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Research article

Profile of the grain physical traits and physicochemical properties of selected Malaysian rice landraces for future use in a breeding program

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Abstract: Malaysia is currently experiencing the same scenario as other countries, as the majority of consumers have shifted their preferences from locally produced rice to imported rice. This has resulted in a significant influx of imported rice into the domestic markets. Food security in the long term cannot be achieved by depending on imported food. Therefore, countries must make an effort to develop high-quality rice to meet the demand of customers. The study aimed to evaluate the grain physical traits and physicochemical properties of 30 Malaysian rice landraces to optimize the use of rice landraces in breeding programs. The grain physical traits were evaluated according to grain size, grain shape, and kernel elongation. Meanwhile, the physicochemical properties were determined by amylose content, alkali spreading value, and gel consistency. The grain length ranged from 4.14 to 8.16 mm and the grain width varied between 1.76 and 2.81 mm. The grain shapes were categorized into three types: medium, long and slender, and bold. Most of the rice landraces exhibited a low amylose content ranging from 16.07 to 19.83, while intermediate amylose content ranged from 20.00 to 23.80. The alkali spreading value showed that most of the rice landraces require an intermediate cooking time.

The gel consistency exhibited a wide range, varying from soft to hard. The gel consistency exhibited the highest phenotypic and genotypic coefficient of variance, with values of 42.44% and 41.88%, respectively. Most of the studied traits except for kernel elongation were identified as having high heritability and high genetic advance as a percentage of the mean. A dendrogram effectively revealed the genetic relationships among Malaysian rice landraces by generating three distinct clusters. Cluster I was primarily composed of glutinous rice landraces with a low to very low amylose content and exhibited the highest mean values for gel consistency and kernel elongation. Cluster II consisted of 13 rice landraces that had the highest mean value for milled grain length and grain shape. Cluster III was composed of rice landraces and control rice cultivars, and they exhibited the highest mean values for alkali spreading value, amylose content, and milled grain width. Bokilong, Kolomintuhon, Silou, Tutumoh, and Bidor in Cluster III exhibited comparable physicochemical properties and cooking quality traits as the control rice cultivars. The findings of this study are important for identifying potential donors for breeding programs focused on developing high-quality or specialty rice cultivars.

Keywords: amylose content; gel consistency; alkali spreading value; gelatinization temperature; kernel elongation; genetic advances; unweighted pair group method with arithmetic mean (UPGMA)

1. Introduction

Rice serves as a major source of calories, contributing to approximately 20% of the total global calorie intake [1]. As per the market summaries on rice published by the Food and Agricultural Organization of the United Nations (FAO) [2], annual rice production was estimated to be around 519.5 million tonnes in the year 2022/23, with the global per capita consumption of rice being approximately 53.9 kg per year. Southeast Asia remained the primary producer of rice in 2023, with Indonesia, Vietnam, Thailand, the Philippines, Myanmar, and Cambodia being the six major rice producers [3].

Consumer preferences for rice are not uniformly distributed among consumers and exhibit substantial variation across different countries [4]. The preferences are influenced by various factors including texture, grain size, grain shape, taste, aroma, color, packaging quality, swelling capacity, viscous consistency after cooking, percentage of broken grains, market availability, price, and degree of whiteness [5–7]. A previous report indicated that people in southern China, southern and southeast Asia, and the United States have a strong preference for rice that is long and slender in shape. Meanwhile, people in northern China, Korea, and Japan have a strong preference for short and round rice [8]. Nevertheless, consumer preferences for rice are currently shifting toward fine-grain, high-quality rice types with long and slender grains and a pleasant aroma [9]. This subsequently led to a significant influx of high-quality imported rice into the domestic markets of numerous countries. This abundance of options provides consumers with additional choices but also results in a transition from consuming locally-produced rice to imported rice [4,5].

Malaysia produces over 2.43 million tons of paddy annually, but this amount only meets approximately 73% of the population's needs [10]. The report also stated that Malaysia imported approximately 1.22 million tons of high-quality rice, including basmati, aromatic, and japonica rice, from several countries, notably Thailand, Vietnam, Pakistan, and India, to meet the growing demand for rice. In Ghana, imported and domestic rice is marketed on the same market, creating a significant disincentive effect for local rice producers [5]. Likewise, fluctuations in rice imports to Indonesia indicate that the average growth rate was 67% and the average volume of imports was 1,226,101 tons [11]. The long-term security of food cannot be guaranteed through reliance on food imports. Moreover, another report highlighted the need to increase awareness of reducing the dependency of rice-importing countries on imported rice [13]. Therefore, it is advisable to encourage the expansion of domestic rice production [12].

Most local markets have a substantial supply of high-quality local rice that could potentially substitute for imported rice [14]. Nevertheless, there is a need to allocate additional resources to enhance the competitiveness of domestic rice against imported rice by focusing on value-added and demand-lifting investments [15]. According to previous reports, the value of rice can be enhanced through breeding programs that incorporate desirable grain attributes and nutritional values [16,17]. Numerous studies have documented the breeding activities for grain quality traits, with a particular emphasis on cooked kernel elongation [18], cooking and eating quality in rice through the marker-assisted backcross (MABc) breeding program [19], and nutritional quality in rice, including protein content, micro- and macronutrients, vitamins, and amino acids [20].

At present, Malaysia has released 52 modern rice cultivars that have been derived through breeding programs. High-yielding rice comprises the majority of rice cultivars, while the remainder are high-quality or specialty rice that exhibit aroma and color traits. Examples include MRQ50 (white aromatic), MRQ74 (similar to Basmati rice), MRQ76 (similar to Jasmine rice), Pulut Hitam 9 (black glutinous), and MRM16 (red rice) [20,21]. Since the 1960s, Malaysian rice landraces have played an important role as donors in the creation of modern rice cultivars such as Mayang Ebos 80, Tangkai Rotan, Pongsu Seribu, and Cuicak Wangi [22]. Rice landraces have been incorporated into breeding programs for decades due to their recognized potential to provide beneficial traits, including increased yield, stress tolerance, and improved nutritional content of the grains [23]. Nevertheless, the utilization of rice landraces in Malaysia's improvement program was restricted due to a lack of official documentation and publication regarding their physicochemical properties and cooking quality traits. Until recently, the documentation on physicochemical properties and cooking quality traits of Malaysian rice landraces was only reported by [24–26]. This restriction may impede the sharing of these data among researchers and has contributed to the underutilization of a substantial number of rice landraces.

This study was carried out to evaluate the two major components of grain quality traits in 30 Malaysian rice landraces and 3 modern rice cultivars as controls, including (1) grain physical and kernel elongation traits, and (2) physicochemical properties and cooking quality traits. The results of this study can assist in enhancing the utilization of rice landraces in breeding programs, particularly in the development of high-quality or specialty rice cultivars to satisfy the increasing demand of consumers.

2. Materials and methods

2.1. Plant materials

Thirty Malaysian rice landraces were selected from the National Rice Genebank database to represent each of Malaysia's three major provinces, including Peninsular Malaysia which comprised three states: Pahang (the central region), Perak (the northern region), and Kelantan (the eastern region);

Sabah, and Sarawak (Table 1). The experiment also included three modern rice cultivars as controls: Malinja (MRGB00839), MR219 (MRGB11633), and Sempadan 303 (MRGB13001).

Table 1. List of 30 Malaysian rice landraces that represent three major Malaysian provinces.

