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Characterization of rice noodles fortified with different levels of stabilized rice bran

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Abstract

The study aimed to evaluate the effects of stabilized rice bran (SRB) on the functional, physicochemical, nutritional, and sensory characteristics of rice noodles. This study assessed the influence of SRB on the cooking quality and functional and nutritional properties of rice noodles. A total of five different levels of SRB (0, 2, 5, 10, and 15% w/w) were incorporated into the rice noodles. Compared to control rice noodles (0% SRB), those incorporating 10 and 15% SRB demonstrated significant differences ($p < 0.05$) in cooking time (CT) and cooking loss (CL). As the level of SRB increased, the water absorption index (WAI), water solubility index (WSI), hardness, adhesiveness, springiness, and chewiness values of rice noodles decreased, respectively. The incorporation of SRB influenced ($p < 0.05$) the colour, proximate constituents (moisture, ash, carbohydrate, protein, fat, and crude fibre), antioxidant activity, and total phenolic contents of rice noodles. Noodles with 10% SRB showed the highest score for overall acceptability (7.86±1.14), while noodles with 15% SRB received the lowest score (6.31±0.81) in all sensory elements tested. Therefore, SRB can be used as a functional ingredient to enhance the nutritional and physicochemical properties of rice noodles with improved acceptability.

1. Introduction

Rice is a popular staple food because it provides energy to humans, is gluten-free, high in digestion, and has good hypoallergenic properties (Wang *et al*., 2018). In 2021, rice production in Malaysia reached 1,677,472 metric tons, an increase of 53,004 metric tons as compared to 2020 (Department of Agriculture Malaysia, 2022). Rice grains need to go through various processing stages such as cleaning, hulling, and post-hulling (whitening, polishing, and grading) before they can be consumed as food (Ahmed *et al*., 2016). Rice and its by-products can be used to save energy, reduce emissions, replenish resources, and transform waste into value-added products (Manaois *et al*., 2020). Rice bran (RB) is one of the rice by-products that can reduce pollution while also adding significant economic value (Li *et al*., 2019).

RB mainly consists of the aleurone, pericarp, sub-aleurone layer, and germ (Pakhare *et al*., 2016). RB is reported to contain a high amount of essential nutrients such as vitamins, minerals, fibre, amino acids, and natural antioxidants like tocopherol, tocotrienol, and oryzanol (Lai *et al*., 2019). However, due to the rapid action of lipolytic endogenic enzymes, RB is extremely sensitive to lipid oxidation (Spaggiari *et al*., 2021). To enable the application of RB in the food industry, a stabilization process needs to be carried out to deactivate the lipase enzyme as well as increase the stability of RB (Gul *et al*., 2015). Moreover, stabilization treatments are reported to improve the functional properties of RB in terms of water binding capacity, emulsion properties, and long-term stability (Liu *et al*., 2018).

Noodles are a convenient and simple food; therefore,

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it is foreseeable that noodles will become a popular food all over the world. Nowadays, noodles are available in a wide variety depending on the consumer's preference in terms of sensory profile, texture, or even method of preparation (Manaois *et al*., 2020). Rice noodles, which are made from rice flour, are the most popular processed food in Southeast Asia (Malahayati *et al*., 2017). Typically, noodles lack essential nutrients such as protein, vitamins, minerals, fibre, and antioxidants but are rich in carbohydrates (Manaois *et al*., 2020). Noodles are a poor source of protein since they are made with refined flour. As a result, fortifying noodles with protein and fibre-rich components is now required, potentially improving not only their nutritional value but also their functional properties (Pakhare *et al*., 2018). Due to the coexistence of these multiple nutrient deficiencies, noodles can be considered suitable food vehicles for fortification (Manaois *et al*., 2020). The fortification of noodles has been investigated by researchers as a possibility for a public health intervention to improve their nutritional qualities (Pakhare *et al*., 2018).

To cope with the demand and application of food, the use of RB as a functional food ingredient can be considered. The high content of dietary fibre in RB makes it physiologically beneficial to food products by offering better nutritional and functional properties (Gul *et al*., 2015; Spaggiari *et al*., 2021). The importance of RB has been suggested in various forms for promoting a healthy diet, including as a functional ingredient in food products (Spaggiari *et al*., 2021). Moreover, it has been reported that the incorporation of RB did not bring any significant changes to the technological and textural attributes of products such as wheat noodles and pasta (Levent *et al*., 2020), wheat noodles (Manaois *et al*., 2020), sweet potato noodles (Astuti *et al*., 2020), wheat pasta (Sethi *et al*., 2020), and rice pasta (Wang *et al*., 2018). However, there is still a lack of study on the fortification of RB in rice noodles. According to Low *et al*. (2020), the quality of rice noodles may be easily altered by implementing minor changes to the ingredients utilized, formulation compositions, and processing conditions. As the second most popular kind of rice product in Asia, rice noodles might be a viable vehicle for fortification (Malahayati *et al*., 2020). Consumption of rice noodles fortified with several fortifiers may help reduce nutrient deficits in developing countries, notably in Southeast Asia (Malahayati *et al*., 2017).

Therefore, this study aimed to compare the overall functional, textural, nutritional, and sensory characteristics of rice noodles before and after incorporation with different levels of SRB. Hence, the potential use of SRB as a functional food ingredient in rice noodles can be established, and hopefully, SRB processing will become more imperative and may gain attention from the industry to create a competitive market for local farmers.

