



## Evaluation of White and Black Glutinous Rice Flour Modified by Popping and Puffing as Ingredients for Rice Noodles

Y. Erning Indrastuti , Narsih Narsih  and Susana Susana 

Department of Agricultural Technology, Pontianak State Polytechnic, Jl. A. Yani, Pontianak, Indonesia

\*Corresponding author: [indrastuti\\_erning@yahoo.com](mailto:indrastuti_erning@yahoo.com)

### ABSTRACT

This study aimed to evaluate changes in the physicochemical and functional properties of rice varieties, moisture content, and the popping and gun-puffing methods to improve the cooking quality of rice noodles. The study used a randomized block design with two factors. The first factor was white and black glutinous rice varieties, and the second factor was processing conditions. White glutinous rice varieties provided better hardness, porosity, color, and pasting properties compared to black glutinous rice varieties. However, black glutinous rice varieties were superior in nutritional components and functional properties, including resistant starch, digestible fiber, and anthocyanin content. Rice with an initial moisture content of 14% produced popping rice with higher porosity, meaning it expanded more than rice with an initial moisture content of 10%. The use of gun-puffing resulted in gun-puffed black rice expanding more than white gun-puffed rice. Brown rice flour and popcorn rice from the popped and puffed processes can be added to instant rice noodles. The addition of popping and puffed rice to instant rice noodles can reduce rehydration time and increase water absorption and cooking loss.

**Keywords:** Popped rice, Gun-puffed rice, Rice noodle, Functional foods.

### Article History

Article # 25-783

Received: 05-Dec-25

Revised: 24-Jan-26

Accepted: 05-Feb-26

Online First: 17-Feb-26

### INTRODUCTION

Rice is one of the most widely grown food crops in the world, along with corn and wheat (FAOSTAT, 2023). More than half of the world's people eat rice as their main food. People usually only process rice into polished rice, which they then eat as cooked rice. Recently, consumers have started to buy more healthy, functional and organic foods (Karelakis et al., 2020; Munaqib et al., 2025), but these foods should also be easy to eat and convenient. Instant rice noodles were made to meet the needs of people who want a fast-paced, modern lifestyle. Instant noodles are a type of ready-to-eat food that only need to be cooked for a few minutes (Zia-ud-Din et al., 2023). Instant noodles are classified into two types based on the dehydration method after steaming: fried and non-fried. The market for fried instant noodles is more dominant than non-fried instant noodles (Li et al., 2023).

Deep frying makes the noodles porous, which is how instant noodles are made (Wang et al., 2022). During the frying process, the water in it quickly evaporates in the boiling oil, leaving a porous structure (Leakhena et al., 2021) that makes it easier to rehydrate. Fried instant noodles contain high levels of fat (16–24%) (Obadi et al., 2022). Some

people are worried about the fat residue in food and the trans fatty acids that come from partially hydrogenated and hydrogenated oils used in frying (Umayangani et al., 2025). The high oil content of fried instant noodles raises concerns about the risk of chronic diseases such as obesity, high cholesterol, high blood pressure, and cancer (Obadi et al., 2022). Recently, there has been an increase in consumer preference for healthier and lower-fat foods, which has shifted the need for non-fried instant noodles. However, non-fried instant noodles result in a less porous matrix and a longer rehydration time, which results in a harder texture than fried instant noodles (Garg et al., 2025). According to Zhang et al. (2024), one of the main indicators of instant noodles is rehydration or cooking time. Therefore, the main challenge in improving the quality of non-fried instant noodles is to increase their rehydration capacity.

To make instant noodles without frying and improve rehydration, researchers have explored a process that produces a more porous noodle structure. For example, they have changed the drying process (Pongpichaiudom & Songsermpong, 2018), used porous materials instead of wheat flour, like cross-linked waxy maize starch (Zhou et al., 2015), use of additives such as oleogel (Oh & Lee, 2020),

**Cite this Article as:** Indrastuti YE, Narsih N and Susana S, 2026. Evaluation of white and black glutinous rice flour modified by popping and puffing as ingredients for rice noodles. International Journal of Agriculture and Biosciences xx(x): xx-xx. <https://doi.org/10.47278/journal.ijab/2026.044>



A Publication of Unique Scientific Publishers

enzim (Zhang et al., 2024), using chemical raising agent and freeze drying (Ye et al., 2024), high-temperature short-time drying (Yan et al., 2025), and adding buckwheat (Wang et al., 2025). Therefore, the main challenge in improving the quality of non-fried dry noodles is to increase their rehydration capacity, one of which is by increasing the porosity of the noodles. All of these steps make the noodles porous, which makes it easier for water and heat to move through them during the rehydration process. The popping and puffing method is one way to change rice so that it is porous. Popping and puffing are inexpensive, simple methods to preparing non gluten rice snacks, which are a good alternative for people with celiac disease or those sensitive or intolerant to gluten.

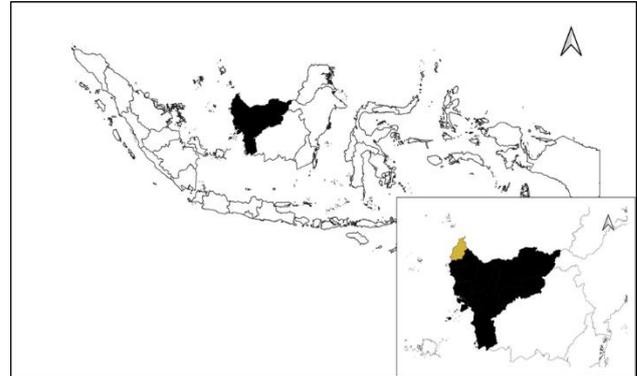
Popping and puffing methods involve physical modifications to grains by heating them to expand the endosperm. Physically modified starch is considered a low-risk material compared to chemical and enzymatic modifications. The use of chemicals and enzymes for starch modification is limited by the potential for chemical residues and the relatively high cost of enzymes. In popping, the pericarp acts as a pressure vessel enveloping the endosperm, while in puffing, grains without the pericarp are pretreated so that the hardened outer layer acts as a pressure vessel (Swarnakar et al., 2022) or using a pressure-puffing gun. The water inside the grain becomes superheated when heated. The most commonly consumed variety is white sticky rice, while data shows the superiority of pigmented rice in having many nutraceutical components and bioactive ingredients (Meher & Jayadeep, 2024), including black sticky rice. The name pigmented rice refers to the color due to anthocyanins and proanthocyanidins in the pericarp, seed coat, aleurone layer and a little in the endosperm (Itagi et al., 2023). Several prior studies have indicated that the popping and gun-puffing processes can modify the physicochemical and functional properties of food ingredients, including the alteration of phenolic content and antioxidant activity (Mbanjo et al., 2020; Kasote et al., 2021; Itagi et al., 2023). To the best of our knowledge, limited information has comprehensively examined the combined effects of glutinous rice variety (white and black), initial moisture content, and both popping and gun-puffing methods, particularly in relation to their application in improving the cooking quality of instant rice noodles.

Therefore, this study aims to evaluate the effects of glutinous rice variety and processing conditions particularly initial moisture content and physical expansion methods (popping and gun-puffing), on the physicochemical, functional, and pasting properties of glutinous rice flour. The study also examined the effect of using popped and gun-puffed rice flour on the cooking quality of instant rice noodles. This study provides a systematic evaluation of how variations in moisture content, rice varieties, and popping and gun-puffing methods affect the physicochemical, functional, and pasting properties of glutinous rice, and may aid the development of non-fried instant rice noodles that are porous, quickly hydrated, yet still offer nutritional and functional benefits.

## MATERIALS & METHODS

### Raw Materials

The materials used in this study consisted of unhulled white and black glutinous paddy varieties obtained from Sambas District, West Borneo, Indonesia (Fig. 1).



**Fig. 1:** Locations for purchasing white and black glutinous paddy in Sambas Regency, West Borneo, Indonesia.

### Popping Process

To get the paddy ready for popping, distilled water was sprayed on it to change the amount of moisture in it. To find out how much water to add, use the formula Eq (1).

$$\text{Water} = \frac{(100\% - \text{Initial moisture content (\%)}) \times \text{Initial Mass (g)}}{(100\% - \text{Targeted moisture content (\%)})} - \text{Initial Mass (g)} \quad (1)$$

Weigh 20g of paddy with the right moisture content and put it in an open vessel that has been heated over a heat source. They roasted the grains for threemin, which made them bigger. This process was done over and over until all the samples were done. A container with holes in it was used to separate the husks, and then any husks that were still there were removed by hand. Before being tested, the popped rice was put in sealed plastic bags.

