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Morphological, Proximate, Mineral, and Cooking Properties of Selected Rice (Oryza sativa L.) Varieties from Sabah, Malaysia

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ABSTRACT

Background: Rice (*Oryza sativa* L.) is vital for food security in Malaysia, serving as both a staple food and an important source of nutrients. However, the nutritional and morphological characteristics of local rice varieties, particularly those cultivated in Sabah, remain underexplored. **Methods**: Six Sabah rice varieties, Tadong, Perang, Pandasan, Wangi, SST, and TQR (control) were analyzed for morphological, nutritional, and mineral composition. Morphological traits were determined through grain dimension analysis, proximate composition using AOAC methods, and mineral content by atomic absorption spectrophotometry to quantify potassium (K), phosphorus (P), calcium (Ca), iron (Fe), and sodium (Na). **Results:** All rice varieties exhibited medium grain length and slender shape. The 1000-grain weight differed significantly (17.10–21.50 g), with Tadong the highest and TQR the lowest. Light-colored varieties showed higher L* values, while pigmented types were darker. Cooking time ranged from 11 to 20 min, with SST cooking the fastest. Volume expansion after cooking varied significantly (3.10–3.91 cm^3), with SST highest. Moreover, Perang had the highest protein and fat contents, whereas Tadong recorded the highest crude fiber and carbohydrate. K and P were the predominant minerals, while Na levels were low across varieties. **Conclusion:** Distinct varietal differences were observed, with Perang and Tadong showing superior nutritional profiles and SST exhibiting favorable cooking qualities. These findings highlight the potential of Sabah rice varieties to enhance dietary quality and strengthen Malaysia's food and nutrition security.

Introduction

Rice (*Oryza sativa* L.) is the world's most important cereal crop, feeding nearly half of the global population (Thomas *et al.*, 2013). Thousands of rice varieties exist worldwide, differing in physical, nutritional, and cooking qualities due to genetic and environmental factors (Mohidem *et al.*, 2022, Patindol *et al.*, 2014, Sitaresmi *et al.*, 2023, Wasan *et al.*, 2022). In developing countries, rice contributes substantially to dietary energy and protein intake (Sanni *et al.*,

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2006) and provides carbohydrates, proteins, vitamins, and minerals (Yadav and Jindal, 2007).

In Malaysia, the total paddy cultivation area in 2023 was 506.4 thousand hectares (Department of Statistics Malaysia, 2025). Major rice types available in retail markets include white, glutinous, brown, black, red, and aromatic rice (Ahmad Shakri *et al.*, 2021). In Sabah, rice is not only a staple food and key economic crop but also holds deep cultural and spiritual significance among indigenous communities (Hashmi and Tianlin, 2016). Beyond its nutritional importance, rice is deeply embedded in the cultural traditions of Malay, Chinese, and Indian communities, symbolising prosperity, unity, and shared heritage (Che Omar *et al.*, 2019).

Despite its importance, limited research exists on the morphological, nutritional, and mineral characteristics of traditional rice cultivated in Sabah. Traditional Sabah rice significantly contributes to the local market but remains poorly documented (Neoh and Lum, 2018). Understanding physical grain properties such as size, shape, color, and weight is essential for designing machinery used in sorting, drying, milling, and other operations (Mir *et al.*, 2013), as well as for improving packaging and processing efficiency. Grain size and shape are also critical for grading and impurity separation (Ahmad Shakri *et al.*, 2021).

Cooking properties strongly influence consumer preferences and market value. Parameters such as cooking time, texture, color, aroma, and stickiness affect product quality and acceptability (Ghadge and Prasad, 2012, Yanjie *et al.*, 2018). Moreover, traditional rice varieties play a vital role in food security, particularly for rural and indigenous communities, by offering genetic diversity and resilience to pests and environmental stress (Begna, 2021, Britwum and Demont, 2022, Ghosh *et al.*, 2023). Scientific characterisation of these varieties is crucial for preserving agrobiodiversity and enhancing sustainable food systems.

While many studies focus on commercial rice varieties in Malaysia, traditional and indigenous varieties in Sabah remain insufficiently studied. This knowledge gap constrains efforts to preserve biodiversity and ensure long-term food security. Therefore, this study investigates the morphological characteristics, nutritional composition, and mineral content of selected rice varieties from Kota Belud, Sabah, Malaysia. The findings aim to provide essential data for local rice development, improve post-harvest management, promote Sabah's rice biodiversity, and strengthen food security and agrobiodiversity conservation.

