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COMPARATIVE ASSESSMENT OF SELECTED EXOTIC HYBRID RICE (*Oryza sativa* L.) BASED ON QUANTITATIVE TRAITS ANALYSIS

SUMMARY

In the plant breeding program, significance and nature of genetic diversity plays a pivotal role in identifying a suitable cultivar for its further improvement. The present study was conducted to compare and analyse the contributions of yield components to grain yield of twenty-one exotic hybrid rice genotypes under field conditions, and evaluate the relationships between 11 grain yield and its components of hybrid rice to identify the suitable cultivars. The principal component analysis showed that the first three components were significant with eigenvalue more than 1 and contributed 50.74%, 16.32% and 11.14% of the total variance, respectively. PC1 included the traits that were related mostly to the plant height (cm), effective tillers, panicle length (cm), grain width (cm), 1000 grain weight (g) and grain yield (t ha^{-1}). Cultivars from Heera-2, Qyou-6, SHD-661, Q-5, Q-28, HS-366 performed well in PC1 while cultivars such as HS-558B, T-35, Xiang-11, Lyongyou-5, RXEL-16, RXME-22 performed well in PC2. The cluster analysis grouped the cultivars into three main clusters in which 14 cultivars were grouped into cluster I. And cluster I showed the highest mean value for plant height, panicle length, filled grain with moderate high rate of

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effective tillers which were directly influenced to produce higher grain yield. Therefore, the Chinese cultivars SHD-661, Qyou-6, Q-5 and Q-28 from the clusters I can be used in the further development of the superior hybrids for commercial cultivation in Bangladesh.

Keywords: hybrid rice, quantitative traits, multivariate analysis, yield

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major and staple food crops, feeding more than half of the global population (USDA, 2022). Asia is the key source of rice genetic diversity in which almost 90% of the world's rice is grown and consumed, where almost 50% people in Asian countries rely on rice grain (Tenorio *et al.,* 2013). In Bangladesh, 11.4 million hectares land area was involved in rice cultivation, generating 51.6 million tons of rice annually. And 77% of the total cropped area was used for its production which contributed more than 80% of the country's food supply (BBS, 2022). Presently, rice singly constitutes almost 93% of the country's total food supply, achieving 75% of the caloric intake along with 50% of total protein intake in the country (Pervez, 2018). But over-increasing population growth rate in Bangladesh is a great threat to its food security, lowering the cultivable land area due to the urbanization and industrialization. And the rice production needs to be increased by at least 60% to fulfil its food requirement of such population by the year 2030 (Masum, 2019). Regarding this issue, increasing the rice yield per unit land area is one of the best possible ways to meet the food demand even in ever-increasing trend of population in Bangladesh.

Hybrid rice has the capability to increase almost 20-30% more yield than high yielding varieties (HYV) and traditional rice varieties (Fazal *et al*., 2022; Hossain *et al*., 2017; Yesmin *et al.,* 2022). In the last two decades, much emphasis has been given to cultivate hybrid rice for the improvement rice production in Bangladesh (Azad *et al*., 2022; Hasan *et al*., 2022). The 0.7 million hectares land were cultivated hybrid rice during Boro season in 2016-17 which has contributed 3-4 million tons of additional rice to the total rice production of the country (AIS, 2018). Although there are few risks of hybrid production in Bangladesh (Kanak Pervez *et al*., 2022), in the meantime by adopting new technology, more than a dozen of hybrid rice varieties have been developed (Rahman *et al.,* 2019; Rabbi *et al*., 2020). For the time being, effective seed production infrastructure is developed in the government, private, or NGO sectors in Bangladesh those are closely linked with hybrid rice research to accelerate the higher yield production. And the government encouraged the private seed companies to import hybrid seeds from abroad which can boost up the production at farmers level through on-farm trials in different locations of Bangladesh (Julfiquar *et al*., 2006; Shah *et al.,* 2014). So, the present study was emphasized the hybrid rice varieties in the farmer's field those were collected from China and India.

Multivariate traits analysis is one of the useful statistical tools which are broadly used to summarize and describe the inherent variations among the cultivars. Principal component analysis (PCA) is used to identify the similar set of accessions which can captures the maximum genetic diversity (Gireesh *et al.,* 2017) and eliminates the redundancy in datasets, as variation occurs commonly found in plants for yield and its attributing traits (Mahendran *et al.,* 2015). And correlation analysis determines the association between yield and its related traits (Oladosu *et al.,* 2018) and also brings out the relative significance of their direct and indirect effects which could help to the breeders for choosing the selection strategies (Rahman *et al*., 2022). A high yield potential with short duration rice varieties is a common objective of a rice breeder (Hasan *et al*., 2008; Hossain *et al*., 2010; Huang *et al*., 2015). Therefore, genetic investigation through multivariate traits analysis could help to select superior rice genotypes.