No.	Accession number	Variety name	Origin	No.	Accession number	Variety name	Origin
1	MRGB12635	Grik	Pahang (PM)	16	MRGB13079	Pandan	Sarawak
2	MRGB12639	Apit	Pahang (PM)	17	MRGB13084	Brio Pendek	Sarawak
3	MRGB12640	Lumpur	Pahang (PM)	18	MRGB13089	Keramat Hitam	Sarawak
4	MRGB12647	Kantan Merah	Pahang (PM)	19	MRGB13080	Kenawit	Sarawak
5	MRGB12482	Jangrai	Perak (PM)	20	MRGB13098	Miyah	Sarawak
6	MRGB12483	Nangka	Perak (PM)	21	MRGB09855	Bokilong	Sabah
7	MRGB12488	Gertok	Perak (PM)	22	MRGB09869	Pulut Bukit	Sabah
8	MRGB12397	Bidor	Kelantan (PM)	23	MRGB09872	Kolomintuhon	Sabah
9	MRGB12387	Kurau	Kelantan (PM)	24	MRGB09909	Kadim	Sabah
10	MRGB12435	Wangi	Kelantan (PM)	25	MRGB09925	Lakatan	Sabah
11	MRGB12938	Muduh	Sarawak	26	MRGB09933	Silou	Sabah
12	MRGB12939	Mepawan	Sarawak	27	MRGB09938	Tutumoh	Sabah
13	MRGB13063	Sanguo Pandan	Sarawak	28	MRGB09951	Beruang	Sabah
14	MRGB13065	Topoi	Sarawak	29	MRGB09955	Tiga Bulan	Sabah
15	MRGB13077	Pulut Belacan	Sarawak	30	MRGB09961	Telinga	Sabah

Note: PM = Peninsular Malaysia.

2.2. Experimental design and sample preparations

The field experiment was conducted at the MARDI Seberang Perai, located in the northern part of Peninsular Malaysia at the coordinates 5°32'37" N 100°28'3" E. The experiment was laid out according to a randomized complete block design (RCBD) with three replications. To ensure uniform germination and seedling development, the seeds with a moisture content of 25 to 30% were sown in a fiberglass trough, and 30-day-old seedlings were then transplanted into the experimental field. Each genotype was planted in two rows, each containing ten plants. The spacing between plants was 25 cm x 25 cm within and between rows, and 30 cm between replicates. The matured grains were harvested manually and dried in a drying room chamber with 15% relative humidity at 15 to 18 °C based on a recommendation by the Millennium Seed Bank [27].

The sample preparation and analysis were conducted at the Rice Quality Laboratory, MARDI Seberang Perai. The procedure was then followed by a threshing process using a QRT-300 small-scale grain threshing machine (SYNMEC, China). The grains were dehusked with a THU35B Testing Husker (Satake, Japan) and polished with a Testing Mill (Satake, Japan). The rice milling procedure followed the laboratory's standard, which involved a milling duration of 1 minute and a roller speed within the range of 750 to 1450 rpm. The TRG05B Testing Rice Grader (Satake, Japan) was then used to separate the broken rice from the unbroken milled rice. The schematic diagram depicted in Figure 1 illustrates the comprehensive sample preparation process for further analysis.

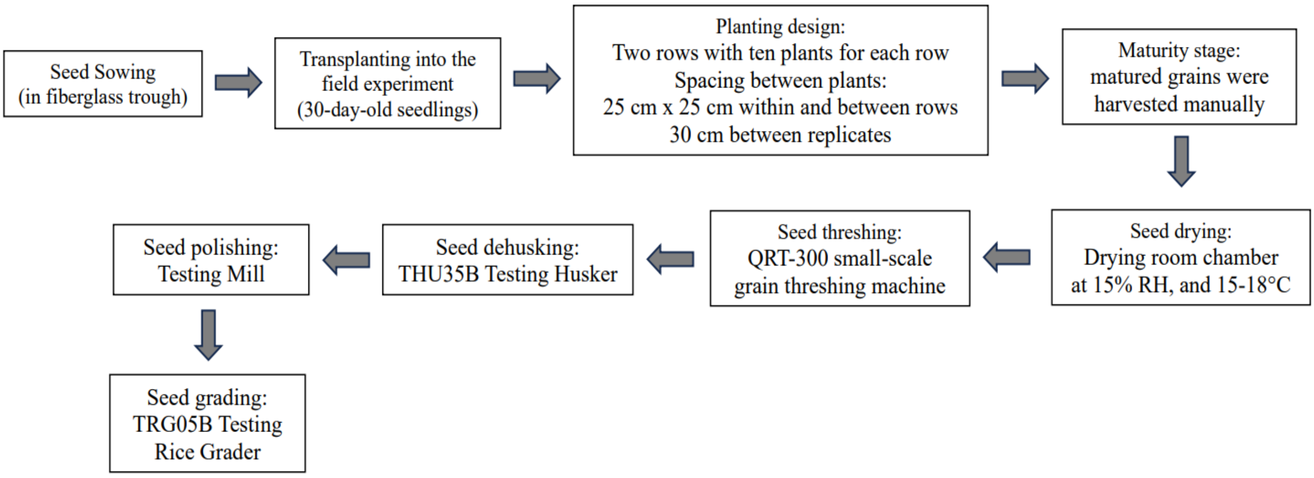

Figure 1. The schematic diagram of the sample preparation for further analysis.

2.3. Grain physical traits evaluation

2.3.1. Grain size and shape

Ten intact milled rice were selected at random from each rice landrace and control cultivar. The length and width of the milled rice were measured manually using a Vernier caliper. The grain shape of milled rice was determined using the length-to-width ratio (L/W) computed by dividing its length by its width. The L/W ratio was used to categorize grain shape into four categories: long and slender (>3.0), medium (2.1–3.0), bold (1.1–2.0), and round (<1.1) following guidelines by the International Rice Research Institute [28].

2.3.2. Kernel elongation ratio

The kernel elongation ratio was determined according to the method described by Sindhu et al. [22]. The experiment was carried out by preparing 10 uncooked rice kernels of each rice genotype for each replicate. After placing the rice kernels in a 145 mm x 20 mm test tube, 20 mL of distilled water was added and the test tube was left for 10 minutes. Then, the rice kernels were cooked in a boiling water bath for 10 to 15 minutes. The test tube was then immersed in cold water until it reached room temperature. The cooked kernels were removed and spread over the Whatman No. 1 filter paper to absorb the extra liquid. The length of cooked rice was then measured with a Vernier caliper. The ratio of kernel elongation was computed by dividing the average length of the cooked kernel by the average length of the uncooked rice. The rice genotypes with elongation traits were classified according to a standard, MRQ74, which was determined by the ratio exceeding 1.70.

2.4. Analysis of physicochemical properties

2.4.1. Amylose content

The amylose content of rice samples was measured using the iodine-binding technique [29]. Finely ground rice samples were prepared for the test samples, which included 30 Malaysian rice landraces and 3 control rice cultivars. A 100 mL volumetric flask was added with 0.1 g of the finely ground rice samples. Using a glass pipette, 1.0 mL of 95% ethanol was poured into the rice powder to wet the samples. Then, 9.0 mL of 1M sodium hydroxide solution was added and mixed with the samples. The samples were kept overnight to allow complete gelatinization of the starch and obtain a clear viscous gelatinous solution [30]. The next day, each test sample, standard, and blank (without rice sample) stock solution was prepared by filling the volumetric flask with distilled water up to 100 mL. Then, 5 mL of each test sample, standard, and blank was pipetted into a new volumetric flask containing 50 mL of distilled water. The volumetric flask was added with 1.0 mL of acetic acid and 2.0 mL of iodine solution. To reach the required volume of 100 mL, an extra 42.0 mL of distilled water was added. After 20 minutes, the absorbance of each reaction mixture was measured at 620 nm using a UV spectrophotometer. A standard curve was drawn against the absorbance and amylose concentration (Figure 2). The absorbance readings of Pulut Siding (Standard 1), MR219 (Standard 2), and MR84 (Standard 3) for amylose content concentrations of 4.1 g/L, 21.9 g/L, and 27.1 g/L, respectively, were 0.10, 0.32, and 0.41. The correlation coefficient was 0.995.

The amylose content of the test samples was then determined by using a standard curve generated from the absorbance values of standard rice cultivars. The amylose content was categorized into several categories based on its percentage: waxy (1 to 2%), very low (2 to 9%), low (10 to 20%), intermediate (20 to 25%), and high (25 to 33%) [29].

