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ARTICLE

Functional Characterization of Brown Rice Flour in an Extruded Noodle System

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Abstract Brown rice flour has been utilized as a health-functional ingredient for extruded gluten-free noodles. Thus, its functional qualities were evaluated. Brown rice flour had greater resistance to dough mixing, whereas the thermo-mechanical values were reduced during heating and cooling. During extrusion, the presence of more non-starch components in brown rice flour led to a lower degree of gelatinization that could be related to the lower cold initial viscosity and expansion ratio of noodles. The structural matrix of the noodles seemed to be weakened by brown rice flour, thereby reducing the breaking strength and tensile properties of the noodles and increasing their cooking loss. However, brown rice noodles exhibited significantly higher 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity, ferric reducing powder, and 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid radical-scavenging activity by 21-, 28-, and 21-fold, respectively, than white rice noodles. Thus, extruded noodles with enhanced antioxidant activities were successfully produced with brown rice flour, probably encouraging food industry to develop a variety of brown rice products with health benefits.

Keywords antioxidant · brown rice · cooking loss · noodles · twin-extrusion

Introduction

Rice is a major staple cereal all over the world, especially in many Asian countries and also regarded as a natural gluten-free and hypoallergenic ingredient (Torbica et al., 2010). FAO reported that the global production of rice reached 723 million tons in 2011 (FAOSTAT, 2013). After harvest, rice grains are mostly milled to produce white rice that is primarily composed of starch. In the case of brown rice, it contains bran, germ, and starch endosperm since only the outer hulls of rice grains are removed. Thus, brown rice is recognized to belong to whole-grain food category (Fung et al., 2002).

As the market for healthy foods has grown rapidly, the demand for brown rice has been increasing due to its nutritional and health-functional properties. Brown rice is rich in dietary fibers as well as higher levels of vitamins and minerals than milled white rice. Flavonoids and phenolic compounds are also included in brown rice (Zhang et al., 2008). In addition, brown rice is known to have a lower mean value of glycemic index (55) than white rice (64) (Hu et al., 2012). Thus, because only the outermost layer (hull) is removed by milling, brown rice is nutritionally superior to milled white rice. Furthermore, a number of studies reported the beneficial health effects derived from the intake of brown rice. Blood pressure in middle-aged men and women can be lowered by the replacement of white rice with brown rice, which also may be of great help to control body weight (Behall et al., 2006). Sun et al. (2010) showed that brown rice may reduce the risk of type 2 diabetes. Thus, the primary research emphasis of brown rice has been placed on its functional components and physiological benefits.

While polished white rice flour has been extensively applied in the food industry, there are only a few preceding studies on the application of brown rice flour to food products although it has more beneficial health effects. Brown rice was utilized in bread-making (Renzetti and Arendt, 2009; Nikoliæ et al., 2011) and also incorporated into the formulation of sheeted noodles (Kong and Lee, 2010; Chung et al., 2012). However, the variety of the food products prepared with brown rice has still been limited, compared to other whole-grain flour as well as white rice flour. Also, most of these studies replaced wheat flour partially with brown rice flour. It indicates the lack of the fundamental knowledge of brown rice in a food system that may discourage the food industry to

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develop new products with the brown rice.

In this study, brown rice flour was analyzed from the compositional and rheological points of view and compared with white rice flour. Also, brown and white rice flours were subjected to twin-screw extrusion to produce gluten-free noodles of which functional attributes were characterized.

Materials and Methods

Preparation of white and brown rice flours. White and brown rice grains (Chucheong variety, harvested in 2011) were obtained from a commercial source. The rice grains were soaked in water with a ratio of rice to water of 2:3 (w/w) at room temperature for 4 h. They were drained and ground by using a roller mill (SJ-201, Shinwoo Machinery Co., Korea). The ground rice was dried in an oven dryer (OF-12GW, Jeio Tech Co., Ltd., Korea) at 40°C for 24 h and then subjected to air-jet milling (ACM-500, Hankook Crusher Co., Korea). The flour samples passed through a 70 mesh sieve (Chung Gye Inc., Korea) and stored in a plastic bag at 4°C.

