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Nutraceuticals and bioactive properties of local Java pigmented rice

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Abstract. *Pradipta S, Siswoyo TA, Ubaidillah M. 2023. Nutraceuticals and bioactive properties of local Java pigmented rice. Biodiversitas 24: 571-582.* Pigmented rice is used in nutraceuticals and has health benefits, on the other side, the characterization of local pigmented rice has not been widely observed. This research aimed to determine the nutraceutical and bioactive properties of ten pigmented Indonesian rice varieties (Segreg, Merah SP, Gogo Niti II, Mansur. Merah Wangi, MS Pendek, Super Manggis, Lamongan I, Aek Sibundong, and Seksek). The proximate composition of pigmented rice was performed based on standard methods. The antioxidant activity was carried out using DPPH radical scavenging activity. Morphological characteristics of these pigmented rice were the weight of 1000 grains ranges 17.47-23.10 g, with slender, medium, and bold shape categories. The proximate analysis revealed a significant difference ($p<0.05$) among cultivars, excluding the lipid. Amylose content varied between 17.43-25.71%. The lowest amylose cultivar had a high peak, trough, and final viscosities but a low pasting temperature. The gelatinization enthalpy was 0.83-1.93 J/g, and the thermal properties of the onset were between 78.6-83.60ºC. The peak was 81.90-86.20ºC, and the conclusion temperature was between 86.00-89.80ºC. The functional properties of the water absorption index were 5.1-7.42 g/g. The water solubility index was 2.32-7.32%, the oil absorption index was 0.92-1.67 g/g, and the bulk density was 0.56-0.70 g/cm^3. The total phenolic range was 2.69-9.51 mg GAE/g, and flavonoids were between 0.61-2.31 mg QE/g. Antioxidant activity has been positively correlated with the percentage of flavonoids in phenolics.

Keywords: Antioxidant, gelatinization, phenolic, physicochemical, pigmented rice

INTRODUCTION

Changes in unhealthy diet patterns affect the degradation of human health. One of the popular staple foods in the world which contains carbohydrates is rice (Mahender et al. 2016). Rice is the main crop that provides more than 20% of the calorie needs in the world (Chen et al. 2013). Half of the world's population consumes rice as a staple food, but the other half suffers from at least one vitamin or mineral deficiency. The impact of vitamin and mineral deficiency affects malnutrition in children during the growth period, especially in developing countries. Nutritional needs have been fulfilled in developed countries through fortifying vitamin and mineral deficiency management programs. Otherwise, in developing countries, fortification programs are inconvenient to be implemented. Therefore, an efficient and cost-effective strategy can be an alternative strategy that needs to be achieved to meet the community's nutritional needs. Modification of the nutritional quality of the main cereal crops, such as rice, could be conducted through biotechnology. The quality of rice is important to be determined, considering its potential and ability to provide human nutrition.

The level of public awareness regarding nutritional needs is increasing along with increasing public interest in pigmented rice due to its health advantages. Pigmented rice is a precious crop used in nutraceuticals, pharmaceutical ingredients, and indigenous medicine (Khoo et al. 2017). Pigmented rice contains phytochemical compounds such as phenolic acids, flavonoids, anthocyanins, proanthocyanidins, tocopherols, tocotrienols, γ-oryzanol, and phytic acid that have been known to have antioxidant components, which can scavenge free radicals, further decrease oxidative stress, and protect biological molecules from potential damage (Goufo and Trindade 2014). Recent studies reported that pigmented rice had many biological activities, including amelioration of iron deficiency anemia, antioxidant, anticarcinogenic, antiatherosclerosis, and antiallergic activities (Deng et al. 2013).

Pigmented rice can be used in several food products, including tortillas, beverages, processed meats, puddings, salad dressings, and gluten-free bread (Morales-Martínez et al. 2014). In addition, the extracts of pigmented rice are also used as a food coloring in bread, ice cream, and alcohol (Deng et al. 2013) due to the physiochemical properties of pigmented rice. Rice properties significantly influence product quality. The amylose content affects the temperature of gelatinization, pasting behavior, and viscosity properties (Albarracin et al. 2019). High-viscosity rice flour can be used in foods as a thickener (Ye et al. 2016), while a low gelatinization temperature promotes complete gelatinization upon cooking or steaming rice flour (Houngbédji et al. 2018). The crystallinity of rice flour is related to thermal properties (Zeng et al. 2015). Functional properties, such as a high water absorption index, are required for processing foods of a smooth and soft texture. In contrast, the oil absorption index predicts shelf-life because of its relation to rancidity (Tharise et al. 2014). Various pasting, thermal, and functional properties are determined by chemical composition, such as amylose, lipid, and protein content (Prasad et al. 2012).

The various rice cultivars in Indonesia show the potential for the diversity of physiochemical characteristics, nutrients, and bioactive compounds. Several pigmented rice cultivars have variations in pigment, flavor, physicochemical properties, and nutritional composition depending on the rice genotype and cultivation condition. This study aimed to analyze Indonesia's selected pigmented rice's physicochemical, functional, and antioxidant properties. The results of the study are expected to promote pigmented rice cultivars as functional food products that benefit health. Furthermore, pigmented rice's diversity in physicochemical, functional, and antioxidant properties is useful for rice breeders.

MATERIALS AND METHODS

Ten pigmented rice cultivars from Indonesia were used in this study, i.e., Segreng, Merah SP, Gogo Niti II, Mansur, Merah Wangi, MS Pendek, Super Manggis, Lamongan I, Aek Sibundong, and Seksek. All rice cultivars were grown in the same condition at the Agrotechnopark, Jember University, East Java, Indonesia, with the geographical conditions of 100-200 masl, 2.396 mm/year rainfall, and 84-95% humidity. These plants were cultivated during the rainy season (October-April). The data of agro-morphological plant samples were observed qualitatively (Table 1) and quantitatively (Table 2) before harvesting. All samples were dried, cleaned, packed in plastic, and stored at 4°C.

Rice flour preparation

Dry, rough rice from all cultivars was dehulled and milled using a commercial machine (MB-RC52W, Yamamoto, Japan). The polished rice grains were ground using a hammermill into powders and passed through a 60-mesh sieve (250 m). The rice flour was then placed in a plastic bag and stored at 4°C before analysis.

Physical properties

1000 grain weight and Length-width ratio (L/W)

A thousand-grain weight of randomly selected rice kernels was calculated using an analytical balance (EP-225SM-DR, Precisa, Switzerland). The length-to-width ratio was determined using a micrometer. The L/W value was calculated by dividing the length by the width. Based on the L/W value, the grain shape was categorized by IRRI as follows: slender >3.0, medium 2.1-3.0, bold 1.1-2.0, and round <1.0.

Color parameter

The color parameters were determined using the color reader (CR-20, Konica Minolta, US), measuring lightness to darkness (L*), redness to greenness (a*), and blueness to yellowness (b*). The colorimeter was calibrated with white calibration paper before sample measurement.

Chemical properties

Proximate composition

The moisture of rice flour was determined using a moisture meter (M-25, Ohaus, US). The measurement of lipid content was carried out using a hexane extraction method. Crude protein, fiber, and ash were determined based on the AOAC (2000) standard method, and carbohydrate content was determined by difference.

$$\text{Carbohydrate content (\%)} = 100\% - (\%\,\text{moisture} + \text{ash} + \text{fiber} + \text{protein}).$$

Amylose content

In a 100 mL Erlenmeyer flask, 100 mg samples were mixed with 1 mL of ethanol (95%) and 9 mL of NaOH (1 N). Samples were then heated in the water bath at a temperature of 80-100 C for 10 min. 5 mL of samples were transferred to a 100 mL Erlenmeyer flask, followed by the addition of 1 mL acetic acid, 2 mL iodine, and distilled water to reach 100 mL, then vortex and incubate for 20 minutes. The absorbance was measured at 620 nm using a UV-Spectrophotometer (U-2900, Hitachi, Japan). At the same time, the amylose was determined using the standard curve of potato amylose.

