



A functional barley-based fermented soup (tarhana) with high β -glucan content

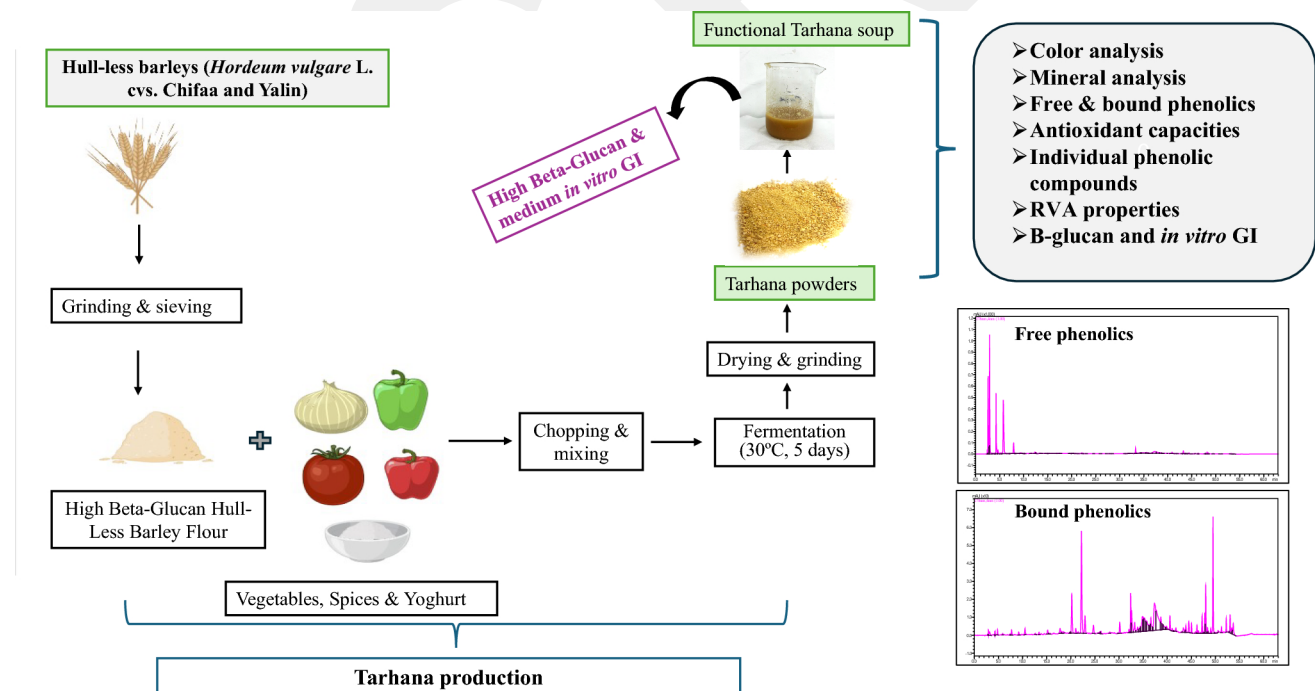
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Abstract

This study investigates the impact of using different flours, including high β -glucan barley, on the nutritional properties of tarhana. Mineral composition, phenolic content, and antioxidant capacity of tarhana powder samples produced using flours of high β -glucan hull-less barley (cv. Chifaa; ChF), hull-less barley cv. Yalin (YF), bread wheat cv. Tosunbey (white flour: TWF₁ and whole wheat flour: TWF₂). Furthermore, *in vitro* glycemic index (GI), pasting properties, and RVA soup index of their soups were investigated. Tarhana made with Chifaa barley flour (Tar-ChF) exhibited significantly higher levels of key minerals (K, Mg, Ca), β -glucan and total phenolic content compared to those made with other flours (Tar YF, Tar TWF₁, and Tar TWF₂). Barley tarhana samples also showed greater antioxidant activity of bound phenolic fractions and lower GI values, indicating a healthier profile. The study highlights the potential of high β -glucan barley flour to enhance tarhana's nutritional benefits without significantly affecting its sensory properties, such as color and viscosity. This research supports the integration of health-promoting ingredients like barley flour into traditional Mediterranean foods to improve their nutritional quality.

Graphical abstract



Keywords Tarhana · β -glucan · Hull-less barley · Glycemic index · RVA soup index



Introduction

Although barley is an important part of the diet in North Africa and the Middle East, it has been barely used in the diets in other regions of the world. Barley is mainly used for animal feeding, however, its utilization in food applications has been gaining popularity in recent years [1]. Mixed-linkage β -glucan ((1-3) (1-4)- β -D-glucan) is usually categorized as a soluble dietary fiber and is a constituent of grains such as oats, and barley and is also found in specific yeasts. Oats and barley contain a greater quantity of β -glucans in comparison to other cereal grains [2]. β -glucans are reported to have anti-inflammatory, immunomodulatory, and antioxidant activities and the ability to recuperate the functionality of the immune, gastrointestinal, and cardiovascular systems [3–9]. β -glucan is not only beneficial for health but also has been used in foods for its functional effects as a thickener, texture enhancer, stabilizer, and fat replacer [10]. β -glucan has found its place in official health claims related to cardiovascular functions and health support. “Food and Drug Administration and European Food Safety Authority” have declared that consuming 3 g/day of β -glucan has favorable effects on health [11, 12]. The health benefits of β -glucans led to the utilization of barley in pasta and bread, but its deteriorative effects on baking and pasta quality hindered its widespread adoption. Barley is suggested to be incorporated into yogurt, soup, beverages, muffins, porridge, cookies, and extruded cereals [13] it is also used in bulgur production [14, 15].

