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High-beta-glucan and low-glycemic index functional bulgur produced from high-beta-glucan barley

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ABSTRACT

A high β-glucan hull-less barley (cv. Chifaa) was used in bulgur production and its technological and nutritional properties were compared with bulgurs of another hull-less barley and durum wheat. Although Chifaa bulgur had longer cooking time (9.5 min) which is expected to have an increasing effect on total organic matter (TOM), it had lower TOM (1.31 g/100 g) than the durum bulgur. The phenolics of barleys were significantly higher than those of Kiziltan wheat. The amounts of total phenolic contents decreased after bulgur production. While glycemic index (GI) of durum bulgur was high, GI of barley bulgurs were medium probably due to their higher β-glucan contents. The GI of Chifaa (56.25) is very close to the limit value of low GI foods (56). The limit to bear the health claim is 3 g of β-glucans/serving. The results indicated that this can be provided per serving of high β-glucan barley bulgur.

1. Introduction

Bulgur is a well-known ancient Mediterranean food product which is generally produced from durum wheat. It is one of the oldest "processed foods" dating back to prehistoric times (Stone et al., 2020). Consumption of bulgur started in Anatolia and the Middle East and continued throughout history mainly as a domestic food product. Nowadays, industrial processing is becoming more common around the world. It can be categorized either as a semi-ready-to-eat food or a ready-to-eat food (Bayram, 2007). Bulgur is the main ingredient used in more than 250 kinds of meals due to its long shelf life, resistance to insects, mites, and microorganisms, low cost, ease of preparation, high nutritional value, and pleasant taste (Bayram et al., 2004). The production process of bulgur includes cleaning, washing, cooking the grains in water until starch is gelatinized, drying until the content reaches a level safe for storage (around 12 %), tempering, debranning, grinding (or cracking), classification based on particle size and polishing (optional) (Balcı & Bayram, 2020). Although commercial bulgurs are commonly produced using durum wheat, other cereals are also used as alternatives to durum wheat such as bread wheat, barley, einkorn, corn, and chickpea (Ertaş & Türker, 2014; Koksel et al., 1999; Shah et al., 2022).

Functional foods are defined as "foods or dietary components that may provide health benefits beyond basic nutrition," according to the International Food Information Council (IFIC) (Bagchi, 2014). During the last few decades, noncommunicable diseases (NCDs) have been spreading around the world becoming one of the biggest challenges facing humanity. The 2030 Agenda for Sustainable Development recognizes NCDs as a "major challenge for sustainable development". As part of the Agenda, Heads of State and Government committed to develop ambitious national responses, to reduce, by 2030, by one-third premature mortality from NCDs through prevention and treatment. The World Health Organization (WHO) reported that dietary behaviors are among the list of key "behavioral risk factors" in NCD incidences. Hence, it is highly desirable to enhance correct diet habits such as the "Mediterranean diet" (Med-Diet). Numerous studies have reported that adherence to a Med-Diet-based lifestyle is beneficial in the prevention of NCDs. According to scientific literature, the Med-Diet includes foods produced from grains (e.g., bread, pasta, bulgur, couscous) and products that use grains as an ingredient, besides vegetables and fruits. In this context, the MEDWHEALTH project, funded by PRIMA, aims at re-

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designing a selection of staple Med-Foods valorizing their healthiness by using innovative raw materials including durum wheat, barley, and lentils.

Among cereal grains, durum wheat (*Triticum turgidum* L. var. *durum*) is one of the most important crops for the Mediterranean basin. Barley (*Hordeum vulgare* L.) is mainly used for feed and almost disappeared from the diets of many countries. However, barley is still an important staple food in North Africa and the Middle East and recently is regaining importance in the developed countries. Barley, domesticated by the first human populations more than 10,000 years ago, is the world's fourth most important grain in terms of total production, after wheat, rice, and maize (Elouadi et al., 2021; Jadhav et al., 1998). Barley grains are rich in a variety of health beneficial functional compounds, such as β-glucan and phenolic compounds. Compared to other grains, barley has a higher content of mixed-linkage (1–3) (1–4)-β-D-glucans (β-glucans) (Wirkijowska et al., 2012). β-glucans are present in soluble and insoluble forms. Most of the β-glucan is located in the endosperm cell walls of barley, but aleurone cell walls are also rich in these polymers. Foods containing certain levels of β-glucan may include health claims on their packaging. "According to the applicant, to bear the claim: Foods should provide at least 3 g/day of β-glucans from barley, barley bran, or from mixtures of non-processed or minimally processed barley β-glucans in one or more servings. A minimum of 0.75 g of β-glucans per serving is recommended, or one-fourth of the 3 g daily amount specified above, to assist consumers in choosing foods to suit their diet" (EFSA Panel on Dietetic Products & Allergies, 2011). The total β-glucan content of most barley grains varies between 2 % and 10 % by grain weight but is usually between 4 % and 7 % (Aaman & Graham, 1987). Higher β-glucan levels have also been reported in some genotypes (Jadhav et al., 1998; Tiwari & Cummins, 2009). In this variation, the genetic structure of barley is a more effective determinant than environmental conditions (Jadhav et al., 1998; Yalçın et al., 2007). β-glucans reduce blood cholesterol concentration, increase satiety, and have a reducing effect on post-prandial glycemic response. β-glucans are also immunostimulants against infectious diseases and some types of cancer (Murphy et al., 2020). Barley cv. Chifaa is a hull-less barley variety released in Morocco in 2016 that has good nutritional value and high β-glucans content (around 8 %) (Romano et al., 2022). Although bulgur is considered a healthy food with its high fiber content, there are a limited number of studies on its GI. The estimated glycemic index (D'egidio et al.) of three commercial bulgur samples was found to be between 74.4 and 76.2 and classified as high GI food (Koseoglu & Celikel, 2021). However, to the best of the authors' knowledge, there are no studies on the GI and technological quality of bulgurs produced from high β-glucan barleys.

In general, the MEDWHEALTH project aims at re-designing a selection of staple Med-Foods enhancing their healthiness by using innovative raw materials. However, the main purpose of this study was more specific and focused on the high β-glucan and low GI bulgur, a traditional Mediterranean food, which is also the novelty of the study. For this purpose, the utilization potential of the high β-glucan hull-less barley cultivar Chifaa in bulgur production was investigated and its properties were compared with another regular hull-less barley sample (cv. Yalin) and a durum wheat sample (cv. Kiziltan) which is the traditional raw material for bulgur production. Bulgurs were produced from durum wheat, and hull-less barley cultivars, and the physical, chemical, technological, and nutritional properties of grain and bulgur samples were compared.

