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GENETIC VARIABILITY AND MULTIVARIATE STUDIES ON THE GRAIN PHYSICAL PROPERTIES OF RICE (*Oryza sativa* L.) LANDRACES

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SUMMARY

Thirty rice landraces were evaluated during the 2020 wet season for the estimation of the genetic variability of six grain physical properties, *viz.* grain length (GL), grain breadth (GB), milled grain length (MGL), milled grain breadth (MGB), milled grain length breadth ratio (MGL/MGB), and 1000-grain weight (TGW), at the Bangladesh Institute of Nuclear Agriculture Substation, Sunamganj, Bangladesh. The relative contribution of these traits to variability was estimated by using principal component analysis (PCA), and the landraces were clustered by using Mahalanobis distance (D^2) statistics. The TGW and MGL/MGB ratio exhibited high estimates of the phenotypic coefficient of variation and genotypic coefficient of variation. The high broad-sense heritability and genetic advance of all the traits indicated that the environmental effect had a weak involvement in the expression of these traits. PCA revealed six principal components, among which two were significant and contributed up to 96.9% of the total variance cumulatively. GL, GB, MGL, and TGW contributed to PC1 to create the variation among the landraces, whereas MGL/MGB ratio, GL, and MGL contributed to PC2. The landraces were grouped into six clusters. Cluster analysis revealed that the maximum and minimum intracluster distances were found in cluster III (235.11) and cluster VI (0.00), respectively. The longest intercluster distance was found between clusters IV and VI, and the shortest distance was found between clusters I and III. The maximum mean values for GL and TGW were observed in cluster VI. The mean values for GB and MGB were highest in cluster V, whereas the MGL/MGB ratio and MGL were highest in cluster II. 'Madhumala'/'Sada Madhumala' and 'Pankhuraj' could be used in hybridization programs to exploit maximum heterosis for rice grain size and shape and for the direct selection of superior quality traits because these traits are less affected by the environment than other traits.

Keywords: Rice landrace, heritability, principal component analysis, clustering

Key findings: Rice grain length and breadth, milled grain length and breadth, milled grain length breadth ratio, and 1000-grain weight showed high heritability and genetic advance in local rice landraces. Distantly clustered genotypes could be used in a hybridization program to improve these traits.

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INTRODUCTION

Rice is the main staple food crop in most Asian countries and contributes approximately 25% of the global dietary calories and 75% of the calories consumed by the developing world's population (Fitzgerlad, 2010). Although rice breeders mainly focus on yield improvement due to the rapidly growing population, the demand for high-quality grain by rice markets has also consistently increased in recent decades with the improvement in living standards (Nirmaladevi *et al*., 2015; Fitzgerlad, 2010). Thus, breeding for rice varieties with high yields combined with quality grain is a current need. Grain quality, a complex trait that comprises appearance, milling, cooking, sensory, hygiene, and nutritional attributes, highly influences consumers' preferences for a rice variety (Zhou *et al*., 2020). These quality characters may vary for rice growers, millers, and consumers (Cruz and Kush, 2000). Growers and millers emphasize milling percentage, head rice recovery, and broken rice percentage, whereas consumers prefer grain size and shape, cooking, and eating qualities. Again, preference for size–shape varies among different consumer groups. Bold grains are preferable in some regions, whereas long fine grains are preferable in others. Size and shape are the grain physical properties and the primary criteria that influence market value greatly. Size and shape are determined mainly by grain length (GL), grain breadth (GB), and length:breadth ratio. On the basis of these traits, grains could be classified into different categories (Cruz and Kush, 2000). In accordance with length, grains are classified as very long, long, medium, and short. Grains are classified as slender, medium, or bold on the basis of shape (IRRI, 2013). Grain size or shape is not only a quality trait but also significantly affects yield (Zhao *et al*., 2018).

Additionally, grain weight is a crucial trait that is directly related to yield and provides information about grain size. Uniformity in grain weight is essential for consistent grain quality. Grain weight is usually represented by 1000-grain weight (TGW) (Li *et al*., 2020; Wu *et al*., 2008). Thus, grain physical properties are the important quality criteria and should be prioritized for selection in rice-quality breeding programs (Tomlins *et al*., 2007; Widyawan *et al*., 2020).

