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Multivariable analysis of physicochemical and functional characterization of four Thai pigmented rice varieties

Tai, N. V., Kunyanee, K. and Luangsakul, N.*

School of Food Industry, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand.

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Abstract Four Thai pigmented rice varieties as know as colored rice — two sources of Manpo red rice [Manpo A (Ounjai company), Manpo B (Thongmanee comapny)], Hommali (red), and Riceberry (purple) were investigated. Result showed the moisture, protein, fat, ash, carbohydrate, and amylose contents of the four types of varieties ranged from 8.62-10.39%, 7.88-9.05%, 1.87-2.90%, 1.67-1.78%, 76.32-79.52%, and 14.17-26.67%, respectively. Abundant fat and protein contents were found in Manpo A, while Manpo B had the highest amylose content. Riceberry and Manpo A varieties were found to have low amylose content. Therefore, the functional properties of the rice varieties were also different. Among the different varieties, Riceberry possessed low swelling power, OAI, and pasting properties; it also exhibited high levels of solubility, WAI, and antioxidant properties. Pearson's correlation illustrated the relationships among the properties of the rice varieties, which revealed that antioxidant compounds could prohibit the gelatinization process. PCA and HCA separated the cultivars into two groups and showed that Riceberry demonstrated significant differences in characteristics from other varieties, which confirmed that the high content of antioxidants could remarkably lower the value of pasting parameters of rice paste. Finally, this study found that colored rice varieties have a high level of antioxidants, which indicates their potential use as nutraceutical foods. The unique characteristics of colored rice warrants further research to facilitate their utilization in appropriate food products to enhance health benefits.

Keywords: Rice, Physicochemical, Functional, Colored variety, Multivariable analysis

Introduction

Over the past few decades, diverse rice varieties have been grown and used for human consumption as major energy sources. Some traditional traits of rice are still maintained in new varieties planted and used to meet consumer demands. Rice varieties are commonly divided into two main groups: colored/pigmented rice and non-colored rice (Ito and Lacerda, 2019). Both are rich in nutrients, including starches, proteins, lipids, minerals, and other components. Recently,

* **Corresponding Author:** Luangsakul, N.; **Email:** naphatrapi.lu@kmitl.ac.th

pigmented rice varieties have been reported to provide enhanced health benefits to consumers due to their high antioxidant content (Zhang *et al.*, 2023a). Pigmented rice varieties come in different colors, including red, black, and purple, primarily visible in the outer layer. Because pigments are present in the bran layer, colored rice varieties have a distinctive property. Red rice contains pro-anthocyanidins, while black rice has anthocyanins, such as cyanidin-3-O-D-glucoside, cyanidin-3,5-diglucoside, peonidin-3-O-D-glucoside, and pelargonidin-3,5-diglucoside (Hosoda *et al*., 2018). Compared to polished and brown rice, black and red rice cultivars have been shown to possess higher levels of antioxidants, including polyphenols and anthocyanins (Chen *et al*., 2012). Zhang *et al.* (2023b) showed that purple rice has a high anthocyanin content, which could promote complexation with starch to reduce the glycemic index. High antioxidant activity could potentially reduce the glycemic index (Ngo *et al.*, 2022). In addition, many studies have demonstrated the antioxidant, anticancer, anti-inflammatory, antiallergic, antimutagenic, and hypoglycemic properties of pigmented rice (Deng *et al*., 2013; Samyor *et al.*, 2017). Rice is consumed not only in directly cooked form but also in processed form as part of other food products. Importantly, in recent decades, there has been considerable interest in studying indigenous foods as potential health promoters in developing countries and in implementing their use in modern medical systems. Therefore, understanding the postharvest features of rice and functional qualities of rice flour is necessary for its use as a functional ingredient of food or in food products, such as breakfast cereal, pasta, cookies, noodles, pancakes, bread, and soup (Ngo *et al.*, 2023). The physicochemical characteristics of flour are of great importance because of its extensive use in the food and non-food industries. These functional properties include physiochemical characteristics that impact the behavior of food macromolecules in food systems. Rice flour has suitable qualities for use as food or a functional food ingredient (Tangsrianugul *et al*., 2019). The functional and antioxidant properties of the three kinds of colored rice in India have been studied and compared; this study also hypothesized that antioxidants could impact the functional properties of rice flours (Reddy *et al*., 2016). Several existing studies have researched the physicochemical, functional, and antioxidant properties of pigmented rice (Burešová *et al.*, 2023; Pradipta *et al*., 2020; Waewkum and Singthong, 2021). However, the interpopulation data on pigmented rice properties are scant. Different rice varieties could lead to different characterizations of flour. Understanding the relationship between their antioxidant, nutritional, and functional properties is crucial.