2. Material and methods

2.1. Material

In the study, two hull-less barley cultivars Chifaa and Yalin, and one durum wheat sample (cv. Kiziltan) were used. The barley cv. Chifaa was grown in Marchouch, Morocco, in the season 2021–2022. The barley cv. Yalin and durum wheat cv. Kiziltan were grown in 2021–2022 in Ankara and was supplied by Field Crops Central Research Institute, Ankara, Turkey. Grain/bulgur samples were ground using a laboratory grinder (CemotecTM, CM290, Hillerod, Denmark) for two minutes and sifted through a 150 μm sieve.

All reagents and solvents used in this study were purchased from Sigma-Aldrich, USA. Megazyme β-glucan and Glucose Assay Kits were purchased from Megazyme International (Ireland Ltd.).

2.2. Bulgur production

In the first phase of bulgur production, barley/wheat samples were soaked separately until no dry spot remains in the central part of the kernels. This was accomplished by adding water to the samples (the ratio of grain to water was 1:1) and then holding the samples in a 60 °C water bath for around 3 h. Bulgurs were produced by cooking at atmospheric pressure. For each cultivar the cooking and other stages of bulgur production were performed in duplicate. A minimum amount of water was used to avoid leaching out of soluble nutrients. The ratio of soaked grain to water was 1:1 for wheat and around 1:1.25 for barley samples during cooking. For cooking at atmospheric pressure, the soaked barley samples were cooked on a hot plate until the starch in the endosperm was entirely gelatinized. The cooking period was around 2 h for all samples.

The cooked material was dried at 50 ± 2 °C in a drying cabinet, by stirring manually at 30 min intervals until a moisture content of below 12 % had been reached. For the production of bulgur, the cooked and dried barley/wheat samples were then tempered for half an hour by adding 2 % water before debranning the lightly. After the slight bran removal, the samples were cracked by using a laboratory type bulgur grinding instrument (Duru Milling Machinery, Karaman, Turkey) and sifted through 0.5-mm sieve to remove fine particles. The product remaining on the sieve is bulgur.

2.3. Characterization of wheat, barley, and bulgur samples

Protein content: Total nitrogen contents of wheat and barley samples were determined by following the Kjeldahl method (AACCI Method 46–30) (AACCI, 2000). A value of 5.7 was used as the nitrogen-protein conversion factor for wheat whereas the value of 6.25 for barley. Ash content determinations were made according to AACCI Standard Method No: 08–01 (AACCI, 2000). β-glucan contents of wheat, barley, and bulgur samples were determined by an enzymatic method using Megazyme β-glucan and Glucose Assay Kits (Megazyme International, Ireland Ltd.). β-glucan contents were assessed using the enzymatic method (McClear and Glennie-Holmes, 1985; McCleary & Codd, 1991).

The color values of the bulgur samples were measured using the L*a*b* color space (CIELAB space) with Konica Minolta CR-400 (Tokyo, Japan).

Elemental analysis was carried out on an Agilent 7500 ce with an Octopole Reaction System Inductively Coupled Plasma Mass Spectrometer (ICP-MS) (7700 Series x, Agilent, Japan) including an Auto Sampler (Cetac ASX-520) and a Nebulizer (Agilent, Japan). The sample was digested using a microwave oven (1200 W) (The Ethos up, Milestone Inc., Monroe, CT, USA) with a mixture of 7.5 ml HNO_3/2.5 ml H_2O_2. Argon (99.95 %) was the main, auxiliary, and nebulizer gas. The nebulizer and auxiliary gas flow rates were 0.70 and 0.20 L/min (Kılıç Altun et al., 2017). The results are given as ppm or ppb.

2.4. Extraction of free and bound phenolics from samples

Free phenolic compounds (FPCs) and bound phenolic compounds (BPCs) were extracted from ground grain and bulgur samples according to the method previously described by Shamanin et al. (2022).

2.5. Determination of phenolic content in free and bound fractions

The Folin-Ciocalteu method was modified to determine the concentrations of free and bound phenolic compounds (Singleton & Rossi, 1965). To summarize, 2 N Folin-Ciocalteu reagent (500 μL), 200 g/L Na_2CO_3 solution (1.5 ml), and distilled water (7.9 ml) were combined with 100 μL of methanol extract and kept in the dark for 120 min. Then, it was centrifuged for 5 min at 2000 *xg*, and the optical density was determined at 760 nm using a spectrophotometer (Shimadzu 150 UV-1800, Kyoto, Japan). The phenolic contents were reported as gallic acid equivalent (GAE). The total phenolic content was estimated from the sum of free and bound phenolic compounds.

2.6. Determination of antioxidant capacity (DPPH and ABTS methods)

The antioxidant capacity was determined as described by Singh et al. (2002) with the DPPH radical scavenging activity method. 4.9 ml of fresh 1,1-diphenyl-2-picrylhydrazil (DPPH) solution was added to 100 μL of the ground grain or bulgur extract. The absorbance value of the solution was measured at 515 nm by a Shimadzu 150 UV-1800 spectrophotometer (Kyoto, Japan) following the incubation at 30 °C for 60 min. The ABTS radical cation scavenging capacity of the wheat extracts was performed to the method described by Arnao et al. (1996) with some modifications. Two ml of ABTS solution were added to 100 μL of extract and incubated at 30 °C for 6 min. After incubation, the absorbance of the solution was measured at 734 nm by a spectrophotometer (Shimadzu 150 UV-1800, Kyoto, Japan). The results are reported as mg Trolox equivalent /100 g dry basis (db).

2.7. The cooking properties of the bulgur samples

The cooking properties determined on the bulgur samples were cooking time, weight and volume increase during cooking, and total organic matter analysis. The cooking process was carried out on a sand bath in order to supply consistent cooking conditions. For the determination of cooking time, 100 ml of water and 10 g of bulgur sample were used in the cooking process. After 4 min from the beginning of the cooking process, a few particles of bulgur were taken and compressed between two glass plates. The sampling of bulgur during cooking was continued with an interval of 30 s until there was no hard/opaque uncooked part in the center of the bulgur particles (Basman et al., 2006).