Materials and Methods

Materials

Six rice varieties were obtained from a local supermarket in Kota Belud, Sabah, Malaysia. The local varieties included Tadong, Perang, Pandasan, Wangi, SST, and TQR, with TQR, commonly consumed in Sabah, serving as the control. **Figure 1** shows all six rice varieties used in this study. Upon arrival at the laboratory, the rice samples were washed with tap water to remove dust and impurities. Each sample was then ground into a fine powder using a waring blender, sealed in airtight plastic bags, and stored at 4 °C until further analysis.

Figure 1. Morphological appearance of six rice varieties from Sabah, Malaysia: Tadong (top, left), Perang (top, middle), Pandasan (top, right), Wangi (bottom, left), SST (bottom, middle), and TQR (control) (bottom, right).

Physical analysis

The physical characteristics of the rice grains, including size, shape, and 1000-grain weight, were analysed to assess varietal differences. Ten intact ~~whole~~ grains from each variety were selected and measured for length and breadth using a micrometer with an accuracy of 0.01 mm. Only undamaged grains were used to ensure precision. The length-to-

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breadth (L/B) ratio was calculated by dividing the mean grain length by its breadth to determine the shape classification, following the criteria described by Graham (**Tables 1 and 2)** (Graham, 2002)**.** For 1000-grain weight, one thousand grains from each variety were randomly selected and weighed using an analytical balance with an accuracy of 0.001 g. The procedure was carried out in triplicate, and the mean values were recorded. These measurements provided indicators of grain morphology, size uniformity, and varietal yield potential.

Table 1. Rice grain size classification.

Size	Size category	Length (mm)
1	Very long	More than 7.50
3	Long	6.61 to 7.50
5	Medium or intermediate	5.51 to 6.60
7	Short	Less than 5.50

Source: Graham (2002)

Table 2. Rice grain shape classification.

Size	Shape category	Length/width ratio
1	Slender	More than 3.0
5	Medium	2.1 to 3.0
9	Bold	2.0 or less than 2.0

Source: Graham (2002)

The color parameters of the rice samples were determined using a colorimeter (HunterLab ColorFlex EZ, Sunset Hills Road, Reston, USA). Each sample was placed in a glass sample cup until the minimum sample depth of 25 mm was reached to ensure consistent readings. The instrument was calibrated using a standard white tile before measurement. Color attributes were expressed in L^*, a^*, and b^* values, where L^* represents brightness (0 = black to 100 = white), a^* indicates the red–green axis (positive for red, negative for green), and b^* represents the yellow–blue axis (positive for yellow, negative for blue) (Good, 2002). Each measurement was repeated three times for all cultivars, and the mean values were used for analysis.

Cooking properties

The cooking properties of the rice samples were evaluated through measurements of cooking volume expansion and cooking time to assess water absorption behaviour and gelatinisation characteristics. For cooking volume expansion, 5 g of rice grains were placed in a beaker containing 15 mL of distilled water, and the initial volume was recorded. The samples were then cooked in a water bath at 90 °C for 20 minutes. After cooking, the rice was transferred into 50 ml of water to remove excess surface moisture, and the final volume was measured. The volume expansion ratio was determined as the ratio of the increase in cooked rice volume to the original uncooked rice volume. For cooking time determination, 5 g of rice grains from each variety were tested following the method described by Thomas (Thomas *et al.*, 2013). Each sample was cooked in 100 ml of distilled water within a 250 ml graduated beaker placed in a water bath. Beginning after three minutes of boiling, 3 g of rice were removed and pressed between two glass slides to assess gelatinisation. This process was repeated at one-minute intervals until no opaque centres were observed in at least 90% of the grains, indicating the minimum cooking time.

