Food Science and Engineering
http://ojs.wiserpub.com/index.php/FSE/

Research Article

Varietal Differences in the Physical and Engineering Attributes of Underutilized Pigmented and Non-pigmented Paddy and Rice Landraces

Kuppathil Unnikrishnan Anjali[1], Annamalai Rajalechumi Kamatchi[1], Sundaramoorthy Haripriya[1*], Arun Kumar[2], Chagam Koteswara Reddy[3]

[1] Department of Food Science and Technology, Pondicherry University, Puducherry 605014, India
[2] Department of Food Science and Technology, Guru Nanak Dev University, Amritsar-143005, India
[3] Department of Microbiology and Food Science & Technology, School of Science, Gandhi Institute of Technology And Management, Visakhapatnam 530045, India
E-mail: shprieya@gmail.com

Received: 13 January 2023; **Revised:** 11 August 2023; **Accepted:** 22 August 2023

Abstract: Traditional rice landraces cannot be processed using standard machinery or unit operations. Traditional rice, on the other hand, is becoming more popular as its purported health benefits spread. Cracked rice grains, broken rice, and subpar milled rice kernels result from using non-standard equipment on landraces. So, studying the physical characteristics of rice and paddy is crucial for modifying milling equipment to lessen post-harvest losses. To preserve and familiarize the underutilized landraces, a comparative study of three pigmented and three non-pigmented landraces were assessed for their physical, gravimetric, and engineering traits using standard analytical protocols. The analysis demonstrated substantial variation among the evaluated properties. The majority of the traditional landraces were classified as long-bold and long-slender grains. The landraces exhibited variations in the equivalent diameter ranging from 0.29 to 0.46 mm and 2.54 to 3.38 mm for rice and paddy samples respectively. The major differences in other attributes like sphericity, aspect ratio, and surface area were also observed. Gravimetric properties of paddy and rice samples of Madumuzhungi (MMP) showed significantly lower values in contrast to other landraces. The highest porosity (51.43%), moisture content (14.97%) and water activity (0.88) was exhibited by the Madumuzhungi paddy sample. The non-pigmented rice samples displayed lower values for thousand kernal weight (TKW), grain volume and surface area. Almost all the variants except White mappillai samba paddy were under 30 g for TKW, indicating the differences between pigmented and non-pigmented landraces. Moisture content significantly affected the gravimetric and engineering properties of the landraces. The correlations between the dimensions and engineering qualities were investigated using principal component analysis (PCA). Five principal components, which account for 100% of the total variance, were used via PCA to reduce the dimensionality of the data.

Keywords: pigmented rice, non-pigmented rice, gravimetric properties, axial dimensions, principal component analysis

1. Introduction

Cereals are the primary source of energy for humans on consumption. In terms of global rice production, India

DOI: https://doi.org/10.37256/fse.4220232342

ranks second. In the overall scenario during 2017, it accounted for around 26% of the area and 22% of the production. In terms of food security and employment, rice has traditionally been a significant crop in India. In addition, it is grown in a variety of agroclimatic situations [1]. The conventional rice landraces were drastically reduced in production and consumption as a result of the Green Revolution introducing high-yield landraces [2]. Traditional landraces are a great resource for many desirable agricultural characteristics and other bioactive components. They are high in fiber, calcium, vitamin D, thiamine, riboflavin, and glutamic acids. Much evidence supports the potential benefits of consuming traditional landraces low in fat, sugar, and gluten for those with diabetes and hypertension. These foods have been found to contain oryzanol, a chemical compound that has been shown to impede the body's fat production capabilities [3]. Consumer demand is influenced by the agricultural practises specific to each location, the amylose content of the grains, and the nutraceutical significance they possess. In general, commercially processed rice is commonly consumed subsequent to the extraction of husk and bran using industrial techniques, resulting in the isolation of the endosperm from the rice grain [4]. Apart from the amylose content, consumer preference stayed focused on milled rice because the mechanical milling and polishing removes almost 7-12% of bran fraction, fiber, and fat from the grain which induces its sensory characteristics and shelf life [3-4]. The bran layer mainly constitutes minerals, dietary fiber, and fat whereas proteins are concentrated in the germ layer [2-3]. Polished or white rice is consumed by a significant proportion of the population primarily because of its extensive accessibility and cost-effectiveness. In contrast, the polishing procedure reportedly eliminates all dietary fiber, important fatty acids, and vitamins.Moreover, a significant portion of the current population suffers from malnutrition due to suboptimal dietary decisions. In order to address this issue, the incorporation of traditional unpolished rice, which is abundant in essential nutrients and bioactive constituents, might offer therapeutic properties that aid in disease prevention [3]. The rice landraces with pigments such as red, black, brown, and purple have gained consumer attention as a healthy substitute since they are rich in phenolic compounds especially anthocyanins [2, 5-6]. The phenolic profile possesses antioxidant, anticarcinogenic, anti-allergic, hypoglycemic, anti-microbial, anti-inflammatory and several other health attributes [9].

The screening of rice and paddy landraces are crucial for determining the quality evaluation of physicochemical characteristics in food, and its industrial applications. The nutritious makeup of rice is diminished by the process of milling, with the extent of nutrient loss being contingent upon the level of polishing [2, 7]. Vast variations of size and shape were observed among the rice landraces reported earlier. In most of the types, the size ranges from 5-7.5 mm in length and 1.9-2.5 mm in breadth but there is a wide variance observed in indigenous landraces compared to those in other countries like China and Japan [7]. This variation may be due to the reduction in hulling percentage. The high degree of milling reinforces the physical and sensorial attributes of the rice but removes some nutritional components during polishing. The yield and quality of paddy milling are influenced by the moisture content, pre-treatment, variety, types of equipment, and cultivation methods [5, 9]. The thousand kernel weight of previously reported rices typically ranged from 15.76 to 29.24 g, but it has been noted that there is an association between grain length and weight [10]. The investigations also concluded that the exposure of long grains to the milling process leads to physical damage under specific conditions of air temperature and moisture content for each rice variety [7, 9]. Higher moisture levels in grains has been observed to result in greater levels of stress and subsequent damage in the form of cracking. The primary distinguishing characteristics for the classification of paddy and rice are morphological traits such as grain length, elongation ratio (L/W), and grain size.

The physical attributes of rice play a substantial role in determining the effectiveness of milling and cooking processes, which are of utmost importance in both the harvesting and postharvest stages. In order to achieve the highest quality in the development of rice products, it is important to possess a comprehensive understanding of the physical properties and engineering characteristics involved. The acquisition of this knowledge confers advantages to farmers,consumers and food processors by enabling more efficient management of production and processing activities.

The physical characteristics of traditional rice landraces exhibit a diverse range, and it is crucial to understand the implications of these attributes on processing techniques. Gaining this understanding will facilitate the incorporation of value, enhance the overall quality of the end product, and optimise post-harvest processing. Thus this research aimed to investigate the engineering, gravimetric, and physical characteristics of traditional landraces.

2. Materials and methods

2.1 *Materials*

The pigmented landraces (Kallundai samba (KSP), Madumuzhungi (MMP), White mappillai samba (WMSP), non-pigmented landraces (Mani samba (MSP), Vazhaippoo samba (VSP), Sivan samba (SSP)) of paddy samples were procured from an organic vendor in Karaikal, Puducherry, India. All the paddy landraces were subjected to cleaning to remove dirt and extraneous materials. The cleaned samples were stored in air-tight containers for further processing.

