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บทความวิจัย

การวิเคราะห์คุณค่าทางโภชนาการและฤทธิ์ต้านอนุมูลอิสระของข้าวพื้นเมือง (*Oryza sativa* L.) เพื่อเพิ่มมูลค่าผลิตภัณฑ์จากข้าว

ชัญญรินทร์ สมพร*

ภาควิชาวิทยาศาสตร์และเทคโนโลยี คณะศิลปศาสตร์และวิทยาศาสตร์ มหาวิทยาลัยราชภัฏร้อยเอ็ด อำเภอเสลภูมิ จังหวัดร้อยเอ็ด 45120 ประเทศไทย

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ชาข้าวกล้องงอกสำเร็จรูป
การอบแห้งแบบโฟมแมต

บทคัดย่อ

การศึกษาครั้งนี้มุ่งสำรวจความหลากหลายของพันธุ์ข้าวพื้นเมืองในจังหวัดร้อยเอ็ด ประเทศไทย โดยวิเคราะห์คุณค่าทางโภชนาการ ความสามารถในการต้านอนุมูลอิสระ ปริมาณสารประกอบฟีนอลิก และศึกษาความเข้มข้นที่เหมาะสมของเมทิลเซลลูโลส (เมโทเซล) สำหรับการผลิตชาข้าวกล้องงอกสำเร็จรูป จากการวิเคราะห์ข้าวพื้นเมืองจำนวน 23 สายพันธุ์ พบว่าข้าวเขี้ยวงูมีปริมาณคาร์โบไฮเดรตสูงที่สุด (ร้อยละ 76.83) ในขณะที่ข้าวเหนียวหอมภูพานมีปริมาณเส้นใยอาหารสูงที่สุด (ร้อยละ 4.97) ข้าวก่ำใบเขียวมีปริมาณสารฟีนอลิกรวมสูงที่สุด (113.73 มิลลิกรัม GAE ต่อ 100 กรัม) และข้าวก่ำน้อยมีความสามารถในการต้านอนุมูลอิสระสูงที่สุด (ร้อยละ 78.40 ของการยับยั้ง DPPH) สำหรับการผลิตชาสำเร็จรูป พบว่าความเข้มข้นของเมโทเซลที่ร้อยละ 2.00 ให้ค่าเสถียรภาพของโฟม (1.95 มิลลิลิตรต่อนาที) และความสามารถในการคืนรูป (ร้อยละ 92.12) สูงที่สุด โดยผลิตภัณฑ์ที่มีเมโทเซลร้อยละ 1.50 และ 2.00 ได้รับการยอมรับจากผู้บริโภคในระดับสูง การศึกษาครั้งนี้พบว่าข้าวพื้นเมือง โดยเฉพาะข้าวก่ำน้อยและข้าวก่ำใบเขียว เป็นวัตถุดิบที่มีศักยภาพสำหรับการพัฒนาเครื่องดื่มเชิงฟังก์ชันจากข้าว ทั้งนี้ ผลการวิจัยสนับสนุนการอนุรักษ์ความหลากหลายทางชีวภาพของข้าวพื้นเมืองและการพัฒนาผลิตภัณฑ์มูลค่าเพิ่มสำหรับตลาดอาหารเพื่อสุขภาพของประเทศไทย

Introduction

Rice (*Oryza sativa* L.) is a staple food for over half of the world's population and is essential in Asian countries. In Thailand, especially in the Northeastern region including Roi Et Province, rice cultivation is a primary agricultural activity and an important cultural heritage. However, the increasing demand for high-yielding rice varieties has led to a marked reduction in the cultivation and diversity of indigenous rice, posing a risk to genetic diversity and potentially overlooking unique nutritional and bioactive properties. According to the the IRRI (2023) gene bank preserves over 6,321 rice accessions from Thailand and has repatriated more than 7,000 samples to Thailand for genetic research since 1976, but fewer than 100 varieties remain in regular cultivation, with the Northeastern region—including Roi Et—showing one of the steepest declines in indigenous-variety planting area over the past two decades. Recent studies have highlighted the importance of preserving rice biodiversity. Vanlalsanga et al. (2019) demonstrated that indigenous rice varieties possess unique genetic traits crucial for developing climate-resilient cultivars. Furthermore, Mbanjo et al. (2020) reported that many traditional rice varieties contain higher levels of bioactive compounds than modern high-yielding varieties, suggesting their potential as functional foods.

