



AGRO-MORPHOLOGICAL CHARACTERIZATION AND GENETIC DIVERSITY ASSESSMENT OF NINETEEN BRRI-RELEASED RICE VARIETIES

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Abstract

Knowledge on genetically determined several growth parameters including morpho- physiological and developmental parameters are essential for rice breeding programs. Genetic divergence helps in the development of superior recombinants, which is prerequisite in any crop improvement program. The aim of the present study was to characterize 19 rice varieties based on agro-morphological descriptors and genetic diversity. The experiment was conducted at Bangladesh Rice Research Institute farm, Gopalganj, using a randomized complete block design with three replications. Both the qualitative and quantitative agro-morphological traits were diversified. The observed variations in the qualitative data were primarily accounted for by the blade pubescence, anthocyanin color of the leaf sheath, lemma-palea color, grain tip color, and awning. The top five axes of PCA contributed 81.04% of the total variation. The varieties were divided into five groups based on the cluster. With six genotypes, Cluster IV was the largest group, whereas Cluster I was the lowest with just one genotype. Cluster IV had the greatest intra-cluster distance, whereas clusters IV and I had the greatest inter-cluster distances. Contrarily, cluster IV had the highest cluster means for most of the quantitative characteristics noticed. Once more, grain length was the trait that contributed most to divergence. While considering results from genetic distance, the varieties under cluster IV (BRRI dhan29, BRRI dhan89, BRRI dhan92 BRRI dhan97, BRRI hybrid dhan3, BRRI hybrid dhan5) might be selected for additional breeding after taking the results of the genetic distance into consideration.

Keywords: Rice, Agro-morphological characterization, Genetic diversity, Variation, BRRI

Introduction

Rice (*Oryza sativa* L.) is one of the most significant crops in the world and provides food for the majority (50%) of the world's population (Al et al., 2022). For the last four years, Bangladesh has been the world's top producer of rice, ranking as the third-largest producer globally (Food Outlook, 2022). In 2021–2022, Bangladesh produced a total of 37.84 million metric tons of rice (BBS, 2022).

Genetic diversity is the primary source of variability for any crop development program. To identify the origin of genes for a specific character within the available germplasm, an evaluation of genetic diversity is crucial (Tomooka, 1991). To separate the genotypes into genetically similar and divergent types, an assessment of the genetic diversity in a collection of breeding materials is necessary (Tripathy et al., 2020). When choosing the right plant genotypes for hybridization to develop high-yielding potential varieties, one must use genetic diversity as a powerful tool to ascertain genetic discrimination among genotypes (Bhatt, 1970).

Agro-morphological characterization of crops is the primary standard technique for providing fundamental data for plant breeding programs (Das and Ghosh, 2011). Agro-morphological features have historically been employed to evaluate associations between genotypes, both qualitatively and quantitatively (Goodman, 1972). Diverse traits that are particular to each variation can be found in each variety. To understand the nature of the variation, morphological characterization is necessary. As a result, the characterization of these varieties along with the determination of variation among varieties will help with the creation of a genetic database for the region's breeding program strategies. Agro-morphological markers have been used by several researchers to characterize and

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study the variety of rice germplasms (Islam et al., 2017; Mau et al., 2017; Akter et al., 2018). On the basis of quantitative and qualitative features, several genetic diversity studies on various crop species have been carried out in order to choose genetically distant parents for hybridization. (Ahmadizadeh et al. 2011; Arega et al. 2007; Haydar et al. 2007; Shekhawat et al. 2001). However, the genetic diversity of BRRI dhan51 to BRRI dhan77 varieties was not determined by morphological characterization in light of qualitative and quantitative traits. The objectives of the current study were to study the qualitative and quantitative traits of nineteen BRRI-released rice varieties and to estimate genetic relationship among the rice varieties; and classify them in respect of yield contributing characters.

Materials and Method

Experimental site

The experiment was carried out from November 2021 to May 2022 (*Boro* season) at the research farm of the Bangladesh Rice Research Institute (BRRI), Regional Station, Gopalganj.

Plant materials

BRRI developed 19 varieties of rice viz. (BRRI dhan28, BRRI dhan29, BRRI dhan50, BRRI dhan63, BRRI dhan67, BRRI dhan74, BRRI dhan81, BRRI dhan84, BRRI dhan86, BRRI dhan88, BRRI dhan89, BRRI dhan92, BRRI dhan96, BRRI dhan97, BRRI dhan99, Bangabandhu dhan100, BRRI hybrid dhan3, BRRI hybrid dhan5 (Table 1) were used.

