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Research Article

The effect of different nitrogen and irrigation levels on grain β-glucan content in some durum wheat cultivars

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Abstract: β-glucan is a non-starchy, water-soluble polysaccharide component of wheat grain that positively affects grain nutrient quality. High β-glucan content in wheat grain also has a cholesterol-lowering effect in humans. The aim of this study was to evaluate the effect of nitrogen and irrigation on durum wheat grain β-glucan content. Correlations between durum wheat grain β-glucan content, and grain yield and some quality characteristics were examined. Kunduru 1149, Kızıltan 91, and Çakmak 79 durum wheat cultivars were used as material, and 0-, 75-, and 150-mm irrigation levels with 0, 40, 80, and 120 kg ha^{-1} nitrogen rates were applied. Higher nitrogen levels generally increased durum wheat grain β-glucan content in both years of the study and the N_3 nitrogen level had the greatest effect on the β-glucan content in durum wheat. Higher irrigation levels negatively affected the β-glucan content in the wheat grain. Non-irrigated treatments generally yielded the highest β-glucan content in both years of the study. The response of grain β-glucan content according to cultivar was significant and C_1 had the best grain β-glucan content of all the cultivars. Correlations between grain β-glucan content, and grain yield, protein content, 1000-grain weight, test weight, seed vitreousness, and the SDS sedimentation were significant. With the exception of protein content in 2005, strong positive correlations were observed between β-glucan content, and grain yield and quality characteristics. These results indicate that higher irrigation levels negatively affected grain β-glucan content in durum wheat, whereas higher nitrogen rates positively affected grain β-glucan content. Moreover, the effect of cultivar characteristics on the β-glucan content in durum wheat grain was statistically significant.

Key words: β-glucan content, irrigation, nitrogen, quality characteristics

Bazı makarnalık buğday çeşitlerinin tane β-glukan içerikleri üzerine farklı azot ve sulama miktarlarının etkisi

Özet: β-glukan, buğday tanesinin besin kalitesini olumlu yönde etkileyen nişasta içermeyen, suda çözünebilen bir polisakkarittir. Buğday tanesindeki yüksek β-glukan içeriği insan sağlığı açısından kolesterol düşürücü etkiye de sahiptir. Bu çalışmanın amacı, makarnalık buğdayın tane β-glukan içeriği üzerinde azot ve sulamanın etkisini belirlemektir. Çalışmada makarnalık buğdayın tane β-glukan içeriği ile tane verimi ve bazı kalite karakteristikleri arasındaki ilişkiler incelenmiştir. Çalışmada Kunduru 1149, Kızıltan 91 ve Çakmak 79 makarnalık buğday çeşitleri materyal olarak kullanılmış olup; 0, 40, 80 ve 120 kg ha^{-1} azot oranları ile birlikte 0, 75 ve 150 mm sulama seviyeleri uygulanmıştır. Her iki yılda yüksek azot seviyeleri genellikle makarnalık buğdayın tane β-glukan içeriğini artırmış olup, makarnalık buğdayda N_3 azot seviyesi en yüksek tane β-glukan içeriğini vermiştir. Artan sulama seviyeleri buğday tanesinin β-glukan içeriği üzerinde olumsuz etkiye sahiptir. Sulama yapılmayan uygulamalar her iki yılda genellikle en yüksek tane β-glukan

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içeriklerine sahiptir. Tane β-glukan içeriğinin çeşide tepkisi önemli olup, tüm çeşitler içerisinde C_1 en iyi tane β-glukan içeriğini vermiştir. Tane β-glukan içeriği ile tane verimi, protein oranı, 1000 tane ağırlığı, hektolitre ağırlığı, camsılık ve sds sedimentasyon arasındaki korelasyonlar önemli bulunmuştur. 2005 yılındaki protein oranı hariç, tane β-glukan içeriği ile tane verimi ve kalite özellikleri arasında yüksek ve pozitif korelasyonlar gözlenmiştir. Çalışma sonuçları, buğday tanesinin ß-Glukan içeriğinin artışı üzerine artan sulama suyu uygulamalarının negatif, azot uygulamalarının pozitif yönde etkili olduğu, çeşit özelliklerinin de istatistiksel olarak önem taşıdığını göstermiştir.

