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Effects of genotype and environment on β-glucan and dietary fiber contents of hull-less barleys grown in Turkey

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Abstract

In this study, the effects of cultivar and environment on β-glucan and total dietary fibre (TDF) contents and various quality characteristics of hull-less barley samples grown in Turkey were investigated. There were significant differences among the barley genotypes and different locations in terms of β-glucan and TDF content ($p < 0.05$). Significant correlations were found between β-glucan content and some quality criteria (sieve analysis and 1000 kernel weight). The correlations between TDF and grain yield, hectolitre weight, 1000 kernel weight and protein content were also generally significant. These results indicated that environmental and genetic factors are involved in the total β-glucan content of barley.

Keywords: Hull-less barley; β-Glucan; Dietary fiber; Environment; Genotype

1. Introduction

Barley (*Hordeum vulgare*, L.) is the fourth most important cereal in the world in terms of total production, after wheat, rice and corn (Jadhav, Lutz, Ghorpade, & Salunkhe, 1998). It is mainly utilized in the malting and brewing industry and for animal feed. Only a small amount of barley is used in human consumption. Taste and appearance factors along with its poor baking quality have limited the use of barley in human foods. However, in recent years there has been a growing research interest in the utilization of barley in a wide range of food applications (Bhatty, 1999; Bilgi & Çelik, 2004; Erkan, Çelik, Bilgi, & Köksel, 2006; Köksel, Edney, & Özkaya, 1999). Since hull-less barley does not require dehulling and offers some advantages for food uses, it has potential for use in human foods. It contains the same level of crude fibre as wheat and corn. Hulled barley contains 5–6% crude fibre, which is a major limitation to its use in foods (Berglund, Fastnaught, & Holm, 1992; Bhatty, 1986). Potential new applications of hull-less barley include preparation of food malt, production of ethanol, extraction and enrichment of β-glucan, preparation of native and modified starches, and preparation of bran and flour. Hull-less barley can be ground or roller milled, pearled, steamed, boiled, baked, extruded, roasted, flaked, or cut into grits for use in foods (Bhatty, 1995).

Starch, dietary fibre and protein are the main components of barley grain. Both genotypic and environmental factors affects its chemical composition (Aman & Newman, 1986). Total dietary fibre (TDF) consist of insoluble and soluble fractions, both of which are resistant to digestion by the alimentary enzymes of humans. The insoluble fraction in cereal grain contains a large proportion of cellulose and has beneficial effects in the gastrointestinal tract (Jenkins, Jenkins, Wolever, Rao, & Thompson, 1985). The soluble fractions contain mostly pectin, arabinoxylan and β-glucan. Barley contains high levels of soluble dietary

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fibre, particularly mixed linkage (1,3)-(1,4)-β-D-glucans (β-glucan). Barley is unique among cereals, containing high concentrations of β-glucan, which is known to have a cholesterol-lowering effect (McIntosh, Whyte, McArthur, & Nestel, 1991; Newman, Lewis, Newman, Boik, & Ramage, 1989), regulating blood glucose level and insulin response in diabetics (Cavallero, Empilli, Brighenti, & Stanca, 2002) and even reducing cancer risk (Jacobs, Marquart, Slavin, & Kushi, 1998).

There are a number of studies on the effects of environment and genotype on β-glucan content (Bourne & Wheeler, 1984; Özkara, Başman, Köksel, & Çelik, 1998; Perez-Vendrell, Brufau, Molina-Cano, Francesch, & Guasch, 1996; Stuart, Loi, & Fincher, 1988; Zhang, Junmei, & Jinxin, 2002) and dietary fibre content (Aman & Newman, 1986; Oscarsson, Andersson, Salomonsson, & Aman, 1996) of barleys. Lehtonen and Aikasalo (1987) showed that β-glucan contents of barleys differed with respect to variety, ear type and the conditions during growth. Investigations on the effects of environment and genotype on composition and general quality characteristics of barleys might give useful information with respect to their final utilization purposes.