Indigenous rice varieties, despite their lower yield, offer several advantages over modern varieties, including better adaptation to local environmental conditions and higher content of phytochemicals and antioxidants. Zhang et al. (2010) conducted a comprehensive review of the health benefits of colored rice, reporting strong evidence for its anti-inflammatory, anti-diabetic, and anti-cancer properties. Germination has been found to enhance the nutritional value and bioactive compound content in rice. A recent study by Tsou et al. (2024) demonstrated that germination can increase the γ-aminobutyric acid (GABA) content in rice by up to 70%, suggesting potential applications in functional foods targeting stress reduction and improved sleep quality. These findings indicate the potential of value-added products derived from indigenous rice varieties, which could enhance their economic

*Corresponding author
E–mail address: stchanyarin@gmail.com (C. Somporn)
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viability and contribute to their preservation, thereby benefiting local farmers and the Thai rice industry.

One promising avenue for value addition is the development of instant tea products from germinated brown rice. The global instant tea market is expected to grow at a CAGR of 6.2% from 2022 to 2030, with functional and herbal teas being the fastest-growing segment (Zohora et al., 2022). Foam-mat drying, a technique used to produce instant powders, has shown potential for preserving heat-sensitive nutrients and bioactive compounds (Süfer et al., 2024). Recent advancements in this technology, such as the incorporation of natural gums and cellulose derivatives as foaming agents, have further improved its efficiency (Abd El-Salam et al., 2021). However, the optimal processing conditions for producing instant germinated rice tea while preserving its nutritional and functional properties have not been fully explored. Therefore, this study aimed to: (1) investigate the diversity of indigenous rice varieties in Roi Et Province, Thailand, in terms of their nutritional composition; (2) examine the antioxidant capacity and phenolic compound content of these indigenous rice varieties; and (3) determine an appropriate methylcellulose (methocel) concentration for producing instant germinated brown rice tea as a value-added product. The findings provide quantitative data for selecting pigmented indigenous rice varieties as functional-food raw materials, and identify processing conditions that retain bioactive compounds, thereby supporting both biodiversity conservation and the development of rice-based functional beverages.

Materials and methods

Rice varieties and sample preparation

Twenty-three indigenous rice varieties were collected from a comprehensive survey conducted in Roi Et Province, Thailand, encompassing 2,412 villages across 193 subdistricts in 20 districts in November 2023. Paddy rice samples underwent a series of preparation steps: rice grains were soaked in water at a 2:1 ratio (water : grain, by volume) at 30 °C for 6 hr. Soaked samples were incubated at 25 °C with a relative humidity of 75–85% for 24 hr to induce germination. After germination, samples were washed with tap water and oven-dried at 50 °C for 12 hr. Dried rice samples were ground using an ultra-centrifugal mill (ZM 200, Retsch, Germany), and the resulting powder was sieved through a sieving and fractioning machine (AS200-Digit, Retsch, Germany) to obtain rice powder of 60-mesh particle size. The prepared samples were stored in sealable polyamide (PA) plastic bags at 4 °C until further analysis. For the development of the instant germinated brown rice tea (foam-mat drying experiment), the three pigmented varieties with the highest total phenolic content and DPPH antioxidant activity—Kum Bai Khiaw, Kum Noi, and Hom Nil Pluerk Dum—were selected as raw materials and blended in equal proportions (1:1:1, w/w/w) to produce the test tea base.

Chemical composition analysis

Rice powder samples were subjected to chemical composition analysis following AOAC (2000) methods, with slight modifications as described by Somporn et al. (2011). The parameters assessed included moisture content, determined by oven drying at 105 °C until a constant weight was achieved; ash content, measured using a muffle furnace at 550 °C; crude protein, analyzed via the Kjeldahl method with a conversion factor of 5.95; crude fat, extracted using the Soxhlet method with petroleum ether as the solvent; and dietary fiber, determined using the AOAC (2000) method. Total carbohydrate content was calculated by difference. All analyses were performed in triplicate.

Assessment of antioxidant capacity

DPPH radical scavenging activity

The DPPH radical scavenging activity of rice extracts was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) method, with butylated hydroxyanisole (BHA) serving as a positive standard. DPPH and BHA (Sigma-Aldrich, USA) were prepared at concentrations of 50, 100, and 200 ppm in methanol. The assay involved mixing 100 µl of the sample solution with 5 ml of 0.1 mM methanolic DPPH solution, followed by vigorous shaking and incubation in the dark at room temperature for 20 min. Absorbance was then measured at 517 nm using a spectrophotometer (Sigma-Aldrich, USA). A control sample, prepared without any extract, was used for comparison, and methanol served as the blank for baseline correction. The radical scavenging activity (% inhibition) was calculated as: % Inhibition = $[(A_{\mathbf{0}} - A_{\mathbf{1}}) / A_{\mathbf{0}}] \times 100$, where $A_{\mathbf{0}}$ is the absorbance of the control and $A_{\mathbf{1}}$ is the absorbance of the sample.