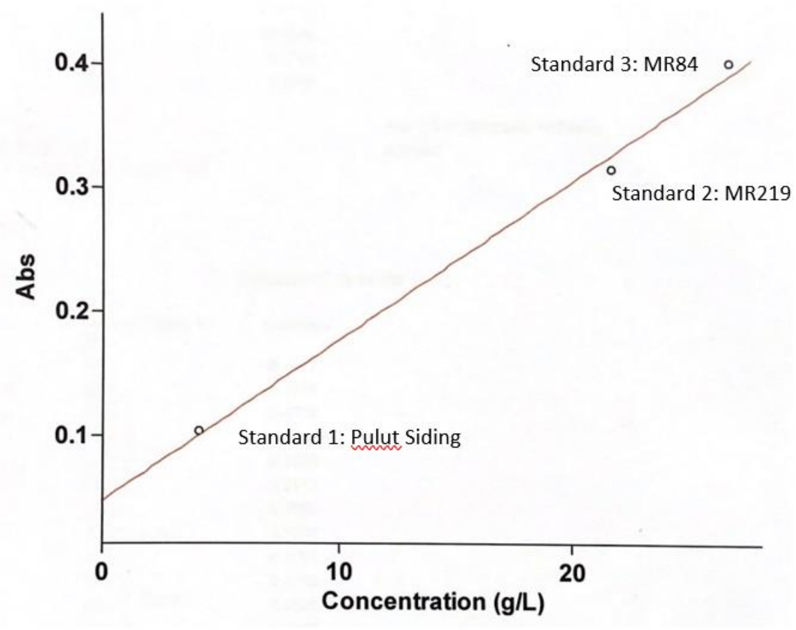

Figure 2. The standard curve was generated from three standard rice cultivars, Pulut Siding, MR219, and MR84, that were used to determine the amylose content of the rice genotypes.

2.4.2. Gelatinization temperature indicated by the alkali spreading value

The alkali spreading value was obtained using a modified version of the method described by Bhattacharya and Sowbhagya [31]. Ten intact milled kernels from each accession were arranged individually. The milled kernels in the Petri dish were soaked in 15 mL of 1.7% potassium hydroxide. The samples of rice were left at room temperature for 23 hours. The next day, each grain was visually examined for its level of intactness or degree of dispersion and rated for spreading according to the seven-point scores specified in the Rice Descriptor [32]. Based on the score, the gelatinization temperature was determined into high, high/intermediate, intermediate, and low, as presented in Table 2 [28].

Table 2. Determination of the gelatinization temperature through alkali digestion analysis.

Score	Observation	Alkali digestion	Gelatinization temperature
1	Grain is not affected but chalky	Low	High (75 to 79 °C)
2	Grain swollen	Low	High (75 to 79 °C)
3	Grain swollen, collar incomplete, and narrow	Low/Intermediate	High/intermediate (75 to 79 °C)/(70 to 74 °C)
4	Grain swollen, collar complete, and narrow	Intermediate	Intermediate (70 to 74 °C)
5	Grain split or segmented, collar complete, and wide	Intermediate	Intermediate (70 to 74 °C)
6	Grain dispersed, merging with collar	High	Low (55 to 69 °C)
7	Grain completely dispersed and cleared	High	Low (55 to 69 °C)

2.4.3. Gel consistency

Gel consistency was assessed using a procedure outlined in the Rice Descriptor [32]. A test tube sized 13 mm x 100 mm was filled with 0.1 g of rice powder. Then, 0.2 mL of 95% ethanol containing 0.025% thymol blue was added to the test tube. Following this, 2.0 mL of 0.2N potassium hydroxide (KOH) was added. The mixture was stirred using a vortex mixer to prevent the coagulation of starch during cooking. The test tubes were immersed in a bath of boiling water for 8 minutes. The test tubes were then removed and left at room temperature for 5 minutes before incubation in ice-cold water for 15 to 20 minutes. After that, the test tubes were laid horizontally on graph paper, and the length of gel traveled was measured between 30 to 60 minutes later. The method for determining the distance traveled by the gel was adapted from a method developed by Cagampang et al. [33]. Three standard cultivars, namely MR84 (hard), Pulut Siding (soft), and MR219 (medium), were employed as benchmarks to precisely represent the gel consistency of each category. The gel consistency was classified into four categories, namely soft (61–100 mm), medium (41–60 mm), medium hard (36–40 mm), and hard (<35 mm) [28].

2.5. Statistical analysis

SAS software version 9.4 (SAS Institute Inc, Cary, NC, USA) was employed to determine the significant differences between attributes using one-way ANOVA at 1% ($p < 0.01$) and 5% ($p < 0.05$) levels of significance. The least significant difference (LSD) test was used to separate the rice landraces using a significance level of 5% ($p < 0.05$). The phenotypic and genotypic variability was estimated by calculating the coefficient of variance using the formula outlined in [25]. The equation is shown below:

$$\text{Genotypic variance } (\sigma_g^2) = \frac{MSG - MSE}{r} \tag{1}$$

Where, σ_g^2 = genotypic variance, *MSG* = mean square of genotype, *MSE* = mean square of error, r = number of replications

$$\text{Phenotypic variance } (\sigma_p^2) = \sigma_g^2 + \sigma_e^2 \tag{2}$$

Where, σ_p^2 = phenotypic variance, σ_g^2 = genotypic variance, and σ_e^2 = environmental variance.

$$\text{PCV } (\%) = \frac{\sqrt{\sigma_P^2}}{\bar{X}} \times 100 \tag{3}$$

$$\text{GCV } (\%) = \frac{\sqrt{\sigma_G^2}}{\bar{X}} \times 100 \tag{4}$$

Where, PCV = phenotypic coefficient of variation, GCV = genotypic coefficient of variation, and $\bar{X}$ = sample mean of the trait. The PCV and GCV were classified as follows: 0 to 10% = low, 10 to 20% = moderate, and above 20% = high [34].

The broad sense heritability was computed for each trait using the formula provided by [35]. Broad sense heritability:

$$\left(h_B^2\ \%\right) = \frac{\sigma_g^2}{\sigma_p^2} \times 100 \tag{5}$$

The percentage of broad sense heritability was classified as follows: 0 to 30% = low, 30 to 60% = moderate, and >60% = high heritability [36].

The expected genetic advance (GA) under selection was calculated at a 5% selection differential (K = 2.06) [37]:

$$\mathrm{GA} = \mathrm{K} \times \sqrt{\sigma^2_p} \times h^2_B \tag{6}$$

Genetic expected mean (GAM) was determined from genetic advance (GA) expressed as a percentage of the population mean (μ):

$$\mathrm{GAM} = \frac{\mathrm{GA}}{\bar{\mathrm{X}}} \times 100 \tag{7}$$

Where $\bar{X}$ = sample mean of the trait. The GAM values were categorized as follows: low (10%), moderate (10 to 20%), and high (>20%) [38].

An unweighted pair group method with arithmetic mean (UPGMA) dendrogram [39] was generated using the Euclidean distance matrix in Past 4.0 software to describe the genetic relationship among Malaysian rice landraces based on grain physical traits and physicochemical properties.

3. Results

3.1. Grain appearance and kernel elongation traits

This study assessed the grain physical traits of rice landraces by examining grain length, grain width, and grain shape. This study also observed kernel elongation after cooking, which is a critical characteristic of high-quality rice types. This trait is used to differentiate basmati rice types from the other types of rice [18]. The results of this experiment, which included 30 rice landraces and 3 control rice cultivars, indicated that all of the rice genotypes exhibited highly significant differences ($p < 0.01$) in grain physical traits, including grain length, grain width, grain shape, and kernel elongation (Table 3).