Recently, Pearson's correlation has been applied as an effective method for understanding the relationships between the different characteristics of rice flour (Qadir and Wani, 2023). It has been used to analyze the inter-relationships among parameters of physically modified rice (Kunyanee *et al*., 2022). Additionally, multivariate analysis, which uses multivariate variables, is a crucial tool for examining the underlying principles of multidimensional data. Principal component analysis (PCA) and hierarchical clustering analysis (HCA), for example, can intuitively clarify the distribution information of multivariate variables and samples during data processing. These distributions, which have recently been widely used in varities classification, can not only disclose the relevant latent information among the variables but also further expose the distribution and classification properties of sample clusters of variables. Thirty-seven flour mill streams were analyzed for quality and rheological properties, and their relationships were studied using a chemometric method (Pojić *et al*., 2014). Metabolization of maize flour has also been studied using these methods, and the results have exhibited good repeatability (Hançerlioğulları *et al.,* 2023). Despite the usefulness of PCA, as well as its similarity to factor analysis (FA) as a variable reduction technique, there are some differences (Reimann *et al*., 2008). FA offers an additional advantage in that it can detect the structure of the relationship between variables and is a good variable selection tool. Key corresponding differential inter-characteristics were investigated. Thus, the main objective was to determine the physicochemical properties, antioxidative properties and pasting properties of rice flour from various Thai pigmented rice cultivars and to elucidate their relationship by multivariable analysis.

Materials and methods

Materials

Four kinds of colored rice cultivars were used in this study, including Manpo A from Ounjai company (Red 1), Manpo B from Thongmanee company (Red 2), Hommali (Red 3) and Riceberry (Purple). These rice paddies were harvested in the same season (October 2022) and de-husked before being transported to King Mongkut's Institute of Technology Ladkrabang. The visual appearance of the grain was taken by a digital camera and then further milled into rice flour (100 mesh) for further analysis.

Determination of flour color

The color of the rice flour was recorded by a colorimeter (Chromameter CR410, Japan) at 10 different points.

Determination of proximate composition and amylose content of rice flour

The moisture content was analyzed by drying in an oven at 105°C. The difference in weight of the sample before and after drying was used to calculate the moisture content. The proximate composition of rice samples was determined by the description method of AOAC (2005), where protein, fat, and ash followed the methods of AOAC 928.08 (conversion factor = 5.95), AOAC 963.15, and AOAC 920.153, respectively. Carbohydrate content was determined using the substation method. The method of Juliano (1993) was used to determine the amylose content.