Determination of total phenolic content

Total phenolic content (TPC) was determined using the Folin–Ciocalteu method. Briefly, 1 ml of appropriately diluted sample or gallic acid standard solution was added to a 25 ml volumetric flask containing 9 ml of distilled water. One ml of Folin–Ciocalteu phenol reagent was then added and mixed. After a 5-min incubation, 10 ml of 7% sodium carbonate solution was introduced, and the mixture was thoroughly mixed. The solution was diluted to 25 ml with distilled water and remixed. After 90 min of incubation at

room temperature, absorbance was measured at 765 nm. Total phenolic content was expressed as milligrams of gallic acid equivalents (GAE) per 100 g of sample.

Production of instant germinated brown rice tea

Preparation of roasted germinated brown rice

Roasted germinated brown rice was prepared following the method of Parnsakhorn & Langkapin (2021). Germinated brown rice was roasted until the grains swelled and developed a fragrant aroma (approximately 5 min). A 33.3 g portion of the roasted rice was soaked in 100 ml of water (1:3, w/v) at 60 °C in a temperature-controlled water bath with intermittent stirring every 10 min for 45 min. The infusion was filtered through white filter cloth and cooled to room temperature before being used as the tea base for the foam-mat drying experiment.

Foam-mat drying process

In the foam-mat drying process, 500 g of roasted germinated brown rice was soaked in 1,500 ml of water and subsequently mixed with methylcellulose (methocel) at concentrations of 1.00%, 1.50%, and 2.00% (w/w). The mixture was blended at maximum speed for 15 min to generate foam. Methocel acts as a surface-active hydrocolloid: its amphiphilic methyl-ether substitutions adsorb at the air–water interface, lowering surface tension and forming a viscoelastic film around air bubbles. This film stabilizes the foam against drainage and coalescence during whipping, and on drying it leaves a porous matrix with greatly increased surface area, which facilitates moisture removal and improves the rehydration behavior of the final powder (Sangamithra et al., 2015). A 150 g portion of the resulting foam was evenly spread onto each drying tray. The foam was dried in a hot-air oven at 50 °C, 60 °C, and 70 °C until a constant moisture level was achieved.

Physical and chemical analysis of instant tea

The physical and chemical properties of the instant tea powder were evaluated as follows. Solids content was assessed both before and after methocel addition. Water activity (aw, the ratio of the vapor pressure of water in the product to that of pure water at the same temperature) was measured with an Aqualab water-activity meter, and moisture content was determined gravimetrically and expressed on a dry-basis (% d.b.). Solubility, rehydration, and dissolving time were determined following standard procedures, and anthocyanin content was quantified by the pH-differential method. Color was measured with a colorimeter to obtain L*, a*, and b* values. The antioxidant activity of the instant tea was evaluated using the DPPH assay as described above.

Phenolic extraction

For the extraction of phenolic compounds from the instant tea powder, a 50 g sample was mixed with 100 ml of acidified methanol (methanol : acetic acid, 100:1, v/v), blended, and incubated in the dark at 35 °C for 12 hr. The mixture was then filtered and centrifuged at 4,000 rpm, and the supernatant was evaporated at 30–40 °C. The residue was dissolved in 25 ml of an aqueous solvent system (80:20, v/v), filtered through Whatman grade 4 paper and anhydrous sodium sulfate, and evaporated again at 35–40 °C. The extract was reconstituted to 5 ml with a 50:50 (v/v) aqueous solvent and filtered through a 0.45 µm membrane. The recovered phenolic extract was used for the subsequent total phenolic content (Folin–Ciocalteu) and DPPH assays.

Consumer acceptance evaluation

The consumer acceptance test was conducted by assessing sensory attributes using 50 selected panelists, randomly recruited from the target consumer group. Panelists were 20–60 years old, in good health, with no history of food allergies or other conditions that could affect taste perception, and were interested in consuming health products such as germinated brown rice tea. Each panelist tasted instant germinated brown rice tea prepared by mixing 1 g of tea powder with 10 ml of hot water. Sensory attributes—appearance/color, smell, flavor, and overall liking—were rated on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). The study protocol was reviewed and approved by the Institutional Human Research Ethics Committee, and written informed consent was obtained from all participants prior to testing.

Statistical analysis

All experiments were carried out in triplicate. Data were subjected to analysis of variance (ANOVA), and mean comparisons were performed using Duncan's multiple-range test at a significance level of $p \leq 0.05$. Statistical analysis was performed using SPSS software version 24 (SPSS Inc., Chicago, IL, USA).

