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RESEARCH ARTICLE

# Nutritional and Phytochemical Composition of Thai Glutinous Rice Cultivars from Different Growing Regions

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**Abstract**

Glutinous rice (*Oryza sativa* L.) is an important staple food in Southeast Asia and a valuable raw material for functional and value-added rice-based products. However, comprehensive comparative information regarding the nutritional and phytochemical characteristics of Thai glutinous rice cultivars from different growing regions remains limited. This study evaluated eight Thai glutinous rice cultivars for their proximate composition, vitamin and mineral contents, amino acid and fatty acid profiles, bioactive compounds, antioxidant activity, color characteristics, and cooking-related functional properties using standardized analytical methods. Clear compositional differences among cultivars were observed. Pigmented cultivars, particularly Kam Yai and Kam Noi, exhibited higher concentrations of anthocyanins, gamma-oryzanol, total polyphenols, and antioxidant activity than non-pigmented cultivars. Kam Yai also showed relatively higher protein and mineral contents. Unsaturated fatty acids, especially oleic and linoleic acids, predominated across all cultivars, while essential amino acids including valine, leucine, and isoleucine were detected in all samples. All cultivars were classified as low-amylose glutinous rice with soft gel consistency and low gelatinization temperature, indicating desirable cooking and processing characteristics. Principal component analysis further demonstrated clear differentiation between pigmented and non-pigmented cultivars based on nutritional, phytochemical, antioxidant, and functional properties. These findings demonstrate compositional differences among Thai glutinous rice cultivars and provide useful information for cultivar selection, food composition databases, and future applications in functional foods, gluten-free products, and rice-based processing industries.

**Keywords:** Thai glutinous rice, Nutritional composition, Phytochemical content, Antioxidant activity, Amino acid profile, Fatty acid composition, Pigmented rice, Functional properties

## Introduction

Rice (*Oryza sativa* L.) is one of the most important staple crops worldwide and serves as the primary energy source for more than half of the global population [1]. In Southeast Asia, glutinous rice plays a central role in

traditional diets, food culture, and regional economies. Unlike non-glutinous rice, glutinous rice is characterized by low amylose and high amylopectin content, resulting in its distinctive sticky texture after cooking [2]. Beyond its traditional culinary role, glutinous rice has gained increasing interest as a raw material for processed foods, gluten-free products, fermented beverages, and functional food formulations. Its nutritional and functional quality is influenced by both genetic background and environmental conditions, with previous studies reporting variation in proximate composition, mineral content, and fatty acid profiles among rice cultivars grown under different agroecological environments [3,4]. Pigmented rice varieties, particularly red and black rice, have been reported to contain higher levels of phenolic compounds, anthocyanins, and antioxidant activity compared with non-pigmented varieties [5-7]. These bioactive compounds have been associated with antioxidant activity and potential health-promoting properties; however, direct biological effects were beyond the scope of the present study [8,9]. In addition to phytochemicals, rice contains essential amino acids, fatty acids, and micronutrients that contribute to its nutritional quality. Although rice protein is generally limited in lysine, it remains an important dietary protein source in rice-based populations. Branched-chain amino acids, including valine, leucine, and isoleucine, play important roles in protein metabolism and physiological regulation [10-12]. Rice lipids, although present in relatively low amounts, are primarily composed of unsaturated fatty acids such as oleic acid and linoleic acid [13-15]. Furthermore, micronutrients such as iron, zinc, magnesium, and potassium are important dietary minerals for populations that rely heavily on rice as a staple food [16,17]. Previous studies on Thai rice have largely focused on individual quality attributes, such as proximate composition, antioxidant activity, physicochemical properties, or specific bioactive compounds in selected cultivars. However, comprehensive comparative studies integrating nutritional composition, amino acid profiles, fatty acid profiles, micronutrient composition, phytochemical compounds, antioxidant capacity, color characteristics, and cooking-related functional properties across multiple Thai glutinous rice cultivars from different geographical regions remain limited. In addition, limited information is available regarding how these compositional differences may influence cultivar selection for functional food development and value-added rice processing applications. Given Thailand's diverse agroecological environments and rich rice biodiversity, understanding cultivar-specific nutritional and functional characteristics is important for selecting rice cultivars for specific food processing and nutritional applications. Functional properties such as amylose content, gelatinization temperature, and gel consistency are key determinants of end-use quality, influencing texture, processing performance, cooking behavior, and consumer acceptance [18,19]. Therefore, this study aimed to provide a comprehensive comparative evaluation of eight Thai glutinous rice cultivars grown in different regions of Thailand by integrating nutritional composition, amino acid and fatty acid profiles, micronutrient content, phytochemical characteristics, antioxidant capacity, color attributes, and cooking-related functional properties to identify cultivar-specific strengths for functional food development and value-added processing applications.

## Materials and methods

### Rice samples and experimental design

Eight Thai glutinous rice (*Oryza sativa* L.) cultivars, namely RD6, RD22, RD24, Sakon Nakhon, Siw Klueang, Niew Daeng Mueang Loei, Kam Noi, and Kam Yai, were collected from representative growing regions in northeastern Thailand during the 2025 cropping season (**Figure 1**). Specifically, RD6 and RD22 were obtained from Ban Prong Samran Subdistrict, Rattanawapi District, Nong Khai Province; RD24 was collected from Rae Subdistrict, Phang Khon District, Sakon Nakhon Province; the Sakon Nakhon cultivar was obtained from Ban Phon Subdistrict, Phon Na Kaeo District, Sakon Nakhon Province; Siw Klueang was collected from Kok Sathon Subdistrict, Dan Sai District, Loei Province; Niew Daeng Mueang Loei was obtained from Loei Wang Sai Subdistrict, Phu Luang District, Loei Province; Kam Noi was collected from Na So Subdistrict, Wanon Niwat District, Sakon Nakhon Province; and Kam Yai was obtained from Chumphon Buri District, Surin Province. Cultivar identity was verified based on regional rice research center records and local cultivar source information. Each cultivar represented a commercially relevant production lot

collected during the same harvest period. Rough rice samples were harvested during a single production season and milled under comparable polishing conditions prior to analysis to obtain commercially representative polished rice grains. All samples were stored in airtight polyethylene bags at ambient temperature (25 ± 2 °C) until analysis. Nutritional, phytochemical, amino acid, fatty acid, mineral, and functional property analyses were conducted using standardized analytical methods by accredited external laboratories. The laboratory reports provided consolidated analytical values for each cultivar; therefore, replicate-level raw analytical datasets were not available for inferential statistical analysis. Unless otherwise specified, all results were expressed on a 100 g basis.