In recent years, there have been significant breeding activities on hull-less barley in various countries, including Turkey. Hence, the aim of this study was to determine general quality characteristics of hull-less barley advanced lines grown in various locations in Turkey and to determine the effects of genotype and growing location on β-glucan and total dietary fibre contents.

2. Materials and methods

2.1. Materials

Sixteen hull-less barley lines and one hulled barley cultivar (cv. Tarm-92), obtained from the Central Research Institute for Field Crops, Ankara, Turkey, were used in this research. Hulled barley was used as the control. It is an alternative type two-rowed barley cultivar commonly grown in Turkey. Hull-less barley advanced lines (indicated as L1-L16.) were developed by cross-breeding of winter and summer type barleys. Hull-less barley lines and hulled barley were grown in experimental fields in 3 different locations (Sincan, Yenimahalle and Haymana) in the highlands of central Turkey. All barley samples were planted in spring. Barley samples were ground using a Retsch Mill (Stanmore, England).

2.2. Tests on barley samples

Hull-less barley samples were analyzed for moisture, protein ($N \times 6.25$) and hectolitre weight by using AACC Methods Nos. 44-01, 46-12 and 55-10, respectively (American Association of Cereal Chemists, 1990). Hectolitre weight measures the density of grain in kg per hectolitre. It is usually carried out using a vessel with a known volume which is overfilled with grain, levelled and weighed. The weight is extrapolated to one hectolitre. Thousand kernel weight was determined by counting the number of seeds in 20 g of grain and is reported on a dry basis. Sieve analysis of barley samples was done according to MEBAK (Mitteleuropäischen Brautechnischen Analysenkommission) Method 2.3.1 (MEBAK, 1984). In sieve analysis three sieves are used with oblong (slotted) holes 2.8, 2.5 and 2.2 mm in width. The amount of grain remaining on $2.8 + 2.5$ mm sieves is reported as sieve analysis over 2.5 mm and the grain passing through 2.2 mm sieve is reported as sieve analysis under 2.2 mm.

For β-glucan analysis by an enzymic method, Megazyme β-glucan and Glucose Assay Kits were used (Megazyme International, Ireland Ltd.). β-Glucan contents were assessed using the McCleary Enzymic Method for barley (McCleary & Codd, 1991; McCleary & Glennie-Holmes, 1985). The principle of the method is depolymerization of β-glucan with endo-(1,3)-(1,4)-β-D-glucan 4-glucanohydrolase (lichenase) to oligosaccharides, hydrolysis of the oligosaccharides to glucose with purified β-D-glucosidase and determination of glucose using a glucose oxidase-peroxidase method. Total dietary fibre (TDF) contents of barley samples were determined by using AACC Standard Method No. 32-07 (American Association of Cereal Chemists, 1990). Duplicate samples of milled barleys were applied to sequential enzymatic digestion by using heat stable α-amylase (Novo Nordisk A/S, Bagsvaerd, Denmark), amyloglucosidase and protease (Sigma, St. Louis, MO, USA) to remove starch and protein. For TDF, enzyme digestate was treated with ethyl alcohol to precipitate soluble dietary fibre before filtering, and TDF residue was washed with ethyl alcohol and acetone, dried and weighed. TDF residue values were corrected for protein, ash and blank. All of the tests on the barley samples were performed in duplicate and the average values were reported.

2.3. Statistical analysis

The data were statistically evaluated by the one-way analysis of variance procedure using the MSTAT-C statistical program (Anonymous, 1988). When significant differences were found, the Least Significant Difference (LSD) test was used to determine the differences among mean values.