Results and Discussion

Nutritional composition of indigenous rice varieties

The proximate composition and pericarp color of 23 indigenous rice varieties collected in Roi Et Province, Thailand, are presented in Table 1. Carbohydrate content ranged from 72.50% to 76.83%, with Kiaw Ngu exhibiting the highest value (76.83 ± 0.29%) and Kum Noi the lowest (72.50 ± 0.50%). Dietary fiber content varied significantly among the varieties, with Niaw Hom Phu Phan showing the highest fiber content (4.97 ± 0.06%) and Dok Ma-kham the lowest (2.40

± 0.10%). Fat content ranged from 2.03% to 3.43%, with Mali Nil exhibiting the highest fat content (3.43 ± 0.12%) and Pama Noi the lowest (2.03 ± 0.06%). Protein content showed less variation, ranging from 0.58 ± 0.13% to 1.16 ± 0.14%, with Hom Mali Daeng containing the highest protein content (1.16 ± 0.14%) and Mali Daeng the lowest (0.58 ± 0.13%).

These results highlight the nutritional diversity among indigenous rice varieties, which is consistent with previous studies. Butsat & Siriamornpun (2010) reported similar ranges of carbohydrate (73.7–76.4%) and fat (2.1–3.1%) content in Thai rice varieties, although their protein values were notably higher (7.6–9.2%). The lower protein values observed in the present study could be attributed to variations in cultivation practices, soil-nitrogen availability, environmental conditions, varietal genetic background, and differences in analytical methodology. The high dietary fiber content observed in some varieties, particularly Niaw Hom Phu Phan, is noteworthy. Dietary fiber has been associated with various health benefits, including improved digestion, blood glucose regulation, and reduced risk of cardiovascular disease (Lattimer & Haub, 2010). These high-fiber rice varieties could be promoted for their health-promoting properties.

Table 1 Pericarp color and proximate composition (carbohydrate, dietary fiber, fat, and protein) of 23 indigenous rice varieties collected from Roi Et Province, Thailand

Rice variety	Pericarp color	Carbohydrate (%)	Dietary fiber (%)	Fat (%)	Protein (%)
Dok Ma-kham	White	73.53±0.50^{bc}	2.40±0.10^{c}	3.03±0.06^{ab}	1.09±0.18^{ab}
Hom Baitoei	White	74.67±0.55^{b}	2.42±0.15^{c}	3.00±0.01^{ab}	1.05±0.17^{ab}
Hom Nil	Dark purple	75.73±0.31^{ab}	2.57±0.10^{c}	2.43±0.06^{bc}	0.86±0.13^{bc}
Mali Daeng	Red	76.30±0.26^{a}	4.40±0.06^{a}	2.33±0.15^{c}	0.58±0.13^{c}
Hom Mali Nil	Dark purple	76.80±0.26^{a}	4.03±0.12^{ab}	2.30±0.17^{c}	0.86±0.12^{bc}
Rice Berry	Dark purple	76.67±3.58^{a}	4.39±0.06^{a}	2.33±0.58^{c}	0.99±0.12^{b}
Niaw Hom Phu Phan	Light brown	75.15±0.61^{ab}	4.97±0.06^{a}	2.67±0.06^{b}	0.93±0.15^{b}
Vessandorn	White	75.20±0.72^{ab}	3.43±0.12^{b}	2.97±0.06a^{b}	1.05±0.17^{ab}
Kum Noi	Dark purple	72.50±0.50^{c}	3.07±0.10^{bc}	2.51±0.02b^{c}	0.88±0.14^{bc}
Pama Noi	Red	75.00±1.00^{ab}	4.10±0.06^{ab}	2.03±0.06^{d}	1.05±0.17^{ab}
Kiaw Ngu	White	76.83±0.29^{a}	3.27±0.06^{bc}	2.97±0.06^{ab}	1.03±0.17^{ab}
Mali Nil	Dark purple	75.00±1.00^{ab}	3.03±0.06^{bc}	3.43±0.12^{a}	0.87±0.14^{bc}
Hom Nil Pluerk Dum	Dark purple	73.67±0.58^{bc}	4.03±0.17^{ab}	2.43±0.06^{bc}	0.89±0.13^{bc}
Niaw Daeng	Red	74.63±0.58^{b}	4.10±0.12^{ab}	2.40±0.17^{bc}	0.90±0.13^{b}
Kum Bai Khiaw	Dark purple	74.33±0.58^{b}	4.07±0.10^{ab}	2.33±0.58^{c}	1.00±0.18^{b}
Pama	Red	73.33±0.58^{bc}	4.00±0.10^{ab}	3.03±0.06^{ab}	1.06±0.17^{ab}
Kum Namg Paya	Dark purple	74.33±0.58^{b}	3.10±0.06^{bc}	2.65±0.07^{b}	0.93±0.15^{b}
Niaw Kiaw Ngu	White	75.86±0.32^{ab}	3.97±0.13^{ab}	2.44±0.34^{bc}	0.97±0.13^{b}
Hom Mali Daeng	Red	73.87±0.23^{bc}	3.65±0.50^{b}	2.77±0.21^{b}	1.16±0.14^{a}
Khao Dawk Pa-yawm	White	76.33±0.58^{a}	4.50±0.20^{a}	2.97±0.06^{ab}	1.06±0.16^{ab}
Pla Sew	White	74.33±0.58^{b}	2.90±0.10^{bc}	2.80±0.10^{ab}	1.00±0.16^{ab}
RD6	White	75.33±0.58^{ab}	3.60±0.10^{b}	2.67±0.13^{b}	0.97±0.14^{b}
Niaw Hom	White	75.30±0.58^{ab}	3.43±0.15^{b}	2.47±0.12^{bc}	0.91±0.14^{b}

