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Insight into the nutritional, physicochemical, functional, antioxidative properties and *in vitro* gastrointestinal digestibility of selected Thai rice: Comparative and multivariate studies

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ABSTRACT

Nutritional, physicochemical, functional, antioxidative and digestion properties of brown and white rice flours from four Thai rice varieties (Luangpatue, upland rice, RD43, and Hommali) were investigated and compared. Due to differences in grain color, the color parameters of flours varied significantly. Protein, fat, ash, carbohydrate, and moisture content, total dietary fiber, and calories of these rice flours were 6.94–10.21%, 1.68–3.16%. 0.554–1.442%, 71.20–79.68%, 9.79–10.53%, 1.07–3.64%, and 350.82–362.73 kcal/100g, respectively. RD43 brown rice (18.4%) and Luangpatue white rice (26.5%) respectively exhibited the lowest and highest amylose content. Luangpatue rice flours also showed higher swelling power, setback value, final viscosity, and thermal properties than other varieties. The variations in hydration properties and oil absorption index were noticeable among these rice flours. In addition, the highest level of total phenolic content and antioxidant activity led to the lowest estimated glycemic index (eGI = 62.92) found in upland brown rice. It was confirmed by the multivariate analysis results. This study reported the diverse physicochemical properties and composition-property relationships of two kinds of flours from four rice varieties collected from Thailand for the first time. It exhibited possible capabilities for the development of various rice-based products that promote health based on their characteristics on industrial scale.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most essential staple foods, which is primary sources of energy for human life is well known. The global production and consumption of rice has been annually increasing, which plays an important role in global food security. Additionally, it provides essential sources of nutrients including macronutrients, vitamins, minerals (Juliano, 1993; Lee et al., 2012). Moreover, it could also be formulated into a wide range of industrial, food and beverage products. Different rice varieties vary in size, shape, flavor, texture, and color, and have the potential for various applications (Falade and Christopher, 2015). Understanding the nutritional composition and techno-functional properties of rice contributes to the successful formulation of different food products as well as more information for selecting type of rice for consumption. A major gap in research is to better explore genetic resources of rice for natural variation in desired quality attributes. Additionally, customers' interest in rice's nutritious content for use in nutraceuticals and the food industry have increased (Devi and Badwaik, 2022).

In Thailand, Luangpatue rice was considered as the traditional rice in Chumpon province (Thailand), which was the main rice variety for consumption. Besides that, due to the climate change as well as the land conditions, upland Luangpatue rice was also planted in recent years. The local community often eats these rice kinds after cooking. Due to their distinctive nutrient, native rice cultivars have been associated with good health since prehistoric times (Qadir and Wani, 2023). However, it is still limited about the characteristic's information about these rice varieties. Furthermore, Hommali rice or jasmine rice, the most popular variety, which has been used in the formulation of flour-based products, such as bread and crackers (Thiranusornkij et al., 2019). Hommali rice has a pleasant texture and a light floral aroma, although it is regarded as having a high glycemic index (GI) (Suklaew et al., 2020; Thiranusornkij et al., 2019). As a result, numerous efforts have been made to create a new rice variety with improved physiochemical and functional characteristics, especially to lower the glycemic index. Recent crossbreeding between Khao Jow Hawm Suphan Buri and Supan Buri 1 resulted in the

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development of a new variety of rice known as RD43 rice-non-GMO rice (Suklaew et al., 2020). Moreover, RD43 rice was reported that possed the high content of slowly digestible starch which help to control the blood sugar level and good for diabetes management (Techanet et al., 2022). Analysis of these rice samples may reveal novel properties, which may be adapted to other parts of the world for breeding new lines with desired functionalities as well as potential for widely applying in food industrial.

The correlation of composition-property as well as relationship between variety and techno-functional plays key important point to assist rice development programmes for developing improved cultivars for targeted applications and crop quality improvement. Principle component analysis (PCA) and hierarchical cluster analysis (HCA) have been found to be the most accurate statistical methods for extracting crucial information and discriminating samples based on the similarities and differences of the performance characteristics (Granato et al., 2018). For instance, the link between the various physicochemical characteristics of Japonica and Indica rice starch has been the subject of earlier research utilizing a multivariate method (Jang et al., 2016). The relationship between the amylose concentration and the rice properties as starch structure, physicochemical, textural properties were examined using Pearson's correlation coefficient (Zhu et al., 2021). Therefore, in this study, four rice varieties (brown and white rice) with commercial significance from Thailand were collected to examine the nutritional, physicochemical, functional, antioxidative and digestion properties. The two main objectives of this study is aimed as follows: (1) to compare the internal characteristics of two types of flours made from four rice genetics and (2) to examine the correlation between various properties and varieties by multivariate analysis. Additionally, studying *in vitro* glycemic index could aid in screening rice cultivars for persons with insulin-independent diabetes and other chronic illnesses to have a better understanding of their role in human nutrition and food application.

2. Materials and methods

2.1. Materials

Four rice varieties were selected in this study, including indigenous traditional *Indica* rice (namely Luangpatue) at Chumpon province (Thailand), upland rice (Chumpon province, Thailand), RD43, and Hommali rice. All rice was purchased at the same harvesting season. Two indigenous traditional *Indica* rice samples [brown (LBR) and white rice (LWR)] were obtained from local rice farmers at Chumpon province (Thailand). While the upland brown rice (UBR) was collected from the group researcher at King Mongkut's Institute of Technology Ladkrabang Prince of Chumphon Campus. Before transport to the laboratory, rice was de-husked, dried to obtain the moisture content of about 10%, and vacuum packed. Upland rice was also polished to obtain the white upland rice (UWR). RD43 rice and Hommali rice were purchased at the Thongmanee company (Thailand) and denoted as RD43-WR (RD43 white rice), RD43-BR (RD43 brown rice), HWR (Hommali white rice), and HBR (Hommali brown rice). To determine the quality of rice, the grain was ground with the pin mill machine (Retsch grinder ZM 1000, Germany) and passed the sieve (100 mesh). The flour was kept in a dark bag and at frozen temperatures (-18^{o}C) until further analysis.

2.2. Visual appearance and color determination

The appearance of grain and flour was taken by digital camera (Canon 50D with len kit 18–55 mm), and the color values of flour was analyzed using colorimeter (Chromameter CR410, Japan) at 10 difference points. The average value of Hunter color parameters was calculated for each rice flour. Besides, hunter whiteness also calculated as Equation below,

$$\text{Hunter whiteness} = 100 - \sqrt{a^2 + b^2 + (100 - L)^2}$$

2.3. Nutritional properties

Proximate composition analysis was determined following the standard method of AOAC (2005). Total carbohydrate content was analyzed by the method of Goñi et al. (1997). Moisture content was analyzed using oven drying at 105^{o}C. Based on the percentage of macronutrients, calories value of 100 g rice was calculated as described equation of Schakel et al. (2009). Amylose content was analyzed by the method of Juliano (1993). Rice flours were evaluated for total dietary fibre (TDF) by enzymatic gravimetric protocol as described in the study of Qadir and Wani (2023) using total dietary fibre assay kit (TDF100A) including heat resistant α-amylase, pepsin and amyloglucosidase from Sigma Aldrich, Saint Louis, USA.

2.4. Antioxidant properties

Extraction process was performed according to the modified method of Shen et al. (2009). Briefly, milled rice powder (50 g) was soaked in 200 mL methanol with 1.5% HCl overnight at room temperature and shaken (150 rpm). Total phenolic content (TPC) of rice extract was determined according to method of Adisakwattana et al. (2010). Briefly, sample solution (10 μL) was incubated with 100 μL of Folin-Ciocalteu's reagent (10-fold dilution) for 5 min. Then 1 M sodium carbonate (80 μL) was added and incubated at room temperature for 30 min. TPC was measured at absorbance 760 nm. Ferric reducing antioxidant power (FRAP) of flour was determined using a method of Benzie and Strain (1996) with minor modifications. The reaction mixture between rice extract and FRAP reagent was incubated in the dark at room temperature for 30 min and the absorbance was read at 595 nm. FRAP value was calculated from the calibration curve of $FeSO_4$. 2,2-Diphenyl-1-picryl hydrazyl (DPPH) radical scavenging activity of rice sample was determined using the method described by Reddy et al. (2016), which expressed as the percentage DPPH's inhibition.

2.5. Swelling power and solubility

Sample (0.25 g) was mixed with 10 mL of distilled water in centrifuge tube before being heated in a water bath in a water bath at 65, 75, and 85^{o}C for 30 min. Then, samples were centrifuged at 2000 rpm for 20 min. Rice flour's swelling power (SP) and solubility (SB) were determined by weighing the precipitated and supernatant portions after it had been dried at 105 °C as the described of Thiranusornkij et al. (2018).

