Current **A**pplied **S**cience and **T**echnology e-ISSN: 2586-9396

Curr. Appl. Sci. Technol. 2025, Vol. 25 (No. 4), e0264208

Research article

Physicochemical, Nutritional, and Functional Properties of Rice Bran from White and Brown Rice in Sri Lanka: A Study of Bg 300 and At 362

Harshaka Maduwantha Jans, Perumpuli Arachchige Buddhika Niroshie Perumpuli* and Arukattu Patabendige Hashini Imalsha Abeysuriya

Department of Food Science and Technology, Faculty of Agriculture, University of Ruhuna, Mapalana, Kaburupiyiya, Matara, 81100, Sri Lanka

Received: 31 July 2024, Revised: 5 December 2024, Accepted: 7 December 2024, Published: 10 March 2025

Abstract

Rice bran (RB), a by-product of rice milling, is increasingly recognized for its versatile applications across various industries. This study analyzes and compares the physicochemical, nutritional and functional properties of RB from two high-yielding and highly consumed Sri Lankan rice varieties: Bg 300, a white rice bran and At 362, a brown rice bran. Bg 300 exhibited higher bulk density (0.40±0.01 mg/mL), oil absorption capacity (192.33±9.82%), water holding capacity (2.91±0.03 g/g), foaming capacity (13.95±2.12%), and foaming stability (64.8±13.1%). In contrast, At 362 demonstrated superior water absorption (261.1±15.9%), swelling power (3.8±0.08 g/g), and water solubility index (3.7±0.05 g/g). Nutritionally, Bg 300 contained higher fat (20.43±0.32 g/100 g), protein (11.09±0.22 g/100 g), and fiber (5.6±0.19%) contents, and potassium (0.54±1.0 g/100g) and sodium (0.007±2.12 g/100g) contents. In contrast, At 362 had significantly higher total flavonoid content (5.52±0.08 mg quercetin equivalent /g), total phenolic content (3.13±0.02 mg gallic acid equivalent/100 g), and antioxidant capacity (27.12±0.80 mmol Trolox/g). Thus, Bg 300 excelled in physical and nutritional properties, while At 362 was superior in antioxidant activity and bioactive compounds. As a whole, both Bg 300 and At 362 rice brans were rich in physicochemical, nutritional and functional properties, making them promising potential ingredients in functional foods.

Keywords: antioxidant; brown rice bran; functional properties; nutritional composition; physicochemical properties; white rice bran

*Corresponding author: E-mail: buddhikap@fst.ruh.ac.lk
https://doi.org/10.55003/cast.2025.264208

1. Introduction

Rice (*Oryza sativa*) is the world's most important food crop and the primary source of energy for more than half of the world's population. More than 90% of the world's rice is grown and consumed in Asia (Khush, 2005). According to Shahbandeh (2023), the global consumption of rice has increased over the last several years whereas, in the 2021/2022 crop year, around 520 million metric tons of rice were consumed globally. Rice remains the major source of energy and protein for Sri Lankans (Thennakoon & Ekanayake, 2022). As a staple food, Sri Lanka produces three million tons of rice annually and rice is cultivated in two seasons, namely *Yala* (May to August) and *Maha* (September to March).

During certain stages of milling process of rice, rice bran (RB) is removed from the grain, as a by-product. RB is the main and highly valuable by-product of rice kernel milling and consists mainly of the germ, pericarp, aleurone, and sub-aleurone layers (Irakli et al., 2021). It is a rich source of essential nutrients, including minerals, vitamins, fiber, proteins, fats, and carbohydrates. Moreover, RB is rich in bioactive compounds, including antioxidants such as tocopherols, tocotrienols, gamma oryzanol, and flavonoids, which contribute to potential anti-inflammatory and cardioprotective properties (Saji et al., 2019; Tan et al., 2023). Additionally, RB is a notable source of fiber, which may promote digestive health and aid in weight management. Research shows that consuming RB can have a positive effect on fat metabolism, lower cholesterol levels, and improve lipid profiles (Cicero et al., 2017) .Additionally, RB is considered to be a valuable source of essential fatty acids, including omega-3 and omega-6 fatty acids.

When consider the rice production in Sri Lanka, the highest yielding, mostly consumed and most cultivated white and brown rice varieties namely Bg 300 and At 362, respectively, were selected. According to statistics available at the Department of Agriculture Sri Lanka (2024), Bg 300 (white variety) gives as average yield of 5.0 t/ha and a milling recovery of 75.50% (based on weight). Comparatively, At 362 gives an average yield of 7.0 t/ha and milling recovery of 68.60% (based on weight). Further to that, since rice is a staple food, a vast amount of rice is processed, leaving RB as a major by-product that is underutilized. It has been mainly utilized as an animal feed in Sri Lanka. This is mainly due to a lack of knowledge about its physiochemical, nutritional and functional properties of RBs.

Thus, the investigation of the physicochemical, nutritional and functional properties of Bg 300 and At 362 is significant due to its providing valuable information for the advancement of the food industry. Understanding the physicochemical aspects of the bran is important in determining the functionality of RB and its potential use in different food formulations. Furthermore, the uncovering of its nutritional properties can facilitate its use as a nutrient-rich additive in foods, catering to health-conscious consumers. Additionally, the analysis of the bran's functional properties, particularly antioxidant capacity and bioactive compounds, provides valuable understanding of the health benefits of both RB types. However, limited research studies are available about the physicochemical, nutritional and functional properties of RB, and to the best of our knowledge, there is no comprehensive study of these commonly cultivated and consumed white and brown rice varieties (Bg 300 and At 362).

Previous research studies have acknowledged RB for its valuable bioactive compounds and nutrient contents (Wanyo et al., 2016; Sapwarobol et al., 2021). However, comprehensive analysis and comparison of the bran of specific varieties, particularly higher- yielding strings like Bg 300 and At 362, are scarce. Furthermore, most of studies

were mainly focused on the overall benefits of RB without delving into the distinct characteristics of individual varieties (Kodape et al., 2025).

By bridging this gap, this research was aimed to explore the physiochemical, nutritional and functional properties of RB from white (Bg 300) and brown (At 362) rice varieties, providing a comparative analysis of these two high-yielding and most extensively cultivated and consumed rice varieties in Sri Lanka. This study uncovered the potential applications of the bran as nutrient-dense functional ingredients in food products, and health forced product development in food industry. Additionally, a deeper understanding of RB can lead to the development of more sustainable practices such as effective waste management and utilization of by-products in effective manner and to reduce the overall environmental footprint of rice production through utilization of RB in food industry.

2. Materials and Methods

2.1 Materials

Two different RB varieties namely, At 362 (brown rice bran (BRB) (Figure 1a) and Bg 300 (white rice bran (WRB) (Figure 1b) were selected for the study since they are derived from the highest-yielding, most-consumed as well as most cultivated brown and white rice varieties in Sri Lanka (Ministry of Agriculture, Livestock, Lands and Irrigation, 2023). The RB samples were collected from rice milling centers of Anuradhapura district, Sri Lanka.

1a

1b

Figure 1. Rice bran of 1a) brown rice (At 362) and 1b) white rice (Bg 300)

2.2 Determination of nutritional properties of rice bran

2.2.1 Proximate composition

Proximate composition of the RB; moisture (AOAC 934.15), ash (AOAC 942.05), crude protein (AOAC 2001.11), crude fat (AOAC 2003.05), and crude fiber (AOAC 978.10) was determined according to the standard methods of AOAC (2019). Total carbohydrate content was determined by subtracting the sum of all other contents from 100 g (Maclean et al., 2003).