Rice landraces are locally adapted to social values but have meager yields (Tiwari *et al*., 2018). In addition, landraces have higher genetic diversity than modern varieties (Hour *et al*., 2020). Therefore, landraces are an excellent source of essential alleles, including those for grain quality, which could be introgressed into modern varieties (Rabara *et al*., 2014). Thus, exploring the genetic diversity of landraces will provide valuable resources for developing modern varieties (Utami *et al*., 2016; Hour *et al*., 2020).

In consideration of the above information, assessing the genetic variability of traits and understanding whether they involve heritable components are necessary before starting a breeding program to improve the grain physical properties of a variety. This understanding is crucial for selecting breeding lines with acceptable grain properties because the environment highly influences some traits. Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) are the two major genetic parameters that are used to quantify variability in a population (Nirmaladevi *et al*., 2015). In addition, broad-sense heritability (h^2b) and genetic advance (GA) in combination can help determine the influence of genetic and environmental effects on the expression of a particular trait. Multivariate analyses, such as principal component analysis (PCA), can describe the inherent variations across landraces by analyzing the relationships among multiple variables and thus can identify the appropriate parental lines for a hybridization program (Dhakal, 2020; Maji and Shaibu, 2012; Mahendran *et al*., 2015). Mahalanobis D^2 statistic, another widely applied multivariate analysis, can reliably estimate the genetic divergence in a population and the relative contribution of different components to the total variation at the inter- and intracluster levels (Nalla *et al*., 2014).

Although the grain physical properties of many rice germplasms have been well studied, the local landraces of Bangladesh have not been investigated thoroughly. Therefore, the objectives of the study are a) to assess the genetic variability, heritability, and GA of the grain physical properties of rice landraces; b) to estimate the relative contribution of these different traits to the total variation; and c) to provide genetic information for parental selection in rice breeding programs for varietal improvement.

MATERIALS AND METHODS

The experimental material comprised 30 traditional rice landraces, which are presented in Table 1. The rice landraces were collected from Sunamganj District, Bangladesh (25°4' 50.2464"N and 91°25'16.8816"E at an altitude

Table 1. Rice landraces used in this study.

Accession No.	Acc. Name	Accession No.	Acc. Name	Accession No.	Acc. Name
1	Tepiboro	11	Akhnisail	21	Mogla
2	Chengermuri	12	Puti Biron	22	Kheyaboro
3	Poshusail	13	Murabadal	23	Malati
4	Sonali Biron	14	Godabiron	24	Laldingi
5	Khagrata	15	Kalibiron	25	Lakhai
6	Asami pijam	16	Gorchi	26	Birosail
7	Lal pijam	17	Nayanhari	27	Gandisail
8	Sada Malati	18	Monfus biron	28	Balam
9	Modhumala	19	Bashful	29	Awned akhnisail
10	Sada Modhumala	20	Benma	30	Pankhiraj

of 9.0 m) and were grown in the wet season during July 2020 to November 2020 at the Bangladesh Institute of Nuclear Agriculture (BINA) Substation, Sunamganj, Bangladesh. The seedlings were transplanted into a 3 m × 2 m plot with 15 cm plant-to-plant and 20 cm row-to-row distances in accordance with the randomized complete block design with three replicates. Urea, TSP, MoP, gypsum, and zinc sulfate fertilizers were applied at the rate of 234:87:115:78:12 kg ha^{-1}. The fertilizers, except for urea, were applied basally. Urea was applied in three splits at 10 days after transplanting, 5 days before the tillering stage, and 7 days before the panicle initiation stage. Crop management, such as weeding and irrigation, was done in a timely manner. Insects, diseases, and other pests were controlled properly. At maturity, each plot of the rice landraces was harvested in bulk. Grains were cleaned properly, dried in a hot air oven to up to 14% moisture content, and kept at room temperature for 4 months. After storage, grain physical properties, such as GL, GB, milled grain length (MGL), milled grain breadth (MGB), MGL/MGB ratio, and TGW, were estimated at the Plant Breeding Division, BINA, Mymensingh, Bangladesh. In this investigation, GL, GB, MGL, and MGB were recorded from 10 randomly selected grains from each replication by using a slide caliper. Each sample was analyzed in duplicate. The MGL/MGB ratio was calculated by dividing the average MGL by the average MGB. TGW was recorded by using an analytical balance.