2.6. Water absorption index, water solubility index and oil absorption index

Rice flour (1 g) was dispersed in 10 mL of distilled water and agitated using a vortex mixer for 1 min. The suspensions were put in a water bath at 30 °C for 30 min. The samples were thereafter subjected to centrifugation at a speed of 3000 rpm for 10 min. The liquid portion was cautiously transferred into an aluminum cup to dry at 105 °C for one night and the weight of supernatant was collected. The wet sediment after centrifuge also was measured by weight. The water absorption index (WAI), water solubility index (WSI) were calculated follow the equation in the study of Kraithong et al. (2018). The oil absorption index (OAI) was also examined based on the protocol describe in Kraitong's study. Briefly, 1 g of rice flour was well mixed with 10 mL of soybean oil. Then, the mixture was centrifure at 4000 rpm for 20 min for decanting the oil to collect the residue (oil-absorbed rice flour). OAI was calculated by dividing the weight of oil absorbed to the weight of rice sample.

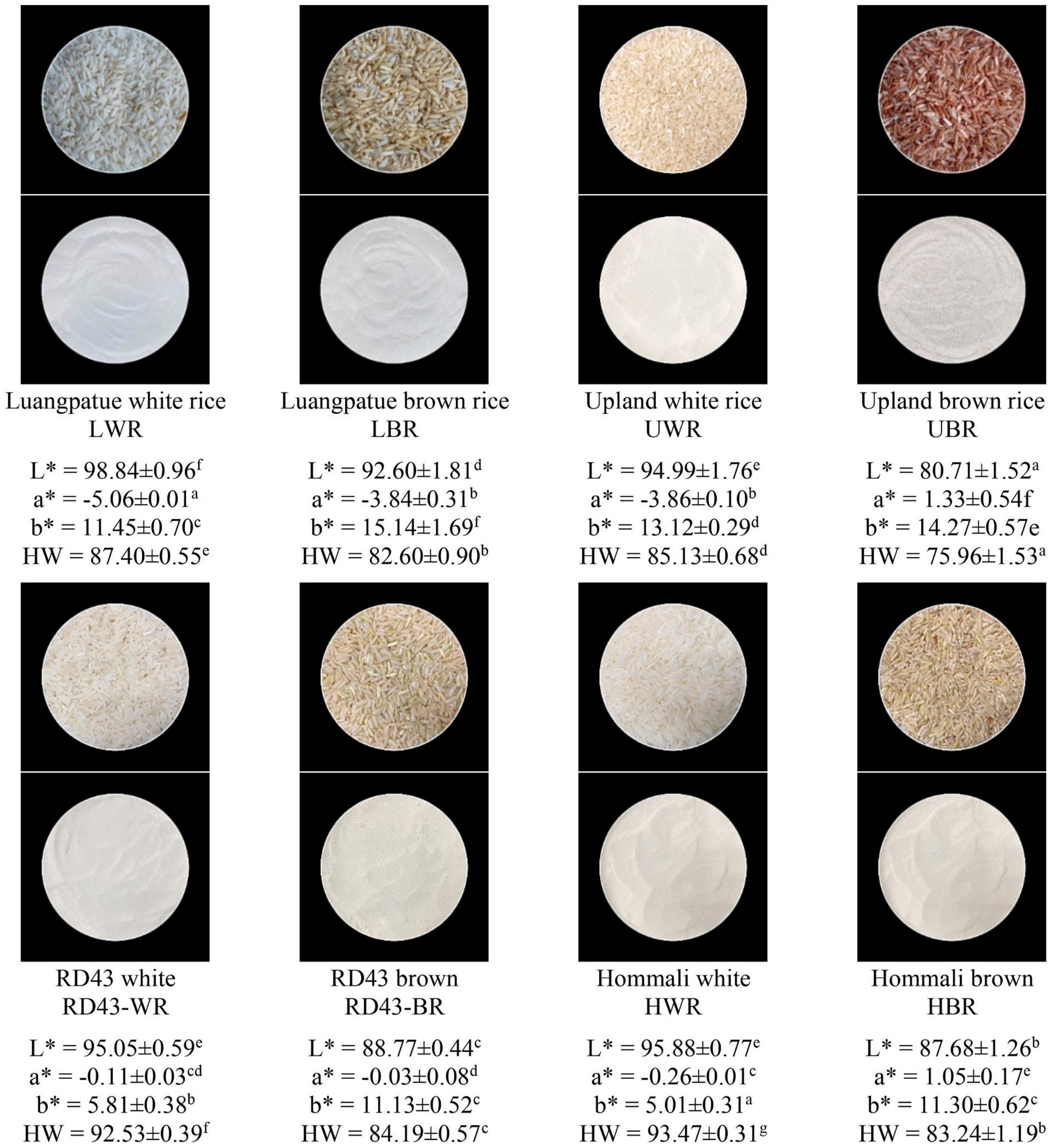

Fig. 1. The appearance of grain, rice flours and their color parameters.
Note: Different letters in the same parameter indicate significant difference from each other ($p \leq 0.05$).

2.7. *Pasting properties*

Pasting properties were analyzed and obtained by using Viscograph E (Barbender, Duisburg). Briefly, the 45 g rice flour (dry weight) in exactly 405 g water suspensions were heated from 50 to 95 °C at a heating rate of 1.5 °C/min, held at 95 °C for 15 min, followed by cooling to 50 °C at a cooling rate of 1.5 °C/min at 75 rpm (Fang et al., 2020).

2.8. *Thermal properties*

Thermal properties of each sample were analyzed using a differential scanning calorimeter (DSC, Mettler Toledo, Switzerland) (Kunyanee and Luangsakul, 2022). Sample (3 mg rice flour and 9 μL deionized water) was added in aluminum cup, then equilibrated for 24 h at room temperature and empty cup considered as reference. DSC system was controlled temperature range for scanning from 20 to 120°C with heating rate of 5 °C/min. Thermal parameters of rice flour were obtained from STAR^{e} software (Mettler Toledo, Switzerland).

2.9. *Fourier-transform infrared spectroscopy (FTIR)*

FTIR spectra (4000-500 cm^{-1} with the resolution of 4 cm^{-1} at the average of 16 scans) of rice flours were obtained using a horizontal Attenuated Total Reflectance Trough plate crystal cell equipped with a Bruker Model Vector 33 FTIR spectrometer (Bruker Co., Ettlingen, Germany) at room temperature. Analysis of spectral data was carried out using the OPUS 8.0 software.

Table 1

Moisture content, proximate compositions, amylose content and calories of different rice varieties.

Rice varieties	MC (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)	TDF (%)	AC (%)	Calories
Luangpatue white	10.53 ± 0.13^{d}	8.73 ± 0.16^{c}	2.07 ± 0.30^{bc}	0.563 ± 0.01^{a}	76.49 ± 0.15^{e}	1.59 ± 0.02^{c}	26.50 ± 0.21^{f}	359.49 ± 3.85^{cd}
Luangpatue brown	10.46 ± 0.21^{d}	10.21 ± 0.16^{d}	3.16 ± 0.21^{e}	1.344 ± 0.01^{d}	71.20 ± 0.16^{a}	3.64 ± 0.06^{f}	24.01 ± 1.80^{e}	354.12 ± 2.45^{ab}
Upland white	10.09 ± 0.06^{bc}	8.56 ± 0.23^{c}	1.76 ± 0.12^{ab}	0.554 ± 0.02^{a}	77.81 ± 0.11^{f}	1.55 ± 0.02^{c}	23.34 ± 0.58^{de}	361.30 ± 1.57^{d}
Upland brown	10.64 ± 0.08^{d}	10.03 ± 0.12^{d}	2.08 ± 0.08^{bc}	1.021 ± 0.03^{c}	72.99 ± 0.15^{b}	3.26 ± 0.03^{e}	21.91 ± 0.44^{c}	350.82 ± 0.60^{a}
RD43 white	9.79 ± 0.04^{a}	8.55 ± 0.38^{c}	1.76 ± 0.28^{ab}	0.544 ± 0.09^{a}	78.17 ± 0.09^{g}	1.18 ± 0.06^{b}	19.62 ± 0.12^{b}	362.73 ± 3.50^{d}
RD43 brown	10.23 ± 0.06^{c}	7.58 ± 0.11^{b}	2.75 ± 0.17^{d}	1.442 ± 0.05^{e}	75.51 ± 0.13^{c}	2.53 ± 0.11^{d}	18.40 ± 0.17^{a}	357.09 ± 1.71^{bc}
Hommali white	9.99 ± 0.13^{b}	6.94 ± 0.08^{a}	1.68 ± 0.11^{a}	0.664 ± 0.06^{b}	79.68 ± 0.18^{h}	1.07 ± 0.01^{a}	22.96 ± 0.08^{cde}	361.64 ± 1.74^{d}
Hommali brown	10.49 ± 0.07^{d}	7.09 ± 0.15^{a}	2.25 ± 0.07^{c}	1.542 ± 0.09^{f}	76.02 ± 0.32^{d}	2.61 ± 0.05^{d}	22.27 ± 0.16^{cd}	352.71 ± 0.91^{a}

Note: Different letters in the same column indicate significant difference from each other ($p \leq 0.05$); MC is moisture content; TDF is total dietary fiber content; AC is amylose content.

