Research Article

Product Development of Nutritious Rice Based Gluten-Free Snacks from Different Formulation of Rice Varieties by Extrusion and their Physical, Physicochemical and Sensory Evaluation

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Abstract
Flour from three high-nutritional rice varieties were used to produce gluten-free extruded rice snacks. This study investigated the optimal formulation of the flour mixes from brown jasmine rice (JR) and two other pigmented varieties, brown black glutinous rice (BGR) and brown riceberry rice (RR) to produce the extruded snack. Chemical compositions, including, dietary fiber and antioxidants of each rice variety were determined. Ten formulations of the flour mixes were evaluated using a Mixture Design and extruded via a single-screw extruder. The physical properties of the extruded snacks from each formulation such as expansion ratio, color, hardness and crispness, as well as their physicochemical properties, including water absorption and solubility indices were analyzed. Three flours showed high protein content (8.1–9.0%). Both pigmented rice (BGR and RR) indicated a higher DPPH scavenging activity at 0.51 ± 0.05 µmol Trolox/g dry weight (DW) and 0.25 µmol Trolox/g DW, respectively. BGR showed the highest % DPPH inhibition (31.63 ± 0.32%). The snack indicated the highest expansion ratio with brown riceberry rice, followed by jasmine rice and brown black glutinous rice. The use of flour mixes indicated higher overall liking scores than one specific flour, while the mixing ratio of jasmine rice, brown black glutinous rice and brown riceberry at 1: 1: 1 (Formulation 7) tended to achieve the highest overall liking (6.47 from 9 points hedonic scale) and the high scores for most of the sensory attributes. The total dietary fiber of the snacks from Formulation 7 was around 4.11% by weight. The results revealed the high potential for using brown jasmine rice and pigmented rice to extrude gluten-free rice snacks.

Keywords: Antioxidant activity, Brown jasmine rice, Crispness, Expansion ratio, Pigmented rice, Riceberry rice

1 Introduction

Rice (*Oryza sativa*) is one of the staple foods consumed widely, especially in Eastern countries. Using rice flour for extruded snacks provides several advantages over other starch sources in terms of its hypo-allergenicity, gluten-free, easy-to-digest [1] and good expansion properties [2]. The only remedy for people with celiac disease is consuming a gluten-free diet [3]. Celiac disease is the body's intolerance to the toxic effects on the small intestinal mucosa of gluten protein in cereals like wheat, barley, and oats [4]. Thailand is one of the top world rice exporter, and Thai jasmine rice, or Khao Dawk Mali 105, was named one of the world's best rice. Jasmine rice contains a specific compound, 2-acetyl-1-pyrroline, which is the major compound contributing to pandan-like or popcorn-like aroma [5]. The grains tend to be sticky when cooked but less sticky than glutinous rice (*Oryza sativa var. glutinosa*), which has a higher amylopectin content. Sasanam *et al*. [6] reported using rice flour, banana flour, and Job's Tears flour to produce gluten-free cookies with acceptable physical and sensory properties. Brown jasmine rice is gaining popularity since it has bran, which contains more nutritional compounds, such as protein, gamma oryzanol, dietary fiber, vitamins, and antioxidants than white-milled rice [7].

Pigmented rice is a potent source of antioxidants such as polyphenols and anthocyanins [8]. Black rice indicates nutritional benefits over common rice in terms of a higher protein, vitamins, and anthocyanin content, which is highly effective for cholesterol reduction [9], [10]. Riceberry rice is developed from two famous Thai rice varieties, Hom Nin rice (a local non-glutinous purple rice) and jasmine rice [7]. Riceberry rice has a soft and deep purple whole grain. Chokchaithanawiwat *et al*. [11] successfully developed nutritious noodles from wheat flour mixed with raspberry flour by extrusion. One of the challenges for the food industry is to produce healthy snacks using whole grain flour, which is naturally rich in nutrients and phytochemicals, without adding any food additives [12]. Using brown rice and pigmented rice flour to extrude gluten-free snacks will potentially attract the attention of rice snack producers and add value to agricultural raw materials.

Extrusion cooking combines many unit operations such as mixing, kneading, and forming in a single process and presents many benefits such as low cost, versatility, limited space required, and environmental-friendly [13]. Extrusion technology efficiently processes many food products, including crispy snacks, rice snacks, pasta, noodles, and protein-based products [14], [15]. Snack products produced by the extrusion process are one of the fastest-growing foods globally. Most extruded snack products are from cereal flour, such as corn, wheat, or rice [16].

Extrusion processing can be designed for optimal conditions and formulations to achieve the final product with acceptable physical and chemical properties. The chemical compositions and properties of the raw materials, such as rice cultivars, carbohydrate or starch content, and amylose content, would significantly influence the properties of the extruded products, especially their expansion and texture. Several reports present the promising bioactivity of pigmented rice, including raspberry rice and black glutinous rice, and a few studies on the use of brown rice or pigmented rice for the extrusion of snack or breakfast cereals [17], [18], however, the development of extruded snacks based on the mixture of non-pigmented jasmine rice and pigmented rice is still limited.

Consequently, this study aimed to develop extruded snacks from whole grains based on the non-pigmented jasmine rice and two pigmented rice, brown black glutinous rice and brown riceberry rice. A Mixture Design was adopted to optimize the mixing ratio of each rice flour to produce the snacks with acceptable properties of color, expansion ratio, texture, and sensory evaluation. The second-order polynomial model was used to generate the regression equations and the contour plots to predict the properties of the extruded snacks as a function of the mixing ratio of the rice flour. The information obtained from this study would provide new insight into the raw materials that show a high potential for producing gluten-free and healthy snacks by extrusion. It is expected that the developed product could be suitable for those who are looking for healthy alternative snacks or gluten-free snacks.

