Received: 13 June 2020 | Revised: 2 December 2020 | Accepted: 28 December 2020

DOI: 10.1111/jfpp.15205

ORIGINAL ARTICLE

Journal of Food Processing and Preservation | Institute of Food Science + Technology ifst | WILEY

A new gluten-free product: Brown rice bulgur, and its physical and chemical properties

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Abstract

In this research, a new alternative food product, defined as brown rice bulgur (BRB), rich in functional components compared to white rice and cooked in a short time compared to brown rice was developed for society especially individuals with gluten intolerance and celiac disease. BRB was produced with two different methods as boiling (BRB-B) and steaming (BRB-S). The cooking time of raw brown rice decreased from 30 to 9 min in BRB samples. The phytic acid content of BRB samples decreased by about 15% and enzyme resistant starch content of BRB-B and BRB-S samples increased by about 9% and 21% compared to brown rice, respectively. The produced BRB samples were in the medium *GI* food group. In conclusion, it was evaluated that the newly developed BRB is superior than brown rice, white rice, and wheat bulgur in terms of short cooking time, lower *GI*, and being gluten-free, respectively.

Practical applications

In this study, brown rice bulgur has been produced from brown rice, unpreferable by consumers due to its long cooking time, hard texture, and dark color, with wheat bulgur production method. This new food product includes the advantages of wheat bulgur such as resistivity to insect and mold activity because of applied high-temperature thermal process and drying process, but do not include the disadvantages of brown rice such as long cooking time. Additionally, it could be attention to some consumers because of being a new gluten-free product. The obtained data can help diversify this product in the food industry.

1 | INTRODUCTION

Cereals are the annual plants that belong to the *Poaceae* family and can produce edible seeds or grains. Wheat, corn, rice, barley, oat, rye, millet, and sorghum are important grains produced in the world. From these grains; wheat, corn, and rice are the major produced cereals in the world (De Vuyst et al., 2017).

Rice (*Oryza sativa* L.) provides a considerable amount of the food-borne energy in the worldwide, especially Asian countries such as China, India, Indonesia etc., and therefore, it is a main food product for more than half of the global population (Liang et al., 2007; Tao et al., 2019). When the rice is harvested, it is in the form of paddy composed from the husk (20%), bran and germ (8%–12%), and endosperm (70%–72%). It is procured the brown rice with separating of the husk. If the brown rice is processed further and the bran and germ layers are removed, the white rice is obtained (Gujral et al., 2012; Liang et al., 2007). Consumers do not prefer the brown rice because of its long cooking time, hard texture, and dark color. However, the nutritional value of the brown rice is very high compared to the white rice due to include the bran and embryo layers contained B group vitamins, tocopherols, oryzanols, phenolic compounds, and insoluble fibers (Gujral et al., 2012). In addition to all these, this product is naturally gluten-free and that is commonly used in preparing the gluten-free food products (Phongthai et al., 2017). Therefore, it has great importance as an alternative product because of its nutritional composition for individuals with gluten intolerance and celiac disease.

Gluten intolerance and celiac are the diseases affecting the small intestine by losing the villous structure in small intestine and they negatively influence the absorption of nutrients. The intensively used treatment for celiac and gluten intolerance is to consume the gluten-free food products. The gluten-free diet helps preventing the gluten-related health problems (Yalcin et al., 2008).

Bulgur is a pre-gelatinized traditional and functional wheat product and it is generally produced from durum wheat with the cleaning, boiling, drying, partially debranning, grinding, and sifting process steps. Bulgur is defined as a whole grain by Whole Grains Council (Anonymous, 2019). This product is available as half-ready to eat or ready to eat with short cooking time and has a long shelf life owing to resistance to insect and mold activity (Erbaş et al., 2016).

The aim of this study was to develop a new alternative rice-based bulgur by using classical wheat bulgur production method for society, especially individuals with gluten intolerance and celiac disease. It was evaluated that a kind of bulgur will be defined as brown rice bulgur, which is not tried before, can be produced from brown rice with wheat bulgur production method. In this way, the food product, rich in functional food components such as bran and germ compared to the white rice and cooked in a short time compared to the brown rice can be obtained. Additionally, it includes the advantages of wheat bulgur such as resistivity to insect and mold activity.