2. Materials and methods

2.1 Raw materials

The RB used in this study was a Malaysian rice variety (MR 219) obtained from the BERNAS Rice Mill Factory in Sekinchan, Selangor, Malaysia. The brans were transported to the Food Biotechnology Research Centre, Agro-Biotechnology Institute (ABI), Serdang, Selangor, and subjected to the stabilization process within 2 hrs. The raw materials used for the preparation of noodles, such as rice flour, xanthan gum, cooking oil, and salt, were procured from the local supermarket in Serdang, Selangor.

2.2 Stabilization treatment

The stabilization process was performed by an autoclaving method using an autoclave, model HVE-50 HICLAVE (Hirayama, Japan). Rice brans were packed into a 5.0 kg autoclave bag and steam-heated in an autoclave at 121±2°C for 20 mins to inactivate endogenous enzymes (lipase and lipoxygenase) and denature trypsin inhibitors (Yu *et al*., 2020). The stabilized rice bran (SRB) was dried in a hot air oven at 60±2°C until the moisture content reached 13% and stored at 4±2°C until further use.

2.3 Formulation of noodles

The noodle formulation was prepared using a fully automatic noodle and pasta maker, model 16009 (KENT, City, India). The machine was fitted with a round, 1 mm diameter shaping disc. The SRB was ground, passed through a 100-mesh sieve, and added to the flour mixture at five different levels ranging from 0, 2, 5, 10, and 15% (w/w flour) based on noodle formulations, as shown in Table 1. A formulation without SRB (0%) was also prepared as a control sample. All ingredient compositions were kept constant except for rice flour and SRB. Rice flour, SRB, and cooking oil were mixed for 2 min in a noodle maker. Salt and xanthan gum were dissolved separately in boiling water and added to the flour mixture. The noodle dough was kneaded for 3 mins and automatically extruded as strands. The noodle strands were boiled in water at a ratio of 1:10 (noodle:water) for 5 mins, followed by cooling under running water for 3 mins. The cooked noodles were packed in high-density polyethylene (HDPE) bags and stored at 4±2°C for subsequent analysis. For proximate analysis, the noodles were dried in a hot air oven at 60±2°C for 4 hrs, allowed to cool at room temperature,

Table 1. Formulation of rice noodles fortified with different levels of stabilized rice bran (0, 2, 5, 10, and 15%) (w/w).

Ingredient	Noodle formulations				
	0% SRB	2% SRB	5% SRB	10% SRB	15% SRB
Rice bran (g)	0	4	10	20	30
Rice flour (g)	200	196	190	180	170
Xanthan gum (g)	2	2	2	2	2
Cooking oil (g)	10	10	10	10	10
Salt (g)	1.8	1.8	1.8	1.8	1.8
Water (mL)	90	90	90	90	90

and ground into powder.

2.4 Proximate composition

The moisture, ash, protein, fat, and crude fibre composition of noodles were determined according to the standard methods of AOAC (2005) Method No. 934.01, 923.03, 960.52, 963.15, and 985.29. The composition analyses were carried out in triplicate. The carbohydrate content was calculated using the AOAC (2002) method:

$$\%\ \text{carbohydrate} = [100 - \%\ (\text{moisture} + \text{ash} + \text{protein} + \text{fat} + \text{fiber})] \quad (1)$$

2.5 Determination of cooking qualities

The cooking qualities of noodles, including cooking time (CT) and cooking loss (CL), were determined according to the American Association of Cereal Chemists (AACC, 2000) Method No. 66-50.01 as described below. All measurements were made in triplicate.

2.5.1 Cooking time

Approximately 10 g of raw noodles were cut into 5.0 cm lengths and cooked in 100 mL of boiling water (ratio 1:10) for 5 mins. The CT was calculated every 20 s by measuring the time it took for the white core to disappear while compressing the noodle strand between two clear glass slides.

2.5.2 Cooking loss

The cooking water from the cooking yield was collected in a pre-weighed beaker and evaporated to a constant weight in an air oven at 105±1°C. The beaker containing the dried residue was weighed, and the CL was calculated by the equation below:

$$\text{Cooking loss}\ (\%) = \frac{\text{Weight of dried residue}}{\text{Weight of raw noodles}} \times 100 \quad (2)$$

2.6 Determination of functional properties

2.6.1 Water absorption index

The water absorption index (WAI) was calculated according to the method described by Wong and Hamzah (2014), with some modifications. In a 15 mL centrifuge tube, 0.5 g of the sample was suspended in 10 mL of distilled water. By inverting twice, the substance was gently mixed. The tube was then set in a water bath with a fixed temperature of about 85.0±0.5°C and mixed for 30 mins by inverting twice at regular intervals (for 1 min during the first 5 min and the remaining 25 min. The tube was immediately chilled in cold water before being centrifuged at 3000xg for 15 min. The supernatant was collected in a tarred evaporating dish, and the resulting sediment was weighed and computed as WAI:

$$\text{Water Absorption Index}\ (\%) = \frac{\text{Weight of sediment (g)}}{\text{Actual weight of dry sample (g)}} \times 100 \quad (3)$$