2 Material and Methods

2.1 *Raw materials and chemicals*

Three types of brown rice (*Oryza sativa* L.), non-milled rice, namely, brown jasmine rice (JR), brown black glutinous rice (BGR), and brown riceberry rice (RR) were purchased from L H Rice International Co., Ltd. (Nakonprathom province, Thailand). All rice grains were milled into flours using a Hammer Mill (Retch, Germany) through a sieve with an opening diameter of 0.25 mm. The chemical 2,2-diphenyl-1-picreylhydrazyl (DPPH), was bought from Sisco Research Laboratories Pvt. Ltd. (India), while the Trolox reagent was obtained from M Tedia (USA). Thiobarbituric acid (TBA) and malondialdehyde (MDA) were the products from Sigma-Aldrich (USA). All other reagents and solvents used were of analytical grade.

2.2 *Chemical composition analysis*

Chemical compositions, moisture, protein, fat, and ash of each rice flour were determined following AOAC [19]; moisture using oven drying (AOAC 930.15 Method), protein by Kjeldahl method (AOAC 984.13 Method), fat by ether extract in food, Gravimetric method (AOAC 954.02 Method), and ash content by oven method at 550 °C (AOAC 942.05 Method). Carbohydrate content was calculated by subtracting the sum of protein, ash, fat, and crude fiber percentages from 100. Total dietary fiber (TDF), including soluble dietary fiber (SDF) and insoluble dietary fiber (IDF), was determined following AOAC 985.29 enzymatic-gravimetric method (2000). In brief, the sample's protein and starch were removed by hydrolysis with the heat-stable α-amylase, protease, and amyloglucosidase (Megazyme analysis kit). Ethanol (95%) was added to precipitate the soluble dietary fiber. The residue from the filtration was washed, dried, and determined for its protein and ash content. Total dietary fiber was the weight of the residue subtracted by the weight of the protein and ash. Insoluble dietary fiber was analyzed following the same method without ethanol at 95%, while SDF was calculated from TDF-IDF. All determinations were performed in triplicate and expressed as the mean value.

2.3 *Antioxidant capacity by 2,2'-Diphenyl-1-picrylhydrazyl (DPPH) assay*

The extracts of rice flour from JR, BGR, and RR were prepared following Peng *et al*. [20] with slight modification. One gram of each rice flour was added with 10 mL of 70% ethanol and mixed using a vortex mixer. The suspension was placed in an ultrasonic bath for 60 min and centrifuged at 6,000 rpm for 15 min. The supernatant was used to determine their radical scavenging activity using DPPH assay according to Sogi *et al*. [21] with some modification. The supernatant (40 µL) was mixed with 0.1 µM DPPH in a methanol solution (260 µL) using a 96-well plate. After that, the samples were incubated in the dark at room temperature for 30 min before their absorbance was measured at 517 nm with a microplate reader. A standard curve was prepared using different concentrations of Trolox from 0 to 150 µM. The antioxidant capacity was calculated as µM Trolox equivalents/g sample (dry weight). All experiments were performed in triplicates and the scavenging capacity was calculated using Equation (1):

$$\%\ Inhibition = [(A_{control} - A_{sample})/A_{control}] \times 100 \qquad (1)$$

where $A_{control}$ is the absorbance of the control that contained all reagents except the test samples. A_{sample} is the absorbance of the flour extracts with reagents added. The percentage of free radical scavenging activity was plotted against the amount of sample, and half-inhibition concentration (IC_{50}) was calculated.

2.4 *Extrusion of gluten-free rice snacks*

Gluten-free rice snacks were produced from the rice flours, JR, BGR, and RR using the mixture design as 10 formulations. Formula 1 (F1), Formula 2 (F2), and Formula 3 (F3) were composed of only JR, BGR, and RR, respectively, while Formula 4 to Formula 10 (F4-F10) consisted of various combinations of each flour (Table 3). The extrusion was carried out using a single screw extruder with a 19.1 mm diameter, a barrel length of 382 mm and a 4:1 screw compression ratio (Brabender 19/20DN, Germany). The schematic diagram of the extruder machine is shown in Figure 1: the feeding zone (Zone 1), the mixing zone or transition zone (Zone 2), and Zone 3, which is the die end, also called the metering zone. A calculated amount of water was added to the mix to control the initial feed moisture content at 13% (wb). The conditions for the extrusion were set following our previous study [16] with a slight modification: The screw speed was controlled at 120 rpm. Barrel temperatures of Zone 1:2:3 were set at 100:120:150 °C. A square die with a 25 mm width and 2 mm thickness was used to shape the extruded rice snacks. The extruded snacks were dried at 60 °C for 30 min in a tray dryer (Binder, USA). The extrudates were kept in polypropylene bags until further analysis.

2.5 *Physical properties*

2.5.1 Diameter and expansion ratio

The thickness of ten randomly collected extruded snacks in each experiment was measured at a minimum of 10 points for each sample using a digital vernier caliper and averaged. The expansion ratio was calculated following Alvarez-Martinez *et al*. [22] with slight modification by the ratio between the cross-section area of the extruded snacks (mm^2) and the cross-section area of the die (mm^2).

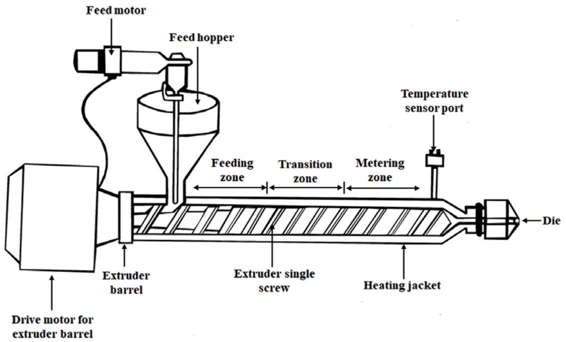

Figure 1: The schematic diagram of the extruder machine.