The comparison of the means for the traits observed in each rice landrace and control cultivar is shown in Table 4. The milled grain length ranged between 4.14 and 8.16 mm, with a grand mean value of 6.42 mm. Kantan Merah had the longest milled grain, measuring 8.15 ± 0.01 mm, which was significantly different from the milled grain length of the control rice cultivars. The shortest milled grain size was recorded in Tutumoh, measuring 4.16 ± 0.01 mm. The milled grain width varied between 1.76 and 2.81 mm, with a grand mean value of 2.27 mm. The greatest milled grain width of 2.81 ± 0.00 mm was observed in Kolomintuhon and exhibited a significant difference compared to other rice landraces. Meanwhile, the smallest width of 1.77 ± 0.01 mm was found in Kenawit. The length/width (L/W) ratio classified the rice landraces into three-grain shape categories; most of the landraces were categorized as medium (53.33%), followed by long and slender (33.33%), and bold (13.33%). The long and slender grain shape ranged from 3.10 ± 0.00 mm in Pulut Bukit and Bidor to 3.80 ± 0.00 mm in Kantan Merah. The medium grain shape varied from 2.33 ± 0.03 mm in Silou and Muduh to 3.00 ± 0.00 mm in Kadim, Jangrai, and Nangka. Meanwhile, the bold grain shape varied from 1.53 ± 0.03 mm in Tutumoh to 2.00 ± 0.00 mm in Beruang. The majority of rice landraces exhibited no elongation trait, except for Topoi, which exhibited a ratio of 1.87 ± 0.03. Compared to the other rice landraces and control rice cultivars, Topoi exhibited a significantly higher kernel elongation ratio.

The coefficient of variation (CV) is primarily used to quantify the extent of trait variation. It is a dimensionless measure of relative variation, allowing for the comparison of the extent of variation among traits with varying unit dimensions [40]. This study found that the grain shape exhibited the highest degree of variation, measuring 18.66%. This was followed by the milled grain length, which demonstrated a percentage of 13.30%.

Table 3. Analysis of variance (ANOVA) of grain physical traits and kernel elongation.

Source of variation	Rice genotypes	Error
Degrees of Freedom	32	66
Milled Grain Length	2.20**	0.016
Milled Grain Width	0.20**	0.001
Grain Shape	0.88**	0.002
Kernel Elongation	0.05**	0.002

Values represent the mean square of three replicates. ** Significant at $p < 0.01$. * Significant at $p < 0.05$.

Table 4. The mean and standard error (±) of grain physical characteristics of 30 Malaysian rice landraces and control cultivars.

Rice genotype	Milled grain length	Milled grain width	Grain shape	Grain shape category	Kernel elongation ratio	Elongation trait
Malinja	6.64 ± 0.10^{lmn}	2.19 ± 0.02^{k}	3.03 ± 0.03^{hi}	medium	1.37 ± 0.03^{jkl}	not elongated
MR219	6.99 ± 0.04^{fghij}	1.96 ± 0.01^{op}	3.60 ± 0.00^{c}	long and slender	1.30 ± 0.00^{lm}	not elongated
Sempadan303	7.12 ± 0.07^{cdef}	1.92 ± 0.01^{p}	3.73 ± 0.03^{b}	long and slender	1.30 ± 0.00^{lm}	not elongated
Bokilong	6.83 ± 0.05^{ijkl}	2.28 ± 0.02^{ghi}	2.97 ± 0.03^{ij}	medium	1.37 ± 0.03^{jkl}	not elongated
Pulut Bukit	5.99 ± 0.04^{q}	1.93 ± 0.02^{p}	3.10 ± 0.00^{gh}	long and slender	1.37 ± 0.03^{jkl}	not elongated
Kolomintuhon	4.99 ± 0.02^{t}	2.81 ± 0.00^{a}	1.80 ± 0.00^{r}	bold	1.70 ± 0.00^{bc}	elongated
Kadim	6.86 ± 0.06^{ghijk}	2.27 ± 0.01^{hi}	3.00 ± 0.00^{ij}	medium	1.43 ± 0.03^{hij}	not elongated
Lakatan	7.33 ± 0.03^{b}	2.17 ± 0.01^{kl}	3.40 ± 0.00^{d}	long and slender	1.30 ± 0.00^{lm}	not elongated
Silou	5.98 ± 0.07^{q}	2.55 ± 0.01^{d}	2.33 ± 0.03^{p}	medium	1.53 ± 0.03^{efg}	not elongated
Tutumoh	4.16 ± 0.01^{u}	2.74 ± 0.03^{b}	1.53 ± 0.03^{s}	bold	1.53 ± 0.03^{efg}	not elongated
Beruang	5.26 ± 0.01^{s}	2.64 ± 0.02^{c}	2.00 ± 0.00^{q}	bold	1.53 ± 0.03^{efg}	not elongated
Tiga Bulan	6.84 ± 0.03^{hijkl}	2.32 ± 0.01^{efg}	2.93 ± 0.03^{jk}	medium	1.43 ± 0.03^{hij}	not elongated
Telinga	6.52 ± 0.03^{no}	2.56 ± 0.02^{d}	2.57 ± 0.03^{o}	medium	1.57 ± 0.03^{ef}	not elongated
Kurau	7.02 ± 0.04^{efghi}	2.53 ± 0.02^{d}	2.77 ± 0.03^{mn}	medium	1.47 ± 0.03^{ghi}	not elongated
Bidor	7.23 ± 0.00^{bcd}	2.34 ± 0.00^{ef}	3.10 ± 0.00^{gh}	long and slender	1.47 ± 0.03^{ghi}	not elongated
Wangi	7.03 ± 0.01^{defgh}	2.21 ± 0.02^{jk}	3.20 ± 0.00^{ef}	long and slender	1.50 ± 0.00^{fgh}	not elongated
Jangrai	7.02 ± 0.04^{fghi}	2.34 ± 0.02^{ef}	3.00 ± 0.00^{ij}	medium	1.40 ± 0.00^{ijk}	not elongated
Nangka	6.78 ± 0.02^{klm}	2.24 ± 0.01^{ij}	3.00 ± 0.00^{ij}	medium	1.43 ± 0.03^{hij}	not elongated
Gertok	7.28 0.01^{bc}	2.55 ± 0.04^{d}	2.87 ± 0.07^{kl}	medium	1.50 ± 0.00^{fgh}	not elongated

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Rice genotype	Milled grain length	Milled grain width	Grain shape	Grain shape category	Kernel elongation ratio	Elongation trait
Grik	7.22 ± 0.36^{bcde}	2.17 ± 0.09^{kl}	3.17 ± 0.03^{fg}	long and slender	1.37 ± 0.03^{jkl}	not elongated
Apit	6.79 ± 0.04^{jklm}	2.28 ± 0.01^{ghi}	2.97 ± 0.03^{ij}	medium	1.40 ± 0.00^{ijk}	not elongated
Lumpur	7.05 ± 0.01^{defg}	2.13 ± 0.02^{lm}	3.27 ± 0.03^{e}	long and slender	1.40 ± 0.00^{ijk}	not elongated
Kantan Merah	8.15 ± 0.01^{a}	2.14 ± 0.02^{l}	3.80 ± 0.00^{ab}	long and slender	1.33 ± 0.03^{klm}	not elongated
Muduh	5.40 ± 0.03^{s}	2.31 ± 0.02^{fgh}	2.33 ± 0.03^{p}	medium	1.57 ± 0.03^{ef}	not elongated
Mepawan	5.99 ± 0.01^{q}	1.92 ± 0.01^{p}	3.13 ± 0.03^{fg}	long and slender	1.33 ± 0.03^{klm}	not elongated
Sanguo Pandan	6.62 ± 0.04^{mn}	2.09 ± 0.01^{mn}	3.17 ± 0.03^{fg}	long and slender	1.33 ± 0.03^{klm}	not elongated
Topoi	4.97 ± 0.04^{t}	2.75 ± 0.02^{b}	1.83 ± 0.03^{r}	bold	1.87 ± 0.03^{a}	elongated
Pulut Belacan	6.33 ± 0.02^{op}	2.36 ± 0.01^{e}	2.70 ± 0.00^{n}	medium	1.27 ± 0.03^{m}	not elongated
Pandan	5.25 ± 0.02s	2.19 ± 0.02^{k}	2.40 ± 0.00^{p}	medium	1.67 ± 0.03^{cd}	not elongated
Kenawit	6.44 ± 0.02^{no}	1.77 ± 0.01^{q}	3.60 ± 0.00^{c}	long and slender	1.50 ± 0.00^{fgh}	not elongated
Brio Pendek	5.88 ± 0.01^{qr}	2.05 ± 0.02^{n}	2.83 ± 0.03^{lm}	medium	1.60 ± 0.00^{de}	not elongated
Keramat Hitam	6.21 ± 0.01^{p}	2.08 ± 0.02^{n}	2.97 ± 0.03^{ij}	medium	1.47 ± 0.03^{ghi}	not elongated
Miyah	5.74 ± 0.01^{r}	1.99 ± 0.02^{o}	2.87 ± 0.03^{kl}	medium	1.40 ± 0.00^{ijk}	not elongated
Grand Mean	6.42	2.27	2.88		1.45	
Maximum	8.16	2.81	3.80		1.90	
Minimum	4.14	1.76	1.50		1.20	
CV (%)	13.30	11.45	18.66		9.23	
LSD (α = 0.05)	0.20	0.05	0.08		0.08	

LSD test significant difference at a 5% ($p < 0.05$) level of significance. A mean followed by the same letter within the same column is not significantly different.

