

Original Research Article

Assessment of genetic diversity of elite Indian rice varieties using agro-morphological traits and SSR markers

Abstract

Assessment of genetic variability of the crop varieties is essential to assure selection of genetically divergent lines useful for the future breeding programmes. Thus, genetic diversity assessment of 24 elite Indian rice varieties was performed based on 24 agro-morphological traits and 86 SSR markers. The morphological and grain traits exhibiting significant variation are useful for discrimination of the rice varieties and were confirmed by Principal Component Analysis. Genetic diversity assessment based on SSR markers displayed genetic similarity coefficients and grouped the varieties into five major clusters. The genetic population structure obtained was predominantly associated with UPGMA clustering and the structure bar plot. Cluster analysis based on both phenotype and SSR marker data did not show perfect congruence between the two measures of genetic diversity. However, the correlation between morphological and molecular diversity was positive and significant ($r = 0.36$ $P < 10^{-4}$) indicating usefulness in classification of rice varieties.

Key words: Genetic diversity, Agro-morphological, Characterization, Indian varieties, Simple Sequence Repeats, *Oryza sativa*

Rice (*Oryza sativa* L.) is one of the most important crops that provide food for more than half of the world population. It plays a vital role in the national food security in India and contributes a major source of calories for the urban and rural populace (Sasaki and Burr 2000). With changing consumer preferences and the demand by the export market, rice breeding program in India has received significant attention with respect to improvement of yield with grain quality. In spite of more than 900 rice varieties have been developed in India, only considerable number of elite rice varieties have been released to suit different agro-climatic conditions which includes in the present study contributing ~ 29% of the total rice production in the country and being cultivated in many rice growing states (<http://agricoop.nic.in>). In order to produce improved varieties in future, assessment of the variability among these elite rice varieties is also essential which will enable the identification of genetically divergent varieties useful in future breeding programmes.

Characterization and genetic diversity of rice germplasm is well progressing globally, nevertheless, knowledge regarding the amount of phenotypic and genotypic variation

specific to the geographical region which will enable to design effective breeding programs in order to achieve high productivity. Further, it has a great importance for seed production, certification and cultivar propagation and implementation of Protection of Plant Varieties and Farmer's Right Act of India (<http://www.plantauthority.org>). Traditionally, morphological traits have been used to evaluate distinctness and to establish broad description of rice varieties (Cooke 1999; Meesang et al. 2001). However, despite the fact that the varieties growing in different agro-climatic regions differ substantially from each other in agronomical traits, they are difficult to characterize using only morphological characteristics recommended by the International Union for the Protection of New Varieties of Plants (UPOV) descriptors (Bonow et al. 2009). Moreover, rice breeding tends to produce elite varieties which are phenotypically less distinct due to narrow genetic base of the populations and in such situations morphological traits seems inadequate because of environmental influence (Cooke 1999). Besides, morphological variation does not always reflect real genetic variation because of genotype x environment interactions and the largely unknown genetic control of polygenic morphological and agronomic traits (Smith and Smith 1992). Molecular marker based approaches provide an opportunity to look into the genotypic basis of the observed phenotypic variation in released varieties (Govindaraj et al. 2009). Different types of molecular markers such as RAPDs (Bhuyan et al. 2006; Ansari et al. 2009), RFLPs (Mochida et al. 2009), AFLPs (Aggarwal et al. 1999) and ISSRs (Hua et al. 2006; Bhuyan et al. 2007) have been used for estimation of genetic diversity and development of molecular fingerprints in rice. Among these, simple sequence repeats (SSRs) or microsatellites are the most popular markers in rice research (Mc Couch et al. 2002). SSR markers are becoming markers of choice for molecular characterization and genetic diversity studies in rice (Wong et al. 2009; Thomson et al. 2009). Banding of rice varieties in India has been developed based on few important traits, mainly plant height, flowering, pest and disease resistance, maturity and yield. So far, no comprehensive study based on molecular marker in particular has been documented in the existing popular rice varieties. In view of the above, we attempt to characterize and estimate the genetic diversity in elite rice varieties grown in India using agro-morpho traits and SSR markers along with a correlation between the two diversity estimates.

Materials and Methods

Plant materials: Pure seeds (breeder seed) of 24 elite rice varieties collected from the Acharya N G Ranga Agricultural University, Hyderabad, Tamil Nadu Agricultural University, Coimbatore and Directorate of Rice Research, Hyderabad, TS, India were used for the present study (Table 1).

Agro-morphological characterization: The field experiments were carried out in three replications (5x6 m plot size with a spacing of 30 x 20 cm) and all the cultivars were grown under screen-house simultaneously to confirm qualitative traits at the centre of Rice Research, Hyderabad, India during dry season 2011-12 and 2012-13 for recording stable and uniform morphological characteristics. Ten plants were selected at random and tagged in each variety per replication. The highly variable plant morphological and grain traits in rice cultivars were selected on the basis of variability among closely related varieties (Keshavulu 2007). A set of 16 key plant morphological traits, which included qualitative and quantitative characteristics and their scores (scoring) were recorded as per

the National/Indian guidelines for the conduct of tests for Distinctness, Uniformity and Stability (DUS) (<http://www.plantauthority.gov.in>) (Supplementary Table 1). The data on quantitative characteristics recorded for two seasons were grouped and the average values were used for statistical analysis. The grain quality traits namely grain weight, grain length and width, decorticated grain length and width, shape of the de-busked grain, amylose content of endosperm (%) and gelatinization temperature was determined and grouped as per DUS testing protocol (<http://www.plantauthority.gov.in>).