### Gun-puffing Process

A hulling machine was used to remove the husk from the glutinous paddy to get rice. A sealed container held 1,500g of rice that had been dehusked. The vessel was heated and turned for 15min straight. A piece of burlap cloth was sewn to the lid of the vessel so that when it was opened, the rice that had expanded would fall directly into the cloth. The gun-puffed rice was then put in sealed plastic bags so that it could be tested.

### Characteristics of Paddy, Dehusked Rice, Popped Rice, and Gun-puffed Rice

The TA.XT Plus texture analyzer (Stable Micro Systems) was used to measure the samples' hardness. A single compression was used to measure hardness (force over time). The maximum force (peak value) during the first compression was used to Fig. out the hardness. The bulk density was determined using a 250mL graduated cylinder filled with a weighed sample and tapped five times, the samples' bulk density was measured (Itagi et al., 2023). The bulk density was given in kg/m<sup>3</sup>. We found the true density by putting the weighed sample into a graduated cylinder with kerosene and calculating the ratio of the sample mass

to the increase in kerosene volume. The result was in  $\text{kg}/\text{m}^3$ . Porosity was determined using the equation Eq (2) (Saha & Roy, 2022).

$$\text{porosity (\%)} = \frac{(\text{true density } (\frac{\text{kg}}{\text{m}^3}) - \text{bulk density } (\frac{\text{kg}}{\text{m}^3}))}{\text{true density } (\frac{\text{kg}}{\text{m}^3})} \times 100\% \quad (2)$$

### Analysis of Nutritional Components and Energy Values

The thermogravimetric method was used to find the moisture content. The samples were weighed and then put in an oven at  $105^\circ\text{C}$  until they stopped changing weight. After that, the samples were put in a desiccator to cool to room temperature and then weighed again to get the final dry weight. To find the moisture content of the samples (on a wet basis), we used the formula Eq. (3) (AOAC, 2011).

$$\text{moisture content (wb, \%)} = \frac{\text{wt of wet sample (g)} - \text{wt of dry sample (g)}}{\text{wt of wet sample (g)}} \times 100\% \quad (3)$$

To find the ash content, the samples were burned at  $550^\circ\text{C}$ . Also, the Kjeldahl method was used to look at the protein content. In this method, sulfuric acid was used to digest the samples with the help of a catalyst, which turned organic nitrogen into ammonium sulfate. We used alkali to neutralize the digest and then distilled it into a solution of boric acid. Then, the borate anions were mixed with a standard acid solution, and the nitrogen content was found and shown as crude protein. Furthermore, the fat content was extracted with petroleum ether ( $40\text{--}60^\circ\text{C}$ ) and measured by weight. Using the difference method, the total carbohydrate content was calculated as Eq. (4) (AOAC, 2011).

$$\text{Total Carbohydrates (\%)} = 100\% - (\text{Protein } (\frac{\text{g}}{100\text{g}}) + \text{Ash } (\frac{\text{g}}{100\text{g}}) + \text{Fat } (\frac{\text{g}}{100\text{g}}) + \text{Moisture } (\frac{\text{g}}{100\text{g}})) \quad (4)$$

where  $\text{g}/100\text{g}$  is the same as percent (%). Moreover, the energy value ( $\text{kcal}/100\text{ g dry basis}$ ) (Saini et al., 2023) was computed as Eq (5).

$$\text{Energy } (\frac{\text{kcal}}{100\text{g}}) = (\text{Protein } (\frac{\text{g}}{100\text{g}}) \times 4) + (\text{Fat } (\frac{\text{g}}{100\text{g}}) \times 9) + (\text{Carbohydrates } (\frac{\text{g}}{100\text{g}}) \times 4) \quad (5)$$

### Analysis of Resistant Starch, Dietary Fiber and Anthocyanin

Resistant starch (RS), dietary fiber (DF), soluble dietary fiber (SDF), and insoluble dietary fiber (IDF) in the samples were determined using a Megazyme assay kit. Anthocyanin content was analyzed following the method described by Itagi et al. (2023). Approximately  $10\text{mg}$  of each sample was  $10\text{mg}$ , was mixed with  $10\text{mL}$  of potassium chloride buffer ( $0.03\text{mol}/\text{L}$ ,  $\text{pH } 1.0$ ) and  $10\text{mL}$  of sodium acetate buffer ( $0.4\text{mol}/\text{L}$ ,  $\text{pH } 4.5$ ). We let the mixtures sit for  $15\text{min}$  before measuring their absorbance at  $550\text{nm}$  and  $700\text{nm}$ , using distilled water as a blank. We measured the anthocyanin content in  $\text{mg}$  cyanidin-3-glucoside (C-3-G) equivalents per  $100\text{mL}$  of sample.

### Instrumental Analysis

The ColorFlex EZ Spectrophotometer was used to measure the color properties of the samples. The CIELAB system shows the color by using  $L^*$ ,  $a^*$ , and  $b^*$ ,  $L$  indicates the lightness of the sample, ranging from black (0) to white (100),  $+a$  indicates the degree of redness to  $-a$  greenness,

and  $+b$  indicates yellowness to  $-b$  blueness, respectively.

Microstructure of black and white glutinous rice under different processing conditions was used scanning electron microscopy (SEM, FEI Inspect-S50). Samples were mounted on aluminum supports, coated with a thin layer of gold, and observed with a SEM. The accelerating voltage was  $20\text{ kV}$  and the magnification was  $500\times$ .

Rapid Visco Analyzer (RVA, Perkin Elmer) was used to find out the pasting properties.  $3.5\text{g}$  sample (based on a  $14\%$  moisture content) was dissolved in distilled water to achieve a total weight of  $28.5\text{g}$ . The measurement conditions were as follows:  $1\text{ min}$  of heating at  $50^\circ\text{C}$ ,  $7\text{min}$  of heating from  $50$  to  $95^\circ\text{C}$ ,  $7\text{min}$  of holding at  $95^\circ\text{C}$ ,  $7\text{min}$  of cooling from  $95$  to  $50^\circ\text{C}$ , and  $2\text{min}$  of holding at  $50^\circ\text{C}$ .

The FTIR spectroscopy measurement was investigated using Fourier-transform Infrared Spectroscopy (Shimadzu ATR IR Spirit) used with a resolution of  $0.8\text{cm}^{-1}$  and scanning range ( $4000\text{--}400\text{cm}^{-1}$ ).

### Preparation of Instant Rice Noodle

To make the dough for instant rice noodles, mix  $80\text{ g}$  of rice flour,  $20\text{g}$  of white and black rice ( $10\%$  popped rice,  $14\%$  popped rice, and  $20\text{g}$  of tapioca),  $2\text{ g}$  of salt, and  $250\text{mL}$  of water. The flour batter is evenly poured into a baking pan, steamed for  $2\text{min}$  to set, and then cooled to room temperature. The rice noodle sheets were cut into strips that were  $1\text{cm}$  wide and dried in an oven at  $60^\circ\text{C}$  for  $2\text{ hours}$ . The making of this rice noodle refers to the method (Cham & Suwannaporn, 2010).

### Cooking Quality of Instant Rice Noodles

The rehydration time, cooking loss, and water absorption all affect the cooking quality of instant rice noodles. The time it took to rehydrate was based on the method described by (Zhang et al., 2024). A beaker with  $200\text{mL}$  of boiling water was filled with  $15\text{g}$  of rice noodles and stirred for  $30\text{ seconds}$ . When the white core in the cooked noodles disappeared when pressed between two petri dishes, the rehydration time was noted. We used the international AACC method  $66\text{--}50$  to look at cooking loss and water absorption. This method involves cooking  $10\text{g}$  of noodles in  $200\text{mL}$  of boiling water for  $5\text{min}$  and then filtering them through a filter paper that has already been weighed. The amount of water absorbed is used to figure out the percentage of weight gain. Then, the water in the weighed beaker is dried in an oven at  $105^\circ\text{C}$  until it reaches a constant weight. The increase in weight of the beaker glass is how cooking loss is figured out.

### Statistical Analysis

The experiment was conducted using a factorial completely randomized design which included two factors that were tested with three replicates for each treatment. The two factors tested in this study were glutinous rice variety which included white and black varieties and processing condition which included moisture level and expansion method testing. Statistical analysis was performed using SPSS software version 23. Duncan's multiple range test was used to do post-hoc comparisons at

a significance level of  $P < 0.05$ . All outcomes are displayed as means  $\pm$  standard deviation (SD).