2.6.2 Water solubility index

The number of dried solids recovered by evaporating the supernatant from WAI values was used to calculate the water solubility index (WSI). The WSI was calculated using the equation below:

$$\text{Water Solubility Index}\ (\%) = \frac{\text{Weight of dried solid (g)}}{\text{Actual weight of dry sample (g)}} \times 100 \quad (4)$$

2.7 Texture profile analysis

The texture profile analysis of cooked noodles was measured using a texture analyser, the TA-XT Plus (Godalming, UK), according to the method by Kong *et al.* (2012) and Tan *et al.* (2016), with some modifications. The probe distance and force of the instrument were calibrated with a 5 kg load cell before analysis. A stainless-steel cylinder probe with a diameter of 6 mm was used. The ten strands of cooked noodles were cut into 5 cm lengths and individually placed in the middle of the compression plate. Two continuous compressions were performed on each sample up to 75% strain. The lapse between two compressions was 1 s. The pre-test, test, and post-test speeds were set at 5 mm/s. Four textural parameters were analysed: hardness (g), adhesiveness (g × s), springiness (mm), and chewiness (g × mm).

2.8 Colour analysis

The colour of cooked noodles was determined by using a spectrophotometer, UltrascanPro (D65, Hunter Lab, USA). All measurements were made in triplicate at random points on the cooked noodle. The colour parameters, including lightness (L^*), redness/greenness

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(a*), and yellowness/blueness (b*) were evaluated. These values were used to calculate the difference in lightness and darkness (ΔL), the difference in red and green (Δa), the difference in yellow and blue (Δb) and the total colour difference (ΔE) using the equations below (Caminiti *et al.*, 2012).

$$(\Delta L/\Delta a/\Delta b = L*/a*/b*\ (sample) - L*/a*/b*\ (control) \quad (5)$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (6)$$

2.9 Preparation of noodle extract

Noodle extract was prepared using the previous method by Razak *et al.* (2015) with some modifications. About 1.0 g of raw SRB noodles were mixed with 10 mL of distilled water and heated for 15 mins. All samples were centrifuged for 15 mins at 10,000 rpm, the supernatant was filtered out, and the filtrates were stored at –20°C for subsequent analysis.

2.10 Antioxidant analysis

The total antioxidant activity of noodles was determined using two in vitro tests, including FRAP and DPPH.

2.10.1 Ferric reducing ability of plasma assay

The ferric reducing ability of plasma (FRAP) assay was carried out by following the method of Razak *et al.* (2015), with some modifications. The FRAP working solution was prepared by combining 2.5 mL TPTZ (2,4,6 -tripyridyl-s-triazine) solution and 2.5 mL $FeCl_3 \cdot 6H_2O$ solution, which was heated to 37°C before use. A 150 µL of noodle extract was kept in the dark for 30 minutes to react with 2850 µL of FRAP solution. A LAMBDA 850 UV/VIS Spectrophotometer (Perkin Elmer Inc., UK) was used to measure absorbance at 593 nm. A standard curve was created by varying the amounts of ascorbic acid from 0 to 200 ppm. The variation in the absorbance of FRAP solution at various ascorbic acid concentrations during a 30-minute period was recorded and plotted. The data were presented in mg ascorbic acid equivalent (AAE)/gram sample.

2.10.2 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity

2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity was determined using the previous method by Razak *et al.* (2015), with some modifications. The 150 µL of noodle extract was kept in the dark for 30 mins to react with 2850 µL of DPPH working solution. A LAMBDA 850 UV/VIS Spectrophotometer (Perkin Elmer Inc., UK) was used to measure absorbance at 517 nm. The following equation was used to calculate the percentage of scavenging activity:

$$\text{DPPH radical cavenging activity (\%)} = \frac{\text{A(blank)}-\text{A(sample)}}{\text{A(blank)}} \times 100 \quad (7)$$

2.10.3 Total phenolic content

Total phenolic content was determined by the Folin-Ciocalteu spectrophotometric method as described by Purwandari *et al.* (2014) with some modifications. A total of 0.5 mL of 10% Folin-Ciocalteu reagent was added to 0.1 mL of noodle extract. After 8 mins, 4.5 mL of 2% Na_2CO_3 was added to the mixture and incubated at room temperature in the dark for 30 mins. Absorbance was measured at 760 nm using a LAMBDA 850 UV/VIS Spectrophotometer (Perkin Elmer Inc., UK) after 30 mins of incubation. The total phenolic content was obtained from the standard calibration curve prepared with gallic acid at concentrations ranging from 0 to 100 mg/g and expressed as gallic acid equivalents (GAE)/100 g of samples.