**Figure 1** Morphological characteristics of milled rice grains from eight glutinous rice cultivars.

**Proximate composition**

Moisture content was determined according to AOAC (2023) method 925.10. Ash content was analyzed using AOAC (2023) method 923.03. Crude protein content was determined using an in-house Kjeldahl method based on AOAC (2023) method 981.10, and a nitrogen-to-protein conversion factor of 5.95 was applied. Total fat content was measured according to AOAC (2023) method 922.06. Energy value (kcal/100 g) was calculated using Atwater conversion factors (4 kcal/g for protein and carbohydrate, and 9 kcal/g for fat). Total carbohydrate content was calculated by difference using the following equation:

$$\text{Carbohydrate (\%)} = 100 - (\text{moisture} + \text{protein} + \text{fat} + \text{ash})$$

**Fatty acid composition**

Fatty acid composition was analyzed using an in-house gas chromatography (GC) method based on AOAC (2023) method 996.06. Lipids were extracted and converted to fatty acid methyl esters (FAMEs) prior to analysis. FAMEs were separated and quantified using gas chromatography equipped with a flame ionization detector (GC-FID). Fatty acid identification was performed by comparison with standard FAME mixtures, and quantification was conducted using external calibration standards. Fatty acids were categorized into saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). Omega-3 (ω-3), omega-6 (ω-6), and omega-9 (ω-9) fatty acids were calculated from the identified fatty acid profiles.

**Vitamin analysis**

Vitamin B1 (thiamine) was determined using an in-house method (TCH-CH-067) based on AOAC Official Method 942.23 with spectrophotometric detection. Vitamin E (α-tocopherol) was analyzed by liquid chromatography according to Chemical Analysis (2006) methodology using external calibration standards. Vitamin B12 (cyanocobalamin) was analyzed by HPLC according to a previously validated chromatographic method reported in Food Chemistry (2016). Vitamin A was determined using AOAC Official Method 2005.02 by spectrophotometric analysis.

**Mineral determination**

Mineral contents were determined after acid digestion of samples. Calcium (Ca), potassium (K), and sodium (Na) were analyzed according to AOAC (2023) method 984.27. Iron (Fe), magnesium (Mg), manganese (Mn), zinc (Zn), and copper (Cu) were determined using AOAC (2023) method 999.10 or validated in-house methods based on AOAC procedures. Mineral concentrations were expressed as mg/kg.

**Amino acid profile**

Amino acid composition was determined using an in-house method (TCH-372) based on Commission Directive 98/64/EC of the Official Journal of the European Communities. Samples were subjected to acid hydrolysis prior to analysis. Amino acids were separated and quantified using high-performance liquid chromatography (HPLC). Amino acid identification and quantification were performed by comparison with certified amino acid standards according to the analytical protocol provided by the accredited laboratory. Results were expressed as mg/100 g. Essential amino acids (EAA) and nonessential amino acids (NEAA) were classified according to nutritional classification criteria. Amino acids reported as not detected or below threshold values were below the analytical detection capability of the applied method.

**Amylose and amylopectin content**

Amylose content was determined according to ISO 6647-2:2020 using the iodine-binding colorimetric method. Results were expressed as percentage on a 14% moisture basis. Amylopectin content was calculated by difference: Amylopectin (%) = 100 − amylose (%).

**Gelatinization temperature and gel consistency**

Gelatinization temperature was evaluated using the alkali spreading value method according to IRRI (1996). Alkali spreading was classified based on the percentage of kernel disintegration. Gel consistency was measured following the Department of Agriculture protocol for Thai Hom Mali rice quality testing. Cooked rice paste was allowed to cool horizontally, and gel length (mm) was recorded. Samples were classified as hard, medium, or soft gel consistency according to IRRI-IBPGR (1980).

**Total anthocyanin content**

Total anthocyanin content was determined using an in-house method based on AOAC Official Method 2005.02. Absorbance was measured spectrophotometrically, and anthocyanin content was expressed as cyanidin-3-glucoside equivalents (mg/kg).

**Gamma-oryzanol**

Gamma-oryzanol content was determined by high-performance liquid chromatography (HPLC) according to a validated chromatographic method described in the Journal of Food Composition and Analysis (2005). Results were expressed as mg/kg.

**Total polyphenol content**

Total phenolic content was determined using the Folin-Ciocalteu method (Singleton and others 1965). Absorbance was measured at 765 nm, and results were expressed as mg gallic acid equivalents (GAE)/g.

**Antioxidant activity**

Antioxidant activity was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. Results were expressed as mg Trolox equivalent (TE)/100 g using Trolox as the reference standard.

**Color measurement**

Color parameters were measured using a colorimeter (Color/Chroma Meter) based on the CIE L*a*b* system. The parameters recorded included: L* (lightness), a* (red/green coordinate), b* (yellow/blue coordinate), Chroma (C), Hue angle (h°).

**Statistical analysis**

Nutritional, phytochemical, amino acid, fatty acid, mineral, and functional property analyses were conducted by an accredited external central laboratory using standardized AOAC, ISO, HPLC, GC, and colorimetric methods. The laboratory provided consolidated analytical values for each cultivar together with method references and limits of detection (LOD). Because replicate-level raw analytical datasets were not available from the external laboratory reports, inferential statistical analyses such as ANOVA and post hoc multiple comparison tests were not applicable to the available dataset. Therefore, the study primarily employed descriptive comparative analysis to evaluate compositional differences among cultivars. Principal component analysis (PCA) was additionally used as an exploratory multivariate tool to visualize compositional relationships and overall cultivar differentiation among the rice cultivars.

