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RESEARCH ARTICLE

Analysis of Proximate, Functional, and Mineral Composition in Processed Black Rice (*Oryza sativa* L. *indica*) Flours: A Comparative Exploration

Hymie Cherik R. Sangma and S. Parameshwari*

Department of Nutrition and Dietetics, Periyar University, Salem - 636011, Tamil Nadu, India; sparameshwari2009@gmail.com

Abstract

Black rice is utilised to make successful nutraceutical food products because of its high nutrient content. This study sought to determine the proximate compositions, functional compositions, and mineral compositions of processed black rice flour based on different processing methods (Raw, Soaked, and Roasted). The analytical procedures for the processed flours were designed using the standard methodology. The proximate analysis of processed black rice flour revealed a differentiation at ($p \leq 0.01$) in every parameter except the moisture content of raw and soaked flour. The functional properties of processed black rice flour range from 1.0 to 1.17 g/g for water absorption capacity, 2.21 to 2.43 g/g for oil absorption, and 1.8 to 2.2 % for foaming capacity, 986.0 cP for raw black rice flour, 997.0 cP for soaked black rice flour, and 951.0 cP for roasted black rice flour, respectively. Bulk density ranged from 1.77 to 1.82 g/cm^3. Compared to other processed flours, raw black rice flour greatly showed increased oil absorption and foaming capacity, whereas soaked black rice flour dramatically increased viscosity and bulk density. Raw black rice flour exhibited the highest composition of minerals (phosphorus, potassium, calcium, magnesium and iron) followed by soaked and roasted flours ($p<0.01$). The roasted black rice flour contained the highest levels of sodium. The investigation's findings demonstrated that raw black rice flour outperformed other processed black rice flour in terms of several proximate, functional, and mineral aspects, proving to be appropriate for the creation of a range of novel food products with positive health effects.

Keywords: Black Rice, Functional, Mineral, Proximate, Roasting, Soaking

1. Introduction

Half of the world's population consumes rice (*Oryza sativa*)[1]. Mostly Asian and around the globe people prefer to eat rice as a staple food but in cooked form, as well as flour and starch made into a range of items, such as puffed rice[2]. Knowing rice's qualities is crucial for properly incorporating it or its flour into products because they have an impact on the final product's quality, uniformity, and consumer pleasure. *O. sativa* L. *indica* is the scientific name for the rice variety known as black rice. Countries in Asia like Bangladesh, China, Indonesia, India, Japan, Myanmar, Sri Lanka, and Thailand are where this rice is primarily harvested. There are several more names for black rice, including emperor's rice, fortune rice, forbidden rice, purple rice, and king's rice[3]. Manipur, Assam, and Meghalaya are the key growing regions of this rice in Northeastern India**.** Different states have different names for this black rice. People from Manipur and Assam called it *Chak Hao* and *Kola sawl*, respectively. Three ethnic groupings refer to the state of Meghalaya by different names: the Garo or A'chik ethnic group call it *Mi-gisim*, while the *Jaintia* and *Khasi* tribes call it *Jaiong*.

There are numerous varieties of rice, some of which are referred to as traditional or old grains and

**Author for correspondence*

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feature colours in the shades of brown, black and red. Traditional coloured rice of these hues is a good source of nutritional fibre, resistant starch, minerals, carotenoids, flavonoids, and polyphenols, all of which are advantageous to human health[5,6]. Black rice has been a mainstay of Indian cuisine for a long time. It is primarily grown in the southern and north-eastern regions; in Tamil it is referred to as "*Kavuni*" respectively (Figure 1). Black rice varieties differ from white rice in that they contain less amylose and shorter starch molecule chains.

Black rice has gained popularity in the current era because the importance of its dietetic value is on peak and distinctive sensory characteristics. In addition to other nutritional and bioactive components, it contains phytic acid, essential amino acids, functional fats, dietary fibre, vitamins, minerals, phenolic compounds, anthocyanins, and oryzanol[3]. When compared to traditional white rice, black rice has higher levels of protein, ash, crude fibre, phytate, polyphenol, and antioxidant activity. Furthermore, black rice, which is cholesterol-free, has a low sugar and fat content[3,7].