2.2 *Processing and milling of sample*

The unsoiled paddy samples were subjected to a dehusker-Stake Testing Rice Husker (THU-34A, Stake, Japan) to obtain the unpolished rice by removing the husk, and the rice samples are named KSR, MMR, WMSR, MSR, VSR, and SSR for Kallundai samba, Madumuzhungi, White mappillai samba, Mani samba, Vazhaippo samba, and Sivan samba, respectively. Following processing, they are packed in an airtight container at 4 °C for further investigation.

2.3 *Physical characteristics*

2.3.1 *Moisture content*

The total moisture content of the landraces were calculated by the following protocol [12]. It was estimated by the hot air oven method where the preweighed samples were kept in a moisture dish at a temperature of 105 °C for 5 h up to a consistent weight loss were observed. The percentage of moisture content was expressed as the equation follows:

$$Moisture\ content\ (\%) = \frac{Loss\ in\ sample\ weight\ (g)}{Weight\ of\ the\ sample\ (g)} \times 100 \tag{1}$$

2.3.2 *Water activity (a_w)*

The water activity of landraces were measured using an electronic water activity meter (Aqualab CX-2, Decagon Devices, Inc., WA, USA) at 25 °C [7].

2.3.3 *Color intensities*

The color intensities of the landraces were assessed by using a Hunter Lab colorimeter (D-25, Hunter Associates Laboratory, Ruston, USA). The instrument calibration was done using Hunter Lab color standards. The hue angle and chroma values were determined from the obtained data [7].

$$Hue\ angle = tan^{-1}\left(b^{*}/a^{*}\right) \tag{2}$$

$$Chroma = \sqrt{a^2 + b^2} \tag{3}$$

2.4 *Dimensional characteristics of landraces*

The axial dimensions such as length (L), breadth or width (W), and thickness (T) of the selected pigmented and non-pigmented samples from each landrace were determined manually by using a Vernier caliper (Mitutoyo, Japan). These dimensions are further used for the determination of physical properties such as equivalent diameter (D_e), sphericity (Ø), surface area (SA), grain volume (GV), and aspect ratio (AR).

2.4.1 *Equivalent diameter (D_e) and Sphericity (Ø)*

The equivalent diameter (D_e) and sphericity (Ø) of the landraces were computed using the given equation [13].

$$Equivalent\ diameter = \left[L\frac{(W+T)^2}{4} \right]^{\frac{1}{3}} \tag{4}$$

$$Ø = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{5}$$

2.4.2 *Grain volume (V) and Surface area (S)*

The grain volume and surface area of the landraces were calculated by the given equations [13].

$$Grain\ volume = 0.25\left[\left(\frac{\pi}{6} \right) L(W+T)^2 \right] \tag{6}$$

$$Surface\ area\ S = \frac{\pi BL}{(2L-B)} \tag{7}$$

$$\text{where, } B = \sqrt{WT} \tag{8}$$

2.4.3 *Aspect Ratio (R_a)*

The aspect ratio of the landraces were measured using the following equation [13].

$$R_a = \frac{W}{L} \tag{9}$$

2.5 *Gravimetric and engineering properties*

2.5.1 *Bulk, tapped, and true density*

The bulk and tapped density of the pigmented and non-pigmented samples were analyzed by following the protocol of Wani et al. [11]. A graduated measuring cylinder was packed up with samples to 10 mL marking and excess samples were taken off. The weight of the measuring cylinder was noted after gently tapping to determine bulk density. Similarly tapped density was calculated by taking the weight of the measuring cylinder after 100 continuous tappings.

$$Bulk\ density\ \&\ Tapped\ density\ \left({}^{g}\!/\!{}_{mL} \right) = \frac{Weight\ of\ the\ cylinder}{Volume} \tag{10}$$

The true density of the landraces were measured by using the following method [12]. 1 g of sample is transmitted to a 10 mL graduated measuring cylinder with a stopper. Petroleum ether (5 mL) was added, and the mixture was shivered to allow all the grains to suspend. Followed by adding 1 mL of remaining petroleum ether and measured the final volume of petroleum ether and the suspended grains. The equation to calculate true density is given below.

$$True\ density\ \left({}^{g}\!/_{mL}\right) = \frac{Weight\ of\ the\ sample}{\left(Total\ volume\ of\ the\ contents - 6\right)} \tag{11}$$

2.5.2 *Compressibility index and Hausner's ratio*

The compressibility index, also known as Carr's index and Hausner's ratio, which represents the cohesiveness of particles, were calculated after the determination of bulk and tapped density [12].

$$Carr's\ index = \frac{Tapped\ density - Bulk\ density}{Tapped\ density} \times 100 \tag{12}$$

$$Hausner's\ ratio = \frac{Tapped\ densit}{Bulk\ density} \tag{13}$$

2.5.3 *Porosity*

Porosity is a desirable attribute that measures the ratio of void space volume to bulk volume. Porosity was computed using the following equation [12].

$$Porosity\ \left(\%\right) = \frac{True\ density - Tapped\ density}{True\ density} \times 100 \tag{14}$$

2.5.4 *Thousand kernel weight (TKW)*

The thousand kernel weight was measured by randomly selecting 1,000 paddy and rice grain samples which were weighed in an electronic weighing balance (Shimadzu, ELB 30,000) [13].

2.5.5 *The angle of repose (θ)*

A funnel of 60 ×10 cm, 0.7 cm internal stem diameter with 9.6 cm stem length was fitted at a fixed height of 10 cm from the base. 20 g of samples were passed through the funnel to the base to form a pile of a cone. The θ was calculated by estimating the height (H) and diameter (D) of the cone [12].

$$Angle\ of\ repose\ \left(\theta\right) = \tan^{-1}\left(\frac{2H}{D}\right) \tag{15}$$

2.6 *Statistical analysis*

The dimensional characteristics were done in multiples of ten for each landrace. The data for physical, engineering, and gravimetric properties were performed in triplicates. The one-way analysis of variance (ANOVA) and test Duncan ($p < 0.05$) using SPSS Statistics version 20.0 (IBM Corporation, Armonk, Newyork) to determine the significant variation among the mean values. Moreover, principal component analysis (PCA) has been performed for understanding the correlation between the variables for both paddy and rice landraces.

3. Results and discussions

3.1 *Physical properties*

The milling attributes including husk and milling recovery were determined and listed in the Table 1. The percentage of husk obtained from the non-pigmented paddy samples were higher compared to the pigmented landraces. The highest husk was obtained from MSP (24.66%) and the least was acquired from MMP (14.75%). The highest husk percentage resulted in the lower head output of the non pigmented paddy samples. The milling recovery was higher in the pigmented paddy samples where the KSP and WMSP recovered 78.66% of the head rice. The variation in the milling attributes is related to the grain loss in the de-husker by the greater dimension of the grains that causes breakage and lower head rice yield [14].

Table 1. Milling attributes of the paddy landraces

Samples	Husk (%)	Milling recovery (%)
KSP	20.66 ± 1.01^{b}	78.66 ± 1.06^{c}
MMP	14.75 ± 1.11^{a}	72.00 ± 0.98^{a}
WMSP	22.33 ± 1.02^{bc}	78.66 ± 1.17^{c}
MSP	24.66 ± 1.00^{d}	74.66 ± 1.21^{b}
VSP	24.09 ± 1.10^{cd}	73.40 ± 1.09^{ab}
SSP	24.41 ± 0.99^{d}	73.52 ± 0.93^{ab}

KSP- Kallundai samba paddy, MMP- Madumuzhungi paddy, WMSP- White mappillai samba paddy, MSP- Mani samba paddy, VSP- Vazhaippoo samba paddy, SSP- Sivan samba paddy
All data were means of triplicates. Values are expressed in mean ± standard deviation. Different superscripts in the column indicate that values are significantly different ($p < 0.05$) by DMRT (Duncan's Multiple Range Test)

3.1.1 *Moisture content*

Moisture is a crucial quality criterion in rice processing since it influences head rice yield, and as a result interferes with the consumer approval, and commercial value. The moisture content in paddy and rice landraces ranged from 12.72% to 14.97% and 13.72% to 15.48%, respectively (Table 2). The moisture content of the pigmented landraces were significantly higher than the non-pigmented landraces in both paddy and rice samples. Results demonstrated that pigmented MMP (14.97%) and MMR (15.48%) had the highest moisture content and the lowest was observed for non-pigmented VSP (12.72%) and VSR (13.72%). The variance in moisture content might be possibly attributed to the moisture level of the rice grain at the time of harvest and storage period which influences the processing circumstances [7]. The rice samples were found to have higher moisture content than their respective paddy samples. Similar results were observed in previous studies on rice [15]. This may be due to the moisture content reduction during the milling of the non-pigmented landraces. Moisture content is requisite in ascertaining quality attributes of the landraces and is important in assuring the milling potential to render a high head rice yield [16].