2.5.2 Bulk density

Ten extruded snacks were recorded for their total weight (g) and added carefully into a 100-mL cylinder that contained sesame seeds. The cylinder was tapped on a table 5 times to allow a uniform packing of the extruded snacks and the grains. Additional sesame grains were added to maintain 100 mL of the container [23]. Bulk density (g/cm^3) was calculated as the weight of the snacks to their unit volume (g/cm^3).

2.5.3 Color

The color of the extruded snacks was determined using a Hunter Lab (Hunter Lab Color Quest, USA). The L^* value represents luminosity on the black and white scale, a^* indicates the shades between the green and red scale, and b^* represents shades between blue and yellow.

2.5.4 Texture analysis

A texture analyzer (Stable Micro System Co., Ltd., UK) was used to measure the hardness and crispness of the snacks. The parameters were constructed at a pre-test speed of 2 mm/s, test speed of 1 mm/s, post-test speed of 10 mm/s, and distance of 10 mm using the HDP/3PH probe. The result was expressed in terms of crispness and hardness. The crispness of the extruded snacks was determined with the Ottawa Cell probe, while their hardness was measured using the Ball probe.

2.5.5 Water Absorption Index (WAI) and Water Solubility Index (WSI)

The extruded snacks were determined for their WAI and WSI followed Kim *et al*. [24]. Each sample at 0.30 g was placed into a 15-mL test tube and mixed with 1 mL absolute ethanol and 10 mL distilled water for 10 min. The mixture was centrifuged at 6,000 rpm for 15 min and the weight of the precipitate was measured. The supernatant was further dried in an oven at 105 °C overnight [19] and weighed. WSI and WAI were calculated using Equations (2) and (3).

$$WAI\ (\%) = (weight\ of\ water\ absorbed\ into\ snacks/weight\ of\ snacks) \times 100 \quad (2)$$

$$WSI = (weight\ of\ dry\ matter\ in\ the\ supernatant/weight\ of\ snacks) \times 100\ (\%) \quad (3)$$

2.6 *Sensory evaluation*

Sensory evaluation of the gluten-free snacks extruded from each formulation was performed using a Balance Incomplete Block (BIB) design (t = 10, k = 5, r = 9, b = 18, λ = 4) (Table 1). The extruded snacks were divided into 2 groups and randomly served and asked their liking for color, odor, taste, crispness, and overall acceptability with 9 points-hedonic scales with 1 as the least liking to 9 as the highest liking scale. The panelists were 90 untrained consumers who are students at King Mongkut's University of Technology North Bangkok, aged 18–25 years old (N = 78) and 26–40 years old (N = 12).

2.7 *Statistical analyses*

All experiments were performed with at least three replications and expressed as the mean ± SD. The significance of variables was assessed by one-way analysis of variance ANOVA) and post-hoc Duncan's test with p-value < 0.05 using IBM SPSS software (SPSS Inc.) version 28 for Windows.

3 Results and Discussion

3.1 *Chemical composition*

Chemical compositions of the rice flours from each brown rice, JR, BGR, and RR, are presented in Table 2. The flours show a high protein content, at 8.10 to 9.00

% (wb), since they contain rice bran, which consists of a high protein fraction [25]. All rice flours presented a closed range for the fat content at 2.63–3.59% (wb). JR contained the highest TDF (6.22% wb), followed by BGR (4.10% wb), and RR (2.71 %wb), of which more than 90% of the total dietary fiber was IDF. In our study, the chemical compositions of JR and BGR were similar to the analysis of brown rice and brown, black glutinous rice reported by Sompong *et al*. [9] and Bhat *et al*. [26]. Prasad *et al*. [27] reported that the dietary fiber content of whole grain rice varies from 2.7 to 9.9% depending on rice varieties.

Dietary fiber is mainly found in the rice hull, and bran rice resulted in a higher dietary fiber content in brown rice than in white rice [28]. SDF and IDF indicate their functionality and physiological effects differently upon consumption [29]. IDF can stimulate an increase in fecal bulk and decrease the intestinal transit time of fecal through the large intestine [30]. SDF can help to lower blood cholesterol and regulate blood glucose levels [31].

The amylose content of the BGR is the lowest one, 7.74% (wb), compared to the amylose content of JR, and RR at 17.24% (wb), and 13.63% (wb), respectively. Amylose content is one factor affecting the physicochemical properties of rice starch, such as gelatinization, swelling power [32] and providing structure for extrudates during die exit and cooling. Both pigmented rice, BGR and RR, indicated a higher DPPH scavenging activity, at 0.51 ± 0.05 µmol Trolox/g DW and 0.25 µmol Trolox/g DW, respectively, than that of non-pigmented JR (0.14 µmol Trolox/g DW), indicating that both pigmented cultivars used in this study be considered rich in bioactive compounds. BGR showed the highest % DPPH inhibition at 31.63 ± 0.32% while JR indicated the lowest % DPPH inhibition at 10.37 ± 0.22%. The antioxidant property as indicated by high DPPH activity in the product contributes positively to the consumer's purchase decision, as antioxidants promote good health. Naturally extracted antioxidants have become popular with consumers as they can prevent cell damage from free radical reactions and reduce the risk of various chronic diseases [33].