Tarhana is a fermented food manufactured traditionally using a mixture of yeast, cereal flour(s), yogurt, various vegetables, and seasonings. These ingredients are homogeneously blended, left for fermentation for up to 7 days, dried, and ground [16]. Tarhana soup is a common component of the diet in Asia, the Middle East, and various regions of Europe. It is stored in powder form and used in soup preparation as needed. “Lactic acid fermentation” is the principal step in the production of this remarkably nourishing food. It is an important source of protein, B-group vitamins, and minerals (i.e. calcium, iron, magnesium, potassium, zinc, and copper). Therefore, also included in the diets of people of all ages, from infants to elder individuals [17]. Although flour, one of the main components of tarhana formulation, lacks certain essential amino acids, especially lysine, yogurt, the other basic component, is rich in these essential amino acids. The combination of these two ingredients makes tarhana a good quality protein source. Tarhana fermentation also increases the amount of B-group vitamins such as riboflavin, thiamine, and niacin [18–20]. Besides these, acetic acid released during tarhana fermentation improves blood glucose regulation by slowing down gastric emptying [21].

Phenolic compounds have antioxidant properties and influence sensory properties (e.g., flavor, aroma astringency, and color) of numerous plant food products. Degirmencioğlu et al. [22] reported that 3-hydroxy-4-methoxy cinnamic acid (9.6 mg/g) and kaempferol (23.6 mg/g) were the most prevalent phenolic acid and flavonol constituents in tarhana samples among seventeen phenolic standards. Kilci and Gocmen [23] conducted a study wherein they observed that the incorporation of tarhana samples with oat flour caused higher phenolic acid content. The authors concluded that vanillic and ferulic acids were the most common phenolic acids, with gallic acid ranking third.

Different findings regarding the glycemic index of tarhana varieties can be found in the literature. The glycemic index of tarhana samples was reported as 59.0–69.4 by Koseoglu and Celikel [24]. In another study, where white bread was referenced as 100, the glycemic index of tarhana varieties was observed as 53 (low, <55). These variations were attributed to differences in tarhana recipes [25].

The purpose of the MEDWHEALTH project is to redesign some of the common Med-Foods and intensify their healthy features using pioneering raw materials [15]. On the other hand, this particular research was more narrowly focused. The aims of the current study were to prepare a tarhana soup with a high β -glucan content and a comparatively lower GI. The properties of tarhana produced using a barley cultivar with high β -glucan were compared to the ones produced using bread wheat and another hull-less barley. Bread wheat flour is commonly used in tarhana production. Hence bread wheat tarhana can be considered as the standard sample. A comparison was made between the chemical, physical, technological, and nutritional characteristics of the tarhana samples produced using hull-less barley cultivars and a bread wheat cultivar.

Material and methods

Materials

Two hull-less barley samples (*Hordeum vulgare* L., cvs. Chifaa and Yalin) and a bread wheat (*Triticum aestivum* L. cv. Tosunbey) were selected for the study. The barley samples, cvs. Chifaa and Yalin were produced in 2021–2022, in Marchouch, Morocco, and Ankara (Turkey), respectively. The bread wheat sample was also produced in 2021–2022 in Ankara (Turkey). The bread wheat (cv. Tosunbey) and the barley (cv. Yalin) were provided by Field Crops Central Research Institute (Ankara, Turkey).

Barley grain samples (Chifaa and Yalin) were ground using a hammer mill to get whole meal barley flours (ChF, YF). The bread wheat sample was milled to obtain

straight-grade flour (without bran, TWF₁) and bran using a Pneumatic Laboratory Mill (Buhler MLU 202, Uzvil, Sweden) using the AACCI Method 26-70.01 [26]. Then a laboratory mill (Perten 3100, Stockholm, Sweden) fitted with a 500 µm sieve was used to grind the fine and coarse brans which were mixed homogenously with the respective flour at the ratio determined during milling to get whole wheat flour (TWF₂). Tomato paste, onion, red and green peppers, yogurt, dry red pepper powder, salt, and fresh baker's yeast used in formulation were bought from regional markets in İstanbul (Turkey). The whole supply of solvents and reagents was obtained from Sigma-Aldrich (St. Louis, MO, USA). The β-glucan and Glucose Assay Kits were purchased from Megazyme International (Wicklow, Ireland).

Methods

Tarhana preparation

Tarhana samples were produced according to Erkan et al. [27] with slight modifications given by Koxsel et al. [28]. Table S1 lists the amounts of the materials needed for tarhana production. Fresh peppers (green and red) and dry onions were cut into small pieces using a food processor (Raks-MR 1001, İstanbul, Turkey) to produce tarhana samples. After adding tomato paste, salt, and powdered dry red pepper, all of the ingredients were blended to obtain a uniform mixture. Yogurt, yeast, and flour samples (YF, ChF, TWF₁, and TWF₂) were added and thoroughly mixed. After that, the mixture was put into covered containers and left for fermentation for five days at 30 °C. Following the fermentation, the tarhana was dried in an air oven (at 40 °C), before grinding and sieving through a 150 µm screen. The resulting product is a tarhana soup base, in powder form, to be used in tarhana soup preparation.

Analyses of tarhana powders

The moisture and β-glucan contents of the tarhana powder samples were determined as described in AACCI Standard Methods No: 44-15A and 32-23.01, respectively [29]. Color values (L*, a*, b*) of the samples were determined utilizing a colorimeter (Konica Minolta CR-400, Tokyo, Japan) in accordance with the CIE L*a*b* color space. Ca, Fe, K, Mg, and Mn contents were determined according to Cankurtaran et al. [30] and Koxsel et al. [28]. Phenolic contents and individual phenolic compounds of tarhana samples were determined using the method of Singleton et al. [31] with some modifications as stated by Koxsel et al. [28]. The DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis (3-ethylbenzothiazoline 6- sulphonic acid) radical scavenging capacity values of the extracts were

measured as described by Singh et al. [32] and Re et al. [33], respectively.

Tarhana soup preparation

Tarhana soup was prepared to determine the glycemic index of tarhana samples by mixing tarhana powder (6 g, dry basis) with water (100 mL, 25 °C) and stirring for 1.5 min to get a homogeneous soup which was gently cooked for 15 min with continuous stirring [28].