2.2.2 Mineral composition

Potassium and sodium contents were analyzed using a flame photometer (Model 360 Sherwood's Scientific's Single Channel Analogue, UK). The wet ashing method was used to prepare the samples (AOAC, 2019). Standard solutions of potassium (400 ppm) and sodium (1000 ppm) were used to develop standard curves and expressed as g/100 g.

2.2.3 Total sugar content

Total sugar contents of the samples were determined using the phenol-sulfuric method (Nielsen, 2017). In brief, 100 mg of the sample and 2.5 N HCl (5 mL) was heated in a water bath for 3 h and Na_2CO_3 was added to neutralize. The prepared solution was centrifuged, and the supernatant (0.2 mL) was taken and made up to a volume of 1 mL using distilled water. Thereafter, 5% phenol (1 mL) and 96 % sulfuric acid (5 mL) were added. The resultant solution was boiled in a water bath at 30°C for 20 min. The absorbance was measured at 490 nm using a spectrophotometer (HACH DR 3900, Germany) The total sugar content (g/100 g) was calculated using a standard curve prepared with standard D-glucose. A standard solution of D-glucose (1 ppm) was prepared using 100 mg of D-glucose in 1000 mL distilled water. A one ppm working solution was used to prepare the standard series of 0.2 ppm, 0.4 ppm, 0.6 ppm, 0.8 ppm, and 1 ppm. Blank was distilled water. A standard curve was drawn using absorbance values corresponding to the D-glucose standard solutions.

2.3 Physical properties of rice bran

2.3.1 Swelling capacity (SC)

The SC was measured according to the method described by Zaky et al. (2020) with some modifications. Each RB sample was filled up to the 10 mL mark in a 100 mL graduated cylinder and tapped at the bottom. Water was added up to 50 mL, and then the top of the graduated cylinder was covered and mixed by inverting the cylinder.

2.3.2 Bulk density (BD)

BD was determined using the pour method as described by Chandi & Sogi (2007). The sample was poured into a graduated cylinder filled up to a marked line. Then, the bottom of the cylinder was lightly taped to remove any air trapped. The volume of the sample and the weight of the sample were taken. The BD was calculated, and expressed as the weight of the sample per unit volume of the sample (g/mL).

2.3.3 Water absorption capacity (WAC)

WAC was assessed by the method described in Khan et al. (2011) with slight adjustments. One gram of the sample was submerged in 10 mL of distilled water and left to settle in a centrifuge tube for 30 min, after which it was centrifuged at 2300 rpm for 25 min. WAC was expressed as grams of absorbed water weight per gram of RB sample.

2.3.4 Oil absorption capacity (OAC)

OAC was measured according to the method described in Khan et al. (2011) with some minor modifications. One gram of the sample was immersed in 10 mL of oil and allowed 30 min for setting in a centrifuge tube. Then, it was centrifuged under 2300 rpm for 25 min. OAC was expressed as grams of absorbed oil per gram of sample weight.

2.3.5 Water retention capacity (WRC)

The WRC of RB samples were measured according to the standard method of the American Association of Cereal Chemists (AACC, 2000) with some modifications. One gram of the sample was immersed in 10 mL of distilled water in centrifuge tubes allowing the solvent to swell for 20 min while shaking at 5th, 10th, 15th, and 20th min. The sample was immediately centrifuged at 1000 rpm for 15 min. Then, the supernatant was discarded, and the weight of the RB was determined by subtracting the weight of the centrifuge tube and the cap. WRC was calculated using the following equation.

$$\text{WRC} = \left\{\left(\frac{\text{gel weight of the bran}}{\text{weight of rice bran}}\right) - 1\right\} \times \left\{\frac{86}{100 - \%\ \text{rice bran moister}}\right\} \times 100 \quad (1)$$

2.3.6 Foaming capacity (FC)

FC was measured according to the method described by Lv et al. (2017) with some modifications. One gram of the sample was added to 50 mL of distilled water and the suspension was mixed vigorously for 2 min. The volume before and after whipping was recorded and the FC was calculated.

2.3.7 Foaming stability (FS)

FS was determined as described by Lv et al. (2017) with some modifications. The change of foam volume was taken at an interval of 30 min and then FS was calculated using the following equation.

$$\boldsymbol{FS}\ \% = \frac{\boldsymbol{Foame\ volume\ difference}}{\boldsymbol{Initial\ foame\ volume\ after\ whipping}} \times \mathbf{100}\ \% \quad (\mathbf{2})$$

2.3.8 Water absorption index (WAI), water solubility index (WSI) and swelling power (SP)

The WAI , WSI, and SP of RB samples were measured according to Abebe et al. (2015) with some modifications. The known weight of RB (2.5 g) was dispersed in 30 mL of distilled water. Then, it was cooked at 90°C for 10 min and cooled to room temperature and centrifuged at 3000 × g for 10 min. The supernatant was poured into a pre-weighed evaporation dish to determine WSI. Then, the sediment was weighed, and the dry solid weight was taken from the supernatant by evaporating it overnight at 110°C. WAI, WSI, and SP were calculated by using the following equations.

$$WAI(g/g) = \frac{Sediment\ weight}{Sample\ weight} \quad (3)$$

$$\boldsymbol{WSI}\ \% = \frac{\boldsymbol{Dry\ solid\ weight\ of\ supernatant}}{\boldsymbol{Sample\ weight}} \times \mathbf{100} \quad (\mathbf{4})$$

$$\boldsymbol{SP}\ (\boldsymbol{g/g}) = \frac{\boldsymbol{Sediment\ weight}}{\boldsymbol{Initial\ sample\ weight - Dry\ solid\ weight\ of\ supernatant}} \quad (\mathbf{5})$$

2.3.9 Water holding capacity (WHC)

WHC was determined according to the method modified by Liu et al. (2021). One gram of RB sample was suspended in 20 mL distilled water and kept for 4 h with vortexing at 30 min intervals. Then, the turbid liquid was centrifuged at 3000×g for 15 min and the excess water was carefully removed. Next, the wet weight of the sample was taken. The dry weight was taken by drying at 105°C in an oven to constant weight, and the WHC was measured by using the following equation.

$$\boldsymbol{WHC\ (g/g) = \frac{Wet\ weight\ - Dry\ weight}{Dry\ weight}} \quad (6)$$

2.3.10 Color determination

The color of the RB samples was determined using a colorimeter (BIOBASE, BC-110/200, China) according to CIE color system. L*, a*, and b* values were taken in semi-dark conditions, and all readings were taken in triplicate. Hue angle (h_{ab}), chroma value (C_{ab}*), and color difference (ΔE) were calculated (Macdougall, 2010).

2.4 Functional properties of rice bran

2.4.1 Preparation of RB extraction

Methanol extracts of the RB samples were extracted according to the method explained in Ghasemzadeh et al. (2018a) with some modifications. One gram of RB sample was extracted by using 7 mL (7.18 s/s ratio) of 78 % (v/v) menthol. Then, the mixture was vortexed by vortex apparatus for 1 h with 5 min intervals. Then, the solution was centrifuged at 2500 x g for 10 min and the supernatant was taken. The extraction was repeated three times, and all three extracts were pooled for further analysis.