SSR marker analysis: Total genomic DNA was isolated from 10-15 day old seedlings as per the protocol of Zheng et al. (1996). A total of 86 hyper-variable SSR (microsatellite) primer pairs (Supplementary table 2) purchased from Integrated DNA Technologies, USA were used for PCR amplification. The SSR markers were selected based on their polymorphism content and distribution across the 12 rice chromosomes. PCR was carried out in 10 μ l reaction containing 0.2 μ M of each primer, 200 μ M of dNTPs, 1X PCR assay buffer (50 mM KCl, 10 mM, Tris HCl (pH 8.3), 1.5 mM of MgCl₂, 0.1 % gelatin, 15 ng of DNA and 0.5 unit of Taq DNA polymerase. The amplification was performed with initial denaturation at 94°C for 5 min followed by 35 cycles of 94°C for 30 sec, 55°C for 1 min, 72°C for 7 minutes before cooling to 10°C. The products were electrophoretically resolved on 3 % superfine grade agarose (Ambios, USA) stained with ethidium bromide and visualized under UV.

Data analysis: Univariate descriptive statistical data for quantitative traits were computed for mean, range, coefficient of variation and standard deviation. Before analysis, the data was standardized by subtracting the mean value and dividing by the standard deviation. Principal Component Analysis (PCA) was done on observed morphological grain traits with the standardized data. Euclidean distances were calculated for all the traits considered together, morphological traits and for the SSR. Each dataset was plotted in a dendrogram using the average linkage method cluster analysis across varieties. With the molecular marker data, Jaccard's index was calculated for genetic distance among the varieties to generate a dendrogram. These analyses were performed in R 2.10 using the software packages Vegan 1.15-4 (Oksanen et al. 2009) and the base package. Only clear and unambiguous SSR amplicons were scored for their presence and absence among the cultivars as '1' and '0', respectively. The binary data matrix was subjected to further analysis. Sequential Agglomerative Hierarchical Non-overlapping (SAHN) clustering was done on the squared Euclidean distance matrix and the similarity matrix was generated based on Jaccard's index by utilizing the UPGMA algorithm through the NTSYS pc 2.0 software (Rohlf 2000). Polymorphism Information Content (PIC) for each SSR was calculated according to the formula: $PIC = 1 - \sum_{i=1}^n p_i^2$ where p_i is the proportion of number of alleles detected for SSR marker and 'pi' is the frequency of the i^{th} allele (Li 1973). All computations were performed with appropriate procedures of the NTSYS pc version 2.1 software (Rohlf 2000).

The genetic structure in the elite Indian rice varieties was inferred using the software STRUCTURE 2.3.2 (Pritchard et al. 2000) based on the unlinked markers of the SSR markers. STRUCTURE employs a model based clustering method that accounts for Hardy-Weinberg and linkage disequilibrium and attempts to find the most likely partitions that minimizes linkage disequilibrium. Markers used in this study were distributed across the rice genome and can therefore be assumed to be independent. To estimate the number of sub-populations (the K parameter), the dataset was analyzed allowing values of K ranging from 1 to 5. Five independent runs were carried out for each K value. The

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parameters were set to their default values. An admixture model was chosen as it can account for some individuals having mixed ancestry. The optimal value for number of sub-populations was determined based on likelihood variance values obtained for each run using ΔK , an *ad-hoc* parameter described by Ewens (1995). A bar plot of line membership in each population was generated using STRUCTURE 2.3.2.

For comparisons between the phenotypic and genotypic data, simple (r) and spearman rank (rs) correlation coefficient was calculated between the Euclidean distances for each variety, across all the datasets. The 'P' value for the correlation coefficient was calculated according to each distribution. To determine the similarity between the distinct, each pair was tested using the Mantel Z statistic (Mantel, 1967). The test was carried out using the R package ade4 (Chessel et al. 2009), which calculate the Z value and the corresponding P value. Significance of Z was determined by comparing the observed Z values obtained and by calculating Z for one matrix with 2000 permuted instances of second matrix.

Results and Discussion

Morphological characterization

Characterization and genetic diversity assessment of elite rice varieties are important in view of identification and selecting suitable parental lines to develop new varietal combinations as well as, for protecting genotypes from unauthorized exploitation. Modern breeding makes the use of natural processes but relies on advancement of available genetic diversity to create new genotypes (Xu et al. 2012) and this needs clear-cut information on the extent of genetic diversity available so that the breeder can exploit the genotypes efficiently. Characterization of 24 elite Indian rice varieties in the present study showed considerable variation in all morpho-grain traits. The detailed qualitative and quantitative morpho-grain traits for plant morphology and grain quality traits observed and their distribution among the varieties are shown in the Table 1 and 2. In case of quantitative traits, the coefficient of variation ranged from 8.01% (anthesis length of main axis) to 25.67 per cent (stem thickness) among the varieties (supplementary file 3). The highest variability was observed for stem thickness (25.67) followed by leaf length (21.05%) and grain weight (19.47%). The leaf length among the varieties ranged from 19.5 cm (RNR 23064) to 47.50 cm (WGL 1340). The lowest (0.47 cm) and the highest (1.45 cm) leaf width were observed in Tellahamsa and MTU 5249 respectively. Among the quantitative traits, time of heading which ranged from 78 days (RER 155) to 122 days (MTU 5249). The lowest stem length (60.51 cm) was observed in RDR 755, while MTU 1010 showed the highest (99.0 cm). Kalkona was characterized with the lowest stem thickness (0.54 cm) against the highest in ADR 19 (1.17 cm). The varieties Tellahamsa and MTU 2077 respectively displayed the shortest (112.06 days) and the longest (147.33 days) time of maturity, respectively. Leaf and stem characters are very important to distinguish the rice cultivars. The variation in the time of heading has been reported as a useful trait by Nethra (2003). According to national DUS testing guidelines of plant protection Act of India and also as per the present study, the stem length was less suitable for classification of the varieties. One of the most effective traits to classify of cultivated rice was variation in the size and shape of grain, among the 11 qualitative traits, only panicle awn trait displayed no variation among the varieties except WGL 20471. The rice varieties were grouped into five categories based on grain length (64