Table 2. Moisture, water activity, and dimensional characteristics of paddy and rice landraces

Samples	Parameters				
	Moisture (%)	Water activity (a_w)	Length (mm)	Breadth (mm)	Thickness (mm)
KSP	14.16 ± 0.03^c	0.85 ± 0.00^d	8.46 ± 0.37^b	2.99 ± 0.25^c	3.81 ± 0.18^c
KSR	15.12 ± 0.05^c	0.78 ± 0.00^b	6.00 ± 0.31^b	2.95 ± 0.32^b	2.02 ± 0.02^b
MMP	14.97 ± 0.25^d	0.88 ± 0.00^e	8.35 ± 1.15^b	2.58 ± 0.50^b	3.20 ± 0.41^b
MMR	15.48 ± 0.13^d	0.85 ± 0.00^d	6.41 ± 0.41^c	2.91 ± 0.29^b	2.01 ± 0.06^b
WMSP	13.56 ± 0.02^b	0.83 ± 0.00^c	8.22 ± 0.27^b	3.25 ± 0.16^c	3.89 ± 0.11^c
WMSR	14.98 ± 0.06^c	0.85 ± 0.00^d	6.04 ± 0.03^b	3.03 ± 0.04^b	2.01 ± 0.01^b
MSP	12.84 ± 0.03^a	0.82 ± 0.00^b	7.03 ± 0.51^a	2.47 ± 0.33^b	3.21 ± 0.25^b
MSR	14.52 ± 0.05^b	0.82 ± 0.00^c	5.27 ± 0.40^a	2.10 ± 0.15^a	1.89 ± 0.15^b
VSP	12.72 ± 0.06^a	0.88 ± 0.00^e	7.80 ± 0.64^b	2.38 ± 0.40^b	3.36 ± 0.33^b
VSR	13.72 ± 0.06^a	0.86 ± 0.00^e	5.82 ± 0.35^b	2.01 ± 0.02^a	1.66 ± 0.31^a
SSP	13.41 ± 0.01^b	0.81 ± 0.00^a	7.17 ± 0.73^a	2.07 ± 0.027^a	2.89 ± 0.23^a
SSR	14.42 ± 0.39^b	0.77 ± 0.00^a	5.39 ± 0.29^a	1.92 ± 0.09^a	1.57 ± 0.22^a

KSP- Kallundai samba paddy, KSR- Kallundai samba rice, MMP- Madumuzhungi paddy, MMR- Madumuzhungi rice, WMSP- White mappillai samba paddy, WMSR- White mappillai samba rice, MSP- Mani samba paddy, MSR- Mani samba rice, VSP- Vazhaippoo samba paddy, VSR- Vazhaippoo samba rice, SSP- Sivan samba paddy, SSR- Sivan samba rice
All data were means of triplicates. Values are expressed in mean ± standard deviation. Different superscripts in the column indicate that values are significantly different ($p < 0.05$) by DMRT.

3.1.2 *Water activity (a_w)*

Water activity, which measures the amount of free water in the grain, is one of the most critical characteristics that impact the food storage. The water activity of the landraces were given in Table 2. Among the non-pigmented landraces, VS displayed the highest water activity (VSP:0.88 & VSR:0.86) and the lowest was seen in SS (SSP:0.81 & SSR:0.77). Higher water activity ushers the escalated microbial growth and metabolic reactions, resulting in grain with a shorter shelf life [12]. The increased water activity in VS indicates a strong affinity for microbial infestation and deterioration in contrast to other landraces. Among the pigmented samples highest water activity was found in MM (MMP:0.88 & MMR:0.85) and the lowest values were exhibited by the paddy sample WMSP (0.83) and rice sample KSR (0.78). The reduced water activity indicates longer shelf life and lower infestation [7].

3.1.3 *Color intensities*

Color is one of the most critical factors in assessing the product quality and, the client preference since the aesthetic of the food product affects the eye appeal. While working with several landraces of brown rice, authors reported varying color values [8, 15] K-332, Koshar, Pusa-3, SKAU-345, SKAU-382 and SR-1, grown in temperate region of India, were studied for the variety difference in their physical properties. Results showed the significant difference in the physical propertiesincluding length, width, thickness, equivalent diameter, surface area, sphericity, aspectratio, volume, bulk density, true density, porosity, thousand kernel weight, angle of repose and coefficient of friction among paddy and brown rice of cultivars ($p < 0.05$. During milling, the brightness of the rice improves with the reduction of red and yellow color characteristics [17]. Figure 1 describes the results of the color intensities observed in the pigmented and non-pigmented landraces. The color-derived property chroma indicates the saturation of the color, which was measured for all the landraces. Higher chroma values were exhibited by non-pigmented landraces, SSR (22.04) and SSP (15.68) respectively. The lowest chroma value were measured in pigmented samples KSP (14.01) and KSR (17.47). The hue angle signifies the perception of color, which lies in the first quadrant (0° to 90°) and coincides with the range of reddish-purple to yellow (48.46° to 79.27°), and for the pigmented to non-pigmented landraces, it ranged from 68.85° to 74.47°. The color variations in the rice landraces were affected by the genetic makeup, kernel pigments, and composition [7, 15].