Anahtar sözcükler: β-glukan içeriği, sulama, azot, kalite karakteristikleri

Introduction

Durum wheat (*Triticum durum* Desf.) is of great importance for human nutrition, and is widely cultivated in Turkey and other regions of the world. Even though durum wheat is a major crop for semolina and pasta production, the flour of durum wheat may be used for human nutrition in other ways (due to grain β-glucan content). Of all the cereals, oats and barley have the highest grain β-glucan content (Aman and Graham 1987). Wheat also has notable dietary fiber content. β-glucan, as a source of dietary fiber in plants, is found in roots, coleoptiles, leaves, stems, and endosperm tissues of the Gramineae (Wood 1986). Gastrointestinal and cardiovascular diseases in humans are primarily related to the deficiency of dietary fiber (Wisker et al. 1985). Durum wheat and durum wheat products with high β-glucan content may be used in the human diet for preventing such diseases. Additionally, β-glucan in oats and barley has a cholesterol-lowering effect in humans (Anderson and Chen 1986; Davidson et al. 1991). The quantity of β-glucan in wheat grain is low in comparison to oats and barley; however, new durum wheat cultivars with high β-glucan content may be mixed with common wheat flour in bread production. Genetic enhancement of grain β-glucan content is a major objective of breeding programs that aim to improve wheat quality. To effectively increase the β-glucan content of wheat cultivars, an understanding of the influence of genetic and environmental factors on grain β-glucan content is essential. Two environmental factors that affect grain β-glucan content are nitrogen fertilization and irrigation.

β-glucan is a minor constituent in wheat grain and the quantity and quality of β-glucan primarily depend on genotype and environment. The effects of genotype and environment on grain β-glucan content have been studied extensively. Several researchers reported differences in β-glucan content between oat cultivars and genotypes (Welch and Lloyd 1989; Peterson 1991; Cho and White 1993; Miller et al. 1993). Differences in the β-glucan content of oats and barley based on locality have been reported (Aman 1986; Aman et al. 1989). Peterson et al. (1995) concluded that the β-glucan content of oats varied depending on location and year. Perez-Vendrell et al. (1996) observed significant differences in the β-glucan content of barley between cultivars, locations, and years. Nitrogen is one of the most important factors that affect the β-glucan content of grain. Brunner and Freed (1994), and Baur and Geisler (1996) reported that higher quantities of nitrogen significantly increased grain β-glucan content in oats and barley. Similarly, Welch et al. (1991) observed significant increases in β-glucan content as the use of nitrogen increased. Extremely low β-glucan values were observed when nitrogen was not applied (Wood et al. 1977). The other factor that affects grain β-glucan is irrigation or rainfall. Peterson (1991) noted that the β-glucan content of rainfed oats was higher than that of irrigated oats. Moreover, the β-glucan content of oats was not only dependent on irrigation or rainfall, but also on other environmental factors (Peterson et al. 1995).

The relationships between the grain β-glucan concentration and some agronomic and quality traits in cereals were investigated by many researchers. Brunner and Freed (1994) reported both positive and negative weak correlations between grain β-glucan content, and grain yield and test weight. They also observed a significant positive correlation between grain β-glucan content and protein content in oats, whereas Saastamoinen et al. (1992) reported a negative correlation between β-glucan content and grain protein content. Welch and Lloyd (1989) reported a non-significant correlation between grain β-glucan content and grain protein. Peterson et al. (1995) reported generally low or non-significant correlations between grain β-glucan content and grain yield in oats. In contrast, no significant correlations between β-glucan content and 1000-grain weight were observed in oats (Aman 1987).

The aims of the present study were to investigate the effects of nitrogen and irrigation on grain β-glucan content, and to evaluate the relationships between grain β-glucan content, and some agronomic and quality traits in durum wheat.

Materials and methods

This study was conducted in Ankara, Turkey, between 2003 and 2005 to evaluate the effects of various levels of nitrogen and irrigation on grain β-glucan content in durum wheat. The soil type was loamy (pH 7.8) and organic matter content was 1.36%. Climatic data for the location are given in Table 1. Planting dates were 15 October 2003 and 13 October 2004. Plants were harvested by hand in the second week of July the following year. The experiment utilized a randomized block, split-split plot design with 3 replications. Three irrigation levels (0, 75, and 150 mm) were applied to the main plots. Nitrogen treatments were subplots and consisted of different nitrogen rates (0, 40, 80, and 120 kg ha^{-1}). The sub-subplot treatments included 3 durum wheat cultivars: Kunduru 1149 (C_1) Kızıltan 91 (C_2), and Çakmak 79 (C_3). Each plot consisted of twelve 5-m rows. Diammonium phosphate fertilizer at 150 kg ha^{-1} was applied prior to planting to meet both the phosphorus and nitrogen requirements. The remainder of nitrogen was applied as ammonium nitrate fertilizer in early spring. Nitrogen rates were 0 (N_0), 40 (N_1), 80 (N_2), and 120 (N_3) kg ha^{-1}. Irrigation levels were 0 (I_0), 75 (I_1), and 150 (I_2) mm, and were applied using a 100-L sprayer tank at 3 growth stages: sowing, jointing, and heading.