## RESULTS & DISCUSSION

### Microstructure

Microstructure scanning electron microscopy (SEM) showed that the internal structure of rice changed a lot before and after the development process (Fig. 2). Dehulled white and black glutinous rice exhibited a compact and relatively homogeneous internal structure, corroborating previous studies (Shi et al., 2023; Jing et al., 2026). Which characterized dense starch granules. After popping and gun-puffing, the dense rice grains turn into a highly porous matrix with many holes of different sizes. When the grain pops, the heat makes the water inside it superheated, and the husk stops the heat from escaping, as Swarnakar et al. (2022) superheated steam pushes the endosperm to expand when the husk breaks open because of high pressure. The gun-puffing method puts husked grain in a high-pressure, closed space. When you heat rice, the water inside the grains gets very hot. When the pressure is suddenly released, this superheated steam makes the endosperm expand (Kaur et al., 2023).

Table 1 summarizes the physical characteristics of popped and gun-puffed rice, indicating that both rice variety and processing method had significant effects ( $P < 0.05$ ) on the hardness, bulk density, true density, porosity, and color ( $L^*$ ,  $a^*$ ,  $b^*$ ) of popped and gun-puffed rice. The data consistently shows this for both white and

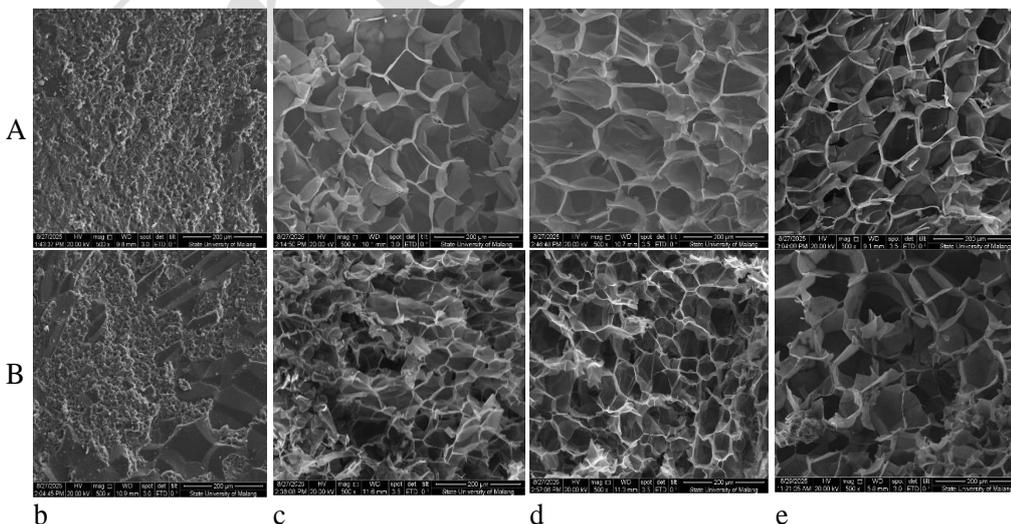
black glutinous rice types when it comes to hardness, bulk density, and true density. Dehusked rice had the highest hardness, bulk density, and true density. Gun-puffed rice and paddy rice were next, and popped rice at 10% and 14% had the lowest values. The order of porosity, from least to most, was dehulled rice, gun-puffed rice, popped rice at 10%, and popped rice at 14%. The most porous was paddy. Dehusked rice made grains that were more uniform and dense, which led to the highest hardness, bulk density, and true density. Rapid heating causes microstructural changes and more porosity during the popping and puffing process.

Swarnakar et al. (2022) concluded that during the popping and puffing process, the superheated steam inside the grain creates high internal pressure, which makes the endosperm expand into a porous structure. The rapidly expanding volume makes porosity much higher, bulk density, true density, and hardness much lower because the structural strength is weaker. These observations align with the physicochemical mechanism of puffing and popping in cereal grains as delineated by Swarnakar et al. (2022). When black glutinous rice was popped at a pre-treatment moisture content of 10%, it was more violent and dense than when it was popped at 14%. At the lower moisture level, both types of rice were less porous than at 14%. This is probably because the pericarp was wetter, which made it sticky and able to handle more pressure. Because of this, the endosperm grew bigger and the porosity grew. Itagi et al. (2023) reported that the best water content for maximum expansion is 12–14%, which gives the right amount of internal pressure.

**Table 1:** Effect of glutinous rice variety and processing condition on hardness, bulk density, true density, porosity and color of rice

Variety	Processing condition	Hardness (kg)	Bulk Density (kg/m <sup>3</sup> )	True Density (kg/m <sup>3</sup> )	Porosity	L*	a*	b*
White	Paddy	3.26 $\pm$ 0.29 <sup>c</sup>	470.5 $\pm$ 25.8 <sup>e</sup>	1004.6 $\pm$ 3.8 <sup>e</sup>	53.17 $\pm$ 2.39 <sup>ef</sup>			
	Dehusked	16.32 $\pm$ 0.07 <sup>e</sup>	837.6 $\pm$ 0.5 <sup>f</sup>	1258.3 $\pm$ 0.6 <sup>f</sup>	33.43 $\pm$ 0.02 <sup>b</sup>	82.58 $\pm$ 0.18 <sup>g</sup>	0.46 $\pm$ 0.01 <sup>a</sup>	11.23 $\pm$ 0.16 <sup>c</sup>
	Popped (10%)	0.34 $\pm$ 0.97 <sup>a</sup>	92.1 $\pm$ 2.4 <sup>b</sup>	173.2 $\pm$ 5.6 <sup>b</sup>	46.71 $\pm$ 0.29 <sup>c</sup>	77.10 $\pm$ 0.23 <sup>e</sup>	3.38 $\pm$ 0.03 <sup>e</sup>	15.05 $\pm$ 0.02 <sup>f</sup>
	Popped (14%)	0.35 $\pm$ 0.71 <sup>a</sup>	84.8 $\pm$ 3.7 <sup>ab</sup>	172.4 $\pm$ 0.9 <sup>b</sup>	50.77 $\pm$ 0.35 <sup>e</sup>	79.08 $\pm$ 0.69 <sup>f</sup>	2.98 $\pm$ 0.21 <sup>d</sup>	14.36 $\pm$ 0.51 <sup>e</sup>
	Gun-puffed	2.72 $\pm$ 0.02 <sup>c</sup>	139.9 $\pm$ 0.9 <sup>d</sup>	252.6 $\pm$ 8.9 <sup>d</sup>	44.62 $\pm$ 3.17 <sup>c</sup>	82.81 $\pm$ 0.67 <sup>g</sup>	2.41 $\pm$ 0.09 <sup>b</sup>	13.18 $\pm$ 0.04 <sup>d</sup>
Black	Paddy	4.21 $\pm$ 0.02 <sup>d</sup>	455.8 $\pm$ 1.0 <sup>e</sup>	1001.1 $\pm$ 0.7 <sup>e</sup>	54.48 $\pm$ 0.39 <sup>f</sup>			
	Dehusked	16.92 $\pm$ 0.01 <sup>e</sup>	1004.9 $\pm$ 1.2 <sup>g</sup>	1255.4 $\pm$ 8.3 <sup>f</sup>	19.96 $\pm$ 2.15 <sup>a</sup>	43.79 $\pm$ 0.70 <sup>a</sup>	3.56 $\pm$ 0.16 <sup>e</sup>	4.64 $\pm$ 0.37 <sup>a</sup>
	Popped (10%)	0.25 $\pm$ 0.03 <sup>a</sup>	92.2 $\pm$ 0.3 <sup>b</sup>	183.0 $\pm$ 0.1 <sup>b</sup>	49.62 $\pm$ 0.12 <sup>d</sup>	70.95 $\pm$ 0.39 <sup>d</sup>	2.76 $\pm$ 0.08 <sup>c</sup>	10.53 $\pm$ 0.52 <sup>b</sup>
	Popped (14%)	0.56 $\pm$ 0.15 <sup>b</sup>	72.3 $\pm$ 2.7 <sup>a</sup>	154.5 $\pm$ 1.1 <sup>a</sup>	53.18 $\pm$ 1.16 <sup>ef</sup>	69.93 $\pm$ 0.14 <sup>c</sup>	2.81 $\pm$ 0.02 <sup>cd</sup>	10.56 $\pm$ 0.09 <sup>b</sup>
	Gun-puffed	1.11 $\pm$ 0.05 <sup>ab</sup>	119.6 $\pm$ 15.6 <sup>c</sup>	218.0 $\pm$ 29.5 <sup>c</sup>	45.10 $\pm$ 0.44 <sup>c</sup>	65.34 $\pm$ 0.46 <sup>b</sup>	2.97 $\pm$ 0.05 <sup>cd</sup>	10.81 $\pm$ 0.18 <sup>bc</sup>

The mean  $\pm$  standard deviation ( $n = 3$ ) is shown in the data. Different superscript letters in the same column show that the differences are statistically significant at  $P < 0.05$ . Color parameters  $L^*$  (lightness),  $a^*$  (redness/greenness),  $b^*$  (yellowness/blueness).