Table 1. Information on variety name, season, important features, amylose content, yield, and year of release according to modern rice cultivation, BRRI

Variety name	Season	Features	Amylose %	Year of release
BRRI dhan28	<i>Boro</i>	Grain is medium thin and white	28.0	1994
BRRI dhan29	”	Grain is medium thin and white	29.4	1994
BRRI dhan50	”	Grain is long, thin, fragrant and white	26.8	2008
BRRI dhan63	”	Rice is thin, tall like <i>Basmati</i> , more productive narrow <i>Balam</i> variety	25.0	2014
BRRI dhan67	”	Grain is medium, white and 8 dS/m salinity tolerant throughout its life	24.6	2014
BRRI dhan74	”	Grain medium coarse and white. 24.2 mg Zn per kg of rice. Medium blast resistant variety	24.2	2015
BRRI dhan81	”	Grain is long and thin, high in protein (10.3%)	26.5	2017
BRRI dhan84	”	Almost like BRRI dhan28, high in Zn (27.6 mg/kg) and red in color	25.9	2017
BRRI dhan86	”	Rice is long and thin and the stem is strong so it doesn't fall easily	25	2017
BRRI dhan88	”	The grain is thin and white. Short life span, suitable for the Haor area	26.3	2018
BRRI dhan89	”	Grain is medium coarse and white	28.5	2018
BRRI dhan92	”	Strong stem so lodging incidence minimum. Rice is long and thin	26	2019
BRRI dhan96	”	Stems are strong, leaves are dark green and erect. Rice short and thick	28	2020
BRRI dhan97	”	Rice is medium coarse and white. Salinity-tolerant <i>Boro</i> variety	25.2	2020
BRRI dhan99	”	Grain is long, thin and white color. Leaves are perpendicular, broad, long and dark green	27.1	2020
Bangabandhu dhan100	”	Broad, green leaves, straw-colored, rich in Zn and grain is thin and white	26.8	2020
BRRI hybrid dhan3	”	Rice is medium coarse	23	2009
BRRI hybrid dhan5	”	Rice medium thin, long and white	23.8	2016

Experimental design

A randomized complete block design (RCBD) with three replications was employed to the experiment. The number of total plots was 57, measuring row-to-row and plant-to-plant distances of about 20 cm and 20 cm, respectively. Each replication was divided into 19 unit plots, where 19 varieties were allocated at random. Thus, the total number of unit plots was 57. Each unit plot measured 2.4 m² (3 m x 0.8 m).

Intercultural operations

Thirty-eight-day-old seedlings with each entry were chosen to transplant maintaining one seedling per hill on January 8, 2022. Throughout the crop-growing season, necessary cultural activities were carried out. Urea, TSP, MOP, Gypsum, and ZnSO₄ fertilizers were applied @260:100:120:110:10 kg/ha, respectively. The other fertilizers, with the exception of urea, were applied during the final land preparation. Three equally spaced applications of urea were made at 15 days after transplanting (DAT), 35 DAT, and right before blooming. When necessary, cross-cultural procedures and pest control measures were also carried out.

Data Collection

Twenty qualitative and fifteen quantitative traits were recorded using the ‘Germplasm Descriptors and Evaluation Form’ approved by Bangladesh Rice Research Institute (BRRI). The qualitative and quantitative traits of 19 varieties and their evaluation technique along with the evaluation phase are shown in Table 2 and 3, respectively.

Table 2. List of qualitative traits of 19 rice varieties and their evaluation phase

Descriptors	Observed phenotypic classes	Evaluation phase
Blade pubescence	1. Glabrous 2. Intermediate 3. Pubescent	Late vegetative stage
Blade color	1. Pale green 2. Green 3. Dark green 4. Purple margins	Booting to heading stage
Leaf sheath: anthocyanin color	1. Absent 9. Present	Late vegetative stage
Basal leaf sheath color	1. Green 3. Light purple	Late vegetative stage
Ligule color	1. White 2. Purple lines	Stem elongation to booting stage
Ligule shape	2. 2-cleft	Late vegetative stage
Collar color	1. Pale green 2. Purple	Late vegetative stage
Auricle color	1. Pale green 2. Purple	Stem elongation to booting stage
Culm: anthocyanin color	1. Absent	After flowering
Culm angle	1. Erect	After flowering
Internode color	1. Green 2. Light green	After flowering
Culm strength	1. Strong	After heading by gently pushing tillers back and forth a few times
Panicle type	1. Compact 5. Intermediate	Dough stage
Panicle exertion	3. Partly exerted 7. Moderately well exerted	Near maturity
Distribution of awning	0. None (awnless) 1. Tip only	Flowering to maturity
Awn color	1. Straw	At maturity
Lemma and palea color	0. Straw 1. Gold and gold furrows 2. Brown spot on straw 3. Brown furrow on straw	At maturity
Lemma and palea pubescence	1. Glabrous 3. Hairs on upper portion	Flowering to maturity
Leaf senescence	3. Early 7. Late and slow	At maturity
Phenotypic acceptability	1. Excellent 3. Good	At maturity