Determination of swelling power, solubility, water absorption index and oil absorption index

Swelling power (SP) and solubility (SB) were analyzed by putting the mixture of rice flour with water (1% w/w) in a water bath at 65, 75, and 85°C for 30 min (Thiranusornkij *et al.,* 2018). The precipitated and supernatant parts were dried at 105°C and weighed to calculate the swelling power and water solubility of the rice flour. The water absorption index (WAI) and oil absorption index (OAI) were determined following the method of Kraithong *et al.* (2018). One gram of pigmented rice flour was suspended in 10 mL of distilled water (WAI) and soybean oil (OAI) mixed with a vortex mixer for 1 min. The suspensions were incubated at room temperature and then centrifuged at 3000 rpm for 10 min. The sediments were collected and weighed to calcualte the amout of water/oil abosrbed by sample. The WAI or OAI (g/g) was calculated by following Equation 1 & 2.

$$WAI = \text{Water absorbed by sample (g)} / \text{Sample weight (g)} \quad (1)$$

$$OAI = \text{Oil absorbed by sample (g)} / \text{Sample weight (g)} \quad (2)$$

Determination of antioxidant properties

The extraction was performed according to the modified method of Shen *et al*. (2009). In brief, the milled rice powder (50 g) was soaked in 200 mL methanol with 1.5% HCl overnight at room temperature and shaken (150 rpm). The total phenolic content of the rice extract was determined according to a method of Adisakwattana *et al.* (2010). Briefly, the 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. The total phenolic content was measured at 760 nm absorbance. The ferric reducing antioxidant power (FRAP) of flour was determined using the 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. The FRAP value was calculated from the calibration curve of $FeSO_4$. The 2,2-diphenyl-1-picryl hydrazyl (DPPH) radical scavenging activity of pigmented rice was determined using the method described by Reddy *et al.* (2016). The data are expressed as the percentage of DPPH inhibition.

Determination of pasting properties

Pasting parameters were analyzed and recorded by using a Viscograph E (Brabender, Duisburg, Germany). Briefly, 45 g rice flour (dry weight) in exactly 405 g water suspensions was heated from 50 to 95°C at a heating rate of 1.5°C/min, held at 95°C for 15 min, and then cooled to 50°C at a cooling rate of 1.5°C/min at 75 rpm (Fang *et al.*, 2020). The pasting parameters such as peak viscosity, final viscosity and pasting temperature were obtained directly from the instrumental software. The breakdown value is peak viscosity value minus trough viscosity value, while setback value was calculated from difference between the final viscosity and trough viscosity.

Data analysis

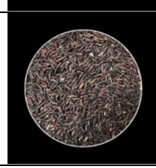
All experiments were performed in triplicate, and the results are reported as the mean ± standard deviation. Analysis of variance (ANOVA) was performed followed by Duncan's multiple range test to examine the statistical significance, $p < 0.05$, using SPSS Version 19 (IBM, SPSS software). Pearson's correlation coefficient and Hierarchical cluster analysis (HCA) and heatmap visualization were derived using Origin Pro 2022 software (Origin Lab Corporation). All the derived independent and dependent parameters were subjected to principal component analysis (PCA), which was performed using the XLSTAT 2022 tool pack of Microsoft Excel. PCA was conducted on different varieties and their properties.

Results

Comparative physicochemical properties of colored rice

Physical appearance showed that the grain had a unique color, even though it was in the color group. Therefore, due to the difference in the appearance of the outer layer, the color parameters of the four kinds of rice were significantly different. Purple rice (Riceberry) had the lowest L, a, and b (Table 1). Among the three varieties of red rice, Manpo B rice had the highest L value, while the lowest a and b values were observed.

Table 1. Physical appearance of grain and flour and color parameters of flours

Varieties	Visual appearance		Color parameters of flour		
	Grain	Flour	L	a	b
Manpo A			79.84 ± 3.48^{c}	6.48 ± 0.41^{c}	9.87 ± 0.44^{c}
Manpo B			83.25 ± 4.82^{d}	5.33 ± 0.54^{b}	9.44 ± 0.56^{b}
Hommali			73.81 ± 1.12^{b}	6.86 ± 0.21^{d}	9.88 ± 0.13^{c}
Riceberry			64.37 ± 1.02^{a}	3.84 ± 0.08^{a}	2.57 ± 0.04^{a}

Different letters in the same column indicate significant difference from each other ($p \leq 0.05$).