2.4.2 Determination of total phenolic content (TPC)

TPC was determined according to the Folin-Ciocalteu (FC) method as described by Ghasemzadeh *et al.* (2018b) with minor modifications. A known volume of the extract (200 µL) was placed in a test tube and 1 mL of the FC solution was added after 2 min. Then, the solution was mixed with 1 mL 7.5 % Na_2CO_3 and the volume was made up to 5 mL by adding distilled water. After that, the mixture was kept in a dark place for 30 min. Finally, the absorbance was taken at 765 nm by a UV visible spectrophotometer (HACH, DR 3900, Germany). Different concentrations of gallic acid were used to prepare the standard calibration curve and the TPC content was estimated using the standard curve. The results were expressed as milligram gallic acid equivalents per gram (mg GAE/g).

2.4.3 Total flavonoid content (TFC)

The TFC of the RB samples was determined according to aluminum chloride colorimetric method (Ghasemzadeh et al., 2018b). Methanolic extraction of the sample (1 mL) or the standard solution or the blank solution were taken for 10 mL volumetric flask separately and was mixed with 4 mL of distilled water. Then, the solution was mixed with 0.3 mL of 5% $NaNO_2$, and 5 min later, 0.3 mL of 10% $AlCl_3$ was added to the solution, and

immediately 2 mL of 1 M NaOH was added. Then, the solution was volumed up to the mark with distilled water and vortexed well. The absorbance was measured by UV visible spectrophotometer (HACH, DR 3900, Germany) at 510 nm. Different concentrations of quercetin solutions were used to prepare the standard curve and the TFC was expressed as mg of quercetin equivalent per gram (mg QE/g)

2.4.4 DPPH radical scavenging assay

DPPH assay was assessed by a method suggested in Gulcin & Alwasel (2023) with some modifications. One mL of 0.1 mmol DPPH methanolic solution was added to 0.1 mL of extract of the sample or the standard solutions. Then, the solution was vortexed well and kept in dark for 30 min and optical density was taken at 517 nm using a UV visible spectrophotometer (HACH, DR 3900, Germany). The antioxidant capacities of the extracts were estimated by a standard curve, and different concentrations of Trolox standards were used for the calibration curve. Antioxidant activity was expressed as mmol Trolox equivalent per gram (Trolox mmol/g).

2.4.5 Scavenging activity effect of DPPH radical

The free radical scavenging activities of RB extracts were determined according to the method described in Lai et al. (2009). A known volume (0.1 mL) of the extract was mixed with 3.9 mL of methanol and 1.0 mL of DPPH solution. The mixture was kept at ambient temperature for 30 min before the measurements were made. Absorbance was taken at 517 nm. The scavenging effect was derived using following equation.

$$\text{DPPH Scavenging } \% = 1 - \left(\frac{\text{Absorbance of the sample}}{\text{Absorbance of the control}}\right) \times 100 \quad (7)$$

2.5 Statistical analysis

The results were presented as mean±standard deviation and the readings were taken in triplicate (n=3). The independent sample *t*- test was used to determine the statistical significance between means ($p<0.05$). All statistical analyses were done using the MINITAB 20 statistical software for windows.

3. Results and Discussion

3.1 Nutritional properties of RB

The results of the proximate composition of At 362 BRB and Bg 300 WRB are shown in Table 1.The WRB (Bg 300) showed significantly lower ($p<0.05$) moisture content (9.0±0.25 g/100 g) compared to the BRB (At 362) (11.5±0.05 g/100 g), indicating superior shelf stability. Also, Bg 300 was significantly higher ($p<0.05$) in ash (7.4±0.14 g/100 g), protein (11.2±0.22 g/100 g), fat (20.5±0.32 g/100 g), and fiber (5.6±0.19 g/100 g) compared to At 362. According to Sharma et al. (2015), fat, protein, and ash in RB can vary between 18-23 g/100 g, 11-16 g/100 g, and 8-12 g/100 g, respectively, and as per the obtained results, both fat and protein contents of both rice brans fell in those ranges. However, the ash content was found to be comparatively less and this discrepancy could be due to variations in the rice varieties, environmental factors, cultivation conditions, etc. (Sharma et al., 2015).

Higher crude fiber content may indicate that such food takes a longer time to digest (Wisetkomolmat et al., 2022), where comparatively higher fiber content in Bg 300 (5.6±0.19 g/100 g) could indicate that it takes a longer time for digestion compared to At 362. Conversely, At 362 has more carbohydrates (50.2±1.44 g/100 g) than Bg 300, suggesting differences in energy levels (Rosniyana et al., 2007). Carbohydrates in RB can also contribute to the texture and stability of products likes energy bars, snack food and bakery items (Gul et al., 2015) Additionally, the higher carbohydrates in At 362 increased the WHC, binding properties, and texture of food products (Yadav et al., 2024). As reported by Antunes et al. (2023), carbohydrates present in RB were shown to be resistant to simulated gastrointestinal conditions, and it was found that the probiotic strains of *Lactobacillus* were able to use these compounds as sugar sources. Thus, with higher carbohydrates content, the At 362 bran could offer an increased resistance through digestion and serve as an enhanced substrate for probiotics, supporting gut health more effectively.

When choosing different types of RB as raw material, it is important to consider specific dietary needs and intended uses. These findings provide useful information for consumers and industries looking for RB with certain nutritional profiles for different purposes. In the comparison of the total sugar content between the WRB and BRB, the WRB (Bg 300) exhibited a significantly higher total sugar content (Table 1) compared to that of BRB (At 362). This nutritional difference may prove pertinent for individuals who maintain a close watch on their sugar intake for health reasons. Potassium and sodium content of RB is also summarized in Table 1. Bg 300 showed significantly higher (p<0.05) potassium content (0.54±1.0 g/100g) compared to At 362 (0.46±1.50 g/100g). Previous studies showed that the potassium content of RB fell within the range of 0.001 to 0.6 g/100g (Tuncel et al., 2014) and the results of the current study are in accordance with those results. Bg 300 was also higher in sodium content (0.007±2.12 g/100g) than At 362 (0.005±0.95 g/100g). Wisetkomolmat et al. (2022) states that the sodium content of the RB was typically within the range of 0.0012-0.0047 g/100g. However, Bg 300 showed a comparatively higher level of sodium than the reported values. Moreover, Bg 300 (WRB) had higher levels of both sodium and potassium compared to At 362 (BRB).

Table 1. Comparison of nutritional composition of both types of rice bran

Nutrient	Rice Bran Type	
	At 362 (BRB)	Bg 300 (WRB)
Moisture (g/100 g)	11.5±0.05^a	9.0±0.25^b
Ash (g/100 g)	6.1±0.16^a	7.4±0.14^b
Crude Protein (g/100 g)	10.3±0.20^b	11.2±0.22^a
Crude Fat (g/100 g)	18.2±1.35^b	20.5±0.32^a
Crude Fiber (g/100 g)	3.8±0.48^b	5.6±0.19^a
Carbohydrate (g/100 g)	50.2±1.44^a	46.4±0.87^b
Total sugar content (g/100 g)	48.5±0.5^b	53.8±1.0^a
Potassium (g/100 g)	0.46±1.50^b	0.54±1.0^a
Sodium (g/100 g)	0.005±0.95^b	0.007±2.12^a

Values are mean±standard deviations (n=3), while different letters for values in each row indicate significant differences (p<0.05)
BRB- Brown RB WRB -White rice bran

3.2 Physical properties of rice bran

Physical properties of RB, namely bulk density (BD), water absorption capacity (WAC), oil absorption capacity (OAC), water holding capacity (WHC), water retention capacity (WRC), water absorption index (WAI), swelling power (SP), swelling capacity (SC), foaming stability (FS), and foaming capacity (FC) were measured and the results are summarized in Table 2

BD is a crucial factor to consider when processing, storing, and formulating dry powder in food products. Compared to the BRB, At 362, a significantly higher BD (p<0.05) was observed for the WRB, Bg 300. A higher BD denotes more compact structure (Irakli et al., 2021), and thus compared to At 362, the Bg 300 (WRB) had a more compact structure. Previous studies showed that BD of RBs typically ranged from 0.22 g/mL to 0.36 g/mL (Bhosale &Vijayalakshmi, 2015; Irakli et al., 2021) where the BD of At 362 fell within the range, while Bg 300 showed a slighty higher BD.

