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Physicochemical Characterization of Black and Aromatic Rice Germplasm for Parent Selection in Rice Breeding

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ABSTRACT

Rice quality is an important consideration for consumers, particularly regarding taste and nutritional value. The development of high-quality rice varieties requires appropriate parent selection based on physicochemical characteristics. This study aimed to identify physicochemical properties of black rice and aromatic rice as potential parents in rice breeding programs. A total of 25 rice varieties were evaluated, consisting of 10 black rices and 15 aromatic rices. Data analysis included correlation analysis, cluster analysis using R-statistics, and principal component analysis (PCA) to determine relationships among physicochemical parameters. The correlation analysis showed that amylose content was positively associated with Differential Scanning Calorimetry (DSC) parameters and several Rapid Visco Analyzer (RVA) parameters, including setback, peak time, and pasting temperature. Negative correlations were observed between fat and breakdown, amylopectin and trough viscosity, and carbohydrates and gelatinization enthalpy (ΔH), as well as moisture content with Tc, trough viscosity, final viscosity, pasting temperature, and peak time. Cluster analysis grouped the rice varieties into three clusters based on physicochemical traits. PCA results indicated eigenvalues of 2.105 and 1.215 for the first two principal components, explaining a large proportion of total variance. Amylose, breakdown, and ΔH showed the highest positive loadings, while protein exhibited the highest negative loading.

Keywords: Amylose; aromatic rice; black rice; physicochemical characteristics; rice breeding

INTRODUCTION

Rice is one of the major crop species considered essential to the global food system and is recognized as a staple food for the world's population. Rice is one of the major crop species that is essential to the global food system and serves as a staple food for a large proportion of the world's population, particularly in Asia (Mohidem et al., 2022). It is also reported that about 90% of global rice production comes from the Asian region, which confirms the strategic importance of rice as one of the major crop species in that region. Indonesia is one of the countries in the Asian region that grows rice and also possesses a high diversity of rice germplasm. The diversity of rice in Indonesia can be characterized by the diversity in the physicochemical properties and the color of rice, including white rice, red rice, and black rice (Sunaryo, 2024).

In the recent past, consumer preferences regarding rice consumption have started changing. The consumers are looking for rice varieties that are not just the source of carbohydrates but also provide them with additional health benefits. Pigmented rice varieties, especially black rice, have attracted

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considerable attention due to their nutritional and functional properties. The color of rice grains is closely related to the presence of bioactive compounds that contribute to health benefits. Black rice and brown rice contain higher levels of anthocyanins compared with white rice. Anthocyanins are natural pigments that act as antioxidants and have been reported to possess anticancer properties (Hyun and Chung, 2004). Anthocyanins have been reported to exert protective effects against several chronic diseases, including cardiovascular diseases, type 2 diabetes, and certain types of cancer (Panchal et al., 2022). In addition, black rice has been reported to provide hypoglycemic effects (Thilavech et al., 2025). Other studies have shown that black rice consumption may reduce blood cholesterol levels. These functional properties make black rice a promising material for the development of functional food products and nutritionally enhanced rice varieties.

Despite the increasing interest in pigmented rice, most consumers still predominantly consume white rice. The desirable texture, taste, and cooking characteristics of white rice primarily influence this preference. White rice varieties are generally classified into aromatic and non-aromatic types. Aroma is one of the most important quality attributes of rice and strongly influences consumer preference and market value. Aromatic rice produces a distinctive fragrance that is not present in non-aromatic rice varieties. This fragrance is primarily caused by the volatile compound 2-acetyl-1-pyrroline (2AP), which is responsible for the characteristic aroma of aromatic rice. The concentration of 2AP in aromatic rice can be up to ten times higher than that found in non-aromatic rice varieties (Buttery et al., 1986). The presence of this compound plays an important role in the sensory value of aromatic rice.

Aromatic rice is generally of higher economic value due to the aromatic smell and good taste of the cooked rice, as opposed to other varieties of rice. In the international market, aromatic rice plays a crucial role, contributing 15–18% of the overall international rice trade, as noted by Giraud (2013). The demand for aromatic rice is driven by the market demand, which is mainly focused on the sensory value of the rice, including the smell, taste, and texture of the cooked rice. Indonesia also has aromatic rice varieties that are known for their quality as well as their aromatic smell. The aromatic varieties include Bengawan Tunggal, Pandan Wangi, Rojolele, Sintanur, and Batang Gadis (Haryanto & Yoshida, 2008). The availability of aromatic varieties is significant in terms of providing breeding materials to improve the quality of rice.

Physicochemical properties significantly influence the quality of rice, particularly its taste, texture, and cooking ability. Physicochemical properties of rice, including amylose content, gelatinization temperature, and viscosity properties, play an important role in determining rice cooking and eating quality (Kong et al., 2015). The physicochemical properties of rice affect several critical rice qualities, including water absorption capacity, gelatinization, and texture of cooked rice. The combined effect of these physicochemical properties determines rice acceptability by consumers (Bao et al., 2024). Physicochemical property evaluation is considered an essential approach for understanding rice quality and for supporting rice breeding programs, especially for selecting parents.

The development of improved varieties of rice that possess good nutritional, aromatic, and cooking qualities is possible through the selection of parents that exhibit these traits. It is known that black rice possesses good nutritional value, as it contains anthocyanin, while aromatic rice varieties are known for their fragrance and popularity. The development of varieties that possess both the nutritional and aromatic qualities of the two rice varieties through breeding programs has the potential to produce improved rice varieties that possess these traits. However, the success of these breeding programs largely depends on the physicochemical characterization of the parents involved in the breeding programs. It has already been established that pigmented varieties of rice possess good nutritional value, while the aromatic quality of fragrant varieties of rice has also been established in the past. However, the physicochemical characteristics of the two rice varieties, i.e., black rice and aromatic rice, as parental lines in breeding programs have not yet been clearly characterized. Therefore, this study aims to determine the physicochemical characteristics of black rice and aromatic rice parents as a basis for selecting potential parental lines in rice breeding programs.

MATERIALS AND METHODS

The research was conducted from 2022 to 2023 at the Agrotechnology Park, University of Jember, and the Laboratory of Molecular Biology and Biotechnology, Environmental Management Unit (UPA), University of Jember, Indonesia. This study used 10 black rice varieties (Hitam Banjarnegara, Hitam Purbalingga, Pari Ireng, Hitam Bantul, Hitam Purwokerto, Hare Lahok, Hitam Lumajang, Toraja, Hitam Melik, and Hitam Blitar) and 15 aromatic rice varieties (Mentik Wangi, Mentik Wangi Banjarnegara, Mapan 05 Banjarnegara, Situpatenggang, Pare Pulu Mandoti, Batang Gadis, Radah Putih, Mentik Susu Karanganyar, Situbagendit, Celebes, Rojo Lele Delanggu, Pendok, Gilirang, Kurik Kusut Karanganyar, and Genjah Arum). Chemicals used in the analysis included H_2SO_4, HCl, NaOH, hexane, ethanol, iodine solution, pure amylose, D-glucose, and distilled water. Instruments used included a moisture meter (Ohaus MB200), Kjeldahl apparatus, spectrophotometer, Rapid Visco Analyzer (RVA), and differential scanning calorimetry (DSC). Rice grains were dehulled, milled into flour, and sieved through an 80 µm (180 mesh) sieve before analysis.