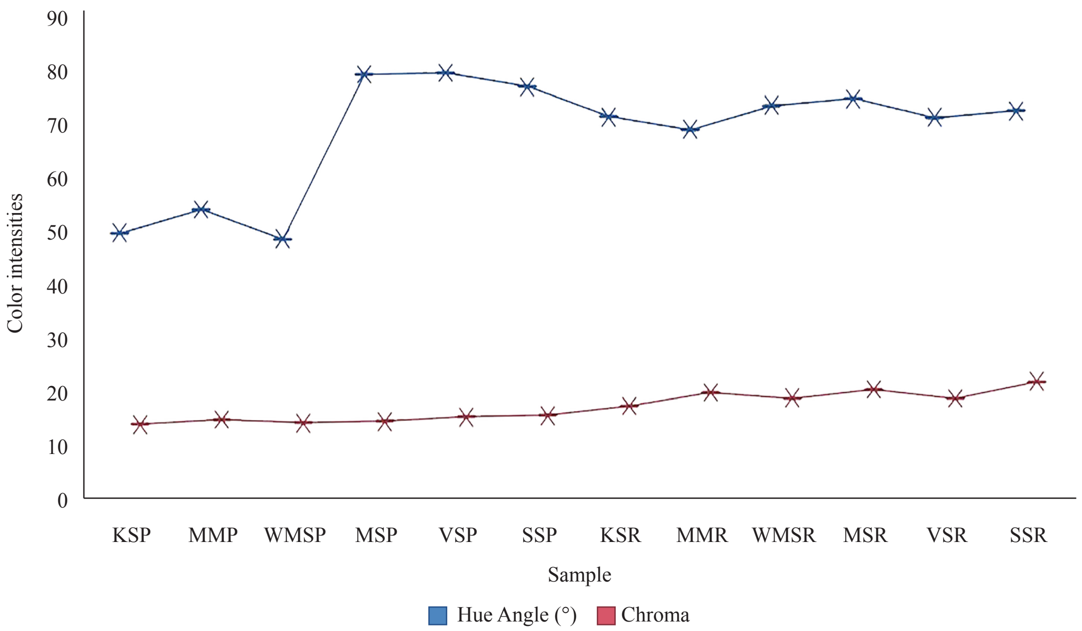

Figure 1. Color intensities in the pigmented and non-pigmented landraces
KSP- Kallundai samba paddy, KSR- Kallundai samba rice, MMP- Madumuzhungi paddy, MMR- Madumuzhungi rice, WMSP- White mappillai samba paddy, WMSR- White mappillai samba rice, MSP- Mani samba paddy, MSR- Mani samba rice, VSP- Vazhaippoo samba paddy, VSR- Vazhaippoo samba rice, SSP- Sivan samba paddy, SSR- Sivan samba rice

3.2 *Dimensional characteristics*

The axial dimensions of the landraces were listed in Table 2. The paddy sample's axial dimensions length, breadth, and thickness were significantly higher than their corresponding rice samples. Various studies indicated that during milling, the moisture content and variety remarkably stimulated the physical dimensions of the landraces. This may be due to the swelling of grains under high moisture content [18]. According to the findings, pigmented landraces exhibited higher axial dimensions than non-pigmented landraces. Using the length-to-breadth ratio, Indica rice landraces were also divided into long and bold grain types [19]. MMR was discovered to be the longest rice grain, categorized as a long and bold grain, followed by WMSR and KSR, which were long and slender grains. These dimensional parameters are the fundamental requirements for calculating other geometrical parameters such as equivalent diameter, surface area, sphericity, and aspect ratio of grain kernels, which are the chief foundation for making adaptations in rice processing equipment.

Rice with a long and slender shape is typically favored as export-quality rice. The dimensions of the rice and paddys have a considerable impact on the size and precision of sieves and graders, making them crucial for building successful machinery. Additionally, the axial dimension of the rice is utilized to compute several engineering parameters that can be implemented in designing machinery for various table post-harvest procedures [20].

Table 3. Dimensional characteristics of paddy and rice landraces

Samples	Parameters				
	Equivalent diameter (De)	Sphericity (Ø)	Grain volume (V)	Surface area (S)	Aspect Ratio (R_a)
KSP	0.44 ± 0.01^c	29.25 ± 1.07^c	4.66 ± 0.29^c	0.35 ± 0.02^b	2.13 ± 0.11^c
KSR	3.33 ± 0.15^c	0.54 ± 0.03^c	19.51 ± 1.50^c	4.82 ± 0.37^c	0.49 ± 0.06^d
MMP	0.37 ± 0.04^b	18.06 ± 0.96^b	3.37 ± 0.63^a	0.31 ± 0.06^b	1.41 ± 0.31^a
MMR	3.38 ± 0.17^c	0.52 ± 0.02^b	20.45 ± 0.90^c	4.68 ± 0.30^c	0.45 ± 0.04^c
WMSP	0.46 ± 0.01^c	30.97 ± 0.75^c	4.88 ± 0.22^c	0.39 ± 0.02^c	2.10 ± 0.10^c
WMSR	3.37 ± 0.02^c	0.55 ± 0.00^c	20.19 ± 0.38^c	4.88 ± 0.04^c	0.50 ± 0.00^d
MSP	0.45 ± 0.02^c	17.62 ± 0.07^b	3.98 ± 0.41^b	0.35 ± 0.04^b	1.87 ± 0.13^b
MSR	2.75 ± 0.13^b	0.52 ± 0.02^b	11.06 ± 1.67^b	3.86 ± 0.24^b	0.39 ± 0.03^b
VSP	0.29 ± 0.01^a	20.46 ± 0.08^b	4.03 ± 0.59^b	0.30 ± 0.05^a	2.04 ± 0.31^c
VSR	2.69 ± 0.19^b	0.46 ± 0.02^a	10.43 ± 0.07^b	3.39 ± 0.36^a	0.34 ± 0.02^a
SSP	0.40 ± 0.03^c	12.88 ± 0.84^a	3.26 ± 0.37^a	0.29 ± 0.03^a	1.60 ± 0.32^a
SSR	2.54 ± 0.15^a	0.47 ± 0.03^a	8.72 ± 1.60^a	3.26 ± 0.36^a	0.35 ± 0.02^a

KSP- Kallundai samba paddy, KSR- Kallundai samba rice, MMP- Madumuzhungi paddy, MMR- Madumuzhungi rice, WMSP- White mappillai samba paddy, WMSR- White mappillai samba rice, MSP- Mani samba paddy, MSR- Mani samba rice, VSP- Vazhaippoo samba paddy, VSR- Vazhaippoo samba rice, SSP- Sivan samba paddy, SSR- Sivan samba rice
All data were means of triplicates. Values are expressed in mean ± standard deviation. Different superscripts in the column indicate that values are significantly different ($p < 0.05$) by DMRT.

The equivalent diameter (D_e) is critical for determining the sieve size and pore diameter. It was observed that high scores of equivalent diameters were observed in pigmented landraces (Table 3). The highest values of D_e in paddy samples were exhibited by WMSP (0.46 mm), and the least in VSP (0.29 mm) while in rice samples pigmented MMR (3.38 mm) showed the highest score, and the least values were found in SSR (2.54 mm). The traditional paddy landraces had a higher sphericity score than rice (Table 3). Substantial variations were observed between pigmented and non-pigmented samples. WMS landrace exhibited the highest sphericity (WMSP:30.97 and WMSR:0.55), whereas the least values were given by non-pigmented samples, SSP (12.88) and VSR (0.46), which could be owing to minor difference in length, breadth, and thickness between paddy and rice. A similar study on Mushki-Tujan paddy inferred that the sphericity of paddy was higher than that of rice landraces [12]. The grain volume and surface area were more elevated in pigmented samples, the highest values of grain volume were evinced by the paddy sample, WMSP (4.88 mm^3), and rice sample, MMR (20.45 mm^3). The lowest was revealed by the SS samples (SSP: 3.26 mm^3 and SSR: 8.72 mm^3). Grains with larger volumes will take up more room during transit. Grains with a larger volume can be favorable for vendors since they fill up more space in the international market, where rice is exported in enormous quantities. On the other hand, grains with smaller volumes will have reduced transportation costs because they take up less room in the transport hub than grains with higher volumes [20].

Similarly, the pigmented landrace WMS (WMSP: 0.39 mm^2 and WMSR: 4.88 mm^2) depicted higher values for surface area, and the least was observed by non-pigmented landrace, SS (SSP: 0.29 mm^2 and SSR: 3.26 mm^2) which may be due to the difference in moisture content [21]. The drying behavior of grains were significantly incited by their volume and surface area. Knowledge about the properties of rice are crucial for the design of grain cleaners, suction tools, pneumatic separators, and dryers, as it assesses the area exposed to turbulent airflow during the drying process [20].