The moisture content of the four rice cultivars ranged from 8.62% to 10.39% (Table 2). In addition, the proximate compositions showed significant differences among the types of rice. The ash content fluctuated from 1.67-1.78%. The highest protein and fat contents were found in Manpo A rice, while Manpo B rice had the lowest protein and fat contents. However, the carbohydrate content followed the order Manpo A < Hommali < Manpo B < Riceberry. A remarkable difference in amylose content was observed, from 14.17% to 26.67%. The Riceberry and Manpo A varieties had the lowest amylose content and were not significantly different.

The functional properties of rice flour, including swelling power, solubility, water absorption index and oil absorption index are shown in Table 2. The swelling power and solubility of different rice flours were determined at temperatures of 65-85°C. The swelling power tended to increase with increasing heating temperature. The Hommali cultivar showed a stronger ability to swell than the other varieties. However, the solubility of Riceberry was greatly different, with the lowest value at the same heating temperature (65-85°C). An increase in solubility was also found when the heating temperature increased.

Table 2. Characterization of four colored rice

Rice varieties		Manpo A	Manpo B	Hommali	Riceberry
Proximate compositions					
Moisture content (%)		10.00±0.14^{b}	10.39±0.17^{c}	9.84±0.10^{b}	8.62±0.16^{a}
Protein (%)		9.04±0.08^{c}	7.88±0.23^{a}	9.05±0.12^{c}	8.00±0.63^{b}
Fat (%)		2.90±0.63^{d}	1.87±0.12^{a}	2.53±0.25^{c}	2.12±0.09^{b}
Ash (%)		1.74±0.05^{c}	1.67±0.03^{a}	1.78±0.03^{c}	1.74±0.02^{b}
Carbohydrate (%)		76.32±0.78^{a}	78.19±1.23^{b}	76.80±0.89^{ab}	79.52±0.98^{bc}
Amylose content (%)		14.17±0.20^{a}	26.67±0.69^{c}	20.02±0.32^{b}	14.58±0.16^{a}
Functional properties					
Swelling power (%)	65°C	3.33±0.03^{a}	3.87±0.16^{b}	5.43±0.20^{c}	3.35±0.09^{a}
	75°C	5.16±0.06^{a}	6.476±0.08^{b}	7.55±0.59^{c}	4.50±0.01^{a}
	85°C	7.99±1.31^{a}	7.120±0.88^{a}	7.91±1.22^{a}	6.54±0.19^{a}
Solubility (g/100 g)	65°C	0.044±0.003^{b}	0.034±0.001^{a}	0.046±0.004^{b}	0.146±0.003^{c}
	75°C	0.032±0.007^{a}	0.045±0.003^{a}	0.037±0.003^{a}	0.144±0.004^{b}
	85°C	0.047±0.002^{a}	0.067±0.001^{b}	0.057±0.003^{ab}	0.095±0.008^{c}
WAI (g/g)		3.64±0.10^{b}	4.09±0.15^{c}	3.34±0.05^{a}	4.23±0.07^{c}
OAI (g/g)		2.07±0.04^{b}	1.69±0.04^{a}	2.05±0.10^{b}	1.59±0.02^{a}
Antioxidant properties					
TPC (mgGAE/100 g)		130.26±9.43^{a}	153.34±7.63^{b}	168.78±18.96^{c}	194.25±9.35^{d}
DPPH (%)		81.23±0.38^{c}	80.38±1.33^{b}	77.30±0.78^{a}	91.09±0.71^{d}
FRAP (µmolFe^{2+}/g)		1.04±0.15^{a}	1.21±0.05^{b}	1.30±0.06^{c}	1.29±0.03^{c}
Pasting properties					
Pasting temperature (°C)		78.8±0.85^{d}	75.2±0.45^{c}	72.9±0.37^{b}	70.2±0.48^{a}
Peak viscosity (BU)		837±31^{b}	982±25^{c}	853±35^{b}	147±24^{a}
Trough viscosity (BU)		538±25^{d}	478±44^{c}	402±18^{b}	91±8^{a}
Final viscosity (BU)		944±11^{c}	985±21^{d}	716±12^{b}	199±36^{a}
Breakdown (BU)		299±24^{b}	504±12^{d}	451±14^{c}	56±10^{a}
Setback (BU)		406±24^{c}	606±37^{d}	361±15^{b}	110±24^{a}