2.11 Sensory evaluation

Sensory evaluation of rice noodles fortified with different levels of SRB was conducted with 30 semi-trained panellists comprised of 10 males and 20 females, ranging in age from 20 to 40. They were chosen because of their excellent health, no allergy to rice products, and willingness to take part. All panellists were regular consumers of rice noodles, the instructions about SRB noodles and the informed consent form were given to the panellists before taking part in this evaluation. Five different SRB levels of rice noodles (0, 2, 5, 10, and 15% SRB levels) were evaluated in the present study. The samples were presented as rehydrated, where the noodles were cooked according to an earlier determined optimum cooking time (OCT). A sample size of 20 g of cooked rice noodles (7 cm in length) was served in a 5 cm diameter white plastic bowl with soup (cooked in measured ingredients (salt, chicken stock, garlic, and onions), vegetables (carrots, potatoes), and chicken meat) and coded with three-digit random numbers. Only noodles (without vegetables and meat pieces) were served to the panellists for evaluation within 20 min after cooking, and drinking water was provided to rinse the mouth between samples. The sensory parameters evaluated were colour, appearance, flavour, texture, and overall acceptability, as described by Hlaing *et al.* (2019). A 9-point hedonic scale score sheet was employed with the following descriptions: liked extremely (9), liked very much (8), liked moderately (7), liked slightly (6), neither liked nor disliked (5), disliked slightly (4), disliked moderately (3), disliked very much (2), and disliked extremely (1). The panellists evaluated the samples in individual booths.

2.12 Statistical analysis

All data were presented as the mean of triplicate determinations. The data were analysed using Minitab software (version 18.0) based on an analysis of variance (one-way ANOVA) and expressed as a mean standard deviation. The confidence level for statistical significance was set at a probability value of 0.05. Tukey's test was used to determine whether there was a significant difference ($p < 0.05$) in the data.

3. Results and discussion

3.1 Proximate analysis

To determine the nutritional profile of the food product, a proximate analysis is required. The proximate compositions of rice noodles fortified with five different levels of SRB (2 – 15%) are shown in Table 2. The control noodle (0% SRB) had significantly lower ($p < 0.05$) ash (0.31±0.12), protein (6.68±0.19), fat (0.42±0.12), and crude fibre (1.30±0.11) content compared to the SRB noodle. It was observed that the incorporation of SRB increased the percentage of all proximate constituents (ash, protein, fat, and crude fibre) in rice noodles, except for moisture and carbohydrates. The moisture content of all SRB noodles is significantly lower ($p < 0.05$) than that of the control noodle (16.10±0.27), ranging from 15.98±0.95 to 15.23±0.15. This aligns with Kumar *et al*. (2018) study on gluten-free pasta, where incorporating soy flour and xanthan gum led to decreased moisture content. The findings suggest a consistent trend of reduced moisture content in modified noodles, supporting the lower moisture content observed in SRB noodles. Additionally, a study by Jamal *et al*. (2016) reported that moisture content greater than 20% promotes microbial development, making a lower moisture content preferable. The lower moisture content observed in the modified noodles and SRB noodles supports this preference, suggesting that these noodles have a lower risk of microbial growth and spoilage.

Ash is made up of inorganic elements and mineral salts (Anggraeni and Saputra, 2018). Studies by Thumrongchote *et al*. (2012) reported that the ash content in rice flour ranges between 0.30 – 0.40%. Likewise, the ash content of the control noodle (0% SRB) in the present study is 0.31±0.12. After incorporation with five different levels of SRB, the ash content increased in a range from 0.40±1.10 (2% SRB) to 1.05±0.13 (15% SRB). It was observed that there were significant increases ($p < 0.05$) in the ash content of rice noodles incorporated with 10% and 15% SRB. This might be attributed to the mineral content in the SRB, including phosphorus, sodium, potassium, magnesium,

Table 2. Functional, physicochemical, nutritional, and sensory properties of rice noodles fortified with different levels of stabilized rice bran (SRB) (0, 2, 5, 10, and 15%)

Cooking quality and functional properties	Noodle Formulations				
	0% SRB	2% SRB	5% SRB	10% SRB	15% SRB
Cooking time (CT) (min)	6.94±0.05^{a}	6.85±0.01^{b}	6.77±0.02^{b}	6.65±0.05^{c}	6.49±0.01^{d}
Cooking loss (CL) (%)	6.47±0.03 ^{a}	6.34±0.07^{ab}	6.30±0.04 ^{ab}	6.24±0.06^{b}	6.15±0.15^{b}
Water absorption index (WAI) (%)	128.96±0.48^{a}	124.98±0.26^{b}	118.26±0.51^{c}	114.05±0.42^{d}	113.16±0.48^{d}
Water solubility index (WSI) (%)	6.34±0.67^{a}	6.28±0.70^{a}	5.13±0.53^{ab}	4.90±0.64^{ab}	3.82±0.71^{b}
Textural properties					
Hardness (g)	2460.08±21.98^{a}	2269.19±36.47^{b}	2180.60±26.96^{c}	2075.64±32.58^{d}	1968.54±29.96^{e}
Adhesiveness (g.s)	-37.09±14.78^{a}	-48.49±16.67^{ab}	-63.20±16.52^{ab}	-81.53±12.03^{b}	-83.61±14.04^{b}
Springiness (mm)	0.73±0.06^{a}	0.72±0.04 ^{a}	0.72±0.05 ^{a}	0.71±0.03 ^{a}	0.70±0.04 ^{a}
Chewiness (g × mm)	1095.77±20.75 ^{a}	841.23±18.38^{b}	759.11±25.86^{c}	617.81±21.25^{d}	546.36±24.64^{e}
Colour parameters					
$L*$	69.53±0.29^{a}	64.91±0.31^{b}	62.76±0.20^{c}	60.15±0.25^{d}	57.39±0.28^{e}
$a*$	2.62±0.10^{a}	3.64±0.07^{ab}	3.90±0.10^{b}	4.05±0.11^{c}	4.29±0.09^{d}
$b*$	14.21±0.21^{a}	10.05±0.13^{b}	8.89±0.20^{c}	8.33±0.14^{d}	7.70±0.15^{e}
ΔE	-	10.44±0.26^{a}	12.27±0.19^{b}	13.79±0.24^{c}	15.43±0.21^{d}
Proximate composition					
Moisture (%)	16.10±0.27^{a}	15.98±0.95^{ab}	15.81±0.23^{ab}	15.54±0.19^{bc}	15.23±0.15^{c}
Ash (%)	0.31±0.12^{a}	0.40±1.10^{a}	0.57±0.08^{bc}	0.71±0.10^{c}	1.05±0.13^{c}
Carbohydrate (%)	37.95±0.17^{a}	36.61±0.21^{b}	33.95±0.18^{c}	32.16±0.10^{d}	29.40±0.15^{e}
Protein (%)	6.68±0.19^{a}	7.24±0.14^{b}	7.99±0.15^{c}	9.06±0.09^{d}	10.31±0.12^{e}
Fat (%)	0.42±0.12^{a}	0.70±0.20^{b}	1.27±0.09^{c}	1.82±0.10^{d}	2.40±0.15^{d}
Crude fibre (%)	1.30±0.11^{a}	1.58±0.09^{b}	2.04±0.16^{c}	2.45±0.13^{d}	2.93±0.10^{d}