2.10. In vitro stimulated gastrointestinal digestibility

In vitro stimulated gastrointestinal starch digestibility was carried out in triplicate using method of Chen et al. (2016), which including two phases as gastric phase with artificial saliva solution and porcine pepsin and small intestinal phase with pancreatin and amyloglucosidase enzyme. Preparation of these solution in gastric and small intestinal phases were followed the description of Zou et al. (2015). Aliquots (0.2 mL) were collected at different time points up to 180 min at small intestinal phase, and the digestion was stopped by adding 0.8 mL of 95% ethanol. The digestibility of starch (%) was determined from the amount of glucose released in the supernatant, which was converted to the mass of digested starch by a factor of 0.9. First-order equation model following Goñi et al. (1997), as shown below, was applied to describe the kinetics of starch hydrolysis.

$$C_{\infty} = C_0[(1 - \exp(-kt))]$$

where: k is the kinetic constant, t is time, C corresponds to the percentage of hydrolyzed starch at time t (min), and C_{∞} is the equilibrium concentration of starch in the simulated small intestinal phase. Hydrolysis index (HI), which indicates the starch hydrolysis of a sample, was calculated from dividing the area under the starch hydrolysis curve during the simulated small intestinal phase (AUC_{sample}) by the starch hydrolysis area of a reference sample ($AUC_{white\ bread}$).

The estimated glycemic index (eGI) was calculated according to the equation described by Goñi et al. (1997): $eGI = 39.71 + 0.549HI$.

2.11. Statistical analysis

All the experiments were performed in triplicates and the results were reported in mean ± standard deviation. Analysis of variance (ANOVA) was performed followed by Duncan's multiple range test for examining the statistical significance, $p < 0.05$ using SPSS Version 19 (IBM, SPSS software). Pearson's correlation coefficient was derived using Origin Pro 2022 software (OriginLab Corporation). All the derived independent and dependent parameters were subjected to the principle component analysis (PCA) and hierarchical cluster analysis (HCA), which was performed using XLSTAT 2022 tool pack of Microsoft Excel.

3. Results and discussion

3.1. Visual appearance and color value of rice flour

The visual appearance of grain, rice flour and color parameters were shown in Fig. 1. The majority of rice varieties grown around the world have light-brown outer layer, which could be seen in the sample of LBR, HBR, RD43-BR. However, some kind of rice varities is rich in antioxidant, especially abundances of anthocyanins and proanthocyanidins, which produce the red-purple color as seen in the UBR. The lightness values and hunter whiteness of white rice are always higher than the brown rice in the same varieties. The hunter whiteness was following in the order: HWR > RD43-WR > LWR > UWR > RD43-BR > HBR > LBR > UBR. It is obvious that the color of rice flour is mainly influenced by the outer layer of grain. However, even the highest value of lightness (L*) was found in LWR sample, but the hunter whiteness was in middle range due to the difference values of other color parameters. The highest

Table 2

Functional properties, pasting properties and antioxidant properties of different rice varieties.

Parameter	LWR	LBR	UWR	UBR	RD43-WR	RD43-BR	HWR	HBR
Swelling power (%)								
65°C	5.75 ± 0.20^{c}	5.05 ± 0.13^{b}	5.77 ± 0.10^{c}	5.07 ± 0.14^{b}	6.19 ± 0.31^{d}	4.22 ± 0.12^{a}	6.70 ± 0.07^{e}	4.97 ± 0.16^{b}
75°C	8.12 ± 0.30^{bc}	7.89 ± 0.44^{b}	8.53 ± 0.12^{c}	8.55 ± 0.11^{c}	8.07 ± 0.44^{bc}	6.17 ± 0.06^{a}	7.67 ± 0.27^{b}	6.09 ± 0.173^{a}
85°C	9.61 ± 0.10^{d}	9.18 ± 0.16^{cd}	9.56 ± 0.10^{d}	8.99 ± 0.26^{cd}	8.83 ± 1.54^{bcd}	7.58 ± 0.63^{ab}	8.32 ± 0.84^{abc}	7.30 ± 0.84^{a}
Solubility (%)								
65°C	0.045 ± 0.023^{a}	0.058 ± 0.023^{a}	0.093 ± 0.002^{b}	0.106 ± 0.035^{b}	0.044 ± 0.001^{a}	0.046 ± 0.001^{a}	0.030 ± 0.003^{a}	0.045 ± 0.002^{a}
75°C	0.047 ± 0.003^{a}	0.064 ± 0.012^{b}	0.124 ± 0.011^{c}	0.178 ± 0.021^{d}	0.045 ± 0.002^{a}	0.047 ± 0.001^{a}	0.035 ± 0.004^{a}	0.048 ± 0.002^{ab}
85°C	0.064 ± 0.006^{a}	0.124 ± 0.010^{b}	0.256 ± 0.010^{c}	0.288 ± 0.034^{d}	0.058 ± 0.001^{a}	0.049 ± 0.001^{a}	0.050 ± 0.004^{a}	0.057 ± 0.001^{a}
WAI (g/g)	3.20 ± 0.03^{b}	3.13 ± 0.06^{ab}	3.15 ± 0.08^{b}	3.06 ± 0.05^{a}	3.56 ± 0.08^{d}	3.39 ± 0.03^{c}	4.01 ± 0.03^{e}	3.62 ± 0.07^{d}
OAI (%)	1.70 ± 0.59^{a}	2.09 ± 0.13^{ab}	1.78 ± 0.04^{a}	2.25 ± 0.37^{b}	1.73 ± 0.02^{a}	2.02 ± 0.09^{ab}	1.74 ± 0.02^{a}	2.01 ± 0.19^{ab}
WSI (%)	3.842 ± 0.137^{d}	3.675 ± 0.043^{c}	3.914 ± 0.012^{de}	3.715 ± 0.020^{c}	3.559 ± 0.076^{b}	3.387 ± 0.026^{a}	4.103 ± 0.033^{e}	3.621 ± 0.067^{bc}
PT (°C)	75.0 ± 1.13^{c}	78.25 ± 0.92^{d}	74.90 ± 1.70^{c}	75.70 ± 0.99^{c}	71.50 ± 0.02^{b}	69.65 ± 0.35^{ab}	68.10 ± 0.28^{a}	71.15 ± 1.63^{b}
PV (BU)	1284 ± 59.40^{d}	935 ± 46.67^{b}	1148 ± 53.74^{c}	831 ± 55.15^{a}	1384.5 ± 6.36^{d}	1083 ± 15.56^{c}	1339 ± 63.64^{d}	774.5 ± 10.61^{a}
BV (BU)	501.0 ± 114.55^{b}	370.5 ± 50.20^{a}	623 ± 43.84^{c}	440.5 ± 36.06^{ab}	780.5 ± 0.71^{d}	722.5 ± 7.78^{cd}	758 ± 42.43^{d}	485 ± 1.41^{ab}
SV (BU)	626.5 ± 14.85^{d}	746.50 ± 34.65^{e}	371 ± 28.28^{ab}	390.5 ± 4.95^{ab}	389.5 ± 0.71^{ab}	414 ± 7.07^{bc}	361.5 ± 0.71^{a}	447.5 ± 28.99^{c}
FV (BU)	1366 ± 18.35^{e}	1206.5 ± 38.98^{d}	828 ± 49.50^{b}	715.5 ± 21.92^{a}	914 ± 5.66^{c}	740 ± 15.56^{a}	884 ± 19.80^{bc}	710.5 ± 12.02^{a}
TPC (mgGAE/g)	10.51 ± 1.59^{ab}	34.75 ± 4.82^{c}	33.64 ± 3.36^{c}	133.05 ± 11.83^{e}	14.68 ± 3.89^{b}	48.89 ± 3.71^{d}	6.74 ± 3.34^{a}	48.32 ± 2.72^{d}
DPPH (%)	56.45 ± 0.29^{b}	72.42 ± 0.27^{f}	71.14 ± 0.27^{e}	89.34 ± 0.88^{h}	59.45 ± 0.22^{c}	74.08 ± 0.15^{g}	46.11 ± 0.21^{a}	70.26 ± 0.16^{d}
FRAP (μmolFe^{2+}/g)	0.035 ± 0.009^{a}	0.288 ± 0.024^{d}	0.281 ± 0.014^{c}	1.035 ± 0.060^{f}	0.095 ± 0.015^{b}	0.424 ± 0.029^{e}	0.065 ± 0.034^{ab}	0.414 ± 0.026^{e}

Note: Different letters in the same row indicate significant difference from each other ($p \leq 0.05$); Pasting temperature (PT), Peak viscosity (PV), Breakdown value (BV), Setback value (SV), Final viscosity (FV).

value of redness (a*) was found in the UBR sample, which has a purple-red color at the outside of grain. The proximate compositions and phenolic components also affected the visual color of flour (Kraithong et al., 2018). Some varieties offer phytochemicals (mainly polyphenols and anthocyanins) in the outer bran layer, which not only imbues them with hues of a different color but also boosts their nutrient content. Due to the significant high content of phenolic compound in UBR (Table 2), which make the color of grain and flour also significant different with other type of rice.