very short (Kalajeera), short (ADT 43, BPT 5204, GER 24, JGL 384, JGL 1798, Mahsuri, MTU 7029 and RDR 7555), medium (ASD 19, MTU 1001, MTU 2077, MTU 5870, MTU 5249, RDR 763, WGL 14 and RDR 23064) and long (IR 64, MTU 1010, WGL 13400, WGL 20471 and RPW6-17) and very long (Tellahamsa). The grain traits showed considerable variation among all the varieties (Table 4). The seed weight was lowest in JGL 384 (13.5g), while the variety RPW6-17 showed the highest (26.5g). The variety Kalajeera with the lowest grain length (6.02 mm) whereas, Tellahamsa had shown having the highest (10.24 mm). Similarly, in BPT 5204, the grain width was very narrow (1.80 mm) and in RDR 7555 it was broader (2.43 mm). Based on the decorticated grain length, the varieties ranged from 4.53 (Kalajeera) to 6.90 mm (WGL 13400), while the decorticated grain width was very narrow (1.8 mm) in WGL 20471 and very broad (2.70 mm) in RDR 7555. Panicle and grain characters such as the presence of awns, length and width of grains as well as for decorticated grain shape of grains were useful for variety characterization. In the present study, the length-width ratio ranged from 2.72 (land race Kalajeera) to 4.32 (Tellahamsa). According to Singh et al. (1996), grain size and shape are important components of rice quality in the long grain varieties and also for determining consumer acceptance. All the short and medium slender varieties were late in flowering and also showed considerable variation between these varieties and other varieties of rice. The amylose content in rice genotype, influenced by amylose: amylopectin ratio is a useful measure to characterize the genotype (Singh et al. 1952). In the current study, all the varieties possessed medium amylose content. MTU 1010, RDR 7555 and Tellahamsa which showed low, medium and high amylose content respectively.

The broad morpho-grain trait diversity existed among the varieties in the present study indicated fair distribution of variation across all of the morphological traits. The significance of agro-morphological characters in diversity assessment of rice varieties has been well documented (Bajracharya et al. 2006). In agreement with Singh et al. (1992), a set of morphological traits are useful to discriminate the varieties from each other. A set of 12 morphological traits viz., altitude of flag leaf blade, time of heading and maturity, stem length and thickness, leaf traits and panicle traits like panicle length, length and width of seed, shape of grain, shape of decorticated grain and grain length to temperature were useful in characterization of the elite Indian rice varieties.

Principal Component Analysis (PCA)

The principal characters with higher Eigen vectors that clustered the varieties into separate groups in the first seven components are presented in Table 4. The 23 variables were scattered by their component scores of the first seven principal components (PC) with Eigen value higher than one and explained a total of 64.08% of the phenotypic variation components. The first PC explained 18.32% of the total variation, mainly related to quantitative variation of leaf length and width, time of heading, panicle traits, panicle number per plant and qualitative traits like intensity of green color, pubescence of leaf blade, attitude of culm and gelatinization temperature. The second PC, which explained 14.59 % of the total variation, pertaining to traits such as leaf length and width of blade, time of heading, stem length, time of maturity, flag leaf width of leaf blade, panicle curvature of main axis, and grain traits (grain weight, grain length, decorticated grain width). The third principal component, which accounted for 12.18% of the total variation, was dominated by traits such as leaf area, stem length, time of maturity, grain and decorticated grain length and shape, flag leaf width. While the fourth PC of

blade, stem thickness, time of maturity, grain length, leaf pubescence of blade surface and grain quality traits (grain weight, grain width and decorticated grain width, endosperm amylase content and gelatinization temperature) were important defining traits associated with the fourth principal component, which documented 10.99 % of the total variation. Principal components 5, 6 and 7 accounted for 8.22 %, 6.11 % and 5.19 % respectively of the total variation and the main characteristics of these components were positively related to the width of leaf blade, stem length, panicle length of main axis, leaf pubescence of blade surface, panicle awn, stem thickness and flag leaf width of blade. The first three PCs, which contributed to 45% of the total variation, were plotted graphically to demonstrate the relationships between varieties (Fig. 1). The plot evidenced considerable diversity among the varieties. However, PCA could not clearly differentiate the varieties according to their pedigree and grain types and the varieties did not form clear-cut distinct groups. The varieties considered for the present study have been developed to suit different rice growing ecosystems and consumer preferences based on their grain type. There were eight short and slender types such as a landrace cultivars viz., ADT 43, BPT 5204, IGL 384, IGL 389, Mahalaxmi, WBL 64, MTU 7029, RDR 763, and a landrace Kalajeera, which had higher factor loadings on PC1 compared to other medium and long grain varieties. These were distinct and formed the most divergent single line group compared to medium and long grain varieties on PC1 while the medium and long slender and bold varieties came from different sources. Rice Research station other than RPW 6-17 and WGL 1540, MTU 106, MTU 2077, MTU 2077, MTU 4870, MTU 5249, MTU 7029, RPW 6-17 and WGL 1540 were markedly distinct from the others in the PC2. The rest of the varieties viz., ASD 19, B 24, RDR 7555 and RNR 2306 showed higher factor loadings on PC3. The PC7 vectors explains progressively less of the variation and hence the last three PCs did grain quality characteristics.