Analyses of tarhana soups

Glucose Assay Kit (Megazyme Int., Wicklow, Ireland) was used for the determination of in vitro glycemic index (GI) values of tarhana samples after cooking following the protocols established by Goni et al. [34] and Tekin-Cakmak et al. [15]. RVA (Rapid Visco-Analyzer 4, Perten Inst., Stockholm, Sweden) was used to determine the pasting properties of tarhana samples according to AACCI Standard Method No: 76-21.01 [29]. The RVA Soup Index Method was employed to determine the “RVA soup index” [28].

Statistical analysis

The data are reported as the mean standard deviation, which represents the average of duplicate or triplicate analyses as indicated at the bottom of the tables. Tukey's post-hoc analysis was used to compare the groups, and one-way ANOVA was performed to assess the significant differences ($p < 0.05$) (SPSS Statistics Software, IBM version 20, USA).

Results and discussion

Tarhana analysis

Mineral compositions of the tarhana powder samples are given in Table 1. Utilization of barley and bread wheat flours in the tarhana preparation led to significant differences in mineral contents of the tarhana powder samples, depending on the grain flours utilized in the formulation of tarhana ($p < 0.05$). The Mg, K, Fe, and Ca contents of the tarhana powders were in the range of 500.4–1415 µg/g, 3710–8577 µg/g, 35.00–68.45 µg/g, and 1507–3326 µg/g, respectively. K, Ca, and Mg levels of the tarhana powder produced from Chifaa barley flour (Tar-ChF) were significantly greater than the ones produced using Yalin barley flour (Tar-YF), Tosunbey white flour (Tar-TWF₁), and Tosunbey whole wheat flour (Tar-TWF₂) except the Mg content of Tar-YF. Tar-ChF had a higher Mg content than Tar-YF but the difference was not significant. Ozdemir et

Table 1 Mineral and β -glucan contents, and color values of tarhana powders
Data are expressed as mean \pm SD of triplicate measurements. Different letters (a–d) on the same row are significantly different ($p < 0.05$) among tarhana powders
Tar-YF tarhana produced using Yalin (barley) flour, *Tar-ChF* tarhana produced using Chifaa (barley) flour, *Tar-TWF₁* tarhana produced using Tosunbey white flour, *Tar-TWF₂* tarhana produced using Tosunbey whole wheat flour

	Tar-YF	Tar-ChF	Tar-TWF ₁	Tar-TWF ₂
<i>Minerals ($\mu\text{g/g}$)</i>				
K	6566 \pm 140 ^b	8577 \pm 183 ^a	3710 \pm 79 ^c	5827 \pm 124 ^b
Mg	1298 \pm 24 ^{ab}	1415 \pm 26 ^a	500.4 \pm 9.2 ^c	1177 \pm 72 ^b
Ca	1957 \pm 53 ^b	3326 \pm 91 ^a	1507 \pm 41 ^c	1882 \pm 51 ^b
Mn	20.80 \pm 0.57 ^b	16.89 \pm 0.46 ^c	9.11 \pm 0.25 ^d	36.27 \pm 0.99 ^a
Fe	56.74 \pm 2.72 ^a	68.45 \pm 3.29 ^a	35.00 \pm 1.68 ^b	59.41 \pm 2.85 ^a
Cu	4.12 \pm 0.12 ^a	3.40 \pm 0.11 ^b	2.19 \pm 0.06 ^c	3.94 \pm 0.11 ^{ab}
Zn	23.68 \pm 0.67 ^a	21.14 \pm 0.60 ^b	10.41 \pm 0.30 ^c	19.96 \pm 0.57 ^b
<i>β-glucan (%)</i>				
	2.20 \pm 0.02 ^b	3.70 \pm 0.16 ^a	0.19 \pm 0.002 ^c	0.20 \pm 0.003 ^c
<i>Color</i>				
L*	83.14 \pm 0.38 ^a	80.93 \pm 0.32 ^b	74.90 \pm 0.09 ^c	75.69 \pm 0.54 ^c
a*	5.71 \pm 0.06 ^a	5.93 \pm 0.14 ^a	6.26 \pm 0.25 ^a	6.19 \pm 0.15 ^a
b*	19.67 \pm 0.04 ^b	21.33 \pm 0.18 ^a	20.72 \pm 0.18 ^{ab}	21.12 \pm 0.26 ^a

al. [18] have shown that tarhana had high K, Mg, and Ca contents. Çalışkan Koç et al. [35] also reported that Ca, Zn, K, Fe, and Cu were abundant in the gluten-free tarhana samples. The mineral content (K, Mg, Fe, and Zn) results of the current study are consistent with those obtained by Daglioglu [36]. In a study by Tekin-Cakmak et al. [15], the K and Mg contents of the Chifaa barley grain were highest compared to another barley and a durum wheat grain. A similar trend was observed in the K (8577 $\mu\text{g/g}$) and Mg (1415 $\mu\text{g/g}$) contents of Tar-ChF. The sample having the lowest Fe content (35.00 $\mu\text{g/g}$) was Tar-TWF₁, whereas Chifaa tarhana had the highest Fe content (68.45 $\mu\text{g/g}$). The tarhana samples contained varying concentrations of Cu and Zn, ranging from 2.19 to 4.12 $\mu\text{g/g}$ and 10.41 to 23.68 $\mu\text{g/g}$, respectively. Tar-YF contained the maximum amounts of Cu and Zn, followed by Tar-ChF. Tar-TWF₂ had the highest level of Mn (36.27 $\mu\text{g/g}$). As also stated in a previous study by Koksel et al. [28] the amount of selenium (Se) of the samples was below the detection limit. The tarhana samples, especially the ones from barley flour, can be regarded as an important source of Mn, Mg, Ca, Zn, K, and Cu.