## Results and discussion

**Proximate composition and energy value**

The proximate composition of the eight Thai glutinous rice cultivars is presented in **Table 1**. Considerable variation among cultivars was observed in energy and macronutrient composition. Energy values ranged from 354.04 to 362.47 kcal/100 g, with RD24 exhibiting the highest energy content. These values are consistent with previously reported energy contents of indigenous rice varieties (350.72 - 370.53 kcal/100 g) [20]. Carbohydrate was the major component (72.99% - 80.53%), confirming that glutinous rice is a carbohydrate-dense staple food [21]. RD6 contained the highest carbohydrate content (80.53%), whereas Kam Yai had the lowest (72.99%). Similar carbohydrate ranges have been reported for rice varieties from Thailand, Ethiopia, Malaysia, India, Vietnam, and China [20,22-25].

**Table 1** Proximate composition of eight Thai glutinous rice cultivars.

| Cultivar | Energy (kcal/100 g) | Protein (%) | Carbohydrate (%) | Fat (%) | Moisture (%) | Ash (%) |
|---|---|---|---|---|---|---|
| RD6 | 355.30 | 6.36 | 80.53 | 0.68 | 11.76 | 0.49 |
| RD22 | 358.11 | 7.69 | 79.79 | 0.91 | 11.06 | 0.55 |
| RD24 | 362.47 | 7.25 | 80.33 | 1.35 | 10.62 | 0.45 |
| Sakon Nakhon | 354.04 | 7.62 | 79.36 | 0.68 | 11.86 | 0.48 |
| Siw Klueang | 356.31 | 8.47 | 78.83 | 0.79 | 11.48 | 0.43 |
| Niaw Daeng Mueang Loei | 355.40 | 7.70 | 79.44 | 0.76 | 11.78 | 0.32 |
| Kam Noi | 354.98 | 6.87 | 79.58 | 1.02 | 12.08 | 0.45 |
| Kam Yai | 355.13 | 12.89 | 72.99 | 1.29 | 12.03 | 0.80 |

Protein content ranged from 6.36% to 12.89%, with Kam Yai exhibiting markedly higher protein levels than the other cultivars. This value exceeds the typical rice protein range of 4-7% from previous reported Jayaprakash *et al.* [11] and Preecharram *et al.* [26]. Higher protein content may improve the nutritional

value of rice-based products and may be relevant for protein-enriched formulations. Total fat ranged from 0.68% to 1.35%, with RD24 containing the highest lipid content. Rice lipids are known to contain relatively high proportions of oleic and linoleic acids, which contribute to the characteristic nutritional profile of rice lipids [27,28]. Ash content ranged from 0.32% to 0.80%, with Kam Yai showing the highest mineral residue. Ash content is generally correlated with total mineral concentration [5]. Moisture contents (10.62% - 12.08%) were within acceptable storage limits and may influence grain stability and cooking quality [29,30].

**Vitamin and mineral composition**

The vitamin and mineral profiles are shown in **Table 2**. Vitamin B1 (thiamine) ranged from 0.12 to 0.22 mg/100 g, with Kam Yai containing the highest concentration. These findings are consistent with the earlier report on rice cultivated in the Kurigram district of Bangladesh, which indicated that Vitamin B1 levels ranged from 0.342 ± 0.3 to 0.673 ± 7.5 mg per 100 g [33]. Vitamin E (α-tocopherol) was detected only in RD24 (0.11 mg/100 g). Tocopherols act as lipid-soluble antioxidants, shielding membranes from oxidative damage. Tocopherols primarily function as lipid-soluble antioxidants that help protect cellular components from oxidative damage [34]. Calcium ranged from 104.40 to 195.70 mg/kg, with RD6 exhibiting the highest concentration. Iron ranged from 4.59 to 9.50 mg/kg, with Kam Yai being the highest level. Increased dietary iron intake is associated with reduced risk of iron-deficiency anemia in rice-dependent populations [35].

**Table 2** Vitamin and mineral content of glutinous rice cultivars.

| Component | RD6 | RD22 | RD24 | Sakon Nakhon | Siw Klueang | Niaw Daeng Mueang Loei | Kam Noi | Kam Yai |
|---|---|---|---|---|---|---|---|---|
| Vitamin A (µg/100 g) | ND | ND | ND | ND | ND | ND | ND | ND |
| Vitamin B1 (mg/100 g) | 0.14 | 0.17 | 0.21 | 0.13 | 0.12 | 0.13 | 0.18 | 0.22 |
| Vitamin B12 (mg/100 g) | ND | ND | ND | ND | ND | ND | ND | ND |
| Vitamin E (mg/100 g) | ND | ND | 0.11 | ND | ND | ND | ND | ND |
| Calcium (mg/kg) | 195.70 | 124.00 | 113.30 | 116.60 | 104.40 | 171.50 | 178.20 | 147.90 |
| Iron (mg/kg) | 5.86 | 5.31 | 6.96 | 5.33 | 4.59 | 6.81 | 5.87 | 9.50 |
| Copper (mg/kg) | 1.31 | 1.84 | 3.73 | 3.14 | 3.54 | <0.75 | 1.72 | 3.44 |
| Magnesium (mg/kg) | 373.00 | 350.00 | 355.10 | 251.60 | 249.50 | 251.50 | 451.30 | 472.60 |
| Manganese (mg/kg) | 15.72 | 12.21 | 16.62 | 13.43 | 8.06 | 9.45 | 10.46 | 13.63 |
| Zinc (mg/kg) | 18.46 | 16.05 | 24.15 | 24.87 | 19.85 | 16.74 | 15.78 | 35.78 |
| Potassium (mg/kg) | 3,688.00 | 1,180.00 | 951.30 | 972.30 | 850.70 | 766.50 | 1,606.00 | 1,831.00 |
| Sodium (mg/kg) | 649.90 | 45.82 | 44.54 | 22.26 | 57.89 | 28.17 | 60.13 | 28.12 |

Magnesium (249.50 - 472.60 mg/kg), manganese (8.06 - 16.62 mg/kg), and zinc (15.78 - 35.78 mg/kg) varied considerably across the examined cultivars. The trace elements of tested glutinous rice cultivars were higher than Yoom Noon rice and Bangladesh rice [36,37]. Trace elements like Zn, Cu, and Mn serve as cofactors in antioxidant enzyme systems, such as superoxide dismutase. These micronutrients contribute to enzymatic activity, immune function, and oxidative stress regulation [38]. Potassium content ranged widely (766.50 - 3,688.00 mg/kg), with RD6 containing exceptionally high levels. Potassium is an important dietary mineral associated with electrolyte balance and physiologyical regulation [39]. The pigmented cultivars, particularly Kam Yai, demonstrated superior micronutrient density.