In the present study grain β-glucan content was determined by the enzymatic method (McCleary and Codd 1991). Grain protein content was determined by the Kjeldahl method given by the American Association of Cereal Chemists (AACC 1969), on a dry weight basis. We measured 1000-grain weight by weighing a 500-seed sample (Özkaya and Kahveci 1990). Test weight was measured using a 1-L volumeter (Özkaya and Kahveci 1990). Seed vitreousness was measured with a Grobecker cutting device (Uluöz 1965). The SDS sedimentation was measured according to Williams et al. (1986). Analysis of variance (ANOVA) was performed for each year. Differences between treatment means were tested using Duncan's multiple range test at the 0.05 level of probability. Correlation coefficients were calculated between grain β-glucan content, and yield and other grain characteristics.

Table 1. Climatic data of the research location.

Months	2003			2004			2005		
	Temp. (°C)	Precip. (mm)	Rel. Hum. (%)	Temp. (°C)	Precip. (mm)	Rel. Hum. (%)	Temp. (°C)	Precip. (mm)	Rel. Hum. (%)
Jan	5.4	42.0	73.3	0.2	46.1	76.4	3.5	19.3	69.4
Feb	- 0.3	54.6	71.8	2.4	18.3	66.7	2.5	27.4	67.0
Mar	3.2	8.6	62.5	7.2	13.0	56.6	6.1	67.6	65.5
Apr	10.3	70.3	62.4	11.5	38.0	55.0	11.6	78.6	58.9
May	19.0	18.0	52.9	15.8	33.8	57.2	16.6	86.7	58.3
Jun	22.6	-	46.6	20.0	25.6	57.4	19.5	37.1	54.7
Jul	23.5	3.0	49.5	23.6	6.2	49.0	25.0	11.9	51.1
Aug	24.3	0.2	48.1	22.9	12.6	54.3	25.4	0.1	51.7
Sep	18.0	15.1	58.9	19.3	2.7	49.7	18.7	42.6	58.7
Oct	14.4	29.8	61.5	14.2	10.9	61.5	10.8	28.0	66.0
Nov	8.0	5.2	68.9	7.2	35.2	66.8	6.1	48.1	69.3
Dec	1.9	61.5	75.9	2.3	8.7	72.8	3.0	14.4	69.0
Aver.	12.5	-	61.0	12.2	-	60.3	12.4	-	61.6
Total	-	308.3	-	-	251.1	-	-	461.8	-

Results

Mean values of grain β-glucan content in durum wheat for both years are shown in Table 2. The results of ANOVA show that irrigation × cultivar and nitrogen × cultivar interactions were significant in 2004 (Table 3). The differences between irrigation levels were evaluated separately for each cultivar. Higher irrigation levels negatively affected grain β-glucan content in durum wheat (Table 4). For Kunduru 1149 (C_1) the highest grain β-glucan content was obtained with the non-irrigation treatment (I_0), while the I_2 treatment yielded the lowest grain β-glucan content. There was no difference in grain β-glucan content between the I_0 and I_1 treatments, and the lowest grain β-glucan content was observed with the I_2 treatment for Kızıltan 91 (C_2). For Çakmak 79 (C_3) the non-irrigation treatment (I_0) resulted in the greatest grain β-glucan content. There were significant differences in grain β-glucan content between the cultivars for each irrigation level. Of all the cultivars, Kunduru 1149 (C_1) had the highest grain β-glucan content, whereas Çakmak 79 (C_3) had the lowest, at all irrigation levels. There were significant differences in grain β-glucan content between the nitrogen levels in all the cultivars, except for Çakmak 79 (C_3) (Table 5). Higher nitrogen levels generally increased grain β-glucan content in durum wheat. Nitrogen level did not affect the grain β-glucan content in Çakmak 79 (C_3). Significant differences were observed in grain β-glucan content between the cultivars at all nitrogen levels. Kunduru 1149 (C_1) had the highest grain β-glucan content at all nitrogen levels.