3.2. Nutritional properties

Rice flours from different cultivars were studied for their proximate composition. The moisture content, protein, fat, ash, and carbohydrate ranged between 9.79% and 10.53%, 6.94%–10.21%, 1.68%–3.16%, 0.554%–1.442%, 71.20%–79.68%, respectively (Table 1). The moisture content, ash and carbohydrate of all the rice varieties was in agreement with the report of Devi and Badwaik (2022). It is also recommended that the appropriate moisture content for food development and storage is lower than 15% (Reddy et al., 2016). Besides, Nath et al. (2022) suggested that the carbohydrate content in rice should to in range approximately 80% for daily calories. The fat and protein content of brown rice varieties were higher than that of white rice, which was mainly due to the bran layer. Bran layer contains a high amount of protein and lipid, which is provided potential health benefits for consumers (Mir et al., 2020). Interestingly, the Luangpatue brown rice had the highest protein and lipid. The genetic and growth conditions are varied the nutritional values of rice (Mir et al., 2020).

TDF contentsof brown and polished rice flour exhibited a highly significant difference ($p < 0.05$). The total dietary fiber content of brown and polished rice, derived from specific cultivars, ranged from 2.53% to 3.64% and from 1.07% to 1.59%, respectively. It was noted that brown rice has a greater quantity of TDF compared to polished rice. The polishing process aided the removal of bran and resulted in a decrease in proteins, dietary fiber, lipids, minerals, and phenolic compounds, while simultaneously increasing the starch content. Out of all the cultivars that were evaluated, upland rice had the highest amount of total dietary fiber. Previous research have shown that colored rice has a higher total dietary fiber (TDF) content compared to plain rice, as reported by rice Savitha and Singh (2011). The observed discrepancies in total dietary fibre content across the rice flours of the examined rice cultivars can be attributed to variations in the genetic composition of the paddy plant.

Amylose content of different rice also varied about from 18.40 to 26.50%. According to the classification of amylose content in rice, the Luangpatue white rice was considered as high amylose content rice (>25%) and low amylose content rice was RD43 varieties (Reddy et al., 2016). The amylose content of rice plays a major role in the cooking and pasting properties. Besides that, the glycemic index is also greatly affected by the amylose content (Mir et al., 2020). High amylose content tends to promote retrogradation, forming a more organized and more rigid crystalline structure led to more tolerance to the digestive enzyme, which could lower rate of digestion (Kunyanee and Luangsakul, 2022). Rice flour with a low amylose content typically gives products a moist, supple, and chewy texture. Additionally, puddings, and soft cakes can benefit from these characteristics (Falade and Christopher, 2015). Due to the creation of a stronger three-dimensional network, high amylose rice can give products firmness and crispness, which could be used in foods like snacks, noodles, and extruded goods that require a hard texture (Kraithong and Rawdkuen, 2021; Wang et al., 2016). The estimated food energy is also calculated and presented differently among rice varieties, which is varied from 350.82 kcal/100 g (Upland brown rice) to 362.73 kcal/100 g (RD43 white rice). Study of Nath et al. (2022) also reported that the calories of rice was approximately 360 kcal/100 g.

3.3. Functional properties

Table 2 presents the functional properties of different rice flours including swelling power and solubility at different temperatures, water soluble index, oil absorption index, water absorption index and pasting properties. Swelling power showed the highest value when the white rice at Chumpon province was heated at 85°C (9.61%), while the lowest values was found on Hommali white rice (7.30%). Heating temperature affected the swelling power of rice flour in this study. Higher temperature was processed, the higher swelling power was found, for example, swelling power of Luangpature rice were increased from 5.75% to 9.61% when it was heated from 65°C to 85°C. It is mainly due to the meachnism of leaching of amylose and the mobility of starch molecules. At higher temperature, rice starch could absorp more water and swell (Thiranusornkij et al., 2019). Among two groups of rice, brown rice always showed lower swelling power than white rice at different heating temperatures. It is mainly due to the higher protein content in the outer layers of the brown rice constraining the floury endosperm from swelling (Qadir and Wani, 2023). One of the methods to measuring flour quality is using swelling power, which presents for tendency of a substance to be hydrated and stands (Aidoo et al., 2022). However, the solubility (SB) of brown rice flour showed higher value than white rice flour in the same variety. At heating temperature of 65°C, LWR, UWR, RD43-WR, HWR has SB of 0.045%, 0.093%, 0.044%, 0.030%, while the brown flours in the same cultivar were corresponded to the value of 0.058%, 0.106%, 0.046%, 0.045%. It could be due to the high mineral and soluble components being mainly presence in the outer layer of grain. Interestingly, the upland rice was found to have the highest solubility (0.288%) when it was heated at 85°C. It proves that different planting region could lead to the variousness of functional properties of rice, especially at the high land region could produce high soluble components. Aidoo et al. (2022) also shown the same trend when measuring the swelling power and solubiliy of cassava flours. Swelling power and solubility index are negatively correlative. For creating dough with great elasticity, flours with low solubility indices against strong swelling powers could be used. It also could be used to good advantage as functional ingredients for pastries (Aidoo et al., 2022; Baah et al., 2005). Because of their comparatively high ability to swell and lesser solubility, flour from Luangpatue varities might be employed in products such as bread, pasta, and other viscous foods.

Water absorption index (WAI) is the capacity of the maximum amount of water a food product absorbs and retains (Aidoo et al., 2022). Comparably, WAI showed significantly different among 8 types of rice and Hommali rice flour showed the highest value in the same kind of flour. The ratio of maximum absorbed water and rice flour could be from 3 to 4 times. Hommali white rice sample presented the highest WAI (4.01 g/g), while the lowest WAI value (3.06 g/g) was found in upland brown rice. The research of Li et al. (2020) showed that a possitive linked between water absorption and amylose content in wheat flour. Moreover, due to low content of protein and lipid than other types of rice, which also could increase the capacity of water absorpotion of HWR. High water absorption has the effect of leading materials easier to soften and digest. While the drawback is that it also rise up water activity, which raises the possibility of food spoiling (Ijarotimi and Keshinro, 2012). This suggests that the Hommali white rice flour might be more easily digested and more likely to deteriorate.

Aidoo et al. (2022) also indicated that oil absorption index (OAI) is one of the most important factors determining the flavor retaining in the flours. The rice flour sample have the OAI in the range of 1.70–2.25% and noticeably highest in UBR sample, which was slightly higher than the study of Qadir and Wani (2023) about brown and polished rice samples in India. It also reported that the brown rice has higher OAI than white rice, which corresponded with the results in this study. Polishing could lead to reduce the OAI due to the reduction of protein content which is the main component interact with lipid molecular through hydrophobic interactions (Qadir and Wani, 2023), which consitent with the resutls of higher content of protein in brown rice. The variations in the results may be attributed to the difference in the hydrophilic components of the samples.

Significant difference in water solubility index (WSI) also presented in Table 2, which valued range from 3.387% to 4.103%. The highest WSI was found in HWR, which indicated that this rice could be have high water soluble components and might leaching out during cooking period. A higher WSI could result in a higher value of adhesiveness and stickiness in food products but has a poor ability to maintain the structure of food (Wang et al., 2016). Typically, the development of connection zones by amylose promotes a stiff structure of starch granules, resulting in reduced WSI. Additionally, because the amount of soluble components inside starch molecules is reduced as a result of complexation with proteins or lipids, rice flour can have a lower WSI value. As a result, RD43-BR had the lowest WSI (3.387%), showing a great capacity to retain food structures during cooking.