The chemical composition of the rice flour mixtures before being fed to the extruder is summarized in Table 3. F3, which consisted of RR only, indicated a higher protein content, 8.80 ± 0.46% (wb), than that of JR in

Table 1: Sensory evaluation using the Balance Incomplete Block (BIB) design

Block						**Block**						**Block**					
(1)	1	2	3	4	5	**(7)**	1	4	5	6	10	**(13)**	2	5	6	8	10
(2)	1	2	3	6	7	**(8)**	1	4	8	9	10	**(14)**	2	6	7	9	10
(3)	1	2	4	6	9	**(9)**	1	5	7	9	10	**(15)**	3	4	6	7	10
(4)	1	2	5	7	8	**(10)**	2	3	4	8	10	**(16)**	3	4	5	7	9
(5)	1	3	6	8	9	**(11)**	2	3	5	9	10	**(17)**	3	5	6	8	9
(6)	1	3	7	8	10	**(12)**	2	4	7	8	9	**(18)**	4	5	6	7	8

Table 2: Chemical compositions and antioxidant capacity of each rice flour

% Component	**Brown Jasmine**	**Brown Black Glutinous**	**Brown Riceberry**
Moisture	11.00 ± 0.08^{b}	11.71 ± 0.05^{a}	7.30 ± 0.50^{c}
Protein	8.10 ± 0.21^{b}	8.78 ± 0.48^{ab}	9.00 ± 0.47^{a}
Fat	2.63 ± 0.05^{b}	3.59 ± 0.27^{a}	2.95 ± 0.13^{ab}
Ash	1.14 ± 0.08^{b}	1.36 ± 0.01^{a}	1.45 ± 0.02^{a}
Carbohydrate*	77.13 ± 0.15^{b}	74.56 ± 0.23^{c}	79.30 ± 0.55^{a}
Total dietary fiber	6.22 ± 0.08^{a}	4.10 ± 0.04^{b}	2.71 ± 0.02^{c}
Insoluble fiber	5.71 ± 0.06^{a}	3.92 ± 0.03^{b}	2.46 ± 0.02^{c}
Soluble fiber	0.51 ± 0.02^{a}	0.18 ± 0.03^{c}	0.25 ± 0.02^{c}
Amylose content (%)	17.24 ± 0.35^{a}	7.74 ± 0.48^{c}	13.63 ± 0.52^{b}
DPPH scavenging activity (µmol Trolox/g DW)	0.14 ± 0.07^{c}	0.51 ± 0.05^{a}	0.25 ± 0.01^{b}
% DPPH inhibition	10.37 ± 0.22^{c}	31.63 ± 0.32^{a}	18.51 ± 0.96^{b}

Mean values in the same row with different letters are significantly different at p-value < 0.05.
* by difference method

F1, 7.92 ± 0.21%. However, the flour mixture from F2, F4–F10 contained protein contents at 8.13–8.58%, which were not significantly different from those proteins in F1 and F3. F3 also showed the highest carbohydrate content but the lowest total dietary fiber content. The physical and chemical analysis results show that were significantly different from each treatment in the experiment. However, the results showed only the nutritional properties of the developed product, but the sensory evaluation was still the main reason for selecting the best condition.

3.2 *Physical properties*

3.2.2 Appearance and color

Color is one of the main qualities related to the acceptability of food products. The appearance and color of the extruded gluten-free snacks from each formation are presented in Table 3. The snacks from JR flour in F1 looked yellowish and had a lighter color (L^* = 69.48 ± 0.17) when compared to the snacks from pigmented flours, BGR (F2, L^* = 26.97 ± 0.06) and RR (F3, L^* = 40.41 ± 0.05) while the snack from the highest ratio of BGR in F9 was the darkest with the lowest L^* at 32.60 ± 0.01. The high a* in F2, and F3 might be due to the high anthocyanin content in black glutinous rice and riceberry rice. The phenolic compounds typically accumulated in black rice, i.e., BGR and RR, are purple-black anthocyanins [9], [10].

In addition, the extrusion cooking of rice flour favors the reaction between amino acids and sugar in the feed materials, leading to color degradation or formation of color compounds [34].

Figure 2: Appearance of gluten-free rice snacks extruded from 10 formulations of the rice flour mixtures.

The product color in Figure 2 confirms the visual perception, in which the samples with a high ratio of BGR were perceived as darker, reddish, and less yellowish (F2, F4, F6, and F9) compared to snacks from RR perceived as dark brown (F3, F5, and F10), while JR yielded a yellowish product such as F1. In addition, the L* value also tended to decrease when a denser or lower expanded product was obtained, which decreased the light absorption because of compact air cells [35]. The surface plot between the L^* values and the ratio of three rice flours in all formulations is illustrated in Figure 3 (a).

The quadratic models obtained from the regression analysis for color in terms of coded levels of the variables are expressed in Equations (4)–(6):

$$L^* = 69.51A + 27.00B + 40.44C - 36.78AB - 87.62AC + 9.92BC - 370A^2BC + 60.65AB^2C + 617ABC^2 \quad R^2 = 0.99 \tag{4}$$

Table 3: The Chemical composition of the rice flour mixtures in each formulation for the extrusion

