Research Article

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Assessment of iron content of cooking water on bulgur by determining chemical, mineral, colour, textural and thermal characteristics

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Abstract

BACKGROUND: Bulgur, a whole wheat product, has attracted attention in the world in recent years because of its wide usage possibility in different meals. The basic ingredients in bulgur production are wheat and water. The influence of water composition on bulgur quality has not been investigated. Iron in water can cause discolouration in foods by oxidizing and reacting with phenolic compounds and also by hardening the structure of the foods. Therefore, in the present study, the effects of the iron content of water on the quality of bulgur were examined.

RESULTS: The effect of the amount of iron in water on bulgur quality was carried out and examined using water containing iron at three different levels (0, 1 and 2 ppm). Using water containing 2 ppm iron in bulgur production caused a decrease in the *L value and an increase in the YI (i.e. yellowness index), thus negatively affecting the colour of the bulgur. In bulgur prepared with water containing 2 ppm iron, the antioxidant activity was also dramatically reduced.**

CONCLUSION: The iron content in the water used in bulgur production did not have a negative effect on bulgur quality up to 2 ppm. The protein, ash, phenolic and mineral amounts and textural characteristics of bulgur were not affected by the concentration of iron in the water. As a result, high iron concentration in cooking water negatively affects bulgur's colour and antioxidant activity. Therefore, it is recommended to use iron-free water in bulgur production.

Keywords: wheat; bulgur; iron; cooking; drying; colour

INTRODUCTION

The consumption of wheat products is an indispensable part of a diet because wheat comprises functional compounds such as unsaturated fatty acids, dietary fibre, minerals, vitamins and phytochemicals alongside carbohydrates and proteins.[1] Bulgur is the wheat product that is most similar to wheat in terms of nutritional value, having been pre-processed to make it easier to cook (as a result of pre-cooking), more durable and palatable.[2,3] The main production stages are cooking, drying, tempering, debranning, milling and classification.[4] Bulgur can be classified as coarse and fine bulgur based on size. Coarse bulgur is generally consumed as pilaf, whereas fine bulgur is used in making tabbouleh and meatballs.[2]

Although the majority of the world's bulgur is produced and consumed in Turkey, the Middle East and North Africa, Western countries have also searched for recipes to find new bulgur dishes.[4,5] Due to its use in tabbouleh salad, research also shows that the consumption of fine bulgur has increased in Europe (as a result of migration from Africa and the Middle East) and it has become an indispensable part of modern French cuisine because of cultural exchange.[6,7] For these reasons, currently, the interest in bulgur has re-ascended in scientific research.

The most important quality parameters in bulgur production are the properties of the wheat and water used in production, the cooking (because of water absorption) and the debranning processes as a result of the loss of functional compounds.[5,8] Although the effects of wheat varieties and processes of production on bulgur quality have been examined and are well documented,[5,8] the impact of water composition has not been investigated.

Although the iron in water is not risky for health, it may cause an undesirable taste and odour. Iron contamination occurs from water sources, equipment and piping systems in bulgur plants. Practically, the bulgur producers try to find the reason for the

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colour loss and hard texture that occurs in bulgur. The present study is important with respect to understanding the effect of iron in water on bulgur colour and texture together with other quality properties. The microbiologically safe well water is commonly used in the food industry. Anaerobic groundwater may contain ferrous iron up to several mg L^{-1} without turbidity or discolouration when directly pumped from a well. Iron in water can react with phenolic compounds in some foods or undergo oxidation, which may eventuate in red–brown discolouration. Examining bulgur factories stated that high concentrations of iron in water caused serious problems in production and negatively influenced the quality of the products. The amount of iron in the water of the two factories was also found to be 1.070 and 1.810 mg L^{-1}, respectively.[9] Because water constitutes the principal component in quantity for bulgur production, the properties of the water used in production might have a crucial effect on bulgur quality. Accordingly, the present study aimed to investigate the possible effects of iron content (0, 1 and 2 ppm) on the various quality attributes (pH, proximate and mineral compositions, bioactive, colour, textural and thermal) of wheat, cooked wheat (to monitor the effect of cooking) and bulgur samples (to reveal the combined effect of drying and debranning).

MATERIALS AND METHODS

Materials and sample production

Durum wheat (*Triticum durum* cv. Güneyyıldızı) supplied by Tiryaki Agro Gıda San. ve Tic. A. Ş. (Gaziantep, Turkey) and distilled water obtained from A MilliQ Advantage A 10 (MilliporeSigma, Molsheim, France) were used to prepare bulgur samples. Before the production of bulgur, wheat was cleaned using both dry and wet methods to remove pollutants. The dry cleaning process was carried out by passing the wheat through 3.6- and 1.6-mm sieves. The wet cleaning process was performed by washing the wheat with half the amount of water for 3 min. One hundred ppm $FeCl_3$ solution was used to adjust the water to 0, 1 and 2 ppm of iron content.