Weight and volume increase during cooking was determined as described below. Ten g of bulgur samples were cooked with 100 ml of boiling water. After cooking, the samples were drained on filter paper for about 5 min to remove excess water. The cooked, drained bulgur sample was weighed to find the cooked bulgur weight (G_2). By subtracting the uncooked bulgur weight (G_1) from this value, the weight gain after cooking was calculated and the % water absorption value was calculated with Eq. (1).

$$\text{Water absorption (\%)} = 100 \times (G_2\text{-}G_1) / G_1 \quad (1)$$

To determine the volume increase, 10 g of bulgur was placed into a measuring cylinder containing a certain amount of distilled water. The increase in water volume is the dry bulgur volume (V_1). The same procedures were repeated for cooked and drained bulgur. The increase in water level is the volume of cooked bulgur (V_2). The % volume increase was calculated according to Eq. (2).

$$\text{Volume increase (\%)} = 100 \times (V_2\text{-}V_1) / V_1 \quad (2)$$

Determination of total organic matter (TOM) was applied to cooked bulgur according to the method suggested for spaghetti by D'egidio et al. (1982) and Basman et al. (2006). Ten g of bulgur were cooked in 100 ml of unsalted tap water (according to the cooking time for each bulgur sample). At the end of this period, the cooked bulgur samples were drained through a strainer and, after resting for 5 min, they were placed in a 500 ml measuring cylinder containing 100 ml of water and kept for 12 min. It was mixed every 4 min. At the end of the period, 5 ml of the thoroughly mixed washing water was taken, transferred to a 600 ml beaker and evaporated at 80 °C for 2 h. After the evaporation, the sample was wetted with 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$), and then 20 ml of 96 % sulfuric acid was added in a fume hood, after stirring for 1 min, it was left for 30 min for the reaction. Then the mixture was diluted with the addition of 200 ml of water, 1 ml of 0.5 % diphenylamine solution was added and the excess potassium dichromate was titrated with 0.5 N $Fe(NH_4)_2(SO_4)_2$. At the titration endpoint, the color changes from purple-violet to green. The result is given as the gram amount of starch transferred from the 100 g sample to the washing water of cooked bulgur.

2.8. Texture profile of bulgur samples

Texture profile analysis (TPA) values of cooked bulgur samples were measured by using Texture Analyzer (TA.XT2 Plus, Stable Micro System Ltd., Surrey, UK) according to the method published by Yılmaz and Koca (2020) with slight modifications. The bulgur samples were cooked according to their optimum cooking times and 25 g of the cooked sample was placed in a metal ring (diameter: 80 mm and height: 50 mm) in the middle of the testing platform of the equipment to have a standard shape for all samples. The sample which is given a cylindrical shape with the metal ring underwent a two-cycle compression process. Speeds were adjusted to 1 mm/s for the pre-test and post-test phases. For both cycles, the samples were compressed to 4 mm using a 36 mm P/36 flat cylindrical probe (Stable Micro Systems Ltd., Surrey, UK). The time between compressions was 5 s. The trigger force was adjusted to 5 g. The texture profile parameters analyzed were hardness, adhesiveness, springiness, cohesiveness, chewiness, and resilience values.

2.9. In vitro glycemic index value of bulgur samples

The cooked bulgur samples were digested according to the method of Aribas et al. (2020) with slight modifications. For this purpose, 100 mg of the sample was weighed into 50 ml tubes containing 10 glass beads (5 mm diameter). Two mL of HCl (0.05 M) containing pepsin (5 mg/mL, Sigma, P7000) were added to the tubes and the tubes were incubated at 37 °C in a shaking water bath for 30 min. Sodium acetate buffer (4 ml, 0.5 M, pH 5.2), 1 ml of enzyme solution containing 0.104 g pancreatin (Sigma, P7545), and 14.45 U amyloglucosidase (3300 U/mL, Megazyme Int., Ireland) were added to each tube. The tubes were incubated horizontally at 37 °C in a shaking water bath. Aliquots (100 μL) were taken into Eppendorf tubes at 0- and 90-min and mixed with 1 ml of absolute ethanol. These solutions were centrifuged at 800 x*g* for 10 min, and glucose content was measured with glucose oxidase–peroxidase (GOPOD) reagent (Megazyme Int., Ireland) by using a spectrophotometer (Shimadzu 1601, Japan) at 510 nm wavelength. The hydrolysis index measures the rate at which starch is digested, and the predicted glycemic index (EFSA Panel on Dietetic Products & Allergies, 2011) compares the sample's digestibility to that of white bread. The hydrolysis index is the ratio of the sample's area under the hydrolysis curve to that of white bread used as the reference sample. The *in vitro* GI was determined by using the following equation (Eq. (3)) of Goñi et al. (1997).

$$GI = 39.71 + (0.549 \times HI) \quad (3)$$

2.10. Statistical analysis

All experiments were carried out in triplicate, and the data were reported as the mean ± standard deviation. Statistical analysis was performed with SPSS Statistics Software (IBM version 20, USA). One-

way ANOVA was used to determine the difference and Tukey's post hoc test was applied for comparisons of the means between the groups. Differences were considered significant if $p < 0.05$.

3. Results and discussions

3.1. Chemical analysis of wheat, barley, and bulgur samples

The protein, ash, and β-glucan contents of the barley and wheat samples are given in Table 1. The protein contents of Chifaa, Yalin, and Kiziltan were 10.75 %, 13.62 %, and 9.44 %, while their ash contents were 2.06, 1.64, and 1.43, respectively. The β-glucan contents of Chifaa, Yalin, and Kiziltan grain samples were 6.95 %, 4.13 %, and 0.69 % on a dry basis. Erkan et al. (2006) reported that hull-less barley flour had the highest β-glucan content (4.25 %) and two hulled barley flours had lower β-glucan contents (2.80 % and 3.38 %) among the barleys used in their study. According to Aaman and Graham (1987), the β-glucan concentration of barley ranges between 2 % and 10 %. Yalçın et al. (2007) reported that hull-less barley β-glucan contents were also significantly affected by genotype and environmental factors.

Bulgur was produced from the high β-glucan hull-less barley cultivar Chifaa and its properties were compared with the bulgurs produced from a hull-less barley cultivar Yalin and a durum wheat cultivar Kiziltan. Chifaa, Yalin, and Kiziltan bulgur samples were produced with the yields of 95.3 %, 96.1 %, and 93.7 %, respectively. The ash contents of the bulgur samples (Chifaa, Yalin, and Kiziltan) were 1.76, 1.58, and 1.33 %. The ash content is a measure of mineral content in cereals and cereal products, so high ash content is an important indicator for mineral content. The ash content of Chifaa bulgur was the highest among the samples. The protein contents of the bulgur samples prepared from Chifaa, Yalin, and Kiziltan were 10.55 %, 13.40 %, and 9.03 %, respectively (Table 1). Protein content of Chifaa bulgur was between the bulgurs of other barley and durum wheat samples. It is an important parameter in terms of nutrition and differences in protein content may result from cultivar differences, genetic structures, environmental conditions and growing season.