2 | MATERIALS AND METHODS

2.1 | Materials

Rice cultivar of Gonen Baldo was used in this research and obtained as the brown rice from well-known company in Turkey (Başhan Agricultural Products Inc., Balıkesir) in 2018. The analytical grade chemicals (Merck, Darmstadt, Germany and Sigma, Taufkirchen, Germany) and resistant starch assay kit (Megazyme Int. Wicklow, Ireland) were purchased for analyses. Samples were used as whole brown grain for physical analyses, while as grounded for chemical analyses. The cooked samples represent the samples that have been prepared as meal.

2.2 | Methods

2.2.1 | Production of brown rice bulgur

Brown rice bulgur (BRB) was produced with two different methods as boiling (B) and steaming (S), and the produced samples with these methods were coded as BRB-B and BRB-S, respectively. The water ratio and time which provides the complete gelatinization of the starch in the rice grains were optimized for two methods with the preliminary tests. It was decided that the gelatinization was completed when there was no mealy region in transversely cutting the grain. In the boiling method, optimization of water was made in such a way as to no water remains when the gelatinization completely becomes for diffusing the nutrients inside the grain and preventing the loss of nutrients caused by pouring water.

The undamaged brown rice were separated from damaged grains and other impurities for the bulgur production. After the separated 150 g of brown rice were washed with running water, it was soaked in water at room temperature for 30 min. The excess water was removed from grains. In the boiling method, the soaked grains boiled for 30 min in 750 ml of water, determined in preliminary tests as fivefold of dry brown rice. In the steaming method, the soaked grains were spread out on a wire-mesh strainer and placed in steaming pot in where there was boiling water. The lid of the pan was closed and the steaming process was finished in 3.5 hr as determined by the preliminary tests. The boiled and steamed brown rice grains were thinly spread out on the coarse filter papers as separate, and dried up to less than 12% moisture content at 25°C. The dried grains were coarsely ground in a grain mill (MF 10 Basic, IKA, Staufen, Germany) and the remaining portion on a 1,217 µm sieve was used as BRB. The images of brown rice and brown rice bulgur samples are given in Figure 1.

2.3 | Physical analyses

The L^*, a^*, and b^* color values of samples was determined according to the CIELAB system with CR-400 Chroma meter (Minolta CR 400, Konica Minolta, Japan).

FIGURE 1 The images of brown rice and brown rice bulgur samples produced with two different methods

For the hardness analysis, it was carried out the Rewthong et al. (2011) method with some modifications. The analysis was made in uncooked and cooked samples with a texture analyzer device (TA-XT plus, Stable Microsystems, Surrey, UK) equipped with 50 mm cylindrical probe (SMSP/50) by placing one rice kernel on the device plate. The analysis performed to the 60% deformation in a probe test speed of 1 mm/s and a trigger force of 5 g by using 50 kg and 5 kg load cells for uncooked and cooked samples, respectively.

The cooking time was detected by boiling the samples until the grain starch completely gelatinized. The weight and volume changes of the samples were calculated as percentage from the difference between the weight and volume of a certain amount of sample (2 g) before and after cooking.

2.4 | Chemical analyses

The moisture content was determined according to the AACC method of 44-01.01 (AACC, 2000) and the water activity (A_w) values were measured by using a Novasina LabSwift-A_w (Lachen, Switzerland) analyzer device. Ash content was detected according to the AACC method of 08-01.01 (AACC, 2000) and expressed on dry basis.

For the pH and total titratable acidity (TTA) analyses, 50 ml of distilled water was added to 5 g of sample. These mixtures were stirred, and then, filtered. The pH of supernatants was detected by using a pH meter (HI 2210, Hanna, Leighton Buzzard, UK). The TTA was determined according to the potentiometric method and the obtained supernatants from pH analysis were titrated with 0.1 N NaOH until the pH was reached up to 8.2. The TTA results were expressed as a sulfuric acid percentage on dry basis (Mutlu et al., 2018).