Iron chloride ($FeCl_3$), hydrochloric acid (HCl), tungstophosphoric acid hydrate, hexane, Ca and Fe standard solutions for AAS, methanol, 2,2-diphenyl-1-picrylhydrazyl (DPPH), sodium carbonate (Na_2CO_3) and Folin–Ciocalteu's reagent were purchased from Sigma (St Louis, MO, USA), whereas Zn, Mn and Na standard solutions for AAS were from PerkinElmer Inc. (Waltham, MA, USA).

The wheat (1 kg) was poured into the boiled water (1.8 L) at 97 °C and cooked. Then, a certain amount of the cooked samples was collected and kept in plastic containers at −18 °C for further analyses (pH, proximate and mineral composition, functional properties and colour parameters). The samples for texture analysis were kept at +4 °C. Subsequent to cooling, they were dried in a fluidized bed dryer (MK II; Sherwood Scientific, Cambridege, UK) at 70 °C. Afterwards, it was soaked to approximately 17% and the bran was separated by a debranner (Merba Makine, Mersin, Turkey). Ultimately, the size reduction was exerted using a disc-type bulgur mill (TM2-Tekpa Bulgur Mill; Tekpa Lab Systems Co., Ankara, Turkey) and bulgur sized between 0.5 and 2 mm (fine bulgur) was taken into plastic containers and stored at +4 °C to be used in further analyses. Differential scanning calorimetry (DSC) and Fourier-transform infrared spectroscopy (FTIR) experiments were performed in the wheat and bulgur samples in addition to the abovementioned analyses of cooked wheat. The analyses in bulgur were made at fine-sized bulgur.

Chemical analyses

The pH measurements were carried out at 25 °C using a pH meter (AZ 86505; AZ Instrument Corporation, Taichung City, Taiwan). The dry matter, ash, fat and protein analyses were conducted according to the standard methods of AACC.[10] The determination of starch was performed by the polarimetric method. To determine starch content, 50 mL of 1% (v/v) HCl was added to 1 g of sample and left in a water bath at 95–100 °C for 15 min, cooled by adding distilled water, and then 10 mL of 4 g 100 mL^{-1} tungstophosphoric acid hydrate solution was added and the volume was made up to 100 mL with distilled water. Following filtration, the polarization value was measured at 20 °C via a polAAr 3000 model polarimeter (Optical Activity Ltd, Bury, UK). The starch content was calculated based on a previously reported equation.[11] The parameters of the equation are V_{TS}, total sample volume (mL); α_p, polarization value; A_D^{20}, the conversion factor of Ewer's starch method for wheat starch [182.7/(dm × g mL^{-1})]; L_p, the length of polarization tube in decimetre (dm); and, lastly, W_s, dry matter content (g) of the sample:

$$\text{Starch amount (\%, dry basis)} = \frac{V_{TS} \times \alpha_p}{A_D^{20} \times L_p \times W_s} \times 100$$

Evaluation of bioactive features

Extraction of phenolic compounds

The phenolic extracts were obtained following the method of Caba *et al.*[12] The sample (4 g) treated with 40 mL of acidified methanol–water solution was stirred (2 h at 200 rpm) in an orbital shaker (Innova 40R; New Brunswick Scientific, Edison, NJ, USA). The resulting mixture was centrifuged (Centrifuge 5810 R; Eppendorf, Hamburg, Germany) at 2040 × g (15 min) and the liquid part was poured into another flask. The procedure was repeated for the solid part and the two extracts obtained were combined. The filtered (0.45 μm) extracts were used for total phenolic content and antioxidant activity analyses.

Measurement of total phenolic content (TPC)

The phenolic content was analysed according to Caba *et al.*[12] After adding 0.5 mL of distilled water to 125 μL of sample extract, it was mixed with 125 μL of Folin–Ciocalteu's solution diluted with distilled water (1:10, v/v). Next, 1.25 mL of Na_2CO_3 (70 g L^{-1}) and distilled water (1 mL) were added and the solution was incubated in the dark for 1.5 h at 25 °C. The absorbance was recorded at 760 nm. The results were stated as mg gallic acid equivalents (GAE) kg^{-1} dry sample.

Assessment of antioxidant capacity

The protocol of Brand-Williams *et al.*[13] was applied for the determination of the antioxidant activity by utilizing DPPH. Mainly, the sample extract (150 μL) was treated with 2850 μL of 60 μmol L^{-1} DPPH solution and held in a lightless place for 30 min. The absorbance was detected at 515 nm using methanol as the blank. The control solution was prepared by implementing the aforementioned protocol apart from using methanol in place of the sample extract.