The aspect ratio was significantly higher in pigmented landraces (Table 3). KSP exhibited a higher value (2.13) among the paddy samples and, it was higher in WMSR (0.50) among the rice landraces. The grain movements like gliding and rolling are determined by aspect ratio. The lower value of 0.34 was expressed by the non-pigmented VSR sample, which will roll on the surface rather than slide [22]. After milling, a substantial decrease in the aspect ratio and elongation ratio in paddy landraces were observed. The elongation ratio was significantly higher in the non-pigmented landraces compared to the pigmented samples, which is a crucial key factor to consider when selecting a mill to attain a high production yield [23]. The elongation ratio of SSP (3.45) was higher than all the other paddy and rice landraces. It was observed that a notable association was exhibited between the aspect ratio and elongation ratio of the paddy samples (Table 5).

3.3 *Gravimetric and engineering properties*

The gravimetric and engineering properties of the pigmented and non-pigmented landraces were tabulated in Table 4 and Table 5.

Table 4. Gravimetric Properties of paddy and rice landraces

Samples	Parameters				
	Bulk density (g/mL)	Tapped density (g/mL)	True density (g/mL)	Carrs index	Hausner's ratio
KSP	0.47 ± 0.01^{b}	0.52 ± 0.01^{b}	0.94 ± 0.05^{b}	8.79 ± 0.59^{a}	1.09 ± 0.00^{a}
KSR	0.70 ± 0.00^{bc}	0.72 ± 0.01^{bc}	1.25 ± 0.00^{a}	2.87 ± 0.68^{a}	1.02 ± 0.00^{a}
MMP	0.33 ± 0.00^{a}	0.37 ± 0.01^{a}	0.77 ± 0.00^{a}	10.65 ± 0.94^{a}	1.12 ± 0.03^{a}
MMR	0.67 ± 0.01^{a}	0.71 ± 0.01^{a}	1.25 ± 0.00^{a}	4.84 ± 0.95^{a}	1.05 ± 0.04^{a}
WMSP	0.51 ± 0.01^{cd}	0.58 ± 0.00^{de}	1.00 ± 0.00^{bc}	11.05 ± 0.44^{a}	1.12 ± 0.03^{a}
WMSR	0.72 ± 0.01^{d}	0.74 ± 0.00^{bc}	1.16 ± 0.07^{a}	1.98 ± 1.22^{a}	1.02 ± 0.01^{a}
MSP	0.53 ± 0.00^{d}	0.59 ± 0.00^{e}	1.12 ± 0.12^{c}	9.33 ± 0.60^{a}	1.10 ± 0.03^{a}
MSR	0.71 ± 0.00^{cd}	0.74 ± 0.00^{bc}	1.20 ± 0.07^{a}	4.37 ± 1.13^{a}	1.04 ± 0.01^{a}
VSP	0.50 ± 0.01^{c}	0.56 ± 0.00^{cd}	0.94 ± 0.05^{b}	10.37 ± 1.63^{a}	1.11 ± 0.02^{a}
VSR	0.68 ± 0.01^{ab}	0.71 ± 0.02^{a}	1.11 ± 0.00^{a}	3.90 ± 1.16^{a}	1.04 ± 0.02^{a}
SSP	0.50 ± 0.012^{c}	0.55 ± 0.00^{bc}	1.00 ± 0.09^{bc}	8.74 ± 1.15^{a}	1.09 ± 0.014^{a}
SSR	0.70 ± 0.00^{cd}	0.75 ± 0.00^{c}	1.27 ± 0.15^{a}	5.69 ± 1.19^{a}	1.06 ± 0.01^{a}

KSP- Kallundai samba paddy, KSR- Kallundai samba rice, MMP- Madumuzhungi paddy, MMR- Madumuzhungi rice, WMSP- White mappillai samba paddy, WMSR- White mappillai samba rice, MSP- Mani samba paddy, MSR- Mani samba rice, VSP- Vazhaippoo samba paddy, VSR- Vazhaippoo samba rice, SSP- Sivan samba paddy, SSR- Sivan samba rice
All data were means of triplicates. Values are expressed in mean ± standard deviation. Different superscripts in the column indicate that values are significantly different ($p < 0.05$) by DMRT.

Table 5. Engineering characteristics of paddy and rice landraces

Samples	Parameters			
	Porosity (%)	TKW (g)	Angle of repose (θ)	L/W ratio
KSP	44.10 ± 0.90^{a}	29.40 ± 0.47^{c}	33.41 ± 0.89^{ab}	2.84 ± 0.24^{a}
KSR	42.52 ± 0.67^{a}	24.64 ± 0.04^{d}	33.70 ± 0.79^{a}	2.06 ± 0.33^{c}
MMP	51.43 ± 2.44^{b}	29.45 ± 0.48^{c}	35.07 ± 0.79^{b}	3.33 ± 0.81^{b}
MMR	43.20 ± 0.87^{a}	24.94 ± 0.04^{e}	33.24 ± 0.89^{a}	2.22 ± 0.23^{c}
WMSP	41.83 ± 0.63^{a}	32.68 ± 0.13^{d}	32.81 ± 1.15^{a}	2.53 ± 0.15^{a}
WMSR	36.19 ± 0.86^{a}	27.63 ± 0.19^{f}	34.17 ± 0.83^{a}	1.99 ± 0.02^{a}
MSP	47.07 ± 0.10^{ab}	18.46 ± 0.00^{b}	34.00 ± 1.01^{ab}	2.87 ± 0.33^{a}
MSR	38.29 ± 0.50^{a}	17.74 ± 0.19^{c}	34.60 ± 1.21^{a}	2.51 ± 0.23^{d}
VSP	43.15 ± 1.03^{a}	18.00 ± 0.10^{b}	34.06 ± 1.05^{ab}	3.35 ± 0.59^{b}
VSR	36.33 ± 0.78^{a}	14.61 ± 0.08^{b}	34.68 ± 0.65^{a}	2.88 ± 0.17^{d}
SSP	44.93 ± 0.66^{a}	13.22 ± 0.07^{a}	32.19 ± 1.57^{a}	3.45 ± 0.35^{b}
SSR	40.19 ± 0.59^{a}	10.43 ± 0.03^{a}	34.98 ± 1.28^{a}	2.80 ± 0.20^{d}

KSP- Kallundai samba paddy, KSR- Kallundai samba rice, MMP- Madumuzhungi paddy, MMR- Madumuzhungi rice, WMSP- White mappillai samba paddy, WMSR- White mappillai samba rice, MSP- Mani samba paddy, MSR- Mani samba rice, VSP- Vazhaippoo samba paddy, VSR- Vazhaippoo samba rice, SSP- Sivan samba paddy, SSR- Sivan samba rice

All data were means of triplicates. Values are expressed in mean ± standard deviation. Different superscripts in the column indicate that values are significantly different ($p < 0.05$) by DMRT.

3.3.1 *Bulk density, tapped density, and true density*

The densities of the non-pigmented samples were much higher than the pigmented landraces. The bulk density is essential in determining the weight of the product in the hopper and for designing silos [13]. The alternation in the moisture content due to temperature and relative humidity alters the bulk density upon storage [24]. Among the rice samples, the highest bulk density was observed in pigmented WMSR (0.72 g/mL) and non-pigmented MSP (0.53g/mL) evinced the highest scores among the paddy landraces (Table 4). Similarly, MSP (0.59 g/mL) exhibited the highest values of tapped density among the paddy samples and SSR (0.75 g/mL) showed the highest value of tapped density among the rice samples. Tapped density of the pigmented landraces were significantly lower than the non-pigmented landraces. Bulk density and tapped density values for all the landraces were lower than true density. This may be due to the void air spaces in grain bulk, increasing the volume while the weight remains constant [15]. Densities exhibited by non-pigmented samples were remarkably higher than in the pigmented landraces. Lower values of densities were found in MM samples and the MS samples exhibited higher range. The true density of paddy dropped as the moisture content increased. The highest score of true density was exhibited by the non-pigmented paddy sample MSP (1.12 g/mL) compared to the pigmented ones (Table 4). There were no notable variations observed in the true density for the rice samples. On de-shelling and milling operations, true density, tapped density, and bulk density increased as the husk was removed from the paddy, leaving the starchy kernel as brown rice [25]. The decline in the volume of the kernel at increasing moisture content levels causes an increase in true density [26]. The true density result signifies that the kernel density is greater than that of water, which is a notable characteristic in the case of cereal grains during wet cleaning as the kernels do not float [27].