The mean data for each of the traits were used for univariate and multivariate analyses. For univariate analysis, the data were subjected to analysis of variance, which was done individually via F-test by using Statistix 10 software. Differences were statistically significant at $P < 0.05$. If significant differences were detected, the least significant difference (LSD) at the 5% level of significance was calculated. PCV and GCV were calculated in accordance with Burton and Devane (1953). h^2b and GA as the percentage of the mean were estimated by using the formulae suggested by Hanson *et al*. (1956) and Johnson *et al*. (1955), respectively. Genetic diversity was calculated through PCA (Rao, 1964) with Minitab software version 18.1. For cluster analysis, the Mahalanobis distance (D^2 statistics) (Mahalanobis, 1936) was obtained by using R software. Clustering was performed by following the modified Tocher's method as proposed by Silva and Dias (2013) with bio tools packages.

RESULTS

Assessing genetic variability, heritability, and GA

Analysis of variance revealed significant differences among the landraces for grain physical parameters, indicating the existence of significant variability among landraces for the traits under study (Table 2). The GL of the landraces varied from 5.71 mm to 8.83 mm with an average of 7.65 mm. The shortest grain was presented by 'Modhumala', and the longest grain was shown by 'Godabiron'. The GB of various rice accessions ranged from 2.02 mm ('Modhumala') to 3.19 mm ('Tepiboro') with an average value of 2.67 mm. 'Modhumala' also showed the shortest length for milled grain (3.99 mm), and 'Mogla' showed the longest (6.25 mm). The average value for milled grain was 5.4 mm. MGB ranged from 1.75 mm ('Modhumala') to 2.77 mm ('Poshusail') with an average of 2.33 mm. 'Poshusail' (1.77) showed the lowest MGL/MGB and 'Kalibiron' showed the highest (2.83). The average MGL/MGB ratio of the landraces was

Table 2. Mean performance of the tested accessions for physical grain properties.