Pasting properties

The pasting properties of rice flour were analyzed using a rapid visco-analyzer (RVA) (RVA-Techmaster, Pertern, Australia). 3 g of dry rice flour in an aluminum canister was mixed with 25 mL of distilled water. The temperature was held at 50ºC for 1 minute before reaching 95ºC over 3.8 minutes. The samples were maintained at 95ºC for 5 min before cooling to 50ºC, where they were maintained for 2 min. A plot of paste viscosity in RVA units (cP) versus time to determine peak viscosity (PV), trough viscosity (TR), breakdown (BD), final viscosity (FV), setback (SB), and pasting temperature (PT).

Thermal properties

Differential Scanning Calorimetry (DSC) (DSC8230, Rigoku, Japan) was used to determine the thermal properties. First, 1:4 was weighed into a DSC aluminum pan and added to distilled water to make flour to water ratio of 1:4. The pan was hermetically sealed and made to stand for 1 h at room temperature, then scanned over the range of 35-120ºC with a heating rate of 10ºC/minute in nitrogen gas. The DSC parameters included the onset (To), peak (Tp), conclusion temperature (Tc), and gelatinization enthalpy (ΔHg).

Table 1. Qualitative agromorphology of Indonesian pigmented rice

Cultivar	Leaf color	Basal sheat	Flag leaf axis	Ligule color	Auricle color	Collar color	Panicle type	Panicle exsertion	Culm color	Culm internode color	Leaf axis	Panicle axis
Segreng	Green	Green	Erect	White	Light green	Green	Open	Just exerted	Green	Green	Intermediate	Intermediate
Merah SP	Dark green	Green	Intermediate	Light Green	White	White	Open	Well exerted	Green	Green	Erect	Droopy
Gogo Niti II	Dark green	Green	Intermediate	White	Light green	White	Intermediate	Well exerted	Green	Green	Erect	Droopy
Mansur	Dark green	Green	Erect	Light Green	Light green	White	Open	Well exerted	Green	Green	Erect	Droopy
Merah Wangi	Green	Green	Erect	White	Light green	White	Compact	Well exerted	Green	Violet lines	Erect	Droopy
MS Pendek	Green	Violet lines	Intermediate	White	Light green	White	Compact	Well exerted	Violet lines	Violet lines	Erect	Droopy
Super Manggis	Green	Green	Intermediate	White	Light green	White	Open	Well exerted	Green	Green	Erect	Droopy
Lamongan I	Green	Green	Intermediate	White	White	White	Open	Just exerted	Green	Green	Intermediate	Droopy
Aek Sibundong	Dark green	Green	Erect	White	Light green	Green	Compact	Just exerted	Green	Green	erect	Droopy
Seksek	Green	Green	Intermediate	Light Green	White	Green	Compact	Just exerted	Green	Green	Intermediate	Droopy

Table 2. Quantitative agromorphology of Indonesian pigmented rice

Cultivar	Panicle length (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Panicle per plant	Plant height (cm)	Culm internode length (cm)	Leaf length (cm)	Leaf width (cm)	Ligule length (cm)
Segreng	19.33 ± 2.52	18.67 ± 2.08	1.33 ± 0.12	8.67 ± 1.53	89.00 ± 5.19	7.50 ± 0.71	25.00 ± 1.65	0.80 ± 0.10	0.57 ± 0.15
Merah SP	24.67 ± 1.61	26.73 ± 1.86	1.37 ± 0.06	6.67 ± 1.53	114.22 ± 0.69	16.03 ± 0.95	33.53 ± 1.27	2.02 ± 0.07	1.97 ± 0.12
Gogo Niti II	27.30 ± 1.67	16.33 ± 0.35	1.23 ± 0.06	7.33 ± 1.53	107.10 ± 2.52	5.93 ± 0.40	27.11 ± 0.94	1.87 ± 0.03	0.98 ± 0.10
Mansur	28.00 ± 1.00	29.13 ± 0.76	1.47 ± 0.06	11.00 ± 1.00	113.67 ± 1.53	5.53 ± 0.38	29.87 ± 1.81	1.93 ± 0.12	1.27 ± 0.08
Merah Wangi	24.70 ± 1.08	25.37 ± 1.10	1.49 ± 0.06	6.00 ± 1.00	112.33 ± 2.08	7.24 ± 0.06	25.70 ± 0.72	1.67 ± 0.06	1.36 ± 0.05
MS Pendek	26.26 ± 0.41	18.63 ± 0.65	1.43 ± 0.06	42.33 ± 2.08	115.22 ± 2.41	6.67 ± 0.15	25.67 ± 0.25	1.50 ± 0.04	1.45 ± 0.08
Super Manggis	23.91 ± 1.41	25.40 ± 0.46	1.03 ± 0.06	38.00 ± 1.00	133.96 ± 2.87	11.17 ± 0.76	34.06 ± 0.92	1.53 ± 0.04	1.23 ± 0.06
Lamongan I	25.67 ± 2.52	25.33 ± 2.08	1.25 ± 0.21	20.67 ± 2.52	106.67 ± 4.57	4.03 ± 0.95	39.67 ± 1.51	1.58 ± 0.06	0.77 ± 0.06
Aek Sibundong	20.73 ± 1.42	24.20 ± 0.66	1.43 ± 0.06	42.67 ± 2.52	78.00 ± 1.00	16.27 ± 0.25	30.27 ± 1.02	1.23 ± 0.06	0.85 ± 0.05
Seksek	25.67 ± 2.52	28.00 ± 2.65	1.13 ± 0.06	14.67 ± 2.52	89.67 ± 6.43	5.57 ± 0.55	33.00 ± 2.65	1.39 ± 0.23	1.40 ± 0.36

Note: Data are the mean ± SD; *n*=3

Functional properties

Water absorption index (WAI) and water solubility index (WSI)

The WAI and WSI were examined based on the Kadan et al. (2008) protocol. One g of rice flour was mixed with 10 mL of distilled water and vortexed for 1 min. The mixtures were heated and stirred in the water bath at 35ºC for 30 min, followed by centrifugation at 3000 rpm. The pellet and supernatant were dried and weighed. WAI was calculated by dividing the weight of wet sediments by the weight of the sample, and WSI was calculated by dividing the weight of dried supernatant by the dry weight of the sample.

Oil absorption index (OAI)

The OAI was determined by Falade and Christopher (2015). One g of rice flour was suspended in 10 mL of corn oil and centrifuged at 4000 rpm for 20 min. After that, the surplus oil was decanted while the residues were weighed. The OAI was calculated by dividing the weight of oil absorbed by the weight of the sample.

Bulk density

Fifty g of rice flour was placed into a 100-mL graduated cylinder and tapped 35 times. The bulk density was calculated as the weight per unit volume of the sample.

Antioxidant properties

Extraction sample

Two g of coarse rice flour was extracted with 6 mL of 50% methanol and macerated on the stirrer at 4ºC for 24 h. The extract was centrifuged at 1000 rpm for 10 min. The supernatant volume was calculated and stored for total phenolic, flavonoid, and antioxidant analysis.