Values are presented as mean±SD. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

and calcium (Anggraeni and Saputra, 2018). Likewise, Islam *et al*. (2011) reported that RB has a greater ash content than other cereals' bran.

The percentage of carbohydrates in SRB noodles significantly declined ($p < 0.05$) from 37.95±0.17 (0% SRB) to 29.40±0.15 (15% SRB) to 36.61±0.21 (2% SRB). The lower carbohydrate content in SRB noodles could be due to the composition of whole grains (bran and germ) in RB that are rich in protein, fat, and fibre (Muniandy and Gannasin, 2019). The control noodle (0% SRB) has a higher carbohydrate content as they are produced from refined white rice flour, which is devoid of the fibre-rich RB layer, leading to a higher carbohydrate concentration (Muniandy and Gannasin, 2019). Moreover, it has been reported that the carbohydrate content of RB is reduced after the milling process (Ameh *et al*., 2013). Among the SRB noodles, 15% of the SRB exhibited the highest ash, protein, fat, and crude fibre, with 1.05±0.13, 10.31±0.12, 2.40±0.15, and 2.93±0.10, respectively, attributed to the higher composition of nutrients in the RB. Overall, the present study showed that the SRB noodle has a higher nutrient content than the control noodle (0% SRB). Therefore, the result suggests that SRB has the potential to be used as a source of ash (inorganic elements and mineral salts), protein, fat, and crude fibre in the development of functional food products.

3.2 Cooking qualities and functional properties

The visual characteristics of the products are important in establishing the quality of the rice noodles developed. The rice noodles must be chewy, firm, and non-sticky with minimal CT and CL (Ahmed *et al*., 2016). The cooking qualities and functional properties of rice noodles fortified with five different levels of SRB are shown in Table 2. The cooking qualities are evaluated in terms of CT and CL, while the functional properties are WAI and WSI.

The results revealed that the CT and CL appeared to be affected by the level of SRB. It was found that the CT of rice noodles significantly decreased ($p < 0.05$) with a corresponding increase in SRB levels. The CT of the SRB rice noodle varied from 6.49±0.01 (15% SRB) to 6.85±0.01 (2% SRB), compared with the control noodle sample (0% SRB) at 6.94±0.05 min, indicating a significant decrease ($p < 0.05$) with the inclusion of SRB. Generally, the CT for rice-based noodles is between 5 – 9 mins and it is affected by a higher WAI and the pre-gelatinization of rice flour (Cabrera-Chavez, 2012).

The CL is a common indicator for the quality of noodles, where a low CL value signifies the good quality of the noodles (Wang *et al*., 2018). Our results revealed that the CL in SRB rice noodles varied from 6.15±0.15 (15% SRB) to 6.34±0.07 (2% SRB), while the control noodle (0% SRB) exhibited the highest percentage of CL with 6.47±0.03. There were significant differences ($p < 0.05$) in the CL of rice noodles incorporated with 10 and 15% SRB. The variations in CL might be attributed to the destruction of matrix structure owing to the high fibre content in the SRB, which may create a strong starch-fibre network and make starch difficult to leach (Wang *et al*., 2018). Our result suggests that SRB may have a better texture and a non-sticky mouthfeel due to lower CT and CL values. According to Ahmed *et al*. (2016), higher CT and CL indicate poor quality of cooked noodles due to poor cooking resistance and an adhesive texture, which leads to a sticky mouthfeel.