Accessions	GL (mm)	GB (mm)	MGL (mm)	MGB (mm)	MGL/MGB ratio	TGW (g)
Tepiboro	7.54 ± 0.06	3.19 ± 0.01	4.87 ± 0.03	2.71 ± 0.01	1.8 ± 0.01	23.27 ± 0.26
Chengermuri	7.66 ± 0.02	2.76 ± 0.02	5.53 ± 0.06	2.39 ± 0.05	2.31 ± 0.07	20.80 ± 0.06
Poshusail	7.18 ± 0.05	3.13 ± 0.02	4.9 ± 0.03	2.77 ± 0.03	1.77 ± 0.02	22.60 ± 0.06
Sonali Biron	7.72 ± 0.03	2.39 ± 0.02	5.25 ± 0.02	2.07 ± 0.01	2.53 ± 0.002	15.90 ± 0.17
Khagrata	7.12 ± 0.07	2.79 ± 0.03	5.01 ± 0.02	2.49 ± 0.02	2.00 ± 0.02	18.23 ± 0.28
Asami pijam	7.49 ± 0.02	2.57 ± 0.03	5.41 ± 0.02	2.30 ± 0.02	2.35 ± 0.02	20.00 ± 0.29
Lal pijam	7.91 ± 0.02	2.32 ± 0.03	5.60 ± 0.02	2.05 ± 0.01	2.73 ± 0.01	17.20 ± 0.06
Sada Malati	7.89 ± 0.04	2.52 ± 0.02	5.65 ± 0.03	2.26 ± 0.01	2.50 ± 0.01	15.77 ± 0.03
Modhumala	5.71 ± 0.02	2.02 ± 0.04	3.99 ± 0.01	1.75 ± 0.03	2.29 ± 0.03	9.10 ± 0.20
Sada Modhumala	5.90 ± 0.04	2.19 ± 0.04	4.05 ± 0.03	1.95 ± 0.01	2.09 ± 0.03	10.30 ± 0.06
Akhnisail	7.56 ± 0.03	2.59 ± 0.02	5.49 ± 0.05	2.28 ± 0.02	2.41 ± 0.004	18.50 ± 0.10
Puti Biron	7.11 ± 0.03	2.59 ± 0.03	5.00 ± 0.02	2.25 ± 0.02	2.24 ± 0.03	15.00 ± 0.06
Murabadal	7.21 ± 0.09	2.81 ± 0.06	5.32 ± 0.08	2.49 ± 0.05	2.13 ± 0.06	20.45 ± 0.09
Godabiron	8.83 ± 0.02	2.89 ± 0.00	6.11 ± 0.01	2.40 ± 0.02	2.55 ± 0.02	21.87 ± 0.09
Kalibiron	8.64 ± 0.02	2.55 ± 0.01	6.09 ± 0.05	2.15 ± 0.07	2.83 ± 0.09	21.77 ± 0.07
Gorchi	8.37 ± 0.00	2.56 ± 0.02	6.11 ± 0.08	2.24 ± 0.05	2.74 ± 0.07	22.10 ± 0.23
Nayanhari	7.91 ± 0.01	3.02 ± 0.04	5.65 ± 0.01	2.65 ± 0.02	2.13 ± 0.01	20.40 ± 0.06
Monfus biron	7.88 ± 0.03	2.57 ± 0.03	5.52 ± 0.04	2.18 ± 0.03	2.53 ± 0.04	17.63 ± 0.07
Bashful	7.21 ± 0.00	2.84 ± 0.02	5.00 ± 0.04	2.51 ± 0.01	1.99 ± 0.02	18.00 ± 0.29
Benma	7.33 ± 0.04	2.78 ± 0.03	5.08 ± 0.04	2.43 ± 0.02	2.09 ± 0.03	18.20 ± 0.21
Mogla	8.73 ± 0.02	2.51 ± 0.03	6.25 ± 0.07	2.23 ± 0.04	2.80 ± 0.04	21.93 ± 0.32
Kheyaboro	7.62 ± 0.03	2.98 ± 0.00	5.37 ± 0.01	2.56 ± 0.02	2.09 ± 0.02	20.93 ± 0.18
Malati	7.77 ± 0.00	2.46 ± 0.02	5.60 ± 0.04	2.12 ± 0.01	2.64 ± 0.02	19.40 ± 0.06
Laldingi	7.52 ± 0.03	3.05 ± 0.01	5.07 ± 0.03	2.68 ± 0.03	1.89 ± 0.02	19.40 ± 0.25
Lakhai	7.63 ± 0.02	2.94 ± 0.02	5.37 ± 0.05	2.57 ± 0.06	2.08 ± 0.04	20.60 ± 0.12
Birosail	8.10 ± 0.03	2.74 ± 0.00	5.84 ± 0.02	2.38 ± 0.03	2.46 ± 0.03	19.40 ± 0.06
Gandisail	7.59 ± 0.09	2.68 ± 0.00	5.51 ± 0.06	2.35 ± 0.04	2.34 ± 0.04	19.10 ± 0.06
Balam	8.19 ± 0.05	2.43 ± 0.07	5.96 ± 0.03	2.15 ± 0.01	2.77 ± 0.02	19.47 ± 0.03
Awned akhnisail	7.53 ± 0.00	2.60 ± 0.02	5.53 ± 0.01	2.31 ± 0.02	2.39 ± 0.02	18.43 ± 0.03
Pankhiraj	8.71 ± 0.05	2.77 ± 0.03	5.83 ± 0.01	2.29 ± 0.03	2.55 ± 0.03	24.55 ± 0.07
Range	5.71–8.83	2.02–3.19	3.99–6.25	1.75–2.77	1.77–2.83	9.1–24.55
Mean	7.65	2.67	5.4	2.33	2.34	9.1–24.55
LSD $_{(0.05)}$	0.12	0.07	0.12	0.09	0.10	0.46

NB: GL = Grain length, GB = Grain breadth, MGL = Milled grain length, MGB = Milled grain breadth, TGW = 1000-grain weight. Data are presented as mean value ± SE

2.34 mm. 'Modhumala' had the lowest 1000-grain weight (9.1 gm) and 'Pankhiraj' had the highest (24.55 gm). The landraces had an average TGW of 19.01 gm. In accordance with the standard evaluation system (IRRI, 2013), 15 genotypes were classified as medium length with medium-shaped grain (Table 3). The grains of six genotypes were classified as short and medium, whereas those of nine were classified as short and bold.

The genetic variability parameters for all the grain physical properties are presented in Table 4. The results indicated that the landraces presented a wide range of genetic variability for the grain physical parameters. For all the parameters, the phenotypic variances (σ^2p) were higher than the genotypic variances (σ^2g) The maximum genotypic and phenotypic variances were obtained for TGW (34.01 and 34.09, respectively), followed by those for GL, MGL, MGL/MGB, GB, and MGB. Similarly, PCV was higher than GCV. These coefficients of variation were categorized as high (>20%), moderate (10%–20%) and low (<10%). High PCV and GCV were observed for TGW (30.71% and 30.68%) and MGL/MGB ratio (22.32% and 22.15%), whereas GB (17.62% and 17.54%), MGB (17.27% and 17.11%), MGL (17.11% and 17.06%), and GL (15.81% and 15.79%) showed intermediate PCV and GCV on the basis of the scale.