Total phenolic and flavonoid

Total phenolic content was determined using the Folin-Ciocalteu reagent, according to Taga et al. (1984). Five µL of extract were mixed with 45 µL of methanol PA, 1 mL of 2% Na_2CO_3, and 50 µL of 50% Folin Ciocalteu. The mixture was incubated for 30 min and measured at 750 nm. Gallic acid was used as a standard, with mg of gallic acid equivalent (GAE)/g sample.

Total flavonoid content was determined with a slight modification using quercetin as a standard, as Itidel et al. (2013) described. First, 10 µL of the sample was mixed with 40 µL methanol p.a, 400 µL distilled water, and 30 µL 5% NaNO2 and incubated for 5 min. Then the mixture was added to 30 µL of 10% AlCl3 and incubated for 6 min. After that, 200 µL of 1 N NaOH was added with 240 µL distilled water. The solution was measured at 415 nm, and quercetin was used as a standard, with an mg quercetin equivalent (QE)/g sample.

Antioxidant activity analysis using 2,2-diphenyl-1-1picrylhydrazyl (DPPH)

Radical scavenging activity was performed using the DPPH method (Yaqoob et al. 2015). Serial sample extracts (10, 20, 40, 60, and 80 µg GAE/mL) were added to 400 µL 0,5 mM DPPH solution and distilled water until 500 µL. The solution was measured at 517 nm, and the scavenging of free radicals was calculated based on the following formula:

$$\text{Scavenging of free radicals (\%)} = \frac{\text{Absorbance of control} - \text{absorbance sample}}{\text{Absorbance of control}}$$

The percentage of activities was graphed against the logarithmic sample concentration. Sequestered 50% of the DPPH free radicals were interpolated and presented as IC_{50}.

Hydroxyl radical scavenging

Hydroxyl radical scavenging activity was performed using the standard method by Halliwell et al. (1987) with slight modification. Twenty µL 2-deoxy-D-ribose 2,8 mM, 100 µL EDTA 1 mM, 10 µL FeCl3 10 mM, 10 µL H_2O_2 1 mM, 100 µL ascorbic acid and sample extract (30, 60, 90, 120, 150 µL) were mixed, and phosphate buffer was added to reach 1 mL of volume. The mixture was incubated at 37ºC for one hour, and 500 µL 2-thiobarbiturate (ATB) 1% and 500 µL ATC 2.8% were added. The solutions were vortexed and re-incubated at 80ºC for 30 min to produce a pink color. The absorbance was measured at 532 nm. The scavenging percentage was calculated using Eq. 50 µL of ascorbic acid, 1 mM, was used as a standard compound. The percentage of activities was graphed against the logarithmic sample concentration. That which sequestered 50% of the hydroxyl free radicals was interpolated and is presented as IC_{50}.

Statistical analysis

All samples were analyzed in triplicate, except for pasting and thermal analysis. The results were presented as a mean ± standard deviation. An analysis of the variance of the data was carried out by One-Way Analysis of Variance (ANOVA), followed by Tukey and the HSD post-hock test using SPSS version 5.0 (SPSS Inc., Wacker Drive, Chicago, IL, USA). The level of significance was considered to be P<0.05. The correlative bivariate SPSS version 5.0 (SPSS Inc., Wacker Drive, Chicago, IL, USA) was used to perform an analysis correlation of the physical, chemical, pasting, thermal, functional, and antioxidant properties. The level of significance was considered to be P<0.05.

RESULTS AND DISCUSSION

Physical properties

1000 grain weight and Length-width ratio (L/W)

The grain morphology of pigmented rice is shown in Figure 1. The results of the weight of 1000 grains showed significant differences (p<0.05) and varied from 16.06 to 23.10 g (Table 3). Aek Sibundong had the highest 1000 grain weight (23.10 g), followed by Merah SP (22.95 g), Segreng (21.75 g), Seksek (21.41) and Merah Wangi (21.03), while the lowest was Gogo Niti II (17.47). The value of 1000 grain weight between 20 and 30 g is a good characteristic, while those less than 20 g may represent immature, damaged, or unfilled seeds (Yinyuan et al. 2021). The weight of 1000 grains is an important parameter of seed quality, which is effective in sprouting, seed potential, seedling growth, and plant performance (Chen et al. 2021).

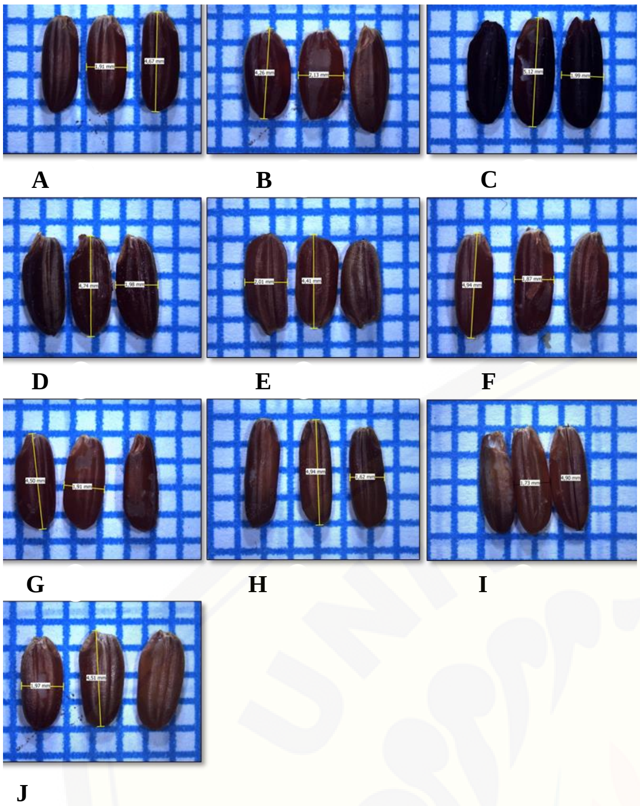

Figure 1. Grain of pigmented rice. A Segreng, B. Merah SP, C. Gogo Niti II, D. Mansur, E. Merah Wani, F. MS Pendek, G. Super Manggis, H. Lamongan I, I. Aek Sibundong, J. Seksek

The length of rice grains ranged from 4.25-5.20 mm, so all samples were short-grain length. The analysis of the L/W ratio was performed to determine the grain's shape; they ranged between 1.97 and 3.06 mm. Based on this result (Figure 1), all samples were classified into three categories, 8 cultivars had medium grain (Segreng, Gogo Niti II, Mansur, Merah Wangi, MS Pendek, Super Manggis, Aek Sibundong, and Seksek), 1 cultivar had slender grain (Lamongan I), and 1 cultivar had bold grain (Merah SP). Falade and Christopher (2015) reported a relatively similar value for the L/W ratio, between 2.82 and 3.06. The size and shape of rice determine the level of marketing feasibility and its commercial value (Yinyuan et al. 2021).

Color parameters

Color parameters (Table 4) consisted of L*, a*, and b*. The L* parameter indicates the lightness of pigmented rice. It varied between 57.07 and 66.67. Gogo Niti II had significantly lower lightness than other cultivars. The a* parameters indicated redness to greenness. It ranged from 0.80-6.47. All samples had a positive value, meaning all samples had redness. MS Pendek had the highest redness value (6.47), followed by Super Manggis (5.70) and Merah Wangi (5.23). The b* parameter indicated a blueness to yellowness. The values ranged from 8.83 and 15.10. All samples had a yellowness in color. The b* parameter was significantly higher in Super Manggis and lowered in Gogo Niti II. The samples differed significantly ($p<0.05$) in the b* parameter.