Mineral content assay

The mineral content was quantified through an atomic absorption spectrophotometer (AAnalyst 800; PerkinElmer Inc.). The acetylene (2 L min^{-1}) was used as the fuel and air (17 L min^{-1}) was used as the oxidant. The detection wavelengths of minerals were: 213.9 nm for Zn, 248.3 nm for Fe, 279.5 nm for Mn, 422.7 nm for Ca and 589.0 nm for Na.

Colour characteristics

The colour parameters were measured as CIE L^* (luminosity), a^* ($-a$, greenness; $+a$, redness), b^* ($-b$, blueness; $+b$, yellowness) and YI (yellowness index) values using a colourimeter (ColorFlex, Model EZ 45-2; HunterLab, Reston, VA, USA). D65 illuminant and 10^0 observing angle were used during the measurements. The total colour difference (ΔE^*) was calculated using a formula where L^*, a^* and b^* represent the colour values of samples, whereas L_0^*, a_0^* and b_0^* indicate the colour values of reference value:

$$\Delta E^* = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2}$$

Textural properties analysis

The texture parameters (hardness, springiness, cohesiveness, gumminess, chewiness and resilience) were acquired via a texture analyser (TA.XT2i-Plus; Stable Micro Systems Ltd, Godalming, UK). The method reported by Li *et al.*[14] was employed. A two-cycle compression test was applied by using a 36-mm diameter probe. The device was adjusted to 2 mm s^{-1} for the pre-test and test, and 0.5 mm s^{-1} for the post-test with 80% strain and 5 *g* of trigger force. Between every compression, there was a 5-s pause.

DSC analysis

The DSC analysis was realized via a calorimeter (Pyris 6 DSC model; PerkinElmer Inc.) in accordance with the procedure of Savas & Basman.[8] The powdered sample (3 mg) and distilled water (15 mg) were weighed in a 50-μL aluminium pan, sealed and maintained at 4 °C in a refrigerator for 24 h. The plot of heat flow was acquired by heating the reference and the sample pans from 20 to 100 °C by increasing the temperature at the rate of 10 °C min^{-1}.

Infrared spectroscopy measurements

The infrared spectrum was imparted with a Spectrum 100 FTIR spectrometer (PerkinElmer Inc.). The mid-infrared spectra (mean of four scans at 4 cm^{-1} of resolution) of samples were collected within the interval of 4000 and 650 cm^{-1} using Spectrum 10 STD software (PerkinElmer Inc.). A background spectrum of air was recorded previous to each measurement.

Statistical analysis

All analyses were carried out as two experiments of duplicate production of each sample group and the results were expressed as the mean ± SD of at least four measurements. The statistical analysis was imparted using SPSS, version 25.0 (IBM Corp., Armonk, NY, USA). The degree of significant differences were detected using one-way analysis of variance test. The level of significance was examined at a 95% confidence level by performing Duncan's multiple range test.

RESULTS AND DISCUSSION

In the bulgur industry, well water that meets the microbiological criteria is used in production after being kept in steel or iron tanks. Therefore, the amount of iron in the water can increase due to both the soluble iron in well water and the transition from iron tanks, pipes and equipment to water and this may influence the quality attributes of bulgur, especially darkening the colour and hardening the texture. Accordingly, the objective of the present study was to examine the effects of iron content (0, 1 and 2 ppm) in water on various quality characteristics of cooked wheat and bulgur samples. The outcomes of the study provide information to manufacturers and scientists about the effect of iron in water on product quality.

pH and proximate composition

The chemical attributes (pH, dry matter, protein, fat, starch and ash contents) of the wheat, cooked wheat and bulgur samples are given in Table 1. Depending on the increment in the iron content of the cooking water, the pH of the cooked wheat also increased. This could be related to the concentration difference between the wheat and water; therefore, more acidic components pass into the water. Furthermore, iron forms complexes with acidic substances such as phytic acid, causing a decrease in acidity and therefore increasing pH.[15] After drying and debranning (D&D), the pH of the samples produced with water containing 0 and 1 ppm of iron increased ($P \leq 0.05$). The reason for this may be that the acidic substances in these samples were mostly

Table 1. Chemical properties of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at different levels