Proximate analysis

The proximate composition of the rice samples was determined following the standard methods of the Association of Official Analytical Chemists (Official Methods of Analysis, 2005). Moisture content was measured using the oven-drying method, where finely ground samples were dried at 105°C until a constant weight was achieved. Ash content was determined using a muffle furnace at 550°C, with samples ashed overnight and cooled before weighing. Crude fiber was also analyzed using an automated Fibretherm FT12 system through sequential digestion, drying, and ashing. Protein content was determined using the Kjeldahl method (Nielsen, 2019), involving digestion with sulfuric acid, distillation, and titration using a KjeltecTM 2300 analyzer. Fat content was analyzed by Soxhlet extraction (SoxhtecTM system) with petroleum ether, and the fat percentage was determined gravimetrically after drying. Finally,

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carbohydrate content was calculated by difference, subtracting the total percentages of moisture, ash, crude fiber, protein, and fat from 100%.

Mineral analysis

Mineral content in the rice samples, including calcium, phosphorus, sodium, potassium, and iron, was determined using Atomic Absorption Spectrophotometry (AAS) (AA-7000, Shimadzu Company, Kyoto, Japan) following the wet acid digestion method described by (Official Methods of Analysis, 2005). Approximately 0.5 g of finely ground rice sample was weighed into a digestion flask and treated with 2 ml of concentrated HCl and 2 ml of concentrated HNO_3. The mixture was allowed to predigest and then was digested for 1 hour using a microwave digestion system. The digested samples were filtered and diluted to 50 ml with deionized water. Standard solutions for each mineral were prepared from 1000 mg/l stock solutions at concentrations of 1, 2, and 3 mg/l. The mineral concentrations in the samples and standards were measured using an atomic absorption spectrophotometer, and results were expressed in milligrams per gram (mg/g) on a dry weight basis. All analyses were performed in triplicate.

Data analysis

Data were statistically analyzed using the Statistical Package for the Social Sciences (SPSS), version 28 (IBM Corp., Armonk, NY, USA). One-way ANOVA was performed to determine significant differences among samples, followed by multiple comparisons using Tukey's B test at a significance level of P-value<0.05. All analyses were conducted in triplicate, and the results were expressed as mean ± standard deviation (SD).

Results

Physical properties

The physical characteristics of the six rice varieties are presented in **Table 3**, including average grain length, width, length-to-breadth (L/B) ratio, 1,000-grain weight, size, and shape, which were evaluated as indicators of grain quality. The average grain length ranged from 5.74 mm (TQR) to 5.91 mm (Tadong), while grain width varied between 1.63 mm (SST) and 1.79 mm (Pandasan). Based on the classification criteria by Tchuisse (Tchuisse *et al.*, 2020), rice grains measuring 5.51–6.50 mm are categorized as medium-grain. All six Sabah rice varieties fell within this range. The L/B ratio ranged from 3.23 (Pandasan) to 3.68 (SST), classifying all varieties as slender-grain types. The 1,000-grain weight ranged from 17.10 ± 0.87 g (TQR) to 21.10 ± 1.35 g (Tadong), with only Tadong falling within the ideal 20–30 g range reported by Adu-Kwarteng *et al.* ,Sujatha *et al.*, *and* Yadav and Jindal.(Adu-Kwarteng *et al.*, 2003, Sujatha *et al.*, 2004), (Yadav and Jindal, 2007).

The colorimetric values also varied among varieties (**Table 4**). Lightness (*L**) ranged from 48.63 (Tadong) to approximately 90 (Pandasan, SST, and TQR). The *a** values (red–green axis) ranged from 0.25 (TQR) to 11.26 (Tadong), while *b** values (yellow–blue axis) ranged from 6.73 to 16.18, with Wangi and Perang recording the highest yellow tones (16.18 and 15.34, respectively). These measurements indicate distinct differences between lighter (SST, Pandasan, TQR) and darker, pigmented (Tadong, Perang, Wangi) varieties.

Table 3. Average of length (L), width (W), the ratio of L/B, size and shape of grain**.**

