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Evaluation of chemical composition and cooking properties of Turkish type gluten-free rice couscous

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Abstract: In this study, the aim was to produce traditional couscous in gluten-free form. For this purpose, rice flour (RF) and pre-treated (gelatinized) rice flour (GRF) were added in varying proportions (15, 20, 25, and 30%) to the recipe instead of gums and enzymes in order to provide the desired structure. The control sample without GRF was also produced. With the addition of GRF, the total dietary fibre (TDF) content in the couscous samples increased, and reversely the carbohydrate and energy values decreased. The GRF reduced the level of total soluble organic material (TSOM) as well as the cooking loss of the couscous samples, which resulted in lower deformability. According to the results, the gluten-free rice couscous was successfully produced with GRF, especially at a 30% ratio. Good cooking properties were observed in these couscous samples. In this context, in the addition of 30% GRF, higher water absorption and swelling volume with lower cooking loss were observed compared with the control sample. In addition, the couscous samples had higher ash, dietary fibre and fat content as well as a lower phytic acid ratio ($P < 0.05$). It was determined that there was significant correlation between the cooking time of the samples with the cooking loss and total soluble organic material. According to the results, the PCA showed that there were clear correlations between cooking trials (water absorption and swelling volume) and chemical composition (moisture, ash, crude fat, and TDF).

Keywords: gluten-free pasta like product; rice flour; pregelatinized flour; chemical constituent; phytic acid; cooking trial

Couscous is a semi-ready foodstuff typical within the Mediterranean region, which has been produced in the winter period for years (Coşkun 2010); it belongs under the so-called 'pasta-like' products. The importance of couscous has been increasing recently due to its practical usage, fast preparation, taste and range of utilization in different meals (Yüksel et al. 2018) as well as its pleasant flavour and nutritional benefits. Couscous is known as 'kuskus' in Türkiye, 'couscous' in Morocco, 'matfoul', 'moghrabieh' in Lebanon, 'seksui', 'keskeu' in Berbers, 'kusksi' in Libya, and 'kouskousaki' in Greece (Coşkun 2013), with local differences in piece diameter between ca 2–10 mm. In contrast to a few studies on couscous in Türkiye, studies conducted in the world mostly focused on sorghum couscous. In Türkiye, couscous, which is obtained by coating wheat bulgur with dough made from flour and water/milk, is a traditional cereal product. In couscous production, the egg can also be used, and couscous can be enriched with different flour types such as soy or oat flour (Çelik et al. 2004).

Depending on product formulation, production technique and utilization, there are three types of couscous: Turkish style, African style and pasta-like. Unlike the African type of couscous that is mainly produced only from semolina and water (Yuksel et al. 2018), traditional Turkish type of couscous includes semolina, egg, milk or water, and bulgur. At the same time, de-

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spite Turkish and African types, which are produced traditionally by hand, pasta-like couscous (e.g. Israeli 'ptitim' as reported by Grosglik and Lerner 2020) is generally produced mechanically using a pressing technology (Çelik et al. 2004).

For the couscous, pasta and noodles, technological properties such as cooking time, water absorption, cooking loss and increase in swelling volume are considered quality characteristics. During pasta cooking, pieces should demonstrate shape stability, low rate of disintegration as well as low cooking loss (Köksel et al. 2000; Yalçın and Basman 2008). The excess amount of substance extracted into the water causes the cooking water to become cloudy, have low cooking tolerance and have pasta stickiness (Sözer and Kaya 2002); finally, the appearance deteriorates. It is desirable the swelling volume increase in pasta, noodles, and couscous should be as high as possible, maintaining the pasta's cohesiveness and texture at the same time. The low change in swelling is an indication of insufficient water absorption, resulting in a harder structure after cooking (Bhattacharya et al. 1999). On the other hand, good quality couscous should not be deformed during cooking. A large amount of starch passed into the cooking water deforms the product, which increases the stickiness and clumps single pasta pieces together. One of the measures of this mass extraction rate is the value of TSOM (Köksel et al. 2000).

In recent years, celiac disease has been one of the most common chronic autoimmune diseases (Rubin and Crowe 2020). It is defined as a genetic disorder caused by the consumption of proteins defined as prolamine in cereals and causes malabsorption in the small intestine (Moroni et al. 2009). Studies have shown that grains of cereals such as maize, sorghum, rice, and altamura (a kind of durum wheat, native to the Apulia region, South-East Italy) and especially pseudocereals quinoa, or buckwheat do not contain any gluten protein and are suitable for consumption by celiac patients (Arendt and Dal Bello 2008). Although rice is generally consumed in cooked form (side dish or e.g. as pilaf), there are many commercial rice products such as baby food, popped grain, noodles, and snack foods. Today, rice or maize starch is also used to substitute wheat in the production of gluten-free foods (Lucisano et al. 2012).