Notes: Different letters in the same row indicate significant difference from each other ($p \leq 0.05$); WAI is water absorption index; OAI is oil absorption index; TPC is total polyphenol content.

The water absorption index (WAI) varied from 3.334% to 4.231% and showed significant differences among cultivars. Riceberry showed the highest WAI value, followed by Manpo B rice, Manpo A rice, and Hommali rice. However, there was no significant difference between the WAI values of Riceberry and Manpo B rice. In addition, the oil absorption index (OAI) showed the opposite trend to the WAI. The OAI of Riceberry and Manpo B was lower than the Manpo A and Hommali varieties.

The antioxidant properties of the four rice samples are also shown in Table 2. The TPC, DPPH, and FRAP values ranged from 130.26 to 194.25 mg GAE/g, 77.30 to 91.09%, and 1.036 to 1.295 (µmolFe^{2+}/g), respectively. Riceberry showed the remarkably highest TPC, DPPH and FRAP values. Among the three red varieties, Hommali had the highest TPC and FRAP values, whereas the opposite value was found in the Ounjai sample. Interestingly, the DPPH value among red cultivars showed the opposite trend with the TPC and FRAP values. Evidently, the Ounjai rice has the lowest value of TPC, but it had the highest value of DPPH.

The pasting properties of four rice varieties, including Manpo A, Manpo B, Hommali and Riceberry are shown in Table 2. The pasting temperature, peak viscosity, breakdown viscosity, trough viscosity, setback viscosity, and final viscosity were recorded directly from the Viscograph instrument. It was observed that the pasting temperature was highest (78.8°C) in the Ounjai sample, while Riceberry had the lowest value (70.2°C). In addition, other parameters of the Riceberry sample were remarkably lower than those of the other rice cultivars. Peak viscosity, breakdown value, trough viscosity, setback value, and final viscosity were 147, 56, 91, 110, and 199 BU, respectively. These values were highest in the Manpo variety which is known to be the highest amylose content.

Pearson's correlation showed the relation among the characterization of four colored rice varieties (Figure 1). It was observed that the color parameters were negatively correlated with solubility and antioxidant properties, whereas they were greatly correlated with pasting properties. The opposite trend was observed between the solubility and swelling power at different temperatures. In addition, fat and protein contents are considered inhibitory factors of water absorption. However, oil absorption was promoted by protein and fat ($r > 0.8$). Interestingly, a negative effect was also found between antioxidant properties and pasting properties. In addition, solubility presented the opposite trend with the antioxidant properties of pigmented rice.

Among the chemometrics techniques used in extracting information from original data, principal component analysis (PCA) is the most commonly used. The results showed that the total of the first two components accounted for 84.67%. The first component was 63.84%, and 20.84% of the variation belonged to the second component (Figure 2). The information extracted from the factor loadings revealed that principal component 1 (F1) was color parameters, carbohydrate content, swelling power at 85°C, solubility, WAI, OAI, TPC, DPPH, and pasting properties. Principal component 2 (F2) was dominated by the protein, fat, ash, and amylose contents. In addition, it was also reported that principal component 3 presented swelling power at 65-75°C and FRAP value. Among the different varieties, Manpo B rice was characterized by F2, while the other rice cultivars were affected by F1. The biplot shows the two main clusters created by the closeness between rice varieties and their characteristics. It was shown that purple rice was closely related to antioxidant properties, solubility, and carbohydrate content in the positive of F1. The other properties and varieties were on the negative side of F1, which was confirmed again by HCA (Figure 3). There were 2 classes of rice as Riceberry in the first class, and the second class included Manpo B and Hommali rice. In addition, the Manpo A rice was separated as the subclass of the second class. The combination between HCA and the solar heatmap also showed that the main differences among samples were pasting properties and TPC. The peak viscosity and final viscosity were also dominant for the first main cluster when clustered by characterization. Other pasting properties were also the main subcluster of the other cluster by rice characteristics.