Table 3. List of quantitative traits of 19 rice varieties and their evaluation technique

Traits	Evaluation technique	Evaluation phase
Culm diameter (CD, mm)	Outer diameter internodes of the 5 culms were measured and averaged	After flowering
Plant height (PH, cm)	The average of height from the base to the tip of last leaf (flag leaf)	After flowering
Days to flowering (DF, days)	The number of days from seeding to flowering day	At flowering
Days to maturity (DM, days)	The number of days from seeding to maturing day	At maturity
Effective tiller number (ET No.)	Counting of effective tiller per hill	Early ripening
Panicle length (PL, cm)	Distance between the apex of the panicle (excluding awn) and top most node (neck node) of the culm	Dough stage
Filled grains panicle ⁻¹ (FGP, no.)	Number of filled grains per panicle was counted from 5 randomly selected panicles and averaged	After harvesting
Unfilled grains panicle ⁻¹ (UFGP No.)	Number of unfilled grains per panicle was recorded from 5 randomly selected panicles and averaged	After harvesting
Grain length (GL, mm)	Length (mm) of grain was measured by a digital slide caliper from 5 randomly selected fertile grains excluding awn and averaged	At maturity
Grain breadth (GB, mm)	Breadth of a grain (mm) was measured from 5 randomly selected fertile grains by a digital slide caliper and averaged	At maturity
Grain length breadth ratio (GLBR)	Dividing grain length by grain breadth	At maturity

Statistical Analysis

Replication means data of the morphological characters under study were subjected to both univariate and multivariate analysis. Mean, range, and coefficient of variation (CV %) were also estimated using Microsoft Excel 2010 software. Multivariate analysis was done by computer using GENSTAT 5.13. A diversity profile was developed using PAST software.

Results and discussion

A total of 35 characters, including 20 qualitative characters and 15 quantitative characters, had been evaluated for comprehensive characterization or to establish distinctiveness among 19 rice varieties.

Qualitative traits

Qualitative traits are regarded as morphological markers for the morphological characterization or identification of landraces of rice since they are less affected by environmental changes (Rao et al., 2013; Kalyan et al., 2017). For almost all of the analyzed morphological features, the rice landraces under research had a wide range of distinctiveness, and comparable findings had also been reported by Joshi et al. (2007), Chakrabarty et al. (2012), and Tirkey et al. (2013).

Leaf traits

The different traits (Table 1) of a leaf weren't characterized at the same stage of plant growth. Blade pubescence is determined at the late vegetative stage. Most varieties leaves were intermediate (53%), pubescent (37%), and glabrous (10%). In the case of blade color information was gathered during the booting to the heading stage. Green leaves were exhibited by 63% varieties, and 27%, 5%, and 5% were dark green, purple margins, and pale green, respectively. In the same way, anthocyanin coloration of the leaf sheath was absent in 84% of varieties, while only 16% of varieties had color. However, among the colored leaf sheaths, the majority (84%) were green, and the rest (16%) were light purple (Table 4). Islam et al. (2018b) reported that most of the germplasm (> 96%) showed green leaf blade color, and more than 95% of leaves showed anthocyanin color. Rawte and Saxena (2018) also reported

that the basal leaf sheath color was 12% light purple, while 72% of accessions showed a green color and 66% of the anthocyanin coloration of the leaf sheath was absent. Again, 81% green basal leaf sheath color, 37% dark green leaf blade color, and 54% intermediate leaf pubescence were found in Pachauri et al. (2017).

Ligule traits

Most of the varieties showed white (89%) colored ligules and only two varieties (11%) exhibited purple lines of ligule color. All the varieties had a 2-cleft (100%) ligule shape. A similar study was also reported by Islam *et al.* (2018c). Again, most of the varieties exhibited a pale green collar color (89%) while only 11% were purple-colored. Auricle color distribution among varieties was exactly as for collar color, namely pale green (89%) and purple (11%) (Table 4). The result showed alignment with Islam et al. (2018b). Rawte et al., (2018) reported in their study that 95% of landraces had split or 2-cleft shapes of the ligule.

Culm traits

All the varieties were devoid of anthocyanin coloration in the culm. At the same time, there were no differences in culm angle and culm strength among 19 rice varieties. All varieties had an erect (<30°) type culm as well as strong culm (no bending). The only difference was in the color of the internodes. However, 95% of the varieties had a light green internode while only one had a green internode (as shown in Table 4). Islam et al. (2018a) found culm angle 36.11% erect, and 75% green internode color.