Recently, it has been reported that pre-gelatinized rice flour (GRF) is widely used in the production of many foods such as gluten-free formulas, pie fillings, cake frostings and puddings (Fennema 1996). Since it can provide viscosity and texture control, it is useful as a thickening and bulking agent (Zhou and Huri 2014). GRF rehydrates instantly in water, providing a uniform high-viscosity batter without the need for heat. It is also reported that GRF improves its technological properties, appearance and sensory attributes, especially in bread and cake manufacturing (Ding et al. 2021). In the production of gluten-free goods, gums such as xanthan, guar, and locust bean one, or enzymes such as transglutaminase, are added to the product in order to alter the function of gluten.

The objective of this study is to produce rice couscous in the gluten-free form which is a traditional food consumed by the majority of Turkish society. However, in order to develop the desired structure of the couscous, GRF was used instead of gums and enzymes. This study should provide an alternative product potentially acceptable for celiac patients and individuals preferring gluten-free diet. As a consequence, manufacturing on a laboratory scale was carried out with the preservation of both traditional and technological properties. In the current research, the effects of the addition of the GRF on the proximate chemical composition and cooking properties of the couscous samples (cooking time, water holding capacity, swelling volume and cooking loss) were determined. By a multivariate statistical method, the couscous variant of the highest nutritional, as well as technological quality was also assessed.

MATERIAL AND METHODS

Material

As a basic material, the local type of rice (*Oryza sativa* L.) called Konuralp Rice was used. It was obtained from a local farmer (Duzce, West Black Sea Region, North Türkiye, 40°53'.51"N and 31°9'.34"E). The whole-fat cow's UHT milk (3%), cage-free chicken eggs and table salt were purchased from a local market in Duzce, Türkiye.

Methods

Production of rice flour. RF was produced by two different methods: one directly from raw rice and the other from GRF. For the production of RF, the raw rice grains were milled in a hammer mill (Bastak 1900; Bastak Instruments, Türkiye, 16 800 rpm, 300 g in 30–50 s) and RF was obtained by sieving it through a 212 µm sieve. Obtained RF was kept in glass jars in a refrigerator (No-frost; Vestel, Türkiye, temperature between 0 and +4 °C) until further analyses.

Production of pre-gelatinized rice flour. The GRF was produced as below. The pregelatinization con-

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dition was determined by preliminary trials (conditions not presented) and obtained results showed that optimal pregelatinization conditions are as follows: firstly, the raw rice grains were steeped in boiling water at a ratio of 1 : 2 and kept for 6 h. The steeped rice grains were then drained by buchner funnel and steamed under pressure (household pressure cooker) for 90 min without contact with water while opened and mixed at 15 min intervals. At the end of this period, the gelatinized rice grains were dried in a hot air dryer (G11540SD; Termal, Türkiye) at 50 °C for 12 h to 13% moisture content and cooled to room temperature. The dried rice grains were then milled in a hammer mill (Bastak 1900; Bastak Instruments, Türkiye, 16 800 rpm, 30–50 s) to obtain gelatinized 212 µm rice flour. Obtained RF was kept in glass jars in a refrigerator (No-frost; Vestel, Türkiye, temperature between 0 and +4 °C) until later usage.

Rice flour mixture. To obtain the rice flour mixture RF and GRF were mixed in varying proportions as follows: 100 : 0, 85 : 15, 80 : 20, 75 : 25, 70 : 30 (RF : GRF). In the text below, codes like 100 RF for the control couscous and simplified ones 15 GRF, 20 GRF, 25 GRF, and 30 GRF for the enhanced foursome are used (instead of the full name 85 RF : 15 GRF, etc.).

Production of broken rice. In order to obtain the broken rice grain, the whole-grain rice sample was ground with a coffee grinder (MKM6; Bosch, Germany), 40 g for max. 25 s. The BR grains were sieved, and the collected fraction had granulation in an interval < 1.25; 1.50 > mm. These BR grains were stored in a glass jar in a refrigerator (No-frost; Vestel, Türkiye, temperature between 0 and +4 °C, RH 13%) and used in traditional couscous manufacturing instead of the fine bulgur.

Production of couscous. The couscous samples were manufactured at Duzce University, Agricultural Faculty, Food Technology Laboratory in Duzce, Türkiye based on the traditional, i.e. home-type couscous production method (Aydin G., personal communication, July 15, 2018). The couscous was produced using a couscous wooden bowl according to completely traditional techniques. The control couscous sample was produced using the quantity of 100% rice flour, i.e. without enhancement by GRF. Control couscous was prepared as follows: 1 000 g broken rice was placed in a wooden bowl and wetted with 20–30 mL of liquid mixture which was prepared with milk, fresh whole egg and salt (three ingredients were mixed manually to obtain a liquid couscous mixture until a homogeneous mixture obtained) to soften the broken rice for 10 min. At the end of this time, RF and liquid couscous mixture were added to the softened broken rice grains. Then, the mixture was rolled by hand while RF was added. These wetting, RF addition and rolling processes were continued until the couscous pieces of 3–5 mm in diameter were formed by rotating in the palm in one direction. Whether the couscous grains reached the desired diameter was determined by sieving them in a couscous sieve, and the same process was continued for the smaller ones. An amount of 150 g RF and a 150 mL liquid couscous mixture were added. The couscous grains, rounded in the desired diameter, were dried until the moisture content fell below 10% in a shady place without receiving direct sunlight. The dried couscous samples were kept in glass jars in a refrigerator (temperature between 0 and +4 °C, RH 13%) until further analyses. The same process was adopted for other samples, which were produced with GRF replacing 15, 20, 25 or 30% of rice flour. Table 1 shows the formulation of the couscous variants.