Table 3. Mean squares from the analysis of variance for grain β-glucan content (%) of durum wheat at different nitrogen and irrigation levels (2004).

Source	d.f[1].	Mean square
Total	107	-
Rep.	2	$0.015^{n.s.}$
Irrigation (I)	2	$0.162^{n.s}$
Error *a*	4	$0.002^{n.s}$
Nitrogen (N)	3	$0.060^{n.s}$
I × N	6	$0.002^{n.s}$
Error *b*	18	$0.006^{n.s}$
Cultivar (C)	2	$0.540^{n.s}$
I × C	4	0.007*
N × C	6	0.021 **
I × N × C	12	$0.001^{n.s}$
Error *c*	48	$0.002^{n.s}$

[1]Degrees of freedom
*P < 0.05, **P < 0.01
n.s.: nonsignificant

Table 2. Mean grain β-glucan contents (%) of 3 durum wheat cultivars at different nitrogen and irrigation levels in 2004 and 2005.

		2004			2005		
		C_1	C_2	C_3	C_1	C_2	C_3
I_0	N_0	0.533 ± 0.023	0.483 ± 0.034	0.456 ± 0.031	0.580 ± 0.020	0.523 ± 0.026	0.430 ± 0.034
	N_1	0.640 ± 0.026	0.523 ± 0.029	0.433 ± 0.058	0.673 ± 0.023	0.540 ± 0.036	0.396 ± 0.029
	N_2	0.706 ± 0.049	0.556 ± 0.033	0.466 ± 0.049	0.756 ± 0.043	0.580 ± 0.026	0.423 ± 0.020
	N_3	0.756 ± 0.044	0.633 ± 0.029	0.476 ± 0.023	0.876 ± 0.055	0.756 ± 0.039	0.430 ± 0.017
I_1	N_0	0.506 ± 0.020	0.436 ± 0.032	0.373 ± 0.034	0.586 ± 0.012	0.513 ± 0.038	0.350 ± 0.011
	N_1	0.590 ± 0.020	0.470 ± 0.036	0.360 ± 0.037	0.616 ± 0.014	0.503 ± 0.047	0.393 ± 0.018
	N_2	0.626 ± 0.017	0.510 ± 0.020	0.390 ± 0.025	0.616 ± 0.008	0.516 ± 0.039	0.386 ± 0.008
	N_3	0.713 ± 0.035	0.606 ± 0.012	0.330 ± 0.015	0.800 ± 0.047	0.683 ± 0.031	0.353 ± 0.008
I_2	N_0	0.483 ± 0.012	0.393 ± 0.024	0.300 ± 0.045	0.540 ± 0.034	0.473 ± 0.027	0.223 ± 0.029
	N_1	0.536 ± 0.014	0.396 ± 0.034	0.273 ± 0.037	0.563 ± 0.017	0.483 ± 0.041	0.236 ± 0.031
	N_2	0.533 ± 0.014	0.453 ± 0.036	0.240 ± 0.045	0.560 ± 0.015	0.480 ± 0.035	0.256 ± 0.031
	N_3	0.663 ± 0.028	0.526 ± 0.018	0.256 ± 0.033	0.726 ± 0.020	0.630 ± 0.026	0.276 ± 0.008

C_1, C_2, C_3: Kunduru 1149, Kızıltan 91, and Çakmak 79 cultivars, respectively.
N_0, N_1, N_2, N_3: 0, 40, 80, and 120 kg ha^{-1} nitrogen rates, respectively.
I_0,I_1,I_2: 0, 75, and 150 mm irrigation levels, respectively.

Table 4. Effect of different irrigation levels on grain β-glucan content (%) of durum wheat cultivars (2004).

	I_0	I_1	I_2
C_1	0.659 ± 0.029 a[1] A[2]	0.609 ± 0.024 a B	0.554 ± 0.021 a C
C_2	0.549 ± 0.021 b A	0.505 ± 0.022 b A	0.442 ± 0.020 b B
C_3	0.458 ± 0.018 c A	0.363 ± 0.014 c B	0.267 ± 0.018 c C

1 Lower-case letters indicate significance between cultivars at each irrigation level at $P < 0.05$ (a, b c:↓).
2 Upper-case letters indicate significance between irrigation levels at each cultivar at $P < 0.05$ (A, B, C:→)

Table 5. Effect of different nitrogen levels on grain β-glucan content (%) of durum wheat cultivars (2004).