Panicle traits

The panicle type varied more among the varieties. Most of the varieties (63%) showed intermediate-type panicle, while the rest (37%) of varieties had compact panicle. Again, 84% varieties were of moderately well exerted and only three varieties (16%) were of partly exerted panicle (Table 4). Islam et al. (2018b) found well-exerted panicles in 95% germplasm and 5% moderately well-exerted panicle. Again, 76% well-exerted panicle and 17% compact type panicle were reported by Pachauri et al. (2017). Islam et al. (2018a) found 5.56% compact, 41.66% intermediate type panicle, 88.88% well-exerted, and 5.56% moderately well-exerted panicle. The results found by the different researchers also supported the variations in different panicle traits due to different rice varieties.

Grain traits

Among 19 varieties, 16 varieties were awnless (84%). Only three varieties (16%) had awns, which were only found at the tip and all (100%) were of straw-colored (Table 4). Islam et al. (2018d) showed that more than 69% of germplasm were of awnless in the variability assessment of aromatic rice. Pachauri et al. (2017) found 96% of varieties were awnless. According to Islam et al. (2018a), 63.89% of spikelets were devoid of awns, 36.11% of awns were restricted to the tip, and 76.93% of awns were straw in color. Rawte and Saxena (2018) also reported 40% of accessions had awns, while the rest of the 60% were awnless.

The varieties showed hairs on the upper portion (95%), glabrous (5%) in the case of the lemma and palea pubescence. On the basis of lemma and palea color, straw (68%), gold and gold furrows (16%), brown spot on straw (11%), and brown spot on furrows (5%) colored. Islam et al. (2018a) found straw lemma and palea color (52.78%), short hairs on the lemma and palea pubescence (88.89%) (Table 4).

Leaf senescence data was determined at the maturity stage. The varieties exhibited late and slow (63%), followed by early (37%). Islam et al. (2018a) reported an early and fast type leaf senescence of 58.33%. For the character of leaf senescence, 7% were of the late, and 54% were of the early type as reported by Rawte and Saxena (2018). Moreover, Pachauri et al. (2017) showed 49% of late leaf senescence.

Maturity traits

Varieties exhibited variation in phenotypic acceptability including excellent (74%), and good (26%) (Table 4).

Table 4. Classification of BRRI-released rice varieties based on 21 qualitative characters

SL No.	Qualitative characters	Classification	Frequency	Sl. No	Frequency %
1	Blade pubescence	1.Glabrous	2	3,12	10
		2.Intermediate	10	28,29,58,67,86,89, 96,97,99,3	53
		3. Pubescent	7	63,74,81,84,88,100,5	37
2	Blade color	1.Pale green	1	92	5
		2.Green	12	28,29,50,58,67,74,81,84,86,89, 99,3	63
		3.Dark green	5	63,88,96,97,100	27
		4.Purple margins	1	5	5
3	Leaf sheath anthocyanin color	1.Absent	3	97,3,5	16
		9. Present	16	28,29,50,58,63,67,74,81,84,86,88,89, 92,96,99,100	84
4	Basal leaf sheath color	1.Green	16	28,29,50,58,63,67,74,81,84,86,88,89, 92,96,99,100	84
		3.Light purple	3	97,3,5	16
5	Ligule color	1.White	17	28,29,50,58,63,67,74,81,84,86,88,89, 92,96,97,99,100	89
		2.Purple lines	2	3,5	11
6	Ligule shape	1. 2-cleft	19	28,29,50,58,67,74,81,84,86,89, 92, 97,99,100, 3,5	100
7	Collar color	1.Pale green	17	28,29,50,58,63,67,74,81,84,86,88,89,92,96, 97,99,100	89
		2. Purple	2	3,5	11
8	Auricle color	1.Pale green	17	28,29,50,58,63,67,74,81,84,86,88,89,92,96, 97,99,100	89
		2. Purple	2	3,5	11
9	Culm: anthocyanin color	1. Absent	19	28,29,50,58,63,67,74,81,84,86,88,89,92,96, 97,99,100,3,5	100
10	Culm angle	1. Erect	19	28,29,50,58,63,67,74,81,84,86,88,89,92,96, 97,99,100,3,5	100
11	Internode color	1.Green	1	100	5
		2.Light green	18	28,29,50,58,63,67,74,81,84,86,88,89,92, 96,97,99, 3,5	95
12	Culm strength	1. Strong	19	28,29,50,58,63,67,74,81,84,86,88,89,92,96, 97,99,100,3,5	100
13	Panicle type	1.Compact	7	58,63,88,89,92,3,5	37
		5.Intermediate	12	28,29,50,67,74,81,84,86, 96,97,99,100	63
14	Panicle exertion	1.Partly exerted	3	100,3,5	16
		7.Moderately well exerted	16	28,29,50,58,63,67,74,81,84,86, 88,89, 92,96,97,99	84
15	Distribution of awning	0.None (awnless)	16	28,29,50,58,63,67,74,81,84,86, 88,89, 92, 96, 99,100	84
		1.Tip only	3	97,3,5	16