Variety itself plays an influential role for the improvement of a specific crop even in a distinct character. And effective utilization of the available genetic diversity exists in rice varieties can helps for its improvement strategies (Sarkar *et al*., 2021; Tabassum *et al*., 2020a; Tabassum *et al*., 2020b). In the meantime, the government of Bangladesh as well as private research organizations has imported some hybrid rice varieties from China, India and Philippines for enhancing the total yield. The wide diversity of such exotic rice could act as a gene pool for the advancement of varietal improvement in Bangladesh. Although, there is available research information on BRRI (Bangladesh Rice Research Institute) derived rice varieties is available, but there is little or no research report on comparative study of exotic hybrid rice varieties in Bangladeshi environment were documented. Thus, the present experiment was investigated to carry out with the objective of studying the genetic diversity, variability and trait relationship associations among the Chinese and Indian hybrid rice varieties based on multivariate analysis.

MATERIAL AND METHODS

Experimental materials and site

In the present study, twenty-one exotic hybrid rice genotypes were grown at the farmer’s field in Muktagacha, Mymensingh, Bangladesh (Figure 1) to study their morphological, yield and yield attributing traits. Geographically, the experimental site is situated at 24°25''N latitude and 90°50''E longitude along with medium-high land properties having silty clay loam soil. Among the studied varieties, five (APH-9696, RXEL-16, RXME-22, RXME-23 and TH-35) were collected from India, fifteen (Q-5, Q-28, SHD-85, SHD-422, SHD-557, SHD-661, SHD-726, HS-11, HS-287, HS-366, HS-558B, HS-600, Xiang-11, Qyou-6 and Lyong you-5) were from China and the check variety (Heera-2) which was introduced earlier from China to Bangladesh. The plants were grown in a paddy field during December 2016 to May 2017. The experimental field was medium high land with soil pH of 6.0. Soil contained 2.2% organic matter, 0.15% total nitrogen, 3.25 ppm available phosphorus, 4.48 ppm available sulphur and 0.12

ppm exchangeable potassium. The climate and soil of the study area was under subtropical climate with well drained and non-calcareous grey floodplain fertile soils.

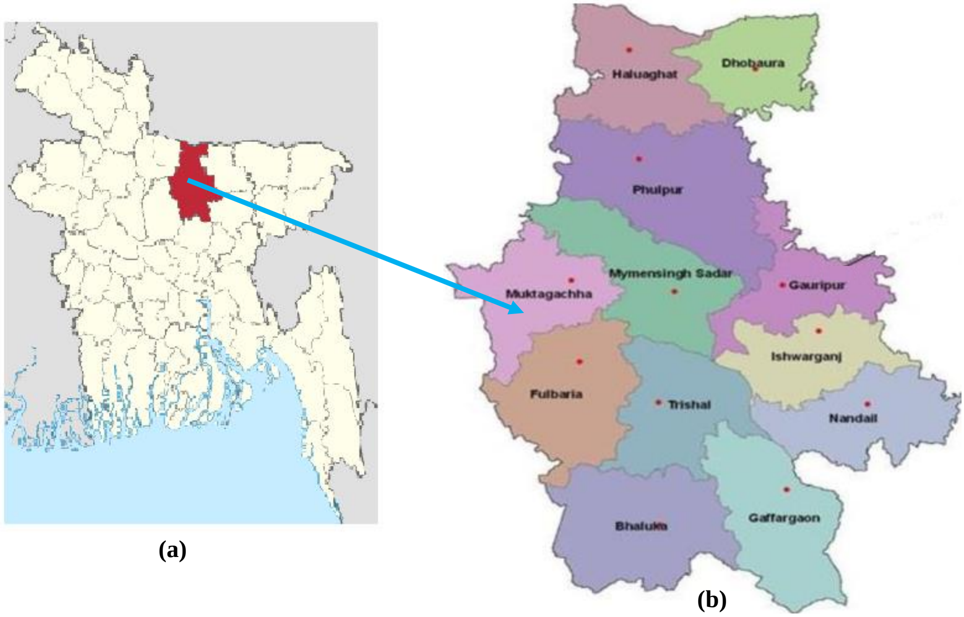


Figure 1. Location of the study area; (a) Bangladesh map showing Mymensingh district (red colour), (b) Muktagacha upazila under Mymensingh district (purple colour)

Experimental design

Single factor experiment was conducted using twenty hybrid rice varieties along with a check variety Heera-2 which were considered as the treatment in the present study. Thirty-five days old single seedling was transplanted per hill for each genotype in randomized complete block design with three replications. Space within and between rows were 20 and 25 cm, respectively and each plot size was 3×2 m= 6 m^2. The fertilizer dose of 280-150-130-70-10 kg per hectare was applied in the form of urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively. Total fertilizers except urea were applied before the final land preparation. Urea was applied in three instalments at 15, 30 and 45 days after transplanting (DAT). Appropriate control measures were taken against pests and diseases when necessary.