Formulation (F)	JR	GR	RR	Protein	Carbohydrate	Fat	Total Dietary Fiber	Insoluble Fiber	Soluble Fiber
1	100	-	-	7.92 ± 0.21^{b}	75.40 ± 0.15^{b}	2.57 ± 0.05^{f}	6.08 ± 0.08^{a}	5.58 ± 0.06^{a}	0.50 ± 0.02^{a}
2	-	100	-	8.58 ± 0.47^{ab}	72.88 ± 0.23^{e}	3.51 ± 0.26^{a}	4.01 ± 0.04^{e}	3.83 ± 0.03^{d}	0.18 ± 0.03^{g}
3	-	-	100	8.80 ± 0.46^{a}	77.52 ± 0.54^{a}	2.88 ± 0.13^{cde}	2.65 ± 0.02^{h}	2.40 ± 0.02^{g}	0.25 ± 0.01^{f}
4	50	50	-	8.28 ± 0.34^{ab}	74.44 ± 0.19^{cd}	3.05 ± 0.16^{bcd}	5.07 ± 0.05^{b}	4.72 ± 0.05^{b}	0.34 ± 0.01^{c}
5	50	-	50	8.19 ± 0.33^{ab}	74.90 ± 0.34^{bc}	2.67 ± 0.09^{ef}	4.28 ± 0.05^{c}	3.91 ± 0.04^{c}	0.37 ± 0.01^{c}
6	-	50	50	8.55 ± 0.46^{ab}	73.96 ± 0.38^{d}	3.14 ± 0.20^{bc}	3.27 ± 0.03^{g}	3.06 ± 0.02^{f}	0.21 ± 0.02^{g}
7	33.33	33.33	33.33	8.34 ± 0.38^{ab}	74.42 ± 0.30^{cd}	2.95 ± 0.15^{cde}	4.20 ± 0.04^{c}	3.89 ± 0.04^{cd}	0.31 ± 0.01^{d}
8	66.67	16.67	16.67	8.13 ± 0.29^{ab}	74.92 ± 0.22^{bc}	2.76 ± 0.10^{def}	5.14 ± 0.06^{b}	4.73 ± 0.05^{b}	0.40 ± 0.01^{b}
9	16.67	66.67	16.67	8.50 ± 0.43^{ab}	73.96 ± 0.27^{d}	3.24 ± 0.21^{b}	4.12 ± 0.04^{d}	3.88 ± 0.03^{cd}	0.24 ± 0.02^{f}
10	16.67	16.67	66.67	8.39 ± 0.41^{ab}	74.44 ± 0.41^{cd}	2.86 ± 0.13^{cde}	3.36 ± 0.03^{f}	3.09 ± 0.03^{f}	0.27 ± 0.01^{f}

Mean values in the same column with different letters are significantly different at p-value < 0.05.
Numbers presented in the table represent the quantities of each component for the respective types of rice and their formulations

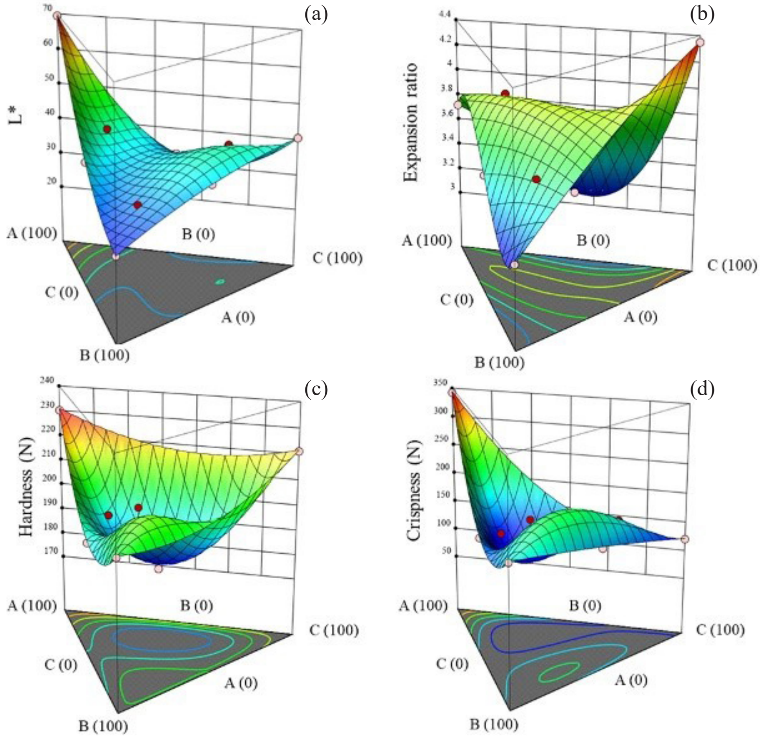

Figure 3: The surface plot between each property of the gluten-free rice snack and different ratios of rice flour mixtures; (a), (b), and (c) represent the percentage ratio of the rice flour from brown jasmine rice, brown black glutinous rice, and brown riceberry rice, respectively.

$$a^* = 3.55A + 8.03B + 6.94C + 11.43AB + 14.73AC + 3.81BC + 43.80A^2BC - 50.16AB^2C - 78.27ABC^2 \quad R^2 = 0.99 \tag{5}$$

$$b^* = 16.50A - 0.14B + 5.23C - 18.13AB - 37.11AC - 1.27BC + 30.49ABC - 4.72AB(A-B) - 38.86AC(A-C) \quad R^2 = 0.99 \tag{6}$$

A, B, and C in all models, represent the percentage ratio of the rice flour from brown jasmine rice, brown black glutinous rice, and brown riceberry rice, respectively.

3.2.1 Expansion ratio and bulk density

The expansion of the extruded snacks and their texture is greatly influenced by the composition of the feed materials as well as the extrusion conditions. During rice extrusion, starch undergoes thermo-mechanical treatment which leads to biochemical reactions such as gelatinization giving a plasticized mass that expands upon exiting the die opening [36]. Starch swells extensively and forms a continuous starch paste matrix of entangled amylose molecules [37]. Generally, high barrel temperature leads to pronounced starch gelatinization and greater expansion. In addition, higher screw speed results in more weakening of intermolecular bonds within starch and protein matrix, which introduces porosity in the products [16], [26]. Feed moisture usually influences expansion more than temperature does [38]. In this study, the feed moisture, barrel temperature and screw speed were controlled with the conditions used in our previous study [16], during the extrusion of all ten formulations. Consequently, the differences in the snack properties could mainly be attributed to the difference in composition and structure of feed ingredients.