Sample	Iron content of CW (ppm)	pH	Dry matter (g kg^{-1} w.b.)	Protein content (g kg^{-1} d.b.)	Fat content (g kg^{-1} d.b)	Starch content (g kg^{-1} d.b.)	Ash content (g kg^{-1} d.b.)
Durum wheat (raw material)	–	6.32 ± 0.01 Ac	903.16 ± 1.26 Ab	139.54 ± 2.39 Aa	16.16 ± 0.62 Aa	648.79 ± 6.46 Ac	16.34 ± 0.81 Aa
Cooked wheat	0	5.58 ± 0.01 B	530.82 ± 1.59 B	132.54 ± 5.07 B	11.69 ± 1.40 BC	593.03 ± 3.38 D	15.89 ± 2.10 A
	1	6.21 ± 0.02 A	535.50 ± 7.40 B	127.86 ± 3.16 B	10.56 ± 0.12 C	601.30 ± 4.21 C	14.63 ± 0.87 A
	2	6.48 ± 0.36 A	530.62 ± 14.96 B	132.06 ± 3.43 B	12.26 ± 1.11 B	608.22 ± 3.05 B	16.90 ± 2.14 A
Fine bulgur	0	6.41 ± 0.01 b	886.76 ± 5.31 c	133.68 ± 1.39 b	14.10 ± 0.57 bc	661.06 ± 6.61 b	14.97 ± 0.84 a
	1	6.41 ± 0.01 b	904.58 ± 3.60 b	134.55 ± 1.77 b	13.50 ± 0.61 c	669.00 ± 6.68 a	14.99 ± 1.71 a
	2	6.45 ± 0.02 a	912.57 ± 1.92 a	131.61 ± 1.09 b	14.88 ± 0.59 b	670.57 ± 9.07 a	14.80 ± 1.14 a

The results are the mean ± SD of two experiments on double production of each sample group. A–D: Different uppercase letters in the same column indicate significant differences between the Durum wheat and cooked wheat samples ($P \leq 0.05$). a–c: Different lowercase letters in the same column indicate significant differences between the Durum wheat and fine bulgur samples ($P \leq 0.05$).
CW, cooking water; d.b, dry basis; w.b, wet basis.

found in the bran part after cooking and were removed with the bran.

As shown in Table 1, the dry matter content of wheat is 903.16 g kg^{-1} [wet basis (w.b.)]. Because of water absorption during the cooking process, the dry matter in all sample groups sharply decreased ($P \leq 0.05$). It was observed that the iron content of cooking water did not affect the dry matter content of cooked wheat and fine bulgur samples. After D&D, it was observed that the amount of dry matter increased to above 880 g kg^{-1} (w.b.). The utilization of wheat high in protein, such as *Triticum durum* during the production is crucial for the formation of a tough texture after the cooking.[16] Both cooking and D&D processes caused significant reductions ($P \leq 0.05$) in the protein content. Nevertheless, no significant differences ($P > 0.05$) were observed among the protein contents of the cooked wheat and fine bulgur samples produced with different waters.

The findings of fat highlight that both all cooked wheat samples and all bulgur samples contained less fat than wheat [16.16 g kg^{-1} dry basis (d.b.)]. In reference to fat content results, Koca & Anıl[16] provided similar results that could account for this decrement. The amount of fat in the same sample groups following the D&D processes is consistent with the outcomes of post-cooking; therefore, the effect of D&D processes on the fat quantity of bulgur is unremarkable. The cause of the increment in the quantity of fat after the D&D processes is the removal of bran and therefore the increase in the amount of fat in the dry matter. Starch is the main energy source in wheat. After the cooking process, it was noted that there was a reduction in all samples compared to wheat; however, as the iron level increased, the starch content in the cooked wheat also increased. This might be linked to the formation of the iron-starch complex[17] and therefore the starch is retained more in the structure of the product. After the D&D processes, there were no significant differences ($P > 0.05$) between the samples. In previous studies, it was reported that wheat contains ash in the range of 12.5–18.5 g kg^{-1} (d.b.) and the amount of ash varies depending on the type of wheat and growing conditions,[8,16] which is consistent with the present findings. It was unveiled that the amount of iron did not cause a statistically significant effect ($P > 0.05$) on the ash content of the samples.

Bioactive properties

Wheat, by virtue of being rich in phytochemicals, can have antioxidant properties and suppress a wide range of diseases by lowering oxidative stress. The phenolics of wheat are principally concentrated in the exterior parts of the grain.[18] The bioactive properties, consisting of total phenolic content (TPC) and antioxidant activity, are presented in Table 2. Based on the TPC results, it can be inferred that the increment of iron content caused a steady decrease in the cooked wheat samples. Considering anthocyanins are water soluble, the reason for this might be the transition of these components from the bran into the water during cooking. The interaction of iron with phenolic substances can explain the lower level of phenolics in cooked wheat prepared with water containing 2 ppm iron.[1,19] No significant variations ($P > 0.05$) were apparent between the TPC of bulgur samples prepared with water containing different amounts of iron.