	N_0	N_1	N_2	N_3
C_1	0.507 ± 0.012 a[1] C[2]	0.588 ± 0.018 a B	0.622 ± 0.029 a B	0.711 ± 0.022 a A
C_2	0.437 ± 0.020 b C	0.463 ± 0.024 b BC	0.506 ± 0.021 b B	0.588 ± 0.019 b A
C_3	0.376 ± 0.029 c A	0.355 ± 0.032 c A	0.365 ± 0.039 c A	0.354 ± 0.034 c A

1 Lower-case letters indicate significance between cultivars at each nitrogen level at $P < 0.05$ (a, b c:↓).
2 Upper-case letters indicate significance between nitrogen levels at each cultivar at $P < 0.05$ (A, B, C:→)

In 2005 irrigation × cultivar and nitrogen × cultivar interactions were significant at the 0.01 level (Table 6). Higher irrigation levels generally decreased grain β-glucan content in durum wheat (Table 7). The non-irrigation treatment (I_0) resulted in the highest grain β-glucan content, while the highest irrigation level (I_2) resulted in the lowest grain β-glucan content in Kunduru 1149 (C_1). For Kızıltan 91 (C_2) the highest grain β-glucan content was obtained with I_0, while the lower grain β-glucan contents were obtained with I_1 and I_2, respectively. Similarly, the highest grain β-glucan content was obtained with the non-irrigation treatment (I_0) in Çakmak 79 (C_3). At each irrigation level, significant differences in grain β-glucan content were observed between cultivars. Kunduru 1149 (C_1) produced the highest β-glucan content, whereas Çakmak 79 (C_3) produced the lowest, at all irrigation levels.

Table 6. Mean squares from the analysis of variance for grain β-glucan content (%) of durum wheat at different nitrogen and irrigation levels (2005).

Source	d.f[1].	Mean square
Total	107	-
Rep.	2	0.006[n.s.]
Irrigation (I)	2	0.144[n.s.]
Error *a*	4	0.007[n.s.]
Nitrogen (N)	3	0.113[n.s.]
I × N	6	0.002[n.s.]
Error *b*	18	0.007[n.s.]
Cultivar (C)	2	0.910[n.s.]
I × C	4	0.008**
N × C	6	0.024**
I × N × C	12	0.002[n.s.]
Error *c*	48	0.002[n.s.]

1Degrees of freedom
*$P < 0.05$, **$P < 0.01$
n.s.: nonsignificant

Table 7. Effect of different irrigation levels on grain β-glucan content (%) of durum wheat cultivars (2005).

	I_0	I_1	I_2
C_1	0.721 ± 0.036 a[1] A[2]	0.655 ± 0.027 a B	0.597 ± 0.024 a C
C_2	0.600 ± 0.031 b	A 0.554 ± 0.028 b B	0.516 ± 0.024 b B
C_3	0.420 ± 0.011 c	A 0.370 ± 0.007 c B	0.248 ± 0.013 c C

[1] Lower-case letters indicate significance between cultivars at each irrigation level at $P < 0.05$ (a, b c:↓).
[2] Upper-case letters indicate significance between irrigation levels at each cultivar at $P < 0.05$ (A, B, C:→)

Differences in grain β-glucan content between nitrogen levels in each cultivar were significant (Table 8). The highest nitrogen level (N_3) considerably increased the grain β-glucan content in Kunduru 1149 (C_1). The lowest grain β-glucan content was obtained with no nitrogen treatment (N_0) in C_1. For Kızıltan 91 (C_2) the N_3 treatment resulted in the highest grain β-glucan content, while lower nitrogen levels decreased its grain β-glucan content. No significant differences were observed in grain β-glucan content between the nitrogen levels in Çakmak 79 (C_3). There were significant differences in grain β-glucan content between the cultivars at each nitrogen level and Kunduru 1149 (C_1) had the highest grain β-glucan content at all nitrogen levels.