Table 4 reveals that the use of only RR (F3) indicated the highest expansion ratio at 4.35 ± 0.39 that was followed by JR (F1), and BGR (F2) at 3.73 ± 0.22, and 3.17 ± 0.12, respectively. An increased amount of RR in formulation led to a higher expansion, while the use of BGR resulted in a lower expansion of the snacks, as shown in Table 4 and Figure 3 (b). The results could be due to the difference in chemical composition and starch properties of the rice flour and rice flour mixture (Table 3). Insoluble fiber indicates a high water absorption, thus decreasing the expansion capability [39]. At the same time, SDF tends to yield higher expansion volumes and affect less on the bulk density of extruded snacks than IDF in cereal bran fiber. Protein could form intermolecular disulfide bonds because of the heat treatment during the extrusion, resulting in decreased starch swelling and the expansion of the snacks [39]. However, none of the formulations showed much difference in protein content in the rice flour mixtures, ranging from 7.92% (F1) to 8.80% (F3). The extruded snacks from RR (F3) indicated the highest expansion ratio at 4.35, even though it had higher protein content than F1, which might be attributed to the highest starch content and lowest IDF at 77.52 ± 0.54%, and 2.40 ± 0.02%, respectively. A similar result was obtained when broken rice was increased (increased starch content), leading to increased expansion and lower hardness of the products [36]. The higher lipid content in BGR could be attributed to the lower expansion ratio of the extruded snacks since lipids could inhibit the degree of starch gelatinization [40].

Bulk density is essential for the quality of extruded snacks since it presents an idea about the volumetric expansion of the product. The bulk density varied between 0.11 and 0.18 g/cm^3. The higher expansion of snacks resulted in a higher porosity, which led to the snack structure being less resistant to breaking, resulting in a low degree of hardness [41]. The quadratic models obtained from the regression analysis for expansion ratio and the bulk density in terms of coded levels of the variables are expressed in Equations (7) and (8).

$$\textit{Expansion ratio} = 3.73A + 3.18B + 4.35C + 0.12AB - 3.76AC + 0.33\,BC + 15.33ABC + 2.41AB(A-B) + 2.51AC(A-C) \qquad R^2 = 0.99 \tag{7}$$

$$\textit{Bulk density} = 0.16A + 0.11B + 0.19C - 0.24AC - 0.65BC + 0.96A^2BC + 4.90AB^2C - 2.07ABC^2 \qquad R^2 = 0.99 \tag{8}$$

3.2.3 Texture

Textural properties such as product expansion and structures of the snacks, are strongly related to the sensory attributes. Harness is the maximum force required to penetrate the product, while crispness indicates the first peak force that fractures the snack. Hardness and crispness are key attributes for snack quality, reflecting the cell structure and puffiness of the snacks [26]. The hardness and crispness of the snacks are presented in Table 5. The surface plot of the crispness of the snacks in Figure 3 (d). The regression model in Equations (9) and (10) indicated that the snacks made from JR indicated higher forces to break the products, as shown by the higher hardness and

Table 4: Physical properties of gluten-free snacks extruded from each formulation of rice flour mixtures

*F**	Color			Expansion Ratio
	*L**	*a**	*b**	
1	69.48 ± 0.17^{a}	3.54 ± 0.03^{h}	16.54 ± 0.07^{a}	3.73 ± 0.22^{cd}
2	26.97 ± 0.06^{i}	8.02 ± 0.01^{f}	-0.10 ± 0.02^{j}	3.17 ± 0.12^{f}
3	40.41 ± 0.05^{c}	6.93 ± 0.00^{g}	5.27 ± 0.02^{b}	4.35 ± 0.39^{a}
4	39.00 ± 0.10^{d}	8.63 ± 0.01^{b}	3.73 ± 0.00^{d}	3.48 ± 0.20^{e}
5	33.01 ± 0.02^{f}	8.91 ± 0.02^{a}	1.67 ± 0.05^{h}	3.89 ± 0.16^{b}
6	36.14 ± 014^{e}	8.42 ± 0.01^{d}	2.31 ± 0.01^{g}	3.84 ± 0.26^{bc}
7	36.45 ± 0.09^{e}	8.39 ± 0.02^{d}	2.42 ± 0.02^{f}	3.92 ± 0.24^{b}
8	41.73 ± 0.14^{b}	8.06 ± 0.02^{e}	3.57 ± 0.04^{e}	3.93 ± 0.25^{b}
9	32.60 ± 0.01^{g}	8.52 ± 0.01^{c}	0.92 ± 0.01^{i}	3.59 ± 0.14^{e}
10	40.24 ± 0.01^{c}	7.99 ± 0.01^{f}	3.92 ± 0.01^{c}	3.85 ± 0.29^{bc}

Note: *F**: Formulation, Mean values in the same column with different letters are significantly different at p-value < 0.05.

crispness, which corresponded to the higher amount of total dietary fiber in the raw materials. Similar results were reported when wheat fiber was used in snack extrusion [42] and the use of fiber material such as xanthan gum, gum acacia, or inulin in the extruded snack generated a product with a harder texture [43].

$$Hardness = 230A + 204B + 221C - 96.28AB - 34.79AC - 34.18BC - 1609A2BC + 1812AB2C - 1487ABC2 \quad R^2 = 0.96 \tag{9}$$

$$Crispness = 343A + 188B + 121C - 434AB - 311AC + 16.97BC - 9311A2BC + 6094AB2C + 3135ABC2 \quad R^2 = 0.98 \tag{10}$$

3.2.4 Water Absorption Index (WAI) and Water Solubility Index (WSI)

WAI and WSI are the main hydration properties of the extruded snacks [44]. WAI presents the weight of gel formed by the dispersion of starch granules in excess water [26], pointing to the digestibility and gelatinization of the starch [36]. The extruded snacks from JR and RR exhibited WAI at 7.40 ± 0.32, and 6.98 ± 0.07, respectively, much higher than that of BGR, 2.71 ± 0.05 (Table 4). The rice flour with a higher starch or carbohydrate content tended to exhibit a higher WAI as presented in Table 4.