3. Results and discussion

Grain yield, sieve analysis, hectolitre weight and 1000 kernel weight results of one hulled barley (control) and 16 hull-less barley lines grown in Sincan, Yenimahalle and Haymana locations are presented in Tables 1–3, respectively. In Sincan and Yenimahalle, L-2 hull-less barley and the control sample gave the highest and lowest grain yields, respectively. In these locations, the sieve analysis over 2.5 mm and 1000 kernel weight of the control

Table 1
Grain yield and physical properties of barley samples grown in Sincan location

Barley lines (L)	Grain yield (kg/ha)	Sieve analysis over 2.5 mm (%)	Sieve analysis under 2.2 mm (%)	Hectolitre weight (kg/hl)	1000 Kernel weight (g)
Control	3142	67.5	11.1	63.2	39.7
L-1	4498	19.5	24.2	72.2	27.3
L-2	5098	27.5	16.2	69.1	35.5
L-3	4002	20.5	34.1	65.4	31.1
L-4	4254	21.0	23.2	71.3	30.0
L-5	4827	44.0	18.1	72.6	35.5
L-6	4287	13.0	32.2	71.3	27.5
L-7	4282	40.0	15.1	61.1	31.4
L-8	4521	50.5	11.2	72.2	32.0
L-9	4470	27.5	18.1	72.2	34.3
L-10	4585	51.0	16.3	73.1	31.5
L-11	4508	15.0	29.2	68.8	27.8
L-12	4671	30.0	18.1	69.4	30.1
L-13	4079	13.0	34.1	70.5	26.3
L-14	4262	46.0	13.2	72.3	31.6
L-15	4204	9.0	35.4	72.4	27.6
L-16	3446	40.0	16.2	74.5	32.6
Mean value	4302.1	31.5	21.5	70.1	31.3
Std. dev.	468.69	16.62	8.43	3.66	3.55

Table 2
Grain yield and physical properties of barley samples grown in Yenimahalle location

Barley lines (L)	Grain yield (kg/ha)	Sieve analysis over 2.5 mm (%)	Sieve analysis under 2.2 mm (%)	Hectolitre weight (kg/hl)	1000 Kernel weight (g)
Control	3187	67.5	10.1	62.1	46.9
L-1	4717	16.5	24.1	72.1	33.3
L-2	5442	27.5	15.1	72.8	25.9
L-3	3960	30.5	20.2	66.4	28.0
L-4	4609	23.5	18.1	76.1	36.0
L-5	5080	57.5	6.2	75.1	40.0
L-6	4793	19.0	25.2	70.1	32.5
L-7	4658	21.0	21.1	73.5	41.0
L-8	5283	54.0	9.2	72.1	40.0
L-9	5299	33.0	13.2	71.8	40.0
L-10	5188	65.5	2.2	76.6	40.0
L-11	5092	10.0	39.3	70.7	29.2
L-12	5032	41.0	11.4	69.6	38.1
L-13	4915	15.5	25.2	72.6	34.1
L-14	4978	59.0	5.2	72.4	41.5
L-15	4863	9.5	38.2	67.1	30.2
L-16	3711	60.0	6.2	72.4	41.2
Mean value	4753.4	35.9	17.1	71.4	36.3
Std. dev.	603.70	20.52	10.92	3.62	5.79

sample were higher than those of hull-less barley lines. As expected, the samples with higher sieve analysis over 2.5 mm had higher 1000 kernel weight values. The control sample had the lowest hectolitre weight in Yenimahalle. In Haymana, the highest and lowest grain yield was obtained with L6 and L16 hull-less barley lines, respectively (Table 3). The highest results of sieve analysis over 2.5 mm were obtained with the hull-less barley line L9 and this value was also high in the control sample. The control sample

Table 3
Grain yield and physical properties of barley samples grown in Haymana location