Table 4. Color parameters of Indonesian pigmented rice

Cultivar	*L**	*a**	*b**
Segreng	64.07^{cd} ± 0.23	4.07^{c} ± 0.21	13.00^{de} ± 0.10
Merah SP	64.57^{d} ± 0.25	4.13^{c} ± 0.06	12.13^{b} ± 0.06
Gogo Niti II	57.07^{a} ± 0.29	0.80^{a} ± 0.10	8.83^{a} ± 0.21
Mansur	66.20^{e} ± 0.61	4.23^{c} ± 0.15	12.80^{cd} ± 0.10
Merah Wangi	64.67^{d} ± 0.31	5.23^{d} ± 0.15	13.93^{f} ± 0.06
MS Pendek	66.67^{b} ± 0.21	6.47^{f} ± 0.06	14.73^{g} ± 0.15
Super Manggis	63.07^{e} ± 0.38	5.70^{e} ± 0.20	15.10^{g} ± 0.10
Lamongan I	64.53^{d} ± 0.08	3.83^{bc} ± 0.06	13.27^{e} ± 0.06
Aek Sibundong	63.37^{bc} ± 0.15	3.90^{bc} ± 0.20	12.53^{c} ± 0.12
Seksek	63.30^{bc} ± 0.20	3.60^{b} ± 0.20	12.57^{c} ± 0.23

Data are the mean ± SD; n=3, values followed by the same letters in the same column are not significantly different ($p<0.05$), *L**: Brightness, *a**: Redness and *b**: Yellowness

Table 3. Physical properties of Indonesian pigmented rice

Cultivar	GW (g)	Length (mm)	Grain length	Width (mm)	L/W ratio	Grain Shape
Segreng	21.75^{cd} ± 0.76	4.63^{abcde} ± 0.08	Short	1.91^{bc} ± 0.03	2.42^{bcd} ± 0.02	Medium
Merah SP	22.95^{d} ± 1.75	4.25^{a} ± 0.16	Short	2.15^{d} ± 0.05	1.97^{a} ± 0.03	Bold
Gogo Niti II	17.47^{a} ± 0.24	5.20^{f} ± 0.10	Short	2.00^{cd} ± 0.11	2.61^{de} ± 0.11	Medium
Mansur	19.90^{bc} ± 0.14	4.84^{bcdef} ± 0.16	Short	1.98^{cd} ± 0.03	2.47^{cd} ± 0.08	Medium
Merah Wangi	21.03^{cd} ± 1.07	4.41^{ab} ± 0.10	Short	2.02^{cd} ± 0.08	2.18^{ab} ± 0.04	Medium
MS Pendek	16.06^{a} ± 0.40	4.55^{abcd} ± 0.08	Short	1.93^{bc} ± 0.05	2.36^{bc} ± 0.02	Medium
Super Manggis	18.33^{ab} ± 0.51	5.05^{ef} ± 0.09	Short	1.84^{bc} ± 0.07	2.75^{e} ± 0.14	Medium
Lamongan I	17.97^{ab} ± 0.27	4.88^{cdef} ± 0.10	Short	1.59^{a} ± 0.07	3.06^{f} ± 0.07	Slender
Aek Sibundong	23.10^{d} ± 0.71	4.98^{def} ± 0.10	Short	1.75^{ab} ± 0.06	2.84^{ef} ± 0.13	Medium
Seksek	21.41^{cd} ± 0.93	4.50^{abc} ± 0.09	Short	1.96^{cd} ± 0.08	2.30^{bc} ± 0.05	Medium

Data are the mean ± SD; n=3, values followed by the same letters in the same column are not significantly different ($p<0.05$), GW: 1000 grain weight and L/W: Length was divided by the width

The color differences in rice flour were influenced by phenolic compounds such as anthocyanin, indicating blueness and purpleness; proanthocyanidins indicating redness; and carotenoids, indicating yellowness (Anggraini et al. 2015). According to Ghasemzadeh et al. (2018), the more the amount of colored pigment in rice flour, the greater the health benefits because they contain antioxidant compounds that can inhibit the formation or reduce the concentrations of reactive cell-damaging free radicals.

Chemical properties

Proximate composition

The results of the proximate analysis and amylose content of pigmented rice are presented in Table 5. The proximate composition of all samples was significantly different, except for lipid content ($p<0.05$). The moisture content ranged from 11.53-13.73%, less than 14%. The moisture content of less than 14% indicated that the samples could be stored longer (Houngbédji et al. 2018). The ash content ranged from 0.77-1.55%. The ash content in a food sample indicates the mineral content in the sample (Thomas et al. 2013). The lipid content ranged from 0.74-0.91%, which is no significant difference among samples. The protein content ranged from 6.54-9.75%, the crude fiber content ranged from 0.87-1.55% and the carbohydrate content ranged from 74.66-78.54%. The carbohydrate content was high in all samples (>70%) and was therefore considered a good carbohydrate source. According to Kaur et al. (2018), pigmented rice flour has more ash, crude fat, protein, and fiber than non-pigmented rice flour.

Amylose content

The amylose content was significantly different ($p < 0.05$) between samples (Table 5). The amylose content ranged from 17.43-25.71%, with MS Pendek and Super Manggis having the highest and Merah Wangi having the lowest. Based on the amylose content, the samples were classified into three categories, one cultivar had low amylose (10-20%), seven cultivars had medium (20-25%), and two cultivars had high (>25%). High amylose rice is characterized by a high-volume expansion during cooking, dry cooked, fluffy, and becomes hard when cooled. In contrast, low amylose rice is characterized by low volume expansion during cooking, moisture when cooked, rough, and soft when cooled (Thomas et al. 2013). High amylose rice provides crispness and firmness to the food product and is suitably applied to hard-textured food products such as extruded products, noodles, and snacks (Wang et al. 2016). Low-amylose rice provides dampness and softness to the product. It is suitably applied to meat, puddings, and soft cakes (Falade and Christopher 2015).

The lowest trough viscosity value was observed in MS Pendek (1241.00 cP), with the lowest peak viscosity (1595.00 cP). The breakdown viscosity reflected the flour paste's resistance to heat and shear. At the same time, the setback indicated the tendency of flour paste to retrograde (Kong et al. 2015). MS Pendek has the lowest breakdown viscosity (354.00 cP), indicating that the network structure of MS Pendek was easy to damage. Merah SP had the highest setback viscosity (1916 cP), indicating that flour pastes can retrograde. The final viscosity represented the stability of cooked flour paste and the ability to form a gel after cooling (Ye et al. 2016). The highest final viscosity was observed in Merah Wangi (4861.00), while the lowest was in MS Pendek (2558.00 cP). According to Ahmed et al. (2015), high setback viscosity of rice flour is suitably applied as sticky rice, noodles, and fried snacks, while high-viscosity rice flour can be applied to salad dressing, pudding, and soft cakes.

Pasting properties

The pasting and thermal properties of rice flour are presented in Table 6. The viscosity patterns of rice flour samples increased to peak, decreased to hold, and rose to final viscosity (Figure 2). Peak viscosity varied from 1595.00 to 3468.00 cP. The highest peak viscosity was observed in Merah Wangi (3468.00 cP). It represented the high ability of starch granules to bind water through hydrogen bonds and showed a high amylopectin content due to the high water-holding capacity (Otegbayo et al. 2014). High amylopectin that required the lowest pasting temperature was found in Merah Wangi (84.55ºC). The trough viscosity (TR) of all cultivars indicated a minimum value at a constant temperature with the highest observed in the Merah Wangi cultivar (2780.00 cP).