Johnson *et al*. (1955) stated that heritability (h^2) estimations are classified as low (<30%), medium (31%–70%), and high (>70%). In this study, all the grain physical properties showed high heritability (broad sense). The highest h^2b was exhibited by TGW (99.77), followed by the h^2b values shown by GL (99.66), MGL (99.41), GB (99.10), MGL/MGB (98.53), and MGB (98.16).

Table 3. Classification of 30 rice landraces based on grain shape (SES, IRRI 2013).

Grain Length (dehulled)	Grain shape (dehulled)	Landraces
Medium (5.51 to 6.6 mm)	Medium (2.1 to 3.0)	Chengermuri, Lal pijam, Sada Malati, Godabiron, Kalibiron, Gorchi, Nayanhari, Monfus biron, Mogla, Malati, Birosail, Gandisail, Balam, Awned akhnisail, Pankhiraj
Short (5.5 mm or less)	Medium (2.1 to 3.0)	Sonali Biron, Asami pijam, Modhumala, Akhnisail, Puti Biron, Murabadal
Short (5.5 mm or less)	Bold (1.1 to 2.0)	Tepiboro, Poshusail, Khagrata, Sada Modhumala, Bashful, Benma, Kheyaboro, Laldingi, Lakhai

Table 4. Variance components and heritability values of grain quality traits.

Variables	Σ^2e	σ^2g	σ^2p	H^2	PCV	GCV	GA	GA%
GL (mm)	0.005	1.46	1.465	99.66	15.81	15.79	2.48	32.46
GB (mm)	0.002	0.22	0.222	99.10	17.62	17.54	0.96	35.97
MGL (mm)	0.005	0.85	0.855	99.41	17.11	17.06	1.89	35.03
MGB (mm)	0.003	0.16	0.163	98.16	17.27	17.11	0.81	34.93
Ratio MGL/MGB	0.004	0.27	0.272	98.53	22.32	22.15	1.06	45.29
TGW (gm)	0.078	34.01	34.09	99.77	30.71	30.68	12.00	63.13

GL: Grain length, GB: Grain breadth, MGL: Milled grain length, MGB: Milled grain breadth, TGW: 1000-grain weight, σ^2e: Error variance, σ^2g: Genotypic variance, σ^2p: Phenotypic variance, PCV: Phenotypic coefficient of variation, GCV: Genotypic coefficient of variation, h^2 (%): heritability (broad sense), GA: Genetic advance, GA%: Genetic advance as the percentage of the mean

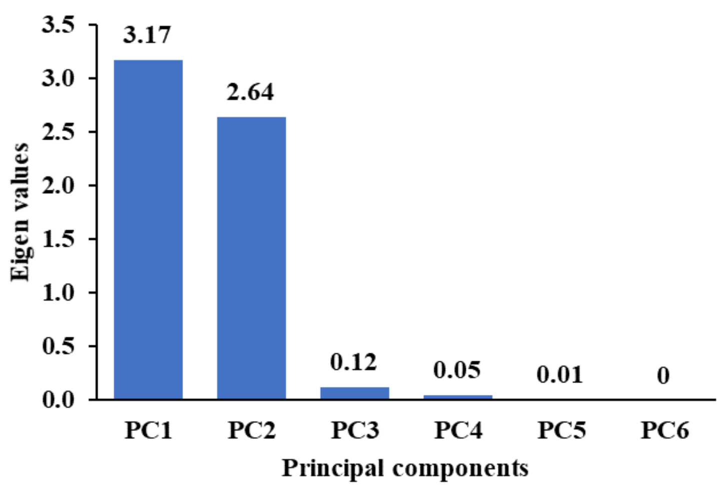

Figure 1. Eigenvalues of different PCs obtained through the PCA of the rice landraces.

The GA as a percent of mean was categorized as high (>20%), moderate (10%–20%) and low (<10%) (Johnson *et al.*, 1955). All the studied grain physical traits exhibited a high estimate of GA in the form of the mean percentage. The highest GA in the form of mean percentage was exhibited by TGW (63.13%), followed by the GA values of MGL/MGB ratio (45.29%), GB (35.97%), MGL (35.03%), MGB (34.93%), and GL (32.46%) (Table 4).