Chemical composition. The amounts of moisture, ash, protein, and fat in white and brown rice flours were determined by the AOAC-approved methods (AOAC, 2005). The contents of ash, protein, and fat were reported on 14% moisture basis. Also, the enzymatic-gravimetric procedure (Abdul-Hamid and Luan, 2000) was applied to analyze the contents of soluble, insoluble, and total dietary fibers.

Thermo-mechanical characteristics. The thermo-mechanical properties of white and brown rice flours in a dough system were characterized by using Mixolab (Chopin, Tripette et Renaud, France). Both flours were placed in a mixing bowl, and the amount of distilled water was adjusted to produce rice dough (90 g) with the same level of water absorption (70%). The dough was kept at 30°C for 8 min, heated to 90°C at 4°C/min, and maintained at 90°C for 7 min. It was then cooled to 50°C at 4°C/min, and kept at 50°C for 10 min.

Pasting property. A starch pasting cell attached to a controlled-stress rheometer (AR1500ex, TA Instruments, USA) was used to investigate the pasting characteristics of white and brown rice flours in an aqueous slurry. Both flours were suspended in distilled water (9.8%, w/w) and the suspension (28 g) was subjected to the programmed heating-cooling cycle where temperature was held at 50°C for 1 min, raised to 95°C at a rate of 12°C/min, held for 2.5 min, cooled to 50°C at a rate of 12°C/min, and held for 2 min.

Preparation of extruded rice noodles. White and brown rice flours that were hydrated to 35% were extruded in a co-rotating twin-screw extruder (Technovel Co., Japan). There was an orifice on the die of which diameter was 2.4 mm. The length-to-diameter (L/D) ratio of the extruder was 30:1. The barrel screw speed was 200 rpm and the feed rate was 287 g/h. Barrel temperature was maintained at 80°C by circulating cooling water. The screw configuration used is described in Table 1. The extruded noodle strips were placed in an oven dryer (OF-12GW, Jeio Tech Co., Ltd., Korea) and dried at 40°C for 1 h. They were then stored in a plastic bag.

Table 1 Screw profile of the extruder

Type of screw element	Screw element details	Number of elements	Total length (mm)
Forward pitch	8/8[a)]	2	16
	12/12	3	36
Kneading block	KB 45/5/12[b)]	1	12
Forward pitch	8/8	1	8
	12/12	1	12
	18/18T[c)]	1	18
Kneading block	KB 45/5/12	2	24
Forward pitch	8/8	2	16
	12/12	1	12
	18/18	1	18
Kneading block	KB 45/5/12	2	24
Forward pitch	8/8	1	8
	12/12	4	48
	18/18	3	54
	18/18D[d)]	2	36
	8/8	1	8

[a)]Screw elements: pitch (mm)/length (mm).
[b)]Kneading blocks (KB): stagger °/number of disks/length (mm).
[c)]T: taper feeding element.
[d)]D: deep feeding element.

Expansion ratio. The expansion ratio of dry noodles was determined as the ratio of noodle diameter to die orifice diameter. The noodle diameter (average of 15 random measurements) was measured by using a digital caliper (Mitutoyo Co., Japan).

Antioxidant activity. The antioxidant activities of white and brown rice flours and noodles were determined by using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, ferric reducing ability power (FRAP), and 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) assays. In the case of rice noodles, they were ground to pass through a 30-mesh sieve for the antioxidant measurements. Rice flour and noodle powder were mixed with 70% ethanol (200 mL) at room temperature for 24 h, and the mixture was centrifuged at 15,000 g for 10 min. After the supernatants were evaporated under vacuum at 40°C, the extract was dissolved in 70% ethanol to obtain 10 mL volume. The extract (0.5 mL) was mixed with 0.1 mM DPPH (Sigma-Aldrich, USA) solution (0.5 mL) and was left standing at 37°C for 30 min. The absorbance was measured at 517 nm by using a spectrophotometer (DU 730, Beckman Coulter Inc., USA) (Butsat and Siriamornpun, 2010). In addition, according to the method of Nilsson et al. (2005), the FRAP assay was applied by reacting rice extract (20 μL) with 600 μL FRAP (Sigma-Aldrich, USA) solution, and the resultant absorbance was recorded at 593 nm. In the case of the ABTS assay, ABTS (Sigma-Aldrich, USA) reagent (1 mL) was added to rice extract (10 μL), and the mixture was incubated at room temperature for 6 min, followed by measuring the absorbance at 734 nm (Das et al., 2008).