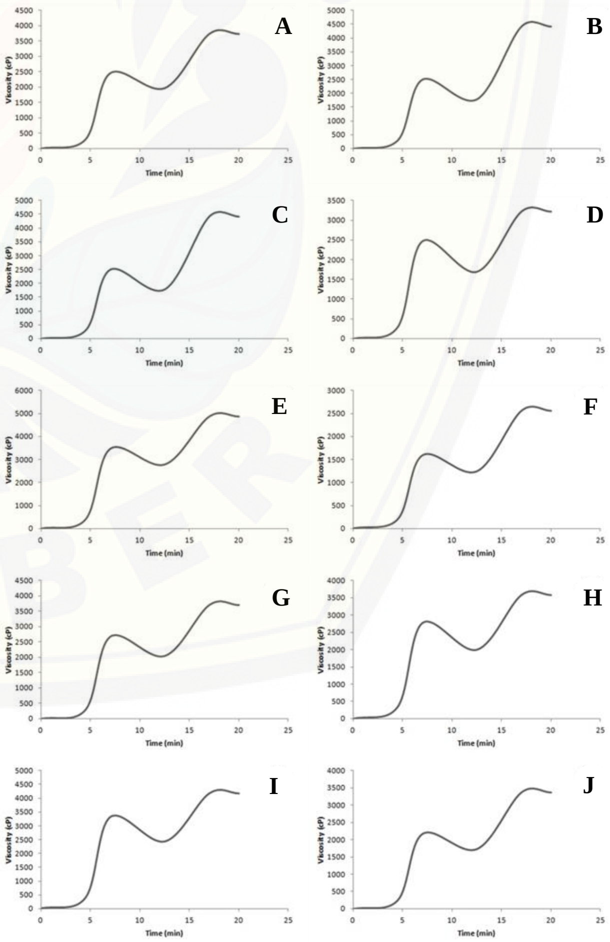

Figure 2. Pasting properties of pigmented rice. A Segreng, B. Merah SP, C. Gogo Niti II, D. Mansur, E. Merah Wani, F. MS Pendek, G. Super Manggis, H. Lamongan I, I. Aek Sibundong, J. Seksek

Table 5. Chemical properties of Indonesia pigmented rice

Cultivar	Moisture (%)	Ash (%)	Lipid (%)	Crude fiber (%)	Protein (%)	Carbohydrate (%)	Amylose (%)
Segreng	11.53^{a} ± 0.25	1.02^{ab} ± 0.10	0.74^{a} ± 0.09	0.96^{a} ± 0.11	8.78^{cd} ± 0.51	77.93^{c} ± 0.57	22.76^{cd} ± 0.16
Merah SP	12.63^{bcd} ± 0.25	1.48^{bc} ± 0.28	0.79^{a} ± 0.12	1.18^{ab} ± 0.16	8.87^{cd} ± 0.61	76.22^{ab} ± 0.36	24.68^{e} ± 0.06
Gogo Niti II	13.23^{de} ± 0.15	1.20^{abc} ± 0.23	0.91^{a} ± 0.07	0.95^{a} ± 0.16	6.97^{ab} ± 0.61	77.68^{bc} ± 0.68	23.11^{cd} ± 0.78
Mansur	11.87^{ab} ± 0.12	1.05^{ab} ± 0.13	0.83^{a} ± 0.04	0.87^{a} ± 0.07	8.26^{bcd} ± 0.74	78.00^{c} ± 0.70	22.68^{c} ± 0.09
Merah Wangi	12.07^{abc} ± 0.31	1.07^{ab} ± 0.10	0.86^{a} ± 0.09	1.22^{ab} ± 0.23	7.47^{abc} ± 0.39	78.54^{c} ± 0.39	17.43^{a} ± 0.22
MS Pendek	12.70^{cd} ± 0.60	1.00^{a} ± 0.09	0.84^{a} ± 0.11	1.21^{ab} ± 0.29	7.88^{abc} ± 0.49	77.58^{bc} ± 1.01	25.71^{f} ± 0.22
Super Manggis	13.73^{e} ± 0.06	1.17^{abc} ± 0.08	0.88^{a} ± 0.11	0.94^{a} ± 0.09	6.54^{a} ± 0.58	77.68^{bc} ± 0.57	25.05^{ef} ± 0.09
Lamongan I	12.37^{bc} ± 0.31	0.92^{a} ± 0.16	0.87^{a} ± 0.09	1.55^{b} ± 0.18	7.68^{abc} ± 0.39	78.17^{c} ± 0.14	22.58^{c} ± 0.06
Aek Sibundong	13.20^{de} ± 0.20	1.55^{c} ± 0.23	0.85^{a} ± 0.09	1.02^{a} ± 0.14	9.75^{d} ± 0.33	74.66^{a} ± 0.25	21.57^{b} ± 0.19
Seksek	12.27^{abc} ± 0.12	0.77^{a} ± 0.08	0.78^{a} ± 0.08	1.07^{ab} ± 0.22	8.08^{bc} ± 0.31	78.10^{c} ± 0.47	23.55^{d} ± 0.07

Table 6. Pasting and thermal properties of Indonesian pigmented rice

Cultivar	PV (cP)	TR (cP)	BD (cP)	FV (cP)	SB (cP)	PT (ºC)	To (°C)	Tp (°C)	Tc (°C)	ΔH_g (J/g)
Segreng	2463.00	1972.00	491.00	3740.00	1277.00	90.80	79.30	85.20	88.30	1.93
Merah SP	2497.00	1782.00	715.00	4413.00	1916.00	90.00	80.00	83.80	87.10	1.55
Gogo Niti II	2769.00	1692.00	1077.00	4457.00	1688.00	89.25	82.40	85.30	88.40	0.86
Mansur	2464.00	1714.00	750.00	3211.00	747.00	88.15	80.10	84.40	88.20	1.45
Merah Wangi	3468.00	2780.00	688.00	4861.00	1393.00	84.55	83.60	86.20	89.50	0.92
MS Pendek	1595.00	1241.00	354.00	2558.00	963.00	90.00	78.60	81.90	86.00	1.14
Super Manggis	2678.00	2047.00	631.00	3704.00	1026.00	90.10	80.90	83.90	87.30	1.28
Lamongan I	2778.00	2002.00	773.00	3587.00	809.00	86.45	82.10	86.10	89.70	1.45
Aek Sibundong	3325.00	2435.00	890.00	4180.00	855.00	85.00	82.50	85.30	88.60	0.83
Seksek	2173.00	1731.00	442.00	3372.00	1641.00	88.34	83.30	86.60	89.80	1.89

PV: Peak viscosity, TR: Trough viscosity, BD: Breakdown. FV: Final viscosity, SB: Setback and PT: Pasting temperature, T_o: Onset temperature, Tp: Peak temperature, Tc: conclusion temperature, and ΔH_g: gelatinization enthalpy

The variation of pasting properties in rice flour is influenced by its composition. Amylose content inhibits swelling and increases the setback value in rice flour due to the three-dimensional network that occurs by re-associating amylose upon cooling (Jamal et al. 2016). High amylose provided low peak, trough, and breakdown viscosity (Ye et al. 2016). The highest amylose (25.71%) with the lowest peak (1585.00 cP), trough (1241.00 cP), breakdown (354.00 cP), and final viscosity (2558.00 cP) was observed in MS Pendek, which had a high pasting temperature (90ºC). In comparison, the lowest amylose (17.43%) with the highest peak (3468.00 cP), and trough (2780.00 cP). The final viscosity (4861.00 cP) was found in Merah Wangi, which had a low pasting temperature (84.55ºC). The other components that influence the pasting properties are lipids and proteins. Amylose-lipid and amylose-protein formation increase the setback and final viscosity. At the same time, these reduce peak and breakdown viscosity (Kaur et al. 2018).