16	Awn color	1.Straw	3	97,3,5	100
		0.Straw	13	28,58,63,81,84,86,88,92,97 99,100,3,5	68
		1.Gold and gold furrows	3	67,74,89	16
17	Lemma and palea color	2.Brown spot on straw	2	29,96	11
		3.Brown furrow on straw	1	50	5
		0.Glabrous	1	50	5
18	Lemma and palea pubescence	3.Hairs on upper portion	18	28,29,58,63,67,74,81,84,86,88 89,92, 96, 97,99,100, 3,5	95
		3.Early	7	58,63, 89, 92, 96, 3,5	37
19	Leaf senescence	7.Late and slow	12	28,29,50,67,74,81,84,86,88,97 99,100	63
		1.Excellent	14	28,29,50,58,63,67,74,81,84,86 88,89, 92, 96	74
20	Phenotypic acceptability	3. Good	5	97,99,100, 3,5	26

Quantitative traits

Table 5 shows the Eigenvalues (latent roots) and the proportion of the overall variation and the percentage of total variation that is explained by them.

Table 5. Latent roots (Eigenvalues) and their variation in 15 quantitative characters in 19 *Boro* varieties

Principal component axes	Latent roots	Variation (%)	Cumulative % of variation
PC 1	4.7149	31.43	31.43
PC 2	2.8139	18.76	50.19
PC 3	1.9466	12.98	63.17
PC 4	1.6760	11.17	74.34
PC 5	1.0057	6.70	81.04
PC 6	0.8714	5.81	86.85
PC 7	0.7371	4.91	91.76
PC 8	0.5159	3.44	95.20
PC 9	0.3295	2.20	97.40
PC 10	0.2074	1.38	98.78
PC 11	0.0726	0.48	99. 26
PC 12	0.0625	0.42	99. 68
PC 13	0.0274	0.18	99.86
PC 14	0.0139	0.09	99.96
PC 15	0.0053	0.04	100.0

The findings showed that the top five PCA components with Eigenvalues >1.0 accounted for 81.04% of all genotype-to-genotype changes for 15 morphological features. The first two axes contributed 50.19% of the total variations among the 15 characters describing 19 rice varieties whereas only 31.43% of variations accounted for the first axis. These outcomes support the conclusions made by Ahmed et al. (2015). In 113 aromatic and fine grain rice landraces, Islam et al. (2016) found that the top nine axes accounted for roughly 90% of the overall variances via

PCA. However, Sohrabi et al. (2012) and Chakravorty et al. (2012) found that the first six and four components, respectively, contributed 76.7% and 75.9% of the overall variance in rice.

Table 6 shows the range, mean, standard error, and coefficients of variation of 15 characters in 19 rice varieties. Since the coefficient of variation ranged from 3.79 to 42.09% there was clearly a lot of variety among the analyzed characters. The 19 traits had a relatively higher coefficient of variation for unfilled grains per panicle, brown rice length-breadth ratio, yield, filled grains per panicle, and grain breadth (42.09, 17.16, 16.66, 15.17, and 15.07%, respectively) than the other traits. These might have happened due to sampling error or because environmental conditions had a bigger impact on characters than usual. The highest standard error was found in filled grains per panicle and lowest in brown rice breadth. Islam et al. (2016) found that unfilled grains per panicle, harvest index, yield per plant, filled grains per panicle, primary branches per panicle, and secondary branches per panicle found with a relatively higher coefficient of variation (35.81, 20.45, 18.70, 16.79, 11.61, and 11.03%, respectively).

Table 6. Variability in different quantitative characters in 19 rice varieties

Characters	Range	Mean	SE	CV %
PH (cm)	81-112	98.84	2.05	9.04
DF	113-131	5.34	1.23	4.49
DM	140-158	146.63	1.28	3.79
CD (mm)	3.50-5.78	4.09	0.11	12.07
PL (cm)	23.67-29.67	26.68	0.39	6.32
ET No.	11-17	14.37	0.36	10.93
FGP	126-234	180	6.27	15.17
UFGP	8-37	19	1.85	42.09
GL (mm)	7.90-11.34	9.16	0.19	8.91
GB (mm)	1.74-3.15	2.48	0.09	15.07
BRL (mm)	5.60-7.34	6.69	0.11	7.43
BRB (mm)	1.50-2.75	2.09	0.07	13.78
BRLBR	2.28-4.80	3.26	0.13	17.16
TGW (g)	17.40-27	22.23	0.62	12.11
YPH (g)	16-27.80	21.00	0.80	16.66

CD: culm diameter, DF: days to flowering, DM: days to maturity, PH: plant height, ET No.: effective tiller number, PL: panicle length, FGP: filled grains per panicle, UFGP: unfilled grains per panicle, GL: grain length, GB: grain breadth, BRL: brown rice length, BRB: brown rice breadth, BRLBR: brown rice length-breadth ratio, TGW: 1000-grain weight, YPH: yield per hill.