WSI relates to the gelatinization degree and solubilization of the starch granules. An intense shear during the extrusion under a low moisture content system leads to starch degradation. A higher WSI

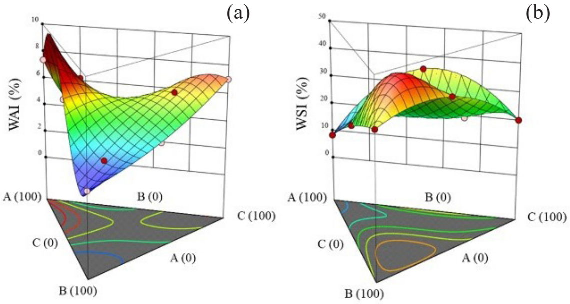

Figure 4: The surface plot between each property of water absorption index (WAI), and water soluble index (WSI) with different ratios of rice flour mixtures; A, B, and C represent the percentage ratio of the rice flour from brown jasmine rice, brown black glutinous rice, and brown riceberry rice, respectively.

indicates a better digestibility of the starch as it implies the extent of gelatinization and dextrinization [38] and [41]. Figure 4(a) and (b) present the surface plot of WAI and WSI with the flour ratio. The quadratic models to predict WAI and WSI of the snacks in Equations (11) and (12) indicate the high coefficients at 0.99.

$$\%\,WAI = 7.42A + 2.73B + 7.00C + 5.88AB - 11.46AC - 2.84AC + 20.41ABC + 26.18AB(A-B) - 17.20AC(A-C) \quad R^2 = 0.99 \tag{11}$$

$$\%\,WSI = 8.42A + 33.29B + 19.90C + 9.34AB + 84.44AC + 36.66BC - 571A^2BC + 1194AB^2C - 1060ABC^2 \quad R^2 = 0.99 \tag{12}$$

Table 5: Physical properties of gluten-free snacks extruded from each formulation of rice flour

*F**	Bulk Density (g/cm^3)	Hardness (N)	Crispness (N)	% WAI	% WSI
1	0.13 ± 0.01^{de}	235.22 ± 2.72^{b}	152.34 ± 7.86^{d}	7.40 ± 0.32^{a}	8.46 ± 0.57^{g}
2	0.18 ± 0.00^{a}	255.24 ± 3.24^{a}	180.06 ± 3.20^{b}	2.71 ± 0.05^{g}	33.33 ± 0.62^{c}
3	0.11 ± 0.02^{f}	213.36 ± 1.51^{d}	116.36 ± 6.27^{e}	6.98 ± 0.07^{b}	19.94 ± 0.15^{f}
4	0.16 ± 0.01^{bc}	212.14 ± 3.25^{d}	124.64 ± 4.72^{e}	6.51 ± 0.03^{c}	23.27 ± 0.75^{e}
5	0.15 ± 0.01^{bc}	215.44 ± 1.77^{d}	172.02 ± 2.16^{c}	4.31 ± 0.07^{e}	35.35 ± 0.69^{b}
6	0.16 ± 0.01^{b}	222.42 ± 4.22^{c}	156.19 ± 8.28^{d}	4.12 ± 0.40^{e}	35.84 ± 0.62^{b}
7	0.14 ± 0.01^{cd}	204.84 ± 7.41^{e}	169.89 ± 2.10^{c}	5.39 ± 0.10^{d}	29.98 ± 0.60^{d}
8	0.12 ± 0.03^{ef}	231.04 ± 4.40^{b}	184.95 ± 2.58^{a}	6.84 ± 0.05^{b}	19.04 ± 0.95^{f}
9	0.16 ± 0.01^{ab}	213.68 ± 4.09^{d}	187.44 ± 4.51^{a}	3.26 ± 0.05^{f}	43.85 ± 0.58^{a}
10	0.13 ± 0.02^{de}	214.76 ± 2.46^{d}	167.84 ± 3.79^{c}	6.36 ± 0.12^{c}	22.53 ± 0.82^{e}

Note: *F**: Formulation, Mean values in the same column with different letters are significantly different at p-value < 0.05.

2.3 *Sensory evaluation*

Though the snacks' color from each formulation differed, as presented in Figure 2, the sensory evaluation shows a non-significant preference in color (Table 6). The consumer's decision to buy the developed products is one of the most important reasons for the optimal formulation selection. The sensory panels seemed to accept the snacks from the mixture of JR+BGR, or the mixture of three rice flours, rather than only one rice flour or the mixture of only JR+RR. However, the snacks from F7, which were composed of JR: BGR: RR at 1:1:1, tended to obtain the highest preference for odor, taste, crispness, and overall liking.

The snacks from F4, F9, and F10 also obtained overall liking at 5.86–5.95, which was not significantly different from that of F7 (6.47 ± 1.17). In this research, the F7 received the highest sensory evaluation score; however, many panelists suggest that adding flavor to the developed product could enhance interest in the product. Bhat *et al*. [26] reported that using brown rice could yield higher texture and taste scores than using white rice because of the high-fat content of brown rice and crisp crust formation during the extrusion. Our study showed that brown rice snacks from a mixture of non-pigmented and pigmented brown rice developed via extrusion tended to obtain higher overall acceptability than those snacks extruded from only one rice variety.