Black rice contains high minerals and bioactive compounds when compared with white rice. It consists of bioactive compounds, certain minerals (Cu, Fe, K, Mg, Mn, P and Zn), and micronutrients such as vitamins (B complex, A complex and E complex). Important amino acids, lipids, and dietary fibre are among its macronutrients[3]. A powerful processing method that frequently increases the amount of genuine aroma components is roasting. Shi and her colleagues assess the impact of black rice's phenolic phytochemicals on the rheological behaviour and starch digestibility *in vitro*[8]. Black rice may generate a distinct flavour and increase customer favourability levels. They discovered that phenolic compounds were more crucial than dietary fibre for delaying the production *in vitro* starch-based meals made with this rice. The functional qualities of rice, such as its potential to absorb water and oil, its emulsifying activity, stability, and foaming capacity, must be evaluated in order to determine whether rice grains have a hopeful future as food ingredients[9].

Phytic acid can be found in the bran layer and embryo of black rice, but it also contains a wide range of other nutrients and bioactive compounds, including functional lipids, dietary fibre, vitamins (B complex, A complex, and E complex), some minerals (Cu, Fe, K, Mg, Mn, P and Zn), anthocyanins, phenolic compounds, tocopherols, and tocotrienols.

As far we are aware, there isn't enough research on the utilisation of food processing techniques to create raw, soaked, and roasted black rice flour. As a result, the goal of this study was to produce several types of processed black rice flour and compare the close-proximate, functional, and mineral components of the final product.

2. Materials and Methods

2.1 Selection of Ingredients

A good quality of organic black rice which is cultivated in Manipur was procured from Northeast Multi Kitchen, Choolaimedu, Chennai, Tamil Nadu, India. The presence of any foreign materials, dirt and stones were removed properly and stored for further processing techniques.

2.2 Processing of Black Rice Flour

2.2.1 Raw Black Rice

The purchase of these black rice grains (300g) was kept as such without inducing any kind of processing. The grains were ground by using a Preethi mixer at 750W to obtain a fine powder and were sieved using a mesh of 100mm[10] in Figure 2.

2.2.2 Soaked Black Rice

The raw black rice (300 g) was soaked for three hours in 1000 ml of tap water at room temperature and was used to process the soaked black rice in Figure 3. After that, the water was drained, and the black rice was

Figure 1. Black rice.

freeze-dried. Then a freeze-dried sample was ground at 750W in a Preethi mixer, and the fine flour was sieved through a 100-mesh screen and kept in an airtight container for further analysis[11].

2.2.3 Roasted Black Rice

The 300g of raw black rice was roasted at a temperature of 200ºC for 15 minutes till the change in colour and aroma of black rice was observed (Figure 4). Then the grains were cooled at room temperature, and it was ground in a Preethi mixer grinder at 750W. Finally, the powder was sieved using 100 mesh and stored for further analysis[11].

2.3 Proximate Analysis

The processed black rice flour's immediate composition, including moisture, energy, carbohydrate, protein, fat, total ash, and dietary fibre, was evaluated using specified analytical techniques. An MB-120 Halogen Moisture Analyzer set to 105°C was used for the analysis to determine the samples' moisture content[12]. The moisture analyzer's lid was lowered until it was tightly closed after one gram of powder sample was weighed and placed within the sample pan. The drying period for each sample was between 2 and 3 minutes. Kjeldahl's method was used to measure the protein content, while the spectrophotometric method was used to determine the nitrogen content given by Atasie *et al*[13]. Each analysis was performed three times.

Energy was calculated by using a formula:

$$\text{Energy(Kcal)}=[(\text{carbohydrate}+\text{protein})\times 4]+[\text{Fat}\times 9].$$

The crude fat was determined by continuous extraction in a Soxhlet apparatus for 18 hours using hexane as the solvent, the ash by burning at 550°C, the crude fiber by hot digestion of the defatted samples sequentially with diluted acid and alkaline solutions, and the total carbohydrate by difference[14]. The well-known enzymatic-gravimetric approach was used to assess the insoluble (IDF) and soluble (SDF) amounts of dietary fiber[14].

2.4 Functional Properties

The following approach was used to examine the functional qualities, such as water and oil absorption capacity, foaming capacity, viscosity, and bulk density.

2.5 Bulk Density

The initial weight was collected and noted on the 10 ml measuring cylinder, which was clean and dry. Individually, the powdered sample was carefully poured into a measuring cylinder with a known weight of 10ml, filled to the 10ml marks, and then repeatedly softly

Figure 2. Raw black rice flour.

Figure 3. Soaked black rice flour.