Amylose content

Amylose content was determined using the iodine colorimetry method (Juliano, 1971). A standard curve was prepared using pure amylose dissolved in ethanol and NaOH, followed by dilution and reaction with iodine solution. The absorbance was measured at 625 nm using a spectrophotometer. For sample analysis, defatted rice flour was treated with ethanol and NaOH, heated, diluted with distilled water, and reacted with iodine solution. The absorbance was measured at 620 nm, and amylose content was calculated using the following equation:

$$\text{Amylose (\%)} = \frac{A}{S} \times \frac{FP}{10} \times V \times 100 \qquad (1)$$

where A is sample absorbance, S is the slope of the standard curve, FP is the dilution factor, and V is the final sample volume.

Moisture content

The moisture content was analyzed using a moisture meter (Ohaus MB200). The sample was subjected to 120°C for 20 minutes. The moisture content was recorded as a percentage for 1.5 g of the sample.

Protein content

Protein content was determined using the semi-micro Kjeldahl method (AOAC, 2019). The procedure involved taking 0.1g of the sample, followed by digestion using K_2SO_4 and concentrated H_2SO_4. After complete digestion, the sample was distilled after the addition of NaOH. The distillate was collected in H_3BO_3 solution containing the indicator methyl red, and the solution was titrated against 0.01 N HCl. Nitrogen content was calculated based on the difference between the titration volumes of the blank and the sample. Protein content was subsequently calculated by multiplying the nitrogen content by a conversion factor of 6.25.

Fat content

The fat content was determined by using the Soxhlet extraction method. A 5 g sample was extracted using 5 hours of n-hexane with filter paper. The solvent was then evaporated, and the residue was weighed to obtain the fat content.

Carbohydrate and amylopectin content

Carbohydrate content was determined using the phenol–sulfuric acid method (Masuko et al., 2005). The sample solution was reacted with phenol and concentrated sulfuric acid, and absorbance was measured at 490 nm using a spectrophotometer with D-glucose as the standard. Amylopectin content was calculated as the difference between carbohydrate and amylose content (Yuan, 2007).

Amylographic properties

Pasting properties were analyzed using a Rapid Visco Analyzer (RVA Tecmaster). A 3 g sample (12% moisture) was mixed with 25 mL distilled water and subjected to a heating–cooling cycle from 50 °C to 95 °C and then cooled to 50 °C. The viscosity curve was used to determine pasting temperature, peak viscosity, trough viscosity, final viscosity, breakdown viscosity, and setback viscosity (Wongsaipun et al., 2018).

Thermal properties

Thermal properties were analyzed using differential scanning calorimetry (DSC). A 3 mg sample mixed with distilled water at a 1:2 (w/v) ratio was sealed in an aluminum pan and heated from 35 °C to 120 °C at 10 °C/min to determine gelatinization parameters, including onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and enthalpy (ΔH).

Statistical analysis

Data analysis was done using correlation analysis, cluster analysis, and principal component analysis (PCA) with R statistical software for the evaluation of the relationship between the 25 black and aromatic rice lines and the observed variables.

RESULTS AND DISCUSSION

Proximate Composition of Black and Aromatic Rice Parents

Amylose is a linear polysaccharide that is constructed by a series of linked glucose units through α-1,4-D-glycosidic bonds. It is one of the main starch components (Naik et al., 2023). The amylose content is one of the significant parameters that reflect the quality of rice since it affects gelatinization as well as texture (Bao et al., 2024). The amylose content is classified into different classes according to Juliano (2006), namely, waxy (0–5%), very low amylose content (5–12%), low amylose content (12–20%), intermediate amylose content (20–25%), and high amylose content (25–33%). Based on the results presented in Table 1, three classes were identified for the tested black and aromatic varieties of rice. The low amylose content varieties were the Batang Gadis, Mentik Susu, and Gilirang varieties. The intermediate amylose group included Hitam Purbalingga, Pari Ireng, Hitam Lumajang, Mentik Wangi Banjarnegara, Mentik Wangi, Mapan 05 Banjarnegara, Pare Palu Mandoti, Situ Bagendit, Celebes, and Genjah Arum. Meanwhile, the high amylose group consisted of Hitam Banjarnegara, Hitam Purwokerto, Hitam Bantul, Hitam Toraja, Hare Lahok, Hitam Melik, Hitam Blitar, and Situpatenggang.

Tabel 1. Proximate Analysis Results of Black and Aromatic Rice Elders

Rice Varieties	Proximate Analysis					
	Amylose (%)	Protein (%)	Fat (%)	Amylopectin (%)	Carbohydrates (%)	Water Content (%)
Padi Hitam Banjarnegara	26.15	10.14	3.57	46.81	72.96	11.93
Padi Hitam Purbalingga	21.07	12.12	3.00	50.11	71.18	12.17
Pari Ireng	24.77	9.40	3.10	48.66	73.43	10.87
Padi Hitam Purwokerto	28.34	12.13	2.13	42.23	70.57	10.97
Hare Lahok	25.31	10.56	2.67	46.31	71.67	11.10
Padi Hitam Bantul	30.48	12.49	5.83	32.3	62.78	12.19
Padi Hitam Lumajang	21.60	10.49	3.00	51.76	73.36	11.33
Toraja	26.95	10.30	3.40	45.06	72.01	11.10
Padi Hitam Melik	30.10	10.86	3.33	43.8	73.90	12.40
Padi Hitam Blitar	25.17	12.96	1.67	46.97	72.14	11.83
Mentik Wangi	21.66	6.50	2.84	55.22	76.88	11.15
Mentik Wangi Banjarnegara	21.81	8.16	3.13	53.7	75.51	10.10
Mapan 05 Banjarnegara	23.94	7.23	2.49	52.43	76.37	11.15
Situpatenggang	25.24	8.32	3.20	48.83	74.07	10.17
Pare Pulu Mandoti	21.16	7.10	2.89	51.88	73.04	12.10
Batang Gadis	19.54	7.00	2.62	57.89	77.43	11.18
Radah Putih Karanganyar	25.91	7.10	2.93	49.23	75.14	10.17
Mentik Susu Karanganyar	14.24	8.17	3.75	59.94	74.18	11.10
Situbagendit	21.48	7.23	3.00	54.17	75.65	11.10
Celebes	21.76	7.12	3.04	52.7	74.46	12.10
Rojo Lele Delanggu	23.17	6.10	2.33	54.36	77.53	11.15
Pendok	25.63	7.10	2.16	50.19	75.82	10.17
Gilirang	16.17	6.12	2.45	61.2	77.37	11.17
Kurik Kusut Karanganyar	25.30	7.19	2.94	50	75.30	12.40
Genjah Arum	23.73	6.52	2.15	52.84	76.57	12.15