The quadratic models to predict sensory attributes to each formulation in Table 7 present a high R^2 at 0.90–0.99 for color, odor, taste, and crispness but a much lower R^2 (0.74) for overall liking. Therefore, the results implied that a high prediction can be expected for each attribute, but the regression model could not be well applied to the prediction for overall acceptability.

Table 6: Sensory evaluation (hedonic test 9-point scale) of gluten-free snacks extruded from each formulation of rice flour mixtures

Formulation (F)	Colorns	Odor	Taste	Texture	Overall
1	6.00 ± 1.40	5.47 ± 1.66^{ab}	4.58 ± 1.76^{b}	4.98 ± 1.93^{c}	5.40 ± 1.35^{b}
2	6.26 ± 1.28	5.70 ± 1.76^{ab}	4.35 ± 1.70^{b}	6.02 ± 1.62^{ab}	5.63 ± 1.36^{b}
3	5.53 ± 1.42	5.07 ± 1.25^{b}	4.51 ± 1.80^{b}	5.98 ± 2.12^{ab}	5.70 ± 1.50^{b}
4	5.84 ± 1.24	5.65 ± 1.55^{ab}	5.21 ± 1.68^{ab}	6.37 ± 1.46^{ab}	5.95 ± 1.40^{ab}
5	6.09 ± 1.54	5.49 ± 1.30^{ab}	4.58 ± 1.45^{b}	5.84 ± 1.76^{b}	5.58 ± 1.35^{b}
6	6.09 ± 1.34	5.58 ± 1.50^{ab}	4.77 ± 1.79^{b}	6.40 ± 1.26^{ab}	5.79 ± 1.61^{b}
7	6.19 ± 1.37	5.93 ± 1.17^{a}	5.70 ± 1.75^{a}	6.72 ± 1.70^{a}	6.47 ± 1.17^{a}
8	5.67 ± 1.61	5.56 ± 1.50^{ab}	5.05 ± 1.87^{ab}	6.49 ± 1.28^{ab}	5.44 ± 1.32^{b}
9	6.16 ± 1.79	5.74 ± 1.33^{ab}	5.12 ± 1.59^{ab}	6.37 ± 1.35^{ab}	5.86 ± 1.37^{ab}
10	5.88 ± 1.43	5.47 ± 1.58^{ab}	5.05 ± 1.84^{ab}	6.49 ± 1.34^{ab}	5.86 ± 1.25^{ab}

Note: Mean values in the same column with different letters are significantly different at *p*-value < 0.05. ns means not significance

Table 7: Regression analysis of each sensory attribute of the extruded snacks and the ratio of each rice flour used

Y	Equation	R^2
Color	$= 5.98A + 6.24B + 5.52C - 1.23AB + 1.24AC + 0.72BC + 1.31ABC - 3.16AB(A-B) - 0.93AC(A-C)$	0.90
Odor	$= 5.45A + 5.69B + 5.69B + 5.06C + 0.23AB + 0.83AC + 0.74BC + 6.01ABC - 0.55AB(A-B) - 0.27AC(A-C)$	0.93
Taste	$= 4.55A + 4.34B + 4.52C + 2.88AB + 0.0889AC + 1.34BC + 17.19ABC$	0.97
Texture	$= 4.98A + 6.03B + 5.98C + 3.52AB + 1.47AC + 1.61BC + 10.39ABC + 5.77AB(A-B) + 0.18AC(A-C)$	0.99
Overall liking	$= 5.36A + 5.60B + 5.67C + 1.64AB + 0.01AC + 0.38BC + 11.01ABC - 1.02AB(A-B) - 2.84AC(A-C)$	0.74

Note: Mean values in the same column with different letters are significantly different at *p*-value < 0.05. A, B, and C represent the percentage ratio of the rice flour from brown jasmine rice, brown black glutinous rice, and brown riceberry rice, respectively

4 Conclusions

An equal ration mix of brown non-pigmented rice, jasmine rice, and brown pigmented rice could be suitable raw materials for developing nutritious gluten-free extruded rice snacks with high overall acceptability. Pigmented rice, brown black glutinous rice, and riceberry rice contained a high content of anthocyanin. Brown black glutinous rice had the highest antioxidant capacity, followed by brown riceberry rice and brown jasmine rice, respectively. The rice flour and mixture presented a high protein content, 7.92% to 8.80% (by weight), and total dietary fiber at 2.65% to 6.08% (by weight). The differences in chemical compositions among the rice varieties could be attributed to the different physical and physicochemical properties and sensory properties of the extruded snacks. Regression models, showing very high coefficients (R^2), were established to predict responses by applying a suitable mixing ratio of the rice flours. The snacks extruded from an equal mixture of brown jasmine rice, brown black glutinous rice, and brown riceberry rice obtained the highest sensory scores of most attributes and overall acceptability. Nevertheless, the addition of flavor to the developed product could enhance the interest in the product and consumer purchasing decisions. Therefore, the addition of flavor to the product is an interesting point for the next research or commercial expansion. The information from the study benefits industries that are interested in producing gluten-free snacks from brown jasmine rice and pigmented rice with nutritionally rich protein, dietary fiber, and antioxidants.

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Author Contributions

S.C.: methodology, software, data curation, formal analysis; N.B.: methodology, data curation; S.K.: methodology; M.S.K.: review & editing; B.L.: review & editing; B.T.: supervision, funding acquisition, formal analysis; V.R.: conceptualization, supervision, funding acquisition, writing - original draft, review & editing.

Conflicts of Interest

The authors declared that there is no conflict of interest.

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