Rice varieties	Length (mm)	Width (mm)	L/B (mm)	1000-grain (g)	Size	Shape
Control (TQR)	5.74 ± 0.15^{a}	1.70 ± 0.09^{a}	3.38 ± 0.17^{a}	17.10 ± 0.87^{a}	Medium	Slender
Tadong	5.91 ± 0.36^{a}	1.78 ± 0.10^{a}	3.33 ± 0.28^{a}	21.50 ± 1.35^{c}	Medium	Slender
Perang	5.83 ± 0.19^{a}	1.68 ± 0.22^{a}	3.54 ± 0.66^{a}	19.50 ± 0.52^{bc}	Medium	Slender
Pandasan	5.79 ± 0.11^{a}	1.79 ± 0.12^{a}	3.23 ± 0.22^{a}	18.50 ± 0.52^{b}	Medium	Slender
Wangi	5.85 ± 0.76^{a}	1.72 ± 0.06^{a}	3.38 ± 0.15^{a}	19.50 ± 0.52^{bc}	Medium	Slender
SST	5.85 ± 0.10^{a}	1.63 ± 0.27^{a}	3.68 ± 0.69^{a}	18.50±0.52^{b}	Medium	Slender

Values (mean ± standard deviation, n=3) were compared using one-way ANOVA; Values in the same column with different superscripts letters, which are significantly different (P<0.05.).

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Table 4. Color parameters properties of different rice varieties

Rice varieties	*L** (lightness)	*a** (red/green value)	*b** (blue/yellow value)
Control (TQR)	90.60±0.02^{e}	0.25±0.00^{a}	7.54±0.00^{b}
Tadong	48.63±0.01^{a}	11.26±0.03^{de}	6.73±0.02^{a}
Perang	80.88±0.00^{b}	2.16±0.02^{cd}	15.34±0.04^{e}
Pandasan	89.01±0.01^{d}	0.58±0.02^{b}	8.78±0.02^{d}
Wangi	80.89±0.02^{b}	2.16±0.01^{cd}	16.18±0.02^{f}
SST	87.63±0.05^{e}	0.62±0.01^{bc}	8.08±0.02^{c}

Values (mean ± standard deviation, n =3) were compared using one-way ANOVA; Values in the same column with different superscripts letters, which are significantly different (P<0.05).

Cooking properties

As shown in **Table 5**, the volume expansion and cooking time of the rice varieties differed significantly, reflecting varietal variations in grain structure, starch composition, and water absorption capacity. The volume expansion ranged from 3.10±0.05 cm³ in Tadong to 3.91±0.08 cm³ in SST, indicating notable differences in the swelling behavior of the grains during cooking. Among the tested varieties, SST exhibited the highest volume expansion (3.91±0.08 cm³), suggesting superior water-uptake capacity and a less compact starch matrix that allows for greater swelling. Similarly, Pandasan (3.65±0.19 cm³) and the control TQR (3.34±0.15 cm³) showed relatively high expansion, while Tadong (3.10 cm³), Wangi (3.15 cm³), and Perang (3.20 cm³) demonstrated lower expansion values.

The cooking time among varieties ranged from 11 ± 2 min (SST) to 20±2 min (Perang and Wangi), indicating statistically significant differences (P<0.05). Shorter cooking durations were recorded for SST and Pandasan, whereas Perang and Wangi required the longest times to achieve complete gelatinisation. These variations reflect intrinsic varietal properties, particularly starch composition and structural compactness. Overall, SST displayed the most desirable cooking performance, characterized by the highest volume expansion and shortest cooking time, followed by Pandasan and TQR. In contrast, Perang and Wangi required longer cooking durations and exhibited lower swelling capacity.

Table 5. Cooking volume expansion and cooking time of different rice varieties.

Rice varieties	Cooking volume expansion (cm^{3})	Cooking time (mins)
Control (TQR)	3.34 ± 0.15^{ab}	15.00 ± 4.01^{ab}
Tadong	3.10 ± 0.05^{a}	14.00 ± 2.00^{a}
Perang	3.20 ± 0.06^{a}	20.00 ± 2.00^{b}
Pandasan	3.65 ± 0.19^{bc}	12.00 ± 2.00^{a}
Wangi	3.15 ± 0.06^{a}	20.00 ± 2.00^{b}
SST	3.91 ± 0.08^{bc}	11.00 ± 2.00^{a}

Values (mean ± standard deviation, n =3) were compared using one-way ANOVA; Values in the same column with different superscripts letters are significantly different (P<0.05).

Proximate analysis

Rice flours from different cultivars were analyzed for their proximate composition to assess their nutritional quality and suitability for food product development. The proximate analysis (**Table 6**) revealed significant varietal differences (P<0.05) across all parameters. Moisture content ranged from 1.96% (Tadong) to 14.53% (Pandasan). These values fall within the acceptable range for rice and align with those reported by Oppong *et al.* (2021), who found moisture levels between 4.25–5.06%.