Barley lines (L)	Grain yield (kg/ha)	Sieve analysis over 2.5 mm (%)	Sieve analysis under 2.2 mm (%)	Hectolitre weight (kg/hl)	1000 Kernel weight (g)
Control	3417	90.0	3.1	68.2	48.2
L-1	3788	27.5	16.1	78.3	31.2
L-2	3566	38.5	8.2	76.6	37.9
L-3	2841	23.0	15.4	76.1	38.0
L-4	3729	30.0	13.2	79.2	34.0
L-5	3438	78.1	3.1	79.2	39.0
L-6	3851	49.8	9.2	78.6	34.2
L-7	3183	33.0	13.0	76.2	36.7
L-8	3489	77.0	4.3	77.6	39.6
L-9	2947	96.0	0.2	76.4	37.0
L-10	3758	74.5	5.1	77.7	38.7
L-11	3516	45.0	10.1	79.2	32.9
L-12	3361	42.0	9.0	79.5	35.2
L-13	3182	45.5	11.0	79.2	34.1
L-14	3656	77.0	4.1	78.4	39.8
L-15	3042	55.0	6.2	79.5	34.9
L-16	2025	61.0	8.2	75.6	38.7
Mean value	3340.5	55.5	8.2	77.4	37.1
Std. dev.	452.70	22.87	4.59	2.71	3.83

had the lowest hectolitre weight value while hull-less barley lines of L12 and L15 had the highest values. The control sample had the highest 1000 kernel weight value whereas L1 line had the lowest value. The ranges of protein contents were 13.4–15.7%, 11.1–15.6% and 12.2–15.1% for Sincan, Yenimahalle and Haymana, respectively (data not presented).

β-Glucan and TDF contents of the hulled barley (control) and 16 hull-less barley lines grown in Sincan, Yenimahalle and Haymana are presented in Table 4. In Sincan, the lowest and highest β-glucan content was detected with the hull-less barley lines L11 and L10, as 3.88 and 5.18%, respectively. TDF values of the samples grown in this location ranged between 10.1% and 21.6%. The hulled control sample had the highest TDF content. In Yenimahalle, β-glucan values were between 4.13% and 5.08% and the hull-less barley L8 had the highest β-glucan content while L11 had the lowest. The difference between the β-glucan contents of the control and L3, L5, L9, L10, L14 and L16 hull-less barley lines were not statistically significant. β-Glucan values of L1, L2, L4, L6, L7, L12, L13 and L15 hull-less barleys were also classified in the same group and their differences were not statistically significant. The hulled control sample had the highest TDF content (17.4%). L14 hull-less barley had the lowest TDF content (8.6%). The difference in TDF contents of L2, L4 – L13 and L15 were found to be statistically insignificant. β-Glucan contents of the samples grown in Haymana were between 3.73% and 4.90%. The highest β-glucan value was obtained with L16 hull-less barley. Hull-less barley lines of L12 and L13 had the lowest β-glucan values. The control sample and L3, L5, L8, L9, L10 and L14 hull-less barley lines were classified in the same group in terms of

Table 4
β-Glucan and total dietary fibre contents of barley samples grown at different locations