Chemical analyses. American Association for Chemical Chemistry (AACC Approved Methods of Analysis 2010) methods were followed for the determination of the moisture, total ash, crude protein, crude fat and total dietary fibre (TDF) content of the couscous sam-

Table 1. Production formula of couscous samples (at 21 ± 1 °C)

Sample codes	Ingredients					
	BR[b] (g)	RF[b] (g)	GRF[b] (g)	milk (mL)	whole egg (g)	salt (g)
100 RF (control)	1 000	500	0	500	100	1
15 GRF	1 000	425	75	500	100	1
20 GRF	1 000	400	100	500	100	1
25 GRF	1 000	375	125	500	100	1
30 GRF	1 000	350	150	500	100	1

[a]14% moisture basis; BR – broken rice; RF – rice flour; GRF – gelatinized rice flour

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ple (AACC Method No. 44–15A, 08–01.01, 46–12, 30–25.01, and 32–21.01, respectively; AACC 2010). The total carbohydrate content and energy values of the couscous samples were determined according to the Food and Agriculture Organization (FAO) and both features were calculated using the Atwater general factor system (FAO 2003), according to Equations 1 and 2, inserting the values of all chemical components in (%):

$$\text{Total carbohydrates (\%)} = 100 - (\text{moisture} + \text{ash} + \text{protein} + \text{fat} + \text{TDF}) \quad (1)$$

$$\text{Energy (kcal)} = 9 \times \text{fat} + 4 \times \text{protein} + 4 \times \text{carbohydrates} \quad (2)$$

where: TDF – total dietary fibre.

The macro (K, P, Ca, Mg) and micro (Fe, Cu, Zn, Mn) mineral matter of the couscous sample was determined by inductively coupled plasma-optical emission spectrometry (ICP-OES) (Optima 3100 XL; Perkin Elmer, USA) equipped with inductively coupled plasma unit (ICP-OES equipment; Perkin Elmer, USA) according to the standards TS 3660 (2007; Determination of metallic elements TS 3660, Turkish Standard Institution, Ankara) and Julshamn et al. (2007). The emission intensities were obtained for the most sensitive lines free of spectral interference. The analyses were performed at the following flow rates: plasma gas of 15 L min^{-1}, auxiliary gas of 1 L min^{-1}, and sample of 0.8 mL min^{-1}. The mineral eluates were monitored at different wavelengths: potassium 766.5 nm, magnesium 285.2 nm, phosphorus 214.9 nm, iron 238.2 nm, calcium 317.9 nm, cupric 327.4 nm, zinc 206.2 nm, and manganese 257.6 nm.

Phytic acid is found in cereals, legumes, nuts and oil seeds; it has the ability to bind minerals, proteins and starches, it reduces the absorption, digestion and functionality of all these nutritional components (Oatway et al. 2007; Demir and Bilgiçli 2020). The phytic acid content of the samples was evaluated by a colorimetric method according to Haug and Lantzsch (1983). The phytic acid in samples (0.3 g) was extracted with a 0.2 N solution of HCl and precipitated with a solution of $Fe(NH_4)2(SO_4)_2 12\ H_2O$. The amount of the ferric ions in the supernatant was measured at 519 nm with a spectrophotometer (UV-1800; Shimadzu, Japan) and distilled water was used as a blank. The phytic acid content of the samples was calculated from this absorbance value. All of the chemical analyses were performed in triplicate.

Couscous cooking test. The cooking properties of couscous are of great importance with regard to consumer acceptance. In the present study, the cooking time, water absorption (weight increase), swelling volume (volume increase) and cooking loss of the couscous samples were determined as described by the AACC methods No 66–50.01, 56–20.01, 56–21.01 and 66–50.01, respectively (AACC 2010). Instead of the sediment volume, the total soluble organic material (TSOM) was determined according to D'Egidio et al. (1982). The fundamentals of this method are based on washing the surface of the couscous samples after cooking, passing the materials on the surface into the water, and then determining the amount of organic matter in the washing water by chemical methods. Briefly, the 100 g couscous sample was cooked in boiled water for 20 min and the cooked samples were drained and let cool for 10 min. At the end of the time, the sample was poured into a beaker which contained 500 mL of distilled water. The sample was stirred three times every 4 min and filtered. The 5 mL filtrate was poured into a beaker and the water was evaporated in the boiling water bath. Then, 10 mL of 1N $K_2Cr_2O_7$ and 20 mL of H_2SO_4 were added and stirred for a minute. After 30 min resting, 200 mL of pure water was added, and diphenylamine was dripped. The 5N solution of $Fe(NH_4)_2(SO_4)_2$ was used for titration. The obtained results were interpreted as follows:

TSOM	2.1–100.0%	low quality pasta
TSOM	1.4–2.1%	good quality pasta
TSOM	0.0–1.4%	very good quality pasta

The cooking test was carried out three times for each sample.