Thermal properties

The thermal profiles of the samples are presented in Figure 3. The gelatinization onset temperature was between 78.60°C and 83.60°C, the peak temperature was between 81.90°C and 86.60°C, the conclusion temperature was between 86.0°C and 89.80°C, while the enthalpy was between 0.83 J/g and 1.93 J/g. This result was similar to the study of Odenigbo et al. (2013).

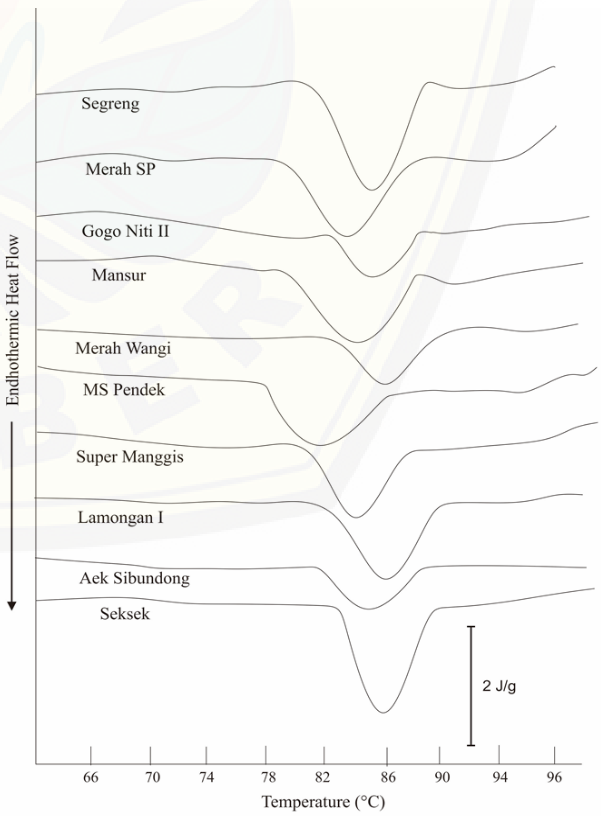

Figure 3. Thermal profile of pigmented rice

A study on flour indica rice showed that the gelatinization onset temperature ranged from 63.42°C to 78.34°C, the peak temperature ranged from 67.66°C to 81.27°C, the conclusion temperature ranged from 74.02-90.18°C, and the enthalpy was 0.62-2.51 J/g. The lowest peak temperature (78.60°C) was observed in MS Pendek, with the lowest amylose (17.43%). In contrast, Merah Wangi had the highest amylose (25.71%), with a high peak temperature (86.20°C). The highest enthalpy was found in Segreng (1.93 J/g), while the lowest enthalpy was observed in Aek Sibundong (0.83 J/g).

High amylopectin branches influence thermal properties in rice flour. High energy was required to disrupt the large crystalline regions of high amylopectin (Singh et al. 2012). Moreover, amylose-lipid and amylose-protein formation increase the gelatinization temperature due to their rigid structures (Morales-Martínez et al. 2014). The size of rice flour also influenced the thermal properties via surface area for binding water molecules (Ye et al. 2016).

Functional properties

The WAI indicated the ability of rice flour to bind water molecules (Jamal et al. 2016). The WAI value of all samples ranged from 5.16-7.42 g/g (Table 7). The result was similar to research conducted by Jamal et al. (2016), that the WAI value of Thai organic rice ranged from 5.38-6.26 g/g. Super Manggis has the highest WAI value, indicating many hydrophilic groups within flour molecules and providing softness and smoothness in the food product (Aprianita et al. 2013). The high WAI content in the rice flour products affects the hydrophobic parts' hydration. Besides, amylose lipid or amylose protein interrupts water binding in rice flour (Falade and Christopher 2015).

The WSI indicated the ability of rice flour to disperse in an aqueous solution during cooking (Shafi et al. 2016). The WSI value of all samples ranged between 2.32 and 7.32% (Table 7). Falade and Christopher (2015) reported a similar result with a WSI value of between 3.11 and 7.89%. Seksek had the highest WSI value, indicating a high amount of water-soluble parts dispersed in an aqueous solution. A higher WSI provided a higher stickiness in the food product (Wang et al. 2016). In addition, the amylose-lipid or amylose-protein complex reduces the WSI because it decreases the soluble parts of flour molecules (Keawpeng and Meenune 2012).

The OAI indicated the ability of rice flour to maintain oil. The OAI value of all samples ranged between 0.92-1.67 g/g. This result was consistent with Sarangapani et al. (2016), who reported an OAI value between 0.88 and 1.39 g/g. Aek Sibundong had the highest OAI value of 1.67 g/g. Rice flour with high lipid content could increase the value of OAI because of the hydrophobic groups within flour molecules (Tharise et al. 2014). The OAI value represents food products' rancidity, mouthfeel, and flavor retention (Falade and Christopher 2015).

The bulk density indicated the rice flour expansion and porosity of the product. The bulk density value of all samples ranged from 0.56-0.70 g/cm^3. The bulk density results are similar to Falade and Christopher (2015), who described the bulk density for Thai organic rice as between values of 0.53-0.89 g/cm3. According to Jamal et al. (2016), high bulk density results in a rough texture of food products, while low bulk density results in a smooth and dense texture. The bulk density also directly influenced the protein content, food preparations, and storage of the sample (Klunklin and Savage 2018).

Antioxidant properties

The total phenolic content (TPC) and total flavonoid content (TFC) are presented in Table 8. The TPC values ranged between 3.52-9.51 mg GAE/g. This result was similar to the previous study by Mahender et al. (2016), that TPC in pigmented rice ranged from 1.65-6.31 mg (GAE)/g. The total flavonoid content (TFC) was between 0.60 and 2.31 mg QE/g. The highest total phenolic and flavonoid levels were observed in Gogo Niti II. Phenolic compounds are secondary metabolites in plants and have many therapeutic uses. The scavenging ability of phenolics was mainly due to hydroxyl groups. It could reduce the oxidation rates of organic matter by transferring hydrogen atoms from their OH groups to the chain-carrying radicals (Rani et al. 2018). Flavonoids are a group of polyphenolic compounds synthesized by the shikimic and malonic acid pathways. They have free radical scavenging activities that prevent oxidative cell damage and have anti-inflammatory, anticancer, and protection against various levels of carcinogenesis (Manukumar and Thribhuvan 2014). Aldose reductase and xanthine oxidase enzymes are phenolic hydroxyl groups and powerful antioxidants categorized as flavonoid compounds (Lin et al. 2016).