WAC and OAC symbolize the ability of water and oil molecules to be absorbed under conditions of limited water and oil. According to Khan et al. (2011), the WAC of a substance can be attributed to the presence of hydroxyl group-bearing polysaccharide components, as well as the polar amino acids, located at the bran particle-water interface. Both Bhosale & Vijayalakshmi (2015) and Irakli et al. (2021) reported that WAC of RB ranged from 2.00 g/g to 4.5 g/g. As per the results, the WAC of both At 362 and Bg 300 fell within this range. However, when comparing At 362 and Bg 300, a higher value was observed for At 362 (2.61±0.16 g/g) compared to Bg 300 (1.96±0.07 g/g). This emphasized that At 362 might have had a higher presence of hydroxyl group-bearing polysaccharide components and higher content of polar amino acids located at the bran particle-water interface.

The OAC is an important functional property because it is related to the mouthfeel perception of the final product. According to the previous studies, OAC of RBs range from 1.5-2.8 g/g (Bhosale & Vijayalakshmi, 2015; Irakli et al., 2021). At 362 and Bg 300 showed OAC values within this range. Bg 300 showed a significantly higher (p<0.05) OAC (1.92±0.098 g/g) compared to At 362 (1.88±0.091 g/g), which indicated higher interaction between oil particles and the fiber matrix may present in Bg 300 compared to At 362 and this also meant higher hydrophobicity is the case of Bg 300 (Irakli et al., 2021).

In industrial application higher WAC and OAC values in RBs are highly valued for their functional contribution to food quality. Higher WAC enables better moister retention, which is for maintaining the freshness and texture. For instance, backed foods like bread and cakes benefit from RB ability to retain moisture, which prevents staling and prolongs shelf life by maintaining a softer texture over the time. This property is especially valuable for industrial applications like gluten-free baking, where alternative ingredients often struggle to retain moisture (Cappelli et al., 2020; Schopf & Scherf, 2021). Conversely, higher OAC enhances the mouthfeel in processed food, adding creaminess and improving flavor retention especially in snacks and bakery formulations. In products like muffins or cake, a high OAC aids in creating a more desirable texture and prolongs the release of flavors, making RB especially Bg 300 a suitable ingredient for such product formulations (Chandi & Sogi, 2007; Tsegay et al., 2024)

WAI is the amount of water absorbed by a particulate material after swelling in an excess of water. The work by Irakli et al. (2021) reported that the WAI of RBs ranged between 3 g/g to 4 g/g while the WAI of both At 362 (3.37±0.08 g/g) and Bg 300 (3.70±0.05 g/g) in our study also fell within this range. But comparing both RBs, Bg 300 showed a

significantly higher (p<0.05) WAI, indicating that a high amount of water may be absorbed by the Bg 300 after swelling in an excess of water instead of At 362.

WSI measures the amounts of soluble compounds released from starch containing materials after a thermal treatment is applied. It is generally used as an indicator of material phase change and/or some degradation of molecular components present in the heated particles(Mcarthur et al., 1989). According to Bhosale & Vijayalakshmi (2015) and Irakli et al., (2021), the WSI of RB was found to be within the range of 7-8%. However, the WSI of both Bg 300 and At 362 did not fit in the range. This could be due to degradation of the molecular components present in the heated particles being less in these two types of RB as reported by Irakli et al. (2021). Comparing both RBs, At 362 showed the higher WSI, indicating that higher amounts of material phase change and/or some degradation of molecular components may present in the heated particles instead of Bg 300 (Irakli et al., 2021).

The FC of RB is generally low due to the presence of amphiphilic lipids. These lipids are readily absorbed at the interface of the proteins, which decreases the strength and elasticity of the film. Consequently, the incorporation of air is hindered, leading to a reduction in the FC of RB. Higher amphiphilic lipid content resulted in lower FC of RBs (Irakli et al., 2021). Previous studies showed that the FC of RB was within the range of 8-22% (Prakash & Ramanatham,1995; Chandi & Sogi, 2007), and the FC of both At 362 and Bg 300 fell within this range. Bg 300 (13.95±2.12 %) had a significantly higher FC compared to At 362 (9.42±1.36 %), implying that Bg 300 may have had fewer amphiphilic lipids than At 362.

The ability to maintain air bubbles without breaking or collapsing is known as FS. As reported by Apinunjarupong et al.(2009) and Irakli et al. (2021), a higher FS is usually due to a higher level of protein-protein interactions, which brings about a thick proteinaceous film around air bubbles. Lv et al. (2017) and Cho et al. (2022) stated that the FS of RB ranged between 20% to 80 %. According to the results, the FS of both RBs were found to be within the reported range. When comparing the obtained results for FS, Bg 300 had higher value (64.8±13.1 %) compared to At 362 (61.7±12.6 %), which indicated Bg 300 had a higher level of protein-protein interactions leading to the formation of a thick proteinaceous film around air bubbles, resulting in higher FS.

Cao et al. (2021) and Zaky et al.(2020) reported that the SC of RB was within the range of 1 g/mL to 10 g/mL, and the SC of both At 362 and Bg 300 were found to be within this range. However, a higher SC was found for Bg 300 (10.95±2.12 g/mL) compared to At 362 (9.42±1.36 g/mL). According to Zaky et al. (2020), the SC of RB depends on the mass of the particles and the variety as well.

For WHC, Bg 300 showed a significantly higher (p<0.05) value (3.01±0.02 g/g) compared to At 362 (2.36±0.10 g/g). Many past research works indicated that the WHC of RB was within the range from 4 g/g to 5 g/g (Liu et al., 2021). However, the WHC of both At 362 and Bg 300 RBs was found to vary in a lower range which was between 2 g/g to 3 g/g. This may be due to lower surface tension and lower capillary action in the fiber structure, and also by the small pores of the fiber structure of these RBs (Forsström et al., 2005).

Both WHC and SC correlated with certain properties of water (Liu et al., 2021). Thus, according to the results shown in Table 2, Bg 300 showed a higher WHC and SC compared to At 362, which could be due to presence of more capillary action in the fiber structure and larger pores with larger particles in fiber in the RB of Bg 300 (Liu et al., 2021). This was because SC and WHC is determined by the structural properties of the RB dietary fibers in the process of water uptake (Liu et al., 2021). This interaction relies on two mechanisms: Firstly, water is held in the capillary structure due to the strength of surface

tension created by water. Secondly, water is held by hydrogen bonds and dipole interactions (Liu et al., 2021).