The combined PCA of the qualitative and quantitative morpho-phen traits grouped most of the varieties into one group, while a few others remained scattered. The first three Eigen values spread up to seven vectors, showed a total account of 45.19 % of the total variation components. In concurrence with Mooring et al. (2004), this may be due to the use of highly adapted genotypes with less phenotypic variation in breeding programmes. In PCA of the present study, the first three PCs explained 45.19 % of the total variance that was observed to a considerable impact of contribution to variation in plant morpho-grain traits. The landrace and Kalajeera stood apart from all other varieties in the PCA plot which may be due to its distinct origin, region of North India (www.mssrf.org/bd/ebooks/ebook8.pdf) and high genetic variability to *indica*. Further, Oka and Chang (1961) also noticed some variation between wild and cultivated types in the rice populations of tropical region. The varieties viz., GEB 24, ASD 19, RNR 23064, Tellahamsa, WBL 20421, B 24 and B 24 were distinct from the others and remained scattered across the plot. The morphological differences among them accounted by flag leaf width, panicle, decorticated grain length and gelatinisation temperature. This analysis in general was consistent with that of PCA study of 120 short and slender varieties displayed a tendency to stand apart from the others (Figs. 1 & 2). (2005), the diversity among varieties can be estimated by the genetic and phenotypic diversity, permitting a more effective breeding programme. The average intra and inter-cluster distance values of 0.15 and 0.25, respectively

distances are presented Figure 2. Intra-cluster Euclidean value ranged from 55.1 (cluster II) to 0.0 (cluster V). Based on the inter-cluster Euclidean value, the highest divergence (100.01) occurred between cluster II and V, while the lowest divergence (47.81) was between cluster III and IV. The inter-cluster distance between I and II and III and IV, were moderately divergent. Cluster analysis based on Euclidean distances of morphological traits classified the varieties in the present study into five major groups and it revealed considerable diversity among the rice varieties. The varieties JGL 384, MTU 2077, BPT 5204 and MTU 4870 in group 1; varieties JGL 23064 and JGL 23064 in group 2; MTU 7029, WGL 13400, JGL 1798, Tellahamsa, MTU 43, MTU 2077, MTU 6617, MTU 5249, GEB 24 and MTU 1001 in group 3 and varieties BPT 5204, MTU 4870, Mahsuri, MTU 2067, WGL 20471, ASD 19 and WGL 13400 showed the closest morphological similarity and were placed in group 4 while RDR 7555 variety was in group 5 and was separated from other varieties. The group 2 varieties were morphologically different with respect to many of the traits characterizing them. The highest intra-cluster distance observed between II and V clusters (100.01) was between the varieties MTU 2077 and the landrace Kalajeera, while the lowest inter-cluster distance (47.81) was between II and IV clusters may be due to the close genetic relationship among the varieties having similar parentages or grain type. The specific groupings of the varieties according to the difference and grain type up to some extent indicated the importance of these morphological traits for genetic diversity analysis. For e.g., the cultivar BPT 5204 (BPT 324 x BPT 225 x BPT 225) and JGL 384 (Kavya / BPT 5204) and MTU 2077 (MTU 2077 x MTU 2077) and MTU 5249 (MTU 4569 x ARC 6650) showed growing association in their pedigree and shared at least one common parent in their pedigree.

Molecular characterization

A total of 251 alleles were amplified using 86 SSR markers distributed across the genome (primers/chromosome) of 24 rice varieties. The number of alleles amplified by each primer pair ranged from 2 to 6 with an average of 3.4. The polymorphism information content (PIC) for these markers ranged from 0.54 (RM 11229) to 0.97 (RM 226). The markers viz., RM 226, RM 11229, RM 16053 and RM 2060 amplified the highest number of alleles (6 each), and was followed by 5 each by RM 106, RM 2060, RM 149, and RM 333. The SSR markers RM 14140, RM 1691, RM 1691, RM 2060, RM 2060, RM 336, RM 248, RM 72, RM 206, RM 207 and RM 207 amplified 4 alleles each. The number of alleles observed for 24 elite varieties of rice presented in Supplementary file 2. The Jaccard's similarity coefficient ranged from 0.04 (between Vysal and RDR 7555) to 0.76 (Kalajeera Vs RDR 7555) with an average similarity index of 0.37 (Supplementary file 4). In pair-wise comparisons, least similarity index was observed between JGL 384 and JGL 1798 (0.26) whereas, landrace Kalajeera and RDR 7555 showed highest similarity index (0.76). The Figure 3 shows the dendrogram of linkage varieties based on SSR amplification pattern, the varieties were grouped into five major clusters. Major cluster I consisting of JGL 384, JGL 1798, BPT 5204, MTU 4870, JGL 23064, ADT 43, ASD 19, GEB 24, Mahsuri, MTU 2067, MTU 2077, MTU 6617, MTU 5249 and MTU 1001 with 73.30 % similarity, whereas cluster II with varieties JGL 23064, MTU 7029, WGL 13400, Tellahamsa and RDR 7555 had average similarity of 0.16. A group of varieties cluster III consisted of MTU 2077, MTU 2067, MTU 2077, MTU 2077 and MTU 2077. A group of grain varieties with a similarity of 42.65%. The variety Tellahamsa (WGL 13400) and a landrace, Kalajeera were distinct from each other and were separated into cluster IV and cluster V respectively. In the present study, 24 varieties grouped the varieties in each cluster predominantly according to their genetic