Table 7. Functional properties of Indonesian pigmented rice

Cultivar	WAI (g/g)	WSI (%)	OAI (g/g)	BD (g/cm^3)
Segreng	6.32^{bcd} ± 0.11	5.46^{ef} ± 0.30	1.09^{abc} ± 0.12	0.58^{ab} ± 0.01
Merah SP	6.27^{bcd} ± 0.11	4.86^{de} ± 0.16	1.57^{de} ± 0.05	0.61^{abc} ± 0.04
Gogo Niti II	6.56^{cde} ± 0.18	3.11^{ab} ± 0.21	1.06^{abc} ± 0.10	0.65^{abc} ± 0.05
Mansur	6.12^{abcd} ± 0.25	5.78^{f} ± 0.22	0.92^{a} ± 0.04	0.67^{bc} ± 0.03
Merah Wangi	6.89^{de} ± 0.26	3.39^{bc} ± 0.42	0.95^{ab} ± 0.11	0.57^{a} ± 0.04
MS Pendek	5.76^{abc} ± 0.57	4.34^{d} ± 0.38	1.32^{bcde} ± 0.08	0.70^{d} ± 0.04
Super Manggis	7.42^{e} ± 0.30	2.32^{a} ± 0.28	1.35^{cde} ± 0.26	0.56^{a} ± 0.03
Lamongan I	7.11^{de} ± 0.42	2.88^{ab} ± 0.37	1.11^{abc} ± 0.02	0.61^{abc} ± 0.01
Aek Sibundong	5.44^{ab} ± 0.47	4.11^{cd} ± 0.17	1.67^{e} ± 0.24	0.61^{abc} ± 0.04
Seksek	5.16^{a} ± 0.59	7.32^{g} ± 0.43	1.22^{abcd} ± 0.12	0.69^{d} ± 0.03

Data are the mean ± SD; n=3, values followed by the same letters in the same column are not significantly different (p<0.05). WAI: Water absorption index, WSI: Water solubility index, OAI: Oil absorption index, and BD: Bulk density

Table 8. Antioxidant properties and activities of Indonesia pigmented rice

Cultivar	TPC (mg GAE)/g)	TFC (mg QE/g)	TFC/TPC (%)	IC_{50} (µg/µL)	
				DPPH scavenging	Hydroxyl scavenging
Segreng	$4.02^{d} \pm 0.05$	$0.71^{b} \pm 0.02$	$17.71^{a} \pm 0.26$	$59,69^{e} \pm 2,44$	$126.63^{e} \pm 2.60$
Merah SP	$3.52^{c} \pm 0.07$	$0.81^{c} \pm 0.03$	$22.93^{cd} \pm 0.30$	$44.84^{b} \pm 1,92$	$88.70^{c} \pm 1.78$
Gogo Niti II	$9.51^{f} \pm 0.17$	$2.32^{f} \pm 0.03$	$24.35^{d} \pm 0.15$	$32.48^{a} \pm 1,85$	$68.61^{a} \pm 2.66$
Mansur	$4.93^{e} \pm 0.07$	$1.03^{d} \pm 0.03$	$20.94^{bc} \pm 0.44$	$54.31^{d} \pm 2,08$	$113.06^{d} \pm 2.74$
Merah Wangi	$3.39^{c} \pm 0.05$	$0.74^{bc} \pm 0.02$	$21.78^{bc} \pm 0.22$	$52.32^{d} \pm 0,61$	$114.82^{d} \pm 2.73$
MS Pendek	$2.69^{a} \pm 0.05$	$0.61^{a} \pm 0.02$	$22.54^{bcd} \pm 1.33$	$46.54^{bc} \pm 0,97$	$80.82^{b} \pm 2.21$
Super Manggis	$3.93^{d} \pm 0.08$	$0.70^{b} \pm 0.03$	$17.83^{a} \pm 0.47$	$61.87^{e} \pm 0,81$	$115.89^{d} \pm 2.07$
Lamongan I	$3.95^{d} \pm 0.11$	$0.67^{ab} \pm 0.05$	$17.02^{a} \pm 1.51$	$63.77^{e} \pm 0,65$	$142.53^{f} \pm 1.95$
Aek Sibundong	$4.83^{e} \pm 0.05$	$1.00^{d} \pm 0.01$	$20.59^{b} \pm 0.30$	$50.70^{cd} \pm 2,06$	$95.14^{c} \pm 3.81$
Seksek	$3.08^{b} \pm 0.03$	$0.67^{ab} \pm 0.04$	$21.87^{bc} \pm 1.23$	$49.95^{cd} \pm 1,42$	$73.55^{a} \pm 1.42$

Data are the mean ± SD; *n*=3, values followed by the same letters in the same column are not significantly different (*p*<0.05), TPC: Total Phenolic Content, TFC: Total flavonoid content. TFC/TPC: Percentage flavonoid in phenolic and IC_{50}: The antioxidant concentration required to inhibit 50% of radical DPPH and Hydroxyl Radical

The DPPH radical scavenging activity is widely used to measure antioxidant activity in food samples. The degree of discoloration in the analysis indicates the scavenging potential of the antioxidant extract (Yaqoob et al. 2015). IC_{50} represented the antioxidant potential. The IC_{50} values ranged from 32.81-63.87 GAE g/mL (Table 8).

Gogo Niti II had the lowest IC_{50} value, indicating a high antioxidant because the extract at a low concentration of extract (32.81 GAE g/mL) can reduce 50% of radicals. In addition, the DPPH method determines the ability of crude extracts to trap unpaired electron species by transferring hydrogen atoms or electrons. Thus, antioxidant compounds scavenge free radicals into stable compounds (Yaqoob et al. 2015).

The hydroxyl radicals are generated from hydrogen peroxide via the Fenton reaction in the cell. Therefore, it is necessary to study the ability of pigmented rice extract to scavenge hydroxyl radicals generated by the reaction ($Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + OH^+$) in vitro (Ghasemzadeh et al. 2018). The IC_{50} values for hydroxyl-radical scavenging activity were 68.61-142.53 GAE µg/mL. Therefore, Gogo Niti II has the most effective activity to scavenge hydroxyl and DPPH radicals due to its lower IC_{50} value than other cultivars.

Table 9. shows the Pearson correlation of physical, chemical, pasting, thermal, and antioxidant properties. Ratios of length and width had a significant ($p<0.05$) correlation with length (0.82) and width (0.92). The carbohydrate had a significant ($p<0.05$) correlation with ash (0.86) and OAI (0.87). The amylose content also had a significant ($p<0.05$) correlation with pasting temperature (0.80), trough viscosity (0.84), and peak viscosity (0.80). Lipid content had a significant ($p<0.05$) correlation with enthalpy gelatinization (0.81). The total phenolic content has a significant ($p<0.05$) correlation with color parameters L* (0.86), a* (0.84), b* (0.84), and bulk density (0.81). The total flavonoid on phenolic had a significant difference ($p<0.05$) correlation with the IC_{50} value of DPPH radical scavenging (0.94), as well as the IC_{50} hydroxyl radical scavenging (0.87).

Ten pigmented Indonesian rice cultivars had different physicochemical, functional, and antioxidant properties. The results showed that the thermal and pasting properties variation was influenced by proximate and amylose content. The higher values of pasting properties, such as peak, trough, and final viscosity, were found in low amylose rice (Merah Wangi). The lower value of the pasting temperature was found in high amylose rice (Super Manggis and MS Pendek). Lower thermal properties such as T0, TP, and TC in MS Pendek and Segreng were obtained in relatively high amylose content. However, higher enthalpy gelatinization negatively correlates with lipid content (r=0.81).

In conclusion, the study on determining the nutraceuticals and bioactive compounds in Java pigmented rice showed that the physicochemical properties of 10 pigmented rice differed significantly. Cultivars of Aek Sibundong, Merah SP, Segreng, Seksek, and Merah Wangi have good characteristics of seeds. All samples of Java-pigmented rice contain carotenoid, anthocyanin, and proanthocyanidins. The pasting, thermal, and functional properties value of Java pigmented rice was affected by rice's amylose, lipid, and protein content. The lower thermal properties are related to high amylose content, such as in MS Pendek and Segreng. The result of antioxidant properties concludes that Gogo Niti has the highest phenolic, flavonoid, and antioxidant activity for DPPH and hydroxyl scavenging. All the data from this study provides essential information for human nutraceutical health applications.