For determining the total phenolic content, 10 ml of 80% methanol was added to 1 g of sample and it was extracted by using a shaking water bath (WNE 29, Memmert, Schwabach, Germany) at 40°C for 2 hr. The 0.5 ml of sample extract was mixed with 2.5 ml of 10% Folin–Ciocalteu solution and 2 ml of 7.5% Na_2CO_3. These mixtures were vortexed and incubated in 50°C water bath for 5 min. After the samples cooled to room temperature by waiting in a dark place, the absorbance of the samples were measured at 760 nm in a spectrophotometer (Cary 60 UV-Vis, Agilent, Santa Clara, USA) against the blank sample prepared by 80% methanol instead of sample extract. The results were calculated by using the curve prepared with gallic acid standard solutions and expressed as mg GAE/100 g dry matter (Škerget et al., 2005).

The extracts obtained for phenolic content determination was also used in the total flavonoid content analysis. The 0.5 ml of sample extract was mixed with 2.5 ml of distilled water and 150 µl of 5% $NaNO_2$ solution. After the mixtures vortexed for 1 min, they were kept in a room conditions for 5 min, and 300 µl of 10% $AlCl_3$ solution, 1 ml of 1 M NaOH solution, and 550 µl of distilled water were added into mixture, respectively. The mixtures were kept in a room conditions for 5 min and the absorbance of the samples were measured at 510 nm in the spectrophotometer against the blank sample prepared by 80% methanol instead of the sample extract. The results were calculated by using a curve prepared with quercetin standard solutions and expressed as mg QE/100 g dry matter (Chang et al., 2006).

Antioxidant activity analysis was carried out with extracts obtained for the total phenolic content analysis. For the analysis, 0.95 ml of 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution was added to 50 µl of sample extract and the mixtures was kept in darkness for 30 min. The absorbance of samples was measured at 515 nm in the spectrophotometer against the blank sample (Fernández-León et al., 2013). The antioxidant activities of samples were given as the percentage of DPPH radical scavenging activity.

For determining the phytic acid content of samples, 25 ml of 0.2 N HCl were added to 0.3 g of sample and the sample extracted for 2 hr with a shaking device (Rocker 2D Basic, IKA, Staufen, Germany). Then, 0.5 ml of extract was taken into tubes and 1 ml of ammonium iron III ($NH_4Fe(SO_4)_2.12H_2O$) solution was added to each tubes. The tubes were kept in a boiling water bath for 30 min, in an ice bath for 15 min and at the room conditions for 1 hr, respectively. At the end of these steps, 2 ml of 2,2′-bipyridine solution was added to the tubes and the absorbance of obtained mixtures were determined by the spectrophotometer at 519 nm against blank sample (distilled water). Phytic acid content of samples was calculated on dry basis by using standard curve prepared with phytic acid sodium salt and expressed as mg/100 g dry matter (Haug & Lantzsch, 1983).

Enzyme resistant starch (ERS) content of samples was detected according to method of AACC 32-40.01 (AACC, 2010) by using resistant starch assay kit (Megazyme Int. Wicklow, Ireland). The following equation was used for calculating ERS content of samples on dry basis.

$$\text{ERS content}\,(\%) = \Delta E \times (F / W) \times 9.27$$

where ΔE, F, and W express the sample absorbance, microgram conversion from absorbance, and the dry weight of the sample, respectively.

The method developed by Goñi et al. (1997) was performed for determining starch hydrolysis rate at different times of in vitro digestion (30, 60, 90, 120, and 180 min) and estimated glycemic index (*eGI*) value of the samples. Hydrolysis curves were obtained from the hydrolyzed starch content graph plotted against time. The hydrolysis curves modeled as nonlinear by Goñi et al. (1997) were evaluated by using the program of SigmaPlot Systat 12 (Erkrath, Germany) according to following equation.

$$C = C_\infty \times \left(1 - e^{-kt}\right)$$

where C, C_∞, and k express the concentration of hydrolyzed starch at t time, the equilibrium concentration of starch hydrolyzed after 180 min, and the kinetic constant, respectively.