Collection of experimental data

Data were collected randomly from 5 selected plants per plot. An area of 1 meter square was selected in the middle portion of each plot to record the yield of grain and straw. The number of effective tillers was counted based on per meter square area of experimental plot. Other yield parameters viz. plant height (cm), panicle length (cm), unfilled grain, filled grain, grain length (cm), grain width (cm), days to maturity were collected just before the harvesting time of rice plant. The 1000 grain weight (g) and grain yield (initially grain yield was measured kg per plot which was then converted in ton per hectare) were measured after the harvesting of rice plant along with proper sun drying of grain and straw.

Statistical analysis

Five plants per plot were collected and the mean data points were used for statistical analysis. The genotypic effects and pair-wise multiple comparison of treatment means were tested by the analysis of variance (ANOVA) and Tukey Post Hoc (Tukey-HSD) test using R's built-in and Agricolae packages (Mendiburu, 2015). The Multivariate analysis with the Pearson correlation coefficients were calculated by using the software Statistical Tool for Agricultural Research (STAR 2.0.1) (IRRI, 2021). Cluster analysis was performed using Ward's hierarchical algorithm based on squared Euclidian distance statistics. Principle component analysis, eigenvalues, eigenvectors, and 2D biplots were built to complement cluster analysis.

RESULTS AND DISCUSSION

Performance evaluation for quantitative traits

The analysis of variance for the studied traits showed significant differences ($p<0.001$) among the hybrid cultivars (Table 1) which is an indication of inherent genetic diversity of the rice genotypes. In this study, Indian cultivar APH-9696 produced the tallest plant (112.45 cm) while Chinese cultivar HS-287 (75.82 cm) produced the shortest plant among the hybrid rice cultivars. Amidst the yield contributing characters, tillering capacity of rice genotypes significantly influences the production of panicles as well as grain yield (Ye *et al*., 2022). In our study, the significant differences were noticed in the number of effective tillers among the cultivars. The highest mean number of tillers per plant was recorded in HS-366 (8.93) followed by Qyou-6 (8.70) and SHD-661 (8.57). The lowest mean number of tillers per plant was observed in Q-28 (6.70) which was followed by TH-35 (7.00) (12.77). Singh and Mishra (2022) and Hasan *et al.* (2022) also indicated that the yield potentiality of rice plants is depend on their efficient or productive tillers. Moreover, the tillering capacity of rice is influenced by the robust stems and deep root system with improved sink size and lodging resistance features (Gong *et al.,* 2023).