The β-glucan contents of the bulgur samples prepared from Chifaa, Yalin, and Kiziltan were 7.03 %, 5.08 %, and 0.56 % on a dry basis. β-glucan contents of the bulgur samples prepared from Chifaa and Yalin increased as compared to the respective barley grain samples. Most of the β-glucan is located in the endosperm cell walls of barley grain. Therefore, the slight removal of bran during bulgur processing might have caused some increase in the β-glucan content of the barley bulgur samples compared to the respective barley samples. Similar small increases were also observed in β-glucan contents of the bulgur samples prepared from hulled barley samples. It was previously reported that the levels of β-glucan were significantly higher in bulgur (between 4.83 and 5.30 % for atmospheric pressure-cooked bulgur and between 4.80 and 5.32 % for pressure-cooked bulgur) than in raw barley (between 4.28 and 4.99 %) for three hulled barley cultivars (Köksel et al., 1999). They concluded that bulgur processing had a significantly increasing effect on the β-glucan level. These findings also indicate that the processing stages of bulgur production such as cooking and drying did not seem to have a deteriorative effect on β-glucans.

The average serving of cooked bulgur is 120 g per portion (Tucci et al., 2021). Based on the cooking analysis results in the present study the following β-glucan values can be calculated for bulgurs investigated: 3.28 ± 0.14 % β-glucan of Chifaa bulgur, 1.85 ± 0.02 % β-glucan of Yalin bulgur, and 0.33 ± 0.03 % β-glucan of Kiziltan bulgur. To bear the health claim related to β-glucans, foods should provide at least 3 g/day of β-glucans in one or more servings (EFSA Panel on Dietetic Products & Allergies, 2011). Hence, the results indicated that it is possible to provide more than 3 g of β-glucans per serving of cooked barley bulgur (pilav) produced from the high β-glucan hull-less barley which is the limit to bear the health claim for barley-containing food.

Table 1
The chemical properties of wheat, barley, and bulgur samples.

Sample	Protein (%)	Ash (%)	Beta-glucan (% dw)
Chifaa (barley)	10.75 ± 0.27^{b}	2.06 ± 0.06^{a}	6.95 ± 0.01^{a}
Yalin (barley)	13.62 ± 0.40^{a}	1.64 ± 0.03^{b}	4.13 ± 0.01^{b}
Kiziltan (durum wheat)	9.44 ± 0.09^{b}	1.43 ± 0.06^{b}	0.69 ± 0.03^{c}
Chifaa bulgur	10.55 ± 0.13^{B}	1.76 ± 0.03^{A}	7.03 ± 0.04^{A}
Yalin bulgur	13.40 ± 0.14^{A}	1.58 ± 0.05^{A}	5.08 ± 0.08^{B}
Kiziltan bulgur	9.03 ± 0.21^{C}	1.33 ± 0.02^{B}	0.56 ± 0.02^{C}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c, A-C) are significantly different ($p < 0.05$). Bulgur samples (A-C) and grain samples (barley and wheat; a-c) were evaluated separately.

3.2. Color properties of wheat, barley, and bulgur samples

In bulgur, bright yellow and homogeneous colors are important factors affecting consumers' preferences (Balcı and Bayram, 2017). The color of raw material significantly impacts the color of finished bulgur which is also influenced by bulgur manufacturing processes such as cooking, drying, debranning, and grinding (Yılmaz & Koca, 2020). Color parameters of the ground and unground wheat, barley, and bulgur samples are presented in Table 2.

For ground Chifaa, Yalin, and Kiziltan grain samples, the L* values were 91.56, 92.14, and 86.25, while their a* values were 0.80, 0.86, and 1.32, and the b* values were 8.68, 8.41 and 15.65, respectively. The L* values of the ground barley samples were higher than that of ground durum wheat sample. As expected, the yellowness (b*) values of the ground barley and ground barley bulgur samples were lower than those of corresponding ground durum wheat and ground durum bulgur sample, respectively. There was no significant difference between the L* values of the ground Chifaa bulgur (84.45) and the ground Kiziltan bulgur (84.07) sample.

As in pasta products, color of bulgur in the unground form (measured without grinding) is an important criterion for consumer acceptance in the market. The L* values of unground barley bulgur samples were lower than that of unground durum bulgur sample. As expected, the yellowness (b*) values of the unground barley (19.36 and 20.80) and the unground barley bulgur (18.87 and 17.15 for Chifaa and Yalin) samples were lower than those of the unground durum wheat (21.70) and the unground durum bulgur (24.03) sample, respectively. The results also indicated that grinding drastically affected the color parameters of the barley, wheat and bulgur samples. Bulgur is generally produced from

Table 2
Color parameters of wheat, barley, and bulgur samples.

Sample	L*	a*	b*
Ground samples			
Chifaa (barley)	91.56 ± 0.23^{a}	0.80 ± 0.01^{b}	8.68 ± 0.23^{b}
Yalin (barley)	92.14 ± 0.49^{a}	0.86 ± 0.02^{b}	8.41 ± 0.25^{b}
Kiziltan (durum wheat)	86.25 ± 0.18^{b}	1.32 ± 0.07^{a}	15.65 ± 0.24^{a}
Chifaa bulgur	84.45 ± 0.16^{AB}	$1.66 \pm 0.0.06^{A}$	13.99 ± 0.25^{B}
Yalin bulgur	84.64 ± 0.23^{A}	1.79 ± 0.07^{A}	12.94 ± 0.14^{C}
Kiziltan bulgur	84.07 ± 0.10^{B}	0.87 ± 0.04^{B}	17.43 ± 0.16^{A}
Unground samples			
Chifaa (barley)	55.77 ± 0.37^{a}	7.17 ± 0.06^{a}	19.36 ± 0.04^{b}
Yalin (barley)	56.46 ± 0.09^{a}	6.71 ± 0.22^{a}	20.80 ± 1.36^{ab}
Kiziltan (durum wheat)	53.45 ± 1.59^{b}	7.42 ± 0.73^{a}	21.70 ± 0.59^{a}
Chifaa bulgur	51.49 ± 0.86^{C}	5.76 ± 0.23^{A}	18.87 ± 0.30^{B}
Yalin bulgur	53.73 ± 0.48^{B}	5.20 ± 0.37^{B}	17.15 ± 0.44^{C}
Kiziltan bulgur	55.10 ± 0.33^{A}	5.81 ± 0.18^{A}	24.03 ± 0.58^{A}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c, A-C) are significantly different ($p < 0.05$). Bulgur samples (A-C) and grain samples (barley and wheat; a-c) were evaluated separately.

durum wheat and preferred by the bulgur production industry. Yellowness is an important parameter. There are some differences in the brightness and yellowness values as the Chifaa and Kiziltan bulgur samples are compared. The L* and b* values of Chifaa bulgur were lower than Kiziltan bulgur. However, the consumers who are aware of the benefits of beta-glucan consumption might possibly ignore the color differences of barley and durum wheat bulgurs to some extent.