Hydrolysis index (*HI*) was detected by dividing the area under the starch hydrolysis curve of the sample to that of the reference sample. The eGI value of the samples was calculated according to following equation by using hydrolysis index.

$$eGI = 39.71 + 0.549 \times (HI)$$

Freshly baked white bread was used as a reference sample for the *eGI* calculation. But the *eGI* values were expressed by converting to glucose reference according to following equation (Schakel et al., 2008).

$$eGI_{bread} = 1.43 \times eGI_{glucose}$$

2.5 | Sensory analysis

For sensory analysis the samples were cooked with only water. The cooked white rice was used as a second control sample in addition to the first control sample of brown rice in the analysis. The color, odor, hardness, taste, aroma, mouthfeel, and overall sensorial parameters were evaluated by 10 trained postgraduate students, using a 5-point hedonic scale (1 extremely disliked; 5 extremely liked) (Yorgancilar & Bilgiçli, 2014).

2.6 | Statistical analysis

The research was carried out in two replicates. All physical analyses were performed quadruplicate and chemical and sensory analyses were performed in duplicate. All statistical calculations were realized by using SAS Statistical software (SAS Institute Inc., Cary, NC, USA). The significance was evaluated by analysis of variance (ANOVA), followed by Duncan's multiple range test ($p < .05$). Results were presented as mean ± standard error.

3 | RESULTS AND DISCUSSION

3.1 | Physical properties of brown rice and brown rice bulgur samples

Physical properties of brown rice and brown rice bulgur samples produced with two different methods are given in Table 1. The L^* values of bulgur samples (BRB-B and BRB-S) were significantly ($p < .01$) affected by the applied methods and decreased according to the unprocessed brown rice sample's L^* value of 61.64. The minimum L^* value of 57.53 was detected in BRB-S sample. There was no significant ($p > .05$) difference in a^* and b^* values between samples, and these values were meanly determined as 3.05 and 17.60, respectively. It was evaluated that the decrease in L^* values were sourced from Maillard reaction occurred during hydrothermal and drying processes. It was reported by Arns et al. (2014) that the color of parboiled rice treated with hydrothermal processes darkened due to the migration of colored phenolic compounds from husk to the endosperm and melanoidins forming as a result of the Maillard reaction between reducing sugars and compounds including amino groups. Yafang et al. (2011) found that the L^*, a^*, and b^* values of different brown rice genotypes were meanly 61.65, 2.88, and 18.81, respectively. In another study, it was determined that the L^*, a^*, and b^* color values of cooked whole rice (brown rice) pasta were 59.99, 4.25, and 14.12, respectively (Morreale et al., 2019).

The applied methods significantly ($p < .01$) affected the hardness value of uncooked samples. Uncooked BRB-B samples had the minimum hardness value as 16.19 kg. In consequence of processing the brown rice to BRB, the hardness of uncooked BRB-B and BRB-S samples decreased. The decrease of hardness in uncooked BRB samples compared to the brown rice (17.19 kg) may be resulted from occurring fracture during the expansion and contraction of grain volume

TABLE 1 Physical properties of brown rice and brown rice bulgur samples produced with two different methods

		Brown rice bulgur		
Physical properties	Brown rice	BRB-B	BRB-S	*Sign.*
Color values				
L^*	$61.64^a \pm 0.08$	$57.95^b \pm 0.13$	$57.53^c \pm 0.05$	**
a^*	$3.01^a \pm 0.35$	$2.90^a \pm 0.06$	$3.25^a \pm 0.15$	–
b^*	$17.53^a \pm 0.43$	$17.37^a \pm 0.14$	$17.91^a \pm 0.07$	–
Hardness (Uncooked, kg)	$17.19^a \pm 0.03$	$16.19^c \pm 0.04$	$16.99^b \pm 0.05$	**
Cooking properties of samples				
Weight changes (%)	$117.21^b \pm 0.97$	$182.82^a \pm 3.99$	$179.38^a \pm 2.05$	**
Volume changes (%)	$121.83^b \pm 5.31$	$184.87^a \pm 9.87$	$174.10^a \pm 11.68$	*
Hardness (kg)	$3.43^a \pm 0.09$	$2.53^c \pm 0.01$	$2.92^b \pm 0.01$	**

Note: The cooked samples represent the samples that have been prepared as meal. Superscript letters beside the mean values denote in the same line are significantly different by Duncan's multiple range test. ** and * represent significance level at $p \le .01$ and $p \le .05$, respectively.