Table 9. Pearson corelation matrix between physic, chemical, pasting, thermal and antioxidant of Indonesia pigmented rice

	GW	Length	Width	L/W	L*	a*	b*	Mois-ture	Ash	Lipid	Crude fiber	Protein	Carbo-hydrate	Amy-lose	PV	TR	BD	FV	SB	PT	To	Tp	Tc	ΔHg	WAI	WSI	OAI	BD	TP	TF	TF/TP	IC50 DPPH	IC50 Hydroxyl
GW	1.00																																
Length	-0.42	1.00																															
Width	0.25	-0.52	1.00																														
L/W ratio	-0.36	0.82*	-0.92**	1.00																													
L*	0.12	-0.58	-0.06	-0.23	1.00																												
a*	-0.10	-0.43	-0.06	-0.18	0.82*	1.00																											
b*	-0.11	-0.31	-0.26	0.01	0.78	0.96**	1.00																										
Moisture	-0.29	0.54	-0.17	0.37	-0.47	-0.06	-0.07	1.00																									
Ash	0.43	0.12	0.16	-0.03	-0.18	-0.12	-0.24	0.49	1.00																								
Lipid	-0.59	0.65	-0.29	0.52	-0.43	-0.17	-0.15	0.66	0.17	1.00																							
Crude fiber	-0.19	-0.32	-0.41	0.16	0.29	0.19	0.24	-0.12	-0.22	0.13	1.00																						
Protein	0.73	-0.33	0.00	-0.15	0.34	-0.01	-0.08	-0.33	0.44	-0.59	-0.04	1.00																					
Carbohydrate	-0.49	-0.10	0.07	-0.11	0.06	0.08	0.16	-0.45	-0.86*	0.02	0.15	-0.69	1.00																				
Amylose	-0.36	0.10	0.03	0.03	0.02	0.10	0.06	0.37	0.00	-0.13	-0.14	-0.08	-0.15	1.00																			
PV	0.43	0.24	-0.19	0.26	-0.29	-0.25	-0.17	0.13	0.44	0.37	0.03	0.07	-0.24	-0.80*	1.00																		
TR	0.51	0.00	-0.19	0.13	-0.04	0.04	0.13	-0.03	0.28	0.15	0.10	0.11	-0.13	-0.84*	0.92**	1.00																	
BD	0.06	0.60	-0.09	0.38	-0.65	-0.71	-0.70	0.38	0.54	0.62	-0.11	-0.05	-0.32	-0.31	0.66	0.32	1.00																
FV	0.48	-0.02	0.26	-0.16	-0.50	-0.42	-0.43	0.13	0.52	0.22	-0.01	0.01	-0.21	-0.62	0.82*	0.72	0.63	1.00															
SB	0.31	-0.43	0.71	-0.67	-0.46	-0.42	-0.51	0.00	0.12	-0.25	-0.08	-0.06	0.03	0.03	-0.03	-0.07	0.06	0.51	1.00														
PT	-0.27	-0.05	0.35	-0.27	-0.08	0.02	-0.03	0.05	-0.11	-0.35	-0.36	-0.19	0.16	0.80*	-0.74	-0.74	-0.37	-0.40	0.29	1.00													
To	0.23	0.16	-0.17	0.20	-0.44	-0.41	-0.29	0.15	-0.07	0.37	0.17	-0.16	0.05	-0.64	0.67	0.62	0.43	0.56	0.20	-0.73	1.00												
Tp	0.40	0.08	-0.24	0.20	-0.35	-0.52	-0.33	-0.29	-0.26	-0.03	0.14	0.03	0.20	-0.66	0.60	0.59	0.31	0.49	0.18	-0.56	0.83*	1.00											
Tc	0.31	0.08	-0.32	0.26	-0.23	-0.43	-0.25	-0.34	-0.35	0.01	0.24	0.01	0.26	-0.67	0.55	0.56	0.27	0.37	0.04	-0.64	0.82*	0.98**	1.00										
ΔHg	0.26	-0.42	0.08	-0.25	0.31	0.06	0.15	-0.57	-0.49	-0.81*	-0.01	0.18	0.32	0.34	-0.49	-0.33	-0.58	-0.38	0.18	0.50	-0.31	0.13	0.12	1.00									
WAI	-0.36	0.28	-0.20	0.29	-0.15	0.08	0.18	0.19	-0.01	0.48	0.23	-0.66	0.41	-0.14	0.35	0.30	0.27	0.32	-0.11	0.03	0.02	0.02	0.01	-0.17	1.00								
WSI	0.46	-0.49	0.37	-0.50	0.29	-0.05	-0.10	-0.59	-0.31	-0.79	-0.28	0.51	0.03	0.12	-0.45	-0.32	-0.47	-0.35	0.23	0.19	-0.12	0.13	0.14	0.66	-0.78	1.00							
OAI	0.36	-0.08	-0.07	0.02	0.05	0.17	0.10	0.56	0.68	-0.10	0.03	0.49	-0.87*	0.41	-0.02	-0.02	-0.01	0.04	0.09	0.06	-0.13	-0.34	-0.40	-0.13	-0.33	-0.04	1.00						
BD	-0.33	-0.07	0.17	-0.16	0.08	-0.13	-0.24	-0.11	-0.35	-0.07	-0.05	0.09	0.07	0.40	-0.68	-0.75	-0.21	-0.63	0.00	0.18	-0.15	-0.24	-0.16	0.09	-0.68	0.55	-0.07	1.00					
TP	-0.22	0.70	0.07	0.29	-0.86*	-0.84*	-0.84*	0.32	0.25	0.52	-0.38	-0.24	-0.07	-0.05	0.27	-0.07	0.81*	0.37	0.19	0.04	0.23	0.18	0.10	-0.43	0.15	-0.30	-0.22	0.06	1.00				
TF	-0.22	0.59	0.21	0.14	-0.85*	-0.82*	-0.87*	0.33	0.27	0.51	-0.38	-0.23	-0.08	-0.04	0.21	-0.12	0.77	0.38	0.30	0.05	0.24	0.12	0.05	-0.47	0.05	-0.23	-0.19	0.17	0.98**	1.00			
TF/TP	-0.01	-0.22	0.72	-0.58	-0.31	-0.31	-0.53	0.14	0.23	0.15	-0.20	0.02	-0.16	0.01	-0.14	-0.28	0.21	0.21	0.57	0.02	0.12	-0.18	-0.21	-0.38	-0.44	0.21	0.07	0.54	0.35	0.53	1.00		
IC50 DPPH	0.08	-0.01	-0.60	0.39	0.55	0.52	0.72	-0.26	-0.31	-0.22	0.24	0.01	0.23	-0.09	0.11	0.32	-0.37	-0.26	-0.59	-0.12	-0.10	0.16	0.22	0.42	0.37	-0.09	-0.11	-0.48	-0.59	-0.73	-0.94**	1.00	
IC50 Hydroxyl	0.03	0.07	-0.55	0.41	0.41	0.31	0.47	-0.36	-0.18	-0.05	0.33	-0.03	0.28	-0.31	0.33	0.44	-0.05	0.01	-0.55	-0.22	-0.09	0.22	0.28	0.22	0.61	-0.31	-0.31	-0.62	-0.31	-0.46	-0.87*	0.87*	1.00

Note: Data are the mean (+): Positive corelation, (-): Negative corelation, *n: significant correlations at 10%, and **n: significant correlations at 5%

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