Statistical analyses. The data obtained in three replicates were evaluated statistically by using ANOVA in the form of the LSD (Least Significant Differences) test and correlation analysis at $P < 0.05$ (JMP IN 7.0.0 software; SAS Institute Inc., USA). Besides verification of the dependence of the cooking trial parameters on the chemical composition, correlation analysis allowed the exclusion of macro- and micro-mineral contents from the data set of the Principal Component Analysis (PCA). The aim of this multivariate explorative method lay in the possibility of prediction of the best consumer's quality of the prepared rice couscous in a complex of determined chemical and technological features.

RESULTS AND DISCUSSION

Chemical composition of couscous

The chemical characteristics of the couscous samples were compared with the Turkish Food Codex Com-

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muniqué on Pasta, standard TS 1620 (Turkish Pasta Standard TS 1620, Turkish Standard Institution, Ankara 1989). The results obtained for the chemical compositions of the couscous samples are given in Table 2.

The amount of moisture in couscous is an important quality criterion in terms of the drying process control (if it is complete or not). The moisture levels of the couscous samples ranged between 13 and 12%; within TS 1620, the prescribed maximum is equal to 13.0%. The lower moisture content in the final product is very important in terms of quality preservation and longer shelf life, or overseas transport in the case of rice noodles. In the present study, with the addition of GRF in the couscous production, the moisture content of the samples increased significantly ($P < 0.05$).

The ash content of the couscous samples was found between 1.120 and 0.940% (Table 2). As the ratio of GRF in the flour mixture increased, the ash portion in the couscous samples also rose. Similarly, Benatallah et al. (2008) reported that gluten-free couscous samples based on rice-chickpea and rice-proteaginous pea (1.34 and 1.12%, respectively) had the slightly higher ash content than the rice-field bean (1.00%). Tarim (2012) reported the ash content in vegetable purée-based couscous specimens was in the range of 1.10–1.18%. In another study of Demir and Demir (2016), in couscous containing different legume flours (soybean, chickpea, common bean, lentil and lupine) the ash content increased from 2.26 to 0.86%.

The protein contents of the manufactured couscous samples diminished from 10.34% to 7.72%, reflecting a stepwise rise in the GRF ratio. The main cause of this decrease could be disruption or dissolution of water-soluble proteins as affected by gelatinization. Çelik et al. (2004) and Demir et al. (2010) published the average protein content of 9.81%, 11.04% and 11.80% in experimental couscous, respectively. The softly increasing trend could be explained by dependence on the flour type included in couscous production (some vegetable purées, soy-oat flour vs. chickpea flour, respectively). In terms of fat content, the level ranged between 2.48 and 2.74% in the own couscous samples (Table 2).

On the other hand, the TDF amount of the couscous samples varied between 1.64 and 1.13%. With the addition of GRF to the couscous production, the TDF content of the couscous samples increased in a statistically verifiable extent, but insignificantly from the nutrition point of view ($P < 0.05$). The highest TDF level was logically determined in the 30 GRF sample. According to the FDA, the recommended dietary fibre intake is 28 g per day (FDA 2022). Namely, the produced couscous samples can provide approximately 6% of dietary fibre per consumed 100 g portion. Although this ratio is rather low, it can be a good source to promote the consumer's health during long-term consumption.

As the carbohydrate mass of the couscous samples varied between 75.94 and 73.95%, the energy values varied softly (between 346.9 and 332.4 kcal). Along with the rising GRF ratio in couscous variants, the carbohydrate and energy values of the couscous samples decreased although it might seem that pre- GRF may have higher digestibility. The lowest values were obtained for the 30 GRF sample.