Figure 4. Roasted black rice flour.

tapped at the base of the lab bench until the sample level remained constant. Weighing and recording the filled measurement cylinder. This method was observed three times for concordant value[14]. The sample's bulk density was calculated as:

$$\text{Bulk density(g/ml)}=\frac{\text{Weight of the sample(g)}}{\text{Volume of sample(ml)}}$$

2.6 Water/Oil Absorption Capacity

One gram of the ground sample was measured in a calibrated centrifugation tube, and ten milliliters of water or oil were added. Later, the sample was stirred for thirty seconds in a vortex mixer. The material was centrifuged for an additional 30 minutes at 5000 rpm after 30 minutes at ambient temperature. The combined mixture was transferred from the graded centrifuge tube to ten milliliters measuring cylinder to calculate the volume of free water or oil. The sample's ability to absorb was calculated in grams[14]. The sample values are computed using the formula.

$$\text{Total oil (or) water absorbed} - \text{Free oil (or) water} \times \text{Density of oil(or)water}$$

2.7 Foaming Capacity

Determination of foam stability (FS) and foam capacity (FC) was done using the Narayana and Narasinga Rao method[15]. Two grams of pulp sample were added to a 100 ml measuring cylinder that was preheated to 30 + 2 °C. The suspension was well mixed and shaken to produce foam; the volume of the foam was then measured after thirty seconds. The FC was articulated as a percentage increase in volume. One hour after whipping, the foam volume was measured in order to determine the FS as a percentage of the original foam volume.

2.8 Viscosity

Using the Visco Basic Plus Viscometer (Fungillab), the sample's viscosity was measured in accordance with the procedure described by Halick *et al*[16]. The developed test samples were reconstituted in water at various solid concentrations (2, 4, 6, and 8 %), heated for 20 minutes on a boiling water bath, cooled to room temperature, and the viscosity was assessed using a Visco Basic Plus Viscometer with varying appropriate spindles at rpms of 20, 30, and 60. Centipoises were used to measure viscosity (cP).

3. Statistical Analysis

The mean values of the processing treatments' triplicates were calculated. To determine whether there were significant differences between the means, an analysis of variance was used. The significance level for the Tukey test, which was used for multiple comparisons, was set at $p \leq 05$. SPSS 16.0 was the statistical software programme used for the analysis.

4. Results and Discussion

4.1 Proximate Analysis of Processed Black Rice Flour

In Table 1, the proximate analysis shows a significant difference among the processed black rice flour at 1% level ($p<01$). The readings for the ash content, which indicated how much minerals were present in processed black rice flour, ranged from 1.55 to 1.71%. Dietary fibre, energy, carbohydrate, protein, and moisture contents varied between 3.3 and 3.79 grams, 353 and 368 kcal, 71.8 g and 74.1 g, 7.4 g and 9.3 g, and 3.15 to 16.11%, respectively. The outcomes matched those of earlier studies by Dhital *et al.,*[17] which said that cultivar, ambient circumstances and processing circumstances, significantly influence protein content.

The amount of moisture in food greatly impacts how long it can last[18]. Moisture influences the flavour and milling characteristics of cooked rice, claim Xheng and Lan[19]. Different rice varieties' moisture content varies depending on their genetic makeup and the environmental factors in which they are cultivated. Table 1 demonstrates that raw and roasted black rice has a lower moisture content than soaked black rice and that the moisture content of processed black rice ranges from 16.1 to 3.15 %.

According to the findings, raw flour has a lower energy value (353 kcal) compared to roasted flour (368 kcal) and soaked black rice flour has gained the lowest energy value of (351kcal). Although roasting has a higher energy content than raw or soaked black rice flour, the amount of carbohydrates was substantially lower in roasted (71.8g) compared to the soaked (74.1g) and raw (73.6g). The ideal carbohydrate level for rice is 80% in order to meet the calorific requirements needed as a staple[20]. The amount of energy acquired from food through cellular respiration is measured as food energy[21].