Abbreviations: BRB-B, brown rice bulgur produced with boiling process; BRB-S, brown rice bulgur produced with steaming process.

in hydrothermal and drying processes, respectively. Moreover, micro fractures occurring because of the applied force during the grinding of dry BRB samples may have led to the measuring of lower hardness values in BRB-B and BRB-S samples by making breakage easier.

The cooking time 30 min in the brown rice sample, was decreased to 9 min in BRB samples. Morreale et al. (2019) reported that the cooking time of gluten-free pasta produced from brown rice flour is 10 min. The determined cooking time for this brown rice pasta, obtained by drying after applying different processes, is close to the cooking time determined in this research. After the cooking process, the weight and volume of samples increased by the reason of trapping water between chains, especially amylose gone out of the starch granule, based on the gelatinization during hydrothermal process. The applied methods were significantly affected the weight ($p < .01$) and the volume ($p < .05$), and caused their increment. It was evaluated that the weight and volume increment more occurred in the bulgur samples than brown rice, because there had many free ends and fractures that can bonded with water due to the bulgur production process. The applied methods significantly ($p < .01$) affected the hardness values of cooked samples, and these values changed between 2.53 kg and 3.43 kg. It was found that the hardness values of the samples decreased between 80% and 85% when cooked as meal. Rewthong et al. (2011) reported that the hardness value was in the range of 11.78–13.06 kg (115.55–128.07 N) after the rehydration of instant rice produced with boiling method.

3.2 | Chemical properties of brown rice and brown rice bulgur samples

Chemical properties and total starch hydrolysis curve of brown rice and brown rice bulgur samples produced with two different methods are given in Table 2 and Figure 2, respectively. The moisture content ($p < .05$), water activity value ($p < .01$), and ash content ($p < .01$) of samples were significantly affected by the applied methods and it was determined that the brown rice sample had the highest moisture and ash contents, and the lowest water activity value. For brown rice and BRB samples, the moisture content was meanly determined as 11.92% and 10.67%, respectively. The water activity values of these samples changed between 0.44 and 0.47. Ribeiro Oliveira et al. (2020) determined that the moisture content of broken rice grains was 12.45%. In a study reported by Shallan et al. (2010), the moisture contents of raw high and low-amylose brown rice samples were changed between 11.32% and 12.43%. In another study

TABLE 2 Chemical properties of brown rice and brown rice bulgur samples produced with two different methods

Chemical properties	Brown rice	Brown rice bulgur		*Sign.*
		BRB-B	BRB-S	
Moisture content (%)	$11.92^{a} \pm 0.27$	$10.23^{b} \pm 0.11$	$11.12^{ab} \pm 0.37$	*
Water activity	$0.44^{c} \pm 0.00$	$0.47^{a} \pm 0.00$	$0.46^{b} \pm 0.00$	**
Ash content (%)	$1.37^{a} \pm 0.00$	$1.17^{c} \pm 0.02$	$1.25^{b} \pm 0.00$	**
pH	$6.72^{a} \pm 0.00$	$6.65^{a} \pm 0.02$	$6.55^{b} \pm 0.02$	*
Total titratable acidity content (%)	$0.04^{a} \pm 0.00$	$0.03^{b} \pm 0.00$	$0.03^{b} \pm 0.00$	**
Total phenolic content (mg GAE/100 g)	$24.57^{a} \pm 0.01$	$15.34^{c} \pm 0.04$	$16.92^{b} \pm 0.09$	**
Total flavonoid content (mg QE/100 g)	$3.99^{a} \pm 0.17$	$2.52^{b} \pm 0.14$	$2.03^{b} \pm 0.13$	**
DPPH scavenging activity (%)	$78.08^{a} \pm 0.32$	$75.81^{b} \pm 0.01$	$77.99^{a} \pm 0.11$	**
Phytic acid content (mg/100 g)	$318.14^{a} \pm 1.92$	$272.57^{b} \pm 6.26$	$271.71^{b} \pm 0.81$	**
ERS content (%)	$0.14^{c} \pm 0.00$	$0.15^{b} \pm 0.00$	$0.17^{a} \pm 0.00$	**
Glycemic index				
C_{∞}	$26.45^{b} \pm 2.58$	$73.45^{a} \pm 10.86$	$68.15^{a} \pm 8.67$	*
k	$0.08^{a} \pm 0.01$	$0.03^{b} \pm 0.00$	$0.02^{b} \pm 0.00$	**
HI	$40.85^{b} \pm 4.26$	$99.13^{a} \pm 14.97$	$82.31^{ab} \pm 10.96$	*
eGI	$43.45^{b} \pm 1.63$	$65.83^{a} \pm 5.75$	$59.37^{ab} \pm 4.21$	*