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Ash content, which indicates total mineral residue after combustion (Otemuyiwa *et al.*, 2018), varied slightly between 0.21–0.25%. Tadong recorded the highest value (0.25%), followed by Pandasan (0.24%) and Perang (0.23%), while the lowest levels were found in TQR (0.21%) and Wangi (0.22%). Crude fiber content ranged narrowly from 0.95% (SST) to 1.05% (Tadong). Protein content ranged from 8.56% (TQR) to 10.52% (Perang), whereas fat content varied from 0.99% (SST) to 10.00% (Perang). Carbohydrate content was the most abundant constituent, ranging from 66.47% (Perang) to 85.50% (Tadong). These compositional data indicate measurable variability in the proximate profiles of the six Sabah rice varieties.

Table 6. Proximate characteristics of different rice varieties.

Parameters	Control (TQR)	Tadong	Perang	Pandasan	Wangi	SST
Moisture	13.70±0.10^{e}	1.96±0.01^{a}	11.80±0.01^{c}	14.53±0.01^{f}	10.35±0.01^{b}	13.39±0.01^{d}
Ash	0.21±0.01^{a}	0.25±0.01^{b}	0.23±0.01^{a}	0.24±0.01^{ab}	0.22±0.02^{ab}	0.22±0.01^{ab}
Protein	8.56±0.05^{a}	9.26±0.01^{c}	10.52±0.01^{e}	9.51±0.01^{d}	9.01±0.01^{b}	9.02±0.02^{b}
Fat	1.00±0.01^{a}	1.97±0.06^{b}	10.00±0.01^{d}	2.00±0.01^{b}	2.99±0.01^{c}	0.99±0.02^{a}
Crude Fiber	0.95±0.06^{a}	1.05±0.41^{a}	0.97±0.01^{a}	0.99±0.01^{a}	0.98±0.01^{a}	0.97±0.01^{a}
Carbohydrate	75.63±0.11^{c}	85.50±0.44^{e}	66.47±0.01^{a}	72.73±0.02^{b}	76.43±0.04^{e}	75.38±0.02^{c}

Values (mean ± standard deviation, n =3) were compared using one-way ANOVA; Values in the same column with different superscripts letters are significantly different (P<0.05).

Mineral content

The mineral content of the six rice varieties was analyzed (**Table 7**) and showed significant variation, with potassium (K) and phosphorus (P) dominating the mineral profile. Potassium ranged from 95.88 to 232.26 mg/g, while phosphorus ranged from 217.96 to 430.98 mg/g, making them the most abundant minerals across all samples. Among the cultivars, Perang recorded the highest K and P levels (232.26 mg/g and 430.98 mg/g, respectively), followed closely by Tadong (216.54 mg/g K, 419.23 mg/g P). The lowest values were observed in Pandasan (95.88 mg/g K, 217.96 mg/g P).

Calcium concentrations ranged from 8.31 mg/g (Wangi) to 21.13 mg/g (TQR), while iron content varied widely from 3.79 mg/g (Wangi) to 26.22 mg/g (TQR). Intermediate Fe values were recorded for SST and Pandasan. Sodium concentrations were low across all varieties, ranging from 0.14 mg/g (Wangi) to 10.07 mg/g (SST). Overall, Perang and Tadong displayed the highest macromineral concentrations (K and P), whereas TQR recorded the highest levels of Ca and Fe. Despite lower mineral concentrations, Pandasan and Wangi maintained acceptable nutritional profiles. All varieties exhibited notably low sodium content, confirming rice's inherent Low-Na characteristic and reinforcing its value as a staple for health-conscious consumers.

Discussion

Physical properties

The morphological evaluation highlights the significance of grain geometry as a key determinant of quality, influencing appearance, processing performance, and consumer preference. Medium-grain rice, as observed in all six Sabah varieties, is highly preferred in many Asian markets due to its balanced cooking characteristics, moderate stickiness, and ease of handling (Abd Rahman *et al.*, 2024, Ishfaq *et al.*, 2023). The predominance of medium–slender kernels aligns with desirable consumer traits such as uniform gelatinization, moderate firmness, and good textural quality after cooking.