3.2. Physicochemical properties and cooking quality traits of Malaysian rice landraces

Amylose content, gel consistency, and gelatinization temperature indicated by the alkali spreading value are major traits affecting the eating and cooking quality of rice. The results indicated that all of the rice landraces and control rice cultivars exhibited highly significant differences ($p < 0.01$) in gel consistency, alkali spreading value, and amylose content (Table 5).

The mean comparison of each trait examined effectively distinguishes the significant level among the rice genotypes (Table 6). The majority of rice landraces exhibited a low amylose content, with values ranging from 16.07 ± 0.03 in Mepawan to 19.83 ± 0.17 in Beruang. Rice with intermediate amylose content was the second-highest among the rice landraces, with values ranging from 20.00 ± 0.26 in Silou to 23.80 ± 0.06 in Muduh. On the other hand, the remaining rice landraces exhibited a very low amylose content, with a range of 3.33 ± 0.22 in Lakatan to 9.53 ± 0.03 in Pulut Belacan.

Table 5. Analysis of variance (ANOVA) of physicochemical analysis.

Source of variation	Rice accessions	Error
Degrees of freedom	32	66
Amylose content	92.49**	0.13
Alkali spreading value	1.92**	0.03
Gel consistency	1061.08**	9.58

Values represent the mean square of three replicates. ** Significant at $p < 0.01$. * Significant at $p < 0.05$.

Table 6. The mean and standard error (±) of physicochemical analysis of 30 Malaysian rice landraces, control, and standard cultivars.

Landrace rice	AC	Category of AC	ASV	Alkali digestion	GT	GC	Category of GC
Malinja	24.73 ± 0.20^{a}	intermediate	4.03 ± 0.03^{fg}	intermediate	intermediate	27.33 ± 0.67^{k}	hard
MR219	21.37 ± 0.32^{de}	intermediate	4.00 ± 0.00^{fg}	intermediate	intermediate	29.33 ± 1.76^{jk}	hard
Sempadan303	24.13 ± 0.07^{b}	intermediate	6.03 ± 0.03^{a}	high	low	28.00 ± 1.15^{jk}	hard
Bokilong	22.23 ± 0.03^{c}	intermediate	4.80 ± 0.01^{cde}	intermediate	intermediate	30.67 ± 0.67^{jk}	hard
Pulut Bukit	3.43 ± 0.50^{t}	very low	4.90 ± 0.06^{c}	intermediate	intermediate	97.33 ± 1.33^{a}	soft
Kolomintuhon	21.67 ± 0.09^{cd}	intermediate	4.97 ± 0.03^{c}	intermediate	intermediate	32.67 ± 1.33^{hij}	hard
Kadim	17.33 ± 0.03^{no}	low	3.97 ± 0.03^{fg}	intermediate	intermediate	47.33 ± 2.91^{def}	medium
Lakatan	3.33 ± 0.22^{t}	very low	5.00 ± 0.00^{c}	intermediate	intermediate	100.00 ± 0.00^{a}	soft
Silou	20.00 ± 0.26^{g}	intermediate	4.97 ± 0.03^{c}	intermediate	intermediate	29.33 ± 0.67^{jk}	hard
Tutumoh	20.10 ± 0.11^{g}	intermediate	4.53 ± 0.09^{e}	intermediate	intermediate	30.00 ± 1.15^{jk}	hard
Beruang	19.83 ± 0.17^{gh}	low	5.00 ± 0.00^{c}	intermediate	intermediate	32.00 ± 0.00^{ijk}	hard
Tiga Bulan	17.67 ± 0.19^{mno}	low	4.73 ± 0.09^{cde}	intermediate	intermediate	46.67 ± 3.71^{def}	medium
Telinga	18.93 ± 0.09^{ij}	low	5.00 ± 0.00^{c}	intermediate	intermediate	36.67 ± 0.67^{ghi}	medium hard
Kurau	19.63 ± 0.12^{gh}	low	4.83 ± 0.09^{cd}	intermediate	intermediate	28.00 ± 1.15^{jk}	hard
Bidor	20.70 ± 0.06^{f}	intermediate	4.57 ± 0.18^{de}	intermediate	intermediate	32.00 ± 1.15^{ijk}	hard
Wangi	19.73 ± 0.47^{gh}	low	3.77 ± 0.03^{gh}	intermediate	intermediate	50.67 ± 2.91^{cd}	medium
Jangrai	17.13 ± 0.07^{o}	low	3.33 ± 0.07^{ijk}	low/intermediate	high/intermediate	32.00 ± 1.15^{ijk}	hard
Nangka	18.03 ± 0.07^{klm}	low	3.17 ± 0.07^{klm}	low/intermediate	high/intermediate	43.33 ± 1.33^{f}	medium
Gertok	19.53 ± 0.17^{gh}	low	3.97 ± 0.03^{fg}	intermediate	intermediate	49.33 ± 1.76^{cde}	medium
Grik	19.30 ± 0.06^{hi}	low	3.90 ± 0.10^{fg}	intermediate	intermediate	30.00 ± 0.00^{jk}	hard
Apit	17.87 ± 0.28^{lmn}	low	3.83 ± 0.03^{fgh}	intermediate	intermediate	32.00 ± 1.15^{ijk}	hard
Lumpur	20.77 ± 0.03^{f}	intermediate	3.47 ± 0.07^{ij}	low/intermediate	high/intermediate	53.33 ± 1.76^{c}	medium
Kantan Merah	18.73 ± 0.03^{ij}	low	3.07 ± 0.03^{klm}	low/intermediate	high/intermediate	46.00 ± 2.00^{def}	medium

Continued on the next page

Landrace rice	AC	Category of AC	ASV	Alkali digestion	GT	GC	Category of GC
Muduh	23.80 ± 0.06^{b}	intermediate	3.80 ± 0.00^{gh}	intermediate	intermediate	72.00 ± 3.06^{b}	soft
Mepawan	16.07 ± 0.03^{p}	low	3.30 ± 0.06^{ijkl}	low/ intermediate	high/ intermediate	45.33 ± 0.67^{ef}	medium
Sanguo Pandan	18.43 ± 0.57^{jkl}	low	3.57 ± 0.09^{hi}	intermediate	intermediate	48.00 ± 2.00^{def}	medium
Topoi	18.57 ± 0.19^{jk}	low	4.87 ± 0.03^{c}	intermediate	intermediate	74.67 ± 4.81^{b}	soft
Pulut Belacan	9.53 ± 0.03^{q}	very low	5.30 ± 0.26^{b}	intermediate	intermediate	71.33 ± 1.76^{b}	soft
Pandan	20.83 ± 0.09^{ef}	intermediate	3.23 ± 0.13$^{j\text{-}m}$	low/ intermediate	high/ intermediate	44.00 ± 1.15^{f}	medium
Kenawit	20.90 ± 0.06^{ef}	intermediate	4.10 ± 0.35^{f}	intermediate	intermediate	38.00 ± 1.15^{g}	medium hard
Brio Pendek	8.17 ± 0.34^{rs}	very low	3.00 ± 0.00^{m}	low/ intermediate	high/ intermediate	36.67 ± 0.67^{ghi}	medium hard
Keramat Hitam	8.47 ± 0.07^{r}	very low	3.03 ± 0.03^{lm}	low/ intermediate	high/ intermediate	44.00 ± 1.15^{f}	medium
Miyah	7.87 ± 0.13^{s}	very low	3.03 ± 0.03^{lm}	low/ intermediate	high/ intermediate	37.33 ± 1.33^{gh}	medium hard
Grand Mean		17.54		4.15		44.71	
Maximum		25.10		6.10		100.00	
Minimum		2.50		3.00		26.00	
CV (%)		31.61		19.39		42.02	
LSD (α = 0.05)		0.60		0.28		5.04	