**Fig. 2:** Scanning electron microscopy (SEM) of glutinous rice varieties subjected to various processing conditions. (A) variety white; (B) variety black; (a) dehulled rice; (b) paddy with 10% moisture content subjected to popping; (c) paddy with 14% moisture content subjected to popping; (d) paddy processed by gun-puffing.

The differences in L\*, a\*, and b\* values for both types of rice after dehulling and popping show that thermal processing (popping/gun-puffing) causes pigment breakdown and non-enzymatic browning reactions like the Maillard reaction (Schutte et al., 2024). After popping, the lightness L\* value of white glutinous rice went down a little, which means it looked darker. The a\* and b\* values went up, which means the rice looked more red and more yellow. This trend is linked to the formation of caramelized compounds or Maillard reaction products that cover the surface of the starch. In black glutinous rice, on the other hand, L\* went up after popping, making it look lighter, while a\* went down and b\* went up. This behavior is due to the breakdown of anthocyanins, which usually give a purple to dark red color. When heated, anthocyanins break down and are replaced by degradation products with yellow-brown tones, thereby altering the overall color profile (Sinela et al., 2017; Oancea, 2021).

### Nutritional Components and Energy Value

Table 2 on nutritional components and energy value shows that the protein, fat, water, ash, carbohydrates by difference, and energy values were very different for each variety and processing condition ( $p < 0.05$ ). Across all treatments, black glutinous rice consistently exhibited higher protein content than white glutinous rice, which is consistent with previous reports showing that pigmented rice varieties generally contain higher protein levels than non-pigmented rice (Amrinola et al., 2022). In white glutinous rice, popping at initial moisture contents of 10% and 14% resulted in higher protein levels compared with dehusked rice. This is because the polished process removes some of the aleurone and the embryo which in high concentrations contain protein. Rice proteins are mainly located in the aleurone layer, the embryo, and to a lesser extent in the endosperm (Evangelista & Schönlechner, 2025). In contrast, black glutinous rice showed a slight reduction in protein content after popping, which may be associated with thermal degradation during high-temperature processing, the presence of anthocyanins bound non-covalently to the hydrophobic groups of proteins, Maillard reactions between carbonyl groups of reducing sugars and amine groups of amino compounds (Jia et al., 2021; Ren et al., 2021; Schutte et al., 2024). Proteins absorb energy from heat, which increases molecular motion, unfolds the protein structure, reveals hydrophobic groups, rearranges disulfide bonds, and decreases the solubility of proteins (Song et al., 2026). The gun-puffing process applied to both rice varieties resulted in higher protein contents relative to dehusked rice. This increase is likely due to moisture loss during thermal expansion, which concentrates the protein fraction on a dry-weight basis.

Dehusked white glutinous rice had much less fat than black glutinous rice. This finding aligns with existing literature, which demonstrates that dehulling white rice eliminates the majority of lipids present in the aleurone and bran layers, while black rice preserves a greater lipid content (Itagi et al., 2023). The popping and gun-puffing processes made the lipid content in both white and black glutinous rice higher. This rise was mainly caused by the quick loss of moisture during heating, which made non-volatile parts like lipids more concentrated, and by the breaking up of the starch-protein matrix, which let lipids out (Liu et al., 2025). Gun-puffing produced the highest lipid levels, which means that the high temperature and pressure helped the aleurone and embryo fractions release more oil. In general, black glutinous rice always had more lipids than white glutinous rice, and the differences were even bigger when the rice was popped or gun-puffed.

In both the popping and gun-puffing processes, the amount of water goes down. The drop happens because when popping and gun-puffing happen, the pressure suddenly drops from a high-pressure environment to atmospheric pressure. This makes the saturated steam inside the grains escape quickly, which makes the moisture content in the grains drop sharply (Swarnakar et al., 2022).

The amount of ash in rice shows how many minerals are in it (Nath et al., 2022). Black glutinous dehusked rice has more ash than white glutinous dehusked rice. This aligns with findings from Ahmad Shakri et al. (2021), which indicated that the ash content in pigmented rice varieties is typically greater than that in non-pigmented rice. Dehusked rice had less ash than popped rice for both types. This is because the dehulling process takes off some of the aleurone layer, which is full of minerals. On the other hand, popping uses whole grains with intact aleurone, which keeps the ash content. The ash content of both types of gun-puffed rice was not very different from that of dehusked rice.

The difference in carbohydrate content between the two types and the way they are processed is due to the effects of protein, fat, water, and ash. After the popping and puffing process, the energy values went up a lot. The main reasons for this rise are lower water content and higher lipid levels. This result shows that gun-puffed glutinous rice has a lot of energy, which makes it a good snack that you can eat right away.

### Functional Properties of Food Include Resistant Starch (RS) and Dietary Fiber (DF)

There are two types of dietary fiber: soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). Table 3 shows that the levels of RS, SDF, IDF, DF, and anthocyanins in different types of rice and under different processing conditions were very different ( $P < 0.05$ ).

**Table 2:** Effect of glutinous rice variety and processing condition on nutritional components and energy of rice

Variety of glutinous rice	Processing condition	Protein (%)	Lipid (%)	Moisture (%)	Ash (%)	Total Carbohydrate (%)	Energy (kkal/100 g)
White	Dehusked	8.24±0.09 <sup>a</sup>	0.54±0.04 <sup>a</sup>	11.90±0.61 <sup>e</sup>	0.49±0.02 <sup>a</sup>	78.83±0.85 <sup>b</sup>	353.11±2.99 <sup>a</sup>
	Popped (10%)	9.19±0.21 <sup>de</sup>	2.51±0.12 <sup>bc</sup>	6.92±0.37 <sup>d</sup>	1.55±0.07 <sup>d</sup>	79.79±0.28 <sup>bc</sup>	378.55±1.98 <sup>c</sup>
	Popped (14%)	9.33±0.45 <sup>e</sup>	2.62±0.06 <sup>cd</sup>	6.92±0.37 <sup>d</sup>	1.50±0.08 <sup>cd</sup>	80.37±1.60 <sup>cd</sup>	382.44±7.21 <sup>cd</sup>
	Gun-puffed	8.88±0.14 <sup>cd</sup>	0.67±0.10 <sup>a</sup>	5.03±0.15 <sup>a</sup>	0.58±0.02 <sup>a</sup>	84.83±0.40 <sup>e</sup>	380.91±0.18 <sup>c</sup>
Black	Dehusked	9.87±0.06 <sup>f</sup>	2.40±0.16 <sup>b</sup>	11.23±0.14 <sup>e</sup>	1.60±0.03 <sup>d</sup>	74.90±0.83 <sup>a</sup>	360.66±4.50 <sup>b</sup>
	Popped (10%)	8.55±0.05 <sup>b</sup>	2.59±0.10 <sup>cd</sup>	5.88±0.12 <sup>b</sup>	1.43±0.04 <sup>bc</sup>	81.55±0.03 <sup>d</sup>	383.71±0.84 <sup>cd</sup>
	Popped (14%)	8.63±0.09 <sup>bc</sup>	2.68±0.04 <sup>cd</sup>	6.79±0.29 <sup>cd</sup>	1.34±0.02 <sup>b</sup>	80.56±0.20 <sup>cd</sup>	380.89±1.23 <sup>c</sup>
	Gun-puffed	10.54±0.16 <sup>g</sup>	2.77±0.10 <sup>d</sup>	4.92±0.16 <sup>a</sup>	1.52±0.10 <sup>cd</sup>	80.25±0.26 <sup>cd</sup>	388.08±1.62 <sup>d</sup>

Values (mean±SD; n = 3) with different superscripts in the same column indicate significant ( $P < 0.05$ ) differences.