background. Based on marker data, distinct clusters were formed with related varieties. As they were developed using same parents for medium slender grain type varieties namely BPT 5204, WGL 14, RDR 2064 and a slender grain type variety RDR 763 were grouped in the same cluster. But these varieties were not grouped together when morphological characteristics were employed. The polymorphic nature of SSR markers is highly favourable to discriminate the individuals more precisely. SSR markers RM 226, RM 11229, RM 16153 and RM 15670 were used for grouping varieties which formed five major groups of different grain types, short, medium or long slender grain types released from other cultivars in diverse geographical locations across India and engaged to be genetically diverse, and it become obvious by looking the coefficient between the varieties (0.26 to 0.76). High similarity observed between JGL 1798 Vs JGL 384 followed by WGL 14 and BPT 5204 and WGL 14 and Telharajera and MTU 2067 of their closely related parental lines. First similarity was observed between and the rest of varieties, as emphasized earlier based on the distinct origin of Kalajeera (Eastern or North Eastern India) and MTU 2067, MTU 4870, MTU 1001, MTU 1010 and MTU 1011. Similarity ranging from 0.34 to 0.71 is seen in their close relationship released from Regional Agricultural Research Station, Madurai, India using similarly adapted genotypes as parent variety. Varieties with one of the genotypes as a common parent, Mahsuri and short bold variety MTU 7029 were clustered in one of the parent for MTU 7029. Similarly, Telharajera and MTU 2067 one cluster showed similarity as one of the parental lines. Interestingly both of them possessed long and bold grain type. RDR 763 and BPT 5204 did not group together with the other varieties. Also the varieties, IR 64, MTU 2067 and MTU 1010 were not a part of the same cluster, which might be due to different selection criteria adopted for the development of these varieties. The study demonstrated the efficacy of SSR markers in ascertaining the relationship between closely related genotypes and to infer the value of all these varieties. In the present study, out of 86 SSR markers analyzed, 14 were polymorphic, RM 204, RM 11229, RM 16153, RM 15670, RM 226, RM 248, RM 307, RM 324, RM 331 and RM 1236 were used for grouping of closely related elite rice varieties.

Population structure

A model based statistical analysis STRUCTURE was performed using 251 polymorphic loci to recognize the genetic structure in the 24 varieties. The genetic structure could be elucidated with more precision by grouping the varieties based on the explained in the materials and methods. The study revealed the existence of a population structure in these rice populations. The estimates of $P(X/K)$ were obtained across the individuals. The genetic population structure was inferred based on ΔK and Q values. The populations were identified among the 24 varieties. The lines have been assigned to different membership in each of these populations, where admixture value > 0.5 and the primary membership were < 0.50 , line was considered as mixed population. The primary

membership. Each line's estimated membership in each of the three clusters is depicted in a STRUCTURE bar plot (Fig. 4) and exact membership is further provided in Table 5. Cluster 1 composed of 10 fine-grain (short and medium grain) varieties except GEB 24, Mahsuri and Kalajeera; cluster 2 contained all coarse grain (long bold types) varieties except MTU 2077 and MTU 2078 medium grain varieties; while the cluster 3 comprised eight fine grain (short and medium grain) varieties. Population structure based on Q values with $k=3$ predominantly matched with UPGMA tree from the distance based analysis (Fig. 2). Differentiation of clusters by statistics values between clusters determined by the software STRUCTURE was 0.13, 0.0805 and 0.2079 in between cluster 1 and 2; 2 and 3 and 1 and 3 respectively, indicating to high differentiation. Genetic structure of rice has been extensively documented in rice (Agrama et al. 2002; Nelson et al. 2008). Based on the cluster analysis, Nelson et al. (2008) identified six primary gene clusters, 1) defined by genotypes. The present study, exhibited a structure with three clusters, overall the varieties were assigned into corresponding clusters with the membership of $Q \geq 0.5$ more than 0.53 except ADT 43 (0.47) in cluster 3. This variety also did not correspond membership with cluster 1 (0.38). However, the slender grain varieties JGL 2047, JGL 7029, Mahsuri and landrace Kalajeera were grouped with cluster 1 and cluster 3 respectively membership with cluster 3 group (short and medium grain) was 0.53. In some cases, the shared ancestry could be because of shared pedigree relationships and in most of the pedigree of these varieties indicates close relationship through the progenies. The simulations in *structure* population indicated that these varieties may have received gametes from subpopulation 3 as they were closely related to the medium slender types.

Comparison of phenotypic and genotypic markers to genetic diversity

The correlation between genotypic and phenotypic markers was highly significant ($r = 0.36$ $P < 10^{-4}$; $r_s = 0.12$ $P < 10^{-4}$). The $K-S$ statistic was highly significant between GS and MS matrices ($P < 10^{-20}$, $P < 10^{-20}$). The high level of correspondence between the two similarity measures of the 24 varieties of rice cultivars of rice which were observed in the present study, although some discrepancies between the morphological traits (Fig. 3) were observed, especially with respect to the varieties JGL 2047, JGL 7029, RPW 6-17, ASD 19, IR 64, MTU 7029 and JGL 7029. The correlation between genetic structure Q values and five clusters based on the UPGMA dendrogram for the 24 varieties corresponded very well with respect to the relationship and morphological traits. However, among the 24 varieties, variety WGL 20471 and landrace Kalajeera were found to have unknown linkage with *structure* population clusters. The correlation between morphological traits of morphological traits among the varieties. Three consistent groups were observed for classifications. The first group consisted of slender grain varieties including a landrace Kalajeera except for JGL 2047, which was one of all the medium and long slender grain varieties. The second group of the State Rice Research Institute of India, which was composed of varieties viz., JGL 384, JGL 1797, JGL 2047, JGL 7029, JGL 7029, JGL 7029 were so diverse with respect to morphological traits. The third group of varieties relationship could be found between the slender grain varieties and the medium slender types.