Note: Values are expressed as mean ± standard deviation (SD) of three independent experiments, on a dry-weight basis. Pericarp color was recorded visually following standard rice color descriptors. Means within the same column followed by different superscript letters are significantly different at $p \leq 0.05$.

Antioxidant activity and total phenolic content of indigenous rice varieties

The antioxidant activity (measured by DPPH scavenging assay) and total phenolic content (TPC) of the 23 indigenous rice varieties are presented in Table 2. The results reveal substantial variation in both parameters across the varieties. DPPH scavenging activity ranged from 10.50% to 78.40% inhibition, with Kum Noi demonstrating the highest antioxidant activity (78.40 ± 1.58%) and Khao Dawk Pa-yawm the lowest (10.50 ± 0.20%). Similarly, TPC varied widely from 9.40 to 113.73 mg GAE/100 g sample, with Kum Bai Khiaw showing the highest TPC (113.73 ± 4.04 mg GAE/100 g) and Pla Sew the lowest (9.40 ± 2.26 mg GAE/100 g). A strong positive correlation was observed between DPPH scavenging activity and TPC ($p<0.05$), indicating that phenolic compounds contribute substantially to the antioxidant properties of these rice varieties. This correlation aligns with findings from previous studies on rice and other cereal grains (Gong et al., 2017; Zhang et al., 2010).

Notably, several pigmented rice varieties—Kum Noi, Hom Nil Pluerk Dum, Niaw Daeng, Hom Mali Daeng, and Kum Bai Khiaw—exhibited substantially higher antioxidant activity and TPC than non-pigmented varieties. As shown in Table 1, these varieties have dark-purple or red pericarps. This finding

is consistent with research indicating that pigmented rice varieties, particularly those with dark-purple or red bran, tend to have higher antioxidant content due to the presence of anthocyanins, proanthocyanidins, and other phenolic compounds (Shao et al., 2018). The considerable variation in antioxidant properties among these indigenous varieties highlights their potential as functional food ingredients. Varieties such as Kum Bai Khiaw and Kum Noi, which combined the highest TPC and antioxidant activity, are particularly suitable candidates for the development of nutraceuticals and functional foods aimed at preventing oxidative-stress–related diseases (Zaupa et al., 2015).

Table 2 Antioxidant activity (DPPH scavenging activity assay) and total phenolic content (TPC) of 23 indigenous rice varieties collected from Roi Et Province, Thailand

Rice variety	DPPH (% inhibition)	TPC (mg GAE/100 g sample)
Dok Ma-kham	16.39±4.26^{de}	12.90±0.85^{ef}
Hom Baitoei	13.28±2.37^{e}	16.16±1.40^{de}
Hom Nil	42.83±2.15^{c}	53.76±3.60^{c}
Mali Daeng	54.21±2.49^{c}	102.13±4.25^{ab}
Hom Mali Nil	44.92±1.04^{c}	56.30±3.37^{c}
Rice Berry	55.69±0.93^{c}	84.60±4.49^{b}
Niaw Hom Phu Phan	20.50±0.68^{d}	16.86±2.79^{de}
Vessandorn	22.83±0.97^{d}	15.00±1.03^{de}
Kum Noi	78.40±1.58^{a}	104.00±4.60^{ab}
Pama Noi	23.97±2.87^{d}	18.76±3.04^{de}
Kiaw Ngu	23.74±2.00^{d}	25.70±2.51^{d}
Mali Nil	44.92±1.04^{c}	56.30±5.37^{c}
Hom Nil Pluerk Dum	72.87±0.34^{ab}	100.73±1.94^{ab}
Niaw Daeng	69.88±0.26^{ab}	101.50±0.26^{ab}
Kum Bai Khiaw	60.39±0.98^{ab}	113.73±4.04^{a}
Pama Noi	23.97±2.87^{d}	18.76±3.04^{de}
Kiaw Ngu	23.74±2.00^{d}	25.70±2.51^{d}
Mali Nil	44.92±1.04^{c}	56.30±5.37^{c}
Hom Nil Pluerk Dum	72.87±0.34^{ab}	100.73±1.94^{ab}
Niaw Daeng	69.88±0.26^{ab}	101.50±0.26^{ab}
Kum Bai Khiaw	60.39±0.98^{ab}	113.73±4.04^{a}
Pama	23.76±1.91^{d}	18.76±1.04^{de}
Kum Namg Paya	37.43±2.41^{cd}	42.63±0.95^{c}
Niaw Kiaw Ngu	20.18±1.22^{d}	16.90±1.45^{e}
Hom Mali Daeng	70.15±2.97^{ab}	85.52±3.62^{b}
Khao Dawk Pa-yawm	10.50±0.20^{e}	19.56±4.76^{d}
Pla Sew	18.58±0.80^{de}	9.40±2.26^{f}
RD6	27.21±0.07^{d}	19.03±0.61^{d}
Niaw Hom	27.21±0.19^{d}	19.03±0.43^{d}