Note: Superscript letters beside the mean values denote in the same line are significantly different by Duncan's multiple range test. ** and * represent significance level at $p \leq .01$ and $p \leq .05$, respectively.

Abbreviations: BRB-B, brown rice bulgur produced with boiling process; BRB-S, brown rice bulgur produced with steaming process.

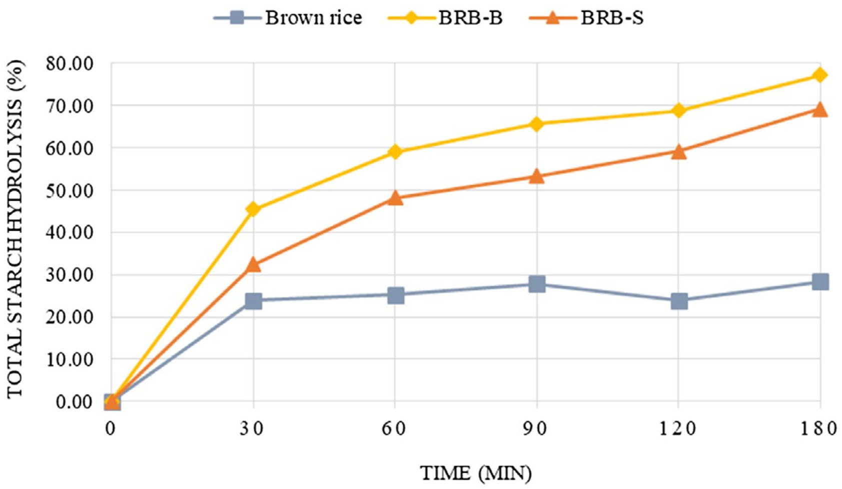

FIGURE 2 Total starch hydrolysis curve of brown rice and brown rice bulgur samples

carried out with 11 rice varieties, the moisture content ranged from 10.90% to 12.20% (Tao et al., 2019). Cao et al. (2004) indicated that the moisture content of rice grains less than 13% is necessary for safe storage. Also, Tapia et al. (2020) reported that the water activity value should be less than 0.61 in order to inhibit microbial growth during storage. Therefore, it was evaluated that the low moisture content and water activity values detected in current research suitable for keeping safe the samples during storage, because they were produced with the high-temperature thermal process and stored as dry. The BRB samples were produced from the brown rice with boiling and steaming methods and the samples were dried and ground as bulgur. Since the grain integrity have been lost in the hydrothermal processes, the bran became easily remove from the grain surface after drying process. It was evaluated that a sum of bran surrounded the grain was flaked off as a consequence of these production steps and grinding process. This ash decreasing in the BRB-B sample was higher than the BRB-S sample, because more attrition of grains each other was during boiling at BRB-B samples. Therefore, the ash content decreased from 1.37% to 1.17% for the boiling method and to 1.25% for steaming method because of bran loss. Shallan et al. (2010) reported that the ash contents of raw high and low-amylose brown rice samples changed between 1.66% and 1.38%.

The pH ($p < .05$) and TTA content ($p < .01$) of samples were significantly different from each other. It was evaluated that this is sourced from washing of brown rice for the production of bulgur samples.