WAI and WSI are the functional characteristics of flour that should be given the utmost attention in product development as they characterize the behaviour of flour after hydration as well as control the optimal consistency of the dough (Islam *et al*., 2012). According to Mattos (2002), WAI is affected by many factors such as size, shape, hydrophilic-hydrophobic balance of amino acids in protein molecules, lipids and carbohydrates associated with protein, thermodynamic properties of the bran, and environmental conditions (pH, ionic strength, vapour pressure, temperature, presence or absence of surfactant). The authors contend that the polar amino groups of protein molecules are the major component of protein-water interactions, which bind varying quantities of water at cationic, anionic, and non-ionic positions. As depicted in Table 2, the WAI value in all SRB noodles decreased significantly ($p < 0.05$) except for the 2% SRB noodle. Control noodles (0% SRB) exhibit the highest WAI value (128.96±0.48), while the lowest WAI value was recorded in 15% SRB noodles (113.16±0.48). The findings suggest that the high protein content in SRB may reduce the WAI value of SRB noodles due to the protein-starch bonding, which may affect the SRB noodles' absorption capacity. Moreover, it has been reported that high protein concentrations provide a greater base to create a superior bond with starch, eventually reducing the WAI value (Yoenyongbuddhagal and Noomhorm, 2002). Therefore, lower WAI values were observed in SRB noodles due to low levels of damaged starch. This could be due to the stabilization process of the rice bran used in the study. Our results are consistent with those of Wang *et al*. (2018) and Kong *et al*. (2012), who reported an increase in RB levels resulting in decreased WAI values in rice pasta and wheat noodles, respectively.

However, the results from the present study are in contrast to the previous study by Mattos (2002). The authors reported a significant increase ($p < 0.05$) in the WAI value of stabilized rice bran. Whereas our study showed that the stabilization of RB decreased the WAI value. The conflicting results could be due to the different varieties of bran and processing conditions used in both studies. The authors used bran from the variety "Lemont" (long grain) and the microwave-heated method at 107°C for 3 mins, whereas the present study used the bran from the Malaysian variety (MR219) and stabilized it via autoclaving at 121°C for 20 mins.

The WSI value of SRB noodles ranged from 3.82±0.71 (15% SRB) to 6.28±0.70 (2% SRB). All SRB noodles exhibit a non-significant decrease ($p > 0.05$) in WSI value, except for the 15% SRB noodles. It was found that decreasing the WSI value corresponds to an increase in the protein content of SRB noodles. This might be due to the higher protein concentration, which results in a lower WSI attributable to poor solid leaching (Ahmed *et al*., 2016). These are consistent with our results, where the highest level of SRB noodles (15%) exhibits the lowest CL value (Table 2).

3.3 Texture profile analysis

The texture is an important quality parameter to determine the consumer's acceptance of rice noodles (Gull *et al*., 2015). The texture profile parameters evaluated in this study are hardness, adhesiveness, springiness, and chewiness. As shown in Table 2, the hardness value decreased correspondingly with the increase in the levels of SRB. The hardness value in SRB noodles ranging from 1968.54±29.96 (15% SRB) to 2269.19±36.47 (2% SRB), decreased significantly ($p < 0.05$) as compared to the control noodle sample (0% SRB) (2460.08±21.98). The findings in this study align with the results presented by Zawawi *et al*. (2019). Their research revealed that the hardness of rice bran (RB) yellow noodles decreased after incorporating 10% RB, and the hardness continued to drop with further increases in RB content. The specific hardness values for RB yellow noodles with 0, 10, and 15% RB reported in their study are 2460.08±21.98, 2326.08±29.95, and 2087.16±32.95, respectively.

The adhesiveness value for SRB noodles varies from –48.49±16.67 (2% SRB) to –83.61±14.04 (15% SRB), while the control noodle (0% SRB) exhibits the highest adhesiveness value (–37.09±14.78). Except for 10 and 15% SRB noodles, the variations in adhesiveness values were found to be non-significant ($p > 0.05$). The 15% SRB noodle exhibits the lowest adhesiveness value (–83.61±14.04), which decreased significantly ($p < 0.05$) as compared to the control noodle (0% SRB). Our results are consistent with the previous studies by Wang *et al*. (2018) and Kong *et al*. (2012), who found a significant decrease ($p < 0.05$) in the adhesiveness value of rice pasta incorporated with different levels of RB fibre and wheat noodles incorporated with different levels of black RB, respectively. Moreover, a lower adhesiveness value indicates the good quality of rice noodles, as they provide a clean and smooth texture (Ahmed *et al*., 2016).

As shown in Table 2, the springiness value for the control noodle (0% SRB) was slightly higher (0.73±0.06) compared to SRB noodles. The incorporation of five different levels of SRB slightly reduced the springiness value of rice noodles, ranging from 0.70±0.04 (15% SRB) to 0.72±0.04 (2% SRB). Nevertheless, the observed changes were non-significant ($p > 0.05$) in all SRB noodles as compared to control noodles (0% SRB). The results also revealed that the control noodle (0% SRB) exhibits the highest chewiness value with 1095.77±20.75. The chewiness value of SRB noodles decreased significantly ($p < 0.05$) from 841.23±18.38 (2% SRB) to 546.36±24.64 (15% SRB). It was observed that the incorporation of SRB reduced the hardness, adhesiveness, springiness, and chewiness values of rice noodles. This could be attributable to the interactions between starch, protein, and fibre constituents that are responsible for controlling the texture of the noodles by strengthening or weakening the development of hydrogen bonds in the noodle structure (Wang *et al*., 2018; Sethi *et al*., 2020). Moreover, the use of non-starch polysaccharides (xanthan gum) in the present study may improve the textural quality of the SRB noodles. According to Lopes *et al*. (2015), xanthan gum is ideal for processing gluten-free food products owing to its non-Newtonian fluid behaviour with superior pseudo-plasticity and non-gelling characteristics. Overall, the control noodle (0% SRB) was harder, springier, and chewier as compared to the SRB noodle. In contrast, the SRB noodle was softer, less adhesive, less chewy, and non-sticky to the mouthfeel. Our results are in agreement with the previous findings by Wang *et al*. (2018), who reported that hardness, adhesiveness, and chewiness values were decreased in rice pasta fortified with different levels of RB fibre. Moreover, it was observed that the SRB noodle strands did not stick together during cooking, although the texture was softer.