Even though the changes in antioxidant capacities between the cooked wheat samples and wheat were not significant ($P > 0.05$), wheat cooked in water containing iron (1 and 2 ppm) exhibited an increase. There is a negative correlation between TPC and antioxidant activity in both cooked wheat and bulgur samples. Other studies have also attained conformable correlations. This may be because samples containing less phenolic substances show higher antioxidant activity.[20]

Colour attributes

Colour is accepted as one of the main quality parameters of bulgur and the luminous yellow colour is desired by consumers.[5] The colour substances in wheat and consequently bulgur consist primarily of carotenoids (mostly located in the endosperm) and anthocyanins (mostly concentrated in the bran).[1] As the wheat was cooked, the b^* and YI values ascended, whereas the L^* and a^* values decreased in comparison with wheat. The D&D processes had the opposite effect (Table 2). The main reason for the change in colour values during the cooking process is the

Table 2. Bioactive and colour features of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at different levels

Sample	Iron content of CW (ppm)	Total phenolic content (mg GAE kg^{-1} d.b.)	Antioxidant capacity (% Inhibition)	L^*	a^*	b^*	YI	ΔE^*_1	ΔE^*_2
Durum wheat (raw material)	–	1057.85 ± 38.39 Aa	87.92 ± 0.27 ABa	52.64 ± 0.85 Ac	9.38 ± 0.23 Aa	25.85 ± 0.21 Bb	75.51 ± 0.52 Ba	–	–
Cooked wheat	0	941.19 ± 63.03 B	87.45 ± 0.61 B	50.61 ± 0.37 B	8.92 ± 0.17 BC	33.33 ± 0.25 A	88.63 ± 0.86 A	2.29 ± 0.25 A	–
	1	871.38 ± 35.66 B	88.76 ± 0.85 A	50.60 ± 0.46 B	8.99 ± 0.21 B	32.99 ± 0.91 A	88.22 ± 1.15 A	2.50 ± 0.95 A	1.08 ± 0.26 A
	2	779.29 ± 45.51 C	88.73 ± 0.71 A	51.27 ± 0.40 B	8.69 ± 0.07 C	33.27 ± 0.57 A	87.58 ± 0.56 A	1.92 ± 0.56 A	0.97 ± 0.31 A
Fine bulgur	0	698.91 ± 25.44 b	85.72 ± 0.39 c	67.35 ± 0.28 b	6.21 ± 0.20 b	30.62 ± 0.24 a	68.16 ± 0.75 bc	15.76 ± 0.36 ab	–
	1	679.77 ± 36.19 b	90.02 ± 0.92 a	68.02 ± 0.60 a	5.95 ± 0.17 b	30.43 ± 0.53 a	67.17 ± 1.11 c	16.49 ± 0.65 a	0.99 ± 0.50 a
	2	709.05 ± 28.20 b	81.79 ± 0.32 d	66.93 ± 0.56 b	6.16 ± 0.11 b	30.74 ± 0.64 a	68.57 ± 1.10 b	15.35 ± 0.57 b	1.06 ± 0.24 a

ΔE^*_1, colour difference determined using wheat as a reference value. ΔE^*_2, colour difference calculated using the cooked wheat (*A* value) and bulgur samples (*a* value) prepared with water containing 0 ppm of iron as a reference value. The results are the mean ± SD of two experiments on double production of each sample group. A–D: Different uppercase letters in the same column indicate significant differences between the Durum wheat and cooked wheat samples ($P \leq 0.05$). a–d: Different lowercase letters in the same column indicate significant differences between the Durum wheat and fine bulgur samples ($P \leq 0.05$).
CW, cooking water; d.b, dry base; GAE, gallic acid equivalent; YI, yellowness index.

transition of anthocyanins into the water, whereas, in the drying process, the colour changes are caused by the removal of bran. The findings show that the amount of iron in cooking water has no observable influence on the colour of bulgur up to 2 ppm. The L^* and b^* values of bulgur samples increased ($P \leq 0.05$) compared to wheat; thus, the bright yellow colour desired in bulgur production was obtained. ΔE_1^* is the total colour alteration of the cooked wheat and bulgur samples in comparison with Durum wheat from the point of L^*, a^* and b^* values. On the other hand, ΔE_1^* denotes the colour changes of the cooked wheat and bulgur samples in comparison with the samples prepared using 0 ppm of iron. No statistical difference ($P > 0.05$) was observed between the ΔE_1^* values of the samples after cooking. Nevertheless, it was determined that ΔE_1^* increased after the D&D processes and the colour change was less in the sample produced with water containing 2 ppm iron. Considering that the colour values of bulgur produced with water containing 2 ppm iron are at an undesirable level (as it has a lower ΔE_1^* value). Eventually, the results showed that the main colour change in bulgur production occurs after the debranning process. Furthermore, it was determined that there was no statistical difference ($P > 0.05$) between the ΔE_2^* values of cooked wheat samples in comparison with the cooked wheat prepared with iron-free water. Similarly, when the ΔE_2^* values of bulgur samples were compared with the bulgur sample prepared with iron-free water, there was no statistical difference ($P > 0.05$). Ultimately, it was revealed that there was not a colour difference ($P > 0.05$) between the total colour changes of the samples containing 1 and 2 ppm iron (Table 2).