3.3.2 *Porosity, compression index, and Hausner's ratio*

Porosity was measured by the kernel densities, and the magnitude of porosity change was determined only by those parameters [28]. The porosity of paddy samples was highest in MMP (51.43%) in contrast to WMSP (41.83%), but no substantial differences were found among rice landraces (Table 5). The moisture substantially influences the bulk density thereby the porosity of the paddy. The porosity of the material increased as the moisture content escalated, allowing for optimal airflow and water vapor diffusion during drying. This was observed for paddy and rice samples that depicted low porosity values with an increase in bulk density. Bulk density significantly influences grain form and porosity because the slender grain displays higher porosity resulting from low bulk density. Previous studies observed drying behavior and porosity; and inferred that the grains with higher porosity dry more rapidly than grains with lower porosity [28]. After de-husking, densities rose, resulting in higher porosity for rice samples than paddy.

The compressibility index (Carr's index) and the Hausner's ratio are two significant characteristics to consider when determining grain flowability (Table 4). All the landraces exhibited good grain flowability since they have Carr's index values and Hausner's ratio lower than 15 and 1.25, respectively which are the limits that decide free-flowing characteristics [17]. Hausner's ratio, porosity, and compressibility index of the paddy and rice landraces did not differ much.

3.3.3 *Thousand Kernel Weight (TKW)*

The thousand-grain weight of the paddy increased as the moisture level in all the landraces increased (Table 5). Higher TKW values of 32.68 g was exhibited by the pigmented paddy sample, WMSP, which was attributed to its moisture content, and the least was obtained for the non-pigmented SS sample for both rice (10.43 g) and paddy (13.22 g). Increased paddy dimensions may explain the variations in paddy shape and TKW with increased moisture content. Paddy samples had much higher kernel weight than rice samples, possibly due to the presence of awns and husks [17]. The loss of moisture content from the rice grains and the removal of awns during handling contributed to the weight reduction. The maximum kernel weight of 27.63 g among the rice landraces was found in WMSR, while the lowest of 10.43 g was seen in SSR. TKW values for all the samples except WMSP were less than 30 g, showing that the pigmented and non-pigmented kinds differ significantly. The TKW of non-pigmented landraces was less than 20 g, indicating that the grains were either unfilled or damaged [29].

3.3.4 *Angle of repose*

The angle of repose denotes the maximum angle of a pile of grain in the horizontal plane for the grains that are not piled at a constant bed depth but are peaked [17]. This is significant when filling a flat storage facility. The use of angle of repose in the design of handling and processing equipment is beneficial. No significant change in the angle of repose was found for rice landraces, but notable differences in the angle of repose for paddy samples were observed (Table 5). Pigmented paddy samples exhibited higher values in contrast to non-pigmented landraces. The experiment inferred that MMP had the highest value of 35.07°, and the least was observed for SSP (32.19°). The higher angle of repose values in grains may be attributed to their larger dimension and rough surface, which prevents smooth flow and makes them easier to stack [30]. With increasing moisture content, the angle of repose of rice grains increases dramatically [9]. Increased moisture absorption causes a more prominent surface layer of moisture to form around the particles, which holds the aggregation of grains together by increasing surface tension. It reduced as the moisture content of paddy landraces dropped. At lower moisture content, the decreasing trend in the angle of repose could be attributable to reduced cohesive force and internal friction between particles [31].

3.4 *Principal component analysis (PCA)*

Principal component analysis was executed to determine the correlation between physical, engineering, and gravimetric attributes of the selected paddy and rice landraces (Table 6). The variance is displayed by a scree plot in

Figure 2 and the biplot of the paddy and rice landraces are depicted in Figure 3 and Figure 4. The rice samples were found to have extracted five principal components (PC) exhibiting 100% of the total cumulative variance with individual eigen values of 12.5, 4.6, 3.4.1.03 & 0.40 for PC1, PC2, PC3, PC4 & PC5 respectively. PC1 accounted for 56.84% variance and was principally attributed to components including moisture, a_w, L/W ratio, grain volume, breadth, D_e, SA, TKW, aspect ratio, and chroma. Whereas PC2 with a variance of 21% was primarily associated with porosity, true density, bulk density, tapped density, and hue angle. From the biplot, it was observed that the pigmented rice landraces fall extensively opposite to the non-pigmented rice landraces. VSR and SSR are found to have a similar correlation among the components falling in PC1. The MSR sample individually plotted in a separate quadrant hardly shows a mere correlation with the other two non-pigmented rice landraces.

Table 6. Principal component analysis for paddy and rice landraces

	Total Variance Explained for paddy landraces		
Principal components	Eigen values	Total variance %	Cumulative %
1	10.01345	43.53674	43.53674
2	8.179843	35.56453	79.10128
3	2.566976	11.16076	90.26204
4	1.355645	5.894111	96.15615
5	0.884085	3.843849	100
	Total Variance Explained for rice landraces		
1	12.50519	56.84177	56.84177
2	4.620634	21.00288	77.84465
3	3.435348	15.61522	93.45987
4	1.032079	4.691268	98.15113
5	0.40675	1.848865	100

Paddy samples exhibited five extracted principal components, PC1, PC2, PC3, PC4 & PC5 with eigen values 10.01, 8.17, 2.56, 1.35 & 0.88 respectively. These components all together rendered a total cumulative variance of 100%. PC1 involving components like L/W ratio, chroma, D_e, grain volume, and aspect ratio together provided a variance of 43.53%. PC2 with a variance of 35.56% was contributed by components including moisture, angle of repose, water activity, true density, bulk density, and husk percentage. The non-pigmented paddy samples clustered together to fall under a single quadrant. The VSP sample was characterized by its superior L/W ratio, water activity, chroma, and Hausner's ratio. Studies inferred that a very high correlation between the grain volume and surface area, which is directly related to the heat and mass transfer rate, can be utilized in drying time and energy calculations [31]. Grain surface knowledge is vital for drying, aeration, heating, and cooling modeling [22].

In broad terms, the analysis was performed to learn more about the correlations and patterns found in the data and to separate groups of landraces based on the components these individual samples share. This information is relevant for a number of objectives, including crop storage conditions, quality assessment, and understanding the effects of environmental conditions on grain qualities. All the rice and paddy landraces majorly had a positive linear correlation between dimensional and gravimetric properties. This indicates the importance of these dimensional properties in processing equipment design.