The highest amylose content was found in the Hitam Melik variety (30.10%), while the rice variety with the lowest amylose was Mentik Susu Karanganyar (14.24%). Hebishy et al. (2024) reported that variations in amylose content in rice are the main factors that can affect pasting properties and gelatinization properties. It is known from previous research that rice with low amylose character will experience swelling faster than rice with high amylose (Ma et al., 2024). As a result, rice with a high amylose content will have a soft texture when cooked and harden when cold. Rice with a low amylose content is soft and sticky, whereas rice with a medium amylose content is soft but not sticky (Huang et al., 2023). The diversity of amylose content in Indonesian aromatic rice is consistent with previous literature, which states that amylose content in rice is influenced by variety and environmental factors (Aka et al., 2025). In this study, the Gilirang variety had the highest amylopectin at 61.2%. Amylopectin is difficult to analyze because it is a starch fraction that is insoluble in water and has a tendency to form water-insoluble aggregates (Kang et al., 2003). Meanwhile, high amylopectin will increase swelling power and reduce the tendency of starch to form a gel (Kang et al., 2022).

Based on the results of the carbohydrate analysis, the sample indicated that the carbohydrate content was mostly above 70%, with only one variety, Hitam Bantul, showing a carbohydrate content below 70%. This indicates that almost all samples are very good for use as an energy source (Adebooye, 2008). The results of the analysis of the protein content of the rice samples ranged from 6.10% to 12.96%. The results of the fat content analysis in this study ranged from 2.13% to 5.83%. Amylose can inhibit the swelling of starch granules by forming a complex bond between lipids and amylose (Xiang et al., 2023). The presence of lipids and proteins in flour can result in the formation of a complex bond between amylose and lipids or proteins that can reduce peak viscosity and damage but increase the breakdown and final viscosity (Duan et al., 2023). The highest moisture content of 12.40% was observed in Melik Hitam and Kurik Kusut Karanganyar rice. All varieties showed moisture contents below 14%, indicating that all tested varieties have the potential for longer storage (Mirani et al., 2013).

Thermal Properties of Black and Aromatic Rice Parents

During the heating process, the starch granules will absorb water and swell as the enthalpy temperature is passed. Starch granules can't convert back into their original form, which is known as the gelatinization process. Crystalline melting and gelatinous starch are two signs of the gelatinization process (Scott & Awika, 2023). In the process of gelatinization, a hydrogen bond occurs between the hydroxyl group in the double helix molecule so that starch is damaged so that hydrogen bonds will form new ones with water molecules. This phenomenon occurs because the bending of starch granules increases the rate of starch granule rupture, which in turn enhances the solubility of starch molecules (Bian & Chung et al., 2016).

The DSC method is a technique that can be used to analyze the gelatinization temperature. This analysis uses a sample of rice flour and then adds water to the sample and puts it in a heated calorimetric pan. The data obtained were further grouped into onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and enthalpy of gelatinization (ΔH), which were the same as the parameters of the amylose-lipid transition complex. The presence of gelatinization temperature is one of the important indicators that can affect the quality of cooking rice. A high amylose value means that the required gelatinization temperature is low; meanwhile, when the amylose amount is low, it means that gelatinization temperature, gel consistency, and pasting properties will have a significant effect on the quality of rice. The gelatinization temperature observed in this study consisted of onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and enthalpy of gelatinization (ΔH). DSC analysis and the highest amylose content were found in the Hitam Bantul varieties,

Tabel 2. Results of DSC and RVA analysis of Black and Aromatic Rice Elders

Varietas Padi	DSC						RVA				
	T0	ΔH	TP	TC	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time	Pasting Temp
Padi Hitam Banjarnegara	85.4	2.33	88.7	91.8	1379	898	481	2992	1613	6.73	91.40
Padi Hitam Purbalingga	85.3	3.49	88.7	92.2	1980	1048	932	3030	1050	6.80	90.75
Pari Ireng	87.8	3.39	90.9	94.4	1100	678	422	1000	1000	5.00	81.45
Padi Hitam Purwokerto	85.3	2.79	88.9	91.2	902	749	153	2077	1175	7.33	93.10
Hare Lahok	87.2	3.4	92.0	96.2	1789	1058	731	2193	404	6.80	87.85
Padi Hitam Bantul	85.9	4.8	89.8	93.8	1567	909	658	1677	101	5.20	80.75
Padi Hitam Lumajang	77.9	2.5	82.3	87.2	806	553	253	1349	534	6.67	91.45
Toraja	76.2	2.4	94.2	98.5	1737	1433	304	1859	122	6.07	85.05
Padi Hitam Melik	87.5	4.0	90.5	94.7	1237	726	511	1011	226	4.87	81.30
Padi Hitam Blitar	87.5	4.07	90.5	94.7	1398	892	506	2548	1150	6.93	92.15
Mentik Wangi	84.8	3	89.3	92.9	1917	1895	22	3387	1470	10	88.5
Mentik Wangi Banjarnegara	84.8	3	89.3	92.9	1917	1895	22	3387	1470	10	88.5
Mapan 05 Banjarnegara	85.2	2.1	90.8	94.2	1393	1158	235	2593	1200	7.4	93.1
Situpatenggang	86.6	2.2	90	93.1	2400	1271	1129	2870	470	6.33	85.04
Pare Pulu Mandoti	74.2	3	79.2	84.4	1811	1044	767	1434	377	4.27	72.15
Batang Gadis	84.9	2.4	87.9	91.9	3066	1843	1223	3748	682	6.8	85.7
Radah Putih Karanganyar	76.9	3	87.3	83.9	1465	1439	26	3601	2136	9.4	92.8
Mentik Susu Karanganyar	88.8	3	92.6	96.9	1709	1140	569	1948	239	6.07	87.1
Situbagendit	88.3	2	92	93.8	2357	1463	894	2941	584	6.53	87.2
Celebes	84.8	3	89.3	92.9	2424	1444	980	3631	1207	7.07	90
Rojo Lele Delanggu	79.5	1.6	98.3	106.7	2416	1465	951	2986	570	6.73	77.15
Pendok	84.7	4.2	89	93.7	2243	1238	1005	2459	216	6.6	87.2
Gilirang	78.6	3	83.4	87.6	2917	1599	1318	3618	701	6.53	90
Kurik Kusut Karanganyar	78.1	4	85.6	89.9	2212	1445	767	3165	953	6.87	90.65
Genjah Arum	85	3.4	89.7	93.8	1891	1273	618	2814	923	6.87	90.8

including To, Tp, and Tc, ΔH was 85.9ºC, 89.8ºC, 93.8ºC, and 4.8 Jg^{-1}. While, for the rice variety with the lowest amylose content (Mentik Susu Karanganyar), the lowest DSC analysis results were 88.8ºC, 92.6ºC, 96.9ºC, and 3 J/g^{-1}.