β -glucan levels of the tarhana samples are given in Table 1. Tekin-Cakmak et al. [15] stated that β -glucan contents of Yalin and Chifaa flours were 4.13% and 6.95%, respectively. Tosunbey white flour and Tosunbey whole wheat flour had β -glucan concentrations of 0.350% and 0.356%, respectively, which were fairly low as expected. Hull-less barley is an important source of non-starch polysaccharides, especially β -glucans, and pentosans [37]. Growing environment, genotype, and milling method were shown to have considerable effects on β -glucan contents of hull-less barleys [38]. This study was focused on increasing the β -glucan level of tarhana powders using the flour from the specific sample of hull-less barley (cv. Chifaa) with high β -glucan content. The use of various cereal flours in the tarhana preparation caused significantly different β -glucan contents ($p < 0.05$). The β -glucan contents of

tarhana powders produced from ChF, YF, TWF₁, and TWF₂ were 3.70, 2.20, 0.19, and 0.20%, respectively. Hence, the β -glucan levels of tarhana powders produced using barley whole meals, Tosunbey white flour, and whole wheat flour were in line with the respective whole meal and flour samples. It was reported by Erkan et al. [27] that the β -glucan content of hull-less barley tarhana (3.55%) was in between the ones produced in the present study using cv. Yalin and cv. Chifaa.

The tarhana powders produced from YF, ChF, TWF₁, and TWF₂ had moisture contents in the range of 7.37–9.50%. In another study, tarhana samples ranged in moisture content from 7.6 to 9.0% [27]. The findings of previous tarhana studies indicate that the drying process and the characteristics of the materials employed in the formulation are the main factors affecting the variations in the moisture content [39]. Moisture values of the samples in the present study were less than 10%, which is in line with the tarhana moisture values found in the study by Aktas et al. [40].

The L* values were 83.14, 80.93, 74.90, and 75.69 for Tar-YF, Tar-ChF, Tar-TWF₁ and Tar-TWF₂, respectively (Table 1). The a* (redness) and b* (yellowness) values were in the range of 5.71–6.26 and 19.67–21.33 respectively. There was no significant difference among the redness value (a*) of the samples ($p > 0.05$). The barley tarhana samples had significantly higher L* values, in other words had brighter color, than the wheat tarhana samples ($p < 0.05$). The difference in the redness scores of the tarhana samples was not significant. The results demonstrated that, while significant differences were observed in their color values, incorporating barley flour in the tarhana recipe did not significantly degrade the color values of the tarhana samples. Tekin-Cakmak et al. [15] stated that the L* values of Chifaa and Yalin in the ground form were determined as 91.56 and 92.14 respectively. These samples possessed a* values of 0.80 and 0.86, while the corresponding b* values were 8.68 and 8.41, respectively. Erkan et al. [27] stated that L*, a*,

and b^* values of the wheat tarhana sample were 75.06, 6.46, and 20.12 while L^* , a^* , and b^* values of the hull-less barley tarhana sample were 75.58, 3.57, and 16.97. It was stated that the a^* and b^* values of the wheat tarhana samples were greater in comparison to the other samples of tarhana. Yalcin et al. [16] studied the gluten-free tarhana prepared with rice and corn flour and stated that the L^* values of wheat, rice, and corn tarhana were 79.98, 82.15, and 82.22, respectively. They also stated that the b^* value of the corn tarhana sample was the highest among the tarhana samples tested due to the yellow color of corn flour.

Tar-YF, Tar-ChF, Tar-TWF₁, and Tar-TWF₂ had free phenolic contents of 345.84, 353.02, 221.05, and 337.92 mg GAE (Gallic acid equivalent)/100 g dw, respectively, and their bound phenolics were in the range of 424.83–534.99 mg GAE/100 g dw (Table 2). The greater part of grain phenolics are in insoluble form and they are covalently linked to lignin, cellulose, hemicellulose, and structural proteins [41, 42]. It has been previously reported that the phenolic contents of different cereals and their derivatives, such as bulgur, wheat, and barley, were comparable [43–45]. In the present study, the free and bound phenolic contents of the barley tarhana samples were higher than those of the wheat tarhana samples. This can be attributed to the different phenolic contents of the flours used since all other ingredients were the same in the tarhana formulation except the flours. Tekin-Cakmak et al. [15] also found that barley cv. Chifaa and cv. Yalin had much more free and bound phenolics than the wheat used in their study.

The sums of free and bounds phenolics (total phenolic contents) of Tar-YF, Tar-ChF, Tar-TWF₁, and Tar-TWF₂ were 860.97, 888.01, 645.88, and 767.59 mg GAE/100 g dw. Kötten [46] reported that the TPC (total phenolic content) of the wheat tarhana samples was <250 mg GAE/100 g, which was much lower than the ones in the current study. In the study by Isik and Yapar [47], it was found that tarhana samples exhibited higher TPC and antioxidant activity values with an increase in the tomato seed addition ratio. The phenolic-rich tomatoes, peppers, and spices in tarhana are the main ingredients contributing to its overall phenolic content. The variations noted in comparison to other tarhana samples documented in the literature could conceivably be due to the changes in tarhana formulation.

The current study employed two different techniques for estimating antioxidant capacity due to the complex structure of grain samples. The DPPH radical scavenging capacity values of tarhana powders in the free fractions were in the range of 28.10–63.76 mg TE (Trolox equivalent)/100 g dw, whereas the ABTS scavenging capacity values were between 48.02 and 219.79 mg TE/100 g dw (Table 2). Antioxidant capacity (DPPH and ABTS) values for the bound fraction of tarhana powders varied between

Table 2 Free and bound phenolic content and antioxidant capacities of tarhana powders