Mineral composition

Minerals are crucial for metabolic processes; therefore, sufficient intake of them is of significance. Even though cereals are reported to be one of the major sources of minerals in nutrition, the concentration of minerals may be reduced during processing. Wheat contains elements such as Ca, Na, Fe, Zn and Mn, which vary according to variety and growth conditions.[21] The results exemplify that the cooked wheat samples had lower iron content than raw wheat, and the cooked wheat prepared by using water containing 1 ppm of iron differed significantly ($P \leq 0.05$) from wheat (Table 3). This is related to the mass transfer of iron between water and wheat. A similar tendency was also observed in Zn. The debranning process induced a reduction in the amount of Fe and

Table 3. Mineral contents of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at different levels

Sample	Iron content of CW (ppm)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Ca (mg kg^{-1})	Na (mg kg^{-1})
Durum wheat (raw material)	–	42.04 ± 6.82 Aa	36.18 ± 1.39 Aa	33.04 ± 1.29 Aa	205.65 ± 13.05 Aa	38.15 ± 3.88 Ac
Cooked wheat	0	34.71 ± 4.96 AB	33.01 ± 3.31 AB	22.55 ± 1.75 B	169.73 ± 7.40 B	19.23 ± 6.19 B
	1	33.19 ± 4.85 B	31.54 ± 1.93 B	19.96 ± 0.04 B	162.78 ± 4.44 B	24.76 ± 3.09 B
	2	37.54 ± 0.14 AB	34.51 ± 0.52 AB	16.68 ± 2.75 C	175.77 ± 11.59 B	20.97 ± 2.43 B
Fine bulgur	0	18.73 ± 0.11 b	26.58 ± 0.95 b	22.67 ± 1.25 b	149.12 ± 4.30 b	72.54 ± 7.72 a
	1	20.91 ± 3.00 b	26.46 ± 0.59 b	24.28 ± 1.21 b	147.76 ± 2.03 b	59.56 ± 5.49 b
	2	22.01 ± 2.64 b	25.72 ± 1.02 b	22.99 ± 0.13 b	144.31 ± 2.33 b	36.18 ± 7.09 c

Mineral concentrations are calculated on a dry basis. The results are the mean ± SD of two experiments on double production of each sample group.
A–D: Different uppercase letters in the same column indicate significant differences between the Durum wheat and cooked wheat samples ($P \leq 0.05$).
a–d: Different lowercase letters in the same column indicate significant differences between the Durum wheat and fine bulgur samples ($P \leq 0.05$).
CW, cooking water.

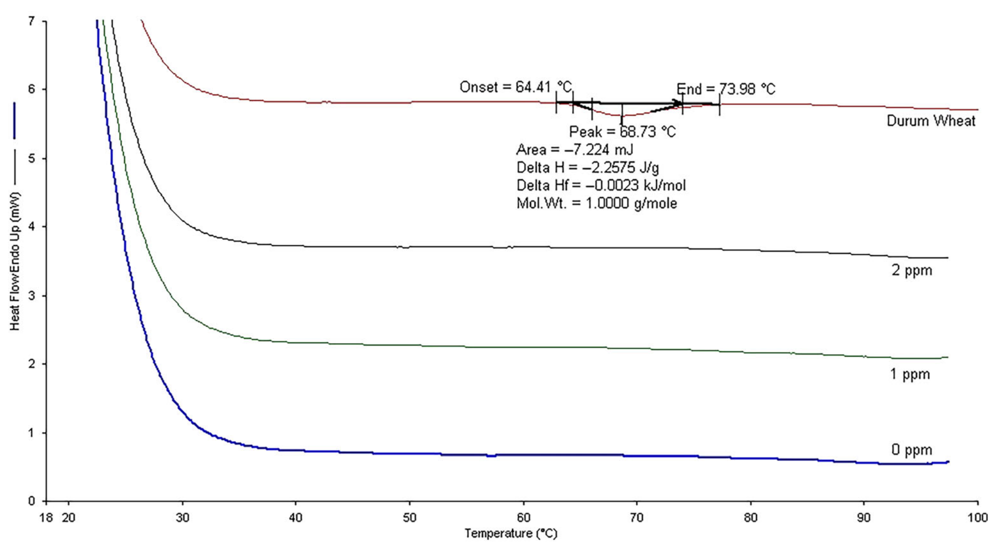

Figure 1. Thermal analysis graph of wheat and bulgur samples obtained by differential scanning calorimetry.