The observed L/B ratios confirm the slender classification, which is associated with premium market value, particularly in international trade (Chen *et al.*, 2025). Slender grains typically exhibit higher elongation and volume expansion during cooking, resulting in a fluffy texture that enhances consumer acceptability (Alaka *et al.*, 2014). SST,

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the variety with the highest L/B ratio, displayed the greatest expansion ratio, reinforcing this relationship. These findings also suggest that kernel geometry is a valuable trait for breeding programs focused on improving both functional and aesthetic quality (Alam *et al.*, 2024, Kabange *et al.*, 2023).

Table 7. The mineral content of different rice varieties

Rice sample	Sodium	Calcium	Potassium	Iron	Phosphorus
Control (TQR)	8.40±0.01^{d}	21.13±0.01^{f}	105.59±0.01^{b}	26.22±0.00^{f}	223.55±0.01^{b}
Tadong	1.78 ±0.01^{b}	15.36±0.01^{d}	216.54±0.57^{e}	7.56±0.01^{c}	419.23±0.00^{e}
Perang	1.80±0.01^{b}	13.91±0.01^{b}	232.26±0.01^{f}	6.62±0.01^{b}	430.98±0.01^{f}
Pandasan	7.56±0.01^{c}	18.43±0.01^{e}	95.88±0.01^{a}	11.40±0.01^{e}	217.96±0.01^{a}
Wangi	0.14±0.01^{a}	8.31±0.01^{a}	149.81±0.01^{d}	3.79±0.01^{a}	340.17±0.00^{d}
SST	10.07±0.01^{e}	15.04±0.01^{c}	106.94±0.00^{c}	12.74±0.01^{e}	277.83±0.01^{c}

Values (mean ± standard deviation, n =3) were compared using one-way ANOVA; Values in the same column with different superscripts letters are significantly different (P<0.05).

The 1,000-grain weight, ranging from 17.10 to 21.10 g, reflects moderate kernel density and yield potential. Tadong, with the heaviest grain weight, may provide superior milling yield and better structural integrity during cooking. Conversely, lighter grains such as TQR and SST may hydrate and cook more rapidly-an advantage for quick-cooking applications. These differences align with previous reports noting that 20–30 g is optimal for desirable texture and reduced stickiness (Adu-Kwarteng *et al.*, 2003, Sujatha *et al.*, 2004, Yadav and Jindal, 2007).

Kernel color proved to be another distinguishing trait among the varieties. The lighter grains (SST, Pandasan, TQR) correspond to conventional white rice, widely preferred in export and retail markets for their neutral flavor and uniform cooked color. In contrast, pigmented varieties (Tadong, Perang, Wangi) displayed darker hues and higher *a** and *b** values, indicating the presence of anthocyanins, proanthocyanidins, and other polyphenolic pigments concentrated in the bran layer (Kim *et al.*, 2008, Mackon *et al.*, 2021). These pigments are associated with enhanced antioxidant activity and nutritional value (Chen *et al.*, 2023, Mbanjo *et al.*, 2020).

From a commercial perspective, while lighter-colored rice remains dominant, the rising consumer demand for functional and health-promoting foods has increased interest in pigmented varieties. These colored grains not only diversify the sensory and nutritional profiles of rice products but also present opportunities for value-added food applications. Overall, the combination of medium grain size, slender shape, moderate grain weight, and distinctive color traits observed in the Sabah rice cultivars highlights their suitability for both conventional and functional food markets. Kernel color, in particular, should be regarded as an essential selection criterion in varietal improvement programs aimed at enhancing both consumer appeal and nutritional functionality.

Cooking properties

The observed variations in cooking properties among rice varieties are closely related to their starch composition, grain structure, and physicochemical characteristics. Varieties with higher swelling capacity and shorter cooking time, such as SST and Pandasan, likely possess lower gelatinization temperatures (GT) and a more porous endosperm structure, facilitating rapid water absorption and starch gelatinization (Farooq and Yu, 2025, Pereira *et al.*, 2023). Conversely, varieties like Perang and Wangi, which required longer cooking durations (~20 min), probably have higher GTs, denser starch matrices, and greater amylose content, factors that retard water penetration and delay softening (Yang *et al.*, 2024).