	TPC (mg GAE/100 g dw)		DPPH (mg TE/100 g dw)		ABTS (mg TE/100 g dw)		Total*
	Free	Bound	Free	Bound	Free	Bound	
Tar-YF	345.84 ± 5.76 ^{ab}	515.14 ± 1.98 ^b	860.97 ± 7.74 ^b	55.89 ± 0.73 ^b	118.32 ± 2.52 ^b	176.34 ± 4.37 ^b	174.20 ± 1.80 ^b
Tar-ChF	353.02 ± 2.44 ^a	534.99 ± 2.44 ^a	888.01 ± 4.89 ^a	63.76 ± 1.20 ^a	137.80 ± 0.72 ^a	219.79 ± 3.24 ^a	201.56 ± 0.48 ^a
Tar-TWF ₁	221.05 ± 3.14 ^c	424.83 ± 3.48 ^c	645.88 ± 6.62 ^d	28.10 ± 1.03 ^d	73.00 ± 1.28 ^d	48.02 ± 0.74 ^c	101.10 ± 2.31 ^d
Tar-TWF ₂	337.92 ± 2.31 ^b	429.67 ± 0.99 ^c	767.59 ± 3.29 ^c	35.82 ± 0.49 ^c	88.03 ± 1.94 ^c	52.49 ± 0.76 ^c	123.85 ± 2.43 ^c

Data are expressed as mean ± SD of duplicate measurements. Mean values in each column with different letters (a–d) are significantly different ($p < 0.05$)

TPC Total phenolic contents, DPPH 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity, ABTS 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) Tar-YF tarhana produced using Yalin (barley) flour, Tar-ChF tarhana produced using Chifaa (barley) flour, Tar-TWF₁ tarhana produced using Tosunbey white flour, Tar-TWF₂ tarhana produced using Tosunbey whole wheat flour

73.00 and 137.80 mg TE/100 g dw and 62.81 to 239.64 mg TE/100 g dw, respectively. In comparison to the free antioxidant capacity, the bound antioxidant capacity values in the Tar-ChF and Tar-YF samples displayed higher DPPH and ABTS values. Çalışkan -Koc and Özçira [48] reported that the DPPH value of the wheat flour tarhana sample was 3122.89 $\mu\text{mol TE/kg dw}$.

Individual phenolic compound contents of tarhana samples

Table 3 displays the individual phenolic compounds found in barley and wheat tarhana samples. The major phenolic compound of free fractions was gallic acid in all of the tarhana samples, however, for the bound fractions, ferulic acid was the major phenolic acid. In the case of the free fraction, gallic acid levels varied between 7.09 and 51.41 mg/100 g while the ferulic acid content ranged from 5.01 to 21.84 mg/100 g. The ferulic acid levels in the bound fractions varied between 24.65 and 262.29 mg/100 g, with the tarhana sample produced from TWF₂ showing the greatest ferulic acid value. The ferulic acid levels in bound phenolic fractions were greater than in the free fractions for all tarhana samples. The findings may be attributed to the association of ferulic acid with the cell wall components of the grain [49]. In addition, the ferulic acid levels in tarhana samples prepared from both barley flours were higher compared to those from white wheat flour. Previous studies have shown that ferulic acid levels were the main phenolic components in the bound phenolic fraction of barley samples [49, 50]. The findings suggested that substituting barley flour for wheat flour in tarhana formulation is likely to increase the ferulic acid concentration.

The gallic acid levels varied significantly between barley and wheat tarhana samples ($p < 0.05$). The tarhana samples containing barley flour exhibited a greater total phenolic material concentration compared to the samples containing wheat flour. The samples produced using barley flour also exhibited higher levels of gallic acid compared to those produced using wheat flour. Gallic acid possesses several functional properties, such as anti-diabetes, anti-bacterial, anti-tumor, anti-microbial, anti-obesity, and antioxidant activities [4]. It was also reported in a previous study that tarhana samples had high levels of ferulic acid and gallic acid [23].

Tarhana samples were found to contain considerable quantities of the phenolic compound “protocatechuic acid”. There was a significant variation in the protocatechuic acid levels of the samples ($p < 0.05$). The Tar-YF sample had the highest amount of protocatechuic acid, whereas the Tar-TWF₁ sample had the lowest concentration of protocatechuic acid. The tarhana samples produced with barley flours

yielded significantly higher concentrations of total protocatechuic acid ($p < 0.05$), similar to the gallic acid levels. The levels of catechin exhibited significant variability among the samples ($p < 0.05$). While the Tar-YF sample exhibited the lowest concentration of catechin, the Tar-ChF sample prepared using Chifaa barley flour demonstrated the highest concentration of catechin. These findings demonstrate that substituting wheat with barley in the tarhana formulation might significantly increase phenolic contents in addition to the higher levels of β -glucan. This study highlighted that barley flour could serve as a beneficial substitute for wheat flour to produce tarhana with relatively higher levels of bioactive compounds.

Tarhana soup analyses

The L* values were in the range of 48.85 to 61.90, for the tarhana soups samples (Table 4). The a* values of the Tar-YF, Tar-ChF, Tar-TWF₁, and Tar-TWF₂ soup samples were -1.80 , 1.10 , -0.47 , and 1.25 , respectively, and their b* values were in the range of 17.28–22.99. Although the utilization of barley and wheat flours influenced the color values of the tarhana soup samples, the differences between L* and b* values of the soups prepared using Chifaa and Tosunbey white wheat flour tarhana powders were not significant indicating that the tarhana soup prepared from high β -glucan barley (Chifaa) was comparable to the common tarhana soup in terms of these values.

The pH values of the tarhana soup samples were between 4.29 and 4.70 (Table 4). The total lactic acid bacteria count in tarhana is high due to the utilization of yogurt in the formulation indicating that the product has a higher lactic acid content [51]. The pH is lowered by the lactic acid and also by other organic acids formed during the fermentation process, and most of the water is removed by drying after the fermentation process. Tarhana samples have a prolonged shelf life due to their low moisture content ($< 10\%$) and the bacteriostatic activity of organic acids produced during fermentation, which inhibits the growth of putrefactive bacteria [18].