**Table 3:** Effect of glutinous rice variety and processing condition on resistant starch, dietary fiber, and anthocyanin of rice

Variety of glutinous rice	Processing condition	RS (%)	SDF (%)	IDF (%)	DF (%)	Anthocyanin (mg/100mL)
White	Dehusked	62.25±0.18 <sup>a</sup>	0.09±0.01 <sup>c</sup>	0.39±0.01 <sup>e</sup>	0.47±0.01 <sup>d</sup>	4.45±0.51 <sup>a</sup>
	Popped (10%)	50.39±0.09 <sup>d</sup>	0.06±0.02 <sup>a</sup>	0.23±0.01 <sup>c</sup>	0.28±0.02 <sup>b</sup>	1.22±6.97 <sup>a</sup>
	Popped (14%)	43.58±0.18 <sup>b</sup>	0.05±0.01 <sup>a</sup>	0.11±0.00 <sup>a</sup>	0.15±0.01 <sup>a</sup>	2.00±0.10 <sup>b</sup>
	Gun puffed	58.50±1.64 <sup>f</sup>	0.11±0.01 <sup>d</sup>	0.28±0.01 <sup>d</sup>	0.38±0.01 <sup>c</sup>	1.67±2.87 <sup>a</sup>
Black	Dehusked	65.53±0.17 <sup>h</sup>	0.21±0.01 <sup>e</sup>	0.87±0.01 <sup>h</sup>	1.08±0.01 <sup>g</sup>	328.19±0.17 <sup>e</sup>
	Popped (10%)	48.59±0.19 <sup>c</sup>	0.12±0.00 <sup>d</sup>	0.40±0.01 <sup>f</sup>	0.52±0.01 <sup>e</sup>	32.90±0.17 <sup>d</sup>
	Popped (14%)	39.41±0.09 <sup>a</sup>	0.09±0.01 <sup>c</sup>	0.21±0.01 <sup>b</sup>	0.29±0.01 <sup>b</sup>	24.32±3.19 <sup>c</sup>
	Gun puffed	56.69±0.25 <sup>e</sup>	0.21±0.01 <sup>e</sup>	0.64±0.01 <sup>g</sup>	0.85±0.01 <sup>f</sup>	15.47±0.51 <sup>b</sup>

Values (mean±SD; n = 3) with different superscripts in the same column indicate significant (P<0.05) differences. RS (Resistant Starch); SDF (Soluble Dietary Fiber); IDF (Insoluble Dietary Fiber); DF (Dietary fiber DF).

The popping and gun-puffing processes lower RS or make starch easier to digest because starch gelatinization and dietary fiber breakdown happen at the same time (Joshi et al., 2014). Starch crystals break down and gelatinize when they are heated and put under pressure quickly. Amyolytic enzymes can get to the starch more easily because the texture is porous and the hardness is lower (Zhu, 2021; Freitas et al., 2025). Furthermore, the microstructure of popped and gun-puffed rice (Fig. 2) shows that the internal structure of the grains changes from dense and compact to sparse and porous, as evidenced by the increase in porosity (Table 1). These results are consistent with research by Jia et al. (2021), which found that porous networks can increase the internal surface area and degree of gelatinization of the grains. Increased internal surface area facilitates enzymatic hydrolysis of starch, thus increasing the digestibility and absorption of starch, or decreasing the RS.

The RS content in dehusked black glutinous rice is greater than that in white glutinous rice. This finding is in line with the report (Rajendran & Chandran, 2020) that says pigmented rice has a unique starch and cell wall matrix composition, as well as anthocyanin compounds that stop enzymes from working.

Dietary fiber is the part of food that the body can't break down with enzymes (Huang et al., 2018). After popping, total DF, SDF, and IDF all tend to go down, with IDF going down the most. The decline results from the partial degradation of cell wall polysaccharides upon heating. Black glutinous rice consistently exhibited elevated dietary fiber content compared to white glutinous rice under similar conditions, corroborating the findings of Sompong et al. (2011) that pigmented rice is abundant in dietary fiber and bioactive compounds. Black glutinous rice demonstrated superior nutritional properties relative to white glutinous rice, as it preserved a higher dietary fiber content.

There was a big difference in anthocyanin content between different types and processing conditions (P<0.05) (Table 3). Under all processing conditions, white glutinous rice had less anthocyanin than black glutinous rice. According to (Mustofa et al., 2024), anthocyanin is the main pigment in black rice varieties, and cyanidin-3-glycoside is the most common type. Anthocyanins diminish during both popping and puffing processes, attributable to their phenolic constituents that are susceptible to degradation at elevated temperatures (Tiozon et al., 2023). During anthocyanin degradation during heating popping and puffing in an aqueous medium, cyanidin-3-glucoside and peonidin-3-glucoside undergo glucose hydrolysis, separating the glucose moiety from C3G and P3G, resulting

in the formation of cyanidin, peonidin, and glucose. As the thermal process continues, the heterocyclic rings of cyanidin and peonidin are hydrolyzed, further forming phloroglucine aldehydes and phenolic acids (Das & Sit, 2021).

### Pasting Properties

Table 4 of the pasting properties shows that the paste profile is greatly (p<0.05) affected by the type of paste and how it was made. Dehulled white glutinous rice has the highest peak viscosity, breakdown, setback, and final viscosity. This means that the starch granules are still whole and swell, break, and retrograde when the temperature changes and the mixture is stirred. On the other hand, popping treatment at 10% and 14% moisture content and puffing caused a big drop in almost all pasta parameters, such as peak and final viscosity. The peak time also dropped significantly, from 10min to 3min. This shows that popping and gun-puffing cause partial pregelatinization, which breaks down starch granules and breaks up amylose and amylopectin chains. This stops the granules from swelling.

These results align with earlier studies by Itagi et al. (2023) and Kumar & Prasad (2018), which reported reduced viscosity in rice following popping and puffing treatments due to starch granule degradation. For example, black glutinous rice has lower peak and final viscosities than white glutinous rice. This is because of phenolic compounds or anthocyanins and interactions between starch, protein, and lipids that stop granules from swelling. This phenomenon corresponds with the results of Itagi et al. (2023), who indicated that black rice typically demonstrates a lower viscosity profile than white rice.

### FTIR Spectroscopy

The peaks observed in the FTIR (Fig. 3) can be grouped into several regions (Shavandi et al., 2022). All samples exhibit a wide absorption band at a wave number of approximately 3280cm<sup>-1</sup>, attributed to O–H stretching, analogous to the findings of Saha & Roy (2022). Both types of rice had lower intensity in popped rice samples (10% and 14%) and gun-puffed rice than in dehusked rice. This means that the heating process changes the way hydrogen bonds form and lowers the amount of water in the food. This also means that the starch has turned into a gel and lost some of the water that was bound to it. The band at 2790–3025cm<sup>-1</sup> (C–H stretching) comes from C–H vibrations in polysaccharides and lipids. There were some small changes in popped rice and gun-puffed rice, which suggests that lipids were rearranged and some aliphatic bonds were partially broken during the popping and puffing process.