Note: Values are expressed as mean ± SD of three independent experiments. Means within the same column followed by different superscript letters are significantly different at $p \leq 0.05$.

Physical properties of instant germinated brown rice tea

The physical transformation of the germinated brown rice tea base during the foam-mat drying process is illustrated in Figure 1, which shows three sequential stages of foam development: (a) the initial well-mixed slurry without foam, (b) an unstable, partially collapsed foam, and (c) the final stable foam used as feed for foam-mat drying. The stable foam structure (Figure 1c) demonstrates successful incorporation of methocel as a foaming agent and is essential for maintaining foam integrity during drying (Raharitsifa & Ratti, 2010). The progression from (a) to (c) confirms that increasing methocel concentration and adequate whipping are necessary to generate the viscoelastic film that supports stable foam, which in turn allows the formation of a porous powder matrix with rapid dissolution potential and a low equilibrium moisture content consistent with extended shelf-life (Kalambe & Guhe, 2026)

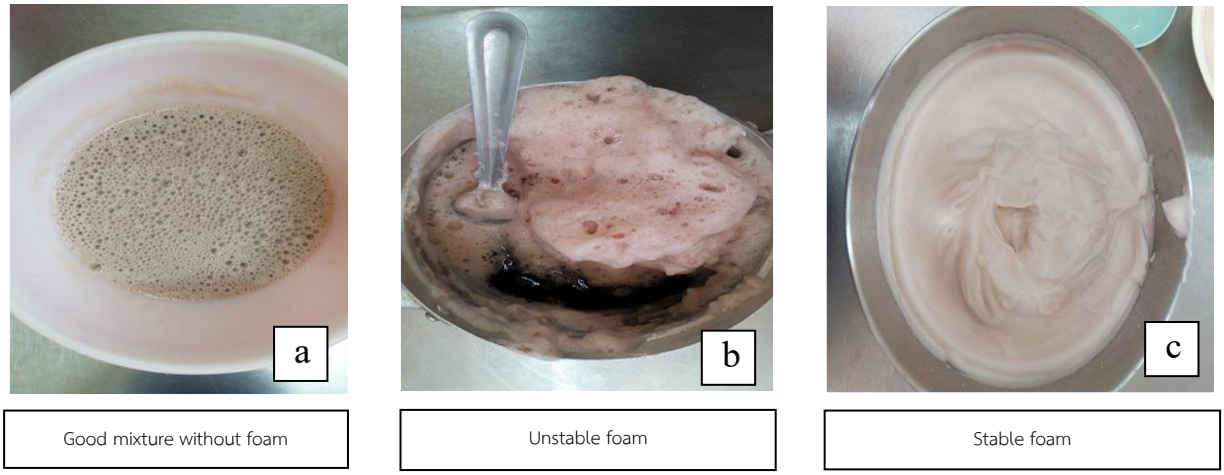


Figure 1 Sequential stages of foam development for foam-mat drying of instant germinated brown rice tea: (a) good mixture without foam, (b) unstable foam, and (c) stable foam used as feed for foam-mat drying

Color measurements of the instant germinated brown rice tea produced through foam-mat drying are presented in Table 3. The results showed minimal changes in color parameters (L*, a*, and b*) between the foam (before drying) and powder (after drying) stages across the three methocel concentrations (1.00%, 1.50%, and 2.00%). This indicates that foam-mat drying effectively preserved the original color of the germinated brown rice base, which is crucial for maintaining the visual appeal of the final product.

Water activity (aw)—defined as the ratio of the partial vapor pressure of water in the product to that of pure water at the same temperature—and moisture content of the instant tea samples are shown in Table 4. All samples exhibited low aw (≤ 0.31) and moisture content (≤ 2.66% d.b.), regardless of methocel concentration. These low values are essential for ensuring product microbiological stability and inhibiting microbial growth during storage (Labuza & Altunakar, 2007). The results suggest that the foam-mat drying process effectively reduced moisture content to levels suitable for long-term storage.