As the color values (L*, a*, and b*) of the wheat and barley grain samples are compared with the bulgurs obtained from them, there were no substantial differences between the color values of the bulgur samples and respective raw materials. Maillard reaction that may occur during the uncontrolled drying stage during the bulgur production processes may cause some bulgur samples to have higher a* values (Asselman et al., 2007). As it can be observed in Table 2, there is no increase in a* values. This is probably due to the mild temperature (50 ± 2 °C) applied during drying.

3.3. Mineral content of grain and bulgur samples

The mineral composition of the three grains and their bulgurs are given in Table 3. Mineral content levels in grains are influenced by genotype, environment, and soil. Furthermore, the bran fraction contains a higher concentration of most mineral components. The manufacturing procedure of bulgur also has an impact on its composition (Ertop & Atasoy, 2019).

Chifaa barley grain had the highest amount of Mg, and K among the three genotypes in accordance with its highest ash value (Table 3). A similar trend was observed in the bulgur sample of Chifaa. The amount of Ca was the same (109 ppm) in the Chifaa and Yalın barleys and higher than in Kiziltan (84 ppm). The highest amounts of Cu and Zn were quantified in Yalin barley while the Kiziltan wheat had the highest level of Mn and Se.

Among the bulgur samples, Ca, Cu, Zn, and Se were the highest in Yalin barley bulgur. Mn was the only mineral that was the highest in Kiziltan bulgur. Bulgur samples generally contain a lower content of total mineral elements suggesting that the bulgur processing stages such as cooking (leaching out to water) and debranning might cause the mineral losses. However, there were no major differences in barley grains and corresponding bulgurs in terms of some minerals while others were lower in bulgur samples. Köksel et al. (1999) stated that cooking at atmospheric pressure led to the preservation of most of the mineral elements in barley bulgur samples. In the present study, a slight debranning step may be the reason for a lower amount of some mineral elements in bulgurs since the bran and germ contain the majority of the mineral components in the kernel.

Singh and Dodda (1979) reported that some minerals (Ca, Cu, Mn, Zn, K, Mg) were higher in Triticale bulgur compared to Triticale grain. In the present study, some minerals were higher in some of the bulgur samples compared to the respective grain. This might be due to the mineral content of the tap water used in bulgur cooking. Noteworthy Chifaa bulgur was richer in terms of Mg, K, and Fe when compared to other bulgur samples.

3.4. Change in the free, bound phenolic content and antioxidant capacity of samples

Phenolic contents and antioxidant capacity values were identified and quantified as free and bound forms and are given in Table 4. The free and bound phenolics of the Chifaa and the Yalin barley samples were significantly higher than those of the Kiziltan wheat sample. Fogarasi et al. (2015) reported that barley samples had high amounts of total phenolics, and antioxidant activity compared with wheat, and einkorn samples. Madhujith and Shahidi (2009) reported that the free phenolic content of barley cultivars ranged from 0.18 to 0.42 mg of ferulic acid equivalents, while insoluble-bound phenolic content ranged from 2.03 to 3.36 mg of ferulic acid equivalents. Their results on bound phenolics of barley samples were found to be similar to the present study. Besides this, the amounts of bound phenolics in all samples were higher than the amounts of free phenolics (Table 4). Bound phenolic contents of the barley and wheat samples ranged from 212.27 to 239.57 mg GAE/ 100 g db (dry basis) while bound phenolic contents of the bulgur samples ranged from 202.69 to 235.71 mg GAE/ 100 g db. It was reported in the literature that most phenolic compounds in cereal-based matrices are in insoluble bound forms. In addition, phenolics in the insoluble bound forms are covalently bound to cell wall structural components such as cellulose, hemicellulose, lignin, and rod-shaped structural protein (Acosta-Estrada et al., 2014; Wong, 2006). A number of studies indicated that the phenolics of various cereals and cereal products like wheat, barley, and bulgur show similar composition (Adom & Liu, 2002; Giambanelli et al., 2020; Liyana-Pathirana & Shahidi, 2006; Özkaya et al., 2018; Pekkirişci et al., 2023).

Total phenolics in the high β-glucan barley (Chifaa) and durum wheat were found as 476.34 mg GAE/100 g db and 423.17 mg GAE/100 g db, respectively (Table 4). For all samples, the amounts of TPC are reduced after bulgur production. The losses in TPC during bulgur production were found to be around 9 % and 6 % in the Chifaa and Kiziltan samples, respectively. Pekkirişci et al. (2023) reported that the average free, bound, and total phenolic contents of einkorn bulgur samples were determined as 200.00, 332.60, and 532.71 mg GAE/100 g db, respectively. On the other hand, Rasheed et al. (2023) investigated the bulgur

Table 4
Free and bound phenolic contents of the grain and bulgur samples.

	Phenolic Content (mg GAE/100 g db)		
	Free	**Bound**	**Total***
Chifaa barley	236.77 ± 2.33^{a}	239.57 ± 3.26^{a}	476.34 ± 1.32^{a}
Yalin barley	235.99 ± 1.17^{a}	238.80 ± 0.70^{a}	474.80 ± 0.66^{a}
Kiziltan (durum wheat)	210.89 ± 2.76^{b}	212.27 ± 0.92^{b}	423.17 ± 5.20^{b}
Chifaa bulgur	213.94 ± 0.47^{A}	214.88 ± 0.47^{B}	428.82 ± 0.15^{B}
Yalin bulgur	214.69 ± 1.18^{A}	235.71 ± 0.70^{A}	450.39 ± 0.67^{A}
Kiziltan bulgur	194.12 ± 0.46^{B}	202.69 ± 1.16^{C}	396.80 ± 0.98^{C}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c, A-C) are significantly different ($p < 0.05$).
Bulgur samples (A-C) and grain samples (barley and wheat; a-c) were evaluated separately.

Table 3
Mineral composition of wheat and bulgur samples.