AC = amylose content, ASV = alkali spreading value, GT = gelatinization temperature, GC = gel consistency. Gelatinization temperature: intermediate = 70–74°C, high/intermediate = 75–79°C/70–74°C, low = 55–69°C. LSD test significant difference at 5% ($p < 0.05$) level of significance. A mean followed by the same letter within the same column is not significantly different.

The gelatinization temperature is a key factor in determining the cooking time of rice. It refers to the temperature at which at least 90% of the starch granules swell irreversibly in hot water [41]. The study revealed that 70% (21) of the rice landraces were classified as having intermediate alkali spreading value, suggesting that these rice landraces require an intermediate cooking time at a temperature range of 70 to 74 °C. Meanwhile, the remaining rice landraces, namely Jangrai, Nangka, Lumpur, Kantan Merah, Mepawan, Pandan, Miyah, Brio Pendek, and Keramat Hitam, were classified as having low/intermediate alkali digestion, suggesting that these rice landraces require a cooking temperature within the range of 75 to 79 °C (high temperature) or 70 to 74 °C (intermediate temperature).

Hard and medium gel consistency was demonstrated by the majority of the rice landraces, with ten and eleven rice landraces exhibiting hard and medium gel consistency, respectively. Hard gel consistency was observed in Bokilong, Kolomintuhon, Silou, Tutumoh, Beruang, Kurau, Bidor, Jangrai, Grik, and Apit. The values vary from 28.00 ± 1.15 in Kurau to 32.67 ± 1.33 in Kolomintuhon. Jangrai was the only rice landrace that exhibited a high/intermediate gelatinization temperature (75 to 79 °C)/(70 to 74 °C), while the remaining rice landraces exhibited an intermediate gelatinization temperature (70 to 74 °C). Medium gel consistency was discovered in Kadim, Tiga Bulan, Wangi, Nangka, Gertok, Lumpur, Kantan Merah, Mepawan, Sanguo Pandan, Pandan, and Keramat Hitam. The range of values is 43.33 ± 1.33 in Nangka and 53.33 ± 1.76 in Lumpur. A high/intermediate gelatinization temperature (75 to 79 °C)/(70 to 74 °C) was observed in Nangka, Lumpur, Kantan Merah, Mepawan, Pandan, and Keramat Hitam, while the remaining rice landraces exhibited an intermediate gelatinization temperature (70 to 74 °C). The medium-hard gel consistency was observed in four rice landraces, with a range of 36.67 ± 0.67 in Brio Pendek and Telinga to 38.00 ± 1.15 in Kenawit. Finally, rice landraces that exhibit a soft gel consistency have a sticky texture, which is a primary distinctive feature of glutinous rice. The range of values was 71.33 ± 1.76 in Pulut Belacan to 100.00 ± 0.00 in Lakatan. These rice landraces exhibited an intermediate gelatinization temperature, ranging from 70 °C to 74 °C.

3.3. Estimation of variance components and genetic parameters

Several genetic factors were evaluated to determine the genetic variability of the evaluated traits among the rice landraces and control cultivars (Table 7). The heritable component of the overall variability can be determined by dividing the phenotypic variance into genotypic and error variance [42]. In this study, the phenotypic coefficient of variance was found to be greater than the genotypic coefficient of variance for all traits. The gel consistency exhibited the highest phenotypic coefficient of variance (PCV) and genotypic coefficient of variance (GCV), with values of 42.44% and 41.88%, respectively. On the other hand, kernel elongation had the lowest PCV and GCV, with values of 9.31% and 8.76%, respectively. The differences between GCV and PCV are important in determining the variation in trait expression, which may be influenced by genetic control or environmental factors. Previous reports stated that traits with large differences between GCV and PCV are primarily influenced by environmental effects on trait expression, while traits with small differences are under genetic control and are less influenced by the environment [43,44]. This study observed that the gel consistency had the highest difference between GCV and PCV, with a value of 0.56. The kernel elongation followed, with a value of 0.55. Amylose content and milled grain width exhibited the least difference, with a value of 0.07.

In this study, all traits revealed a high degree of heritability, exceeding 90%, except for kernel elongation, which had a heritability of only 88.44%. The highest heritability was observed in amylose content, at 99.57%. Determination of genetic advance (GA) among the traits observed that only gel consistency was categorized as high with a value of 38.05%, while the remaining traits were observed as low genetic advance. Genetic advance as a percentage of mean (GAM) is a measure of the predicted genetic gain for a particular trait under selection cycles. It also indicates the extent of stability of the trait under selection intensity [45]. The study revealed that the majority of the traits demonstrated a higher GAM, except for kernel elongation, which was classified as a moderate GAM.

The gel consistency exhibited the highest GAM value of 85.11%, while the amylose content followed with a value of 65.51%. Patel et al. [46] indicated that selecting traits based on phenotypic expression should prioritize traits with high heritability and high GAM to guarantee effective selective breeding. This study identified all traits except for kernel elongation, which exhibited a high GAM (>20%) and a high heritability with values exceeding 90%.

Table 7. Genetic components study for grain appearance and physiochemical components.

Traits	Mean	$\sigma^2 g$	$\sigma^2 e$	$\sigma^2 p$	PCV (%)	GCV (%)	h^2_B (%)	GA	GAM
Milled Grain Length	6.42	0.73	0.02	0.75	13.49	13.29	97.07	1.74	26.97
Milled Grain Width	2.27	0.07	9.04E-04	0.07	11.56	11.49	98.68	0.53	23.5
Grain Shape	2.88	0.29	2.22E-03	0.29	18.86	18.78	99.25	1.11	38.55
Kernel Elongation	1.45	0.02	2.12E-03	0.02	9.31	8.76	88.44	0.25	16.96
Alkali Spreading Value	4.15	0.63	0.03	0.66	19.58	19.39	95.51	1.6	38.52
Gel Consistency	44.71	350.5	9.58	360.08	42.44	41.88	97.34	38.05	85.11
Amylose Content	17.54	31.25	0.13	31.38	31.94	31.87	99.57	11.49	65.51

σ^2_g = genetic variance, σ^2_e = error variance, σ^2_p = phenotypic variance, PCV (%) = phenotypic coefficient of variance, GCV (%) = genotypic coefficient of variance, h^2_B (%) = broad sense heritability, GA = expected genetic advance, GAM = expected genetic mean.

3.4 Clustering analysis

The UPGMA (unweighted pair group method with arithmetic mean) [39] was used to construct a dendrogram from an Euclidean distance matrix to illustrate the genetic relationships among Malaysian rice landraces (Figure 3). The coefficient of cophenetic correlation was 0.89, indicating that the produced dendrogram was a precise illustration of the data. The rice landraces and control rice cultivars were grouped into three clusters by the dendrogram, which was generated using K-means from the Past 4.0 software. Cluster I consisted of five rice landraces, Cluster II of 13 rice landraces, and Cluster III of control rice cultivars with 12 rice landraces. Cluster I is primarily composed of rice landraces with a very low amylose content and soft gel consistency. This rice type is also known as glutinous, which is referred to as "*Pulut*" in Malaysia. The majority of Cluster II is composed of rice landraces with intermediate gel consistency and low amylose content. Meanwhile, Cluster III is predominantly composed of rice landraces with a hard gel consistency and a low to intermediate amylose content. Grain shapes that are medium to long and slender are found throughout all clusters.