These findings support previous reports that cooking time is positively correlated with GT and

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amylose content (Karim *et al.*, 2024), while volume expansion is inversely related to starch compactness. The superior cooking attributes of SST, combining rapid gelatinization, efficient hydration, and high expansion highlight its potential for energy-saving processing and convenience food applications. From a consumer and industrial standpoint, these results demonstrate that grain morphology and color are also linked to cooking quality. The slender, light-colored varieties (SST and Pandasan) exhibited faster cooking and greater expansion, making them suitable for modern markets prioritizing efficiency and visual appeal. In contrast, the pigmented types (Tadong, Perang, Wangi) required longer cooking durations, consistent with their higher amylose and resistant starch content, which enhances firmness and nutritional value (Govindaraju *et al.*, 2025). Although these varieties may be less ideal for quick cooking, they remain valuable for functional food development, given their richer bioactive composition and antioxidant potential.

Overall, the interplay between grain geometry, starch characteristics, and pigmentation underscores the multifactorial determinants of rice cooking quality. SST and Pandasan emerge as favorable candidates for high-yield and rapid-cooking applications, whereas Perang, Wangi, and Tadong represent promising options for nutrient-dense, health-oriented rice products.

Proximate analysis

According to Reddy *et al.'s study* (Reddy *et al.*, 2019), the recommended moisture content for safe food development and storage should be below 15%, while Nath (Nath *et al.*, 2022) emphasized that rice typically contains approximately 80% carbohydrates, providing a substantial portion of daily caloric intake. The moisture values obtained in this study fall within the safe range for long-term storage, as stated by Food Act 1983 (Act 281) and Regulations (Ministry of Health Malaysia, 1993), with the particularly low level in Tadong (1.96%) potentially advantageous for shelf life but possibly affecting milling efficiency due to increased grain hardness (Verma and Srivastav, 2017).

The slightly higher ash content in Tadong suggests greater mineral retention, possibly linked to lower milling intensity. Although the differences were minor and statistically insignificant (P>0.05), they indicate consistent mineral uniformity among the samples. Crude fiber content was slightly higher in pigmented varieties, supporting previous findings by Nicholas (Nicholas *et al.*, 2014) and Thongkaew and Singthong (Thongkaew and Singthong, 2020), who attributed elevated fiber levels to partial bran retention. Even modest increases in fiber can contribute to better digestive health and glycaemic control.

Perang exhibited the highest protein concentration (10.52%), indicating superior nutritional value compared with SST (9.01%) and Wangi (9.03%). These values fall within the reported range of 4–14% for Asian rice varieties (Kennedy *et al.*, 2002) and correspond to levels found in Sri Lankan traditional cultivars (Samaranayake *et al.*, 2017). The elevated protein and fat contents in Perang may result from bran preservation during minimal polishing, as the bran layer is rich in lipids and proteins that enhance energy density and functionality (Frei *et al.*, 2003, Mir *et al.*, 2013). Conversely, the lower fat level in SST suggests a higher degree of polishing, which extends shelf life but reduces nutritional value.

Carbohydrate content was the highest in Tadong (85.50%) and the lowest in Perang (66.47%), consistent with the inverse relationship between carbohydrate concentration and protein or lipid content. The high carbohydrate content of Tadong and Wangi indicates suitability as energy-dense staple varieties. Carbohydrates remain the dominant energy source in rice, supporting sustained energy release (Otemuyiwa *et al.*, 2018).

Overall, these compositional variations underscore the importance of varietal selection based on nutritional objectives. Perang stands out for its high protein and fat levels, supporting applications in nutrient-fortified or functional food formulations, while Tadong and Wangi are ideal for energy-focused diets. Such profiling provides valuable guidance for both consumer nutrition

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planning and breeding programs aimed at developing rice varieties optimized for health, quality, and processing functionality.

Mineral content

The dominance of K and P in the mineral profile of the Sabah rice varieties is consistent with previous findings in other rice genotypes, such as Nigerian rice, where K (~110–120 mg/100 g) and P (~115–120 mg/100 g) are major constituents (Michael *et al.*, 2022). However, the much higher concentrations observed in Perang and Tadong suggest that these local cultivars may possess enhanced mineral accumulation capacity potentially influenced by genotype, soil composition, or reduced polishing levels (Tiozon *et al.*, 2023). From a nutritional perspective, potassium supports electrolyte balance, nerve transmission, and cardiovascular health, while phosphorus contributes to bone mineralization and energy metabolism (Razzaque and Wimalawansa, 2025). Thus, these two varieties may provide meaningful contributions to dietary K and P intake in populations that rely heavily on rice as a staple.