The phytic acid content of the couscous samples was determined between 110.6 and 104.4 mg 100 $^{g-1}$ (Table 2). As was expected, the phytic acid content of the couscous samples decreased significantly ($P < 0.05$)

Table 2. Chemical compositions of selected samples of gluten-free rice couscous

Couscous sample	Moisture (%)	Ash (%)	Crude fat (%)	Proteins (%)
100 RF (control)	12 ± 0.03^{b}	0.940 ± 0.005^{b}	2.48 ± 0.01^{c}	10.34 ± 0.32^{a}
20 GRF	13 ± 0.01^{a}	1.070 ± 0.008^{ab}	2.59 ± 0.00^{b}	8.33 ± 0.05^{b}
30 GRF	13 ± 0.01^{a}	1.120 ± 0.006^{a}	2.74 ± 0.01^{a}	7.72 ± 0.61^{c}
Couscous sample	**Total dietary fibre (%)**	**Phytic acid (mg 100g^{-1})**	**Carbohydrates (%)**	**Energy (kcal)**
100 RF (control)	1.13 ± 0.00^{c}	110.65 ± 3.58^{a}	75.94 ± 0.12^{a}	347 ± 2^{a}
20 GRF	1.32 ± 0.01^{b}	107.34 ± 3.48^{b}	74.70 ± 0.42^{bc}	336 ± 2^{b}
30 GRF	1.64 ± 0.01^{a}	104.36 ± 4.13^{d}	73.25 ± 1.23^{c}	332 ± 0^{c}

$^{a-c}$Mean values ± standard deviation with different superscript in the same column are significantly different ($P < 0.05$); RF – rice flour; GRF – pre-gelatinized rice flour; 20 GRF – flour blend (couscous sample) mixed in ratio 80 : 20 of RF and GRF, respectively with the GRF addition. The phytic acid content of the raw rice grain was found to be 330 mg 100 g^{-1} (Yilmaz 2018). While the phytic acid content was reported as 198 mg 100 g^{-1} in wheat flour (Demi et al. 2010), this rate was reported as 987 mg 100 g^{-1} in chickpea flour, which is a legume. It has been reported by Bilgiçli and Elgün (2004), some process techniques such as fermentation, germination, soaking and cooking are effective in the extinction of phytic acid.

A change in the macro and micro mineral contents for the selected couscous variants is illustrated in Figures 1A and 1B, respectively. According to the results, the most abundant macro mineral was found to be K, ranging from 1 523 mg kg^{-1} to 1 792 mg kg^{-1} dry weight. Compared with the control samples, contents of K, P, Mg, Zn, and Mn in the couscous samples increased as a result of enhancement with the GRF. On the other hand, the level of Ca, Fe, and Cu decreased with the diminishing ratio of RF in blends. The Zn element (21–19 mg kg^{-1}) was detected as the most abundant micro mineral in the manufactured couscous. Demi et al. (2010) noted these amounts of minerals for the own couscous types: 1 014 ± 31.68 mg kg^{-1} Ca, 467 ± 15.4 mg kg^{-1} Mg, 6 420 ± 245 mg kg^{-1} K, 2 980 ± 35.7 mg kg^{-1} P, 30 ± 0.73 mg kg^{-1} Fe and 17 ± 0.37 mg kg^{-1} Zn. In another study, K, Ca and Fe contents of couscous prepared from oat were found to be 4 096 ± 35.74 mg kg^{-1}, 600 ± 6.12 mg kg^{-1} and 34 ± 0.02 mg kg^{-1}, respectively (Çelik et al. 2004). It has been determined that the mineral contents of the couscous samples in the presented references are quite different from each other depending on the raw materials used.

Couscous cooking properties

Structural properties of cereal products such as couscous, pasta and noodles are related to the cooking quality of the goods. For this reason, it is very important to provide the desired structure, especially in the manufacture of gluten-free food. Alternating plant gums and enzymes used in industry, GRF was tested to provide the demanded structure in the gluten-free rice couscous.

The cooking properties of the couscous samples are summarised in Table 3. It could be noticed the optimal cooking time of the control and enhanced counterparts have been shortened from 15 to 12 min. As reported by Ma et al. (2022), pregelatinization may enhance the water absorption and swelling power of starch. This may explain the shorter cooking time for couscous samples produced with GRF. Yalçın and Basman (2008) found that the cooking time (10 min) of rice noodles was shorter than that of the noodles made from wheat flour and explained the finding by the higher protein content of wheat. In the present study, the cooking time of couscous samples was found to be longer than that of rice noodles. It is thought that this is due to the use of rice directly instead of semolina or bulgur in couscous production. It has been reported that not only the particle size and shape (Nawaz et al. 2016) but also the high protein (Martin and Fitzgerald 2002) and amylose content (Yu et al. 2009) of the flour can cause the prolongation of cooking time.