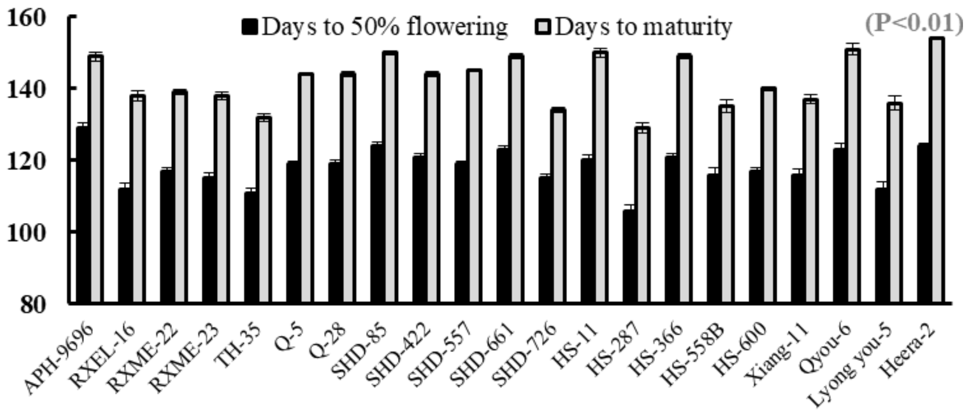


Figure 2. Days to 50% flowering and maturity of hybrid rice varieties

In this investigation, the genotype APH-9696 needed more days for 50% flowering (129 days) while HS-287 was the earliest flowering (106 days) cultivar (Figure 2 and Table 1). In our previous work, we noted the wide variation in days to 50% flowering in the studied cultivars because of the influence of genetic inheritance (Hossain *et al.,* 2017). In addition, Hossain *et al.* (2022) obtained the significant variations in the flowering dates of exotic hybrid rice genotypes grown in Bangladesh throughout the Boro season. In case of maturity, the genotype HS-287 needed the shortest time (129 days) while Heera-2 needed the longest time to mature (154 days). Here, the early heading lines matured earlier and late heading lines matured lately. Yesmin *et al*. (2022) stated that medium maturing genotypes produced better yield as compared to late genotypes in Aman rice in Bangladesh. Among the quantitative traits, panicle length is also an important aspect for improving grain yield in rice. The Chinese cultivar SHD-661 had the maximum panicle length (25.53 cm) followed by Q-28 (24.71 cm) and Qyou-6 (24.54 cm) (Table 1). Panicle length together with spikelet number and seed set determines the grain number per panicle, hence, yield increases in rice (Zheng *et al.,* 2022). The number of filled grain plant^{-1} was the highest in SHD-661 (158.34) followed by Qyou-6 (147.53), HS-366 (135.38) and Heera-2 (146.10). Interestingly, the same cultivars Qyou-6 (14.82), Heera-2 (15.07), SHD-661 (27.93) and HS-366 (28.24) produced the lowest number of unfilled grain plant^{-1}. Kumar *et al.* (2020) demonstrated that the grain yield is directly influenced by the number of filled and unfilled grains per panicle. They found the positive correlation (0.62) for filled grain number and negative and significant correlation for the unfilled grain number with grain yield (-0.47*). Therefore, the grain yield is increased by increasing the number of filled grains and decreasing the number of empty grains per panicle which was noticed earlier by Parida *et al.* (2022) and Fazal *et al.* (2022). Not only the panicle length but also the filled grain number and 1000 grain weight also important determining traits for improving grain yield. Moreover, Qyou-6 showed the highest 1000 grain weight (30.67 g) followed by SHD-661 (26.69) and Heera-2 (26.65) among the tested varieties. This difference might be due to weight and size of the grain. Bai *et al.* (2023) also stated that the weight of rice grain increases with bigger grain size.

In the Table 1, grain yield was markedly differed ($p < 0.001$) among the studied rice varieties. The Chinese hybrid rice SHD-661, Qyou-6 and check variety Heera-2 gave the highest grain yield valued of 10.45 t ha^{-1}, 10.39 t ha^{-1} and 10.29 t ha^{-1}, respectively. These differences happened may be due to the maximum number of effective tillers, panicle length, filled grains and 1000 grain weight. Moreover, regarding the grain yield, Chinese cultivars performed better compared to the Indian as well as check variety due to the higher number of filled grains, effective tillers and 1000 grain weight. Azad *et al*., (2022) and Anwar *et al*. (2022) reported that greater numbers of effective tillers hill^{-1}, filled grains panicle^{-1}, and 1000 grain weight were associated with higher grain yields in hybrid rice.

Association among the quantitative traits

Correlations coefficients measure the strength of association between variables and to determine correlated responses in selection activities. Thus, Pearson correlation analysis was employed in the study to identify the positive or negative correlation among the yield and yield contributing traits to the yield of twenty-one hybrid rice (Table 2). We found that the number of filled grain and the thousand grain weight (g) had a correlation value of 0.82. The number of filled grains produced the more grain weight. Days to flowering had positively significant association with days to maturity. In addition, panicle length (cm) had positive correlation with plant height (cm) and grain yield (t ha^{-1}) but not significantly differ with former to the latter. On the other hand, days to flowering showed significant negative association with panicle length (cm). Moreover, we found a large increase in the number of unfilled grains influenced a decreasing trend in the rice grain yield (t ha^{-1}). Days to flowering had positively significant association with days to maturity, grain width and 1000 grain weight but significant negative association with panicle length (Hasan-Ud-Daula and Sarker 2020; Kumar *et al*., 2018; Rahman *et al*., 2022). The yield component, a quantitative attribute, has a significant impact on grain yield (Kumar *et al*., 2021). The entire effect of quantitative traits on grain yield, either directly or indirectly caused by environmental factors, genetic factors, and their interactions, is one way to quantify the correlation coefficient (Faysal *et al.*, 2022).

Principal component analysis

Multivariate analysis technique was used to assess magnitude of genetic variation in the Chinese and Indian hybrid rice varieties. Figures 3 and 4 showed that the eigenvalue and contribution of each principal component to the total explained variance in the phenotypic diversity of rice, respectively. It was found that three of the eleven principal components had eigenvalue more than 1 and contributed to 78.19% of the variance. PC1 accounted for the highest variance (50.74%) and traits that positively contributed to variation included plant height (0.35), panicle length (0.32), filled grain (0.38), grain width (0.01), days to 50% flowering (0.38), days to maturity (0.38), thousand grain weight (0.37) and yield (0.39) that were mainly related to grain yield, yield attributing, and grain characteristics. PC2 contributed 16.32% of the total variation where plant height (0.24), panicle length (0.23), grain length (0.37) and grain width (0.58) contributed in a positive way. The PC3 accounted for 11.14% variance included plant height (0.05), panicle length (0.20), unfilled grain (0.55), filled grain (0.06), grain width (0.05), days to 50% flowering (0.16) and days to maturity (0.11) (Table 3). Principal components with eigenvalues>1 suggest that the corresponding component explains more variance than a single observed variable (Greenacre *et al.,* 2022; Shrestha *et al*., 2021). Similarly, in an assessment of physico-chemical and cooking characteristics of rice, Pokhrel *et al*. (2020) reported that the first four principal components with vector values>1 retained 73.8% of the total variance.