3.4. *Pasting properties*

Pasting properties of rice flour varied significantly among different types of rice (Table 2). The pasting temperature ranged from 68.10 to 78.25°C. Low amylose content rice flour requires less energy for cooking (Kraithong et al., 2018). Consequently, the low pasting temperature was found in RD43 and Hommali rice varieties ($p < 0.05$). In addition, the lowest and highest peak viscosity values were found in HBR sample (774.5 BU) and RD43-WR (1384.5 BU), respectively. Peak viscosity indicates the ability of the starch granule to bind water via hydrogen bonds (Otegbayo et al., 2014). Increased water binding decreases the free water between swelled granules resulting in more frictional interactions that is measured as higher viscosity. It also gives an estimate of the expected viscosity load to be faced during mixing, which is frequently connected with the quality of the finished product (Maziya-Dixon et al., 2007). Among the same varieties, brown rice always has lower peak viscosity than that of white rice. The increase of starch components due to the removal of rice bran layer could result in the high peak viscosity of rice (Sandhu et al., 2018), which is also positively correlated with the swelling power results at high temperatures. Moreover, low amylose content variety (RD43 rice) had the highest peak viscosity (1384.5 BU for white rice flour and 1083 BU for brown rice flour) in comparison with other varieties at the same type of flour. Increased peak viscosity is brought on by higher breakdown viscosity (Kraithong et al., 2018; Qadir and Wani, 2023). Therefore, RD43 rice samples were also observed to have the highest value of breakdown viscosity [780.5 BU (RD43-BR) and 722.5 BU (RD43-WR)], indicating that they can find wide applications in industries where gelation is strongly desired (pharmaceuticals, adhesives, textiles, paper, paint industries). They can also be used as thickeners, stabilizers, or gelling agents in several products in the food industries (Maziya-Dixon et al., 2007). The ability of leached amylose to reorganize after being exposed to high temperatures is shown by setback viscosity, which also indicates the tendency of starch to retrograde (Otegbayo et al., 2014). The capacity of heated starch to create gel is described. LBR flour (746.5 BU) and HWR flour (361.5 BU) flour had the highest and lowest setback viscosity, respectively. High pasting temperatures may have increased the rate at which starch molecules burst, contributing to the high setback viscosity of Luangpatue rice flours [626.5 BU (LWR) and 746.5 (LBR)]. Setback viscosity has been linked to the texture of cooked rice. Setback value were correlated positively with cooked rice hardness, and negatively with cooked rice stickiness (Devi and Badwaik, 2022). In addition, syneresis or weeping during freeze/thaw cycles are related to high setback. The ability of a substance to produce a viscous paste or gel after cooking and cooling, as well as the resistance of the paste to shear force during stirring, are both indicated by the final viscosity, which is one of the metrics most frequently used to characterize the quality of starch products (Maziya-Dixon et al., 2007). High retrogradation of starch molecules might have contributed to high final viscosity of rice flour by promoting starch re-crystallization process (Kraithong and Rawdkuen, 2021; Maziya-Dixon et al., 2007). The highest final viscosity also was found in flours of Luangpatue rice in white form (1366 BU) and brown form (1206.5 BU), which consistent with result of their amylose content and also indicated that these flours is suitable for producing rice noodles. Kraithong and Rawdkuen (2021) reported that a high final viscosity indicates the great integrity of the structure of commercial rice noodles after chilling. The creation of a three-dimensional network by amylose contributes to the high setback that supports the high quality of rice noodles. The high setback is a result of a strong capability for starch molecules to reassociate after cooking, which gives stability of rice noodles (Detchewa et al., 2022; Kraithong and Rawdkuen, 2021).

3.5. *Antioxidant properties*

After polishing, TPC of rice samples considerably declined. White and brown rice's TPC ranged from 6.74 to 33.64 mgGAE/g and 34.75 to 133.05 mgGAE/g, respectively (Table 2). Upland brown rice varieties had the highest TPC levels, whereas Hommali white rice varieties had the lowest TPC levels. The loss of the bran, pericarp, and germ, which were important sources of phenolic compounds, may have caused the TPC of polished rice grains to decrease (Devi and Badwaik, 2022; Reddy et al., 2016; Shen et al., 2009). Because upland rice cultivars have an abundance of polyphenolic compounds in their bran, which could be seen by the purple-red color of the grain's outer layer in Fig. 1. Therefore, these samples were found to have the greatest TPC of all the cultivars. Our study also supports the previous findings of high antioxidant contents in colored brown rice than the others. In terms of phenolic compounds, pigmented rice varieties are abundant (Devi and Badwaik, 2022; Ratseewo et al., 2019).

DPPH assay's fundamental working theory involves the reduction of the DPPH radical upon acceptance of electrons from the antioxidant compound's –OH groups to hydrazine, which causes the radical's color to change from violet to yellowish (Qadir and Wani, 2023). Similar to the trend of TPC in rice, DPPH radical scavenging activity of rice varied significantly ($p < 0.05$) after polishing. As also shown in Table 2, The DPPH radical scavenging activity of different rice varieties varied from 46.11 ± 0.21% to 89.34 ± 0.88%, The highest DPPH radical scavenging activity was observed for brown upland rice (89.34%), which might have been due to the abundance of pro-anthocyanidin compounds as the flour was processed from colored rice variety (Rocchetti et al., 2022). After polishing, rice flour's ability to scavenge DPPH radicals was shown to have decreased. Polished rice flour's decreased ability to scavenge DPPH radicals may have been impacted by the loss of polyphenol-rich bran (Qadir and Wani, 2023). In addition, the existence of additional bioactive compounds including carotenoids, oryzanol, is linked to rice's antioxidant activity, which showed decrease in rice flours' ability to scavenge DPPH radicals after polishing treatment (Ma et al., 2020; Qadir and Wani, 2023).

The reducing power of rice cultivars varied significantly ($p < 0.05$) from 0.035 to 1.035 μmolFe^{2+}/g (Table 2). Upland brown rice was discovered to have a higher FRAP than Luangpatue brown rice. While white rice from Hommali and Luangpatue was found to have the lowest reducing power. Indicators of high phenolic content in food items include high reducing power activity. According to Melini and Acquistucci (2017), the indigenous rice types with pigments had a higher absorbance, indicating strong reducing and antioxidant properties. The phenolic compounds play a major role as antioxidants and show good activity against oxidative compounds. The total antioxidant capacity, which defines the capacity of diverse food antioxidants in scavenging free radicals, has been proposed to be scrutinizing the health effects of antioxidant-rich foods. Our study suggests that upland brown rice could be potentially ingredients for nutraceuticals foods.

Table 3
Thermal properties of different rice samples.

Varieties	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
LWR	69.29 ± 0.53^{d}	75.10 ± 0.21^{d}	79.13 ± 0.28^{cd}	1.25 ± 0.25^{c}
LBR	69.89 ± 0.06^{d}	76.10 ± 0.10^{f}	79.93 ± 0.18^{d}	1.35 ± 0.05^{c}
UWR	69.93 ± 0.42^{d}	75.40 ± 0.19^{de}	79.67 ± 0.52^{d}	0.38 ± 0.29^{ab}
UBR	71.18 ± 0.36^{e}	75.94 ± 0.47^{de}	79.46 ± 0.77^{d}	0.45 ± 0.17^{ab}
RD43-WR	64.17 ± 0.86^{a}	69.29 ± 0.29^{a}	74.62 ± 1.30^{b}	0.42 ± 0.22^{ab}
RD43-BR	67.33 ± 1.34^{c}	73.23 ± 0.73^{c}	77.87 ± 0.71^{c}	0.61 ± 0.48^{b}
HWR	64.82 ± 0.94^{a}	68.83 ± 1.21^{a}	72.78 ± 1.59^{a}	0.11 ± 0.09^{a}
HBR	66.22 ± 0.50^{b}	70.99 ± 0.41^{b}	75.44 ± 0.18^{b}	0.35 ± 0.13^{ab}

Note: onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and gelatinization enthalpy (ΔH); Different letters in the same column indicate significant difference from each other ($p \leq 0.05$).

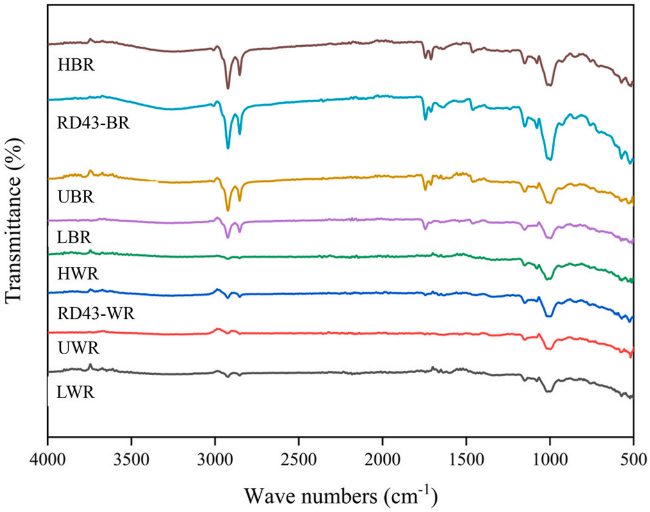

Fig. 2. FTIR spectrum of different rice samples.