The relationships between grain β-glucan content, and some traits in wheat are more important for wheat yield and grain quality. Correlation coefficients between grain β-glucan content and some important traits are presented in Table 9. Grain yield was positively correlated with grain β-glucan content in both years of the study. The results of correlation analysis of grain yield are not in agreement with the findings of several other studies (Brunner and Freed 1994; Peterson et al. 1995). A significantly positive correlation was observed between grain β-glucan content and protein content in 2004, but not in 2005. Our protein content correlations are similar to those reported by Brunner and Freed (1994), but are not in agreement with those of Welch and Lloyd (1989), or Saastamoinen et al. (1992). Correlations between grain β-glucan content and 1000-grain weight were significant both years of the present study, while Aman (1987) reported no significant correlations between grain β-glucan content and 1000-grain weight. Test weight had a significant positive correlation with β-glucan content in 2004 and 2005. These results are not in agreement with the findings of Brunner and Freed (1994). A significant positive correlation ($P < 0.01$) between grain β-glucan content

Table 8. Effect of different nitrogen levels on grain β-glucan content (%) of durum wheat cultivars (2005).

	N_0	N_1	N_2	N_3
C_1	0.568 ± 0.014 a[1] C[2]	0.617± 0.018 a B	0.644 ± 0.032 a B	0.801± 0.030 a A*
C_2	0.503 ± 0.017 b B	0.508± 0.022 b B	0.525 ± 0.022 b B	0.690 ± 0.024 b A
C_3	0.334 ± 0.033 c A	0.342± 0.029 c A	0.355 ± 0.027 c A	0.353 ± 0.023 c A

[1] Lower-case letters indicate significance between cultivars at each nitrogen level at $P < 0.05$ (a, b c:↓).
[2] Upper-case letters indicate significance between nitrogen levels at each cultivar at $P < 0.05$ (A, B, C:→)

Table 9. Correlation coefficients between grain β-glucan content and grain yield, protein content, 1000-grain weight, test weight, seed vitreousness and sds sedimentation of durum wheat in 2004 and 2005.

Variable	2004	2005
Grain yield	0.420**	0.291**
Protein content	0.630**	0.613$^{n.s.}$
1000-grain weight	0.347**	0.264**
Test weight	0.409**	0.244*
Seed vitreousness	0.685**	0.702**
Sds sedimentation	0.473**	0.525**

*P < 0.05, **P < 0.01
n.s.: nonsignificant

and seed vitreousness was observed in both years. A significant positive correlation (P < 0.01) between grain β-glucan content and the SDS sedimentation was observed in both years.

Discussion

The grain β-glucan content in the present study varied according to cultivar, and nitrogen and irrigation treatments. The response of grain β-glucan content according to cultivar was significant in both years of the study. These results are similar to those of other researchers (Welch and Lloyd 1989; Peterson 1991; Cho and White 1993; Miller et al. 1993; Perez-Vendrell et al. 1996). The effect of nitrogen on grain β-glucan content was very significant and higher nitrogen levels usually increased the grain β-glucan content in durum wheat cultivars at 3 irrigation levels, except for Çakmak 79 (C_3). These results are in agreement with the findings reported by Brunner and Freed (1994), Baur and Geisler (1996), Welch et al. (1991), and Wood et al. (1977). In both years of the present study higher irrigation treatments decreased grain β-glucan content in durum wheat and the non-irrigation treatment resulted in the highest grain β-glucan content in all cultivars. These results are similar to those reported by Peterson (1991) and Peterson et al. (1995).

β-glucan content in durum wheat grain varied according genotype, and nitrogen and irrigation levels. In particular, nitrogen and irrigation levels affected grain β-glucan content in durum wheat. Significant differences in grain β-glucan content were observed between cultivars in both years of the study, and grain β-glucan content in the cultivars varied by year. High nitrogen rates positively affected grain β-glucan content and the highest grain β-glucan contents were generally observed in response to 120 kg N ha^{-1}.

Higher irrigation levels significantly decreased grain β-glucan content in durum wheat and the non-irrigation treatment yielded the highest grain β-glucan content in our study. If durum wheat is used for bread making high-level nitrogen fertilization should be recommended to increase β-glucan content. As high irrigation levels or rainfall negatively affected the grain β-glucan content and most other quality traits in durum wheat, the application of irrigation should be minimized during the grain-filling period in order to increase β-glucan content. In addition, possible correlations between β-glucan content, and some agronomic and quality characteristics are of particular interest to breeders that are attempting to elevate this quality factor.

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