3.4 Colour analysis

Colour plays a very important role in assessing the visual quality and marketability of the noodles; therefore, the appearance of the white colour should be maintained in the production of fresh noodles (Ahmed *et al*., 2016). Table 2 presents the effect of five different levels of SRB on the colour of rice noodles. The control noodle (0%) shows the highest L^* value with 69.53±0.29. The L^*

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value of SRB noodles decreased ($p < 0.05$) corresponding to the increase in SRB, with the lowest L^* value recorded at 57.39±0.28 (15% SRB noodle). This could be due to the colour of the anthocyanin pigment found in the bran fraction (Ahmed *et al*., 2016). The authors also reported that the higher bran content led to the darker colour of noodles due to the higher concentration of polyphenol oxidase in the bran layer. The incorporation of SRB consistently increased ($p < 0.05$) the a^* value (redness) of the rice noodle, ranging from 3.64±0.07 (2% SRB) to 4.29±0.09 (15% SRB). While the b^* value decreased from 10.05±0.13 (2% SRB) to 7.70±0.15 (15% SRB), compared to the control noodle (0% SRB: 14.21±0.21). The decrease in the b^* value indicates a significant ($p < 0.05$) reduction in the yellowness of rice noodles as the SRB level is increased. The ΔE is determined to establish the colour difference between the control noodle (0% SRB) and the SRB noodle. The results show that the ΔE value of SRB noodles decreased from 10.44±0.26 (2%) to 15.43±0.21 (15%), indicating that the incorporation of SRB significantly ($p < 0.05$) influenced the colour of rice noodles. Our results are consistent with the previous studies by Sethi *et al*. (2020) and Wang *et al*. (2018), who reported a significant ($p < 0.05$) increase in ΔE value of rice pasta incorporated with black RB and RB fibre, respectively.

3.5 Antioxidant activity and total phenolic contents

Determining total antioxidant activity utilizing various assays is critical for calculating the total antioxidant capacity of any food product. Therefore, the antioxidant activity of the methanol extracts of control and SRB rice noodles was determined with both the FRAP and DPPH methods. The FRAP test can assess the ability of antioxidants to reduce a ferritic tripyridyltriazine complex (Fe^{3+} - TPTZ) to produce a blue-coloured ferrous tripyridyltriazine compound (Fe^{2+} - TPTZ) (Wanyo *et al*., 2009). While DPPH is a stable free radical and is used to detect radical scavenging in samples at 517 nm. The absorption value will decrease as antioxidants are proton donors to these free radicals (Wanyo *et al*., 2009; Gull *et al*., 2018).

Figure 1 shows the antioxidant activity of rice noodles fortified with five different levels of SRB. The incorporation of SRB into rice noodles significantly increased ($p < 0.05$) the FRAP value of SRB noodles from 22.45±0.48 (2% SRB) to 53.16±0.43 (15% SRB) as compared to the control noodle (0% SRB) (19.97±0.32). Gull *et al*. (2018) reported an antioxidant activity value of less than 0.5, which is considered weak. Likewise, the percentage of DPPH radical scavenging activity significantly increased ($p < 0.05$), ranging from 0.75±0.37 (2% SRB) to 14.53±0.34 (15% SRB). The higher antioxidant content in SRB noodles could be associated with the presence of tyrosine and phenylalanine in the RB (Phongthai *et al*., 2018). In addition, phenolics, flavonoids, and anthocyanins were reported as the main contributors to the total antioxidant activity in RB (Friedman, 2013). It has been recorded that RB contains more than 100 different natural antioxidants, among which the most recognizable are tocopherol, tocotrienol, and oryzanol (Gul *et al*., 2015).

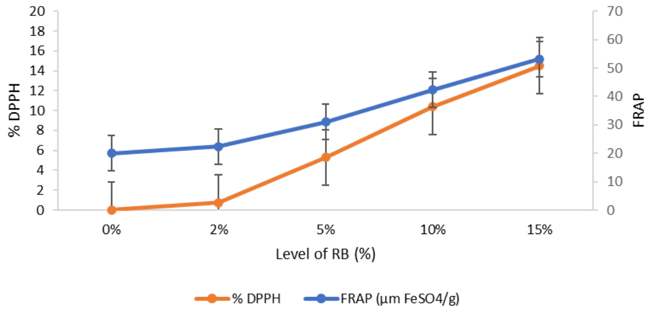

Figure 1. Antioxidant scavenging activity in rice noodles fortified with different levels of stabilized rice bran (SRB) (0, 2, 5, 10, and 15%).