	Na (ppm)	Mg (ppm)	K (ppm)	Ca (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Se (ppb)
Chifaa (barley)	57.2 ± 4.2^{a}	1463 ± 89^{a}	7000 ± 200^{a}	109 ± 3.0^{a}	22.0 ± 0.7^{b}	56.3 ± 0.9^{a}	5.52 ± 0.16^{b}	27.4 ± 0.8^{b}	17.4 ± 0.8^{c}
Yalin (barley)	47.5 ± 3.5^{b}	1180 ± 72^{ab}	5300 ± 200^{b}	109 ± 3.0^{a}	22.4 ± 0.7^{b}	50.6 ± 0.8^{b}	6.23 ± 0.18^{a}	31.1 ± 0.9^{a}	27.5 ± 1.3^{b}
Kiziltan (durum wheat)	23.3 ± 1.7^{c}	1083 ± 66^{ab}	5000 ± 200^{b}	84 ± 2.3^{b}	33.9 ± 1.1^{a}	31.4 ± 0.5^{c}	5.08 ± 0.14^{c}	27.7 ± 0.8^{b}	28.7 ± 1.4^{a}
Chifaa bulgur	63.8 ± 4.6^{A}	1251 ± 76^{A}	6100 ± 200^{A}	102 ± 3.1^{B}	18.7 ± 0.6^{C}	61.8 ± 1.2^{A}	5.69 ± 0.16^{B}	25.9 ± 0.7^{B}	17.5 ± 0.8^{C}
Yalin bulgur	39.9 ± 2.9^{B}	1148 ± 70^{AB}	4900 ± 200^{B}	112 ± 3.0^{A}	22.1 ± 0.7^{B}	57.9 ± 0.9^{B}	7.30 ± 0.21^{A}	29.3 ± 0.8^{A}	21.3 ± 1.0^{A}
Kiziltan bulgur	27.5 ± 2.0^{C}	1016 ± 62^{B}	5200 ± 200^{B}	82 ± 2.3^{C}	27.0 ± 0.9^{A}	28.7 ± 0.4^{C}	5.15 ± 0.15^{C}	19.7 ± 0.6^{C}	18.3 ± 0.9^{B}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c, A-C) are significantly different ($p < 0.05$). Bulgur samples (A-C) and grain samples (barley and wheat; a-c) were evaluated separately.

production with three different wheat varieties using traditional and autoclave cooking methods, and it was reported that the highest TPC was found in the bulgur produced from one of these varieties (Dilkash-2020) produced by the autoclave method.

Due to the complex structures of grain samples, their antioxidant capacity values were evaluated using two or more different methods. Therefore, in the present study, two antioxidant capacity estimation methods were used. DPPH radical scavenging capacity and ABTS radical cation scavenging capacity values of the free and bound fractions from the barley and wheat cultivars and their bulgurs are listed in Table 5. DPPH radical scavenging capacity of free fractions in the wheat and barley samples ranged from 88.66 to 322.16 mg TE/100 g db, while ABTS radical cation scavenging capacity of free fractions ranged from 174.69 to 252.84 mg TE/100 g db. Madhujith and Shahidi (2009) reported that the DPPH radical scavenging capacity of free phenolic fraction in barley cultivars ranged from 1.76 to 2.56 μmol ferulic acid equivalents/g. The bound antioxidant capacity in Chifaa and Yalin barley samples showed a stronger DPPH value (399.64 and 342.28 mg TE/100 g db, respectively) compared to the free antioxidant capacity. Similar results were reported by Li et al. (2019). The results of the DPPH and ABTS analyses showed similarities, as expected, the antioxidant capacities of the barley and wheat samples were higher than the respective bulgur samples. The results are in line with the study by Yilmaz and Koca (2017) which was carried out on einkorn and durum bulgurs. The same authors also reported that treatments like soaking, cooking, drying, grinding, and debranning are important factors affecting the phenolic acid content of the end product. Free, bound and total antioxidant capacities of Kiziltan (durum) bulgur were found to be lower than those of Yalin and Chifaa bulgur samples (Table 5). The total DPPH and ABTS values of Chifaa, Yalin, and Kiziltan bulgurs were 560.15, 637.80, and 123.35 mg TE/100 g db and 472.47, 383.70, and 311.01 mg TE/100 g db, respectively. Baumgartner et al. (2023) reported that free, bound, and total antioxidant activity (DPPH) of bulgur bran ranged from 145 to 149 μmol TE/ 100 g, 274–284 μmol TE/ 100 g to 419–431 μmol TE/ 100 g, respectively, while Pekkirişci et al. (2023) reported that the total antioxidant activity (DPPH) of einkorn and firik bulgurs were found as 33.57 and 49.68 mg TE/100 g db, respectively. Chifaa and Yalin (barley) bulgur samples may be considered a potential dietary source of natural antioxidants with significantly higher antioxidant activity compared to Kiziltan (durum) bulgur.

Table 5
Antioxidant capacities of the grain and bulgur samples.

	DPPH			ABTS		
	Free	Bound	Total*	Free	Bound	Total*
Chifaa barley	294.08 ± 3.84^{b}	399.64 ± 7.80^{a}	693.72 ± 2.36^{a}	252.84 ± 5.56^{a}	265.03 ± 2.47^{a}	517.86 ± 4.37^{a}
Yalin barley	322.16 ± 2.21^{a}	342.28 ± 1.17^{b}	664.44 ± 4.29^{a}	216.56 ± 0.50^{b}	251.10 ± 3.72^{a}	467.67 ± 5.97^{b}
Kiziltan (durum wheat)	88.66 ± 5.46^{c}	117.05 ± 5.40^{c}	205.72 ± 13.10^{b}	174.69 ± 0.97^{c}	205.40 ± 0.49^{b}	380.10 ± 2.07^{c}
Chifaa bulgur	252.62 ± 5.79^{B}	307.53 ± 8.16^{B}	560.15 ± 0.04^{B}	234.21 ± 2.98^{A}	238.26 ± 4.35^{A}	472.47 ± 0.1.93^{A}
Yalin bulgur	302.93 ± 2.22^{A}	334.87 ± 4.32^{A}	637.80 ± 7.46^{A}	179.45 ± 1.75^{B}	204.45 ± 11.25^{AB}	383.70 ± 18.38^{B}
Kiziltan bulgur	51.38 ± 0.81^{C}	71.96 ± 4.98^{C}	123.35 ± 6.13^{C}	143.22 ± 4.91^{C}	167.79 ± 0.98^{B}	311.01 ± 0.5.56^{C}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c, A-C) are significantly different ($p < 0.05$).
Bulgur samples (A-C) and grain samples (barley and wheat; a-c) were evaluated separately.
DPPH 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity, ABTS 2,2′-azino-bis (3-ethylbenzothiazoline6- sulphonic acid).
* The sum of free and bound antioxidant capacities expressed as mg TE/ 100 g db.