Table 1. Performance of hybrid rice cultivars for different quantitative characters

Traits	Plant Height (cm)	Effective Tiller	Panicle length (cm)	Unfilled grain	Filled grain	Grain length (cm)	Grain Width (cm)	Days to 50% flowering	Days to maturity	1000 grain weight (g)	Yield (ton/ha)
APH-9696	112.45^{a}	7.83^{a-e}	23.70^{b-d}	66.31^{ab}	107.54^{d-g}	7.20^{m}	1.93^{k}	129^{a}	149^{a-c}	24.10^{d}	9.07^{fg}
RXEL-16	100.44^{e-h}	7.53^{b-e}	22.26^{fg}	48.76^{b-e}	79.39^{hi}	9.20^{ef}	2.47^{h}	112^{ef}	138^{e-g}	21.11^{f}	7.77^{i}
RXME-22	104.38^{b-e}	8.47^{a-c}	22.20^{fg}	42.19^{d-f}	95.24^{f-h}	8.80^{h}	2.87^{bc}	117^{c-e}	139^{d-f}	23.33^{de}	7.80^{i}
RXME-23	94.03^{j}	7.63^{a-e}	22.93^{d-f}	59.99^{b-d}	94.34^{f-h}	8.73^{hi}	2.43^{hi}	115^{d-f}	138^{e-g}	16.57^{g}	7.16^{j}
TH-35	97.13^{h-j}	7.00^{de}	22.60^{ef}	29.36^{e-g}	96.98^{e-h}	9.10^{fg}	2.63^{ef}	111^{fg}	132^{gh}	21.28^{f}	7.93^{i}
Q-5	105.40^{b-d}	7.33^{c-e}	24.09^{bc}	31.18^{e-g}	120.41^{c-f}	10.10^{a}	2.67^{ef}	119^{b-d}	144^{c-e}	23.46^{de}	8.46^{h}
Q-28	98.84^{f-i}	6.70^{e}	24.71^{ab}	33.54^{e-g}	135.68^{a-c}	8.83^{h}	2.70^{d-f}	119^{b-d}	144^{c-e}	25.68^{bc}	9.60^{de}
SHD-85	107.58^{b}	8.13^{a-d}	23.49^{c-e}	63.74^{bc}	126.33^{b-d}	9.10^{fg}	2.47^{h}	124^{ab}	150^{a-c}	24.62^{c}	9.68^{cde}
SHD-422	102.35^{c-f}	8.20^{a-d}	24.02^{bc}	28.95^{e-g}	122.89^{b-e}	7.80^{l}	2.73^{de}	121^{bc}	144^{c-e}	26.35^{b}	10.04^{bc}
SHD-557	101.64^{d-g}	7.50^{b-e}	24.38^{bc}	32.66^{e-g}	88.66^{g-i}	9.80^{b}	2.50^{gh}	119^{b-d}	145^{b-d}	23.53^{cd}	8.71^{gh}
SHD-661	98.71^{f-i}	8.57^{a-c}	25.53^{a}	27.93^{fg}	158.34^{a}	8.27^{j}	3.07^{a}	123^{b}	149^{a-c}	26.69^{b}	10.45^{a}
SHD-726	95.06^{ij}	7.97^{a-e}	23.64^{c-e}	19.79^{g}	98.60^{e-h}	8.87^{h}	2.10^{j}	115^{d-f}	134^{f-h}	24.11^{cd}	9.41^{ef}
HS-11	96.58^{h-j}	7.07^{de}	21.23^{gh}	26.15^{fg}	134.04^{a-d}	8.03^{k}	2.33^{i}	120^{b-d}	150^{a-c}	24.41^{cd}	9.77^{cde}
HS-287	75.82^{k}	8.40^{a-c}	17.31^{j}	65.61^{bc}	50.50^{jk}	9.27^{e}	2.50^{gh}	106^{g}	129^{h}	13.37^{h}	4.49^{l}
HS-366	107.91^{b}	8.93^{a}	23.53^{c-e}	28.24^{e-g}	135.38^{a-c}	8.77^{h}	2.47^{h}	121^{bc}	149^{a-c}	25.82^{bc}	9.84^{cd}
HS-558B	93.17^{j}	7.50^{b-e}	21.36^{gh}	12.83^{g}	67.62^{ij}	9.43^{d}	2.80^{cd}	116^{c-e}	135^{f-h}	13.42^{h}	6.66^{k}
HS-600	105.13^{b-d}	8.57^{a-c}	19.29^{i}	45.34^{c-f}	108.17^{d-g}	9.03^{g}	2.60^{fg}	117^{c-e}	140^{d-f}	23.61^{de}	8.92^{g}
Xiang-11	98.19^{g-i}	7.67^{a-e}	20.99^{h}	14.82^{g}	83.01^{g-i}	9.60^{c}	2.60^{fg}	116^{c-e}	137^{fg}	16.60^{g}	7.63^{i}
Qyou-6	102.40^{c-f}	8.70^{ab}	24.54^{a-c}	20.67^{g}	147.53^{ab}	9.63^{c}	2.60^{fg}	123^{b}	151^{ab}	30.67^{a}	10.39^{ab}
Lyongyou-5	95.02^{ij}	7.60^{b-e}	21.91^{f-h}	86.38^{a}	25.22^{k}	8.60^{i}	2.70^{d-f}	112^{ef}	136^{fg}	11.47^{i}	3.45^{m}
Heera-2	105.80^{bc}	7.37^{c-e}	24.37^{bc}	15.07^{g}	146.10^{a-c}	7.97^{k}	2.93^{b}	124^{ab}	154^{a}	26.65^{b}	10.29^{ab}
Level of sig.	***	***	***	***	***	***	***	***	***	***	***
CV (%)	2.52	10.24	2.83	32.97	15.26	1.07	3.02	2.73	2.76	2.65	5.26