Table 7. Distribution of 19 *Boro* varieties into five clusters

Cluster	No. of genotypes	% Total	Name of Varieties
I	01	16.13	BRRI dhan58
II	04	25.81	BRRI dhan28, BRRI dhan63, BRRI dhan67, BRRI dhan50
III	05	16.13	BRRI dhan74, BRRI dhan81, BRRI dhan84, BRRI dhan86, BRRI dhan96
IV	06	22.58	BRRI dhan29, BRRI dhan89, BRRI dhan92, BRRI dhan97, BRRI hybrid dhan3, BRRI Hybrid dhan5
V	03	19.35	BRRI dhan88, BRRI Hybrid dhan99, Banghabandhu dhan100

PCA, which depicts the makeup of five clusters with varieties, was used to determine the clustering pattern (Table 7). Cluster IV contains a maximum of six different types followed by clusters III, II and V with five, four, and three varieties, respectively. Cluster I had just one variety compared to any other cluster. In mountainous regions of Bangladesh, Siddique *et al.* (2011) discovered five clusters from 38 rice landraces. Similar research was conducted on five clusters from 43 upland rice genotypes by Khan et al. (2015). Additionally, five clusters from 30 Jhum rice landraces were discovered by Islam et al. (2017). Islam et al. (2016) found 10 clusters in the assessment of 113 aromatic and fine rice germplasms.

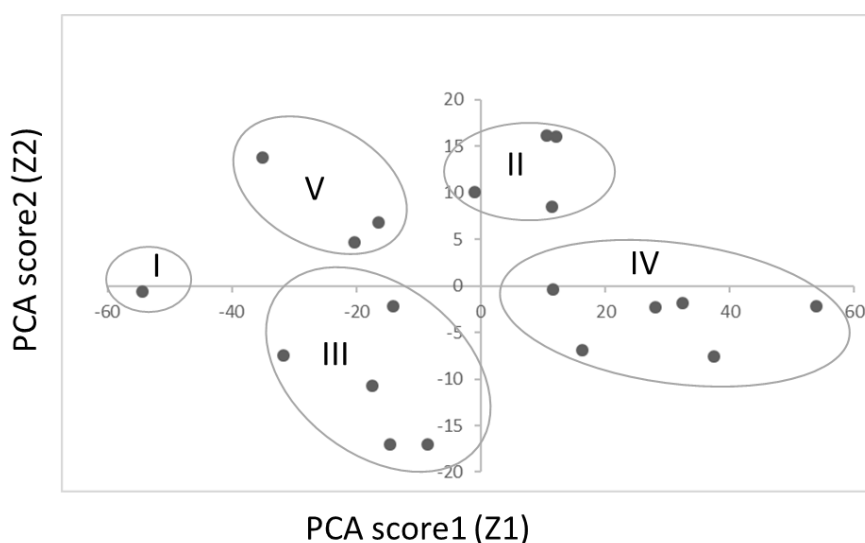


Figure 1. Scatter diagram of 19 rice varieties based on their principal component scores superimposed with clustering

A two-dimensional map (Z1-Z2) of the varieties based on primary axes is shown in Figure 1. The BRRI rice varieties appear to have been dispersed into five clusters, according to the scattered diagram.

Table 8. Intra (bold) and inter-cluster distances (D^2) for 19 *Boro* varieties

Clusters	I	II	III	IV	V
I	0.62	17.07	15.75	24.16	15.32
II		0.67	13.0	19.12	18.16
III			0.58	9.89	7.70
IV				0.92	9.22
V					0.73