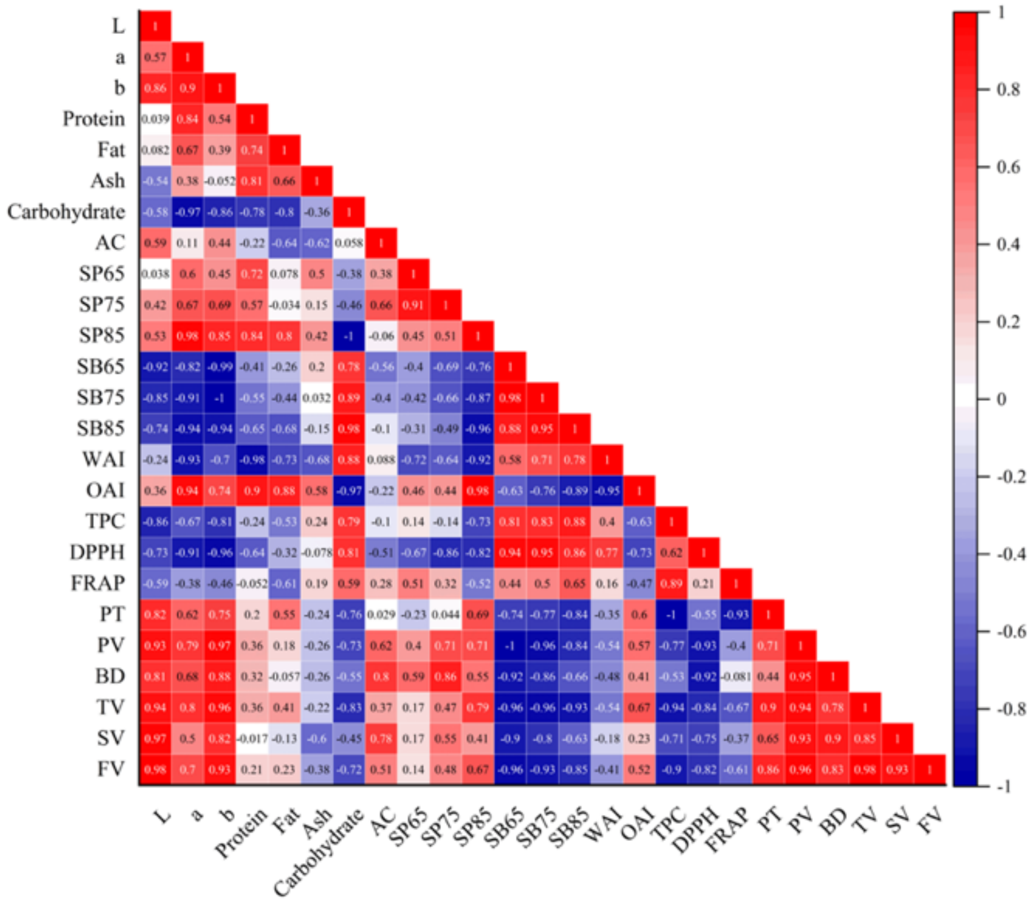


Figure 1. Pearson's correlation among characteristics of four colored rice cultivars

Note: AC is amylose content; SP65, SP75, SP85 are swelling power at 65, 75, and 85ºC, respectively; SB65, SB75, SB85 are solubility at 65, 75, and 85ºC, respectively; PT is pasting temperature; PV is peak viscosity; BD is breakdown viscosity; TV is trough viscosity; SV is setback viscosity; FV is final viscosity.