3.5. Cooking properties

The cooking properties (cooking time, weight and volume increase values during cooking, and total organic matter analysis) of the bulgur samples are given in Table 6. The cooking times of the Kiziltan, Yalin and Chifaa bulgur samples were determined as 6.0, 6.5, and 9.5 min, respectively. Relatively, shorter cooking times and higher-water absorption capacity are the desired cooking characteristics for bulgur, but cooking times are also affected by the particle size and composition of the bulgur sample. In different studies with durum bulgur and einkorn bulgur, the optimum cooking time of durum bulgur (14.22 min) was found to be twice as compared to einkorn bulgur samples (6.44 min). The water absorption capacity and weight increase of durum bulgur was reported as significantly higher than those of einkorn samples (Hendek Ertop, 2019; Yılmaz & Koca, 2020). It was stated that these differences were entirely due to the grain structure and particle size. In our study, weight increase ranged from 129.39 to 169.01, while volume increase ranged from 124.7 to 166.3. The highest volume increase observed in the bulgur sample prepared from Chifaa might be related to its longer cooking time as compared to the others.

Total organic matter (TOM) analysis is widely used in the evaluation of pasta quality, but it is also applied for the assessment of bulgur quality (Özboy and Köksel, 2002). Lower TOM values of the bulgur indicate better quality. The TOM values of the bulgur samples were in the range of 1.14 and 1.48 (g/100 g). TOM values indicate < 1.4 good; 1.4–2.1 medium; > 2.1 poor pasta quality (D'egidio et al., 1982). According to this assessment, both of the barley bulgur samples were of good quality. The durum wheat bulgur prepared from cv. Kiziltan had a TOM value of 1.48 g starch/100 g, hence it can be classified as medium quality. The TOM values of the barley bulgurs prepared from Chifaa and Yalin were 11 % (1.31 g/100 g) and 23 % (1.14 g/100 g) lower than the TOM value of the durum wheat bulgur (1.48 g/100 g). Köksel et al. (2003), reported the average TOM values of the bulgurs prepared from durum wheat, bread wheat, and triticale as 2.2 g/100 g, 3.7 g/100 g, and 2.5 g/100 g, respectively.

The bulgur sample prepared from Chifaa had a longer cooking time (9.5 min) and the longer cooking time is expected to cause disintegration on the outside of the bulgur particles during cooking, resulting in higher levels of starch diffusing to the surface of bulgur particles. This is likely to have an increasing effect on TOM values. However, this was not the case for the bulgur sample prepared from Chifaa which had a lower TOM value than that of Kiziltan bulgur. This is a great advantage for the preparation of high β-glucan bulgur with good cooking properties.

3.6. Texture profiles of bulgur samples

The hardness, adhesiveness, springiness, cohesiveness, chewiness, and resilience values of the bulgur samples are given in Table 7. Hardness is defined as the force necessary to compress the food between the teeth or between the tongue and the mouth to cause deformation.

Table 6
Cooking properties of the bulgur samples.

Sample	Cooking Time (min)	Weight Increase (%)	Volume Increase (%)	TOM (g/100 g)
Chifaa bulgur (barley)	9.5 ± 0.5^{a}	162.1 ± 2.45^{a}	166.3 ± 6.15^{a}	1.31 ± 0.06^{ab}
Yalin bulgur (barley)	6.5 ± 0.5^{b}	169.0 ± 3.48^{a}	163.2 ± 5.03^{a}	1.14 ± 0.10^{b}
Kiziltan bulgur (durum wheat)	6.0 ± 0.9^{b}	129.4 ± 6.51^{b}	124.8 ± 5.20^{b}	1.48 ± 0.11^{a}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c) are significantly different ($p < 0.05$).

Table 7
The textural properties of bulgur samples.

Sample	Hardness (gram)	Adhesiveness	Springiness	Cohesiveness	Chewiness	Resilience
Chifaa bulgur (barley)	608.1 ± 13.60^{b}	−2.62 ± 0.05^{b}	0.36 ± 0.04^{c}	0.22 ± 0.03^{c}	150.6 ± 3.66^{b}	0.21 ± 0.02^{b}
Yalin bulgur (barley)	720.0 ± 17.17^{a}	−4.31 ± 0.56^{c}	0.64 ± 0.04^{b}	0.33 ± 0.03^{b}	164.6 ± 9.11^{a}	0.23 ± 0.02^{ab}
Kiziltan bulgur (durum wheat)	314.2 ± 11.65^{c}	−1.56 ± 0.12^{a}	0.87 ± 0.03^{a}	0.48 ± 0.01^{a}	134.1 ± 8.59^{c}	0.25 ± 0.01^{a}

Data are expressed as mean ± standard deviation, mean values in each column with different letters (a–c) are significantly different ($p < 0.05$).

Neither very low nor very high hardness is preferred for bulgur (Yılmaz & Koca, 2020). When the hardness values of the bulgur samples were compared, the Yalin bulgur was harder (720.0 g) than both Chifaa (608.1 g) and Kiziltan (314.2 g) bulgur samples, and the hardness values of the barley bulgur samples were found significantly higher than Kiziltan (durum wheat) bulgur ($p < 0.05$). The results indicated that hull-less barleys gave harder cooked bulgur samples compared to durum wheat bulgur, but further work is necessary to confirm these results with a larger number of samples. Adhesiveness was defined as a negative force to pull the probe from the sample. High adhesiveness is a sensorial and visual problem for consumers. The adhesiveness values of the bulgur samples varied between − 4.31 and − 1.56 and barley (Yalin and Chifaa) bulgurs resulted in higher adhesiveness than the durum wheat (Kiziltan) bulgur. Pekkirişci et al. (2023) reported similar but slightly higher adhesiveness values for the firik and einkorn bulgur samples as compared to the ones obtained in the present study. The ratio of the time (distance) spent between the second and first compression operations during texture analysis is used to determine the springiness value, which is defined as the elasticity of the samples. Cohesiveness may be described as the expression of tensile strength and may be seen as a tendency to interact with the probe and to remain as a whole (Yılmaz & Koca, 2020). There were statistically significant differences in terms of both the springiness and cohesiveness values of the bulgur samples. While the highest springiness and cohesiveness values were determined in Kiziltan (durum wheat) bulgur, the lowest values were observed in Chifaa (barley) bulgur.