**Amino acid composition**

Amino acid profiles are presented in **Table 3**. Both essential amino acids (EAA) and nonessential amino acids (NEAA) were detected, with glutamic acid being the most abundant amino acid (400.30 - 1,295.19

mg/100 g). High glutamic acid content may contribute to umami taste and protein functionality. RD22 consistently exhibited relatively higher concentrations of several amino acids, including alanine, arginine, leucine, lysine, and valine. Branched-chain amino acids (BCAAs), particularly leucine, isoleucine, and valine, were also relatively higher in RD22 and Kam Yai. BCAAs are known to play important roles in protein metabolism and physiological regulation [10,40]. These findings are consistent with previous reports demonstrating cultivar-dependent variation in amino acid composition among glutinous rice varieties [41,42]. The elevated protein content observed in Kam Yai corresponded with relatively higher concentrations of several essential amino acids, suggesting compositional differences in protein quality among cultivars and potential suitability for protein-enriched rice-based products.

**Table 3** Amino acid composition of glutinous rice cultivars (mg/100 g).

| Amino acid | RD6 | RD22 | RD24 | Sakon Nakhon | Siw Klueang | Niaw Daeng Mueang Loei | Kam Noi | Kam Yai |
|---|---|---|---|---|---|---|---|---|
| Alanine | 240.99 | 397.39 | 164.09 | <150.00 | 352.47 | 173.81 | 157.56 | 362.56 |
| Arginine | 313.62 | 534.45 | <250.00 | <250.00 | 495.55 | <250.00 | <250.00 | 517.75 |
| Aspartic acid | 399.72 | 684.36 | 270.49 | 200.65 | 615.10 | 286.37 | 248.48 | 641.40 |
| Cystine | <200.00 | <200.00 | ND | ND | <200.00 | ND | ND | <200.00 |
| Glutamic acid | 741.35 | 1,295.19 | 510.97 | 400.30 | 1,163.28 | 570.13 | 504.41 | 1,249.85 |
| Glycine | 189.51 | 322.80 | 130.03 | <100.00 | 286.62 | 134.83 | 117.95 | 292.45 |
| Histidine | <100.00 | 177.00 | <100.00 | 0.49 | 150.81 | <100.00 | <100.00 | 158.01 |
| Isoleucine | 142.33 | 241.41 | <100.00 | <100.00 | 209.56 | 107.32 | <100.00 | 236.13 |
| Leucine | 344.69 | 586.20 | 231.84 | 191.02 | 524.89 | 261.41 | 225.87 | 542.05 |
| Lysine | 150.25 | 253.60 | <100.00 | <100.00 | 215.45 | <100.00 | <100.00 | 217.10 |
| Phenylalanine | <250.00 | 378.48 | ND | ND | 317.28 | <250.00 | <250.00 | 354.69 |
| Proline | <200.00 | 321.41 | <200.00 | <200.00 | 270.55 | <200.00 | <200.00 | 285.18 |
| Serine | 234.64 | 402.77 | <200.00 | <200.00 | 357.62 | <200.00 | <200.00 | 374.78 |
| Threonine | <200.00 | 242.67 | ND | ND | 211.94 | <200.00 | ND | 218.51 |
| Tyrosine | <250.00 | <250.00 | <250.00 | ND | <250.00 | <250.00 | <250.00 | <250.00 |
| Valine | 266.55 | 449.11 | 180.24 | 139.42 | 398.93 | 192.25 | 170.85 | 440.60 |
| Tryptophan | <150.00 | <150.00 | <150.00 | <150.00 | <150.00 | <150.00 | <150.00 | <150.00 |

ND = Not detected.

**Fatty acid composition**

The fatty acid composition (**Table 4**) showed that unsaturated fatty acids (0.49 - 0.96 g/100 g) were present at higher levels than saturated fatty acids (0.20 - 0.39 g/100 g) across all examined cultivars. RD24 and Kam Yai exhibited relatively higher total unsaturated fatty acid contents. Oleic acid (ω-9) and linoleic acid (ω-6) were the predominant fatty acids, which is consistent with previous reports on rice lipid composition [43-45]. Trace-level peaks corresponding to eicosapentaenoic acid (EPA; 0.01 - 0.02 g/100 g) were detected in several cultivars based on chromatographic analysis. However, these observations should be interpreted cautiously due to the naturally low lipid content of rice grains and the absence of confirmatory GC-MS analysis. Linoleic acid and oleic acid are commonly reported as the major

unsaturated fatty acids in rice and may contribute to the nutritional characteristics of rice-derived ingredients [46-49]. The predominance of unsaturated fatty acids, particularly oleic and linoleic acids, reflects the characteristic lipid profile of glutinous rice cultivars and may be relevant for future studies related to rice quality and functional ingredient development.

**Table 4** Fatty acid composition of glutinous rice cultivars.

| Fatty acid (g/100 g) | RD6 | RD22 | RD24 | Sakon Nakhon | Siw Klueang | Niaw Daeng Mueang Loei | Kam Noi | Kam Yai |
|---|---|---|---|---|---|---|---|---|
| Total saturated | 0.26 | 0.26 | 0.39 | 0.19 | 0.22 | 0.20 | 0.28 | 0.38 |
| Total unsaturated | 0.60 | 0.65 | 0.96 | 0.49 | 0.57 | 0.56 | 0.74 | 0.91 |
| Oleic acid (ω9) | 0.28 | 0.31 | 0.47 | 0.20 | 0.24 | 0.26 | 0.27 | 0.41 |
| Linoleic acid (ω6) | 0.30 | 0.31 | 0.46 | 0.26 | 0.30 | 0.28 | 0.44 | 0.45 |
| Eicosapentaenoic acid (ω3) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |

**Bioactive compounds and antioxidant activity**

Bioactive compound concentrations are shown in **Table 5**. Anthocyanin content ranged from 3.48 to 51.23 mg/kg, with Kam Yai exhibiting the highest concentration. Pigmented rice varieties are well recognized for elevated anthocyanin levels [5]. Gamma-oryzanol ranged from 9.82 to 90.27 mg/kg, again highest in Kam Yai. Gamma-oryzanol has been previously reported as a bioactive rice bran component with antioxidant-related properties [50,51]. Total polyphenol content ranged from 0.10 to 1.16 mg GAE/g, with Kam Noi and Kam Yai showing the highest values. Colored rice varieties typically contain higher phenolic content than white rice [52]. Antioxidant activity (54.12 - 105.10 mg TE/100 g) strongly paralleled anthocyanin and polyphenol levels, suggesting that pigmented cultivars generally exhibited higher antioxidant activity [53]. The higher antioxidant activity observed in Kam Yai and Kam Noi closely corresponded with their elevated anthocyanin and total phenolic contents, suggesting that phenolic compounds were major contributors to radical scavenging activity in pigmented rice cultivars. This trend is consistent with previous reports demonstrating strong associations between rice pigmentation and antioxidant potential.

**Table 5** Bioactive compounds and antioxidant capacity.

| Cultivar | Anthocyanin (mg/kg) | Gamma-oryzanol (mg/kg) | Total polyphenol (mg/g) | Antioxidant capacity (mg TE/100 g) |
|---|---|---|---|---|
| RD6 | 4.39 | 28.90 | 0.19 | 63.83 |
| RD22 | 4.27 | 15.09 | 0.15 | 59.50 |
| RD24 | 3.60 | 50.60 | 0.22 | 61.87 |
| Sakon Nakhon | 3.48 | 9.82 | 0.12 | 57.00 |
| Siw Klueang | 4.78 | 18.55 | 0.10 | 54.12 |
| Niaw Daeng Mueang Loei | 17.36 | 33.12 | 0.32 | 72.74 |
| Kam Noi | 35.22 | 42.78 | 1.16 | 105.01 |
| Kam Yai | 51.23 | 90.27 | 0.80 | 105.10 |

**Color characteristics**

Color parameters (**Table 6**) showed clear differentiation between white and pigmented cultivars. L* values ranged from 52.60 to 88.98, with Siw Klueang showing the highest lightness. Kam Yai and Kam Noi had the lowest L* values, corresponding to darker pigmentation. Higher a* values were observed in red and black cultivars, consistent with anthocyanin

accumulation. In addition, lower L* values and higher a* values observed in pigmented cultivars reflected the accumulation of anthocyanin pigments in the bran layer. These findings agree with previous reports linking rice pigmentation with phenolic concentration [53].

**Table 6** Color parameters of glutinous rice cultivars.

| Cultivar | L* | a* | b* | C | h° |
|---|---|---|---|---|---|
| RD6 | 87.05 | 0.09 | 17.53 | 17.88 | 88.34 |
| RD22 | 85.55 | 0.22 | 16.29 | 14.95 | 89.54 |
| RD24 | 84.80 | 0.42 | 15.23 | 15.16 | 88.89 |
| Sakon Nakhon | 81.03 | 1.58 | 18.42 | 14.93 | 87.25 |
| Siw Klueang | 88.98 | -0.40 | 10.86 | 12.05 | 90.84 |
| Niaw Daeng Mueang Loei | 76.99 | 6.55 | 12.73 | 15.17 | 63.33 |
| Kam Noi | 52.60 | 3.52 | 0.22 | 3.98 | 11.71 |
| Kam Yai | 55.66 | 4.54 | 4.32 | 6.47 | 46.10 |

**Amylose content and cooking quality**

Amylose content ranged from 6.56% to 7.97% (**Table 7**), indicating that all cultivars were classified as low-amylose glutinous rice [54,55]. In contrast, amylopectin accounted for more than 92% of every sample. All cultivars exhibited 100% alkali spreading values, indicating low gelatinization temperature (<70 °C) [56]. Gel consistency values (82 - 112 mm) classified all samples as soft gel type [57], suggesting soft and sticky texture after cooking. These physicochemical properties are characteristic of high-quality glutinous rice and align with previous studies of Thai highland glutinous rice landraces [58]. The combination of low amylose content, high amylopectin proportion, low gelatinization temperature, and soft gel consistency may enhance processing performance in products that require high viscosity, soft texture, and rapid cooking characteristics. Therefore, these cultivars may be particularly suitable for traditional desserts, rice beverages, fermented rice products, and gluten-free food applications. In addition, future studies should further investigate starch digestibility and glycemic response to better support the development of health-oriented rice products [25].

**Table 7** Amylose, amylopectin, and cooking quality characteristics.

| Cultivar | Amylose (%) | Amylopectin (%) | Alkali spreading (%) | Gel consistency (mm) | Gel type | Cooked texture |
|---|---|---|---|---|---|---|
| RD6 | 7.97 | 92.03 | 100 | 82 | Soft | Sticky-soft |
| RD22 | 7.49 | 92.51 | 100 | 98 | Soft | Sticky-soft |
| RD24 | 6.56 | 93.44 | 100 | 87 | Soft | Sticky-soft |
| Sakon Nakhon | 7.19 | 92.90 | 100 | 92 | Soft | Sticky-soft |
| Siw Klueang | 6.99 | 93.01 | 100 | 84 | Soft | Sticky-soft |
| Niaw Daeng Mueang Loei | 7.39 | 92.61 | 100 | 82 | Soft | Sticky-soft |
| Kam Noi | 7.48 | 92.52 | 100 | 89 | Soft | Sticky-soft |
| Kam Yai | 7.37 | 92.63 | 100 | 112 | Soft | Sticky-soft |

**Multivariate analysis of nutritional and phytochemical differentiation among Thai glutinous rice cultivars**

Principal component analysis explained 80.4% of the total variance (PC1 = 62.4%, PC2 = 17.6%). The PCA score plot (**Figure 2(A)**) showed a clear trend of separation between pigmented and non-pigmented cultivars. Kam Yai was distinctly separated from other cultivars and was strongly associated with higher protein, mineral content, anthocyanin, γ-oryzanol, and antioxidant activity. In contrast, most white glutinous rice cultivars were associated with higher lightness (L*) and carbohydrate content. The PCA loading plot (**Figure 2(B)**) further demonstrated that anthocyanin, total polyphenol, antioxidant activity, and mineral content were major variables contributing to cultivar differentiation, while L* and carbohydrate were associated with white rice cultivars. The hierarchical clustering heatmap (**Figure 2(C)**) further confirmed compositional differences among cultivars by grouping samples according to their nutritional, phytochemical, and functional characteristics. Kam Yai and Kam Noi formed distinct clusters characterized by elevated bioactive compounds and antioxidant potential, whereas most white rice cultivars clustered separately with relatively lower phytochemical concentrations. These findings further support cultivar-specific selection for functional food and value-added rice product development. Nevertheless, because the present study was based on cultivar samples collected from different growing regions under practical production conditions, environmental factors such as climate, soil characteristics, and cultivation practices may have contributed to part of the observed compositional variation. Future studies using multi-location replicated cultivation trials under controlled agronomic conditions would help further distinguish genotype-specific effects from environmental influences.