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Zn. In all cooked wheat samples, less Mn was found than in wheat ($P \le 0.05$). On the other hand, after the D&D processes, this effect disappeared and no significant differences ($P > 0.05$) were observed between the Mn contents of bulgur samples. The elimination of differences in Mn after D&D processes might result from the transition of Mn into wheat during cooking.

All cooked wheat and bulgur samples were found to have lower calcium than wheat. This is because Ca passes from the bran to the water during cooking and it is subsequently removed by the debranning process. Both cooked wheat and bulgur samples show no statistically significant variation among sample groups ($P > 0.05$) in terms of *Ca*. There was a decrement ($P \le 0.05$) in Na in all cooked wheat samples compared to wheat. However, in cooked wheat, no statistical difference ($P > 0.05$) was detected between sample groups in terms of Na. There is a difference in Na between bulgur samples and wheat and also between sample groups of bulgur produced.

Thermal characteristics

Water addition and heating lead to physicochemical modifications in wheat, resulting in the gelatinization of the starch that makes the grain structure firm and glassy.[22] The lack of a gelatinization peak (Fig. 1) in the bulgur samples confirms that starch in

Table 4. Texture profile parameters of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at different levels

Sample	Iron content of CW (ppm)	Hardness (g)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Durum wheat (raw material)	–	46 965.05 ± 5094.59 Aa	0.70 ± 0.06 Aa	0.63 ± 0.05 ABa	29 872.59 ± 5389.39 Aa	20 992.35 ± 4408.81 Aa	0.48 ± 0.05 Aa
Cooked wheat	0	6302.40 ± 223.35 B	0.65 ± 0.07 A	0.58 ± 0.04 B	3683.81 ± 303.08 B	2381.70 ± 252.48 B	0.37 ± 0.03 B
	1	9130.21 ± 961.60 B	0.74 ± 0.07 A	0.64 ± 0.03 AB	5892.28 ± 858.64 B	4410.78 ± 1020.14 B	0.38 ± 0.02 B
	2	9004.26 ± 682.55 B	0.72 ± 0.03 A	0.67 ± 0.03 A	6083.93 ± 658.72 B	4408.21 ± 501.47 B	0.39 ± 0.02 B
Fine bulgur	0	8668.39 ± 693.35 c	0.48 ± 0.07 b	0.39 ± 0.01 c	3364.07 ± 332.29 c	1634.57 ± 387.55 b	0.17 ± 0.01 c
	1	14 380.57 ± 1379.31 b	0.49 ± 0.04 b	0.45 ± 0.01 b	6492.41 ± 790.69 bc	3146.10 ± 331.90 b	0.24 ± 0.02 b
	2	17 618.12 ± 2138.29 b	0.54 ± 0.06 b	0.47 ± 0.02 b	8302.68 ± 1414.61 b	4455.02 ± 986.71 b	0.26 ± 0.02 b

The results are the mean ± SD of two experiments on double production of each sample group. A–D: Different uppercase letters in the same column indicate significant differences between the Durum wheat and cooked wheat samples ($P \le 0.05$). a–d: Different lowercase letters in the same column indicate significant differences between the Durum wheat and fine bulgur samples ($P \le 0.05$).
CW, cooking water.