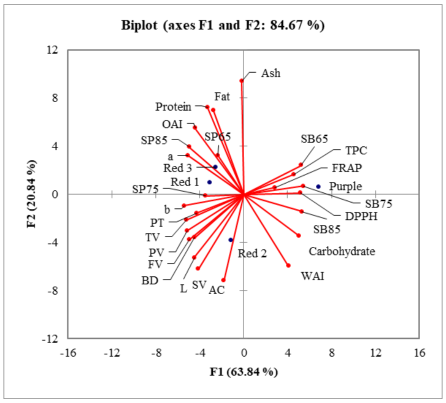


Figure 2. PCA biplot between sample and its characteristics

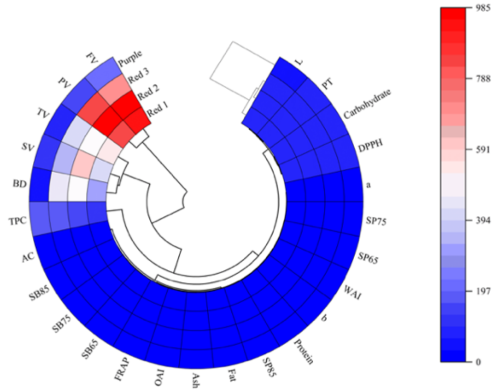


Figure 3. The clustering characteristics of four rice varieties versus their properties by HCA combined with a solar heatmap plot

Discussion

The main difference in value of color parameters due to the visual appearance of grain was recorded. The deep purple color of Riceberry made the flour's color became more darker than other varieties. Besides, it also resulted in different of proximate composition. With the moisture content was approximately 10%, which could lead to enhance the storability of grain and flour (Reddy *et al.*, 2016). The range of protein, fat and carbohydrate of four cultivars also were compared with the report of Kowsalya *et al.* (2022). This report also presented that rice is decent in energy source and protein, as well as also a good food to take in a balanced diet and is sodium-free with less fat and cholesterol. The aleurone protein in rice contains 66% albumin, 27% prolamin, 27% glutelin, and 7% globulin (Tanaka *et al.*, 2004). Besides, depending on the variety, rice bran oil contains approximately 80% unsaturated fatty acids. In order to keep the brain system and cell membranes functioning properly, humans are unable to synthesize these critical fatty acids (Kowsalya *et al.*, 2022). In addition, based on the content of amylose, the Riceberry and Ounjai rice were considered as low amylose varieties, while Hommali and Manpo B rice were known as inter-medium high amylose content (Lal *et al.*, 2021). Amylose content is one of key factors affected the functional properties of flour as well as the digestion behavior (Kunyanee *et al.*, 2022).

During heating process, the starch of rice is gelatinized, which is process of the hydrogen disruption process inside starch molecule and forming new bonds with water molecules lead to swell starch granules. Due to the high amylose content, Manpo B and Hommali rice have high swelling power and low solubility. Because it is primarily found in the center of the granules, amylose preserves the structure of the starch granule. High amylose starch has a more compact granular structure and is less soluble because starch has a harder time spilling outside the granules (Hasjim *et al*., 2012). Besides, the solubility also depends on the other factors as amylose and amylopectin structure, degree of granulation, but also starch components, and antioxidant compounds content (Ngo *et al*., 2022). Li and Zhu (2017) revealed that various components of flours including starch, protein, dietary fiber, minerals, and phenolics may contribute to apparent difference in swelling power and solubility. Therefore, colored rice flour in general had lower swelling and higher solubility than polished white rice flour (Thiranusornkij *et al*., 2019). In addition, the linking between the polyphenol and starch during heating process could reduce the starch aggreation, which reduce the visocity of paste (Erna *et al*., 2022).