HI values were determined as 50.92, 44.16, 84.46, and 59.52 while in vitro GI values were 67.66, 63.95, 86.08, and 72.39 for the soups prepared with Tar-YF, Tar-ChF, Tar-TWF₁, and Tar-TWF₂ tarhana powder samples, respectively (Table 4). The GI classification method categorized barley tarhana samples as medium (GI: 55–69) and wheat flour tarhana samples as high GI (> 70). Simsek et al. [52] found that the GI of 15 tarhana samples varied between 86.2 and 102.5.

The barley tarhana samples had lower glycemic index values than those of the wheat tarhana samples. This is probably caused by the GI-lowering effect of β -glucan

Table 3 Phenolic compound contents of tarhana powders (mg/100 g dw)

	Free	Bound	Total
<i>Ferulic acid</i>			
Tar-YF	15.08 ± 0.02 ^b	144.26 ± 0.04 ^b	159.34 ± 0.05 ^b
Tar-ChF	12.51 ± 0.02 ^b	57.70 ± 0.02 ^c	70.71 ± 0.03 ^c
Tar-TWF ₁	5.01 ± 0.01 ^c	24.65 ± 0.01 ^d	29.66 ± 0.01 ^d
Tar-TWF ₂	21.84 ± 0.02 ^a	262.29 ± 0.04 ^a	284.13 ± 0.05 ^a
<i>Gallic acid</i>			
Tar-YF	51.41 ± 2.25 ^a	nd	51.41 ± 2.25 ^a
Tar-ChF	50.16 ± 0.70 ^a	1.05 ± 0.02 ^a	51.22 ± 0.71 ^a
Tar-TWF ₁	7.69 ± 0.10 ^b	nd	7.69 ± 0.10 ^b
Tar-TWF ₂	7.09 ± 0.04 ^b	1.03 ± 0.02 ^a	8.11 ± 0.03 ^b
<i>Protocatechuic acid</i>			
Tar-YF	4.13 ± 0.04 ^a	nd	4.13 ± 0.04 ^a
Tar-ChF	1.49 ± 0.05 ^b	0.94 ± 0.01 ^a	2.43 ± 0.06 ^b
Tar-TWF ₁	0.24 ± 0.02 ^c	nd	0.24 ± 0.02 ^d
Tar-TWF ₂	1.46 ± 0.04 ^b	nd	1.46 ± 0.04 ^c
<i>Catechin</i>			
Tar-YF	0.66 ± 0.04 ^d	nd	0.66 ± 0.04 ^d
Tar-ChF	6.45 ± 0.06 ^a	0.23 ± 0.02 ^a	6.69 ± 0.05 ^a
Tar-TWF ₁	1.11 ± 0.08 ^c	nd	1.11 ± 0.08 ^c
Tar-TWF ₂	1.77 ± 0.01 ^b	nd	1.77 ± 0.01 ^b
<i>p-hydroxybenzoic acid</i>			
Tar-YF	nd	nd	nd
Tar-ChF	0.43 ± 0.02 ^a	nd	0.43 ± 0.02 ^a
Tar-TWF ₁	0.16 ± 0.01 ^b	nd	0.16 ± 0.01 ^c
Tar-TWF ₂	0.14 ± 0.01 ^b	0.19 ± 0.02 ^a	0.33 ± 0.02 ^b
<i>Ellagic acid</i>			
Tar-YF	0.94 ± 0.09 ^b	1.04 ± 0.03 ^c	1.97 ± 0.08 ^b
Tar-ChF	1.11 ± 0.03 ^a	1.68 ± 0.05 ^a	2.79 ± 0.08 ^a
Tar-TWF ₁	0.17 ± 0.01 ^d	1.13 ± 0.02 ^b	1.30 ± 0.03 ^d
Tar-TWF ₂	0.59 ± 0.06 ^c	0.90 ± 0.02 ^d	1.49 ± 0.07 ^c
<i>m-coumaric acid</i>			
Tar-YF	nd	1.12 ± 0.02 ^a	1.12 ± 0.02 ^a
Tar-ChF	nd	0.32 ± 0.01 ^c	0.32 ± 0.01 ^c
Tar-TWF ₁	nd	nd	nd
Tar-TWF ₂	nd	0.97 ± 0.01 ^b	0.97 ± 0.01 ^b
<i>Chrysin</i>			
Tar-YF	0.12 ± 0.01 ^a	0.11 ± 0.01 ^b	0.24 ± 0.01 ^b
Tar-ChF	nd	1.74 ± 0.03 ^a	1.74 ± 0.03 ^a
Tar-TWF ₁	nd	nd	nd
Tar-TWF ₂	0.12 ± 0.01 ^a	nd	0.12 ± 0.01 ^c
<i>Caffeic acid</i>			
Tar-YF	0.47 ± 0.03 ^b	0.61 ± 0.03 ^a	1.09 ± 0.04 ^a
Tar-ChF	0.45 ± 0.01 ^b	0.57 ± 0.01 ^a	1.02 ± 0.01 ^a
Tar-TWF ₁	0.54 ± 0.06 ^a	nd	0.54 ± 0.06 ^b
Tar-TWF ₂	0.51 ± 0.02 ^a	0.58 ± 0.01 ^a	1.09 ± 0.02 ^a
<i>p-coumaric acid</i>			
Tar-YF	nd	0.39 ± 0.01 ^a	0.39 ± 0.01 ^a
Tar-ChF	nd	nd	nd
Tar-TWF ₁	nd	nd	nd
Tar-TWF ₂	nd	0.10 ± 0.01 ^b	0.10 ± 0.01 ^b
<i>Myricetin</i>			
Tar-YF	nd	4.71 ± 0.12 ^a	4.71 ± 0.12 ^b
Tar-ChF	3.73 ± 0.10 ^{ab}	4.71 ± 0.04 ^a	8.44 ± 0.14 ^a

Table 3 (continued)