According to Juliano (1992), there is a relationship between the gelatinization temperature and the time in the rice cooking process. This means that a higher gelatinization temperature will increase the cooking time. Rice that has low amylose will increase gelatinization (Rodríguez-torres et al., 2017). Meanwhile, rice with a low gelatinization temperature will have the ability to absorb water and also expand at a lower temperature range than rice with a high gelatinization temperature. Gelatinization temperature will correlate with amylose content; rice with low amylose content will experience lower granule swelling. This is due to low molecular associations. On the other hand, rice with high amylose content is more prone to swelling. The results of the lowest and highest gelatinization enthalpy values were found in the varieties Situbagendit (2 J g^{-1}) and Mapan 05 Banjarnegara (2.1 Jg-1) (Table 2). The high and low enthalpy values can be caused by the molecular weight and also the low distribution of amylopectin bonds. The existence of variations in thermal properties between one variety and another is influenced by internal factors including the content of amylose, amylopectin, fat, and protein (Dhital et al., 2014).

Amylographic Properties of Black and Aromatic Rice Parents

Analysis of paste properties was carried out using a Rapid Visco Analyzer (RVA). Determination of the nature of the RVA paste is based on the viscosity value consisting of peak 1 (PV), trough 1 (TV), breakdown (BV), final viscosity (FV), setback viscosity, peak time (PT), and pasting temperature. Peak viscosity is the viscosity that occurs at the peak of gelatinization, and this indicates gelatinized starch. The results of variations in peak viscosity can be related to the ability of swelling and the level of granule damage (Wu et al., 2018). Peak viscosity indicates the point at which starch granules first expand and then burst. This is due to the stages of the heating and stirring process; peak viscosity is also used as an indicator of water-binding capacity, and this is also related to the texture of the final result of rice. The highest peak viscosity value is found in the Batang Gadis variety, 3066 cP. The results show that the peak viscosity is inversely proportional to the amylose content, where the rice with the highest PV has a low amylose content; namely, Batang Gadis has an amylose content of 19.54, where the amylose value is in the low-value category. This is consistent with the previous theory that rice with low amylose content tends to take longer to reach swelling. Hitam Lumajang Rice has a low PV of 806 cP. Higher viscosity values indicate the granules expand longer. Rice varieties that have a low peak viscosity value indicate a faster swelling of the granules. Rice samples that have amylose values are inversely proportional to high trough viscosity values, whereas rice with low amylose values has a higher TV (Bian & Chung et al., 2016).

Trough viscosity values of black rice and aromatic rice varieties are 806 cP (Hitam Lumajang rice) and aromatic rice (Batang Gadis) with an average value of 3066 cP. Based on the results of the study, it can be seen that the samples that have a low trough viscosity of 553 cP are Black Lumajang, which has an amylose of 21.60%, while the varieties that have high TV are Mentik Wangi Banjarnegara and Mentik Wangi at 1895 cP with amylose content of 21.66% and 21.81%. The results of this study generally align with previous research on 28 Indian rice varieties, which shows that the through-viscosity value is inversely proportional to the amylose content. The breakdown viscosity value ranges from 22 cP (Mentik Wangi Mentik Wangi, Banjarnegara) to 1223 cP (Batang Gadis). Batang Gadis has the highest breakdown viscosity value. Breakdown viscosity is related to the swelling process of starch granules that occurs during heating. Rice varieties that have a high breakdown value correlate with a better level of palatability (Pode, 2016). Final viscosity is a parameter used to determine the ability of starch to become a gel structure or thick paste after the heating process. In this process, it is seen that there is viscosity stability in starch to the processing stages starting from heating, stirring, and cooling (Zhu et al., 2011).

In this study, the final viscosity values ranged from 1000 cP (Pari Ireng) to 3748 cP (Batang Gadis). Setback viscosity indicates the tendency of starch granules to retrograde upon cooling. A high setback is an indication of the swelling rate of rice, which is correlated with the amylose content in the studied sample (Nie et al., 2026) and a low setback value indicates a low retrogradation rate. The value of setback viscosity is also correlated to the formation of different textures from each sample. In this study, black rice and aromatic rice varieties with low setback viscosity values were Hitam Bantul rice (101 cP) and Toraja (122 cP) to Toraja (2136 cP) (Radah Putih Karanganyar) with average values. The setback viscosity value is correlated with the amylose value, which indicates heating and cooling cycles between the same sample concentrations (Li et al., 2022). The peak time value is the value calculated from the beginning of the cooking time, ranging from 5 minutes (Pari Ireng) to 10 minutes (Mentik Wangi Banjarnegara and Mentik Wangi), with the pasting temperature value ranging from 72.25 °C (Pare Palu Mandoti) to 93.10 °C (Black Rice Purwokerto). The content with higher amylose (28.34%) had a greater pasting temperature when compared to Pare Palu Mandoti (21.16%), which also had the lowest pasting temperature. The pasting temperature marks the beginning of an increase in temperature during the gelatinization process, and a certain level of amylose can influence this temperature. High pasting temperatures indicate the potential swelling resistance of rice. In this study, the main influencing factor was the amylose content of each sample (Lee et al., 2016).

Principal Component Analysis and Correlation Analysis

Principal Component Analysis (PCA) was carried out to reduce the variables and determine the relationship between the physicochemical parameters of black rice and aromatic rice. PCA helps reduce the number of variables by identifying relationships among them and converting these relationships into components. It reduces the problem of multicollinearity. The results of the PCA are presented in Table 3. The PCA results showed two principal components (PC) with eigenvalues greater than 1. The first principal component (PC1) had an eigenvalue of 1.215 and explained 91.750% of the total variance. Amylose content, breakdown viscosity, and gelatinization enthalpy (ΔH) had the highest positive loading values in PC1. Several other variables also showed positive loading values, including carbohydrates, water content, Tc, amylopectin, peak viscosity, setback viscosity, final viscosity, pasting temperature, and peak time. In contrast, protein showed the highest negative loading value in this component. The second principal component (PC2) had an eigenvalue of 2.105 and explained 50.673% of the total variance, with setback viscosity showing the highest positive loading value.