Figure 1 Scatter plot of the three principal components (PC1, PC2 and PC3) using agro-morphological traits (1-ADT 43; 2-ASD 19; 3-AT 384; 4-GEN 24; 5-IR 64; 6-JGL 384; 7-JGL 1798; 8-Kalajeera; 9-Mosam; 10-MTU 10; 11-MTU 100; 12-MTU 2067; 13-MTU 2077; 14-MTU 4870; 15-MTU 7199; 16-MTU 7029; 17-MPW6-17; 18-RDR 7555; 19-RDR 763; 20-RNR 2008; 21-RNR 2009; 22-WGL 1300; 23-WGL 14; 24-WGL 20471



In conclusion, SSR markers provide a greater ability to discriminate among the elite Indian rice varieties than morphological traits. The SSR markers can be reliably used along with morphological traits for the characterization and genetic diversity assessment of rice varieties and can be used to design better experiments in DUS testing of rice varieties.

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- 526

527 Figure legends:

528 Figure 1 Scatter plot of the three principal components (PC1, PC2, PC3) using morphological traits

529 traits

530

531 Figure 2 Euclidean distances among elite Indian rice varieties

532

533 Figure 3 Dendrogram based on 256 SSR alleles derived from 20 elite rice varieties using Jaccard's coefficient

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536 Figure 4 Estimation of population structure based on 80 SSR markers. Each variety in a population is represented by bar plot proportionally to the values of 24 alleles from varieties with three colours into three subpopulation based on their pedigree

537

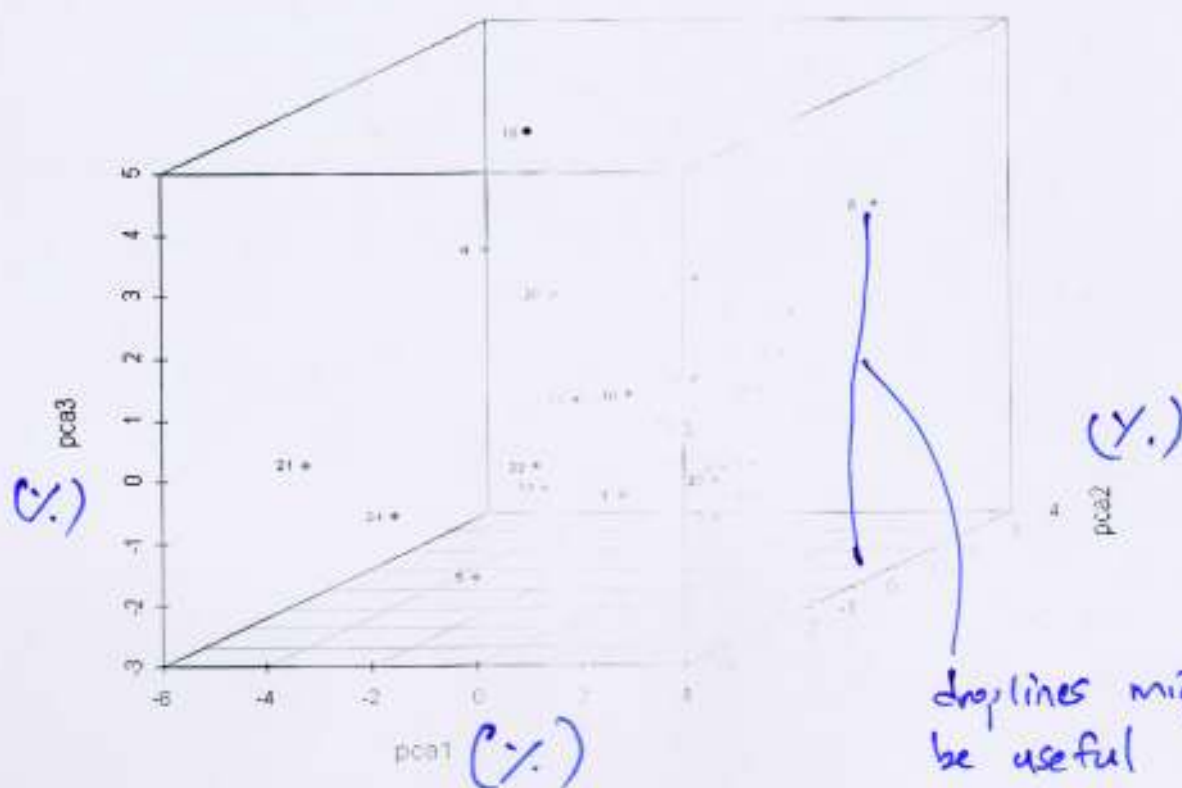
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539 Figure 5 Correlation between of SSR marker and morphological traits using elite Indian rice varieties