Relative contribution of different grain physical parameters

Six principal components were obtained through PCA. Among the six components, two with an eigenvalue of more than 1 were considered as significant (Figure 1). These two components contributed 96.9% of the cumulative variance. PC1 accounted for the highest variance (52.9%), followed by PC2, which accounted for 44.0% of the variation

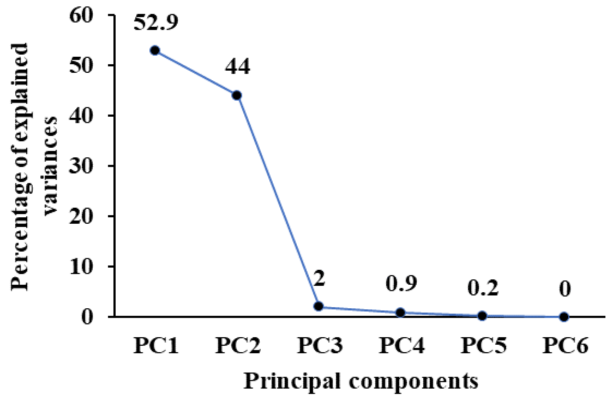

Figure 2. Contribution of each PC to the total explained variance in the phenotypic diversity of the rice landraces.

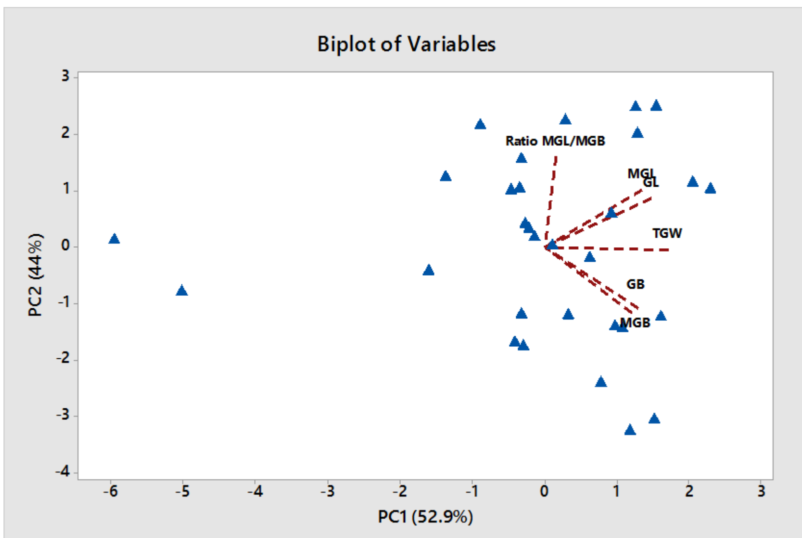

Figure 3. Biplot of 30 rice landraces for PC1 and PC2. The arrows show the contribution (magnitude and direction) of the traits to PC1 and PC2.

(Figure 2). Figures 1 and 2 show the eigenvalue and contribution of each principal component to the total explained variance of the phenotypic diversity of rice, respectively. The results of PCA and vector loading in Table 5 show that TGW (0.537) had the highest contribution to the creation of the first principal component. GL (0.464), MGL (0.425), and GB (0.41) also positively contributed to PC1. PC2 was positively contributed by the MGL/MGB ratio (0.612), MGL (0.386), and GL (0.33), whereas MGB (−0.442) and GB (−0.413) contributed negatively (Table 5). The direction of the contribution of different traits in the principal components, including the first two principal components, is shown in Figure 3.

Clustering of the landraces

D^2 statistics were applied to elucidate the genetic divergence among the landraces. Modified Tocher's method was used to group the landraces. The landraces were grouped into six clusters on the basis of the six grain physical traits (Table 6). TGW, GL, and GB contributed highly to the formation of these clusters (Figure 4). Cluster I was the largest and included 16 landraces. Cluster III, which included five landraces, was the next-largest cluster. Cluster II included four landraces, clusters IV and V contained two, and cluster VI included one landrace. The maximum intracluster distance was found in cluster III

Table 5. PCA and its component values for six grain physical traits of 30 landraces.