	Free	Bound	Total
Tar-TWF ₁	3.98 ± 0.11 ^a	nd	3.98 ± 0.11 ^c
Tar-TWF ₂	3.67 ± 0.11 ^b	4.76 ± 0.12 ^a	8.43 ± 0.11 ^a
<i>Quercetin</i>			
Tar-YF	1.99 ± 0.13 ^a	2.30 ± 0.01 ^a	4.29 ± 0.13 ^a
Tar-ChF	1.85 ± 0.01 ^a	2.31 ± 0.03 ^a	4.15 ± 0.03 ^a
Tar-TWF ₁	1.98 ± 0.01 ^a	2.36 ± 0.01 ^a	4.34 ± 0.02 ^a
Tar-TWF ₂	1.85 ± 0.04 ^a	2.37 ± 0.08 ^a	4.22 ± 0.13 ^a
<i>Kaempferol</i>			
Tar-YF	1.06 ± 0.11 ^a	0.88 ± 0.01 ^a	1.93 ± 0.11 ^a
Tar-ChF	0.78 ± 0.01 ^{ab}	0.88 ± 0.02 ^a	1.66 ± 0.01 ^b
Tar-TWF ₁	0.80 ± 0.05 ^{ab}	0.89 ± 0.03 ^a	1.69 ± 0.03 ^b
Tar-TWF ₂	0.72 ± 0.01 ^b	0.89 ± 0.01 ^a	1.61 ± 0.02 ^b
<i>Chlorogenic acid</i>			
Tar-YF	0.12 ± 0.01 ^b	0.14 ± 0.01 ^a	0.26 ± 0.01 ^b
Tar-ChF	0.20 ± 0.02 ^a	0.19 ± 0.01 ^a	0.39 ± 0.02 ^a
Tar-TWF ₁	0.23 ± 0.01 ^a	nd	0.23 ± 0.01 ^b
Tar-TWF ₂	0.10 ± 0.01 ^b	0.13 ± 0.01 ^a	0.23 ± 0.01 ^b
<i>Rutin</i>			
Tar-YF	nd	2.03 ± 0.01 ^a	2.03 ± 0.01 ^a
Tar-ChF	0.20 ± 0.04 ^b	1.92 ± 0.02 ^b	2.12 ± 0.05 ^a
Tar-TWF ₁	0.32 ± 0.01 ^a	0.19 ± 0.01 ^c	0.51 ± 0.01 ^b
Tar-TWF ₂	0.33 ± 0.01 ^a	0.10 ± 0.01 ^c	0.43 ± 0.01 ^b
<i>Sinapic acid</i>			
Tar-YF	nd	nd	nd
Tar-ChF	nd	0.28 ± 0.02 ^a	0.28 ± 0.02 ^a
Tar-TWF ₁	nd	0.11 ± 0.01 ^b	0.11 ± 0.01 ^b
Tar-TWF ₂	nd	0.10 ± 0.01 ^b	0.10 ± 0.01 ^b

Data are expressed as mean ± SD of triplicate measurements. Different letters (a–d) on the same column for each phenolic fraction are significantly different ($p < 0.05$) among tarhana powders

nd not determined. *Tar-YF* tarhana produced using Yalin (barley) flour, *Tar-ChF* tarhana produced using Chifaa (barley) flour, *Tar-TWF₁* tarhana produced using Tosunbey white flour, *Tar-TWF₂* tarhana produced using Tosunbey whole wheat flour

Table 4 Color, pH values, hydrolysis index (HI), and in vitro glycemic index (GI) of tarhana soup samples

	pH	Color			HI	GI
		L*	a*	b*		
Tar-YF	4.29 ± 0.01 ^c	61.90 ± 1.12 ^a	− 1.80 ± 0.07 ^c	17.28 ± 0.72 ^b	50.92 ± 0.27 ^c	67.66 ± 0.15 ^c
Tar-ChF	4.70 ± 0.02 ^a	56.41 ± 1.75 ^b	1.10 ± 0.08 ^a	22.99 ± 0.75 ^a	44.16 ± 1.85 ^d	63.95 ± 1.02 ^d
Tar-TWF ₁	4.66 ± 0.00 ^{ab}	55.11 ± 0.38 ^b	− 0.47 ± 0.12 ^b	22.67 ± 0.22 ^a	84.46 ± 1.98 ^a	86.08 ± 1.09 ^a
Tar-TWF ₂	4.50 ± 0.06 ^b	48.85 ± 0.85 ^c	1.25 ± 0.20 ^a	21.72 ± 0.16 ^a	59.52 ± 1.71 ^b	72.39 ± 0.94 ^b

Data are expressed as mean ± SD of triplicate measurements. Different letters (a–d) on the same column are significantly different ($p < 0.05$) among tarhana powders

Tar-YF tarhana produced using Yalin (barley) flour, *Tar-ChF* tarhana produced using Chifaa (barley) flour, *Tar-TWF₁* tarhana produced using Tosunbey white flour, *Tar-TWF₂* tarhana produced using Tosunbey whole wheat flour

which is also supported by the literature. Cavallero et al. [53] reported a linear decrease in GI with increasing levels of β -glucan in bread and there are various studies supporting this relationship [54–56]. The level of β -glucan was much higher in the barley flour than in wheat flour. Furthermore, among barley tarhana samples, Tar-ChF had lower GI values and higher β -glucan than those of Tar-YF. This provides

additional evidence that the β -glucan content in barley has a reducing effect on the GI.

Viscosity is a key parameter in soup quality evaluation. Tarhana samples produced using hull-less barley cultivars (Chifaa and Yalin) exhibited lower viscosity than the samples produced using wheat flours, and Tosunbey white wheat flour tarhana had the highest viscosity values. The lower peak, trough, and final viscosity values of barley tarhana

samples as determined by RVA (Table 5) might be attributed to changes during fermentation, endogenous enzyme activity on barley flours, or interactions between them.