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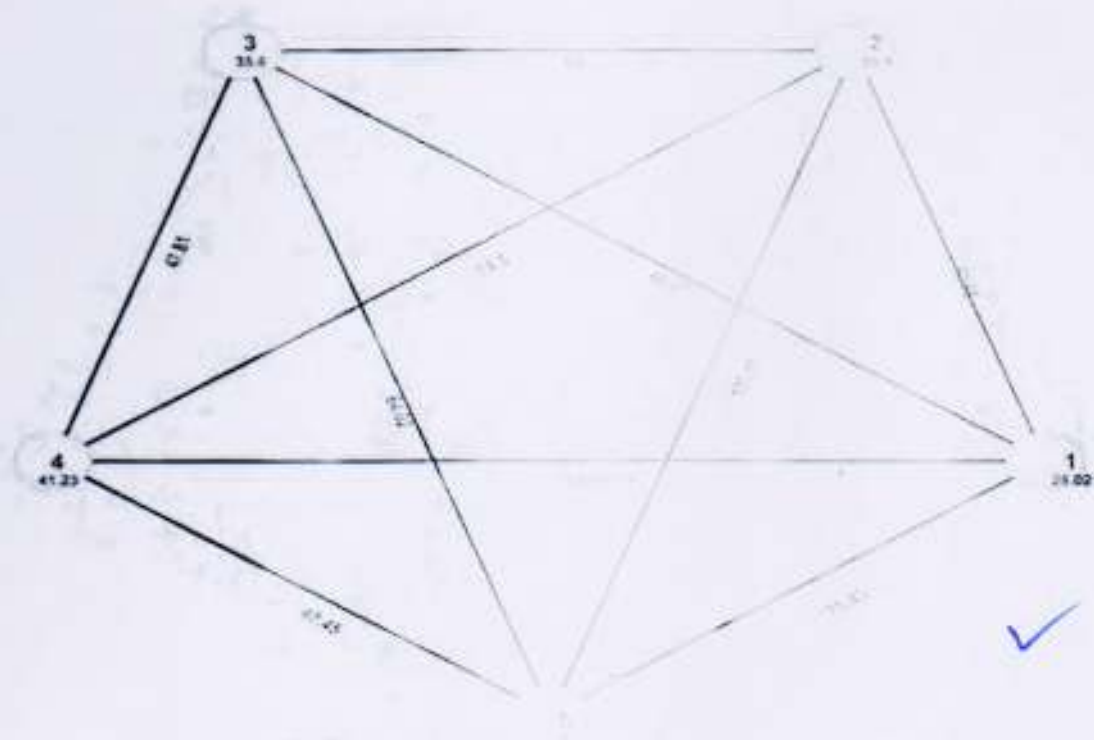
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3D Principal Component Plot



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Euclidean Distance (Plot to the Space)

Figure 2 Euclidean distances among elite baller (low) models



Figure 4 Estimation of population substructure based on 100 SNPs. The population of 2500 individuals in a population is represented by four pigmentation traits (i.e. 50, 250, 1250 and 500 individuals) and divided them into three colours into three subpopulation based on their phenotype.



Figure 5 Correlation between of SSR marker and morphological traits among 20 Italian rice varieties

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638 Table 1 Details of 24 elite Indian rice varieties used in this study

Variety	Year of Release	Parentage
ADT 43	1995	IR 50 x IR 52 (Mahsuri)
ASD 19	1995	Labakking x IR 50
BPT 5204 (Samba mahsuri)	1995	GEB 24 x IR 50 (Mahsuri)
Variety	Year of Release	Parentage
ADT 43	1995	IR 50 x IR 52 (Mahsuri)
ASD 19	1995	Labakking x IR 50
BPT 5204 (Samba mahsuri)	1995	GEB 24 x IR 50 (Mahsuri)
GEB 24	1992	Mahsuri x IR 50
IR 64	1962	IR 50 x IR 52 (Mahsuri) x IR 50
JGL 384 (Polasa prabha)	1993	WGL 14 x IR 50 (Mahsuri)
JGL 1798 (Jagtiar samrta)	1993	IR 50 x IR 52 (Mahsuri)
Mahsuri	1995	IR 50 x IR 52 (Mahsuri)
MTU 1001 (Vijetha)	1995	MTU 1010 x IR 50 (Mahsuri)
MTU 1010 (Cottonchinnamalu)	1995	MTU 1010 x IR 50 (Mahsuri)
MTU 2067 (Chaitanya)	1995	MTU 1010 x IR 50 (Mahsuri)
MTU 2077 (Krishnaveni)	1995	MTU 1010 x IR 50 (Mahsuri)
MTU 4870 (Deepthi)	1995	MTU 1010 x IR 50 (Mahsuri)
MTU 5249 (Vajram)	1995	MTU 1010 x IR 50 (Mahsuri)
MTU 7029 (Swarna)	1995	MTU 1010 x IR 50 (Mahsuri)
RDR 7555 (Rudram)	1995	IR 50 x IR 52 (Mahsuri)
RDR 763 (Indar samrta)	1995	IR 50 x IR 52 (Mahsuri)
WGL 14 (Warangal samrta)	1995	IR 50 x IR 52 (Mahsuri)
WGL 13400 (Surekha)	1995	IR 50 x IR 52 (Mahsuri)

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WGL 20471 (<i>Erythrina</i>)		DC
RPW6-17 (<i>Phalgora</i>)		DC
RNR 23064 (<i>Tarumata</i>)		DC
Tellahamsa		DC
Kalajeera		DC

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640

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(64) Table 2 Plant morphological traits among elite Indian rice varieties