*Means with the same letters within the same column do not differ significantly. *** Significant at the 0.001 probability level*

Table 2. Pearson correlation coefficients among the yield and yield contributing traits of twenty-one hybrid rice genotypes

Traits	Plant Height (cm)	Effective Tiller	Panicle length (cm)	Unfilled grain	Filled grain	Grain length (cm)	Grain Width (cm)	Days to 50% flowering	Days to maturity	1000 grain wt. (g)
Effective Tiller	-0.20**									
Panicle length (cm)	0.70^{ns}	-0.36**								
Unfilled grain	-0.31^{ns}	0.09*	-0.30**							
Filled grain	0.57**	-0.16^{ns}	0.57*	-0.33^{ns}						
Grain length (cm)	-0.12^{ns}	-0.06^{ns}	-0.18**	-0.19**	-0.48**					
Grain Width (cm)	0.29*	-0.34**	0.13^{ns}	-0.28**	-0.10**	0.17**				
Days to 50% flowering	0.68**	-0.03^{ns}	0.66*	-0.21*	0.81*	-0.45**	-0.06^{ns}			
Days to maturity	0.67^{ns}	-0.05**	0.62^{ns}	-0.21^{ns}	0.77**	-0.36*	0.06**	0.90**		
1000 grain wt. (g)	0.62*	0.20^{ns}	0.53*	-0.37**	0.82^{ns}	-0.30**	-0.11^{ns}	0.68^{ns}	0.75**	
Yield (t ha^{-1})	0.66**	0.08*	0.59^{ns}	-0.54**	0.86**	-0.24*	-0.08**	0.75**	0.74*	0.94**

*** Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level, ns is non-significant*

The magnitude and direction of contribution of different traits in the different principal components are shown in Figure 5. The PC scores of the genotypes separated them from each other due to variability in the traits along PC1 and PC2. Loading plot identified that the PC1 had the largest amount of varietal variation due to the greater coefficient of plant height, days to 50% flowering, panicle length, filled grain, grain width, days to maturity, thousand grain weight and yield compared to the lower coefficient of unfilled grain and tiller number. The Chinese genotypes SHD-661, Q-5, Q-28, HS-366, Qyou-6 and Heera-2 showed good performance in PC1. Baloch *et al.* (2016) illustrated the positive loadings for days to flowering, panicle length, number of grains panicle-1 and plant height in the PC1 out of three principal components which was accounted for 26.80% of total variance for 12 characters in 20 mutant and aromatic rice genotypes.

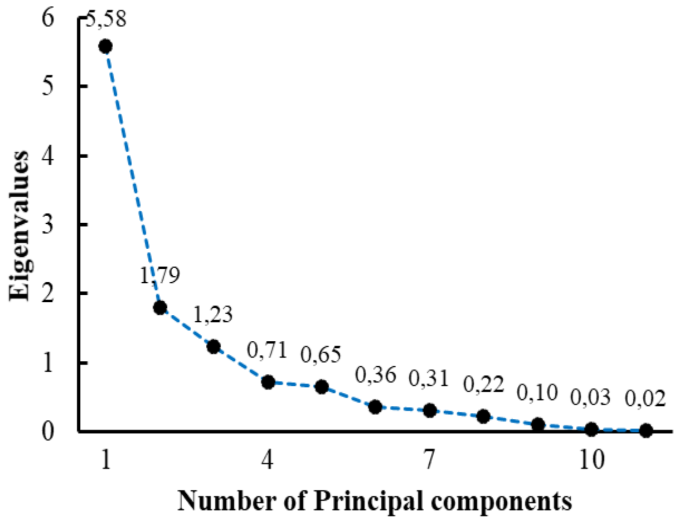


Figure 3. Eigenvalues of different principal components as shown by principal component analysis of rice landraces