**Table 4:** Effect of glutinous rice variety and processing condition on pasting properties of rice

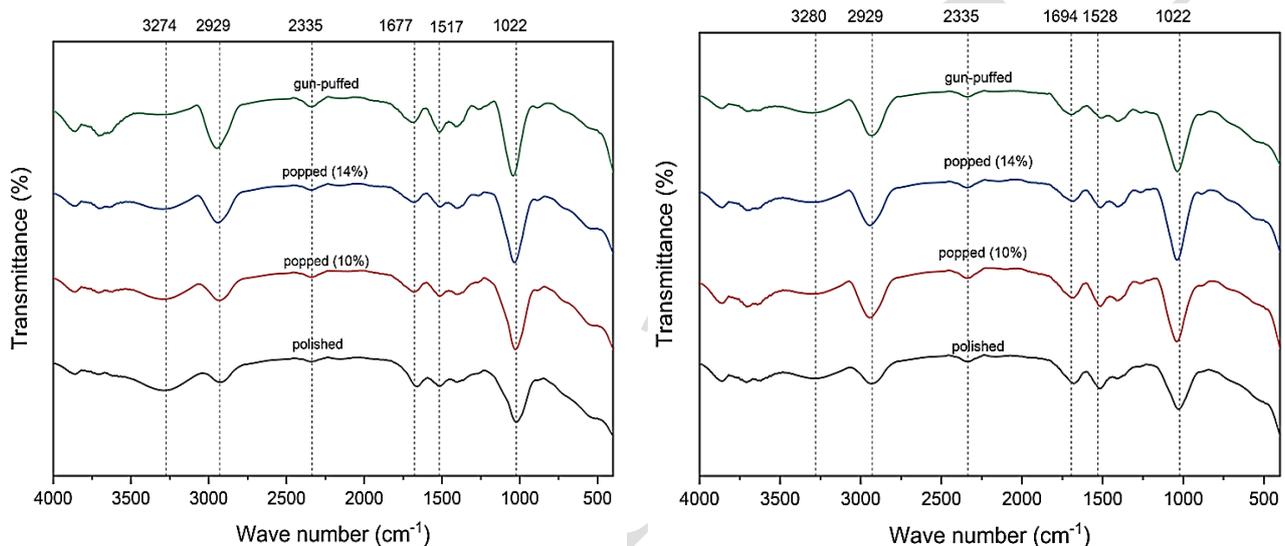
Variety of glutinous rice	Processing condition	Peak Viscosity (cP)	Trough Viscosity (cP)	Breakdown Viscosity (cP)	Setback Viscosity (cP)	Final Viscosity (cP)	Peak Time (s)
White	Dehusked	1665±43 <sup>f</sup>	1160±47 <sup>g</sup>	505±4 <sup>cd</sup>	1022±39 <sup>f</sup>	2182±77 <sup>e</sup>	10.04±0.08 <sup>b</sup>
	Popped (10%)	724±28 <sup>b</sup>	635±4 <sup>bc</sup>	89±0 <sup>b</sup>	257±1 <sup>c</sup>	892±4 <sup>c</sup>	3.25±0.10 <sup>a</sup>
	Popped (14%)	1219±75 <sup>d</sup>	777±22 <sup>e</sup>	443±6 <sup>c</sup>	314±5 <sup>d</sup>	1090±26 <sup>d</sup>	3.07±0.31 <sup>a</sup>
	Gun puffed	1416±33 <sup>e</sup>	829±19 <sup>f</sup>	586±9 <sup>d</sup>	445±27 <sup>e</sup>	1274±32 <sup>d</sup>	3.07±0.00 <sup>a</sup>
Black	Dehusked	149±45 <sup>a</sup>	147±5 <sup>a</sup>	2±79 <sup>a</sup>	77±16 <sup>a</sup>	224±18 <sup>a</sup>	11.49±0.00 <sup>b</sup>
	Popped (10%)	832±26 <sup>c</sup>	718±23 <sup>d</sup>	114±80 <sup>b</sup>	242±17 <sup>bc</sup>	960±29 <sup>c</sup>	3.07±0.00 <sup>a</sup>
	Popped (14%)	1190±103 <sup>d</sup>	650±18 <sup>c</sup>	540±51 <sup>d</sup>	259±33 <sup>c</sup>	909±18 <sup>c</sup>	3.07±0.00 <sup>a</sup>
	Gun puffed	653±23 <sup>b</sup>	595±17 <sup>b</sup>	58±9 <sup>ab</sup>	210±29 <sup>b</sup>	805±37 <sup>b</sup>	3.31±0.27 <sup>a</sup>

Values (mean±SD; n = 3) with different superscripts in the same column indicate significant ( $P < 0.05$ ) differences.

**Table 5:** Cooking quality of instant rice noodles substituted with modified rice flour

Variety of glutinous rice	Modified Rice Flour	Cooking Time (min)	Cooking Loss (%)	Water absorption (%)
White	Dehusked	2.55±0.06 <sup>d</sup>	4.08±0.09 <sup>e</sup>	119.76±3.12 <sup>a</sup>
	Popped (10%)	1.89±0.05 <sup>c</sup>	3.19±0.13 <sup>b</sup>	127.26±1.04 <sup>b</sup>
	Popped (14%)	1.78±0.05 <sup>b</sup>	4.26±0.09 <sup>f</sup>	147.41±0.64 <sup>c</sup>
	Gun puffed	1.67±0.03 <sup>ba</sup>	3.58±0.03 <sup>c</sup>	168.95±0.58 <sup>d</sup>
Black	Dehusked	2.55±0.05 <sup>d</sup>	3.51±0.07 <sup>c</sup>	120.46±4.29 <sup>a</sup>
	Popped (10%)	1.93±0.06 <sup>c</sup>	3.05±0.02 <sup>a</sup>	130.36±0.77 <sup>b</sup>
	Popped (14%)	1.85±0.10 <sup>bc</sup>	3.73±0.08 <sup>d</sup>	139.76±3.31 <sup>c</sup>
	Gun puffed	1.60±0.04 <sup>a</sup>	3.25±0.06 <sup>b</sup>	161.92±4.75 <sup>d</sup>

Values (mean±SD; n = 3) with different superscripts in the same column indicate significant ( $P < 0.05$ ) differences.



**Fig. 3:** FTIR spectra of glutinous white rice (above) and glutinous black rice (below) under different processing conditions: dehusked, popped 10%, popped 14%, and gun-puffed.

There are peaks between 1770 and 1500 $\text{cm}^{-1}$  (C=O stretching, protein amide I, and carbonyl bonds). The peak at 1667 $\text{cm}^{-1}$  was stronger in the popped rice (14%) and gun-puffed rice samples than in the dehusked rice. This means that the protein has been denatured and new carbonyl bonds may have formed because of heat reactions, like the Maillard reaction between proteins and carbonyl compounds. The amide II, C–N vibrations, and N–H bending are all in the range of 1500–1200 $\text{cm}^{-1}$ . The peak at 1517 $\text{cm}^{-1}$  is more pronounced in popped rice and gun-puffed rice samples than in brown rice, suggesting a modification in the protein's secondary structure during heating. The 1200–900 $\text{cm}^{-1}$  range is where starch has its fingerprint: C–O, C–C, and glycosidic bonds. The peak at 1022 $\text{cm}^{-1}$  for sharp and clear dehusked rice shows that the starch structure is still crystalline. The bands are wider and have different intensities for popped rice (10% and 14%). This means that the crystalline structure has been broken and changed into a more amorphous form.

### The Quality of Cooking Instant Rice Noodles

Table 5 shows the results of cooking rice noodles. The findings indicate that incorporating white and black rice flour varieties into rice noodles from the popping/puffing process diminishes cooking time, enhances rehydration capacity, and reduces cooking loss of instant rice noodles. This change is in line with the way that expansion works, where heat and pressure treatment makes pores and weak membranes that let water in faster and cut down on cooking time. However, as reported by Yadav et al. (2024), expansion treatments may also increase the leaching of soluble solids from starch granules during cooking. Rehydration capacity increased significantly for dehusked rice to popped and gun-puffed rice, indicating that the porous structure of rice flour resulting from the expansion process supports water absorption ability. Adding popped and gun-puffed rice to rice noodles speeds up the rehydration process.

### Conclusion

This research focused on the effects of rice varieties,

water content, and the popping and puffing processes on the physicochemical and functional properties of popcorn rice. Rice modified by popping and puffing processes is used to improve the cooking properties of instant rice noodles. White glutinous rice varieties have better hardness, porosity, color, and pasting properties than black glutinous rice varieties. However, black glutinous rice varieties have better nutritional components and functional properties, such as resistant starch, digestible fiber, and anthocyanin content. Gun-puffing can be used to make gun-puffed rice from black glutinous rice instead of white glutinous rice, which makes less expanded gun-puffed rice. The use of gun-puffing technology may be considered as an alternative for producing gun-puffed black glutinous rice, while white glutinous rice tends to yield less expanded gun-puffed rice under the same treatment. The porosity of gun-puffing in black glutinous rice increases 2.3 times compared to dehusked rice, but only 1.3 times in white glutinous rice. The addition of glutinous rice flour can shorten the cooking time (24.3-37.3%) for instant noodles and increase their weight. Therefore, the initial water content treatment and development method produced value-added glutinous rice flour adapted for non-fried instant rice noodle applications.

## DECLARATIONS

**Funding:** This research was funded by Ministry of Higher Education, Science, and Technology, Indonesia with contract No 046/C3/DT.05.00/PL/2025 08 May 2025.

**Acknowledgement:** All authors would like to thank the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia for funding this research through Penelitian Fundamental (Fundamental Research).

