadian cultivars and unregistered lines. Can. J. Plant Sci. 73:429-436.
Newman, C. W., and Newman, R. K. 1992. Nutrition aspects of barley seed structure and composition. Pages 351-362 in: Barley: Genetics, Biochemistry, Molecular Biology, and Biochemistry. P. R. Shewry, ed. CAB International: Wallingford, UK.
Peterson, D. M. 1991. Genotype and environment effects on oat β-glucan concentration. Crop Sci. 31:1517-1520.
Peterson, D. M., Wesenberg, D. M., and Burrup D. E. 1995. β-Glucan content and its relationship to agronomic characteristics in elite oat germplasm. Crop Sci. 35:965-970.
Stuart, I. M., Loi, L., and Fincher, G. B. 1988. Varietal and environmental variations in (1–3),(1–4)–β–D–glucanase potential in barley: Relationship to malting quality. J. Cereal Sci. 7:61-71.
Welch, W. R., and Lloyd, J. D. 1989. Kernel (1–3),(1–4)–β–D–glucan content of oat genotypes. J. Cereal Sci. 9:35-40.

[Received July 11, 1996. Accepted April 30, 1997.]