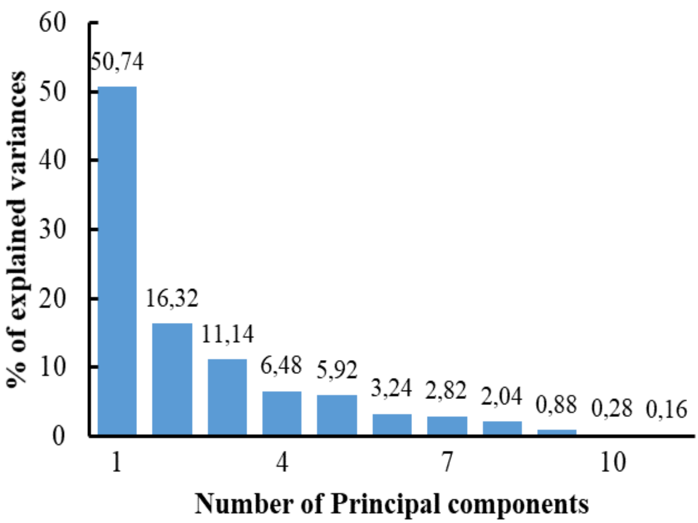
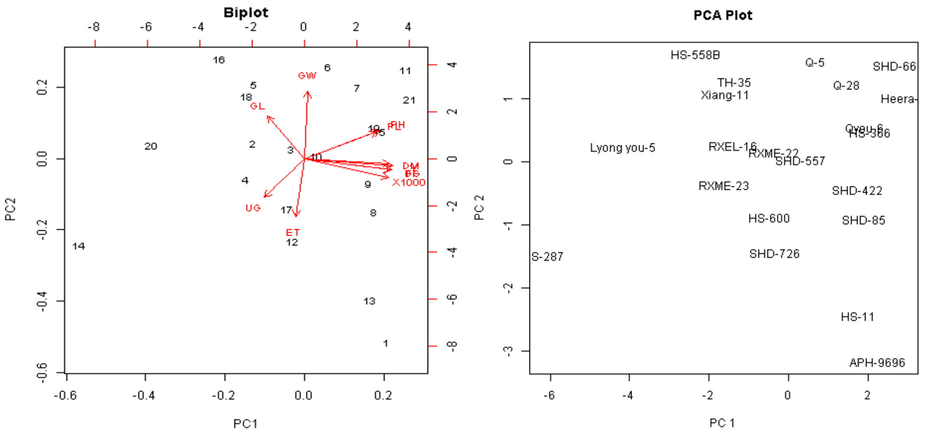


Figure 4. Contribution of each principal component to total explained variance in the phenotypic diversity of rice landraces

Table 3. Principal components for hybrid rice genotypes based on eleven quantitative characters

Statistics	PC1	PC2	PC3	PC4
Standard deviation	2.36	1.34	1.11	0.84
Proportion of Variance	0.51	0.16	0.11	0.06
Cumulative Proportion	0.51	0.67	0.78	0.85
Eigenvalues	5.58	1.79	1.23	0.71
Variables	Eigenvectors			
Plant Height (cm)	0.33	0.24	0.05	-0.19
Effective Tiller	-0.04	-0.50	-0.49	-0.49
Panicle length (cm)	0.32	0.23	0.20	0.24
Unfilled grain	-0.18	-0.34	0.55	-0.13
Filled grain	0.38	-0.10	0.06	0.17
Grain length (cm)	-0.16	0.37	-0.47	0.29
Grain Width (cm)	0.01	0.58	0.05	-0.70
Days to 50% flowering	0.38	-0.10	0.16	-0.06
Days to maturity	0.38	-0.05	0.11	-0.18
1000 grain weight (g)	0.37	-0.16	-0.25	-0.03
Yield (t/ha)	0.39	-0.06	-0.28	0.10



A) B)

Figure 5. Biplot (A) and Loading plot (B) of 11 quantitative characters in the principal component analysis of 21 rice genotypes. The eigenvectors were represented by red arrows showed how (the direction) and how much (the length) each traits contributes to the individual correlations represented by PC1 and PC2

Diversity analysis

A hierarchical clustering was performed to study the patterns of groupings of genotypes (Table 4). The dendrogram (Figure 6) was generated from Ward's linkage method based on squared Euclidean distance metric. By incision the dendrogram at 11 units distance, 21 rice genotypes were categorized into 3 main clusters, showing the availability of wide genetic diversity among the tested genotypes. Cluster I was the largest cluster which included fourteen genotypes. Meanwhile, Cluster II and Cluster III comprised five and two rice genotypes, respectively.