The cooking loss is an important criterion in terms of determining the quality of pasta and noodles. Any type of pasta should not be dispersed and deformed dur-

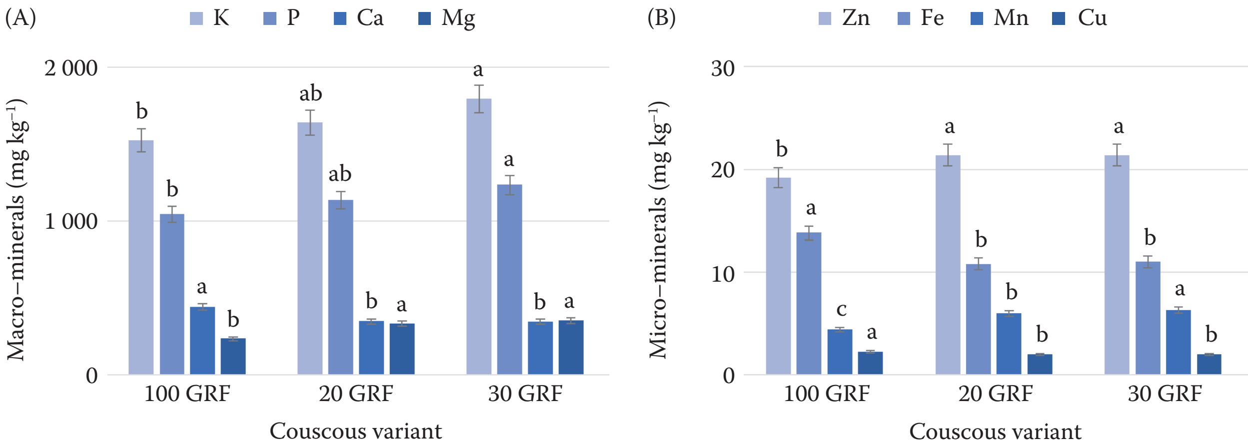

Figure 1. Effect of enhancement by pregelatinized rice flour on (A) macro and (B) micro mineral contents in gluten-free rice couscous

100 RF – control; non-enriched rice flour couscous; 20 GRF – couscous variant mixed in ratio 80 : 20 from rice flour and pre-gelatinized rice flour, respectively

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Table 3. Cooking trial results of selected samples of gluten-free rice couscous

Couscous sample	Cooking time	Water absorption	Swelling volume	Cooking loss	TSOM
	(min)	(%)	(%)	(%)	(%)
100 RF (control)	15.0	114 ± 1[e]	104 ± 0[e]	16 ± 5[a]	3.18 ± 1.07[a]
20 GRF	12.0	119 ± 7[c]	116 ± 2[c]	8 ± 0[c]	2.62 ± 9.75[c]
30 GRF	12.0	136 ± 6[a]	173 ± 4[a]	7 ± 0[e]	2.33 ± 9.76[d]

[a–e]Mean values ± standard deviation with different superscript in the same column are significantly different ($P < 0.05$); TSOM – total soluble organic material (mass extracted during cooking); RF – rice flour; GRF – pre-gelatinized rice flour; 20 GRF – flour blend (couscous variant) mixed in ratio 80 : 20 of RF and GRF, respectively

ing cooking, and it should maintain its shape and fresh feature. In other words, the cooking loss should be low (Köksel et al. 2000). The high cooking loss can be identified according to a sticky surface. Aboubacar and Hamaker (2000) reported the stickiness of the cooked couscous is related to the amount of damaged starch present. Likewise, Izydorczyk et al. (2005) mentioned that the cooking loss could be attributed to the weakening and/or disruption of the protein-starch matrix. It can be concluded that applying the pregelatinization process before milling rice to flour can reduce the rate of starch damage. According to the results of the present study, the cooking loss values for the control couscous and fortified counterparts were reduced twice at least by 30GRF (from 15.94 to 6.65%; Table 3). Here the known relation to shortened cooking time was confirmed (correlation $r = 0.87$, Table 4. Together with the shorter intervals of couscous preparation, the addition of GRF demonstrated a similar verifiable effect ($P < 0.05$). According to the Turkish Food Codex Communiqué on Pasta, the level of pasta cooking loss should be at most 10%. With the exception of the control sample, all couscous variants containing the GRF fulfil this recommendation. Demi et al. (2010) reported that in the couscous samples produced from raw chickpea flour the values of the cooking loss were found between 5.50 and 8.15%. For a better understanding of the cooking loss of pasta from different plant materials, some retention capacity test or pasting proof (e.g. the visco-amylograph one) with the determination of hot gel stability and rate of its retrogradation should be carried out. Marti et al. (2013) found the cooking loss of gluten-free pasta samples made using GRF was higher than that of pasta samples produced from untreated rice flour. From a microscale viewpoint, the pregelatinization treatment caused an increase in the hardness of starch molecules due to the recombination of amylose and/or amylopectin, thus reducing the formation of water-soluble substances (Lai and Cheng 2004).