3.6. Thermal properties

Thermal characteristics of the four types of brown/white rice flour was studied by DSC and showed in Table 3. All samples had significantly varied onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and gelatinization enthalpy (ΔH) values that ranged from 64.17 to 69.93°C, 68.83–76.10°C, and 72.78–79.93°C, 0.35–1.25 J/g, respectively. These results were consitent with the findings of Falade and Christopher (2015) for studying thermal properties of six Nigerian rice cultivars. Because of the high amylose content (Table 1), the peak and conclusion temperature of the Luangpatue variety were practically higher than other samples. The high gelatinization peak recorded by the DSC was also consistent with the high pasting temperatures obtained from Table 2. The enthalpy value shows the energy is needed to break down starch in the order of the double helix (Sun et al., 2020). Table 3 also shows that the brown rice flour has the higher value of ethalpy than white rice flour in the same cultivar. The presence of non-starches like protein, fat, and fiber, which prevent the production of gelatinization, caused the starch to have a high enthalpy. Among these rice flours, Luangpature brown rice flour has the highest ethalpy value (1.35 J/g), which also to the highest protein content and total dietary fiber as shown in Table 1. Additionally, because rice flour contains the most durable starch structure—a complex of amylose and lipids (amylose-lipid complex) or amylose and protein (amylose protein complex)—the temperature utilized for gelatinization was raised (Kraithong et al., 2018; Qadir and Wani, 2023). Moreover, white rice flour has a high capacity to absorb water and expand, which helps to facilitate the gelatinization process (Sun et al., 2020).

3.7. Fourier transforms infrared spectroscopy (FTIR)

The FTIR spectrum after scanning under the range of 4000–500 cm^{-1}, which was utilized to compare the structures of various rice flours, correlates to the structural position of many chemical bonds inside the molecule. It could be possible to use FTIR to identify chemical composition, clarify the chemical structure, and understand the function of functional groups as bioactive molecules in phytopharmaceutical formulations and nutritional composition (van Soest et al., 1995). Fig. 2 displays the FTIR spectra of various types of rice. Despite showing some variances due to the various nutritional compositions and functional qualities, a pattern that was relatively comparable across different rice flours were also identified. The stretching vibration of the "free" OH group is represented by the weak band at 3750 cm^{-1} (Wójcik et al., 2022). The asymmetric stretching vibration of methylene is linked to the peak at 2982 cm^{-1} that is visible in all samples (Wei et al., 2021). Stretching of the –CH_2 groups was responsible for a strong peak with a wavenumber of 2930–2840 cm^{-1}. The fingerprint zone, which has a specific characteristic pattern for each sample, is represented by the absorption peaks between the wavenumbers of 1800 and 750 cm^{-1}. The presence of fat, polyphenols, secondary protein structures, and carbohydrates are shown by the bands in this region. The benzene ring ($C{=}C/C{=}N/C{=}O$) is confirmed by the band at 1500 to 2000 cm^{-1} in the FTIR spectrum (Bhushan et al., 2023). Beyond this, there are strong structural bonds like C–N and C–C bonds as well as additional structural substituents, alterations, and derived forms (Bhushan et al., 2023; Wei et al., 2021). Two distinct peaks for brown rice were detected in the current investigation in this area, at peak of 1766 and 1676 cm^{-1}, which supports the findings of the antioxidant component concentration in Table 2. Brown rice additionally exhibited a strong band at 1483–1404 cm^{-1}, which is consistent with phenols' C–O deformation (Bhushan et al., 2023). The $C{=}O$, C–C, and C–O–C stretching in starch and lipid are represented by the FTIR bands around wavenumbers 1300-900 cm^{-1}. Aromatic rings are present, as evidenced by the absorption band in the wavenumber from 1000 to 600 cm^{-1} range (Bhushan et al., 2023). Because it is primarily linked to intricate vibrational shifts in the molecule, this area is known as the fingerprint region from which we can determine the type of molecule. The current investigation also showed that the tested rice varieties' peak intensities varied. It was discovered that the peak intensity of the colored rice was higher than that of the white rice. Furthermore, it was discovered that FT-IR spectroscopy was

Table 4
In vitro gastrointestinal digestibility characteristics of selected rice.

Varieties	Luangpatue rice		Upland rice		RD43 rice		Hommali rice	
	White	Brown	White	Brown	White	Brown	White	Brown
***k* (min^{-1})**	2.02 ± 0.10^{abc}	1.82 ± 0.05^{ab}	1.89 ± 0.04^{abc}	1.71 ± 0.19^{a}	2.13 ± 0.09^{bcd}	2.21 ± 0.04^{cd}	2.38 ± 0.02^{d}	2.20 ± 0.32^{cd}
C_∞ (%)	44.59 ± 0.04^{ab}	43.23 ± 0.12^{a}	50.55 ± 0.78^{c}	41.99 ± 0.44^{a}	47.29 ± 0.38^{b}	47.15 ± 2.04^{b}	51.54 ± 2.52^{c}	51.09 ± 3.97^{c}
AUC	61.17 ± 1.99^{cd}	59.80 ± 0.87^{bc}	60.75 ± 1.88^{bcd}	52.84 ± 1.81^{a}	64.02 ± 0.27^{e}	58.84 ± 0.26^{b}	70.18 ± 0.81^{f}	62.51 ± 1.05^{de}
HI	48.94 ± 1.60^{cd}	47.85 ± 0.70^{bc}	48.61 ± 1.50^{bcd}	42.28 ± 1.44^{a}	51.22 ± 0.21^{e}	47.08 ± 0.21^{b}	56.16 ± 0.65^{f}	50.02 ± 0.84^{de}
eGI	66.58 ± 0.88^{cd}	65.98 ± 0.38^{bc}	66.40 ± 0.83^{bcd}	62.92 ± 0.79^{a}	67.83 ± 0.12^{e}	65.56 ± 0.12^{b}	70.54 ± 0.36^{f}	67.17 ± 0.46^{de}

Note: k is kinetic constant, C_∞ is the equilibrium concentration of starch in the simulated small intestinal phase, HI is hydrolysis index, eGI is estimated glycemic index; Different letters in the same row indicate significant difference from each other ($p \leq 0.05$); AUC of white bread is 124.97 ± 0.24.

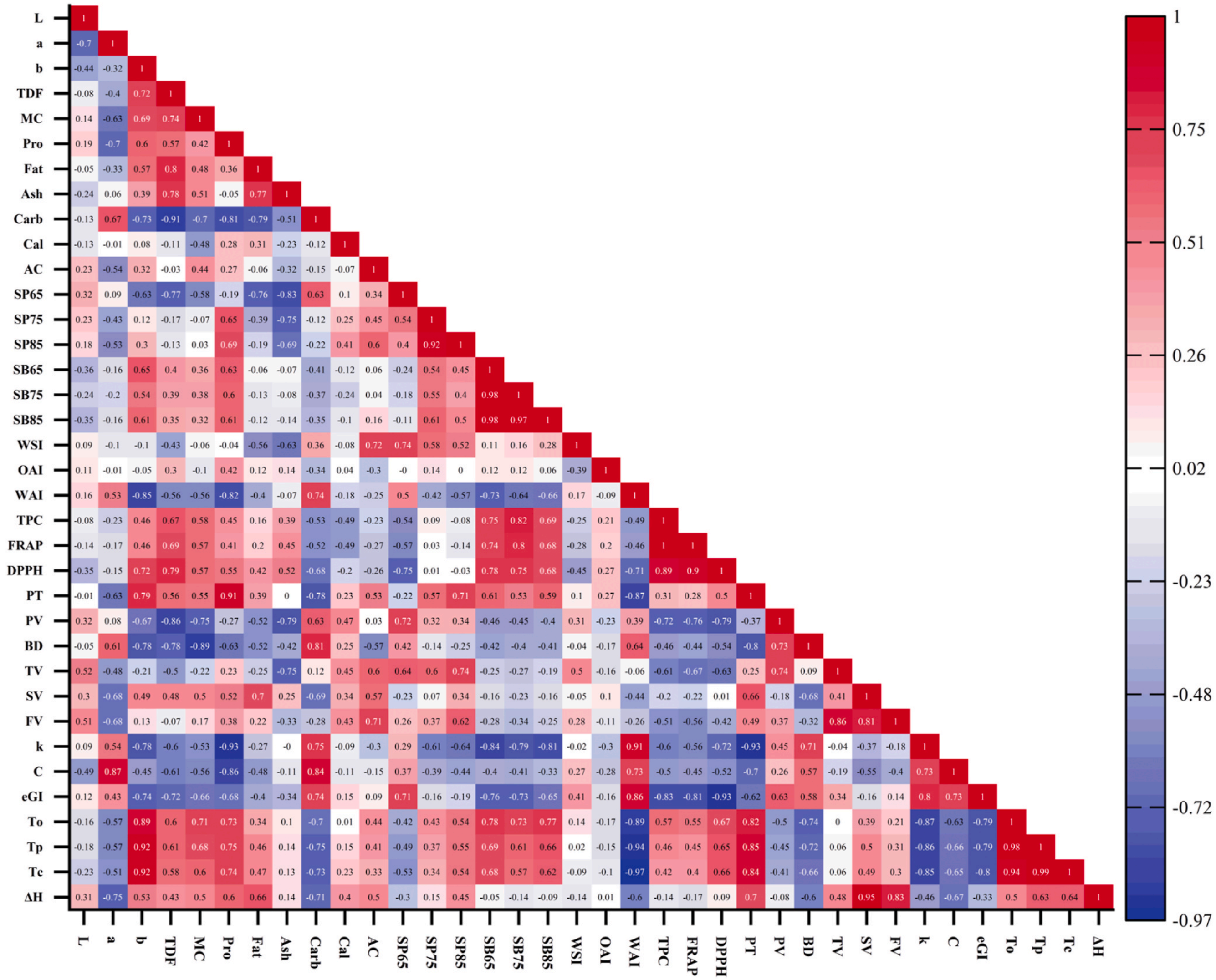

Fig. 3. Correlation test among rice flour characteristics.