Noodle texture. The textural properties of white and brown rice noodles before and after cooking were investigated by using a texture analyzer (TMS-Pro, Food Technology Co., USA). A three-point break test was employed to measure the breaking strength of dried rice noodles. A metal probe (0.5 cm width and 2 cm long) was lowered at a crosshead speed of 50 mm/min until the noodles (10 cm) placed on two stationary bending supports (4 cm apart) were fractured. After the noodles (5 cm long, 5 g) were cooked in boiling water (150 mL) for 3, 6, and 9 min, they were subjected to the tension test which was conducted with a Kieffer dough and gluten extensibility rig at a crosshead speed of 3.3 mm/s.

Cooking loss. The cooking loss of rice noodle samples was measured as a function of cooking times (3, 6, and 9 min). After the noodles (5 cm long, 5 g) were cooked in 150 mL of boiling water, they were drained in a strainer for 5 min. The water used for cooking was retained, dried in an oven (105°C) to constant weight, and weighed. Cooking loss was expressed as a percentage weight ratio of the dry matter of cooking water to noodles before cooking.

Statistical analysis. All experiments were carried out in triplicate. The Statistical Analysis Program System for Windows (SAS Institute Inc. USA) was employed to statistically analyze the experimental results with ANOVA and Duncan's multiple range test at a level of 5%.

Results and Discussion

The chemical composition of brown rice flour was investigated and compared with that of white rice flour. Brown rice flour contained higher amounts of ash (10.1 g kg^{-1}), protein (60.9 g kg^{-1}), and fat (21.1 g kg^{-1}) than white rice flour (2.6, 57.6, and 1.8 g kg^{-1}), respectively (Table 2). Moreover, the content of dietary fiber, as expected, was higher in the brown rice flour (33.9 g kg^{-1}) than in the white rice flour (11.1 g kg^{-1}). These compositional differences between white and brown rice flours can be explained by the fact that brown rice retains bran layers that are abundant in nutrients (Ohtsubo et al., 2005). The compositional superiority of brown rice flour to white rice flour has been also observed in several preceding studies (Champagne, 2004; Heinemann et al., 2005; Panlasigui and Thompson, 2006).

Fig. 1 presents the Mixolab thermo-mechanical properties of white and brown rice flours. Both flours showed the typical Mixolab curve of rice flour that consists of an abrupt torque increase to C1 at the initial mixing, a decrease to C2 during the continuous mixing stage, a starch gelatinization-derived peak during heating (C3), a decline to C4 at temperature hold, and a rise to C5 upon cooling (Heo et al., 2013). There was no significant difference in the C1 values between the two rice flour samples under the same condition of water absorption (70%). However, the brown rice flour exhibited greater mixing resistance (higher values of C2). The values of C3, C4, and C5 indicate starch gelatinization, stability of gelatinized starch granules, and starch retrogradation, respectively (Heo et al., 2013). It was noted that brown rice flour had lower values of the C3, C4, and C5 than white rice flour during the heating and cooling (Fig. 1), mainly due to a lesser amount of starch and the presence of more non-starch compounds in the brown rice flour. Thus, Mixolab works in a dough system under the controlled temperature condition that seems to be more appropriate for practical baking and noodle applications (Ozturk et al., 2008).