The calcium content, ranging between 8.31 and 21.13 mg/g, aligns well with or exceeds earlier reports on Indian rice varieties (~15.07–15.96 mg/100 g) (Lavanya and Pinky, 2019). The higher Ca values observed in TQR and Pandasan likely reflect reduced polishing or enhanced soil calcium availability. Even at moderate concentrations, these values are nutritionally relevant for populations with limited access to dairy or calcium-fortified foods. The iron concentrations, particularly in TQR (26.22 mg/g), are substantially higher than the ~1.67–2.53 mg/100 g reported in Indian rice (Lavanya and Pinky, 2019). Such elevated Fe levels may arise from minimal polishing or iron-rich soils in Sabah's paddy ecosystems. Given the global prevalence of iron deficiency, these findings highlight the biofortification potential of TQR, SST, and Pandasan as nutritionally enriched rice cultivars.

All varieties displayed low sodium content (0.14–10.07 mg/g), consistent with recent Malaysian data for both fragrant and colored rice types (Kabir *et al.*, 2024, Neoh and Lum, 2018, Rohin *et al.*, 2023). This characteristic is particularly beneficial for individuals managing hypertension or cardiovascular risks, strengthening the case for rice as a naturally low-sodium staple. In summary, the mineral composition results underline distinct varietal advantages: Perang and Tadong excel as sources of macrominerals (K and P), TQR provides superior levels of Ca and Fe, and SST maintains favourable Na and Fe balance. Such diversity supports their utilization in targeted breeding programs and functional food development, especially for enhancing micronutrient intake and promoting dietary diversity. These findings further affirm the nutritional value of traditional Sabah rice varieties and their potential contribution to sustainable food and nutrition security.

This study provides valuable baseline data on physical, cooking, and nutritional characteristics of traditional rice varieties from Sabah, a region where scientific documentation remains limited. A major strength of this work is the comprehensive evaluation combining morphological, proximate, mineral, and cooking quality analyses using standardised and widely accepted analytical methods. The inclusion of several local varieties also offers useful comparative insights relevant to food security, varietal selection, and biodiversity conservation.

Nevertheless, several limitations should be acknowledged. The study focused on a limited number of varieties obtained from a single district, which may not fully represent the diversity of Sabah rice. Environmental factors such as soil conditions and seasonal variation were not assessed. In addition, sensory attributes and mineral bioavailability were not evaluated, which could provide further insight into consumer acceptance and nutritional impact. Future research incorporating broader sampling, sensory evaluation, and bioavailability studies would strengthen the applicability of these findings.

Conclusions

This study examined the physical, cooking, and

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nutritional characteristics of six rice varieties cultivated in Kota Belud, Sabah, Malaysia. All varieties were classified as medium-grain and slender, traits that support high consumer preference and favourable cooking behavior. Significant differences were found in color and grain traits, emphasizing the relevance of physical properties for optimizing milling efficiency and storage design. Among the varieties, Tadong exhibited the highest 1000-grain weight, while SST showed the most balanced morphology and best cooking performance, with high volume expansion and short cooking time. Proximate and mineral analyses revealed substantial varietal differences. Perang was rich in protein and fat, indicating superior nutritional density, whereas Tadong had the highest carbohydrate and lowest moisture contents, suggesting excellent storability and energy value. All rice samples exhibited low sodium levels and moderate iron and calcium contents, beneficial for balanced diets. Overall, Perang and Tadong demonstrated the greatest nutritional promise, Perang for its protein and mineral richness, and Tadong for its energy density and shelf stability, highlighting the potential of local Sabah rice varieties for functional food development and dietary diversification.

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Conflict of interests

The authors declared no conflict of interests.

Authors' contributions

Ibrahim SN conducted data curation, formal analysis, writing original draft; Abdul Aziz AA was involved with conceptual, visualization, and validation, Mohd Ridhwan N did the formal analysis; Putra NR carried out visualization and validation; and Mamat H did review, editing, and supervision.

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