Significant ($p < .01$) differences were determined between brown rice and BRB samples in terms of the total phenolic and flavonoid contents and these values decreased in BRB samples about 35% and 45% as regards brown rice sample, respectively. It was considered that this decrease resulted from being exposed to high temperature and flaking off the bran realized as a result of the applied hydrothermal and grinding processes in the bulgur production. The phenolics and flavonoids of cereal grains are found intensively in bran layer and their contents reduce with the bran separation (Tian et al., 2004; Yafang et al., 2011). Li et al. (2018) reported that the total phenolic content of different raw brown rice samples was ranged from 18.39 to 25.91 mg GAE/100 g. Gujral et al. (2012) reported that the total phenolic content decreased 50% after the extrusion process and as the extrusion temperature increased, total phenolic content decreased further. The total flavonoid contents of different brown rice varieties were found as 3.97–5.05 mg CE/100 g by Mir et al. (2016a) and it was indicated in the same study that the flavonoid content decreased with applied heat in puffing process.

The antioxidant activity of samples was significantly ($p < .01$) affected by applied methods and the BRB-B sample had the lowest DPPH scavenging activity of 75.81% result of the flaking off more bran compared to the other samples as expected. Mir et al. (2016b) found that the DPPH scavenging activity of brown rice changed between 46.18% and 70.51% based on the rice variety.

The applied methods significantly ($p < .01$) affected the phytic acid content of samples. Phytic acid prevents the absorption of divalent cationic minerals such as Fe, Zn, Mg, and Ca, because it constitutes complexes with these minerals. Therefore, the phytic acid is evaluated as an antinutrient factor (Liang et al., 2007). This value was meanly determined in brown rice and BRB samples as 318.14 and 272.14 mg /100 g, respectively. In BRB samples, the phytic acid content decreased by 15% according to the brown rice sample. The phytate, the salt form of phytic acid, is found intensively in outer bran and aleurone layers of rice. When these layers are separated for any reason or thermal process is applied to the grain, the phytate content decreases (Almana, 2000). Therefore, it was considered that the applied hydrothermal processes, and then, flaked off the bran in grinding process after drying were effective on this decreasement. In a study, it was reported that there was 551.00–750.00 mg/100 g of phytic acid in high and low-amylose raw brown rice samples, but these values decreased to 480.00–671.00 mg/100 g in cooked samples. In the same study, the phytic acid reduction by cooking process was calculated as 13% and 11% for high and low-amylose samples, respectively (Shallan et al., 2010).

The ERS, defined as the starch form resistant to digestive enzymes (Kim et al., 2020), was significantly ($p < .01$) affected by applied methods. The ERS content of BRB-B (0.15%) and BRB-S (0.17%) samples was higher than that of brown rice (0.14%) about the ratio

TABLE 3 Sensorial properties of brown rice and brown rice bulgur samples produced with two different methods

			Brown rice bulgur		
Sensorial properties	White rice	Brown rice	BRB-B	BRB-S	*Sign.*
Color	$4.75^{a} \pm 0.05$	$3.50^{b} \pm 0.20$	$3.90^{b} \pm 0.10$	$3.70^{b} \pm 0.20$	*
Odor	$3.75^{b} \pm 0.05$	$3.95^{a} \pm 0.05$	$3.80^{ab} \pm 0.00$	$3.85^{ab} \pm 0.05$	*
Hardness	$3.25^{b} \pm 0.05$	$3.15^{b} \pm 0.15$	$4.10^{a} \pm 0.10$	$3.75^{a} \pm 0.15$	*
Taste	$2.80^{c} \pm 0.20$	$4.05^{a} \pm 0.05$	$3.75^{ab} \pm 0.15$	$3.05^{bc} \pm 0.25$	*
Aroma	$2.85^{b} \pm 0.05$	$4.00^{a} \pm 0.10$	$3.55^{ab} \pm 0.05$	$3.35^{ab} \pm 0.35$	*
Mouthfeel	$3.10^{b} \pm 0.10$	$3.95^{a} \pm 0.25$	$3.70^{ab} \pm 0.00$	$3.30^{ab} \pm 0.20$	*
Overall	$2.90^{b} \pm 0.10$	$3.75^{a} \pm 0.25$	$3.75^{a} \pm 0.05$	$3.40^{ab} \pm 0.10$	*

Note: Sensory analysis was carried out with cooked samples as meal. Superscript letters beside the mean values denote in the same line are significantly different by Duncan's multiple range test. ** and * represent significance level at $p \le .01$ and $p \le .05$, respectively.