Location	Sincan		Yenimahalle		Haymana	
Barley lines (L)	β-Glucan (%)[A]	Total dietary fiber (%)[A]	β-Glucan (%)[A]	Total dietary fiber (%)[A]	β-Glucan (%)[A]	Total dietary fiber (%)[A]
Control	5.07 ab	21.6 a	4.80 ab	17.4 a	4.58 ab	15.9 a
L-1	4.35 e	11.9 cdef	4.38 cd	16.2 a	4.20 cd	11.8 cd
L-2	4.45 cde	10.3 ef	4.35 cd	10.6 cde	3.90 de	9.9 ef
L-3	4.75 bcd	16.9 b	4.93 ab	13.4 b	4.65 ab	10.1 ef
L-4	4.25 ef	10.1 f	4.28 cd	10.3 cde	4.20 cd	12.9 b
L-5	4.90 ab	13.4 c	5.05 ab	9.3 de	4.68 ab	9.5 f
L-6	4.45 cde	11.4 cdef	4.40 cd	10.7 cd	3.95 de	10.9 de
L-7	4.43 de	10.4 def	4.45 c	9.9 cde	3.88 de	9.5 f
L-8	4.75 bcd	12.8 cd	5.08 a	9.6 cde	4.65 ab	9.9 ef
L-9	4.83 abc	12.6 cde	4.78 b	9.3 de	4.35 bc	10.2 ef
L-10	5.18 a	11.2 cdef	4.93 ab	10.2 cde	4.68 ab	10.0 ef
L-11	3.88 f	10.9 def	4.13 d	10.6 cd	3.80 e	10.4 ef
L-12	4.30 e	10.8 def	4.45 c	10.6 cd	3.73 e	9.9 ef
L-13	4.13 ef	10.6 def	4.20 cd	9.7 cde	3.73 e	10.9 de
L-14	4.80 abcd	10.4 def	4.96 ab	8.6 e	4.50 bc	9.6 f
L-15	4.10 ef	11.8 cdef	4.20 cd	9.8 cde	3.93 de	10.1 ef
L-16	5.10 ab	11.8 cdef	4.78 b	11.2 c	4.90 a	12.7 bc
LSD value	0.392	2.49	0.277	1.90	0.370	1.09
Mean value	4.6	12.3	4.6	11.0	4.3	10.8
Std. dev.	0.38	2.90	0.33	2.40	0.41	1.68

Means with the same letter within a column are not significantly different ($p < 0.01$) by least significant differences (LSD) analysis except grain yield where $p < 0.05$.
[A] Dry weight basis.

β-glucan content and they were not statistically significant. The highest TDF value was detected with the control sample (15.9%) while the hull-less barley lines L5 and L7 had the lowest TDF value (9.5%). TDF values of L2, L3, L5, L7 – L12, L14 and L15 were classified in the same group and their difference was not statistically significant. As expected, the hulled control sample had the highest TDF values at each location.

Average results of grain yield, sieve analysis, hectolitre weight, 1000 kernel weight, protein, β-glucan and total dietary fibre contents of the barley samples grown in three different locations are presented in Table 5. The influence of location on the grain yield, sieve analysis, hectolitre weight, 1000 kernel weight was found to be statistically significant. The highest average β-glucan contents were in Sincan and Yenimahalle. The highest average TDF content was found in Sincan location (12.3%). The difference between the average TDF values of Yenimahalle and Haymana were not statistically significant. Hull-less barley β-glucan and TDF contents were significantly affected by the environment (Table 5). There were significant differences in the average β-glucan and TDF contents between the locations. Haymana, which had the barley with the lowest β-glucan content cannot be suggested for planting hull-less barley high β-glucan content. Hull-less barley β-glucan and TDF contents were also significantly affected by genotype (Table 4). There have been several studies on the dependence on β-glucan content of barley grain on genetic and environmental factors (Bourne & Wheeler, 1984; Edney, Marchylo, & MacGregor, 1991; Lehtonen & Aikasalo, 1987; Özkara et al., 1998; Perez-Vendrell et al., 1996; Stuart et al., 1988; Zhang et al., 2002).

Correlation coefficients were calculated between β-glucan, TDF and all other parameters investigated in the present study. Correlation coefficients higher than 0.40 were presented in Tables 6 and 7 for β-glucan and TDF contents, respectively. Sieve analysis and 1000 kernel weight results gave significant correlations with β-glucan content, except sieve analysis results under 2.2 mm for Haymana (Table 6). The samples used in the present study varied in

Table 5
Grain yield, physical and chemical properties of barley samples grown at different locations

Location	Grain yield (kg/ha)	Sieve analysis over 2.5 mm (%)	Sieve analysis under 2.2 mm (%)	Hectolitre weight (kg/hl)	1000 Kernel weight (g)	Protein (%)[A]	β-Glucan (%)[A]	Total dietary fiber (%)[A]
Sincan	4302 b	31.5 c	21.5 a	70.1 c	31.2 c	14.2 a	4.6 a	12.3 a
Yenimahalle	4753 a	35.9 b	17.1 b	71.4 b	36.3 b	13.0 c	4.6 a	11.0 b
Haymana	3340 c	55.5 a	8.2 c	77.4 a	37.0 a	13.3 b	4.3 b	10.8 b
LSD value	196.6	0.49	0.11	0.10	0.20	0.06	0.08	0.43

Means with the same letter within a column are not significantly different ($p < 0.01$) by least significant differences (LSD) analysis except grain yield where $p < 0.05$.
[A] Dry weight basis.