an effective technique for identifying and assessing the functional groups of antioxidant chemicals contained in rice samples (Bhushan et al., 2023; Min et al., 2012; van Soest et al., 1995; Wei et al., 2021).

3.8. In vitro gastrointestinal digestibility and estimated glycemic index (eGI)

Table 4 presents the flour's starch digestibility kinetic characteristics for the four rice varietals. Compared to their polished form, brown rice flour from the studied rice cultivars showed slower rates of starch digestion. Rice flour from brown Luangpatue (43.23%) and white Hommali (51.54%) had the lowest and highest hydrolysis percentages (C_∞), respectively. The first-order model could adequately characterize the kinetics of digestion in all rice samples. Varieties of rice have k values (kinetic constant) that ranged from 1.71 to 2.38×10^{-1} min^{-1}. Brown upland rice has the lowest k value, which denotes a slow rate of starch breakdown. The white Hommali rice, in contrast, has the highest k value. Since reduction in C_∞ and k facilitated decrease in hydrolysis index (HI), AUC and estimated glycemic index (eGI) values. As a result, white rice flour's eGI ranged from 66.40 to 70.54, and brown rice flour's eGI ranged from 62.92 to 67.17. Brown upland rice and polished Hommali rice had the lowest and highest eGI, respectively. Noticeably, thte upland rice trait has the lower glycemic index than other brown/white rice flours. Hydrolysis characteristic, including C_∞, HI, AUC and eGI, significantly varied after polishing ($p < 0.05$). The Luangpatue and upland types of rice were found to have low eGI due to their high amylose content. Amylose has a tight molecular structure and could occur intermolecular interactions, which is hence less likely to be digested (Falade and Christopher, 2015; Kunyanee and Luangsakul, 2022). Because of the high amounts of protein and fat molecules that may have encircled starch particles in brown rice flours restricts the enzymatic induced conformation necessary for hydrolysis, the lowest rates of starch digestion may have occurred (Mir et al., 2020; Qadir and Wani, 2023). This may have prevented swelling and restricted the starch granules' interaction with digestive enzymes, which could be seen in the swelling power of brown rice (Table 2). The findings of the present investigation were consistent with the findings of Qadir and Wani (2023), who expected that rice flour would have a higher eGI following the removal of the proteins and lipids in the flour. Furthermore, this is probably because rice flour also contains other substances including phenolics, anthocyanins, and non-starch substances like cell walls that slow down the digestion of starch. The rate of starch digestion may be low in rice types with high phenolic content (Ngo et al., 2022; Qadir and Wani, 2023). It was clearly presented in the upland brown rice, as know as the highest TPC and lowest eGI among eight types of flour. These findings suggested that the ability of anthocyanins and phenolic compounds to affect the digestion of starch. The activity of the amylolytic enzyme has been demonstrated to be inhibited *in vitro* by phenolic

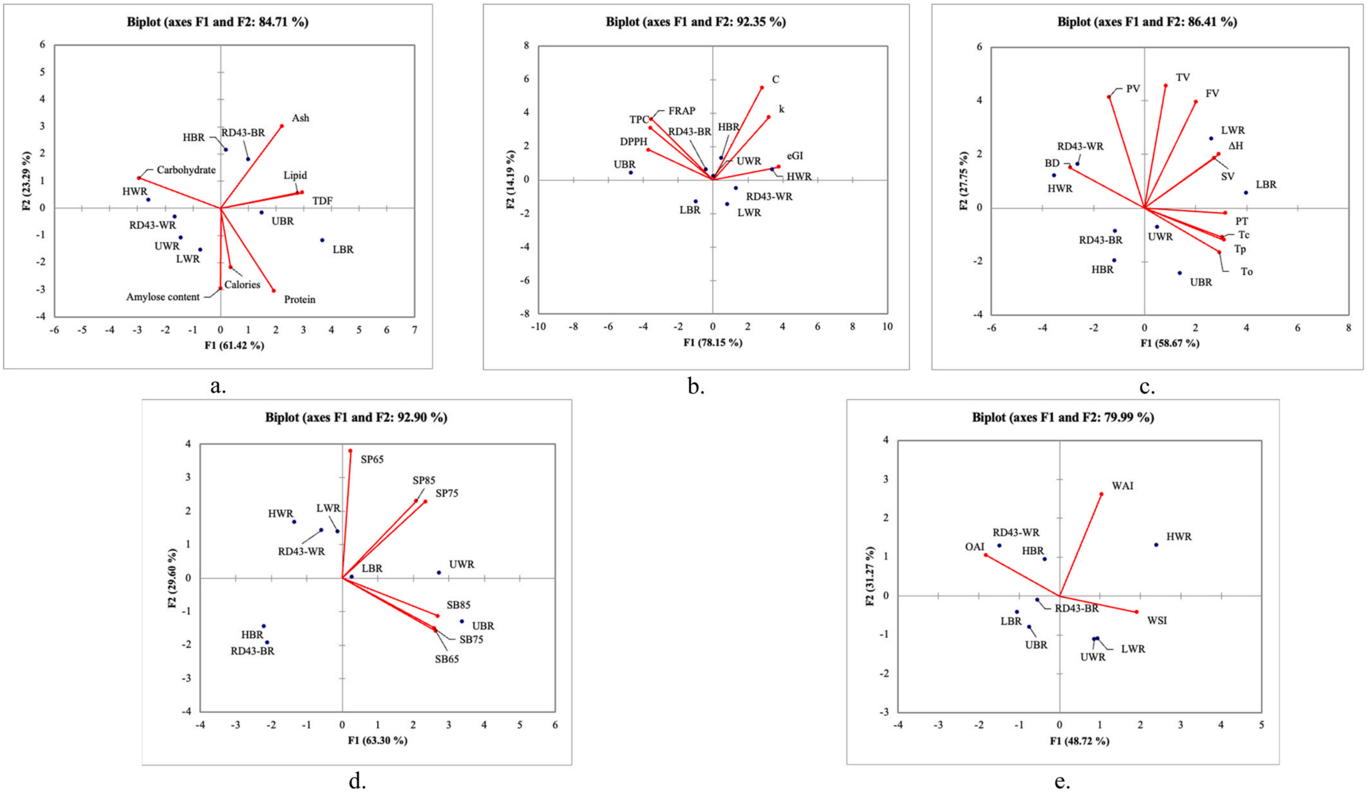

Fig. 4. PCA analysis between rice varieties with nutritional characteristic (a), antioxidant and digestion properties (b), pasting and thermal properties (c), solubility and swelling power (d) and WSI, WAI, OAI (e).

compounds, which are extensively present in fruit and vegetables (Ngo et al., 2022). In contrast to white rice, colored rice has decreased digestibility, as shown by our research, which also showed that polyphenol in rice also could alter starch structure. The risk of acquiring diabetes, cardiovascular disease, and obesity is lower when starches are consumed that are digested slowly (Mir et al., 2020; Ngo et al., 2022). As a result, our research has given valuable information for the creation of slow-release functional food components that can be used in the dietary control of metabolic illnesses including type 2 diabetes.