The average intra- and inter-cluster distances (D^2) are shown in Table 8. Cluster IV had the highest intra-cluster distance (0.92) with six genotypes BRRI dhan29, BRRI dhan89, BRRI dhan92, BRRI dhan97, BRRI hybrid dhan3, BRRI hybrid dhan5, followed by cluster V (0.73), cluster II (0.67) and cluster I (0.62) with three, four and one genotypes), respectively. Cluster III had the lowest intra-cluster distance (0.58) with five genotypes BRRI dhan74, BRRI dhan81, BRRI dhan84, BRRI dhan86, BRRI dhan96. According to these findings, varieties in cluster IV were the most different (heterogeneous) while those in cluster III were the most similar or less diversified (homogeneous). In terms of the genetic distance between clusters, clusters I and IV had the greatest distance (24.16), followed by clusters II and IV (19.12), and clusters III and V had the least distance (7.70), followed by clusters IV and V (9.22), and then cluster III and IV (9.89). The highest inter-cluster distance showed that genotypes in cluster IV and cluster I were very divergent from one another. Clusters III and V had the lowest inter-cluster divergence (7.70) demonstrating that the genotypes of all such clusters were genetically closer. All of the clusters had greater inter-cluster distances. Every cluster had greater inter-cluster distances than intra-cluster distances, indicating greater genetic variation between the genotypes of various groupings. The outcomes were in agreement with Islam et al. (2017), Akter et al. (2016), Ahmed et al. (2015), Islam et al. (2014), Siddique et al. (2013), and Sohrabi et al. (2012). Once more, Islam et al. (2016) showed that for the aromatic and fine rice genotypes the intra and inter-cluster distances varied from 0.61 to 1.27 and 3.71 to 16.12, respectively.

Table 9. Cluster means for fifteen characters in *Boro* rice varieties

Characters	I	II	III	IV	V
Plant height (cm)	102.00	92.50	91.40 (L)	105.50 (H)	104.29
Days to flowering	121.00	117	116 (L)	123 (H)	120
Days to maturity	152.00	144	142 (L)	153 (H)	149
Culm diameter (mm)	3.93	3.77 (L)	4.36 (H)	4.14	4.05
Panicle length (cm)	24.5 (L)	26.92	25.80	27.22 (H)	27.12
Effective tiller (no.)	14	13	12	16 (H)	11 (L)
Filled grains panicle ⁻¹	215 (H)	142 (L)	169	202	198
Unfilled grains panicle ⁻¹	24	21	14	13 (L)	32 (H)
Grain length (mm)	8.55 (L)	9.34	9.59 (H)	8.98	8.79
Grain breadth (mm)	2.38	2.31	2.22 (L)	2.88 (H)	2.37
Brown rice length (mm)	6.30 (L)	6.78 (H)	6.76	6.73	6.51
Brown rice breadth (mm)	2.18	1.92	1.88 (L)	2.34 (H)	2.15
Brown rice length-breadth ratio	2.88 (L)	3.68 (H)	3.52	2.91	3.02
1000 grain weight (g)	24.00 (H)	19.45	18.30 (L)	23.49	20.33
Yield hill ⁻¹ (g)	25.00 (H)	19.45	18.60 (L)	23.49	20.75

For each of the 15 quantitative characters, the cluster-mean values are shown in Table 9. The highest cluster means for plant height, days to flowering, and days to maturity were obtained from cluster IV, while the minimum cluster means for those characteristics were found in cluster III. Moreover, in cluster III highest culm diameter, grain length, and lowest grain breadth, brown rice breadth, 1000-grain weight, and yield were observed. Maximum good characters were accumulated in cluster IV. The highest filled grains per panicle were found in cluster I which contributed to the maximum yield in cluster I. The genotypes of cluster I and cluster IV might be crossed to get a new combination with desired traits. Cluster V had the medium cluster means for different characters except for unfilled grains per panicle. Cluster IV can be used in hybridization to produce higher-yielding genotypes. It is clear from the description above that all of these *Boro* varieties are genetically distinct from one another. Similar result was found by Islam et al. (2018). Ahmed et al. (2015) and Sohrabi et al. (2012) earlier reported a similar trend of conclusions on rice germplasm using D² statistics.

Table 10. Relative contributions of the fifteen characters to the total divergence in *Boro* rice varieties

Characters	Vector 1	Vector 2
Plant height (cm)	- 0.3546	0.0410
Days to flowering	- 0.1912	0.3995
Days to maturity	- 0.2328	0.4078
Culm diameter (mm)	- 0.0304	- 0.0257
Panicle length (cm)	- 0.2263	0.1499
Effective tiller (no.)	- 0.0335	0.3473
Filled grains per panicle (no.)	0.0073	- 0.1559
Unfilled grains per panicle (no.)	0.0179	0.0953
Grain length (mm)	0.2462	0.3860
Grain breadth (mm)	- 0.4016	- 0.0026
Brown rice length (mm)	0.0886	0.4708
Brown rice breadth (mm)	- 0.4094	- 0.0872
Brown rice length-breadth ratio	0.3845	0.2853
1000 grain weight (g)	- 0.2818	0.1888
Yield/hill (g)	- 0.3244	- 0.003

Canonical vector analysis

Table 11 represents the contributions of the characters toward divergence. The canonical variate analysis exposed that both the vectors (vector 1 and vector 2) for unfilled grains per panicle, grain length, brown rice length, and

brown rice length-breadth ratio were positive. These findings suggested that these four features were the main contributors to divergence.