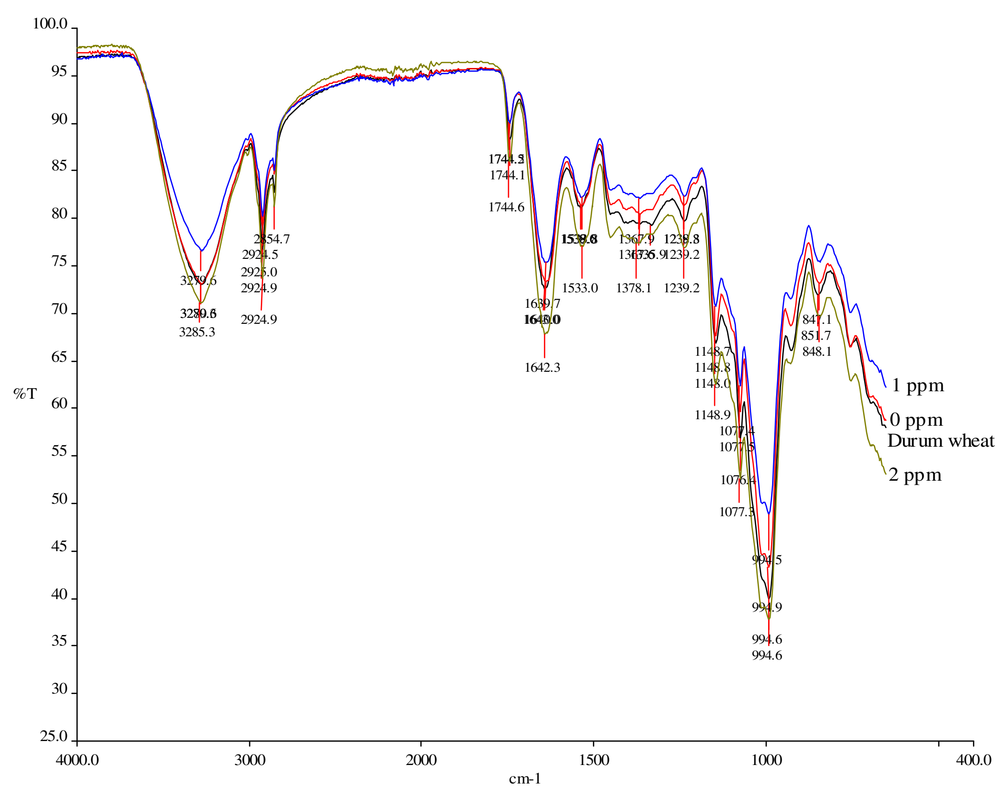

Figure 2. Mid-infrared spectra of wheat and bulgur samples.

the wheat was fully gelatinized and it was not notably impacted by the iron content of the cooking water.

Textural features

The impact of cooking and D&D processes on the textural properties of wheat is demonstrated in Table 4. No significant differences ($P > 0.05$) were observed in springiness and cohesiveness values in all sample groups of cooked wheat. In relation to the hardness, gumminess, chewiness and resilience values of cooked wheat in all sample groups were diminished ($P \leq 0.05$) compared to wheat. All texture profile parameters measured of entire fine bulgur samples were declined in comparison with wheat, which confirms that cooking and D&D processes have a noteworthy influence on the texture of bulgur. It was also determined that the hardness, cohesiveness, gumminess and resilience parameters of the bulgur sample produced with iron-free cooking water (0 ppm) were lower than the other bulgur samples. This might be linked to the moisture content of the samples, rather than the iron content of cooking water because the difference occurred after the drying process.

Evaluation of FTIR spectra

Regarding the components they contain, the FTIR spectra (Fig. 2) of the wheat and bulgur samples exhibited multiple bands. Concerning former studies, it is deduced that the peaks between 1150 and 840 cm^{-1} are related to the polysaccharides. The profound peak amid this band at 995 cm^{-1} indicates C-OH bending, which is associated with β-glycosidic linkages. Cellulosic conformation may be associated with peaks at 1368 and 1239 cm^{-1}, which could be the consequence of C—H bond breakdown. Peptides responsible for the stretching of C═O and C—N, as well as the bending of N—H, were identified by means of the peaks in the bands of 1643 (amide I) and 1533 cm^{-1} (amide II). The small peak observed at 1744 cm^{-1} is relevant to the linkages of esters with cellulosic or carboxylic groups. As stated in previous research,[23,24] the peaks at around 3285 and 2924 cm^{-1} were a result of cellulosic groups and starch. Earlier reports suggest that the peak at 2925 cm^{-1} is caused by the C—H and C═O stretch bonds, which are connected to lipids. Lastly, the O—H bonds, which are connected to the structures of water and alcohol, are the cause of the peaks at about 3270 cm^{-1}.[23,24] Based on the acquired FTIR spectra, it can be concluded that bulgur is chemically almost identical to wheat and no significant conformational variations occurred throughout the production process. Ultimately, the FTIR spectrum confirms that there were no structural alterations brought about by the iron content of the cooking water used to produce bulgur.

CONCLUSIONS

The outcomes of the present study revealed that the utilization of iron content of cooking water at 2 ppm in bulgur production caused a reduction in the L^* value at the same time as increasing the YI value and consequently affected the colour negatively. Considering the DSC plot, it has been established that wheat starch gelatinized properly during the bulgur production in all samples. The iron content of cooking water has no substantial effect on the protein and ash contents of bulgur samples. The mineral content of cooked wheat samples was affected variedly by the iron content of cooking water, although this effect was eliminated by the debranning process. As a result, it can be concluded that the iron content of the cooking water does not create significant differences in the textural properties of cooked wheat and fine bulgur samples. However, because of the negative effects it may have on colour and antioxidant activity, it can be recommended that water containing more than 1 ppm iron should not be used in bulgur production.

AUTHOR CONTRIBUTIONS

SM was responsible for the methodology, investigations, formal analysis, acquisition of data, visualization and writing the original draft. SM and MB were responsible for conceptualization, as well as reviewing and editing. MB was responsible for project administration and supervision.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

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