Table 4. Distribution of 21 hybrid rice genotypes in different cluster for various quantitative characters

Cluster	Genotypes#	Name of genotypes
I	14	APH-9696, RXME-22, Q-5, Q-28, SHD-85, SHD-422, SHD-557, SHD-661, SHD-726, HS-11, HS-366, HS-600, Qyou-6, Heera-2
II	5	RXEL-16, RXME-23, TH-35, HS-558B, Xiang-11
III	2	HS-287, Lyongyou-5

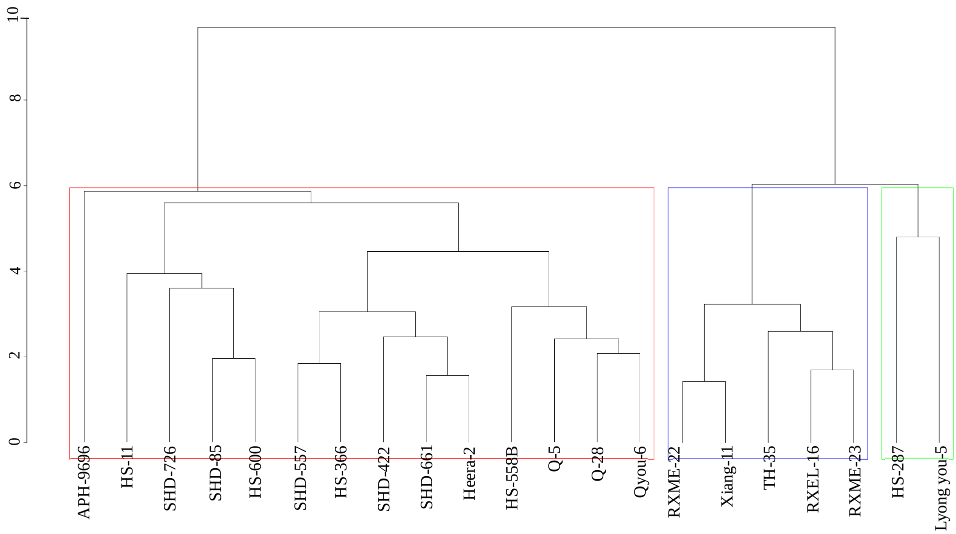


Figure 6. The hierarchical cluster analysis grouped the cultivars into 3 groups of 21 hybrid rice genotypes using Wards method and squared Euclidean distance (quantitative characters)

The cluster mean values showed a wide range of variations for all studied traits (Table 5). In more specific, cluster I containing genotypes producing the highest mean values for plant height, panicle length, filled grain and grain yield with moderate high rate of effective tillers. Except APH-9696, all the popular Chinese cultivars were included in cluster I. Meanwhile, genotypes belonging to India tend to fell together in the cluster II exhibited a high mean for the number of days to 50% flowering and maturity. clusters III contained Chinese cultivars HS-287 and Lyong you-5 either the highest or the lowest value for a particular character. However, considering the cluster means and Euclidean distances between the genotypes, cluster I exhibit high heterosis for yield potential. According to AbdEl-Aty *et al.* (2022) who found the variation in rice genotypes that showed significant and desirable particular combinability impacts, suggesting that it might be used in rice hybrid breeding program. Selecting the lines belonging to diverse clusters and showing high mean performance for desirable characters can be used in the selection of the parents for the breeding program (Dhakal *et al*., 2020; Hasan *et al.*, 2020; Shrestha *et al.*, 2021). So, based on this result, the genotypes under cluster I might have broad prospects for commercial application.

Table 5. The cluster means for yield and yield contributing traits in twenty-one hybrid rice genotypes

Traits	CLUSTER I	CLUSTER II	CLUSTER III	Contribution to diversity (%)
Plant Height (cm)	103.16	96.59	80.42	9.48
Effective Tiller	7.95	7.47	8	0.51
Panicle length (cm)	23.48	22.03	19.61	1.89
Unfilled grain	34.41	33.15	37.86	16.91
Filled grain	123.21	84.27	76	16.99
Grain length (cm)	8.73	9.21	8.93	0.54
Grain Width (cm)	2.57	2.59	2.6	0.20
Days to 50% flowering	114	120.79	109	3.40
Days to maturity	136	145.86	132.5	4.33
1000 grain weight (g)	25.22	17.8	12.42	2.23
Yield (t ha^{-1})	9.47	7.42	3.97	3.73

CONCLUSIONS

Determination of genetic diversity is important to select the more efficient plant cultivars for developing high yielding variety. In the present study, we quantified the magnitude of genetic diversity within the exotic hybrid rice genotypes those were collected from China and India by employing multivariate analysis based on elucidean cluster statistics and principal component analysis (PCA). Both analyses indicated the existence of the wide genetic diversity among the genotypes. PCA revealed that three of the eleven principal components having eigenvalue>1 contributed 78.19% of the variance. The analysis also identified plant height, panicle length, filled grain, grain width, thousand grain weight and yield as the most important traits for classifying the variation. Moreover, after assessing the yield attributing traits, the Chinese cultivars SHD-661, Qyou-6, Q-5 and Q-28 from cluster I had performed the better yield potentials among the studied rice cultivars. Therefore, the study will be highly beneficial to the rice breeders for selecting superior exotic hybrid rice genotypes to improve the rice grain productivity.

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