WRC is defined as the quantity of water that remains bound to a hydrated fiber following the application of an external force (pressure of centrifugation) (Raghavendra et al., 2004). Therefore, based on the results, At 362 may be able to hold more water after facing external forces than Bg 300 since At 362 has a higher WRC (2.01±0.12 g/g) compared to Bg 300 (1.52±0.44 g/g). Further, this may be due to the interaction of water and the fiber (dipole interaction) in At 362 being strong compared to Bg 300 (Liu et al., 2021). Zaky et al. (2020) stated that the range of WRC for the RB was from 1 g/g to 2 g/g, and the WRC values of both At 362 and Bg 300 were found to be within this range. Finally, considering SP of the two RBs, a significantly higher (p<0.05) SP was observed for At 362 when compared to Bg 300 (Table 2). Moreover, the SP of both At 362 and Bg 300 fell within the range stated by previous studies (Irakli et al., 2021). RB offers a good potential to supplement or be used instead of costly fiber and protein sources such as oat bran and wheat bran in diets. Thus, understanding and comparing the physical properties of these rice brans can indicate how the different types of RB will interact with other ingredients when trying to develop a product with RB, and how to keep the good quality of the developed product which offers a great economic importance.

In particular, the BD, WAC, OAC, WHC, FC physical properties are useful in understanding the water actively, product quality, storage conditions and durability of products made by RB (Lavanya et al ., 2017)

Table 2. Comparison of physical properties of both types of rice bran

Parameters	Bg 300 (WRB)	At 362 (BRB)
Bulk density (g/mL)	0.40±0.01^{a}	0.29±0.02^{b}
Water absorption capacity (g/g)	1.96±0.07^{b}	2.61±0.16^{a}
Oil absorption capacity (g/g)	1.92±0.09^{a}	1.88±0.09^{b}
Water holding capacity (g/g)	3.01±0.02^{a}	2.36±0.10^{b}
Water retention capacity (g/g)	1.52±0.44^{b}	2.01±0.12^{a}
Water absorption index (g/g)	3.37±0.08^{b}	3.70±0.05^{a}
Water solubility index (%)	2.33±0.64^{b}	4.34±0.99^{a}
Swelling power (g/g)	3.45±0.10^{b}	3.85±0.11^{a}
Swelling Capacity (g/mL)	10.95±2.12^{a}	9.42±1.36^{b}
Foaming Stability (%)	64.8±13.10^{a}	61.7±12.60^{b}
Foaming Capacity (%)	13.95±2.12^{a}	9.42±1.36^{b}

Values are mean±standard deviation (n=3), while difference letters for values in each raw indicate significant differences (p<0.05).
BRB- Brown RB WRB -White rice bran

3.3 Color parameter

The color of the RB was determined using the CIE Lab color system, a standard color system commonly applied in food science for accurate color assessment and comparison (Afonso et al., 2017). In this system, L* value is the lightness of the sample and ranges from 0 (black) to 100 (pure white), while a* value describes the color spectrum from red (+) to green (-);the b* represents the blue (-) to yellow (+) and zero values of a* and b* represent the gray (Thanonkaew et al., 2012). This method provides a standardized framework for evaluating RB color differences, and is valuable in understanding the sensory and quality attributes of food products (Siswantoro, 2019). According to the results summarized in Table 3, Bg 300 had higher lightness than At 362. In contrast, At 362 showed more redness than Bg 300. Moreover, Bg 300 showed more yellowness. The hue angle indicates the relative amount of redness and yellowness; where Bg 300 (WRB) had a higher hue value compared to At 362 (BRB) which means it is more towards yellowness. This finding is consistent with the color variation range reported by Pang et al. (2018)**.** This hue angel provides insight into the perceived color of a substance. A high hue angle indicates a shift towards the yellow spectrum, suggesting increased yellowness, while lower value corresponds to a shift towards the red spectrum, indicating greater redness (Giesel et al., 2009). Accordingly, since Bg 300 (WRB) exhibited a higher hue angle compared to At 362 (BRB), Bg 300 reflected greater yellowness. This difference in hue angle not only affects the visual appeal of these RB varieties but also influences consumer perception and preference when used in food products. Thus, understanding these color characteristics will be essential in product formulation.

Further, this distinct color difference between At 362 and Bg 300 may be due to presence of bioactive compounds, where the higher redness of At 362 was likely to be associated with increased levels of anthocyanins and other flavonoids, which are known to impart red to purple hues in plant based foods (Khoo et al., 2017). In contrast, the yellowness observed in Bg 300 may by attributable to the presence of carotenoids, which produce yellow to orange color in plant based foods (Meléndez-Martínez et al., 2022). These color associated compounds not only enhance visual appeal but also contribute to the antioxidant properties and nutritional value of RBs, supporting their role as functional ingredients in health-oriented food products.

Considering the color difference (ΔE) between At 362 BRB and Bg 300 WRB, a high ΔE value (21.32 ± 0.83) was observed, suggested that considerable color difference between the two RB samples were perceivable. The CLE Lab color space ΔE values quantify the difference in color in the CLE Lab color space, where higher color values correspond with greater perceptible differences (Goodman, 2012). A value above 05 is generally considered visibly distinct to the human eye, and a value as high as 21.30 confirms that the samples would be easily distinguishable in appearance (Macdougall, 2002), Such difference color variances between RB samples can impact sensory qualities in food applications and may influence consumer perception and acceptance in functional food and nutraceuticals (Pathare et al., 2013)

3.4 Functional properties of rice bran

Total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity, and DPPH scavenging effect of both types of RB are summarized in Table 4. Comparing both RB, At 362 (BRB) showed a significantly higher ($p<0.05$) level of TPC (3.13±0.02 mg GAE/g)

Table 3. Color differences of the two types of rice bran

Type	L *	a*	b*	Hue Angle (h_{ab})	Chroma (C^*_{ab})	ΔE*
At 362 (BRB)	23.15±0.34[b]	22.84±4.78[a]	3.63 ± 8.15[b]	0.14±0.03[b]	26.1±1.85[a]	21.32 ± 0.83
Bg 300 (WRB)	32.34±2.45[a]	8.54 ±3.41[b]	11.60±1.60[a]	0.93±0.06[a]	14.4±1.83[b]	

Values are mean±standard deviation (n=3), while difference letters for values in each column indicate significant differences *(p*<0.05)
BRB- Brown rice bran WRB -White rice bran

compared to Bg 300 (WRB) (0.85±0.01 mg GAE/g). Studies conducted by Ghasemzadeh et al. (2018b) and Pang et al. (2018) showed the same range for TFC for both white (1-2 mg GAE/g) and brown (1- 4 mg GAE/g) RB varieties.

According to the observed results, the TFC was also found to be significantly higher *(p* < 0.05) for At 362 BRB (5.52±0.08 mg QE /g) compared to that of Bg 300 WRB (1.14±0.01 mg QE/g). This range of TFC in RB was observed in most of the past studies. For instance, the TFC of WRB fell within the range from 1 mg QE/g to 13 mg QE/g, while that of BRB fell within the range from 0.5 mg quercetin QE/g to 8 mg QE/g (Zhang et al., 2010).