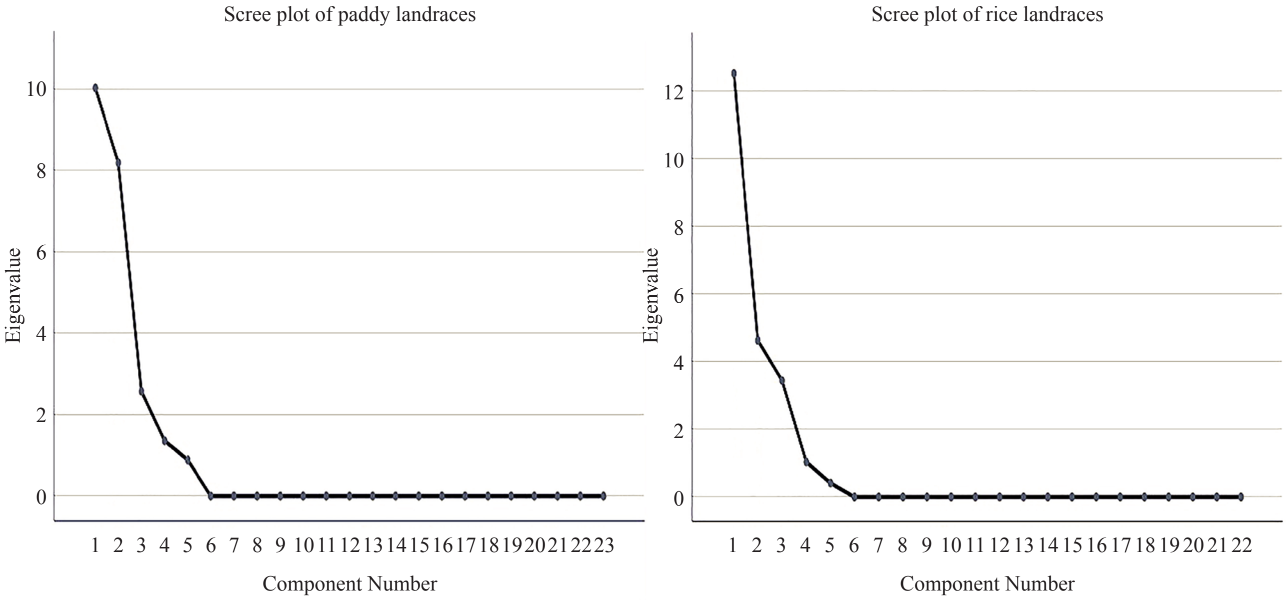

Figure 2. Scree plot of principal component analysis

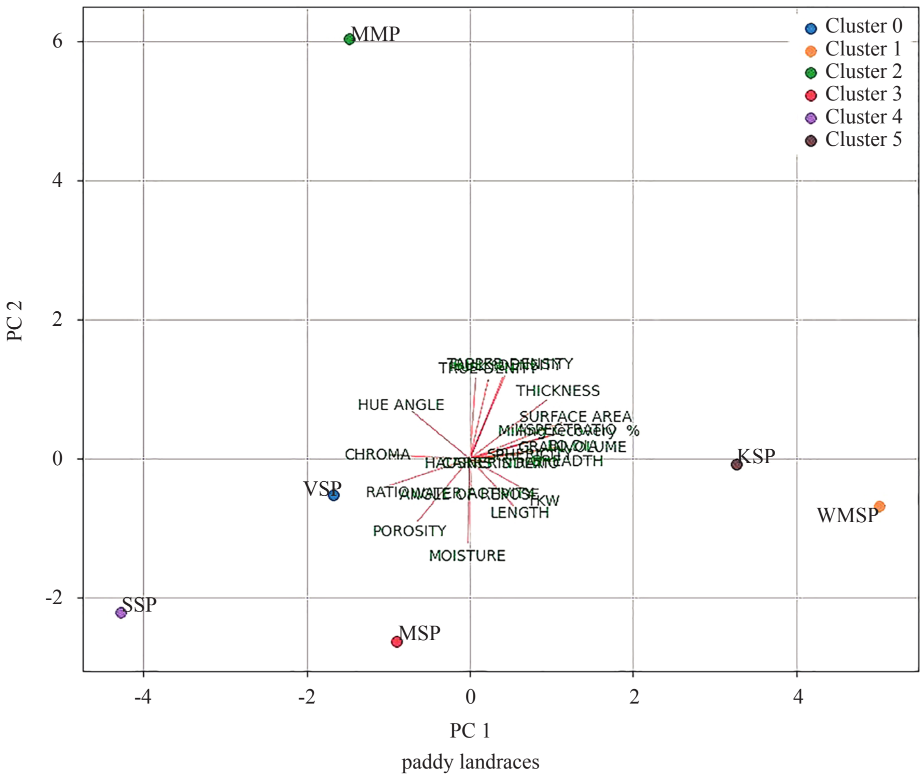

Figure 3. Projections of the variables and observations as of PCA on the factor plane for paddy landraces-PC1 versus PC2
KSP- Kallundai samba paddy, MMP- Madumuzhungi paddy, WMSP- White mappillai samba paddy, MSP- Mani samba paddy, VSP- Vazhaippoo samba paddy, SSP- Sivan samba paddy

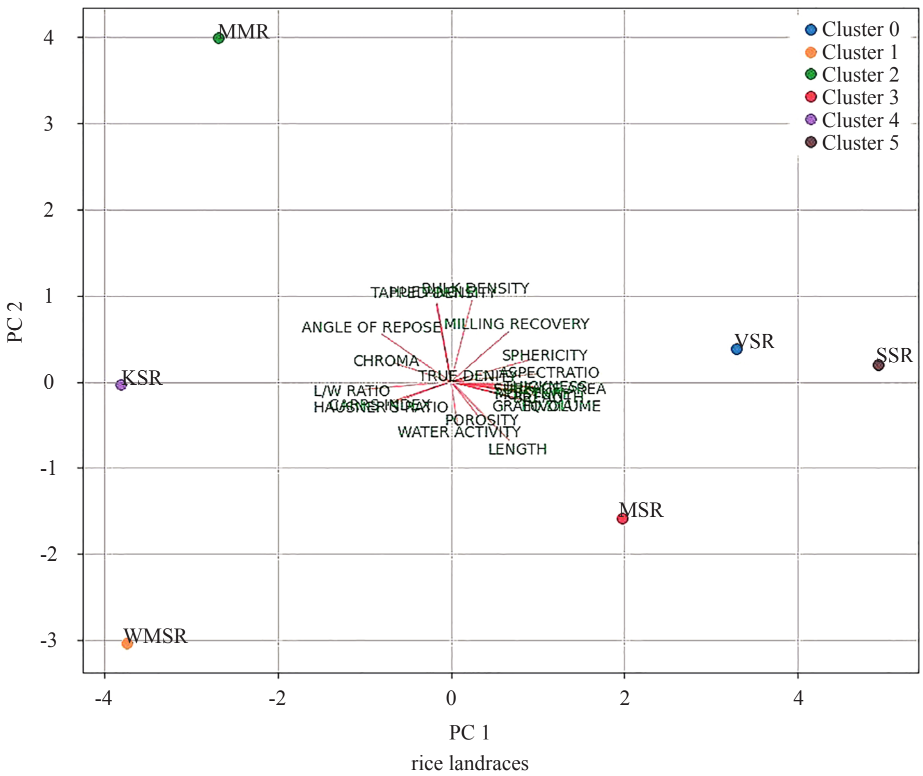

Figure 4. Projections of the variables and observations as of PCA on the factor plane for rice landraces- PC1 versus PC2 KSR- Kallundai samba rice, MMR- Madumuzhungi rice, WMSR- White mappillai samba rice, MSR- Mani samba rice, VSR- Vazhaippoo samba rice, SSR- Sivan samba rice

4. Conclusion

The results of this investigation revealed significant variations in the physical, engineering, and gravimetric qualities across traditional paddy and rice landraces. The implementation of suitable processing and handling technologies can contribute to the mitigation of post-harvest losses, as these characteristics are vital in the development of effective processing machinery. The correlation analysis has identified relationships between several characteristics that can be utilised to enhance the overall performance of the milling equipment. Comprehending the characteristics exhibited by various rice landraces is vital in the pursuit of minimising post-harvest losses, enhancing overall quality, increasing value addition, and developing efficient post-harvest processing equipment. Consequently, this phenomenon results in an increased production of premium quality rice grains, thereby providing additional backing for the expansion of farming practises pertaining to these lesser-utilized rice landraces on a broader scope. Furthermore, it serves as a source of motivation for farmers to expedite their farming practises, develop advanced post-harvest processing machinery, and improve overall production efficiency.