Abbreviations: BRB-B, brown rice bulgur produced with boiling process; BRB-S, brown rice bulgur produced with steaming process.

of 9% and 21%, respectively. This increment may have resulted from the retrogradation of gelatinized starch, occurred in hydrothermal processes, during drying step of brown rice bulgur production at 25°C. In addition, the starch gelatinization may have more actualized in steamed samples because the hot vapor can have easily reached into the deep of grain and that cannot have accessed with boiling method. Therefore, it was evaluated that this situation had increasing effect on ERS content of BRB-S sample. Hu et al. (2004) found that the ERS content of different brown rice cultivars ranged from 0.00 to 3.20 and the ERS content of rice cultivars containing high amylose were higher than those of rice cultivars containing low amylose. In another study, the ERS contents of cooked with different methods and dried brown rice samples were reported between 1.07% and 2.63% (Kim et al., 2020).

There was a significant effect of the applied methods on the C_∞ ($p < .05$), k ($p < .01$), and HI ($p < .05$) hydrolysis kinetics parameters and eGI value ($p < .05$) of samples. The foods are classified into three groups as high ($GI \ge 70$), medium ($56 \le GI \le 69$), and low ($GI \le 55$) GI foods based on the glucose reference (Schakel et al., 2008). According to obtained eGI results, brown rice sample was in the low GI food group, while BRB samples were in the food group of medium GI. It was evaluated that the eGI values of BRB samples were higher than that of the brown rice samples because of the lack of retrogradation and decreasing the bran ratio to the grain. White rice has high starch content, and therefore, it is taken part among the high GI foods in classification (Kim et al., 2020). However, it was evaluated that the eGI value of brown rice used in this research was low as the brown rice has high bran content compared to the white rice. Hu et al. (2004) stated that the eGI values of cooked brown rice samples were ranged from 60.10 to 106.30 compared to white bread reference (42.03–74.34 in glucose reference) and these values decreased with retrogradation process to 54.90–94.60 (38.39–66.15 in glucose reference). Srikaeo and Sopade (2010) indicated that when the retrogradation and molecular reorganization are not realize adequately, the gelatinization increases the digestibility.

3.3 | Sensorial properties of brown rice and brown rice bulgur samples

Sensorial properties of white and brown rice and brown rice bulgur samples produced with two different methods are given in Table 3. The significant ($p < .05$) differences were determined between samples in terms of all sensorial parameters. It was determined that the produced BRB samples were scored 3 or more when these samples were evaluated according to 5-point hedonic scale, and the BRB samples were generally liked further with respect to the white rice. In addition, some of panelists attended to the sensory analysis specified that the taste and aroma of BRB samples resemble to wheat bulgur. When it is made an overall evaluation, it is considered that the sensory acceptability of generated product by processing of brown rice to BRB is very high.

4 | CONCLUSION

The brown rice, a gluten-free cereal product, has important nutritional components such as dietary fiber, phenolic compounds, and flavonoids. In addition, the eGI value of brown rice is very low compared to the white rice. Therefore, the brown rice consumption instead of white rice is recommended. However, the brown rice is not preferred by consumers due to the dark color, hard texture, and long cooking time. While the brown rice bulgur as a new gluten-free food product was produced by using brown rice, the 30 min cooking time in brown rice was decreased to 9 min in brown rice bulgur samples with the study. The produced bulgur samples were in the group of medium GI foods and they have low phytic acid content compared to brown rice. In addition, the new bulgur product more liked compared to white rice in sensory evaluation. It is concluded that the new improved brown rice bulgur is superior than brown rice in terms of short cooking time, white rice in terms of lower GI and wheat bulgur in terms of being gluten-free.

ACKNOWLEDGMENTS

The authors would like to thank Başhan Agricultural Products Inc., because of providing the brown rice, and Akdeniz University for technical support.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

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

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How to cite this article: Candal-Uslu C, Mutlu C, Koç A, Bilgin DG, Erbaş M. A new gluten-free product: Brown rice bulgur, and its physical and chemical properties. *J Food Process Preserv*. 2021;00:e15205. https://doi.org/10.1111/jfpp.15205