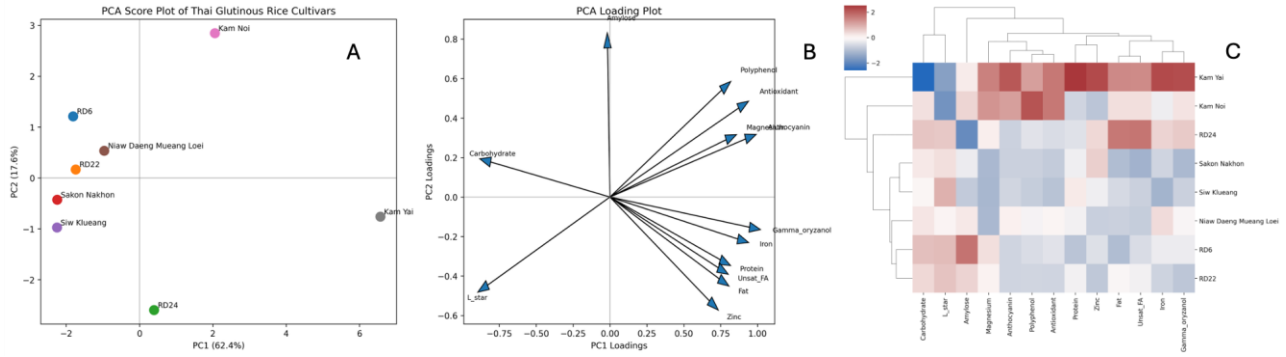



**Figure 2** Multivariate analysis of eight Thai glutinous rice cultivars: (A) PCA score plot, (B) PCA loading plot, and (C) hierarchical clustering heatmap based on nutritional, phytochemical, antioxidant, and functional properties.

**Conclusions**

Thai glutinous rice cultivars grown across different regions exhibited distinct nutritional, phytochemical, antioxidant, and functional characteristics. Pigmented cultivars, particularly Kam Yai and Kam Noi, demonstrated superior protein content, mineral density, antioxidant activity, and bioactive compound concentrations. Multivariate analysis further confirmed clear compositional differentiation among cultivars. These findings provide useful information for cultivar selection and support future applications of pigmented Thai glutinous rice in functional foods, gluten-free products, and value-added rice processing.

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**Declaration of generative AI in scientific writing**

Generative AI tool was used only to improve the readability and language of a manuscript.

**CRediT author statement**

**Apichai Sawisit**: Conceptualization; Methodology; Validation; Formal analysis; Project administration; Writing - Original Draft. **Apichat Seiyot**: Conceptualization; Methodology; Investigation. **Jirawut Patsada**: Conceptualization; Methodology; Investigation. **Wariya Chunjaturas**: Conceptualization; Methodology; Investigation. **Tunvaraporn Proongkhong**: Conceptualization; Methodology; Investigation. **Nuntipa Khumkarjorn**: Conceptualization; Methodology; Investigation. **Nattha Sittilop**: Conceptualization; Methodology; Investigation. **Surawee Jampatesh**: Conceptualization; Methodology; Validation; Formal analysis; Data Curation. **Surachai Rattanasuk**: Conceptualization; Data Curation; Investigation; Writing - Original Draft; Writing - Review & Editing.

**References**

[1] L Kammapana. Physical characteristics, phytochemical contents and antioxidant activity of ten organic-pigmented rice varieties from Surin Province. *Trends in Sciences* 2023; **20(4)**, 4566.

[2] MM Ali and N Hashim. Exploring nutritional compositions, volatile compounds, health benefits, emerging processing technologies, and potential food products of glutinous rice: A review. *Rice Science* 2024; **31(3)**, 251-268.

[3] J Park and HS Kim. Rice-based gluten-free foods and technologies: A review. *Foods* 2023; **12(22)**, 4110.

[4] Q Zhang, B Liu, M Zhang, L Guan, G Ye, M Zhang, J Sun and S Li. Comprehensive evaluation of varietal differences in glutinous rice: Multidimensional assessment of cooking quality and processing characteristics. *Foods* 2026; **15(7)**, 1215.

[5] Wisetkomolmat, C Arjin, A Satsook, M Seel-Audom, W Ruksiriwanich, UTC Prom and K Sringarm. Comparative analysis of nutritional components and phytochemical attributes of selected Thai rice bran. *Frontiers in Nutrition* 2022; **9**, 833730.

[6] C Bani, C Cappa, P Restani, M Sala, F Colombo, F Mercogliano and CD Lorenzo. Physicochemical and nutritional quality of pigmented rice and bran: Influence of milling and cooking. *LWT* 2024; **208**, 116653.

[7] AP Oliveira, TMR Albuquerque and EL Souza. Deciphering pigmented rice varieties as sustainable and unexplored valuable sources of bioactive components with health-related properties and technological applications - a systematic review. *Comprehensive Reviews in Food Science and Food Safety* 2026; **25(1)**, e70355.

[8] SJ Kang, SY Jeong, MZ Islam, BK Shin, YJ Park, JK Kim, YT Lee and JH Lee. Bioactive compounds and quality evaluation of red-pigmented rice processed by germination and roasting. *Foods* 2022; **11(18)**, 2735.

[9] F Colombo, C Cappa, C Bani, M Magni, S Biella, P Restani and C Di Lorenzo. Characterization of color, phenolic profile, and antioxidant activity of Italian pigmented rice varieties after different technological treatments. *Food Bioscience* 2023; **53**, 102674.