Acknowledgements

The authors are thankful to the Department of Food Science and Technology, Pondicherry University, Pondicherry, for providing a laboratory. The author also would like to thank University Grants Commission (UGC), New Delhi, for providing a national fellowship.

Conflict of 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

[1] Bora K. Spatial patterns of fertilizer use and imbalances: Evidence from rice cultivation in India. *Environmental Challenges.* 2022; 7: 100452.

[2] Krishnankutty J, Blakeney M, Raju RK, Siddique KHM. Sustainability of traditional rice cultivation in Kerala, India-a socio-economic analysis. *Sustainability.* 2021; 13(2): 980. Available from: https://doi.org/10.3390/su13020980.

[3] Kowsalya P, Sharanyakanth PS, Mahendran R. Traditional rice varieties: A comprehensive review on its nutritional, medicinal, therapeutic and health benefit potential. *Journal of Food Composition and Analysis.* 2022; 114: 104742.

[4] Somaratne GM, Prasantha BDR, Dunuwila GR, Chandrasekara A, Wijesinghe DGNG, Gunasekara DCS. Effect of polishing on glycemic index and antioxidant properties of red and white basmati rice. *Food Chemistry.* 2017; 237: 716-723. Available from: https://doi.org/10.1016/j.foodchem.2017.06.002.

[5] Reddy CK, Kimi L, Haripriya S, Kang N. Effects of polishing on proximate composition, physico-chemical characteristics, mineral composition and antioxidant properties of pigmented rice. *Rice Science.* 2017; 24(5): 241-252. Available from: https://doi.org/10.1016/j.rsci.2017.05.002.

[6] Shao Y, Hu Z, Yu Y, Mou R, Zhu Z, Beta T. Phenolic acids, anthocyanins, proanthocyanidins, antioxidant activity, minerals and their correlations in non-pigmented, red, and black rice. *Food Chemistry.* 2018; 239: 733-741. Available from: https://doi.org/10.1016/j.foodchem.2017.07.009.

[7] Meera K, Smita M, Haripriya S. Varietal distinctness in physical and engineering properties of paddy and brown rice from southern India. *Journal of Food Science and Technology.* 2019; 56(3): 1473-1483.

[8] Reddy CK, Kimi L, Haripriya S. Variety difference in molecular structure, functional properties, phytochemical content and antioxidant capacity of pigmented rice. *Journal of Food Measurement and Characterization.* 2016; 10(3): 605-613.

[9] Paiva FF, Vanier NL, Berrios JDJ, Pinto VZ, Wood D, Williams T, Pan J, Elias MC. Polishing and parboiling effect on the nutritional and technological properties of pigmented rice. *Food Chemistry.* 2016; 191: 105-112. Available from: https://doi.org/10.1016/j.foodchem.2015.02.047.

[10] Ganesan KN, Rangaswamy M. Combining ability studies in rice hybrids involving wild abortive (WA) and *Oryza* perennis sources of CMS lines. *Oryza.* 1998; 35(2): 113-116.

[11] Chen H, Siebenmorgen TJ, Griffin K. Quality characteristics of long-grain rice milled in two commercial systems. *Cereal Chemistry.* 1998; 75(4): 560-565.

[12] Bashir M, Haripriya S. Assessment of physical and structural characteristics of almond gum. *International Journal of Biological Macromoleculesl.* 2016; 93(Part A): 476-482.

[13] Varnamkhasti MG, Mobli H, Jafari A, Keyhani AR, Soltanabadi MH, Rafiee S, et al. Some physical properties of rough rice (*Oryza Sativa* L.) grain. *Journal of Cereal Science.* 2008; 47(3): 496-501. Available from: https://doi.org/10.1016/j.jcs.2007.05.014.

[14] Haq R, Wani M, Prasad K. Engineering properties of high and low altitude rice varieties from Kashmir valley at different processing levels. *Cogent Food & Agriculture*. 2016; 2: 1133371. Available from: https://doi.org/10.1080/23311932.2015.1133371.

[15] Mir SA, Bosco SJD, Sunooj KV. Evaluation of physical properties of rice cultivars grown in the temperate region of India. *International Food Research Journal.* 2013; 20(4): 1521-1527.

[16] Bhat FM, Riar CS. Effect of amylose, particle size & morphology on the functionality of starches of traditional rice cultivars. *International Journal of Biological Macromolecules*. 2016; 92(2016): 637-644. Available from: https://doi.org/10.1016/j.ijbiomac.2016.07.078.

[17] Singh Y, Prasad K. Physical characteristics of some of the paddy varieties as affected by shelling and milling operations. *Oryza.* 2013; 50(2): 174-180.

[18] Baryeh EA. Physical properties of millet. *Journal of Food Engineering.* 2002; 51(1): 39-46.

[19] Joshi ND, Mohapatra D, Joshi DC. Varietal selection of some indica rice for production of puffed rice. *Food and Bioprocess Technology.* 2014; 7(1): 299-305.

[20] Venkatesan S, Udhaya Nandhini D, Senthilraja K, Prabha B, Jidhu Vaishnavi S, Eevera T, et al. Traditional cultivars influence on physical and engineering properties of rice from the Cauvery Deltaic region of Tamil Nadu. *Applied Sciences*. 2023; 13(9): 5705. Available from: https://doi.org/10.3390/app13095705.
[21] Pandiselvam R, Thirupathi V, Mohan S. Engineering properties of rice. *Journal of Agricultural Engineering*. 2015; 3: 69-78.
[22] Al-Mahasneh MA, Rababah TM. Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering.* 2007; 79(4): 1467-1473.
[23] Tikapunya T, Fox G, Furtado A, Henry R. Grain physical characteristic of the Australian wild rices. *Plant Genetic Resources.* 2017; 15(5): 409-420.
[24] Cheng XD, Yan XJ, Hu MZ. The effect of storage pressure on the mechanical properties of paddy grains. *Journal of Stored Products Research.* 2016; 68: 19-24.
[25] Parnsakhorn S, Noomhorm A. Effects of storage temperature on physical and chemical properties of brown rice, parboiled brown rice and parboiled paddy. *Thai Journal of Agricultural Science.* 2012; 45(4): 221-231.
[26] Ravi P, Venkatachalam T. Important engineering properties of paddy. *Agricultural Engineering.* 2014; 4: 73-83.
[27] Ghadge PN, Prasad K. Some physical properties of rice kernels: Variety PR-106. *Journal of Food Process and Technology*. 2012; 3(8): 175. Available from: https://doi.org/10.4172/2157-7110.1000175.
[28] Amini MM, Alizadeh MR, Padasht F, Elahinia SA, Khodaparast SA. Rice grain discoloration effect on physical properties and head rice yield in three rice cultivars. *Quality Assurance and Safety of Crops & Foods.* 2016; 8(2): 283-288. Available from: https://doi.org/10.3920/QAS2014.0582.
[29] Adhiguna RT, Thahir R. Comparison of physical properties, proximate composition and milling quality of rice grains from different branches within a panicle. *International Journal of Scientific & Engineering Research.* 2016; 7(9): 1647-1652.
[30] Bhat FM, Riar CS. Cultivars effect on the physical characteristics of rice (rough and milled) (*Oryza Sativa* L.) of temperate region of Kashmir (India). *Journal of Food Science and Technology.* 2016; 53(12): 4258-4269.
[31] Zareiforoush H, Hosseinzadeh B, Adabi ME, Motavali A. Moisture-dependent physical properties of paddy grains. *Journal of American Science.* 2011; 7(7): 175-182.