Tabel 3. Results of Principal Component Analysis (PCA)

Parameter	PC1	PC2
Amylose (%)	0.721	0.441
Protein (%)	-0.709	0.005
Fat (%)	0.021	0.000
Amylopectin (%)	0.629	0.810
Carbohydrates (%)	0.306	0.397
Water Content (%)	0.409	0.030
T0	0.022	0.436
ΔH	0.708	0.051
TP	0.429	0.005
TC	0.303	0.204
Peak 1	0.406	0.000
Trough 1	0.034	0.000
Breakdown	0.977	0.048
Final Visc	0.055	0.116
Setback	0.041	0.986
Peak Time	0.010	0.106
Pasting Temp	0.378	0.060
Eigenvalue	1.215	2.105
% variance	91.750	50.673

Correlation analysis was conducted to determine the relationship between physicochemical parameters in the rice samples studied. The results of the correlation analysis are presented in Table 4. Overall, the analysis revealed positive correlations among several parameters. The results indicated that amylose content was positively correlated with all DSC parameters. This occurs because amylose plays an important role in controlling the gelatinization process, as amylose diffuses out of starch granules during swelling (Ding et al., 2018). These results are consistent with previous studies reporting positive correlations between amylose and gelatinization temperatures, including onset, peak, and conclusion temperatures (0.84, 0.88, and 0.85, respectively) (Varavinit et al., 2003). Similar findings were also reported in several local African rice varieties, where amylose showed positive correlations with DSC parameters (Odenigbo et al., 2013). The positive relationship between amylose and DSC parameters has also been reported previously (Dhital et al., 2014).

Amylose content was positively correlated with several Rapid Visco Analyzer (RVA) parameters, including setback viscosity, peak time, and pasting temperature. These findings are consistent with previous studies reporting a positive relationship between amylose content and RVA characteristics (Singh et al., 2003). The positive correlation between amylose content and peak time suggests that starch granules require longer heating time to reach maximum swelling and gelatinization, where structural disruption occurs and a continuous gel network is formed (Rodríguez-Torres et al., 2017). Both positive and negative correlations were observed among the physicochemical and pasting properties of the rice samples. Positive correlations were identified between pasting temperature

Tabel 4. Correlation Analysis Results

	Amylose (%)	Protein (%)	Fat (%)	Amylopectin (%)	Carbohydrates (%)	Water Content (%)	*T0*	*ΔH*	*TP*	*TC*	*Peak 1*	*Trough 1*	*Breakdown*	*Final Visc*	*Setback*	*Peak Time*	*Pasting Temp*
Amylose (%)																	
Protein (%)	0.941																
Fat (%)	0.701	0.109															
Amylopectin (%)	0.392	0.427	0.006														
Carbohydrates (%)	0.66	0.348	0.07	0.842													
Water Content (%)	0.307	0.261	0.023	0.24	0.309												
T0	0.353	0.073	0.071	0.037	0.126	0.243											
ΔH	0.316	0.106	0.032	0.647	-0.768	0.281	0.068										
TP	0.052	0.124	0.093	-0.129	0.007	0.192	0.2	0.001									
TC	0.596	0.126	0.058	0.054	0.029	-0.03	0.172	0.011	0.911								
Peak 1	0.265	0.314	0.184	0.541	0.468	0.104	0.077	0.119	0.037	0.116							
Trough 1	0.525	0.108	0.039	0.023	0.083	-0.374	0.096	0.097	0.058	0.016	0.301						
Breakdown	0.406	0.177	-0.221	0.27	0.147	0.173	0.147	0.019	0.051	0.112	0.756	0.297					
Final Visc	0.14	0.142	0.035	0.485	0.502	-0.193	-0.131	-0.244	0.017	0.094	0.681	0.179	0.25				
Setback	0.647	0.072	0.111	0.14	0.261	0.146	0.095	0.287	0.119	-0.347	0.157	0.108	-0.472	0.55			
Peak Time	0.631	0.037	0.054	0.277	0.371	0.454	0.004	0.25	0.079	0.106	0.088	0.01	-0.469	0.674	0.724		
Pasting Temp	0.115	0.27	0.189	0.116	0.145	0.122	-0.065	0.239	0.057	-0.249	-0.14	0.078	-0.276	0.45	0.573	0.594	

and ΔH (r = 0.239) and between pasting temperature and peak time (r = 0.594), indicating that higher pasting temperatures are associated with greater thermal energy requirements and prolonged gelatinization time. In contrast, negative correlations were observed between several parameters, including fat content and breakdown viscosity, amylopectin content and TP, carbohydrate content and ΔH, moisture content and TC, trough viscosity and final viscosity, T0 and final viscosity, TC and setback viscosity, peak viscosity and pasting temperature, and breakdown viscosity and setback viscosity.

Cluster and Dendrogram Analysis of Black and Aromatic Rice

The clustering of black rice and aromatic rice was based on physicochemical analysis using a two-dimensional scatter plot derived from principal component analysis (PCA). As shown in Figure 1, the rice varieties were grouped into four clusters based on similarities in their physicochemical characteristics. Group I consisted of Pendok, Harelahok, Toraja, Mentik Susu Karanganyar, and Pare Palu Mandoti, which were characterized by low-to-moderate amylose content, high carbohydrate and protein content, low fat content, high amylopectin content, high To, Tp, Tc, ΔH, and peak time values, and low pasting temperature. Group II consisted of Hitam Lumajang, Pari Ireng, and Hitam Purwokerto, which showed characteristics of high amylose content, high carbohydrate and