In food products of pasta type, the rate of water absorption during cooking has a direct impact on consumer quality. The low water absorption level causes a hard structure after cooking. The water absorption values of the couscous samples varied between 114% and 136%. A similar tendency was uncovered for the swelling volumes, which were calculated in a range of 104–173%. It was observed that the gelatinization process applied to RF had a statistically significant effect on both parameters of couscous consumer quality ($P < 0.05$; Table 3). Similarly, Yalçın and Basman

Table 4. Significant correlation between results of the couscous cooking trial

Variable	Cooking time	Water absorption	Swelling volume	Cooking loss	TSOM
Cooking time	–	–	–	0.98	0.92*
Water absorption	–	–	0.96*	–0.70	–0.90*
Swelling volume	–	0.96*	–	–	–
Cooking loss	0.98*	–	–	–	0.93*
TSOM	–	–0.90*	–	0.93*	–

TSOM – total soluble organic material (mass extracted during cooking); *significant correlation at $P < 0.05$ (for $n = 5$, $r_{crit} = 0.87$); r_{crit} – critical values for the correlation coefficient r

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(2008) investigated the increase in the swelling volume of noodles containing GRF. According to this study, the swelling volume of the noodles was found to be between 140 and 158%. The low swelling volume increase is an indication of lower water absorption, which causes an elevation in noodle hardness after cooking (Bhattacharya et al. 1999). Marti et al. (2013) reported that the swelling of gluten-free pasta samples made using GRF was higher than that of pasta samples produced from untreated rice flour. Besides, it is noteworthy that as the protein ratio of the couscous samples decreased, the water absorption rates increased (Table 5). As the amount of protein increases, the strong protein network prevents the diffusion of water to starch granules (Sözer and Kaya 2002). Pasta hydrated at a lower rate could not likewise demonstrate a higher cooking loss.

The analysis of the TSOM is based on the detection of starch and other organic components on the surface of cooked spaghetti (Yalçın and Basman 2008). An excessive amount of 'free' material on the pasta surface increases the total soluble organic material (TSOM) value (Kruger and Matsuo 1996), worsening the final quality. With the higher ratio of starch extracted into the cooking water, the higher stickiness of the pasta could be considered, followed by an undesirable rise of the value (Köksel et al. 2000). As mentioned in the part of Methods (couscous cooking test), critical limits are 1.4–2.1% and > 1.4% for the pasta of good and very good quality, respectively. These values are valid for pasta made from durum wheat flour (Köksel et al. 2000). In the present study, the TSOM value of the couscous sample became lower from 3.18% to 2.33%, i.e. for 100 RF control and 30 GRF specimen (Table 3). For rice noodles, Yalçın and Basman (2008) calculated the TSOM between 1.40 and 2.15%. These results are lower than in the present study about ca 1.0 percent point. The couscous sample with RF was found to be of lower quality compared to pasta made from durum wheat ‑ as mentioned above, rice protein could not form gluten in the case of water-dough preparation. Compared to the control couscous, however, the TSOM levels diminished due to the magnifying rate of fortification with GRF, resulting in weaker deformation of the couscous.

Statistical evaluation of data

Correlation analysis. The correlation analysis showed that there are significant correlations between the chemical composition of manufactured couscous and cooking trials, some of which are positive, and the rest are negative (Table 5); they were mentioned above within the test. Similarly, significant correlations between the parameters of cooking trial were observed: the longer the cooking time, the higher the cooking loss and TSOM increased. Swelling volume is logically based on the rate of water absorption, while TSOM is decreasing.

Principal component analysis. The results of the PCA (PCA) visualised the results of the correlation analysis, i.e. the relationships between samples and observed traits. For all five variants of couscous, whose quality was described by 8 analytical parameters and 5 cooking trial attributes, the first and the second principal components (PC1, PC2) explained 90% and 8% of input data scatter, respectively. Although the PC2 had a secondary role in distinguishing the samples and the variables, it covered a non-negligible rate of scatter of the characteristics moisture, cooking time, water absorption, swelling volume and cooking loss (from 14 to 20%; Table 6). In the biplot, a clear gradient of cooking trials and chemical composition of manufactured couscous along the first axis of the ordination plane PC1 could thus be observed (Figure 2). For example, the higher the GRF ratio in a couscous recipe, the lower the protein content and energy per portion

Table 5. Significant correlation between the chemical composition of manufactured couscous and results of the cooking trial

Variable	Ash	Crude fat	Proteins	TDF	Phytic acid	Carbo-hydrates	Energy
Cooking time	0.93*	–	0.95*	–	–	–	0.90*
Water absorption	–	0.97*	–	0.92*	0.93*	0.92*	0.87*
Swelling volume	0.87*	0.97*	–	0.97*	0.95*	0.96*	0.88*
Cooking loss	0.92*	–0.82*	0.95*	–	–	–	0.87*
TSOM	0.98*	–0.95*	0.99*	–0.91*	0.96*	0.94*	0.97*

TDF – total dietary fibre; TSOM – total soluble organic material (mass extracted during cooking); *significant correlation at $P < 0.05$ (for $n = 5$, $r_{crit} = 0.87$); r_{crit} – critical values for the correlation coefficient r

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Table 6. Communalities, a portion (%) of explained variability by the first three principal components (PC)