Table 3 Color values of instant germinated brown rice tea through foam-mat drying

Levels of methocel concentration	Before (foam)			After (powder)		
	L*	a*	b*	L*	a*	b*
1.00	86.38±6.26^{ns}	2.03±1.56	5.80±1.09	84.61±5.88	4.28±2.32	5.22±0.80
1.50	86.28±6.35	2.05±1.57	5.79±1.16	84.61±5.89	4.28±2.31	5.21±0.81
2.00	86.25±6.36	2.06±1.57	5.86±1.10	84.59±5.88	4.29±2.31	5.22±0.81

Note: The values represent the means of three independent experiments ± standard deviation (SD).
^{ns}=Means of the color values are not significantly different at $p \leq 0.05$.

Table 4 Water activity (a_w) and humidity of instant germinated brown rice tea through foam-mat drying

Levels of methocel concentration	a_w	Humidity (% d.b.)
1.00	0.31±0.03^{ns}	2.11±0.92
1.50	0.30±0.01	2.11±0.92
2.00	0.30±0.02	2.66±0.86

Note: Values represent the means of three independent experiments ± standard deviation (SD).
^{ns}=Means of the water activity (a_w) and humidity values are not significantly different at $p \leq 0.05$.

The stability, rehydration, and dissolving time of the instant tea samples are presented in Table 5. Foam stability slightly increased with higher methocel concentrations, although the differences were not statistically significant ($p>0.05$). Rehydration rates were high (> 92%) for all samples, indicating good reconstitution properties. Dissolving time decreased significantly ($p<0.05$) with increasing methocel concentration, from 5.06 ± 0.50 min at 1.00% to 3.33 ± 1.20 min at 2.00%. This improvement in dissolving time can be attributed to the enhanced foam structure and the consequent increase in surface area of the porous powder matrix generated at higher methocel concentrations (Karim & Wai, 1999).

Table 5 Stability, rehydration, and dissolving time of instant germinated brown rice tea

Levels of methocel concentration (percentage by weight)	Stability (ml/min)	Rehydration (percentage)	Dissolving (min)
1.00	1.85±1.06^{ns}	92.71±7.18^{ns}	5.06±0.50^{a}
1.50	1.88±1.08	92.58±7.41	4.28±0.78^{ab}
2.00	1.95±1.14	92.12±7.82	3.33±1.20^{b}

Note: Values are expressed as the mean ± standard deviation of three independent experiments.

^{ns}=Means of the stability, rehydration, and dissolving time values are not significantly different at $p \leq 0.05$.

Bioactive compounds and antioxidant activity of instant germinated brown rice tea

The contents of bioactive compounds and antioxidant activity in the instant germinated brown rice tea samples are presented in Table 6. Anthocyanin content remained essentially constant (0.09 μg CGE/g DW) across all three methocel concentrations, with no significant differences among treatments (p>0.05), suggesting that the foam-mat drying process did not adversely affect anthocyanin stability. This stability is consistent with the findings of Goufo & Trindade (2014), who reported that appropriately optimized drying techniques can effectively preserve anthocyanins in plant-based products. Total phenolic content of the instant tea showed only marginal variation across methocel concentrations (2.60–2.64 mg GAE/g DW), and the differences were not statistically significant (p> 0.05). This minimal variation aligns with Carciochi et al. (2016), who demonstrated that optimized drying conditions can minimize the loss of phenolic compounds in thermally processed plant matrices. DPPH antioxidant activity ranged from 29.39% to 31.22% inhibition, with the highest value at 1.00% methocel; differences among the three concentrations were not statistically significant (p>0.05). These values are comparable to those reported by Vichit & Saewan (2015) for various Thai herbal teas, indicating that the instant germinated brown rice tea retains substantial antioxidant capacity. Overall, the choice of methocel concentration within the tested range (1.00–2.00%) did not substantially impact the bioactive profile of the final product, which is advantageous for product formulation and scale-up (Kumar et al., 2022).

Table 6 Content of anthocyanin, phenolic compounds, and antioxidant activity in instant germinated brown rice tea

Levels of methocel concentration	Anthocyanin (μg CGE/g DW)	Total phenolic compounds (mgGAEg/DW)	Antioxidant activity DPPH (% inhibition)
1.00	0.09±0.04^{ns}	2.64±0.30^{ns}	31.22±2.80^{ns}
1.50	0.09±0.03	2.63±0.26	29.39±3.79
2.00	0.09±0.04	2.60±0.27	30.14±1.66

Note: Values represent the mean ± SD of three independent experiments.

Means within the same column followed by different letters indicate statistically significant differences at $p \leq 0.05$.