Table 1. Proximate analysis of processed black rice flour

Proximate analysis	Raw	Soaked	Roasted	F Value
Moisture (%)	12.3 ± 0.05^{a}	16.1 ± 0.4^{b}	3.15 ± 0.01^{c}	59.81**
Energy (kcal)	353 ± 0.57^{a}	351 ± 0.56^{c}	368 ± 0.56^{b}	842.33**
Carbohydrate (g)	73.6 ± 1.25^{a}	74.1 ± 1.21^{ac}	71.8 ± 0.89^{b}	129.23**
Fat (g)	2.02 ± 0.87^{b}	2.71 ± 0.78^{ac}	3.17 ± 0.95^{a}	30.20**
Protein (g)	8.6 ± 2.14^{a}	9.3 ± 1.65^{c}	7.4 ± 1.86^{ab}	77.00**
Dietary fiber (g)	3.79 ± 0.89^{b}	3.61 ± 0.85^{c}	3.3 ± 0.76^{a}	185.59**
Total ash (%)	1.55 ± 0.05^{a}	1.60 ± 0.05^{ab}	1.71 ± 0.03^{c}	60.30**

**- Significant at 1% level

Values are mean ± SD for three samples of each variety, each subjected to independent, triplicate analysis.

Significant variations in means ($p<0.01$) between processed black rice flours are indicated by small superscript letters in the corresponding columns.

Protein, rice's second-most important element after starch, has an impact on both the eating quality and nutritional content of the grain. Soaked black rice flour (9.3g) has considerably more protein than raw black rice flour (8.6g) and roasted flour (7.4g) (Table 1). The albumin content of rice bran proteins is higher than that of endosperm proteins. The aleurone protein bodies are composed of glutelin, prolamin, albumin, and globulin to varying extents[22].

The three principal fatty acids present in the lipid-rich core of lipid bodies are linoleic, oleic, and palmitic acids[23]. Monoacyl lipids (fatty acids and lysophosphatides), which are complex with amylose, are found in the starch lipids of rice. Raw black rice flour had 2.02g fat, which is nearly as much as what was discovered in soaking flour and roasted flour based on the amount of fat found in processed black rice flour (Table 1).

Dietary fibre makes faeces bigger, which makes the digestive tract feel laxative. 0.5–1.0 % of well-milled rice contains fibre. In rice, arabinoxylans and β-d-glucan account for most of the soluble dietary fibre. Additionally, soluble dietary fibre includes the sugars galactose, glucose, xylose, rhamnose, and mannose. Insoluble dietary fibre is made up of cellulose, hemicellulose, insoluble-glucan, and arabinoxylans. However, the type of rice grown, the level of milling, and the water solubility all affect the amount of non-starch polysaccharide and how much it contains[23]. Compared to raw flour (3.79 g) and soaked flour (3.61g), roasted black rice flour (3.3g) has comparatively less dietary fibre (Table 1) but when it was processed, biochemical processes would have reduced the amount of fibre.

Due to genetic variations or variances in the mineral makeup of the soil, certain rice cultivars may have varying levels of ash[24]. Ash is a sign that black rice flour has a mineral composition and is present in all varieties of processed black rice flour. Following raw and soaking flour in increasing ash content was found to be roasted flour (Table 1).

4.2 Functional Properties

The functional traits of this experiment are displayed in Table 2 and were significantly different at ($p<0.01$). Between 1.0 to 1.17 g/g, the water absorption capacity was measured. The data matched the range of 5.44 to 7.14 g/g published by Kraithong *et al.*,[25] for the water absorption capacity value. The main factors influencing the samples' measurements of water absorption capacity are their composition in terms of carbohydrates, proteins, fats, and amylose. Rice flour has a high level of protein and carbohydrates, and this is mirrored in the structure of the molecule, which has a charged or molar side chain that makes hydrogen bonds stronger. The molecule's structure, which features a hydrophobic region that hinders the hydration of flour granules, also reveals the presence of lipids. Granule size has a significant influence. The water molecules can attach to the enormous surface area of small-particle flour. Water absorption capability is an important consideration for baking applications. Roasted flour has the highest water absorption capacity, which means that it is composed of low-structural polymers that give food its soft, smooth texture. The flour that had been soaked had the lowest water absorption capacity, which is related to how compact the polymer structure is. These results are in

Table 2. Functional characteristics of processed black rice flour

Functional characteristics	Raw	Soaked	Roasted	F Value
Water absorption (g)	1.15 ± 0.78[ab]	1.0 ± 0.45[b]	1.17 ± 0.56[a]	59.27**
Oil absorption (g)	2.43 ± 0.15[c]	2.21 ± 0.16[b]	2.40 ± 0.17[a]	70.26**
Foaming capacity (%)	2.2 ± 0.52[ac]	1.8 ± 0.42[b]	2.0 ± 0.40[a]	54.50**
Viscosity cP	986 ± 24.51[c]	997 ± 23.15[ab]	951 ± 21.65[b]	51.93**
Bulk density (gm/ml)	1.79 ± 0.85[c]	1.82 ± 0.86[b]	1.77 ± 0.75[a]	74.33**