**Conflict of Interest:** None

**Data Availability:** Data will be available at request.

**Ethics Statement:** This study is based on in vitro work and thus does not require ethical approval.

**Author's Contribution:** Y. Erning Indrastuti contributed to manuscript preparation, review, and editing. Narsih contributed to idea, conceptualization, and review. Susana contributed to review and editing. All authors contributed approved the final version.

**Generative AI Statement:** The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

**Publisher's Note:** All claims stated in this article are exclusively those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated/assessed in this article or claimed by its manufacturer is not guaranteed or endorsed by the publisher/editors.

## REFERENCES

- Ahmad Shakri, A.N., Kasim, K.F., & Rukunudin, I.B. (2021). Chemical compositions and physical properties of selected Malaysian rice: A review. *IOP Conference Series: Earth and Environmental Science*, 765(1). <https://doi.org/10.1088/1755-1315/765/1/012024>
- Amrinola, W., Sitanggang, A.B., Kusnandar, F., & Budijanto, S. (2022). Characterization of pigmented and non-pigmented flakes glutinous rice (ampiang) on chemical compositions, free fatty acids compositions, amino acids compositions, dietary fiber content, and antioxidant properties. *Food Science and Technology (Brazil)*, 42, 1–7. <https://doi.org/10.1590/fst.86621>
- AOAC (2011). *Official methods of analysis of the AOAC* (18th ed18t). Association of official analytical chemists. Arlington, USA.
- Cham, S., & Suwannaporn, P. (2010). Effect of hydrothermal treatment of rice flour on various rice noodles quality. *Journal of Cereal Science*, 51(3), 284–291. <https://doi.org/10.1016/j.jcs.2010.01.002>
- Das, A., & Sit, N. (2021). Modification of Taro Starch and Starch Nanoparticles by Various Physical Methods and their Characterization. *Starch/Staerke*, 73(5–6), 1–8. <https://doi.org/10.1002/star.202000227>
- Evangelista, G.C., & Schönlechner, R. (2025). Potential of Pigmented Rice in Bread, Bakery Products, and Snacks: A Narrative Review of Current Technological and Nutritional Developments. *Applied Sciences (Switzerland)*, 15(12), 1–31. <https://doi.org/10.3390/app15126698>
- FAOSTAT (2023). *Crops and livestock products*. Food and Agriculture Organization. <https://www.fao.org/faostat/en/#data/QL>
- Freitas, D., Lazaridou, A., Duijsens, D., Kotsiou, K., Corbin, K.R., Alongi, M., Perez-Moral, N., Simsek, S., El, S.N., Gwala, S., Karakaya, S., Le Feunteun, S., Grauwet, T., Martinez, M.M., & Edwards, C.H. (2025). Starch digestion: A comprehensive update on the underlying modulation mechanisms and its in vitro assessment methodologies. *Trends in Food Science and Technology*, 159, 104969. <https://doi.org/10.1016/j.tifs.2025.104969>
- Garg, P., Gulia, N., Singh, O., & Bouchon, P. (2025). Impact of impingement drying on microstructure, porosity and textural properties of instant noodles compared to frying. *Food Structure*, 46, 100475.
- Huang, R., Pan, X., Lv, J., Zhong, W., Yan, F., Duan, F., & Jia, L. (2018). Effects of explosion puffing on the nutritional composition and digestibility of grains. *International Journal of Food Properties*, 21(1), 2193–2204. <https://doi.org/10.1080/10942912.2018.1514634>
- Itagi, H., Sartagoda, K.J.D., Pratap, V., Roy, P., Tiozon, R.N., Regina, A., & Sreenivasulu, N. (2023). Popped rice with distinct nutraceutical properties. *Lwt*, 173, 114346. <https://doi.org/10.1016/j.lwt.2022.114346>
- Jia, L., Huang, R., Wang, S., Dong, Y., Lv, J., Zhong, W., & Yan, F. (2021). Effects of Explosion Puffing on the Composition, Structure, and Functional Characteristics of Starch and Protein in Grains. *ACS Food Science and Technology*, 1(10), 1869–1879. <https://doi.org/10.1021/acfoodscitech.1c00232>
- Jing, L., Gong, X., Cai, Y., Su, Y., Ait-El-Mokhtar, M., Lu, M., wang, Z., Yang, L., Han, Q., & Wang, Y. (2026). Effects of elevated atmospheric CO2 on hybrid rice (*Oryza sativa* L.) starch granules: Structural, functional changes and their underlying causes. *Carbohydrate Polymers*, 371(2025). <https://doi.org/10.1016/j.carbpol.2025.124419>
- Joshi, D. C., Mishra, G., Joshi, D. C., & Kumar Panda, B. (2014). Popping and Puffing of Cereal Grains: A Review. *Journal of Grain Processing and Storage*, 1(2), 34–46. <https://www.researchgate.net/publication/283355236>
- Karelakis, C., Zevgitis, P., Galanopoulos, K., & Mattas, K. (2020). Consumer Trends and Attitudes to Functional Foods. *Journal of International Food and Agribusiness Marketing*, 32(3), 266–294. <https://doi.org/10.1080/08974438.2019.1599760>
- Kasote, D., Tiozon, R.N., Sartagoda, K.J.D., Itagi, H., Roy, P., Kohli, A., Regina, A., & Sreenivasulu, N. (2021). Food Processing Technologies to Develop Functional Foods With Enriched Bioactive Phenolic Compounds in Cereals. *Frontiers in Plant Science*, 12, 771276. <https://doi.org/10.3389/fpls.2021.771276>
- Kaur, R., Kumar, A., Kumar, V., Kumar, S., Kumar Saini, R., Nayi, P., & Gehlot, R. (2023). Recent advancements and applications of explosion puffing. *Food Chemistry*, 403, 134452. <https://doi.org/10.1016/j.foodchem.2022.134452>
- Kumar, S., & Prasad, K. (2018). Effect of parboiling and puffing processes on the physicochemical, functional, optical, pasting, thermal, textural and structural properties of selected Indica rice. *Food Measure*, 12, 1707–1722. <http://dx.doi.org/10.1007/s11694-018-9786-4>
- Leakhena, O., Thong-gnam, M.U.B., Jhoo, J.W., & Boonsupthip, W. (2021). Microstructural, dehydration and rehydration properties of rice starch granules in noodles as affected by water and oil addition using vacuum impregnation. *Journal of Food Process Engineering*, 44(8), 1–13.