[10] P Rai. Role of essential amino acids in protein synthesis and muscle growth. *Journal of Biochemical Research* 2023; **6(4)**, 92-96.

[11] G Jayaprakash, A Bains, P Chawla, M Fogarasi and S Fogarasi. A narrative review on rice proteins: Current scenario and food industrial application. *Polymers* 2022; **14(15)**, 3003.

[12] J Yang, Y Zhou and Y Jiang. Amino acids in rice grains and their regulation by polyamines and phytohormones. *Plants* 2022; **11(12)**, 1581.

[13] MDW Samaranayake, WKSM Abeysekera, IGN Hewajulige, HPPS Somasiri, KRR Mahanama, DMJB Senanayake and GAS Premakumara. Saturated, monounsaturated and polyunsaturated fatty acid profiles of commercially important traditional and new improved red and white rice varieties of Sri Lanka. *Journal of Food Composition and Analysis* 2024; **130**, 106154.

[14] T Tufail, HBU Ain, J Chen, MS Virk, Z Ahmed, J Ashraf, NUA Shahid and B Xu. Contemporary views of the extraction, health benefits, and industrial integration of rice bran oil: A prominent ingredient for holistic human health. *Foods* 2024; **13(9)**, 1305.

[15] K Zhou, Z Luo, W Huang, Z Liu, X Miao, S Tao, J Wang, J Zhang, S Wang and X Zeng. Biological roles of lipids in rice. *International Journal of Molecular Sciences* 2024; **25(16)**, 9046.

[16] Avnee, S Sood, DR Chaudhary, P Jhorar and RS Rana. Biofortification: An approach to eradicate micronutrient deficiency. *Frontiers in Nutrition* 2023; **10**, 1233070.

[17] S Junaid-ur-Rahman, MFJ Chughtai, A Khaliq, A Liaqat, I Pasha, S Ahsan, S Tanweer, K Saeed, A Siddiqa, T Mehmood, A Ali, S Aziz and N Sameed. Rice: A potential vehicle for micronutrient fortification. *Clinical Phytoscience* 2022; **8(1)**, 14.

[18] A Bandara, B Batugahage, B Prasantha and D Senanayake. Impact of amylose content on physical properties, cooking qualities, and water absorption of long-grain basmati-type rice (*Oryza sativa* L.) varieties. *Ceylon Journal of Science* 2025; **54(1)**, 8418.

[19] T Teanthong, P Praisomrong, Y Jirakiattikul and B Harakotr. Comparative analysis for physicochemical and pasting characteristics of advanced non-glutinous rice genotypes under irrigated condition in Thailand. *Crops* 2026; **6(2)**, 31.

[20] TV Ngo, K Kunyanee and N Luangsakul. Insight into the nutritional, physicochemical, functional, antioxidative properties and in vitro gastrointestinal digestibility of selected Thai rice: Comparative and multivariate studies. *Current Research in Food Science* 2024; **8**, 100735.

[21] A Mustofa, C Anam, D Praseptiangga and Sutarno. A comparative study on physicochemical properties of rice and starch of white rice, black rice and black glutinous rice. *Food Research* 2024; **8(S2)**, 55-65.

[22] AM Ali, MD Ateye, HM Jama and HM Mohamud. Physicochemical properties, proximate and functional properties of different rice varieties produced in Somali region of Ethiopia and imported rice. *East African Journal of Pastoralism* 2025; **4(2)**, 15-21.

[23] M Yamsaray, T Sreewongchai, C Phumichai and P Chalermchaiwat. Yield and nutritional properties of improved red pericarp Thai rice varieties. *ScienceAsia* 2023; **49**, 155-160.

[24] MAK Rohin, N Ridzwan, N Abd Hadi, R Ishak and AA Baig. Compositional analyses of fragrant white rice and local brown rice varieties of selected Malaysian rice. *Journal of Applied Biology & Biotechnology* 2023; **11(3)**, 224-228.

[25] TV Ngo, K Kunyanee and N Luangsakul. Insights into recent updates on factors and technologies that modulate the glycemic index of rice and its products. *Foods* 2023; **12(19)**, 3659.

[26] S Preecharram, S Posoongnoen, T Thummawongsa, T Sripakdee, S Tawil, N Poomsuk and J Jandaruang. Proximate composition and antioxidant activity of young flattened rice (Khao-Mao). *Trends in Sciences* 2023; **20(4)**, 6575.

[27] M Fox, K Newcomb, C Oliveira, E Shakiba and IN Nawarathne. Facile analysis of rice bran oil to compare free unsaturated fatty acid compositions of parental and hybrid rice lines. *Journal of the American Oil Chemists' Society* 2022; **99(12)**, 1103-1111.

[28] MG Sahini and E Mutegoa. Extraction, phytochemistry, nutritional, and therapeutical potentials of rice bran oil: A review. *Phytomedicine Plus* 2023; **3(2)**, 100453.

[29] A Müller, MT Nunes, V Maldaner, PC Coradi, RSd Moraes, S Martens, AF Leal, VF Pereira and CK Marin. Rice drying, storage and processing: Effects of post-harvest operations on grain quality. *Rice Science* 2022; **29(1)**, 16-30.

[30] H Palacios-Cabrera, K Jimenes-Vargas, M González, O Flor-Unda and B Almeida. Determination of moisture in rice grains based on visible spectrum analysis. *Agronomy* 2022; **12(12)**, 3021.

[31] MA Farooq and J Yu. Starches in rice: Effects of rice variety and processing/cooking methods on their glycemic index. *Foods* 2025; **14(12)**, 2022.

[32] V Campos, L Tappy, L Bally, JL Sievenpiper and K-A Lê. Importance of carbohydrate quality: What does it mean and how to measure it? *The Journal of Nutrition* 2022; **152(5)**, 1200-1206.

[33] M Ashraf Ali, MZ Sultan, ML Mia, A Islam, UH Ria and MA Salam. Evaluation of thiamine and riboflavin in different varieties of rice grown in Kurigram district, Bangladesh. *Heliyon* 2024; **10(21)**, e39868.