**- Significant at 1% level
Values are mean ± SD for three samples of each variety, each subjected to independent, triplicate analysis.
Significant variations in means ($p<0.01$) between processed black rice flours are indicated by small superscript letters in the corresponding columns.

line with those of Aprianita *et al.,* study, who noted that the maximum water absorption index value suggested that the flour had a high concentration of hydrophilic groups inside flour molecules, which contributes to the softness and smoothness of the food product[26].

The oil absorption capacity value ranges from 2.21 to 2.43 g/g in contrast to the 0.88 to 1.39 g/g range. The fact that raw black rice flour had the highest oil absorption capacity value when compared to soaked and roasted flour demonstrated the black rice flour's power to bind oil molecules. The quantity of protein and fats serve as AOAC's defining characteristics. Proteins are composed of both hydrophilic and hydrophobic components. As a result of rice flour's higher lipid content, which contains more hydrophobic molecules, its ability to absorb oil can increase. This is because the hydrocarbon chain of lipids and the side chains of non-polar amino acids can interact hydrophobically[27]. For food production, the oil absorption capacity is essential because it tells us how much oil to keep in flour to preserve flavour, rancid taste, and mouth feel.

Based on a liquid's foaming activity, the likelihood that it would produce foam upon aeration is stated to be assessed[28]. Because proteins have surface-active properties, they can help create foam by reducing surface tension at "water-air" interfaces[29]. If the aqueous phase allows for the solubilization and unfolding of the protein, a strong protein coating may surround the gas or air droplets. The current investigation's processed black rice sample's foaming capacity ranged from 1.8 to 2.2 %. Black rice flour that had been soaked had the least propensity to froth, whereas raw and roasted black rice flour had the highest. Islam *et al.*, recently released a report on the foaming capability of brown rice flour, which was four times higher than our observation[30]. It is very possible that a range of baked items, including rice cakes and bread, will use rice with a sufficient foaming capability[31].

The viscosity of a beverage product affects its texture and consistency in the mouth[32]. The processed black rice flour's relative viscosities for raw, roasted, and soaked black rice were 986cP, 951cP, and 997cP. Whether raw, soaked, or roasted, the viscosities of the three samples did not differ substantially ($p<0.01$). The raw and roasted starch samples' high viscosities show how quickly heated starch granules can shatter after attaining their maximum expansion at the peak viscosity which contributes to the paste's stickiness, is often found in rice with a low amylose level[33]. Samples without the addition of enzymes are more fluid due to higher starch content, which renders them poor in hardness, chewy, sticky, and particularly adhesive[34]. Rice starch swells when cooked in water, which allows the amylose to leak out. When the gelatinized starch granules disintegrate, the larger starch granules cause the viscosity of the starch to rise[35].

The bulk density of the produced, processed black rice flour was found to be 1.77-1.82 gm. According to numerous studies, the bulk density of flour manufactured from cereals ranges from 0.60 to 0.88 g per cubic centimetre[36]. In addition, in a previous study[37] the sprouted mix exhibited a higher bulk density, while the unprocessed and roasted mixes showed similar values. Our results showed a considerably different and somewhat greater bulk density ($p<0.01$). The bulk density of the powders increases with decreasing amounts of trapped air, which reduces the likelihood of product oxidation and increases storage stability.

In addition to having an impact on other powder properties like flow ability and immediate characteristics and providing options to save transportation and packaging costs, flour's high bulk density signals that it is acceptable for use in food preparations[38]. A greater packing fraction is produced by higher bulk processed black rice flours because they require less volume to pack. Flour's bulk density is impacted by interactions between its particles, which also hinder powder flow.

4.3 Minerals Composition

The most common minerals in rice are potassium (K), magnesium (Mg), and calcium (Ca)[39]. The refined black rice flour had large levels of these minerals' compositions are shown in Table 3 as well as Figure 5. Among the three processed flours, the raw black rice flour had the highest content of minerals ($p<0.01$), followed by the soaked and roasted flours. These minerals included phosphorus, potassium, calcium, magnesium, sodium, iron, zinc, and copper.