As per previous studies, the antioxidant activity of both brown and white RBs (At 362 and Bg 300, respectively) were found to be higher than the range reported by Abubakar et al.(2017) and Igbal et al. (2005), who reported a range of 1.10 Trolox mmol/g and 11.99 Trolox mmol/g. However, as per the results in Table 4, At 362 (BRB) showed a significantly higher (*p*<0.05) antioxidant activity (27.12±0.80 Trolox mmol/g) than Bg 300 (WRB) (16.85±0.92 Trolox mmol/g). Further, Arab et al., (2011) stated that the radical scavenging effect of ethanolic extracted RB fell within the range of 20-80%; the results for both At 362 and Bg 300 were within this range. Moreover, a higher radical scavenging activity was observed in At 362 brown RB variety (83.67±0.07%)

Anthocyanin is a bioactive phytochemical (flavonoid sub group) responsible for the dark color of the RB (Chen et al., 2024). These compounds are usually accumulated in the pericarp and the testa or the rice bran part in the rice kernel (Pitija et al., 2013). According to Min et al. (2011), WRB contain a lower anthocyanin content compared to BRB varieties. Khoo et al. (2017) explained that a higher level of anthocyanin in BRB was due to the reddish to purplish blue color in BRB. Furthermore, many previous studies proved that a higher anthocyanin content in RB resulted in higher TFC, TPC and antioxidant capacity (Min et al., 2011; Pitija et al., 2013). So, a higher anthocyanin content was probably the reason that At 362 BRB had a higher TFC, TPC and antioxidant capacity than Bg 300 white rice bran.

The anthocyanins, which are a flavonoid sub-class, are recognized as potential antioxidants, with their antioxidant capacity determined by their chemical structure (Merecz-Sadowska et al., 2023). In general, anthocyanins neutralize reactive radical species by transferring a signal electron or by removing hydrogen atoms from phenolic groups. The antioxidant activity of anthocyanins is largely due to the oxidation of their phenolic groups (Enaru et al., 2021). This hydrogen donation mechanism may support the superior antioxidants properties of At 362 compare to Bg 300 as the anthocyanins phenolic structure allowed effective radical scavenging. This mechanistic insights clarifies the greater antioxidant activity in At 362 (BRB) compared to Bg 300 (WRB) (Tena et al., 2020).

Table 4. Functional properties of both types of rice bran

RB Type	Total Phenolic Content (mg GAE/g)	Total Flavonoid Content (mg QE/g)	Antioxidant Activity (Trolox mmol/g)	Scavenging Activity Effect (%)
At362 (BRB)	3.13±0.02[a]	5.52±0.08[a]	27.12±0.80[a]	83.67±0.07[b]
Bg300 (WRB)	0.85±0.01[b]	1.14±0.01[b]	16.85±0.92[b]	79.81±0.14[a]

Values are mean±standard deviation (n=3), while difference letters for values in each column indicate significant differences (p<0.05)
BRB- Brown RB WRB -White rice bran

4. Conclusions

The present study demonstrated that the physicochemical, nutritional and functional properties of WRB (Bg 300) and BRB (At 362) were significantly different from each other. Bg 300 (WRB) demonstrated advantages in many important physical properties like bulk density, OAC, WHC, SC and certain proximate compositions like fat, protein, and fiber content, while At 362 (BRB) excelled in key nutritional properties, exhibiting significantly higher levels of bioactive compounds including total phenolic content, total flavonoid content, and antioxidant capacity. These findings underscore the importance of considering both types of rice bran and their unique physicochemical and nutritional contributions in various industrial applications. Both types of rice bran are highly nutritious and can be used as raw materials in the food industry. Further, the incorporation of At 362 (brown rice bran) into the diet should offer protective health benefits due to its higher phenolic compounds and antioxidant capacity. Furthermore, the findings of the current study suggest that using RB for rice bran oil and as ingredients in food industry, especially in production of functional foods, will be economically beneficial. The results of this study not only mitigate the carbon footprint in rice production but also foster resource efficiency in food production, ultimately reducing waste and enhancing environmental sustainability.

5. Conflicts of Interest

The authors declare that they have no competing interest

ORCID
Harshaka Maduwantha Jans https://orcid.org/0009-0001-5459-4559
Perumpuli Arachchige Buddhika Niroshie Perumpuli https://orcid.org/0000-0002-8397-493X
Arukattu Patabendige Hashini Imalsha Abeysuriya https://orcid.org/0000-0002-3799-573X

References

Abebe, W., Collar, C., & Ronda, F. (2015). Impact of variety type and particle size distribution on starch enzymatic hydrolysis and functional properties of tef flours. *Carbohydrate Polymers*, 115, 260-268. https://doi.org/10.1016/j.carbpol.2014.08.080

Abubakar, T., Marikkar, N., Salleh, A., Azlan, A., & Jivan, M. (2017). Evaluation of brans of different rice varieties for their antioxidative and antihyperglycemic potentials. *Journal of Food Biochemistry*, 41(2), Article e12295. https://doi.org/10.1111/jfbc.12295

Afonso, T., Moresco, R., Uarrota, V. G., Navarro, B. B., Nunes, E. da C., Maraschin, M., & Rocha, M. (2017). UV-Vis and CIELAB based chemometric characterization of *Manihot esculenta* carotenoid contents. *Journal of Integrative Bioinformatics*, 14(4), 1-13. https://doi.org/10.1515/jib-2017-0056

AACC. (2000). *Solvent retention capacity profile (*11th ed*.)*. American Association of Cereal Chemists.

Antunes, L. L., Back, A. L., Kossar, M. L. B. C., Spessato, A. G., Colla, E., & Drunkler, D. A. (2023). Prebiotic potential of carbohydrates from defatted rice bran – Effect of physical extraction methods. *Food Chemistry*, 404, Article 134539. https://doi.org/10.1016/j.foodchem.2022.134539

AOAC. (2019). *Offical methods of analysis of AOAC internatioanl* (*21st ed.*). AOAC International.

Apinunjarupong, S., Lapnirun, S., & Theerakulkait, C. (2009). Preparation and some functional properties of rice bran protein concentrate at different degree of hydrolysis using bromelain and alkaline extraction. *Preparative Biochemistry and Biotechnology*, 39(2), 183-193. https://doi.org/10.1080/10826060902800858

Arab, F., Alemzadeh, I., & Maghsoudi, V. (2011). Determination of antioxidant component and activity of rice bran extract. *Scientia Iranica*, 18(6), 1402-1406. https://doi.org/10.1016/j.scient.2011.09.014

Bhosale, S., & Vijayalakshmi, D. (2015). Processing and nutritional composition of rice bran. *Current Research in Nutrition and Food Science*, 3(1), 74-80. https://doi.org/10.12944/CRNFSJ.3.1.08

Cao, Y., Zhao, J., Tian, Y., Jin, Z., Xu, X., Zhou, X., & Wang, J. (2021). Physicochemical properties of rice bran after ball milling. *Journal of Food Processing and Preservation*, 45(10), Article e15785. https://doi.org/10.1111/jfpp.15785

Cappelli, A., Oliva, N., & Cini, E. (2020). A systematic review of gluten-free dough and bread: Dough rheology, bread characteristics, and improvement strategies. *Applied Sciences*, 10(18), Article 6559. https://doi.org/10.3390/APP10186559

Chandi, G. K., & Sogi, D. S. (2007). Functional properties of rice bran protein concentrates. *Journal of Food Engineering*, 79(2), 592-597. https://doi.org/10.1016/j.jfoodeng.2006.02.018

Chen, T., Xie, L., Wang, G., Jiao, J., Zhao, J., Yu, Q., Chen, Y., Shen, M., Wen, H., Ou, X., & Xie, J. (2024). Anthocyanins-natural pigment of colored rice bran: Composition and biological activities. *Food Research International*, 175, Article 113722. https://doi.org/10.1016/j.foodres.2023.113722