3.9. Multivariable analysis of rice characteristics

3.9.1. Pearson's correlation

Pearson's correlation coefficient (r) was calculated to determine the relationships between their

properties of different rice varieties (Fig. 3). The color parameters affect the properties of rice varieties. It could be seen that the Hunter b value is the most influenced on the characteristics, as positive correlation with thermal properties, antioxidant properties, while negative correlation with carbohydrate, WAI, and digestibility. It might be due to the b value of grain mainly produced from the nutritional of bran of grain as protein, lipid, and polyphenol compounds (Qadir and Wani, 2023), which could be seen the red and brown color of grain in Fig. 1. Besides, among macronutrients, protein content has strong positively correlated with pasting temperature (r = 0.91), followed by thermal properties, solubility, swelling power, respectively. Otherwise, the negative correlation was found between protein and digestion properties, between protein and WAI. Whereas carbohydrate content showed the opposite trend. Protein could restrict the water absorption of flour; however, it also leads to increase the required energy for gelatinization (Kraithong et al., 2018; Qadir and Wani, 2023). In this study, amylose content mainly affected setback viscosity, finally viscosity and WSI. Reordering of the amorphous regions occurs which potentially affects the digestibility, thermal, and swelling properties of rice flours (Chuwech et al., 2023). However, amylose content led to the formation of amylose entanglements and enhanced the amount of less ordered structure which led to the increase SV, FV. Interestingly, the solubility has negatively correlated with antioxidant properties, which might be due to the soluble antioxidant compounds being mainly presented in rice grain. It also confirms again the results of high antioxidant rice has high solubility index. However, it also makes the mobility of antioxidants to inhibit the hydrolysis enzyme. Polyphenol could modulate the digestion behavior by various mechanism (Ngo et al., 2022). Therefore, the lower eGI was found in antioxidant-rich rice. Estimated glycemic index in selected rice was strongly negatively correlated with antioxidant properties [TPC ($r = -0.83$), DPPH ($r = -0.81$), FRAP ($r = -0.93$)], b value ($r = -0.74$) and total dietary fiber ($r = -0.72$) as well as protein content ($r = -0.62$), while it had positive correlation with WAI ($r = 0.86$), carbohydrate content ($r = 0.74$), swelling power at 65^{o}C ($r = 0.71$). Pasting temperature also negatively correlated with kinetic constant and estimated glycemic index. Besides, the syneresis effect of protein and antioxidant properties is negative effect on peak viscosity and breakdown viscosity. Recent studies also showed that the dietary fiber and protein are of the strong barrier capacity that restrict the digestion of starch by hydrolysis enzyme (Devi and Badwaik, 2022; Reddy et al., 2016; Savitha and Singh, 2011).

3.9.2. Principal component analysis (PCA)

PCA explains the interactions and associations between the parameters by increasing the interpretability. To achieve a higher level of prediction variability, two principal components were selected based on their Eigen values (>1) and the total variation (>80%). Therefore, to get highly accurate predicted, Fig. 4 depicts the link between the varieties with rice characteristic. By grouping the characteristics of rice, the PCA plot shows the variations in rice types and the loading plot highlights the relation between different variables. PCA bi-plot diagram shows the

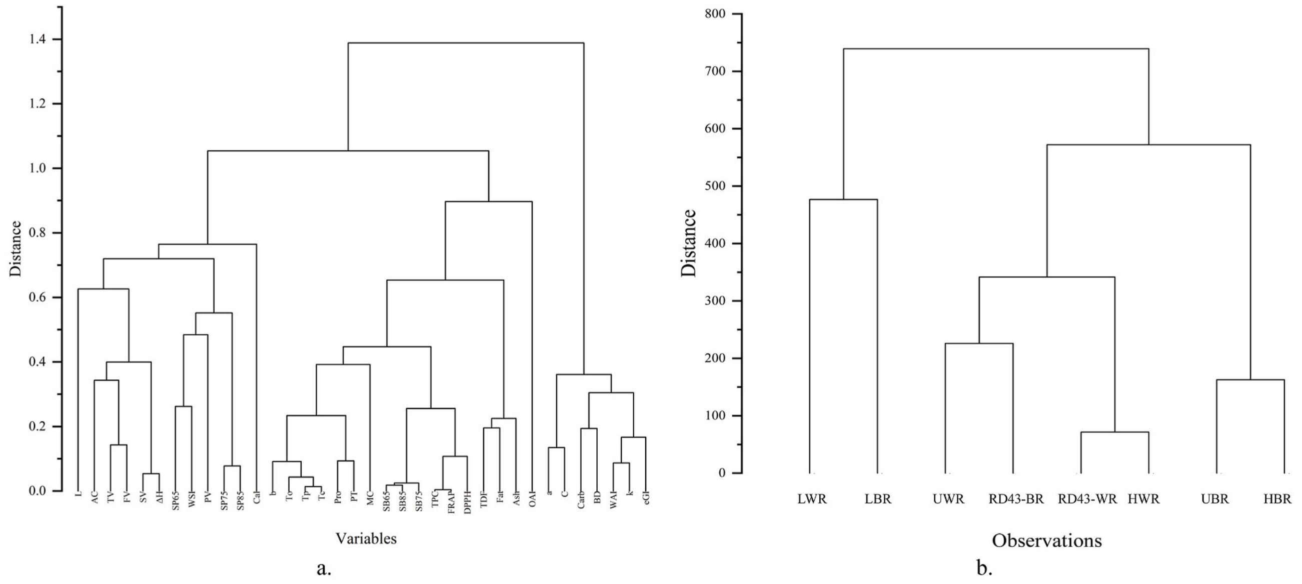

Fig. 5. Dendrogram obtained from hierarchical cluster analysis (a) dependent variables (rice properties) (b) independent variables (rice varieties).

closeness of LBR and UBR with protein, lipid and total dietary fiber content (Fig. 4a), antioxidant properties (Fig. 4b), gelatinization enthalpy, pasting temperature (Fig. 4c), solubility (Fig. 4d), and OAI (Fig. 4e), which are confirmed the previous results. Moreover, the opposite side of the antioxidant properties and digestion behaviors was observed in line with the Pearson's correlation. Polyphenol could reduce the digestion rate of rice products (Ngo et al., 2022). In addition, the setback viscosity and gelatinization enthalpy in PCA biplot shows very close. High amylose content could lead high SB and require higher energy for gelatinizing process (Devi and Badwaik, 2022; Qadir and Wani, 2023). It also confirms that there is a positive correlation between them. Besides, the opposite distribution of OAI and WSI was observed in this study. The trend was in accordance with the study of Qadir and Wani (2023).

3.9.3. Hierarchical cluster analysis (HCA)

The rice flours were categorized using PCA according to varieties and their characteristics, although it was incorrectly found that they might be grouped together mostly based on similarities. By obtaining quantitative information and distributions from the experimental data set, HCA is one of the most effective techniques for identifying the distinct classes (Lee et al., 2012). The average connecting method and Euclidean distance squared were used to create a dendrogram (Fig. 5). The dependent variables and different samples were first clustered by dendrogram, which are shown in Fig. 5a and b, respectively, using the group average cluster technique with Euclidean distance. The dependent variables in Fig. 5a were divided into two main clusters: cluster I included the parameters WAI, eGI, HI, PV, BD, %starch hydrolysis, and kinetic constant, while cluster 2 included other parameters. The tree dendrogram (Fig. 5b) shows the Luangpatue rice (LWR, LBR) is grouped together in one group (group 1), which showed the unique characteristics with other samples. Also, separated into 3 subgroups were samples of another group (group 2) represented by HAC in Fig. 5b: groups 2.1 (UWR, RD43-BR), 2.2 (RD43-WR and HWR), and 2.3 (UBR, HBR). This is also supported by results in the PCA biplot (Fig. 4). It's interesting that the clusters' development matches that of the PCA biplot, which clearly shows substantial grouping.

4. Conclusions

The rice flours from four rice varieties in Thailand differed significantly in their physicochemical, functional, antioxidant, and digestion properties. Although the proximate composition was different between rice varieties, the calories of all samples ranged from 363.16 to 368.70 kcal/100 g. High setback, final viscosity and thermal properties in high amylose rice (Luangpatue varieties) could have the potential to produce pastry products. Interestingly, high antioxidant content and activity were found in upland brown rice, which also led to a reduction in digestion rate and had a medium glycemic index. A similar pattern of FTIR spectrum is also found in different rices; however, there are still some intense peaks in brown rice. Besides, applying multivariate analysis showed the correlation effect of different parameters among samples. It confirms that the high endogenous antioxidants, dietary fiber, and protein of rice could lead to a low digestion rate, which is important for selecting types of rice for diabetic patients. The results obtained from this study provide basic information that is beneficial to the food industry, which might select desirable characteristics based on functional and physicochemical factors for product development. It also suggested that brown rice from upland and Luangpatue varieties could have the potential to produce low-GI products for diabetic consumption. More research should be done in the future on the molecular basis of GI differences, such as differences in functional components and antioxidant profiles, as well as the diversity of starch structure properties, in order to get a better understanding of the differences that happen and affect how these types of rice are digested. *In vivo* glycemic index of these kinds of rice also needs to be studied for confirmation.

CRediT authorship contribution statement

Tai Van Ngo: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization, Writing – original draft. **Kannika Kunyanee:** Writing – review & editing. **Naphatrapi Luangsakul:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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