Table 8 presents the highest mean values of each trait for each cluster. Cluster I exhibited the highest mean values of gel consistency and kernel elongation. This cluster exhibited the highest mean value in kernel elongation as a result of the presence of the rice landrace, Topoi. The cluster also exhibited the highest mean value in gel consistency, as the rice landraces are predominantly glutinous rice types. Cluster II exhibited the highest mean values of milled grain length and grain shape. Meanwhile, Cluster III exhibited a wide range of variation, as it encompassed rice landraces from various origins and also the control rice cultivars. This cluster exhibited the highest mean value in the alkali spreading value, amylose content, and milled grain width.

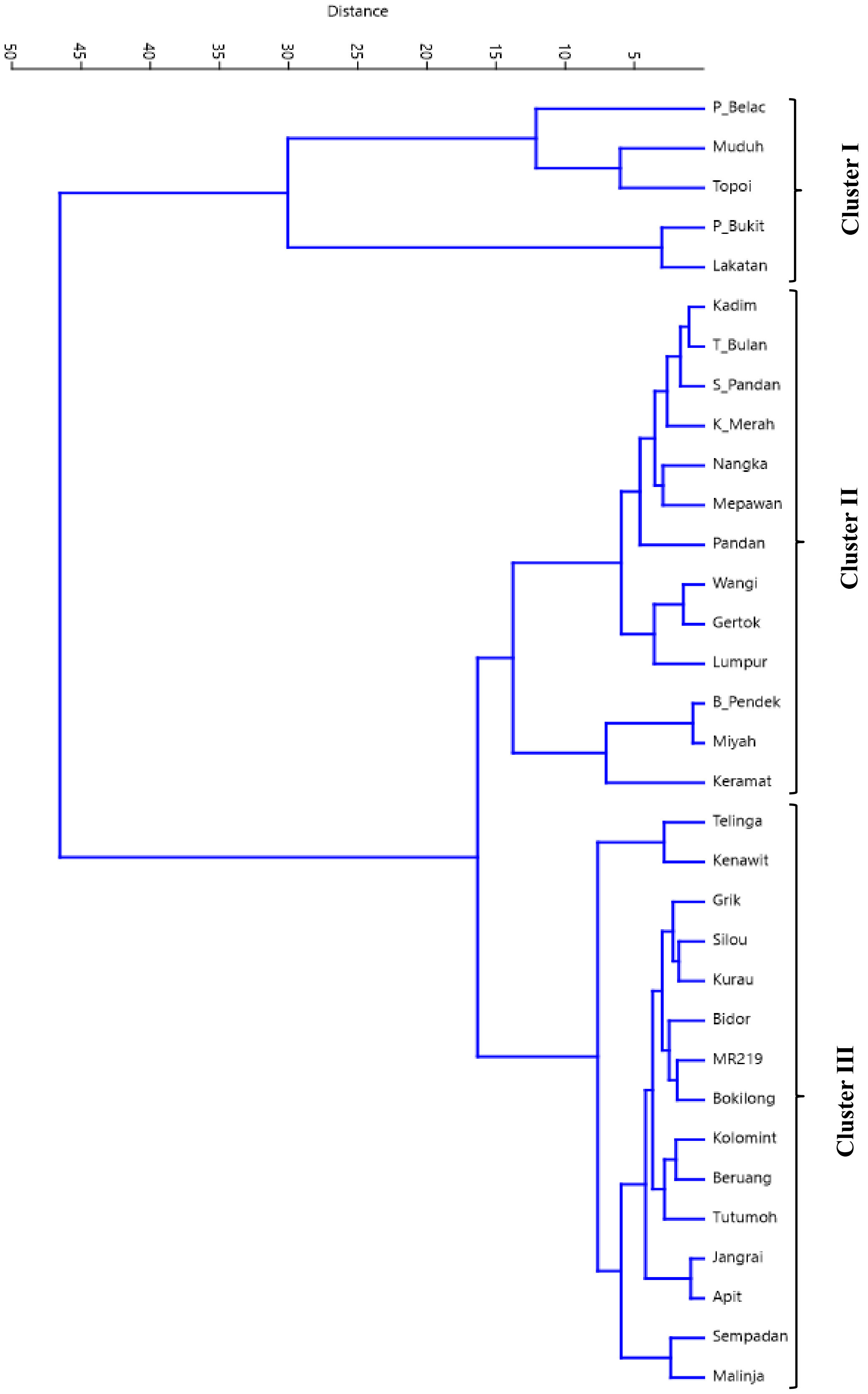

Figure 3. A dendrogram was constructed to illustrate the genetic relationships among Malaysian rice landraces using the Euclidean distance matrix.

Table 8. Mean values with the ranking of five clusters for all traits in rice landraces and control rice cultivars.

Traits	CLUSTER I	CLUSTER II	CLUSTER III
Alkali Spreading Value	5.30 (2)	4.73 (3)	6.03 (1)
Gel Consistency	100.00 (1)	53.33 (2)	38.00 (3)
Amylose Content	23.80 (2)	20.83 (3)	24.73 (1)
Milled Grain Length	7.33 (2)	8.15 (1)	7.23 (3)
Milled Grain Width	2.75 (2)	2.55 (3)	2.81 (1)
Grain Shape	3.40 (3)	3.80 (1)	3.73 (2)
Kernel Elongation	1.87 (1)	1.67 (3)	1.70 (2)

Note: Numbers in parentheses indicate the ranking among clusters.

4. Discussion

Grain shape is one of the important traits that determines the appearance of the grain. It plays a significant role in determining the quality of the grain and also in defining its ability to attract consumers [47]. An extensive array of grain shapes is the primary characteristic of rice landraces, which provide a plethora of genetic diversity sources. In Malaysia, rice landraces have been reported to exhibit various grain shapes, including long, medium, and bold, with the bold grain reported to be consumed by locals for specific purposes [48]; however, Malaysian rice landraces have been commonly reported to exhibit medium and slender grain shapes [25]. Similarly, another study observed that the grain shape of Malaysian black and brown rice was medium; while white, red, and aromatic rice had a slender grain shape [24]. Other countries have also identified a range of grain shapes among their rice landraces, including medium, slender, and bold [49]; and long, slender, and bold [50]. Malaysia is among several countries, including the Philippines, Indonesia, Thailand, Vietnam, Cambodia, India, and Bangladesh, that have identified long and slender rice as the preferred choice among consumers [51]. This is reinforced by the previous report, which indicated that the long grain size received the highest part-worth score (0.533) from Malaysian consumers, followed by medium (0.488) and short grain size (−1.021) [6]. The part-worth score, which reflects the direction in which the attributes influence the preferences, also revealed that grain size (30.84%) was the second most significant consideration for Malaysian consumers when selecting a rice variety, following rice texture (31.50%). Consequently, the selection of rice landraces with a long and slender grain shape is crucial in rice development programs, as it is in alignment with the preferred choice of most Malaysian consumers.

Kernel elongation is a key factor in determining the quality of cooked rice. The preferred rice kernels should elongate without significant changes in width or linear elongation, notably in premium rice of high quality, such as Basmati rice from India and Pakistan [52]. Topoi exhibited the highest ratio compared to the laboratory standard for kernel elongation, MRQ74. The study revealed that Topoi with a bold grain shape exhibited more potential for elongation compared to other grain shapes. The previous finding also revealed this fascinating discovery: The Ratnagiri 2 rice variety, which is short and bold, exhibited the highest kernel elongation ratio in comparison to medium slender rice [53]. Nevertheless, the bold grain type is not preferred among Malaysian consumers, thus it may receive less attention from breeders. Nevertheless, Topoi can be beneficial in genetic studies for elucidating the mechanism and discovering genes that regulate the trait of elongation in cooked kernels.