The highest concentrations of the majority of the minerals were found in the raw black rice flour compared to that of soaked and roasted. Similarly, Zhang *et al.,* showed that black rice had higher levels of phosphorus, iron, zinc, and manganese than popular white rice varieties[40]. Due to the soaking and roasting procedure's leaching action and the removal of various layers' loss effects, both processes reduced the mineral content of the rice kernel.

Table 3. Minerals composition of processed black rice flour

Minerals	Raw	Soaked	Roasted	F Value
Phosphorus (mg)	41 ± 11.25^{a}	38 ± 10.56^{b}	31 ± 14.23^{ac}	123.58^{**}
Potassium (mg)	226 ± 23.14^{c}	208 ± 25.16^{b}	201 ± 26.14^{a}	264.54^{**}
Calcium (mg)	11.0 ± 3.02^{b}	10.8 ± 1.57^{c}	10.5 ± 1.68^{ac}	73.16^{**}
Magnesium (mg)	136.1 ± 21.41^{c}	135.5 ± 20.54^{b}	134.0 ± 23.14^{a}	32.41^{**}
Sodium (mg)	3.01 ± 0.87^{b}	3.11 ± 0.86^{a}	3.48 ± 0.89^{c}	16.38^{**}
Iron (mg)	1.03 ± 0.07^{b}	0.79 ± 0.01^{c}	0.22 ± 0.01^{ac}	15.30^{**}
Zinc (mg)	1.65 ± 0.14^{c}	1.79 ± 0.21^{a}	1.25 ± 0.11^{b}	21.28^{**}
Copper (mg)	0.23 ± 0.01^{b}	0.25 ± 0.02^{a}	0.19 ± 0.01^{ab}	28.69^{**}

**- Significant at 1% level

Values are mean ± SD for three samples of each variety, each subjected to independent, triplicate analysis.

Significant variations in means ($p<0.01$) between processed black rice flours are indicated by small superscript letters in the corresponding columns.

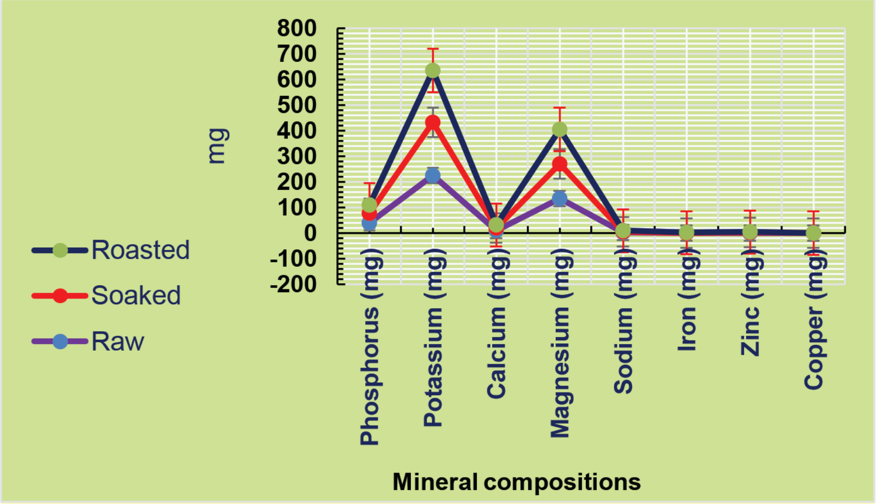

Figure 5. Minerals composition of processed black rice.

5. Conclusion

A study was conducted to assess the proximate compositions, functional properties, and mineral contents of processed black rice flour using different processing methods (Raw, Soaked, and Roasted). The results indicated that raw black rice flour exhibited no significant differences in proximate compositions compared to other flours. However, when compared to other processed flours, raw flour exhibited a notable increase in oil absorption and foaming capacity, while soaked flour showed a significant rise in viscosity and bulk density. Roasted black rice flour had the highest sodium levels among the processed flours. The study concluded that raw black rice flour surpassed other processed varieties in terms of proximate, functional, and mineral aspects, making it suitable for the development of novel food products with positive health effects. Furthermore, flour derived from soaked and roasted black rice demonstrated lower mineral content than raw black rice flour. The researcher suggested that processed black rice flour could serve as an excellent-quality substitute in various food formulations due to its high proximate compositions, favourable functional characteristics, and increased mineral content. The study encourages further research on the composition of food products incorporating processed black rice. Overall, the findings can be utilized to advocate for the consumption of processed black rice.

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