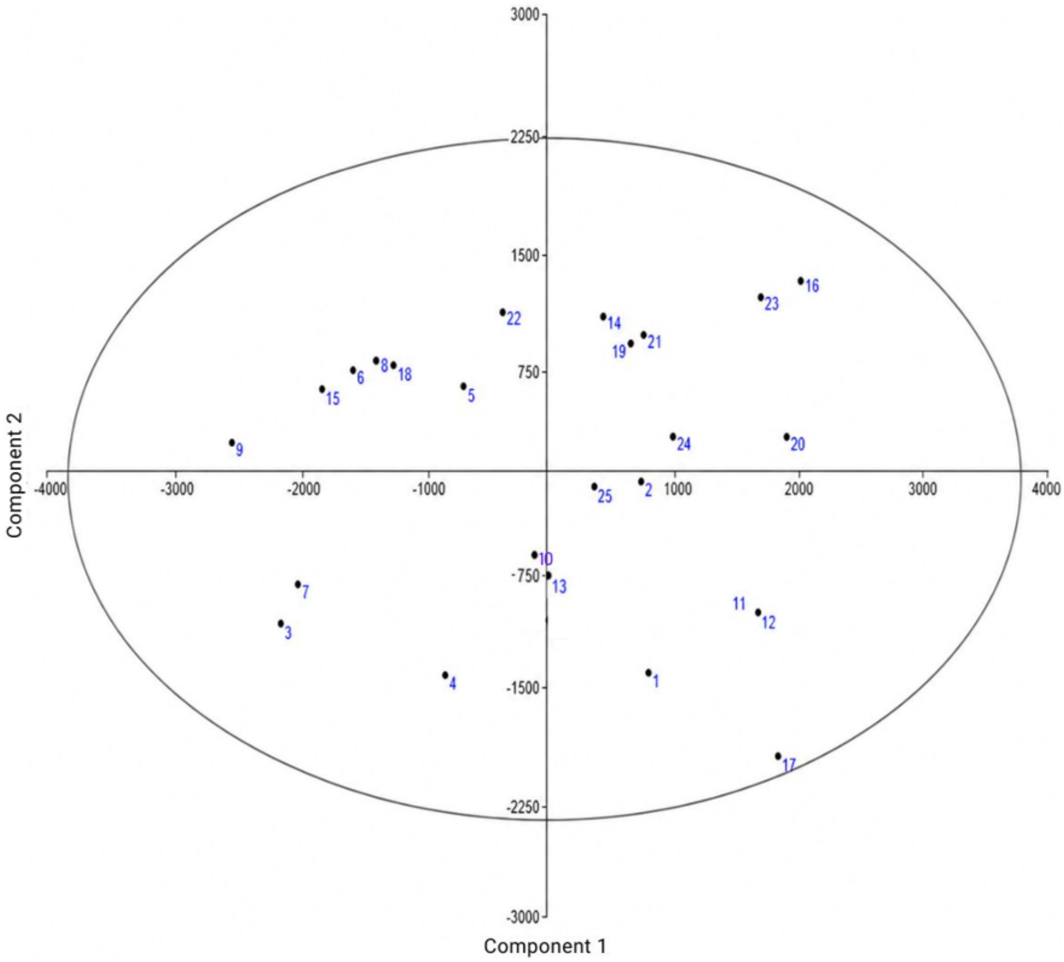

Figure 1. Clustering of Black and Aromatic Rice Based on Physicochemistry

protein content, low fat content, low amylopectin content, and low To, Tp, Tc, ΔH, peak time, trough viscosity, breakdown, and final viscosity. Group III consisted of Situ Patenggang, Situbagendit, Rojo Lele Delangu, Gilirang, Batang Gadis, Kuri Kusut, and Celebes, which were characterized by low-to-moderate amylose content; high carbohydrate and protein content; low fat content; high amylopectin content; high To, Tp, Tc, ΔH, and peak time values; and low pasting temperature. Group IV consisted of Mapan 05 Banjarnegara, Genjah Arum, Hitam Purbalingga, Mentik Wangi, Mentik

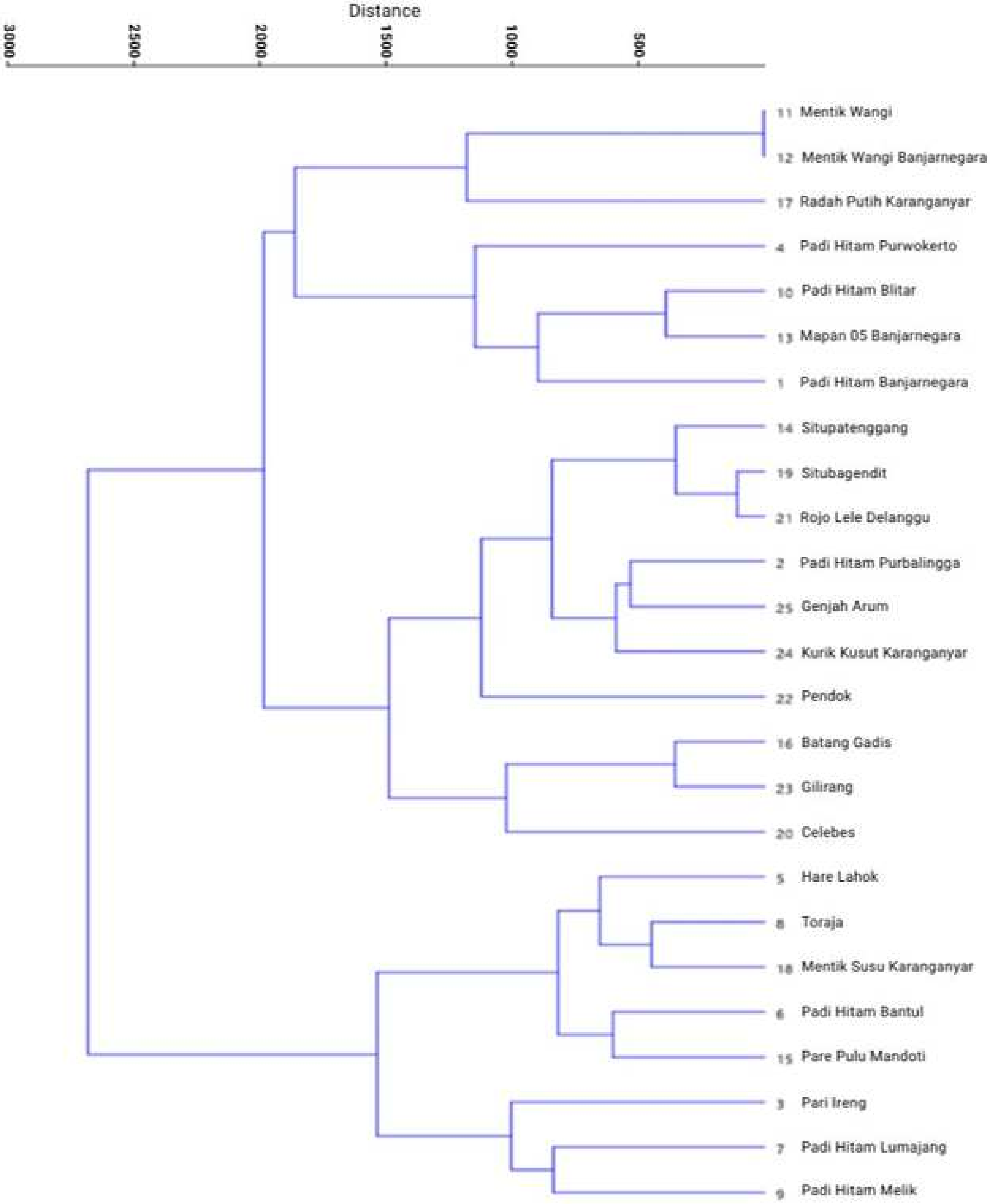

Figure 2. Black and aromatic rice dendrogram based on physicochemical properties

Wangi Banjarnegara, and Radah Putih Karanganyar, which showed moderate amylose content, high carbohydrate and protein content, low fat content, high amylopectin content, high To, Tp, Tc, ΔH, and peak time values, and low pasting temperature.