Cho, S.-J., Lee, S.-D., & Han, S.-W. (2022). Functional properties of rice bran proteins extracted from low-heat-treated defatted rice bran. *Molecules*, 27(21), Article 7212. https://doi.org/10.3390/molecules27217212

Cicero, A. F. G., Fogacci, F., & Colletti, A. (2017). Food and plant bioactives for reducing cardiometabolic disease risk: An evidence based approach. *Food and Function*, 8(6), 2076-2088. https://doi.org/10.1039/c7fo00178a

Department of Agriculture Sri Lanka. (2024, Novermber 1). *Recommended rice varities.* https://doa.gov.lk/rrdi_rice_varities/

Enaru, B., Drețcanu, G., Pop, T. D., Stănilă, A., & Diaconeasa, Z. (2021). Anthocyanins: Factors affecting their stability and degradation. *Antioxidants*, 10(12), Article 1967. https://doi.org/10.3390/antiox10121967

Forsström, J., Andreasson, B., & Wågberg, L. (2005). Influence of pore structure and water retaining ability of fibres on the strength of papers from unbleached kraft fibres. *Nordic*

Pulp and Paper Research Journal, 20(2), 176-185. https://doi.org/10.3183/npprj-2005-20-02-p176-185

Ghasemzadeh, A., Baghdadi, A., Jaafar, H. Z. E., Swamy, M. K., & Wahab, P. E. M. (2018a). Optimization of flavonoid extraction from red and brown rice bran and evaluation of the antioxidant properties. *Molecules*, 23(8), Article 1863. https://doi.org/10.3390/molecules23081863

Ghasemzadeh, A., Karbalaii, M. T., Jaafar, H. Z. E., & Rahmat, A. (2018b). Phytochemical constituents, antioxidant activity, and antiproliferative properties of black, red, and brown rice bran. *Chemistry Central Journal*, 12(1), Article 17. https://doi.org/10.1186/s13065-018-0382-9

Giesel, M., Hansen, T., & Gegenfurtner, K. R. (2009). The discrimination of chromatic textures. *Journal of Vision*, 9(9), Article 11. https://doi.org/10.1167/9.9.11

Goodman, T. M. (2012). International standards for colour. In J. Best. (Ed.). *Colour design* (2nd ed., pp. 417-452). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-101270-3.00018-7

Gul, K., Yousuf, B., Singh, A. K., Singh, P., & Wani, A. A. (2015). Rice bran: Nutritional values and its emerging potential for development of functional food - A review. *Bioactive Carbohydrates and Dietary Fibre*, 6(1), 24-30. https://doi.org/10.1016/j.bcdf.2015.06.002

Gulcin, İ., & Alwasel, S. H. (2023). DPPH radical scavenging assay. *Processes*, 11(8), Article 2248. https://doi.org/10.3390/pr11082248

Iqbal, S., Bhanger, M. I., & Anwar, F. (2005). Antioxidant properties and components of some commercially available varieties of rice bran in Pakistan. *Food Chemistry*, 93(2), 265-272. https://doi.org/10.1016/j.foodchem.2004.09.024

Irakli, M., Lazaridou, A., & Biliaderis, C. G. (2021). Comparative evaluation of the nutritional, antinutritional, functional, and bioactivity attributes of rice bran stabilized by different heat treatments. *Foods*, 10(1), Article 57. https://doi.org/10.3390/foods10010057

Khan, S. H., Butt, M. S., Sharif, M. K., Sameen, A., Mumtaz, S., & Sultan, M. T. (2011). Functional properties of protein isolates extracted from stabilized rice bran by microwave, dry heat, and parboiling. *Journal of Agricultural and Food Chemistry*, 59(6), 2416-2420. https://doi.org/10.1021/jf104177x

Khoo, H. E., Azlan, A., Tang, S. T., & Lim, S. M. (2017). Anthocyanidins and anthocyanins: Colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food and Nutrition Research*, 61(1), 1-21. https://doi.org/10.1080/16546628.2017.1361779

Khush, G. S. (2005). What it will take to feed 5.0 billion rice consumers in 2030. *Plant Molecular Biology*, 59(1), 1-6. https://doi.org/10.1007/s11103-005-2159-5

Kodape, A., Kodape, A., & Desai, R. (2025). Rice bran: Nutritional value, health benefits, and global implications for aflatoxin mitigation, cancer, diabetes, and diarrhea prevention. *Food Chemistry*, 464(Part 2), Article 141749. https://doi.org/10.1016/j.foodchem.2024.141749

Lai, P., Li, K. Y., Lu, S., & Chen, H. H. (2009). Phytochemicals and antioxidant properties of solvent extracts from *Japonica* rice bran. *Food Chemistry*, 117(3), 538-544. https://doi.org/10.1016/j.foodchem.2009.04.031

Lavanya, M. N., Venkatachalapathy, N., & Manickavasagan, A. (2017). Physicochemical characteristics of rice bran. In A. Manickavasagan, C. Santhakumar, & N. Venkatachalapathy (Eds.). *Brown rice* (pp. 79-90). Springer Cham. https://doi.org/10.1007/978-3-319-59011-0

Liu, Y., Zhang, H., Yi, C., Quan, K., & Lin, B. (2021). Chemical composition, structure, physicochemical and functional properties of rice bran dietary fiber modified by cellulase treatment. *Food Chemistry*, 342, Article 128352.

https://doi.org/10.1016/j.foodchem.2020.128352
Lv, S.-W., Sun, L.-H., Zhao, S.-Y., & Bao, Y.-M. (2017). Effect of dry heat stabilisation on the functional properties of rice bran proteins. *International Journal of Food Science and Technology*, 52(8), 1836-1843. https://doi.org/10.1111/ijfs.13458
Macdougall, D. B. (2010). 13 - Colour measurement of food: principles and practice. In M. L. Gulrajani (Ed.), *Colour measurement. Principles, advances and industrial applications* (pp. 312-342). Woodhead Publishing. https://doi.org/10.1533/9780857090195.2.312
Maclean, W., Harnly, J., Chen, J., Chevassus-Agnes, S., Gilani, G. S., Livesey, G., Munoz De Chavez, M., Mathioudakis, B., Devasconcellos, M., & Warwick, P. (2003). Food energy - methods of analysis and conversion factors. In *Food and Agriculture Organization of the United Nations Technical Workshop Report*. Food and Agriculture Organization of the United Nations.
Mcarthur, E., Britten, M., Lavoie, L., Mcarthur, E., Britten, M., & Lavoie, L. (1989). Foaming properties of protein as affected by concentration. *Food Science*, 57(5), 1219-1241. https://doi.org/10.1111/j.1365-2621.1992.tb11303.x
Meléndez-Martínez, A. J., Mandić, A. I., Bantis, F., Böhm, V., Borge, G. I. A., Brnčić, M., Bysted, A., Cano, M. P., Dias, M. G., Elgersma, A., Fikselová, M., García-Alonso, J., Giuffrida, D., Gonçalves, V. S. S., Hornero-Méndez, D., Kljak, K., Lavelli, V., Manganaris, G. A., Mapelli-Brahm, P., … O'Brien, N. (2022). A comprehensive review on carotenoids in foods and feeds: status quo, applications, patents, and research needs. *Critical Reviews in Food Science and Nutrition*, 62(8), 1999-2049. https://doi.org/10.1080/10408398.2020.1867959
Merecz-Sadowska, A., Sitarek, P., Kowalczyk, T., Zajdel, K., Jęcek, M., Nowak, P., & Zajdel, R. (2023). Food anthocyanins: Malvidin and its glycosides as promising antioxidant and anti-inflammatory agents with potential health benefits. *Nutrients*, 15(13), Article 3016. https://doi.org/10.3390/nu15133016
Min, B., McClung, A. M., & Chen, M.-H. (2011). Phytochemicals and antioxidant capacities in rice brans of different color. *Journal of Food Science*, 76(1), 117-126. https://doi.org/10.1111/j.1750-3841.2010.01929.x
Ministry of Agriculture, Livestock, Lands and Irrigation (2023, December 29). *At 362, Bg 300 and Bg 352 paddy varieties introduced by Ambalantota and Bathalagoda Paddy Research Institutes were able to produce high yields in several districts*. https://www.agrimin.gov.lk/web/index.php/news-and-events/2125-22-05-2023-2e? lang=en
Nielsen, S. S. (2017). *Food analysis*. (5th ed.). Springer Cham. https://doi.org/10.1007/978-3-319-45776-5
Pang, Y., Ahmed, S., Xu, Y., Beta, T., Zhu, Z., Shao, Y., & Bao, J. (2018). Bound phenolic compounds and antioxidant properties of whole grain and bran of white, red and black rice. *Food Chemistry*, 240, 212-221. https://doi.org/10.1016/j.foodchem.2017.07.095
Pathare, P. B., Opara, U. L., & Al-Said, F. A.-J. (2013). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology*, 6(1), 36-60. https://doi.org/10.1007/s11947-012-0867-9
Pitija, K., Nakornriab, M., Sriseadka, T., Vanavichit, A., & Wongpornchai, S. (2013). Anthocyanin content and antioxidant capacity in bran extracts of some Thai black rice varieties. *International Journal of Food Science and Technology*, 48(2), 300-308. https://doi.org/10.1111/j.1365-2621.2012.03187.x
Prakash, J., & Ramanatham, G. (1995). Effect of stabilisation treatment of rice bran on nutritional quality of protein concentrates. *International Journal of Food Sciences and Nutrition*, 46(2), 177-184. https://doi.org/10.3109/09637489509012547
Raghavendra, S. N., Rastogi, N. K., Raghavarao, K. S. M. S., & Tharanathan, R. N. (2004). Dietary fiber from coconut residue: effects of different treatments and particle size on