Sensory evaluation of instant germinated brown rice tea

Consumer sensory evaluation results for the instant germinated brown rice tea are presented in Table 7. Higher methocel concentrations resulted in improved sensory scores across all attributes (color, smell, flavor, and overall liking). The tea produced with 2.00% methocel received the highest scores for color (7.63 ± 1.50) and smell (6.66 ± 1.66), while the 1.50% concentration scored highest for flavor (6.36 ± 2.12) and overall liking (7.03 ± 1.30). Statistical analysis revealed significant differences (p<0.05) between the 1.00% concentration and higher concentrations for most attributes; however, differences between 1.50% and 2.00% concentrations were generally not significant, except for color. These results suggest that increasing methocel concentration beyond 1.50% does not provide substantial improvements in sensory acceptance. The improved sensory scores at higher methocel concentrations can be attributed to better foam stability during drying, resulting in a more uniform and visually appealing final product, and to the faster dissolving time observed at higher concentrations (Table 5), which likely contributed to improved flavor perception and overall liking.

Table 7 Sensory evaluation of the germinated brown rice tea produced through foam-mat drying

Sense	Concentration		
	1.00	1.50	2.00
Color	5.56±1.89[b]	6.33±1.82[ab]	7.63±1.50[a]
Smell	5.23±1.94[b]	6.36±1.90[a]	6.66±1.66[a]
Flavor	5.13±2.08[b]	6.36±2.12[a]	6.20±2.00[ab]
Overall linking	5.46±1.90[b]	7.03±1.30[a]	7.16±1.34[a]

Note: Values represent the mean ± SD of three independent experiments.

Means within the same column followed by different letters indicate statistically significant differences at the 0.05 level.

Conclusion

This study characterized 23 indigenous rice varieties from Roi Et Province, Thailand, and demonstrated the feasibility of using foam-mat drying to develop an instant germinated brown rice tea from selected pigmented varieties. Among the varieties screened, the dark-purple pigmented varieties Kum Bai Khiaw (113.73 mg GAE/100 g) and Kum Noi (78.40% DPPH inhibition) showed the highest total phenolic content and antioxidant activity, respectively, making them strong candidates for functional-food applications. Foam-mat drying with methylcellulose (methocel) at 1.50–2.00% produced an instant tea powder with low water activity (≤0.31), high rehydration (> 92%), short dissolving time (3.33–4.28 min), retained anthocyanin and phenolic content, and the highest consumer sensory acceptance. These findings indicate that integrating indigenous-rice varietal selection with foam-mat drying is a practical pathway for converting under-utilized local rice biodiversity into market-ready functional beverages. Future work should: (1) quantify and identify individual phenolic compounds in the most promising pigmented varieties by HPLC–DAD or LC–MS to provide chemical fingerprints; (2) evaluate storage stability (color, anthocyanins, phenolics, antioxidant activity) of the instant tea powder under different packaging and temperature conditions for at least six months; (3) assess *in vitro* and *in vivo* bioavailability of the bioactive compounds, including GABA, after rehydration; and (4) scale up the process to pilot-plant level and conduct a techno-economic analysis to support commercialization with smallholder rice farmers in Roi Et Province.

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Research article

Nutrient and Antioxidant Analysis of Indigenous Rice (*Oryza sativa* L.) Varieties for Adding Value to Rice Products

Chanyarin Somporn*

Department of Science and Technology, Faculty of Liberty and Science, Rajabhat Roi Et University, Selaphum District, Roi Et Province, 45120, Thailand

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ABSTRACT

This study investigated the diversity of indigenous rice varieties in Roi Et Province, Thailand; examined their nutritional content, antioxidant capacity, and phenolic compound content; and determined optimal methylcellulose (methocel) levels for producing instant germinated brown rice tea. Twenty-three rice varieties were analyzed for nutritional composition, antioxidant capacity, and total phenolic content. Kiaw Ngu showed the highest carbohydrate content (76.83%), while Niaw Hom Phu Phan exhibited the highest dietary fiber (4.97%). Kum Bai Khiaw had the highest total phenolic content (113.73 mg GAE/100 g), and Kum Noi displayed the highest antioxidant capacity (78.40% DPPH inhibition). For instant tea production, a 2.00% methocel concentration yielded the highest foam stability (1.95 mL/min) and rehydration capacity (92.12%). Consumer acceptance was highest for teas containing 1.50% and 2.00% methocel. This study provides quantitative evidence that selected pigmented indigenous varieties, particularly Kum Noi and Kum Bai Khiaw, are promising raw materials for functional rice-based beverages, supporting both the conservation of local rice biodiversity and the development of value-added products for the Thai functional-food market.

*Corresponding author
E–mail address: stchanyarin@gmail.com (C. Somporn)

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