On the contrary, both vectors for culm diameter, grain breadth, brown rice breadth, and yield had lower contribution towards the divergence. Plant height, days to flowering, days to maturity, panicle length, number of effective tillers, filled grains per panicle, and 1000-grain weight were all positive for one vector, but negative for the other. Ovung et al. (2012) found that spikelets per panicle, plant height, and biological yield mainly contributed to genetic divergence. Islam et al. (2017) found a positive contribution of both canonical vectors for culm diameter, days to flowering, days to maturity and length-breadth ratio on Jhum rice landraces which were collected from Rangamati district in Bangladesh. Biswash et al. (2016) also found that plant height, flag leaf blade length, panicle length, primary branches per panicle, number of filled grains per plant, and 1000- seed weight were major characteristics that contribute to the genetic divergence. Again, Ahmed et al. (2016) showed the grain LB ratio, culm diameter, effective tillers per hill, panicle length and days to maturity contributed for maximum divergence.

Crosses with parents from the most divergent clusters may have high-yield heterosis. The maximum distances between clusters I and VI in the current investigation were present, however, given the yield and number of filled grains, this may not be enough for practical reasons. Crosses between clusters I and V may show increased heterosis for earliness and dwarf stature when growth time and yield are taken into account. Habib et al. (2005) observed similar results in rice. In light of this viewpoint, it would seem that crossings between the genotypes/parents of clusters I and VI and clusters I and V would show strong heterosis as well as higher levels of yield potential. Therefore, the genotypes under clusters I, V and VI may be chosen for a future breeding effort based on this result. It's remarkable to note that the larger divergence in the current materials caused by these four traits will provide a solid opportunity for yield improvement through thoughtful parent selection for heterotic rice hybrids. Islam et al. (2009) reported comparable results for local rice germplasm.

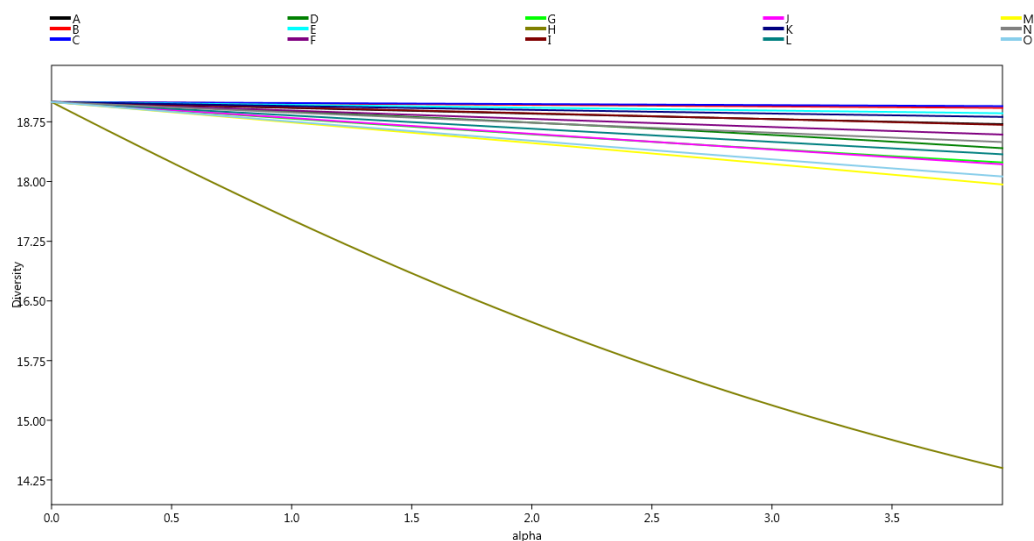


Figure 2. Diversity profile of tested rice varieties based on 15 quantitative phenotypic traits

The resulting diversity profile is shown in Figure 2. This profile was developed using PAST (PALEontological Statistics) software. The effective representativeness of the variety present in the germplasm is indicated by an increase in the H-based evenness score across the characteristics.

Conclusions

Based on the results of the current study, we made some conclusions as follows: (i) The varieties showed good diversity in both qualitative and quantitative agro-morphological traits as a result most of the varieties were also

diversified. Cluster analysis using quantitative traits of 19 varieties grouped them into five clusters and cluster IV contains maximum (six) genotypes. Observed variances in qualitative data were mostly explained by blade pubescence, anthocyanin color of leaf sheath, lemma-palea color, grain tip color and awning. (ii) While considering results from genetic distance, the varieties under cluster IV (BRRI dhan29, BRRI dhan89, BRRI dhan92, BRRI dhan97) might be selected as parents for further breeding program.

Conflict of interest

The authors declare that there is no conflict of interest.

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