While Mixolab continuously monitors the thermo-rheology of cereal flour in dough during dual-mixing, the starch pasting cell used in the present study is applied to measure its pasting property in an aqueous slurry. Therefore, these two instruments provide the rheological response of the cereal flour to temperature in different concentration regimes (Kim et al., 2012). Fig. 2 exhibits the pasting profiles of white and brown rice flours that were compared with those of white and brown rice noodle powder samples. Both raw rice flours exhibited similar pasting patterns - peak viscosity during heating, breakdown viscosity during the temperature hold, and setback viscosity upon cooling. However, it is interesting that brown rice flour showed lower values for all the pasting parameters. These pasting behaviors could be primarily attributed to the difference in the amount of starch between the two rice flours. Moreover, the amylase activity in brown rice flour might be a contributor to the reduced peak viscosity (Mariotti et al., 2009). A similar pasting trend was observed by Hung et al.

Table 2 Chemical compositions of white and brown rice flours (Means with different letters in the same row differ significantly at p <0.05)

Proximate composition (g kg^{-1})	White rice	Brown rice
Moisture	83.1±0.2^{a}	81.7±1.5^{a}
Ash	2.6±0.1^{b}	10.1±0.1^{a}
Protein	57.6±0.6^{b}	60.9±1.6^{a}
Fat	1.8±0.0^{b}	21.1±0.1^{a}
Total dietary fiber	11.1±4.2^{b}	33.9±0.9^{a}
Soluble dietary fiber	2.1±0.6^{a}	9.4±4.8^{a}
Insoluble dietary fiber	8.4±3.6^{b}	24.2±6.4^{a}

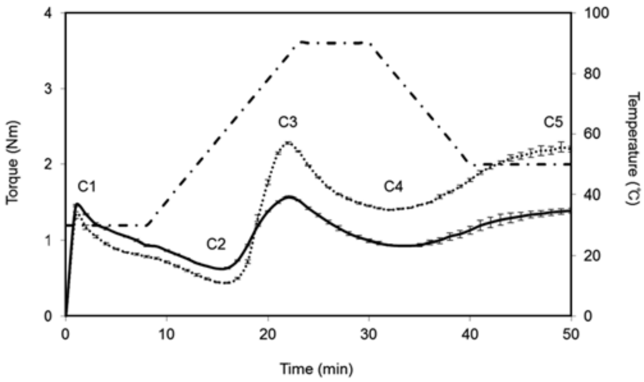

Fig. 1 The Mixolab thermo-mechanical properties of white and brown rice flours (······ White rice flour, —— Brown rice flour, — · – Temp.).

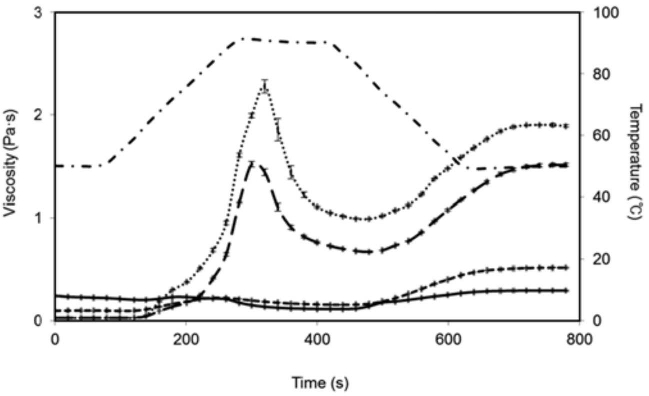

Fig. 2 The pasting properties of white/brown rice flours and noodle powders (······ White rice flour, — – Brown rice flour, —— White rice noodle, – – – Brown rice noodle, – · – Temp.).