Eingenvectors	Variable	PC1	PC2	PC3
Chemical composition	moisture	78*	20	2
	ash	98*	0	0
	crude fat	96*	4	0
	proteins	**95***	3	2
	TDF	92*	4	3
	phytic acid	**98***	2	0
	carbohydrates	**96***	2	1
	energy	**95***	0	2
Cooking trial	cooking time	**83***	17	0
	water absorption	82*	13	1
	swelling volume	82*	17	1
	cooking loss	**84***	14	1
	TSOM	**97***	0	2
Average		90	8	1

PC – principal component; TDF – total dietary fibre; TSOM – total soluble organic material (mass extracted during cooking); *pair correlation between the PC and variable significant at $P < 0.05$; numbers in bold – negative pair correlation

of the product. In a horizontal direction of Figure 2 (+PC2 vs. –PC2), a reverse position of the measured characteristics is more interesting from a viewpoint of the potential manufacturer of that type of couscous. Briefly, according to the selected RF-GRF blend, consumer quality of the final product as well as production budget estimate could be predicted with acceptable statistical error. For example, the wetter the couscous, the cheaper the manufacturing and the lower is the cooking loss; but there is a larger risk of microbial damage of the final product during longer storage.

CONCLUSION

In this study, GRF was used in gluten-free couscous production due to its coating and thickening properties. Thus, besides the chemical properties of gluten-free couscous samples, it was desired to improve their technological properties such as cooking quality and appearance. Based on the results of the cooking properties, it was clearly observed that the GRF addition positively affected the cooking quality of the couscous samples. The results of the correlation analyses also support this

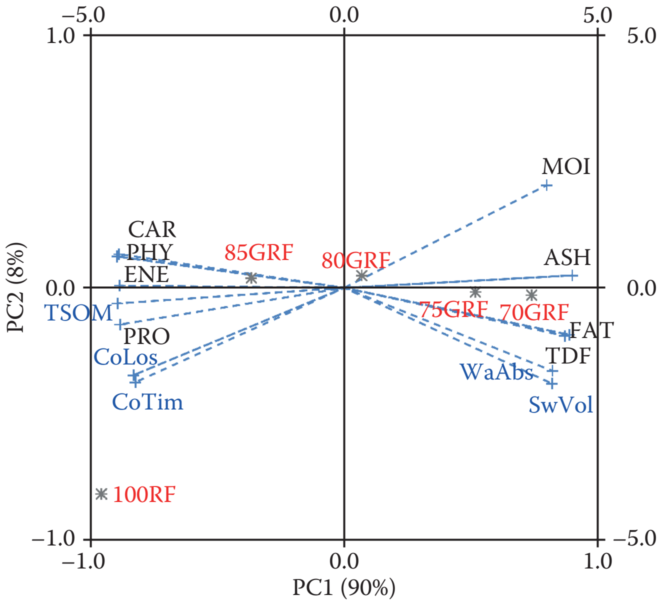

Figure 2. Principal components (PCA) biplot of scores and loadings

Codes of chemical components (content in couscous): MOI – moisture; ASH – ash; FAT – crude fat; PRO – proteins; TDF – total dietary fibre; PHY – phytic acid; CAR – carbohydrates; ENE – energy; couscous cooking trial parameters: CoTim – cooking time; WaAbs – water absorption; SwVol – swelling volume; CoLos – cooking loss; TSOM – total soluble organic material (mass extracted during cooking); RF – rice flour; GRF – pre-gelatinized rice flour

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data. The GRF reduced the cooking loss of the couscous samples compared to the control sample. It was determined that as the ratio of GRF increased, the water absorption level of the couscous samples decreased. On the other hand, compared to the control sample, the reduction in the TSOM amount resulted in lower deformation of the obtained couscous samples. These results are a proof that the cooking quality of the produced couscous samples is quite good, especially in 30% GRF added samples in terms of higher water absorption and swelling volume level with lower cooking loss. Pregelatinization appears to have a positive effect on improvement in cooking properties. The TDF content of the couscous samples increased with the increase in the level of GRF. Contrary to this, it was determined that there was a slight decrease in the protein and fat amounts as well as in the carbohydrate and energy values of the couscous compared to the control couscous. At the same time, increased substitution rates of GRF caused a decrease in the phytic acid content of samples. Gluten-free couscous samples were successfully produced from RF and GRF obtained from rice, without any additives. Statistical evaluation of the dataset was carried out by correlation analysis and PCA. Both methods gave results meaningful for potential manufacturers of such or similar couscous. According to the biplot of the PCA analyses of the collected data, moisture content, ash, crude fat and total carbohydrates showed a positive influence on water absorption and swelling volume of the couscous. Secondly, crude protein, carbohydrates, energy and phytic acid contributed to the final product quality in terms of cooking time and cooking loss. The finding could serve for the prediction of consumer quality of couscous, made from a definite blend of RF and GRF. Finally, the original aspect of this research, which was the preparation of a traditional Turkish product called couscous in the gluten-free version, was fulfilled successfully.

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