Variable	Eigenvectors					
	PC1	PC2	PC3	PC4	PC5	PC6
GL	0.464	0.330	0.195	0.672	−0.422	0.088
GB	0.410	−0.413	0.174	0.332	0.713	−0.108
MGL	0.425	0.386	0.381	−0.527	0.200	0.455
MGB	0.382	−0.442	0.318	−0.363	−0.455	−0.468
Ratio MGL/MGB	0.049	0.612	−0.021	−0.073	0.253	−0.743
TGW	0.537	−0.017	−0.827	−0.152	−0.039	0.047

GL = grain length, GB = grain breadth, MGL = milled grain length, MGB = milled grain breadth, and TGW = 1000-grain weight

Table 6. Distribution of 30 landraces into six clusters.

Clusters	Number of landraces	Name of landraces
Cluster I	16	Akhnisail, Awned akhnisail, Gandisail, Monfus biron, Asami pijam, Malati, Benma, Birosail, Chengermuri, Murabadal, Bashful, Khagrata, Lakhai, Kheyaboro, Laldingi, Nayanhari
Cluster II	4	Kalibiron, Mogla, Gorchi, Godabiron
Cluster III	5	Sonali Biron, Lal pijam, Sada Malati, Puti Biron, Balam
Cluster IV	2	Modhumala, Sada Modhumala
Cluster V	2	Tepiboro, Poshusail
Cluster VI	1	Pankhiraj

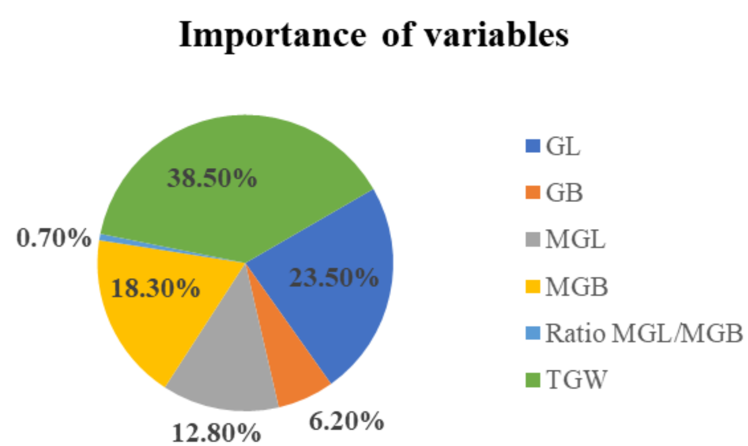

Figure 4. Contribution of the variables in clustering.

(D^2 = 235.11) followed by that in cluster I (D^2 = 131.65) (Table 7). The intracluster distance was 0.00 in cluster VI because this cluster included only one landrace. The maximum intercluster distance was found between clusters IV and VI (D^2 = 7164.35), followed by that between clusters IV and V (D^2 = 5460.08). The minimum intercluster distance was obtained between clusters II and VI (D^2 = 248.29).

The cluster mean values of six characters indicated a wide range of variation among the characters (Table 8). The maximum mean value of the MGL/MGB ratio (2.57) and MGL (5.88) were shown by cluster II. The maximum mean values of GB (3.16) and MGB (2.74) were found for cluster V. However, the minimum MGL/MGB ratio (1.78) was shown by this cluster. The maximum GL (8.71) and TGW (24.55) were found in cluster VI. Cluster IV showed the minimum mean values for all the traits, except for the MGL/MGB ratio.

Table 7. Intracluster (diagonal) and intercluster distance among six clusters.

Clusters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Cluster I	131.65	-	-	-	-	-
Cluster II	522.53	56.42	-	-	-	-
Cluster III	332.38	879.64	235.11	-	-	-
Cluster IV	3127.96	5454.26	2272.32	63.81	-	-
Cluster V	626.46	713.62	1392.61	5460.08	69.69	-
Cluster VI	1049.09	248.29	1724.34	7164.35	641.58	0.00

Table 8. Mean performance of different traits in each cluster.