Table 3 Expansion ratio and breaking strength of extruded rice noodles (Means with different letters in the same column differ significantly at p <0.05)

	Expansion ratio	Breaking strength (N)
White rice	1.19±0.03^{a}	7.80±0.44^{a}
Brown rice	1.02±0.03^{b}	4.95±0.34^{b}

(2007), who investigated the bread-making properties of whole waxy wheat flour. In addition, the onset temperature of starch gelatinization became higher in the brown rice flour, because non-starch components compete with starch for water, thereby delaying the hydration and swelling of starch granules. In the case of rice noodle powders, their pasting profiles were distinctly different from those of raw rice flours. Especially, a high cold initial viscosity that is a measure of a high level of gelatinization was clearly observed in the white rice noodle sample. However, the brown rice noodle powder exhibited a low cold initial viscosity and a small peak viscosity was also observed, suggesting that a lower degree of starch gelatinization took place during the extrusion of brown rice flour. Thus, higher amounts of non-starch components in brown rice flour such as dietary fiber and fat appeared to affect its extrusion cooking.

Table 3 presents the expansion ratio of the noodle samples prepared with white and brown rice flours. There were significant differences in the noodle expansion ratio among the samples

Table 5 Effects of white and brown rice flours on the cooking loss of extruded noodles (Means followed by different letters in the same column (lower case) and row (upper case) differ significantly at p <0.05)

Cooking loss (%)	3 min cooking	6 min cooking	9 min cooking
White rice	16.63±2.37^{bC}	34.01±1.33^{bB}	49.38±2.65^{bA}
Brown rice	20.89±1.34^{aC}	39.01±1.73^{aB}	54.94±2.66^{aA}

(p <0.05). Specifically, the expansion ratio of white rice noodles was 1.19, whereas it was reduced to 1.02 for brown rice noodles. This finding was primarily correlated to the lower swelling power of brown rice flour as expected from the lower degree of starch gelatinization.

The breaking strength of dried rice noodles was investigated by using a three-point break test (Table 3). The breaking strength, the mean force required for a probe to break noodle samples, was 7.80 and 4.95 N for the white and brown rice samples, respectively. Thus, reduced breaking strength was observed in the brown rice noodles. This result could be correlated to the lower torque values of brown rice flour in a dough system after heating and cooling (Fig. 2). Additionally, the different noodle thickness derived from the expansion ratio appeared to affect the breaking strength of the noodles prepared with white and brown rice flours (Table 3).

The tensile properties of noodles were investigated as a function of cooking times. Table 4 shows the R_{max} and extensibility (E) of the noodles that indicate the maximum resistance to extension and the distance at the maximum force (Kim et al., 2013). The values of R_{max} were significantly reduced with increasing cooking times (p <0.05). However, lower tensile properties were distinctly observed in the noodles prepared with brown rice flour at the same cooking time. The presence of non-starch components in brown rice flour appeared to weaken the structural starch matrix of the noodles. Hence, in the case of brown rice noodles, shorter cooking times seemed to be necessary to obtain cooked noodles with texture similar to white rice noodles.

Table 5 exhibits the cooking qualities of rice noodles over cooking times. There was a significant difference in the cooking loss between two rice noodle samples (p <0.05). The cooking loss of white rice noodles was determined as 16.6, 34.0, and 49.4% after 3, 6, and 9 min cooking, whereas the use of brown rice flour increased cooking loss to 20.9, 39.0, and 54.9%, respectively. It is

Table 4 Effects of white and brown rice flours on the tensile properties of extruded noodles after cooking (Means followed by different letters in the same column (lower case) and row (upper case) differ significantly at p <0.05)

		3 min cooking	6 min cooking	9 min cooking
R_{max} (N)	White rice	4.63±0.81^{aA}	1.07±0.29^{aB}	0.19±0.04^{aC}
	Brown rice	2.17±0.28^{bA}	0.33±0.08^{bB}	0.07±0.02^{bC}
E (mm)	White rice	16.69±2.85^{aB}	23.03±2.74^{aA}	15.95±2.77^{aB}
	Brown rice	11.73±0.77^{bA}	9.57±0.86^{bB}	3.81±1.04^{bC}
Area of extension curve (N · mm)	White rice	46.89±7.42^{aA}	16.62±3.50^{aB}	3.38±1.04^{aC}
	Brown rice	15.36±1.51^{bA}	3.32±0.77^{bB}	0.40±0.17^{bC}