Meanwhile, the data for TPC was obtained from a standard calibration curve prepared with gallic acid at concentrations of 0 to 100 mg/L and expressed as mg gallic acid equivalent per 100 g of noodles. As depicted in Figure 2, the TPC value of SRB noodles increased significantly ($p < 0.05$) from 6.27±0.57 (2% SRB) to 27.24±0.56 (15% SRB), compared to 3.24±0.45 in the control noodle (0% SRB). RB is high in phenolic substances, which are associated with an increase in TPC and are concentrated in the bran's outer layer (aleurone) (Ahmed *et al*., 2016). Furthermore, Gull *et al*. (2018) reported that foods high in phenolic compounds have higher antioxidant activity. A high correlation between TPC and antioxidants is expected since both TPC and antioxidant assays measured the reducing capacity of the samples (Min *et al*., 2011). Our findings concur well with those of Dar *et al*. (2014) and Sethi *et al*. (2020), who found a significant increase ($p < 0.05$) in the antioxidant and phenolic content in RB-enriched chapatti and black RB-enriched noodles, respectively.

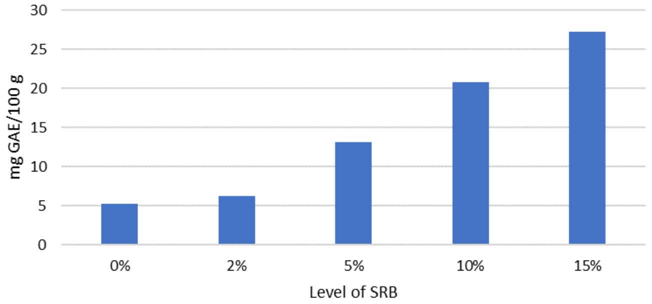

Figure 2. Total phenolic content of rice noodles fortified with different levels of stabilized rice bran (SRB) (0, 2, 5, 10, and 15%).

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3.6 Sensory characteristics

Figure 3 shows the sensory score of rice noodles fortified with five different levels of SRB. Overall, all samples showed good overall acceptability in terms of appearance, colour, flavour, and texture, with non-significant changes ($p > 0.05$) as compared with the control noodles (0% SRB). However, the panellists noted that SRB noodles have a slightly bitter aftertaste. This could be attributed to the anthocyanin pigment found in the bran fraction, which is responsible for the bitter aftertaste and darker colour of the SRB noodles (Ahmed *et al*., 2016). Nevertheless, these changes did not significantly ($p > 0.05$) affect the overall acceptability score for SRB noodles. Furthermore, consumers' awareness of natural pigments in food has been growing nowadays due to the increasing interest in healthy, organic, and natural products (Ndwandwe *et al*., 2024). These pigments not only provide colour but also offer potential health benefits as interesting bioactive compounds (Molina *et al*. (2023). Among the SRB noodles, the 10% SRB noodles showed the highest score for overall acceptability (7.86±1.14), while the 15% SRB noodles received the lowest score (6.31±0.81) in all sensory elements tested. Hence, the incorporation of 10% SRB into the rice flour is recommended for the preparation of rice noodles.

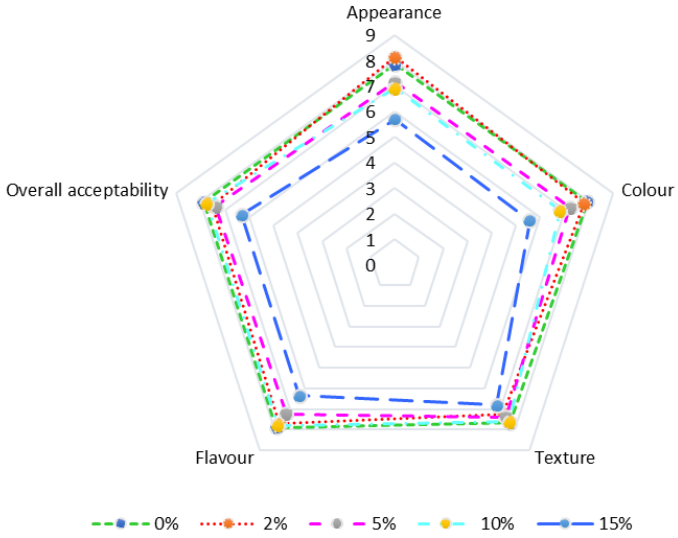

Figure 3. Sensory characteristics of rice noodles fortified with different levels of stabilized rice bran (SRB) (0, 2, 5, 10, and 15%).

4. Conclusion

According to the results of the present study, the incorporation of different levels of SRB profoundly changed the physicochemical and nutritional properties of rice noodles. SRB noodles were found to have higher ash, protein, fat, crude fibre, antioxidant, and total phenolic content. Likewise, SRB noodles performed better than the control noodles (0% SRB) in terms of cooking, functional, and textural properties. As rice noodles are deficient in essential elements including protein, fibre, antioxidants, vitamins, and minerals, SRB can be used as a functional ingredient to increase the acceptability of rice noodles while enhancing their physicochemical and nutritional qualities. The results indicate that 10% SRB noodles had the highest overall acceptability, followed by control noodles. This suggests that fortifying rice noodles with 10% SRB is ideal for creating value-added products. By incorporating SRB at this level, manufacturers can enhance the quality of rice noodles, offering consumers nutritious and appealing options. This finding highlights the potential of fortification to improve both the nutritional value and sensory appeal of rice noodles.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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