Similar findings were also observed in a previous study, which exhibited that the majority of Malaysian rice landraces had low to intermediate amylose content [25]. Rice with low amylose content generally refers to glutinous rice, which serves as the main source of carbohydrates in most Malaysian traditional desserts [54]. In addition, rice with a low amylose content was reported to exhibit more stickiness and tenderness than rice with a high amylose content [55]. Meanwhile, rice with intermediate amylose content is tender, moist, and non-sticky after cooking [56]. This makes them the most preferred by consumers in many countries, including Malaysia, Iran, Pakistan, the Philippines, India, several Chinese provinces, Vietnam, Indonesia, and Uruguay [57].

Another important feature of eating quality is gel consistency, which evaluates the tendency of gelatinized starch granules to retrograde upon cooling or, in other words, describes the texture of cooked rice and its ability to stick together or remain separate [58]. This test is frequently employed in rice improvement programs to ascertain the texture of high amylose rice genotypes after cooking, to determine if they exhibit a soft or hard consistency [59]. The study revealed that Malaysian rice landraces exhibited a wide range of gel consistencies, including soft, medium, medium-hard, and hard. This finding is consistent with previous studies [25,58].

The consumer's preferences should be determined by considering both the amylose content and gel consistency together. Consumers' preferences for amylose content and gel consistency varied by country, with Philippines consumers preferring intermediate to low amylose content and a soft gel consistency, Pakistan and India preferring intermediate to low amylose content and soft to medium gel consistency, and Thailand preferring intermediate to hard amylose content and hard to soft gel consistency [60]. Control rice cultivars were developed following the preferences of Malaysian consumers, which demonstrated a preference for rice with an intermediate amylose content and hard gel consistency. This study observed that Bakilong, Kolomintuhon, Silou, Tutumoh, and Bidor exhibited similar eating and cooking quality as the control rice cultivars.

Contradictory results of the study revealed that Beruang, Kurau, Jangrai, Grik, and Apit, with low amylose content, had a hard gel consistency, whereas Brio Pendek, Keramat Hitam, and Miyah, with very low amylose content, had medium to medium-hard gel consistency. A prior study also found that several rice germplasms having low to very low amylose content exhibited a hard gel consistency [61]. This circumstance may occur due to insufficient water while cooking. Inadequate water during the cooking process prevents the gelatinization of the starch in the central region of the rice kernels, leading to a harder texture [62]. Meanwhile, high-protein rice may also tend to be less tender and harder due to the protein forming a thicker barrier surrounding the starch granule. This barrier slows down water absorption, which in turn retards the process of gelatinization and grain swelling [63].

The gelatinization temperature is the range of temperatures at which water is absorbed and at least 90% of starch granules swell irreversibly [64]. The alkali spreading value, which relies on the breakdown of starch granules in a diluted solution of potassium hydroxide, is commonly employed for determining the gelatinization temperature in a breeding program [56]. Rice disintegration was characterized into three distinct classifications: rice with a low gelatinization temperature exhibited complete disintegration, whereas rice with an intermediate gelatinization temperature showed partial disintegration. On the other hand, rice with a high gelatinization temperature remained unaffected when exposed to the alkali solution [64]. It has been stated that high-quality rice should have a gelatinization temperature within the intermediate range [65]. Rice with high gelatinization temperatures is not preferred over those with intermediate or low gelatinization temperatures, as they necessitate longer cooking times and a greater amount of water [66]. Similar to the aforementioned rice landraces, Bokilong, Kolomintuhon, Silou, Tutumoh, and Bidor also exhibited intermediate gelatinization temperatures, which may be beneficial for incorporating them in breeding programs.

The study revealed that the physicochemical properties and grain physical traits were influenced by some environmental factors, which contributed to the variations in their expression. However, the environmental factors that affected the expression of the traits were of low magnitude, indicating that the traits were still under genetic control. Moreover, the physicochemical traits exhibited a higher PCV and GCV, suggesting that the traits possessed a high level of variability. Traits with high variability suggest that the traits have the potential for effective selection for trait improvements [45]. Traits with high heritability and high genetic advance as a percentage of the mean (GAM) were observed in all traits except for kernel elongation. Traits with a high heritability and high genetic advance as a percentage of the mean were indicative of the predominance of additive gene action [45]. The additive gene effect has been described as being accumulated over generations and serving as the primary source of genetic variation [67]. Therefore, these traits were considered desirable, and the primary emphasis of the plant breeding program was on the selection of genotypes that manifested these features [68].

Clustering analysis is used to understand the genetic relationship between rice genotypes. The dendrogram showed a close genetic relationship between varieties, which was attributed to their high degree of genetic relatedness and closed percentage among them [69]. Moreover, clustering analysis indicated that it could assist rice breeders in selecting rice genotypes that are suited to specific breeding objectives [25]. Rice landraces in Cluster I are useful in the improvement program for the creation of new glutinous rice cultivars that can meet the demands of the glutinous rice market in the country. Furthermore, to enhance the physical traits of grain, it is advisable to select rice landraces from Cluster II, specifically focusing on enhancing the length of the grain, which subsequently has an indirect effect on the shape of the grain. Rice landraces comprising Cluster 3 have the potential to assist in the creation of new novel rice cultivars that exhibit desirable physiochemical and cooking quality traits.

The present study was conducted within the confines of the MARDI Rice Quality Laboratory, which particularly focuses on assessing grain specialty traits and evaluating the eating and cooking quality for various breeding lines. It is undeniable that multiple methods have been integrated into the analysis to ascertain rice's eating and cooking quality. The methods include pasting properties using a Rapid Visco Analyzer, thermal properties using a different scanning calorimeter (DSC), rice flour color using a colorimeter, swelling capacity, and also water absorption capacity and solubility [26,70]. Furthermore, the evaluation of rice starch structure, which plays a crucial role in determining the appearance of rice grains and the eating quality of rice, can be performed by examining the starch granules in the grain using various analytical techniques such as a Gel Pro Analyzer, Fourier Transformed Infrared Spectroscopy (FT-IR), ^{13}C nuclear magnetic resonance (^{13}C NMR), and a Polycrystalline X-ray Diffractometer [71,72]. Therefore, it is advisable to incorporate these methods into future studies to evaluate the quality of eating and cooking of various Malaysian rice landraces.

5. Conclusions

The study revealed that the physicochemical properties and grain physical traits of 30 Malaysian rice landraces exhibited a diverse spectrum of variation. Rice landraces including Bokilong, Kolomintuhon, Silou, Tutumoh, and Bidor showed comparable eating and cooking quality as the control rice cultivars. The rice landraces were grouped with the control rice cultivars in the same cluster, indicating that the rice landraces have the closest genetic relationship with the control rice cultivars.

This is owing to their significant genetic similarity, which makes them suitable for incorporation in a breeding program. Most of the studied traits exhibit high heritability and high genetic advance as a percentage of the mean. This implies that such traits were predominantly influenced by additive gene action and were regarded as desirable. In addition, other rice landraces with their valuable traits may also contribute to breeding programs. Topoi, which had a high kernel elongation ratio, can be promoted into the genetic studies for elucidating the mechanism and discovering genes that regulate the trait of elongation in cooked kernels. Rice landraces with low amylose content along with long slender grain shape may also be promoted in the rice improvement program to facilitate the development of new glutinous rice cultivars. This study effectively discovered potential rice accessions that possess valuable traits and can be employed as beneficial donors in future breeding programs to satisfy the country's demand for high-quality or specialty rice cultivars.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflicts of interest or personal relationships with other people or organizations that can inappropriately influence this work.

Author contributions

Conceptualization: S.N.A.R. and R. N.; data curation: S.N.A.R., M.R.O., N.I.A.R., and N.S.S.; statistical analysis: S.N.A.R. and R.N.; methodology: S.N.A.R. and N.S.S.; writing original draft: S.N.A.R.; writing review and editing: R.N., F.Q.Z., K.H.N., and M.H.I. All authors have read and agreed to the published version of the manuscript.

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