Variables	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
GL (mm)	7.57	8.32	7.76	5.81	7.36	8.71
GB (mm)	2.76	2.67	2.45	2.10	3.16	2.77
MGL (mm)	5.39	5.88	5.49	4.03	4.89	5.83
MGB (mm)	2.42	2.32	2.15	1.85	2.74	2.29
Ratio MGL/MGB	2.24	2.57	2.56	2.19	1.78	2.55
TGW (gm)	19.34	21.3	16.67	9.7	22.93	24.55

GL: Grain length, GB: Grain breadth, MGL: Milled grain length, MGB: Milled grain breadth, TGW: 1000-grain weight

DISCUSSION

The PCV estimates of the grain physical parameters were slightly higher than the GCV estimates. A similar result was reported by Bornare *et al*. (2014), who found that for the yield attributes of rice, PCV was higher than GCV. However, in the current study, the very small differences between the PCV and GCV estimates were indicative of low environmental involvement with high genetic influence on the expression of the grain physical traits. Therefore, phenotype-based selection for such traits only could also be worthwhile (Babu *et al*., 2012; Karuppaiyan *et al*., 2013). The high GCV for MGL/MGB ratio and TGW and intermediate GCV for other parameters provide an idea for selection with considerable improvement. However, using GCV alone to estimate the total heritable variation is inadequate (Roychowdhury and Randrianotahina, 2011). GCV and heritability estimates should be combined to improve the results of the estimation of heritable variation (Shivani and Reddy, 2000; Rathi *et al*., 2010).

Heritability is a prime parameter in quantitative genetics because it determines the response to selection. In the current study, the high heritability shown by all the parameters implied the low involvement of environmental effect in the expression of a particular trait. Given the low environmental influence, a simple selection approach based on phenotypic characters can be followed in the breeding program to improve the characters of interest of the landraces (Sarawgi *et al*., 2000; Rathi *et al*., 2010; Babu *et al*., 2012).

GA estimates are expressed as mean percentages to provide accurate information on the effectiveness of selection in enhancing features. The improvement in the genotypic value of the new population over that of the original population is referred to as GA. In this study, the highest GA in the form of mean percentage was exhibited by TGW, followed by that shown by MGL/MGB, GB, and MGL; these results were similar to the findings reported by other researchers (Shivani and Reddy, 2000; Rathi *et al*., 2010; Babu *et al*., 2012). The high heritability with high GA in the form of percent mean observed for all of the grain physical properties indicated that the expression of these traits is less influenced by the environment and controlled by additive gene action (Panse and Sukhatme, 1957). Therefore, these traits could be improved through direct selection or progeny selection.

Principal components with eigenvalue > 1 explain more of the total variation in the data than individual attributes. In PCA, the appropriate value reflects the significance and influence of each component on the creation of the total variance. The coefficient of the vectors indicates the degree of the involvement of each variable with which each principal component is associated (Sanni *et al*., 2012). A high coefficient (regardless of the sign) is associated with the high effectiveness of the corresponding parameters in discriminating the genotypes. The characters that together contribute to form a principal component should be emphasized and taken into consideration in breeding programs because they tend to be exploited together (Chakravorty *et al*., 2013). TGW and MGL/MGB ratio contributed highly to creating the variability in the first two principal components, which were responsible for 96.9% of the variation present in the study population. These two characters could be considered during parental selection to start a breeding program for improving the grain physical properties of rice landraces.

The formation of six clusters based on the Mahalanobis D^2 statistic implied that a wide range of variation in the grain characters was present among the landraces. The distance within a cluster reflects the heterogeneous nature of the landraces. A short intercluster distance implies that the cluster members are closely related (Dhakal *et al*., 2020). Widely distant clusters represent landraces with a wide genetic distance. In this study, none of the landraces possessed all of the desirable grain characters in combination. Thus, hybridization should be conducted between the landraces from widely distant clusters (clusters IV and VI) to develop a desirable genotype. Cluster IV included 'Modhumala' and 'Sada Modhumala.' These two genotypes have very short GLs and have very low TGW. By contrast, cluster VI included only the genotype 'Pankhiraj', which is medium shaped with medium grain length. Parental selection in a hybridization program should be done based on the highest genetic divergence to obtain a wide range of variability and transgressive segregations with the highest heterotic effect (Chandra *et al*., 2007; Ye *et al*., 2013).

CONCLUSIONS

Significant variability was present among the studied rice landraces. Heritability and genetic variability studies indicated that the grain physical properties of the landraces were less influenced by the environment. PCA revealed that GL, GB, and TGW contributed together to the formation of variation among the landraces. Distantly clustered landraces, *viz.* 'Madhumala'/'Sada Madhumala'' and 'Pankhuraj' could be used as parents in hybridization programs aiming to improve the grain characters of landraces, and direct progeny selection might be helpful to plant breeders.

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