The presence of macronutrient as protein and lipid could lead to change WAI and OAI. The inverse trend of WAI and OAI was found in four rice varieties, which also find the similar results with the study of Kraithong *et al.* (2018). The WAI was a result of the numerous hydrophilic groups found in starch molecules, which give food products their softness, smoothness, and viscosity (Kraithong *et al*., 2018). Because of its high protein and carbohydrate content and polar or charged side chains, rice flour tends to have strong hydrogen bonds (Pradipta *et al*., 2020). Additionally, the amylopectin's phosphate groups' negative charges result in an increase in water binding ability (Kraithong *et al.,* 2018; Pradipta *et al*., 2020). Rice flour's high lipid content could potential to enhance OAI by interfering with the hydration of the starch granules with hydrophobic components, in contrast, reducing of WAI was found (Alcázar-Alay and Meireles, 2015).

The different color and growing conditions leaded to the change in antioxidant properties of rice. However, in this study, the antioxidant properties is comparable with the study of Bhat and Riar (2017). High polyphenol content could potential to reduce the glycemic index as well as provide health benefits (Ngo *et al*., 2022). Great diversity in pasting properties among the rice flour samples has been noted. Several pasting parameters of flour are correlated with AAM (apparent amylose content) and antioxidant content, suggesting the important role of starch and antioxidant in flour pasting. It suggested that factors other than starch influenced the pasting properties. Other components such as protein, lipids, dietary fiber, and polyphenols could interact with starch during pasting (Li & Zhu, 2017). The low value of peak viscosity and final viscosity when gelatinization of colored rice flour was probably due to the formation of starch–phenol complexes that interfered with the alignment of polymer chains (Wu *et al.,* 2011). Some researchers believed that phenolic compounds and starch can interact through hydrogen bonding and van der Waals force during pasting (Bhat and Riar, 2017; Ngo *et al.,* 2022; Wu *et al.,* 2011). Therefore, various of pasting properties of different pigmented rice flours to different extents, probably because of the structural diversities of its starch, which determine the ease with which type of polyphenols interact with starch.

Effect of the internal characteristics of four rice varieties were confirmed by multivariable analysis' results. As previous mentioned, the increasing of WAI due to the hydrophilic side chains, which also reduce the ability to bonding with fat molecules (Kraithong *et al.,* 2018; Pradipta *et al.,* 2020). It was confirmed by Pearson's correlation method, which presented negative correlation these parameters among four pigmented rices. Moreover, through analysis physico-functional parameter by PCA and HCA, it proved that antioxidant compounds strongly affected functional properties of colored rice, especially pasting properties. Recently, the report of Chou *et al.* (2019) showed that apple polyphenol might change the pasting properties of starch. It reported that the reducing of pasting parameters as peak viscosity could be due to polyphenol affect intermolecular entanglement and weakening the intermolecular hydrogen bonds between starch molecules. Green tea polyphenol also reduced pasting viscosity, trough viscosity, and final viscosity of rice starch (Wu *et al.*, 2020). It is strongly related to the cross-linking between pigment of rice and starch chains that decreased the amylose leaching and starch recrystallization upon cooling (Erna *et al*., 2022; Wu *et al.*, 2011). Riceberry was reported that have high antioxidant compounds, especially anthocyanin – a water soluble compound (Settapramote *et al.*, 2018). Therefore, the closeness of Riceberry and solubility was found in PCA-biplot. Furthermore, it could provide more evidence that it might due to high free polyphenolic content in Riceberry, which greatly leached out during heating process and affected on pasting properties of their flour.

This study showed that all colored rice traits were rich in the antioxidant compounds, which could be utilized more in food application or nutraceutical products. Besides that, these rice also were found to be a good source of nutrients compared with previous studies. However, due to the differences on nutritional and antioxidative properties which lead to dramatical change on the functional characteristics. Moreover, applying multivariable analysis could increase interpretability covering the most of the explained physico-functional properties within the cultivars. Therefore, the end-use of these flours could be selected depending on their characterization.

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