Although, tarhana soup contains several ingredients, gelatinized starch is the main constituent of tarhana soup affecting its viscosity. The barley samples, especially Chifaa had much higher β -glucan content than the wheat samples [15]. This is also reflected in the β -glucan contents of barley and wheat tarhana samples. Higher β -glucan levels are expected to have a lowering effect on the starch content of tarhana, this might have a little negative effect on soup viscosity. On the other hand, β -glucans, in their native form, are also expected to contribute to the soup viscosity to some extent if not degraded by β -glucan hydrolyzing enzymes. It was reported by Bathgate et al. [57] that the presence of the endo- β -glucanase enzyme in ungerminated barley grains can lead to partial breakdown of β -glucans, resulting in a decrease in the apparent viscosity of the extracted β -glucans. Barley and malt are also reported to have endo- β -glucanase activity, and the pH optimum of two barley endo- β -glucanase isoenzymes was reported as 4.7 [58]. During the tarhana production, the mixture of ingredients was incubated for 5 days at 30 °C for fermentation and then dried in an air oven at 40 °C. Hence the conditions are favorable, during the long fermentation and early stages of drying, for the endo- β -glucanase activity and expected to modify the β -glucan content and molecular size distribution. This is in turn estimated to influence the viscosity of the resulting tarhana soup. Further studies are required to elaborate on the modification of β -glucan content and molecular size distribution during the course of the tarhana fermentation and the effects on tarhana soup viscosity.

The soup index values of the tarhana soup samples obtained using RVA were in the range of 0.062–0.244 Pa.s (Table 5). Tarhana samples produced from barley had significantly lower soup index values than the wheat tarhana samples ($p < 0.05$). Tar-TWF₁ had the highest soup index (0.244 Pa.s) among the samples ($p < 0.05$), while the lowest soup index (0.062 Pa.s) was observed in the Tar-ChF ($p < 0.05$). Erkan et al. [27] stated that RVA soup index

values of tarhana samples varied from 16.9 to 24.3 RVU (1 RVU = 0.012 Pa.s). Similar to the present study, wheat tarhana soup had the highest RVA soup index value (24.3 RVU = 0.2916 Pa.s) and hull-less barley tarhana had the lowest RVA soup index value (16.9 RVU = 0.2028 Pa.s). The lower RVA soup index values of barley tarhana soup samples can be attributed to the alterations that may occur during fermentation and the activity of endogenous enzymes on barley flour as explained above.

At first glance, the comparatively lower soup index values observed in the barley tarhana samples could be perceived as a disadvantage. However, increasing the high β -glucan barley flour level in the tarhana recipe is not expected to cause huge increases in soup viscosity. Therefore, it might be possible to substantially enhance the β -glucan content of tarhana soups by adding larger quantities of high β -glucan barley flour in tarhana formulations, without causing too much increase in soup viscosity.

Conclusion

The purpose of the MEDWHEALTH project is to redesign a number of med foods to enhance their healthiness by including innovative raw materials in their formulation such as high β -glucan barley. This study was focused on increasing the β -glucan content of tarhana, a traditional fermented soup, using hull-less barley (cv. Chifaa) flour with high β -glucan levels. Utilization of Chifaa flour resulted in significantly higher β -glucan content in the tarhana sample ($p < 0.05$). The K, Mg, and Ca contents of the high β -glucan tarhana sample (Tar-ChF) were significantly higher than the ones produced using other flours (Tar-YF, Tar-TWF₂, and Tar-TWF₁) and Tar-ChF also had the highest TPC. The bound fractions of tarhana samples showed higher antioxidant activities in comparison to their free fractions. The barley tarhana samples had lower GI values than those of wheat tarhana samples. RVA soup index values of the barley tarhana samples were significantly lower than those of wheat tarhana samples ($p < 0.05$). Due to relatively lower soup

Table 5 Pasting properties and RVA soup index of tarhana soup samples

	Pasting properties						RVA soup index (Pa.s)
	Peak viscosity (Pa.s)	Trough (Pa.s)	Breakdown (Pa.s)	Final viscosity (Pa.s)	Setback (Pa.s)	Peak time (min)	
Tar-YF	0.080 ± 0.0057 ^c	0.068 ± 0.0042 ^b	0.012 ± 0.0014 ^c	0.178 ± 0.0028 ^c	0.110 ± 0.0014 ^b	5.4 ± 0.00 ^b	0.108 ± 0.0014 ^c
Tar-ChF	0.052 ± 0.0042 ^d	0.043 ± 0.0057 ^c	0.009 ± 0.0014 ^c	0.092 ± 0.0020 ^d	0.049 ± 0.0085 ^c	5.6 ± 0.10 ^a	0.062 ± 0.0028 ^d
Tar-TWF ₁	0.174 ± 0.0028 ^a	0.134 ± 0.0057 ^a	0.040 ± 0.0028 ^a	0.276 ± 0.0028 ^a	0.142 ± 0.0085 ^a	5.47 ± 0.04 ^{ab}	0.244 ± 0.0028 ^a
Tar-TWF ₂	0.111 ± 0.0057 ^b	0.084 ± 0.0028 ^b	0.027 ± 0.0028 ^b	0.211 ± 0.0042 ^b	0.127 ± 0.0014 ^{ab}	5.13 ± 0.03 ^c	0.163 ± 0.0021 ^b

Data are expressed as mean ± SD of duplicate measurements. Different letters (a–d) on the same column are significantly different ($p < 0.05$) among tarhana powders

Tar-YF tarhana produced using Yalin (barley) flour, Tar-ChF tarhana produced using Chifaa (barley) flour, Tar-TWF₁ tarhana produced using Tosunbey white flour, Tar-TWF₂ tarhana produced using Tosunbey whole wheat flour

index values, barley tarhana samples can tolerate higher levels of high β -glucan barley flour in their formulation without excessive increases in viscosity which might be an advantage, resulting in a healthier soup. The results of this study showed that it was possible to produce tarhana samples with improved nutritional properties by using high β -glucan hull-less barley flour. Traditional foods including tarhana play a key role in the Mediterranean diet. Hence, increasing the amount of health-promoting nutrients by adding barley flour may be beneficial for individuals who adhere to the Mediterranean Diet.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical approval This article does not present studies involving human or animal subjects.

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