- <https://doi.org/10.1111/jfpe.13763>
- Li, J., Yuan, F., Teng, J., Li, F., Zhou, P., & Bi, Y. (2023). Effects of tea polyphenols and tertiary butylhydroquinone on quality of palm oils and losses of endogenous vitamin E during batch frying and oxidative stability of fried instant noodles. *Food Chemistry*, *X*, *20*, 101049. <https://doi.org/10.1016/j.fochx.2023.101049>
- Liu, X., Zhang, Y., Zhu, K., Xie, F., Si, H., Wu, S., Chen, B., Zheng, Q., Wang, X., Zhao, Y., & Qiao, Y. (2025). Comparative Evaluation of Puffing Effects on Physicochemical and Volatile Profiles of Brown and Refined Rice. *Foods*, *14*(16), 2812. <https://doi.org/10.3390/foods14162812>
- Mbanjo, E.G.N., Kretschmar, T., Jones, H., Ereful, N., Blanchard, C., Boyd, L.A., & Sreenivasulu, N. (2020). The Genetic Basis and Nutritional Benefits of Pigmented Rice Grain. *Frontiers in Genetics*, *11*, 1–18. <https://doi.org/10.3389/fgene.2020.00229>
- Meher, T., & Jayadeep, A. (2024). Effect of bioprocessing through germination and hydrothermal treatment on nutrients, nutraceuticals, and antioxidant properties in red and black rice. *Journal of Food Measurement and Characterization*, *18*(4), 2935–2951. <https://doi.org/10.1007/s11694-024-02372-6>
- Munafiq, P., Darzi, M.A., Bhat, S.A., Islam, S.B., & Mushtaq, N. (2025). Understanding Millennials and Gen Z's organic food buying intentions: A mediation and segmentation study. *Cleaner Waste Systems*, *11*, 100294. <https://doi.org/10.1016/j.clwas.2025.100294>
- Mustofa, A., Anam, C., Praseptianga, D., & Sutarno (2024). A comparative study on physicochemical properties of rice and starch of white rice, black rice and black glutinous rice. *Food Research*, *8*, 55–65. [https://doi.org/10.26656/fr.2017.8\(S2\).566](https://doi.org/10.26656/fr.2017.8(S2).566)
- Nath, S., Bhattacharjee, P., Bhattacharjee, S., Datta, J., & Dolai, A.K. (2022). Grain characteristics, proximate composition, phytochemical capacity, and mineral content of selected aromatic and non-aromatic rice accessions commonly cultivated in the North-East Indian plain belt. *Applied Food Research*, *2*(1), 100067. <https://doi.org/10.1016/j.afres.2022.100067>
- Oancea, S. (2021). A review of the current knowledge of thermal stability of anthocyanins and approaches to their stabilization to heat. *Antioxidants*, *10*(9), 1337. <https://doi.org/10.3390/antiox10091337>
- Obadi, M., Li, Y., & Xu, B. (2022). Identifying key factors and strategies for reducing oil content in fried instant noodles. *Journal of Food Science*, *87*(10), 4329–4347. <https://doi.org/10.1111/1750-3841.16301>
- Oh, I., & Lee, S. (2020). Rheological, microstructural, and tomographical studies on the rehydration improvement of hot air-dried noodles with oleogel. *Journal of Food Engineering*, *268*, 109750. <https://doi.org/10.1016/j.jfoodeng.2019.109750>
- Pongpichaidom, A., & Songsermpong, S. (2018). Characterization of frying, microwave-drying, infrared-drying, and hot-air drying on protein-enriched, instant noodle microstructure, and qualities. *Journal of Food Processing and Preservation*, *42*(3), 1–10. <https://doi.org/10.1111/jfpp.13560>
- Rajendran, M., & Chandran, K.R. (2020). Grain dimension, nutrition and nutraceutical properties of black and red varieties of rice in India. *Current Research in Nutrition and Food Science*, *8*(3), 903–923. <https://doi.org/10.12944/CRNFSJ.8.3.20>
- Ren, S., Jiménez-flores, R., & Giusti, M.M. (2021). *The interactions between anthocyanin and whey protein: A review*. September, 5992–6011. <https://doi.org/10.1111/1541-4337.12854>
- Saha, S., & Roy, A. (2022). Selecting high amylose rice variety for puffing: A correlation between physicochemical parameters and sensory preferences. *Measurement: Food*, *5*, 100021. <https://doi.org/10.1016/j.meafoo.2021.100021>
- Saini, P., Kumar, N., Kumar, S., Panghal, A., & Attkan, A.K. (2023). Analysis of engineering properties, milling characteristics, antioxidant potential, and nutritional benefits of purple wheat and its bran. *Food Bioengineering*, *2*, 406–419. <https://doi.org/10.1002/fbe2.12073>
- Schutte, M., Hayward, S., & Manley, M. (2024). Nonenzymatic Browning and Antioxidant Properties of Thermally Treated Cereal Grains and End Products. *Journal of Food Biochemistry*, *38*, 65849. <https://doi.org/10.1155/2024/3865849>
- Shavandi, M., Javanmard, M., & Basiri, A. (2022). Novel popping through infrared: Effect on some physicochemical properties of popcorn (Zea Mays L. var. Everta). *Lwt*, *155*, 112955. <https://doi.org/10.1016/j.lwt.2021.112955>
- Shi, S., Zhang, G., Zhao, D., Ma, J., Wang, X., Chen, D., Liu, J., Wang, J., Li, L., Cao, C., & Jiang, Y. (2023). Changes in water absorption and morphology of rice with different eating quality during soaking. *European Food Research and Technology*, *249*(3), 759–766. <https://doi.org/10.1007/s00217-022-04173-x>
- Sinela, A., Rawat, N., Mertz, C., Achir, N., Fulcrand, H., & Dornier, M. (2017). Anthocyanins degradation during storage of Hibiscus sabdariffa extract and evolution of its degradation products. *Food Chemistry*, *214*, 234–241. <https://doi.org/10.1016/j.foodchem.2016.07.071>
- Sompong, R., Siebenhandl-Ehn, S., Linsberger-Martin, G., & Berghofer, E. (2011). Physicochemical and antioxidative properties of red and black rice varieties from Thailand, China and Sri Lanka. *Food Chemistry*, *124*(1), 132–140. <https://doi.org/10.1016/j.foodchem.2010.05.115>
- Song, J., Ma, C., Xu, Y., Wang, B., Xu, X., Zhang, G., & Yang, Y. (2026). Mechanisms by which cooking processing and protein distribution synergistically affect the structural, physicochemical and digestive properties of black rice starch. *Carbohydrate Polymers*, *374*, 124739. <https://doi.org/10.1016/j.carbpol.2025.124739>
- Swarnakar, A.K., Mohapatra, M., & Das, S.K. (2022). A review on processes, mechanisms, and quality influencing parameters for puffing and popping of grains. *Journal of Food Processing and Preservation*, *46*(10), 16891. <https://doi.org/10.1111/jfpp.16891>
- Tiozon, R.J.N., Sartagoda, K.J.D., Fernie, A.R., & Sreenivasulu, N. (2023). The nutritional profile and human health benefit of pigmented rice and the impact of post-harvest processes and product development on the nutritional components: A review. *Critical Reviews in Food Science and Nutrition*, *63*(19), 3867–3894. <https://doi.org/10.1080/10408398.2021.1995697>
- Umayangani, S., De Silva, I., Munasinghe, D., Deshika, C., Chandrapala, J., & Silva, M. (2025). Elimination of Trans Fatty Acids from Foods Using Novel Technologies. *Food Reviews International*, *10*, 1–29. <https://doi.org/10.1080/87559129.2025.2502439>
- Wang, J., Li, A., Hu, J., Zhang, B., Liu, J., Zhang, Y., & Wang, S. (2022). Effect of Frying Process on Nutritional Property, Physicochemical Quality, and in vitro Digestibility of Commercial Instant Noodles. *Frontiers in Nutrition*, *9*, 1–14. <https://doi.org/10.3389/fnut.2022.823432>
- Wang, Y., Wang, Y., Yu, X., Wang, K., Lu, Y., Xu, H., Wang, L., & Wang, J. (2025). Effect of buckwheat inclusion fractions on the drying characteristics and quality attributes of instant noodle sheets. *Food Control*, *169*, 110992. <https://doi.org/10.1016/j.foodcont.2024.110992>
- Yadav, G. P., Kumar, D., Dalbhagat, C. G., & Mishra, H. N. (2024). A comprehensive review on instant rice: Preparation methodology, characterization, and quality attributes. *Food Chemistry Advances*, *4*, 100581. <https://doi.org/10.1016/j.focha.2023.100581>
- Yan, X., Xiao, H., Ye, J., Luo, S., & Liu, C. (2025). Reduction of Rice Noodle Rehydration Time by High-Temperature Short-Time Treatment. *Foods*, *14*(7), 1079. <https://doi.org/10.3390/foods14071079>
- Ye, H., Ou, Y., Xu, Y., Mou, T., Zhang, Y., & Fan, F. (2024). Physicochemical properties and water migrations in freeze-dried rice noodles during rehydration: Effects of raising agent addition and water state variation. *Lwt*, *204*, 116433. <https://doi.org/10.1016/j.lwt.2024.116433>
- Zhang, J., Zhao, F., Li, C., Ban, X., Gu, Z., & Li, Z. (2024). Acceleration mechanism of the rehydration process of dried rice noodles by the porous structure. *Food Chemistry*, *431*, 137050. <https://doi.org/10.1016/j.foodchem.2023.137050>
- Zhou, M., Xiong, Z., Cai, J., & Xiong, H. (2015). Effect of cross-linked waxy maize starch on the quality of non-fried instant noodles. *Starch/Staerke*, *67*(11–12), 1035–1043. <https://doi.org/10.1002/star.201500132>
- Zhu, F. (2021). Structure and physicochemical properties of starch affected by dynamic pressure treatments: A review. *Trends in Food Science and Technology*, *116*, 639–654. <https://doi.org/10.1016/j.tifs.2021.07.036>
- Zia-ud-Din, Qazi, I.M., Ayub, M., Wahab, S., Khan, S.A., Ullah, H., Ali, S., & Ullah, I. (2023). Measurement of physicochemical and dough pasting properties of fresh potato instant noodles as influenced by addition of emulsifiers. *Measurement: Food*, *11*, 100107. <https://doi.org/10.1016/j.meafoo.2023.100107>