As shown in Figure 2, dendrogram analysis divided black rice and aromatic rice varieties into three major groups based on their physicochemical properties. Group I consisted of Wangi Mentik, Banjarnegara Wangi Mentik, Radah Putih Karanganyar, Hitam Purwokerto, Hitam Blitar, Mapan 05, and Hitam Banjarnegara. Group II consisted of Situ Patenggang, Situbagendit, Rojo Lele Delangu, Hitam Purbalingga, Genjah Arum, Kuri Kusut, Pendok, Batang Gadis, Gilirang, and Celebes. Group III consisted of Here Lahok, Toraja, Mentik Susu, Hitam Bantul, Pare Palu Mandoti, Pari Ireng, Hitam Lumajang, and Hitam Melik. The dendrogram shows the degree of similarity between different varieties of rice, with the degree of similarity between varieties indicated by the distance between them.

The clustering and dendrogram analyses provide useful information for the selection of parental lines in rice breeding programs. Varieties grouped into different clusters exhibited substantial physicochemical variation, indicating the presence of broader diversity among genotypes. Crossing parents from distinct clusters may increase the opportunity to combine desirable traits and generate wider segregation in the subsequent generations. Therefore, varieties belonging to different clusters could be considered potential parental materials for the development of new rice cultivars with improved grain quality characteristics.

In addition, the PCA results revealed that amylose content, gelatinization enthalpy (ΔH), and breakdown viscosity were among the major contributors to the observed variability. These traits may serve as important selection criteria in breeding programs aimed at improving cooking quality, texture, and processing characteristics of rice. Black rice varieties possessing high amylose content and distinct physicochemical profiles, such as Hitam Melik, Hitam Bantul, and Hitam Purwokerto, may be utilized as donor parents for grain quality improvement. Likewise, aromatic rice varieties with contrasting physicochemical properties could be crossed with black rice genotypes to combine desirable eating quality and nutritional attributes in future breeding populations.

CONCLUSION

Physicochemical characterization of 10 varieties of black rice and 15 varieties of aromatic rice was done, showing that the varieties exhibited considerable variation in their physicochemical properties. The varieties of rice were classified into three clusters by the principal component analysis method and the dendrogram method, showing the degree of similarity between them. Physicochemical properties of the varieties of rice were shown to be an important criterion in selecting varieties of rice that could act as the parent material in breeding new varieties of rice with desirable properties.

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AUTHORS' CONTRIBUTIONS

The author conceptualized and designed the study, developed the research methodology, conducted the experiments and data collection, performed data analysis and interpretation, prepared the original draft of the manuscript, and revised the manuscript critically for important intellectual content.

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.

REFERENCES

Adebooye, O. C., & Singh, V. (2008). Physico-chemical properties of the flours and starches of two cowpea varieties (*Vigna unguiculata* (L.) Walp). *Innovative Food Science & Emerging Technologies*, *9*(1), 92-100. https://doi.org/10.1016/j.ifset.2007.06.003

Aka, S. R., Sarker, U., Talukder, M. Z. A., Azam, M. G., Ercisli, S., Hossain, N., ... & Ullah, R. (2025). Genetic variation of barley genotypes using morphological traits, amylose content, and molecular markers. *Scientific reports*, *15*(1), 34840.

AOAC International. (2019). Official Methods of Analysis of AOAC International (21st ed.). AOAC International.

Bao, J., & Bergman, C. J. (2024). Rice flour and starch functionality. In Starch in food (pp. 275-307). Woodhead Publishing. https://doi.org/10.1016/B978-0-323-96102-8.00011-5

Bian, L., & Chung, H. J. (2016). Molecular structure and physicochemical properties of starch isolated from hydrothermally treated brown rice flour. *Food Hydrocolloids*, *60*, 345-352. https://doi.org/10.1016/j.foodhyd.2016.04.008

Buttery, R. G., Ling, L. C., & Mon, T. R. (1986). Quantitative Analysis of 2-Acetyl-1-Pyrroline in Rice*. Journal of agricultural and food chemistry*, 34(1), 112-114.

Dhital, S., Warren, F. J., Zhang, B., & Gidley, M. J. (2014). Amylase binding to starch granules under hydrolysing and non-hydrolysing conditions. *Carbohydrate polymers*, *113*, 97-107. https://doi.org/10.1016/j.carbpol.2014.06.063

Ding, J., Hou, G. G., Dong, M., Xiong, S., Zhao, S., & Feng, H. (2018). Physicochemical properties of germinated dehulled rice flour and energy requirement in germination as affected by ultrasound treatment. *Ultrasonics sonochemistry*, *41*, 484-491. https://doi.org/10.1016/j.ultsonch.2017.10.010

Duan, Y., Chao, C., Yu, J., Liu, Y., & Wang, S. (2023). Effects of different sources of proteins on the formation of starch-lipid-protein complexes. *International Journal of Biological Macromolecules*, *253*, 126853. https://doi.org/10.1016/j.ijbiomac.2023.126853

Giraud, G. (2013). The world market of fragrant rice, main issues and perspectives. *International Food and Agribusiness Management Review*, *16*(2), 1-20.

Haryanto, T. A. D., & Yoshida, T. (2008). Yield stability of aromatic upland rice with high yielding ability in Indonesia. *Plant Production*, *11*(1), 96-103. https://doi.org/10.1626/pps.11.96

Hebishy, E., Buchanan, D., Rice, J., & Oyeyinka, S. A. (2024). Variation in amylose content in three rice variants predominantly influences the properties of sushi rice. *Journal of Food Measurement and Characterization*, *18*(6), 4545-4557.

Huang, H., Li, Y., Zeng, J., Cao, Y. (2023). Comparative quality evaluation of physicochemical and amylose content profiling in rice noodles from diverse rice hybrids in China. *Agriculture*, *13*(1), 140. https://doi.org/10.3390/agriculture13010140

Hyun, J. W., & Chung, H. S. (2004). Cyanidin and malvidin from Oryza sativa cv. Heugjinjubyeo mediate cytotoxicity against human monocytic leukemia cells by arrest of G2/M phase and induction of apoptosis. *Journal of agricultural and food chemistry*, *52*(8), 2213-2217.

Juliano, B. O. (1971). A simplified assay for milled-rice amylose. *Cereal Sci, 12*, 334-360.

Juliano, B. O. (1992). Structure, chemistry, and function of the rice grain and its fractions. *Cereal Foods World, 37*(10), 772–779.

Juliano, B. O. (2006). Trend in rice quality demand in Asia. In S. Suparyono (Ed.), *Proceedings of the International Rice Conference 2005* (pp. 43–54).

Kang, H. J., Hwang, I. K., Kim, K. S., & Choi, H. C. (2003). Comparative Structure and Physicochemical Properties of Ilpumbyeo, A High-Quality Japonica Rice, and Its Mutant, Suweon 464. *Journal of Agricultural and Food Chemistry*, 51(22), 6598-6603.