Table 6
Correlations between β-glucan content and some physical properties of barley samples

Location	Sieve analysis over 2.5 mm (%)	Sieve analysis under 2.2 mm (%)	1000 Kernel weight (g)
Sincan	0.787**	−0.619**	0.703**
Yenimahalle	0.845**	−0.799**	0.568*
Haymana	0.508*	–	0.601**
All locations	0.817**	−0.755**	0.725**

* $p < 0.05$ level.
** $p < 0.01$ level.

Table 7
Correlations between total dietary fiber content and some physical properties of barley samples

Location	Grain yield (kg/ha)	Hectolitre weight (kg/hl)	1000 Kernel weight (g)	Protein (%)*
Sincan	−0.602**	−0.441	0.597*	0.595*
Yenimahalle	−0.697**	−0.601**	–	0.435
Haymana	–	−0.686**	0.404	–
All locations	−0.642**	−0.755**	0.459	0.677**

* $p < 0.05$ level.
** $p < 0.01$ level.

their physical kernel characteristics, especially in terms of sieve analysis and 1000 kernel weight results. Some of them generally had small kernels (e.g. L1, L13, L15) while others had larger and plump kernels in all growing locations. It is generally known that large, dense kernels normally have a higher ratio of endosperm to non-endosperm components than smaller kernels. Higher values in sieve analysis and 1000 kernel weight results indicate larger kernel size and a relatively high proportion of endosperm which has a higher β-glucan content. A positive correlation between β-glucan content and kernel size in rye was also reported by Saastamoinen, Plaami, and Kumpulainen (1989) Hansen, Rasmussen, Knudsen, and Hansen (2003). On the other hand, hectolitre weight which is a measure of density of grain did not give a statistically significant correlation with the β-glucan content. The correlation coefficient was lower than 0.40 and therefore not presented in the table. The overall correlation results indicated that β-glucan content is influenced by the kernel size, rather than the grain density.

Grain yield, hectolitre weight, 1000 kernel weight and protein content resulted in significant correlations with TDF content in some locations (Table 7). Increased grain yield and hectolitre weight generally cause increases in starch content, which is probably a major factor in finding negative correlations between TDF and these two parameters.

Higher kernel size might be desirable in barleys for human consumption purposes. The 1000 kernel weight and sieve analysis results indicated that some of the hull-less barley samples (e.g. L5, L8, L10, L14, L16) generally had higher kernel size. Their hectolitre weights were also generally high. These samples also had relatively high levels of β-glucan. Therefore, these barley samples might be suitable for human consumption. Larger kernel size and higher hectolitre weight are expected to result in higher flour yields which will reduce cost.

4. Conclusions

Increased incorporation of barley into the human diet is recommended, since it is naturally healthy, readily available and inexpensive. It has been reported that hull-less barley can be successfully substituted for wheat flour in many food products (Berglund et al., 1992). Foods containing hull-less barley may appeal to consumers who are interested in high fibre food products. Therefore, Turkey has started an active breeding program for hull-less barley, as in many other countries. In the present study, β-glucan analyses of various advanced Turkish hull-less barley lines grown in three different locations indicated that both environment and genetic factors influence the β-glucan content, confirming the previous studies reported in the literature. The study also revealed the information on β-glucan and TDF contents and other quality characteristics of hull-less barleys grown in Turkey. These results may contribute to an increase in the utilization of hull-less barley samples in human food.

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