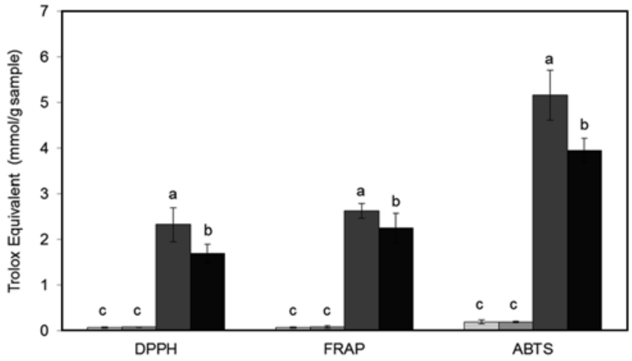

Fig. 3 The antioxidant characteristics of white/brown rice flours and noodles (Different letters on bars indicate a significant difference at the 5% level) (■ White rice flour, ■ White rice noodle, ■ Brown rice flour, ■ Brown rice noodle).

recognized that the cooking loss of noodles is associated with their degree of starch gelatinization and structural network (Chansri et al., 2005). Therefore, this increased cooking loss of the brown rice samples could be correlated to their low degree of starch gelatinization and weakened structure (Fig. 2 and Table 4), producing more solid loss to cooking water. Moreover, the lower expansion ratio of brown rice noodles (Table 3) caused cooking loss to increase (Wójtowicz and Moœcicki, 2009). These results were favorably compared with the study of Kong and Lee (2010), who incorporated germinated brown rice into the formulation of wheat-based sheeted noodles. Since increased cooking loss leads to turbid cooking water and sticky noodles, a further study will be necessary to retard the cooking loss of brown rice noodles.

The antioxidant capacities of white and brown rice noodles that were expressed as Trolox equivalents were investigated and compared with those of the flours (Fig. 3). Higher antioxidant values were observed in the brown rice flour and noodles for all the assays. Specifically, the brown rice noodles exhibited significantly higher DPPH radical-scavenging activity, ferric reducing ability power, and ABTS radical-scavenging activity by 21-, 28-, and 21-fold, respectively, when compared to the white rice noodles. It could be explained by the presence of high amounts of antioxidant compounds in brown rice such as phenolics, flavonoids, and tocopherols (Chotimarkorn et al., 2008). These results clearly indicate the effectiveness of brown rice in preventing oxidation of foods. It could be favorably compared with the preceding study by Butsat and Siriamornpun (2010), who reported the antioxidant activities and phenolic compounds of Thai rice depending on its milling fractions. Additionally, the antioxidant activity of brown rice noodles became lower, compared to brown rice flour. Thus, the shearing and heat generated during the extrusion process seemed to cause the degradation of the antioxidant compounds, consequently reducing the antioxidant activities (Fares et al., 2010).

In this present study, the physicochemical and antioxidant properties of brown and white rice flours were investigated, and their noodle-making performance was evaluated. Brown rice flour exhibited lower pasting and thermo-mechanical properties, consequently affecting the textural and cooking qualities of the rice noodles. The use of brown rice flour produced extruded noodles with enhanced health-related functionalities such as a high level of dietary fiber and improved antioxidant activities. From this aspect, the present study contributes to the development of new brown rice products not only retaining nutrients but also providing health benefits. Thus, the extensive application of brown rice to a wider variety of food products as a natural whole grain will help consumers make a transition towards healthful diets. Compared to brown rice, white rice undergoes further milling in order to remove the bran and germ of the rice, thus much less energy will be needed to produce brown rice. However, because brown rice has a shorter shelf life than white rice, proper care and handling are necessary during transport and storage. Furthermore, the lower demand for brown rice prevents mass production, driving the price high. Therefore, the increasing demand of brown rice derived from its beneficial health effects will make it available at lower cost in the market.

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