Kang, T., Yoon, M. R., Lee, J. S., & Choi, K. O. (2022). Branched chain length distribution of amylopectin in rice flour as a key attribute for determining the quality of extruded rice noodles. *Journal of Food Processing and Preservation*, *46* (4), e16473. https://doi.org/10.1111/jfpp.16473

Kong, X., Zhu, P., Sui, Z., & Bao, J. (2015). Physicochemical properties of starches from diverse rice cultivars varying in apparent amylose content and gelatinisation temperature combinations. *Food chemistry*, *172*,433-440. https://doi.org/10.1016/j.2014.09.085

Lee, K. J., Lee, G. A., Lee, J. R., Raveendar, S., Cho, Y. H., Lee, S. Y. & Ma, K. H. (2016). Comparison of eating quality and seed storage protein among Korean rice landraces. *Journal of crop science and biotechnology*, *19*(3), 241-247.

Li, H. T., Kerr, E. D., Schulz, B. L., Gidley, M. J., & Dhital, S. (2022). Pasting properties of high-amylose wheat in conventional and high-temperature Rapid Visco Analyzer: Molecular contribution of starch and gluten proteins. *Food Hydrocolloids*, *131*, 107840. https://doi.org/10.1016/j.foodhyd.2022.107840

Ma, M., Gu, Z., Cheng, L., Li, Z., Li, C., & Hong, Y. (2024). Chewing characteristics of rice and reasons for differences between three rice types with different amylose contents. *International Journal of Biological Macromolecules*, *278*, 134869.

Masuko, T., Minami, A., Iwasaki, N., Majima, T., Nishimura, S. I., & Lee, Y. C. (2005). Carbohydrate analysis by a phenol–sulfuric acid method in microplate format. *Analytical biochemistry*, *339*(1), 69-72. https://doi.org/10.1016/j.ab.2004.12.001

Mirani, A. A., Kalwar, S. A., & Ahmad, M. (2013). A rice husk gasifier for paddy drying. *Science Technology and Development (Islamabad)*, *32*.

Mohidem, N. A., Hashim, N., Shamsudin, R., & Che Man, H. (2022). Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture*, *12*(6), 741. https://doi.org/10.3390/agriculture12060741

Naik, B., Kumar, V., Goyal, S. K., Dutt Tripathi, A., Mishra, S., Joakim Saris, P. E. & Rustagi, S. (2023). Pullulanase: unleashing the power of enzyme with a promising future in the food industry. *Frontiers in Bioengineering and Biotechnology*, *11*, 1139611.

Nie, M., Zhang, Y., Li, J., Wang, A., Shan, Y., Li, Y., ... & Tong, L. T. (2026). An Overview of the Retrogradation Properties of Starch in Rice Based Foods: Influencing Factors, Regulating Approaches and Mechanisms. *Comprehensive Reviews in Food Science and Food Safety*, *25*(1), e70347. https://doi.org/10.1111/1541-4337.70347

Odenigbo, A. M., Ngadi, M., Ejebe, C., Nwankpa, C., Danbaba, N., Ndindeng, S., & Manful, J. (2013). Study on the gelatinization properties and amylose content of rice varieties from Nigeria and Cameroun. *International Journal of Nutrition and Food Sciences*, *2*(4), 181-186. https://doi.org/10.11648/j.ijnfs.20130204.14

Panchal, S. K., John, O. D., Mathai, M. L., & Brown, L. (2022). Anthocyanins in chronic diseases: The power of purple. *Nutrients*, *14*(10), 2161. https://doi.org/10.3390/nu14102161

Pode, R. (2016). Potential applications of rice husk ash waste from rice husk biomass power plant. *Renewable and sustainable energy reviews*, *53*, 1468-1485. https://doi.org/10.1016/j.rser.2015.09.051

Rodríguez-Torres, D., Murillo-Arango, W., Vaquiro-Herrera, H. A., & Solanilla-Duque, J. F. (2017). Thermal and physicochemical properties of starches from three Colombian rice varieties. *Agronomía Colombiana*, *35*(1), 116-124.

Scott, G., & Awika, J. M. (2023). Effect of protein–starch interactions on starch retrogradation and implications for food product quality. *Comprehensive Reviews in Food Science and Food Safety*, *22*(3), 2081-2111. https://doi.org/10.1111/1541-4337.13141

Singh, N., Sodhi, N. S., Kaur, M., & Saxena, S. K. (2003). Physico-chemical, morphological, thermal, cooking and textural properties of chalky and translucent rice kernels. *Food chem-*

istry, *82*(3),433-439.

Sunaryo, W. (2024). Genetic diversity and cluster analysis of local pigmented rice from East and North Kalimantan, Indonesia based on quantitative and qualitative characters. *Journal of Biological Diversity*, *25*(5). https://doi.org/10.13057/biodiv/d250510

Thilavech, T., Suantawee, T., Chusak, C., Suklaew, P. O., & Adisakwattana, S. (2025). Black rice (*Oryza sativa* L.) and its anthocyanins: mechanisms, food applications, and clinical insights for postprandial glycemic and lipid regulation. *Food Production, Processing and Nutrition*, *7*(1), 15.

Varavinit, S., Shobsngob, S., Varanyanond, W., Chinachoti, P., & Naivikul, O. (2003). Effect of amylose content on gelatinization, retrogradation and pasting properties of flours from different cultivars of Thai rice. *Starch-Stärke*, *55*(9), 410-415. https://doi.org/10.1002/star.200300185

Wongsaipun, S., Krongchai, C., Jakmunee, J., & Kittiwachana, S. (2018). Rice grain freshness measurement using rapid visco analyzer and chemometrics. *Food Analytical Methods*, *11*(2), 613-623.

Wu, K., Gunaratne, A., Gan, R., Bao, J., Corke, H., & Jiang, F. (2018). Relationships between cooking properties and physicochemical properties in brown and white rice. *Starch Stärke*, *70*(5-6), 1700167. https://doi.org/10.1002/star.201700167

Xiang, G., Li, J., Lin, Q., Zhang, Y., Ding, Y., Guo, X, & Fang, Y. (2023). The effect of heat-moisture treatment changed the binding of starch, protein and lipid in rice flour to affect its hierarchical structure and physicochemical properties. *Food Chemistry: X*, *19*, 100785. https://doi.org/10.1016/j.fochx.2023.100785

Yuan, Y., Zhang, L., Dai, Y., & Yu, J. (2007). Physicochemical properties of starch obtained from Dioscorea nipponica Makino comparison with other tuber starches. *Journal of food engineering*, *82*(4), 436-442. https://doi.org/10.1016/j.jfoodeng.2007.02.055

Zhu, L. J., Liu, Q. Q., Wilson, J. D., Gu, M. H., & Shi, Y. C. (2011). Digestibility and physicochemical properties of rice (*Oryza sativa* L.) flours and starches differing in amylose content. *Carbohydrate Polymers*, *86*(4), 1751-1759. https://doi.org/10.1016/j.carbpol.2011.07.017