the hydration properties. *European Food Research and Technology*, 218(6), 563-567. https://doi.org/10.1007/s00217-004-0889-2

Rosniyana, A., Hashifah, M. A., & Norin, S. A. S. (2007). The physico-chemical properties and nutritional composition of rice bran produced at different milling degrees of rice (Ciri fiziko-kimia dan kandungan nutrien bagi dedak beras yang dihasilkan daripada pengilangan berbeza). *Journal of Tropical Agriculture and Food Science*, 35(1), 99-105.

Saji, N., Francis, N., Schwarz, L. J., Blanchard, C. L., & Santhakumar, A. B. (2019). Rice bran derived bioactive compounds modulate risk factors of cardiovascular disease and type 2 diabetes mellitus: An updated review. *Nutrients*, 11(11), Article 2736. https://doi.org/10.3390/nu11112736

Sapwarobol, S., Saphyakhajorn, W., & Astina, J. (2021). Biological functions and activities of rice bran as a functional ingredient: A review. *Nutrition and Metabolic Insights*, 14, 1-11. https://doi.org/10.1177/11786388211058559

Schopf, M., & Scherf, K. A. (2021). Water absorption capacity determines the functionality of vital gluten related to specific bread volume. *Foods*, 10(2), Article 228. https://doi.org/10.3390/foods10020228

Shahbandeh, M. (2023). *Total global rice consumption 2008/09-2022/23*. Statistica. https://www.statista.com/statistics/255977/total-global-rice-consumption/

Sharma, R., Srivastava, T., & Saxena, D. C. (2015). Studies on rice bran and its benefits-A review. *International Journal of Engineering Research and Applications*, 5(5), 107-112.

Siswantoro, J. (2019). Application of color and size measurement in food products inspection. *Indonesian Journal of Information Systems*, 1(2), 90-107. https://doi.org/10.24002/ijis.v1i2.1923

Tan, B. L., Norhaizan, M. E., & Chan, L. C. (2023). Rice bran: From waste to nutritious food ingredients. *Nutrients*, 15(11), Article 2503. https://doi.org/10.3390/nu15112503

Tena, N., Martín, J., & Asuero, A. G. (2020). State of the art of anthocyanins: Antioxidant activity, sources, bioavailability, and therapeutic effect in human health. *Antioxidants*, 9(5), Article 451. https://doi.org/10.3390/antiox9050451

Thanonkaew, A., Wongyai, S., McClements, D. J., & Decker, E. A. (2012). Effect of stabilization of rice bran by domestic heating on mechanical extraction yield, quality, and antioxidant properties of cold-pressed rice bran oil (*Oryza saltiva* L.). *LWT-Food Science and Technology*, 48(2), 231-236. https://doi.org/10.1016/j.lwt.2012.03.018

Thennakoon, T. P. A. U., & Ekanayake, S. (2022). Sri Lankan traditional parboiled rice: A panacea for hyperglycaemia? *PLoS ONE*, 17(9), Article e0273386. https://doi.org/10.1371/journal.pone.0273386

Tsegay, N., Admassu, H., Zegale, B., & Gosu, A. (2024). Nutritional and functional potentials of wheat, cowpea, and yam composite flours on bread formulations: Effect of blending ratio and baking parameters. *Journal of Agriculture and Food Research*, 18, Article 101294. https://doi.org/10.1016/j.jafr.2024.101294

Tuncel, N. B., Yilmaz, N., Kocabıyık, H., & Uygur, A. (2014). The effect of infrared stabilized rice bran substitution on B vitamins , minerals and phytic acid content of pan breads : Part II. *Journal of Cereal Science*, 59, 162-166. https://doi.org/10.1016/j.jcs.2013.12.005

Wanyo, P., Kaewseejan, N., Meeso, N., & Siriamornpun, S. (2016). Bioactive compounds and antioxidant properties of different solvent extracts derived from Thai rice by-products. *Applied Biological Chemistry*, 59(3), 373-384. https://doi.org/10.1007/s13765-016-0173-8

Wisetkomolmat, J., Arjin, C., Satsook, A., Seel-audom, M., Ruksiriwanich, W., Prom-u-Thai, C., & Sringarm, K. (2022). Comparative analysis of nutritional components and

phytochemical attributes of selected thai rice. *Frontiers in Nutrition*, 9, Article 833730. https://doi.org/10.3389/fnut.2022.833730

Yadav, K. C., Mitchell, J., Bhandari, B., & Prakash, S. (2024). Unlocking the potential of rice bran through extrusion: a systematic review. *Sustainable Food Technology*, 2(3), 594-614. https://doi.org/10.1039/d4fb00027g

Zaky, A. A., Chen, Z., Qin, M., Wang, M., & Jia, Y. (2020). Assessment of antioxidant activity, amino acids, phenolic acids and functional attributes in defatted rice bran and rice bran protein concentrate. *Progress in Nutrition*, 22(4), Article e2020069. https://doi.org/10.23751/pn.v22i4.8971

Zhang, M. W., Zhang, R. F., Zhang, F. X., & Liu, R. H. (2010). Phenolic profiles and antioxidant activity of black rice bran of different commercially available varieties. *Journal of Agricultural and Food Chemistry*, 58(13), 7580-7587. https://doi.org/10.1021/jf1007665