Chewiness may be described as the energy needed to chew samples and derived by multiplying hardness, cohesiveness, and springiness values. Chewiness values were higher in both of the barley bulgur samples (Chifaa and Yalin) in comparison to Kiziltan (durum wheat) bulgur (Table 7). The Kiziltan bulgur sample may be recognized as more chewable than the other bulgur samples since the lower chewiness value indicates easier chewing ability. Furthermore, the hardness of the Kiziltan bulgur was found to be lower than the other bulgur samples ($p < 0.05$). It might be concluded that lower hardness would improve the chewability of the bulgur samples. Yilmaz (2020) reported that traditional cooked + hot air-dried and microwave-cooked hot air-dried emmer bulgur (*Triticum turgidum* ssp. *dicoccum*) samples had the lowest chewiness value among bulgur samples. Resilience is defined as the amount of energy required to apply a force to a material without causing it to rupture, with or without residual strain, up to a certain proportionality limit. Compared to the Kiziltan bulgur the resilience value of Chifaa bulgur was lower, whereas no significant difference was observed between Chifaa and Yalin bulgur samples ($p < 0.05$).

3.7. Estimated GI and HI of bulgur samples

The hydrolysis index and glycemic index GI values of the cooked bulgur samples are shown in Table 8. Foods are classified as low (GI ≤ 55), medium (GI 56–69), and high (GI ≥ 70) glycemic index foods (Kumar et al. 2018). The results indicated that the differences between the cooked bulgur samples in terms of glycemic index were statistically significant ($p < 0.05$). The HI values ranged from 30.13 to 63.55. Chifaa (barley) bulgur had the lowest HI and GI values. According to the GI classification, while the GI of Kiziltan (durum wheat) bulgur was high, the GI values of both Chifaa and Yalin (barley) bulgurs were medium. In fact, GI of Chifaa (56.25) is very close to the limit value of low GI foods (56) and can be considered as low GI food. The GI values of the barley bulgurs (Chifaa: 56.25; Yalin: 66.90) were lower than that of durum wheat (Kiziltan: 74.60) bulgur (Table 8). Furthermore, among barley bulgurs Chifaa had higher β-glucan and lower GI values than those of Yalin. Hence, there might be a GI-lowering effect of barley due to its β-glucan content. Chillo et al. (2011) reported that durum wheat semolina was enriched with β-glucan concentrate (BGC) containing 25 % β-glucan to produce spaghetti and the GI of spaghetti decreased from 64 to 29 by 10 % BGC addition. Besides this, the GI of cookies produced with hull-less barley (Deng et al., 2020) and biscuits (Martínez-Subirà et al., 2020) produced with hull-less barley supplementation decreased compared to the one produced with wheat flour.

Table 8
in vitro GI values of bulgur samples.

Sample	HI	*in vitro* GI
Chifaa bulgur (barley)	30.13 ± 1.88^{c}	56.25 ± 1.03^{c}
Yalin bulgur (barley)	49.52 ± 1.63^{b}	66.90 ± 0.90^{b}
Kiziltan bulgur (durum wheat)	63.55 ± 3.40^{a}	74.60 ± 1.87^{a}

HI: hydrolysis index, GI: glycemic index, $^{a\text{-}c}$ Means with different letters within each column are significantly different ($p < 0.05$).
GI ≤ 55: low, GI 56–69: medium, and GI ≥ 70: high glycemic index foods.

A considerable part of β-glucan is water-soluble and it is present in rather high concentrations in barley (Goudar et al., 2020). Soluble fibers may decrease starch digestion rate by altering the microstructure of food products. Furthermore, the water absorption of non-starch polysaccharides such as β-glucan restricts the water availability for starch gelatinization, thus decreasing starch hydrolysis by α-amylase. β-glucan lowers glycemic response by increasing the viscosity of food. Gastric-emptying rate, transition time, and absorption of nutrients are inversely associated with food viscosity (Regand et al., 2011).

Pasta generally has a lower GI than bread (Augustin et al., 2013; Jenkins et al., 1981). There might be a similar trend in bulgur due to its processing technology which includes boiling and drying. In a study by Candal et al. (2020), the GI values of brown rice bulgur produced with boiling and steaming processes were found as 65.83 and 59.37, respectively. Further studies are needed to confirm the GI-lowering effect of β-glucan in barley bulgur.

4. Conclusion

It is highly desirable to acquire correct diet habits such as the Med-Diet which includes considerable amount of cereal-based foods besides vegetables and fruits. MEDWHEALTH project, funded by PRIMA, aims at re-designing a selection of staple Med-Foods improving their healthiness using innovative raw materials including durum wheat, barley, and lentils. Cereal-based foods such as bulgur have a significant part in the diet of certain Mediterranean countries. Hence, improving its health constituents will be an advantage for the people following the Med-Diet.

The main novelty of the study was to improve the health benefits of bulgur, using a high β-glucan hull-less barley (cv. Chifaa) as a raw material and compare its physical, chemical, technological, and nutritional properties with the bulgurs produced from a regular hull-less barley and durum wheat. Although, the bulgur sample prepared from cv. Chifaa had a longer cooking time, it had a lower TOM value (1.31 g/100 g) than that of the durum bulgur. This is a great advantage for the preparation of

high β-glucan bulgur with good cooking properties. The GI of durum wheat bulgur was high, while the GI values of barley bulgurs were medium. Furthermore, the GI of Chifaa (56.25) was very close to the limit value of low GI foods (56). The lower GI values of the barley bulgurs might be attributed to their higher β-glucan contents. It can be concluded that high β-glucan hull-less barley can be successfully used as a raw material in the production of bulgur with improved health benefits as well as comparable or better technological properties. The present study also indicated that it is possible to provide at least 3 g of β-glucans per serving of cooked barley bulgur (i.e., pilav) produced from the high β-glucan hull-less barley. This is the limit level to bear the health claim related to the nutritional benefits of a barley-containing foods.

CRediT authorship contribution statement

Zeynep Hazal Tekin-Cakmak: . **Cagla Ozer:** Writing – review & editing, Writing – original draft, Data curation. **Kubra Ozkan:** Writing – review & editing, Writing – original draft, Supervision, Data curation. **Halide Yildirim:** Writing – review & editing, Writing – original draft. **Francesco Sestili:** . **Abderrazek Jilal:** . **Osman Sagdic:** . **Muhammet Ozgolet:** Writing – review & editing, Writing – original draft. **Hamit Koksel:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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