[34] B Es-Sai, H Wahnou, S Benayad, S Rabbaa, Y Laaziouez, R El Kebbaj, Y Limami and RE Duval. Gamma-tocopherol: A comprehensive review of its antioxidant, anti-inflammatory, and anticancer properties. *Molecules* 2025; **30(3)**, 653.

[35] B Kolarš, V Mijatović Jovin, N Živanović, I Minaković, N Gvozdenović, I Dickov Kokeza and M Lesjak. Iron deficiency and iron deficiency anemia: A comprehensive overview of established and emerging concepts. *Pharmaceuticals* 2025; **18(8)**, 1104.

[36] P Summpunn, N Deh-Ae, W Panpipat, S Manurakchinakorn, P Bhoopong, N Donlao, S Rawdkuen, K Shetty and M Chaijan. Nutritional profiles of Yoom Noon rice from Royal Initiative of Southern Thailand: A comparison of white rice, brown rice, and germinated brown rice. *Foods* 2023; **12(15)**, 2952.

[37] KT Akhter, HB Shozib, MH Islam, S Sarwar, MM Islam, MR Akanda, MA Siddiquee, M Mohiduzzaman, ATMA Rahim and N Shaheen. Variations in the major nutrient composition of dominant high-yield varieties (HYVs) in parboiled and polished rice of Bangladesh. *Foods* 2023; **12(21)**, 3997.

[38] JF de Carvalho and ATA Martinez. Zinc, copper, and manganese supplementations in rheumatic disease: A narrative review. *Mediterranean Journal of Rheumatology* 2025; **36(3)**, 479-481.

[39] RJ Chan, N Parikh, S Ahmed, M Ruzicka and S Hiremath. Blood pressure control should focus on more potassium: Controversies in hypertension. *Hypertension* 2024; **81(3)**, 501-509.

[40] S Xu, G Zhao, MD Hanigan, G Cantalapiedra-Hijar and M Li. Branched-chain amino acids in muscle growth: Mechanisms, physiological functions, and applications. *Journal of Animal Science and Biotechnology* 2025; **16(1)**, 164.

[41] J Zhu, X Wang, A Li, R Wang, X Ni, J Hu, H Wei, H Zhang and Q Xiong. The main nutritional components in colored rice grains. *LWT* 2024; **191**, 115663.

[42] T Moontree, A Moongngarm, N Saetung and P Loypimai. Comparative insights into cultivar-dependent nutritional and antioxidant responses to germination across eight rice cultivars. *Applied Food Research* 2026; **6(1)**, 101930.

[43] L Zhang, Y Xia, Y Dong, T Xie, W Sun and S Yu. Natural variation of fatty acid desaturase gene affects linolenic acid content and starch pasting viscosity in rice grains. *International Journal of Molecular Sciences* 2022; **23(19)**, 12055.

[44] S Coniglio, M Shumskaya and E Vassiliou. Unsaturated fatty acids and their immunomodulatory properties. *Biology* 2023; **12(2)**, 279.

[45] S Zafar and X Jianlong. Recent advances to enhance nutritional quality of rice. *Rice Science* 2023; **30(6)**, 523-536.

[46] JJ Li, KF Dou, ZG Zhou, D Zhao, P Ye, JJ Zhao and LX Guo. Role of omega-3 fatty acids in the prevention and treatment of cardiovascular diseases: A consensus statement from the Experts' Committee of National Society of Cardiometabolic Medicine. *Frontiers in Pharmacology* 2022; **13**, 1069992.

[47] A Tutor, EL O'Keefe, CJ Lavie, A Elagizi, R Milani and J O'Keefe. Omega-3 fatty acids in primary and secondary prevention of cardiovascular diseases. *Progress in Cardiovascular Diseases* 2024; **84**, 19-26.

[48] R Xu, AJ Molenaar, Z Chen and Y Yuan. Mode and mechanism of action of omega-3 and omega-6 unsaturated fatty acids in chronic diseases. *Nutrients* 2025; **17(9)**, 1540.

[49] E Kaviani, F Hajibabaie, N Abedpoor and K Safavi. Synergic effects and possible mechanism of omega-6 fatty acids (ω-6) on immune system, inflammation, and cancer. *Molecular Nutrition & Food Research* 2025; **69(12)**, e70092.

[50] H Juricic, M Cuccioloni, L Bonfili, M Angeletti, D Uberti, AM Eleuteri, G Abate and V Cecarini. Biochemical, biological, and clinical properties of γ-oryzanol. *Antioxidants* 2025; **14(9)**, 1099.

[51] S Pansiri and S Duangsrisai. Health properties of γ-oryzanol and its applications: A review. *Journal of Functional Foods* 2025; **134**, 107064.

[52] M Zhao, X Xiao, D Jin, L Zhai, Y Li, Q Yang, F Xing, W Qiao, X Yan and Q Tang. Composition and biological activity of colored rice-a comprehensive review. *Foods* 2025; **14(8)**, 1394.

[53] N Srisuk and K Tudpor. Identification of nutraceuticals and antioxidant activity in low-cost

broken rice varieties. *Journal of Pharmaceutical Negative Results* 2022; **13(4)**, 1486.

[54] B Wang, J Xu, D Guo, C Long, Z Zhang, Y Cheng, H Huang, P Wen, H He and X He. Research on the relationship between the amylopectin structure and the physicochemical properties of starch extracted from glutinous rice. *Foods* 2023; **12(3)**, 460.

[55] P Srinang, S Khotasena, J Sanitchon, S Chankaew, S Jogloy and T Monkham. New source of rice with a low amylose content and slow in vitro digestion for improved health benefits. *Agronomy* 2023; **13(10)**, 2622.

[56] B Teng, C Zhang and H Wang. Impact of partial gelatinization on structure, physicochemical and enzymatic digestion properties of rice starch used for rice noodle-making. *Polymers* 2025; **17(22)**, 3003.

[57] MD Karim, M Abuhena, MD Hossain and MM Billah. Assessment and comparison of cooking qualities and physio-chemical properties of seven rice varieties in terms of amylose content. *Food Physics* 2024; **1**, 100014.

[58] S Toosang, S Jamjod and T Pusadee. Characterization of grain quality traits of Thai highland glutinous rice landraces. *Chiang Mai Journal of Science* 2024; **51**, e2024007.