Variety	Leaf intensity of green colour	Leaf pubescence of blade surface	Attitude of culm	Flag leaf attitude of blade (early observation)	Flag leaf attitude of blade (late observation)	Panicle curvature of main axis	Panicle awn	Panicle exertion	Leaf length of blade	Leaf width of blade	Time of heading	Stem length	Stem thickness	Panicle length of main axis	Panicle number per plant	Time of maturity (days)
ADT 43	Light	Weak	Semi-erect	Erect	Erect	Semi-straight	Absent	Exserted	Long	Medium	Early	Very short	Thick	Medium	Medium	Early
ASD 19	Dark	Medium	Semi-erect	Horizontal	Deflexed	Drooping	Absent	Well exserted	Long	Medium	Medium	Very short	Thick	Short	Medium	Medium
DDP 204	Medium	Medium	Open	Erect	Semi-erect	Semi-straight	Absent	Exserted	Long	Narrow	Late	Very short	Thick	Short	Medium	Late
ADT 44	Light	Weak	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Late	Very short	Thick	Long	Medium	Late
ASD 20	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 205	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 21	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 206	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 22	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 207	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 23	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 208	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 24	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 209	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 25	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 210	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 26	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 211	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 27	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 212	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 28	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 213	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 29	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 214	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 30	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 215	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 31	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 216	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 32	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 217	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 33	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 218	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 34	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 219	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 35	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 220	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 36	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 221	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 37	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 222	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 38	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 223	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 39	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 224	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 40	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 225	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 41	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 226	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 42	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 227	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 43	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 228	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 44	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 229	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 45	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 230	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 46	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 231	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 47	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 232	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 48	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 233	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 49	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 234	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 50	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 235	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 51	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 236	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 52	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 237	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 53	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 238	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 54	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 239	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 55	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 240	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 56	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 241	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 57	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 242	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 58	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 243	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 59	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 244	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 60	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 245	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 61	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 246	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 62	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 247	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 63	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 248	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 64	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 249	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 65	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 250	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 66	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 251	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 67	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 252	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
ASD 68	Medium	Medium	Semi-erect	Horizontal	Horizontal	Semi-straight	Absent	Exserted	Long	Medium	Medium	Very short	Thick	Long	Medium	Medium
DDP 253	Medium	Medium	Semi-erect	Horizontal												

Table 3 Grain morphological traits among elite Indian rice varieties

[illegible]

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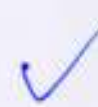
Kulajetra	Very low	Very small	Narrow	Small	Medium	Short slender	Medium	High intermediate
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Table 4 Contribution percentage and agro morphological traits associated with the seven principal components of elite Indian rice varieties and their Eigenvectors

Factor	1	2	3	4	5	6	7
Contribution percentage (%)	18.32	14.07	12.01	10.09	8.72	6.25	5.39
Characters	Eigenvector						
Length of leaf blade (cm)	1.738	1.000	0.42	-2.000	-2.000	-0.023	0.518
Width of Leaf blade (cm)	1.059	1.000	0.00	0.00	0.00	-0.000	-0.661
Time of heading (days)	3.739	1.000	0.00	0.00	0.00	-0.000	0.093
Stem length (cm)	-0.006	0.000	0.00	0.00	0.00	0.000	-0.253
Stem thickness (cm)	1.959	-2.000	0.00	0.00	0.00	0.000	-1.238
Panicle length of main axis (cm)	-0.946	-1.000	0.00	0.00	0.00	-0.000	1.616
Panicle number per plant	-0.233	-0.000	0.00	0.00	0.00	0.000	0.135
Time of maturity (days)	4.033	1.000	0.00	0.00	0.00	0.000	0.108
1000 grain weight(g)	-2.703	0.000	0.00	0.00	0.00	0.000	0.772
Grain length (mm)	-1.401	0.000	0.00	0.00	0.00	0.000	-0.504
Grain width (mm)	-1.115	0.000	0.00	0.00	0.00	0.000	0.434
Decorticated grain length (mm)	-3.135	0.000	0.00	0.00	0.00	0.000	-0.084
Decorticated grain width (mm)	-0.199	0.000	0.00	0.00	0.00	0.000	0.962
Intensity of green leaf Colour	2.260	0.000	0.00	0.00	0.00	0.000	-1.274
Pubescence of leaf blade surface	2.000	0.000	0.00	0.00	0.00	0.000	0.441
Attitude of culm	0.000	0.000	0.00	0.00	0.00	0.000	0.363
Flag leaf attitude of blade early observation	0.000	0.000	0.00	0.00	0.00	0.000	0.474
Flag leaf attitude of blade late observation	-0.000	0.000	0.00	0.00	0.00	0.000	-0.796
Curvature of main panicle axis	0.000	0.000	0.00	0.00	0.00	0.000	1.069
Panicle awn	-1.200	0.000	0.00	0.00	0.00	0.000	2.227
Panicle exertion	1.000	0.000	0.00	0.00	0.00	0.000	2.540
Decorticated grain shape	-2.000	0.000	0.00	0.00	0.00	0.000	0.691
Endosperm amylose content	-1.200	0.000	0.00	0.00	0.00	0.000	1.016
Gelatinization of temperature	2.000	0.000	0.00	0.00	0.00	0.000	0.732



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Variety	Cluster 1	Cluster 2	Cluster 3
JGL 384	0.011	0.003	0.000
JGL 1798	0.007	0.004	0.000
BPT 5204	0.041	0.003	0.000
WGL 14	0.010	0.008	0.000
RDR 703	0.000	0.000	0.000
RNR 2306	0.000	0.000	0.000

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Table 5 Estimated membership values of the varieties in the three clusters

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MTU 2077	0.000	0.000	0.000
MTU 4870	0.000	0.000	0.000
MTU 1001	0.000	0.000	0.000
MTU 2067	0.000	0.000	0.000
MTU 7029	0.000	0.000	0.000
MTU 1010	0.000	0.000	0.000
MTU 5249	0.000	0.000	0.000
RPW6-17	0.000	0.000	0.000
WGL 134	0.000	0.000	0.000
WGL 20471	0.000	0.000	0.000
Telohansa	0.000	0.000	0.000
RDI 7555	0.000	0.000	0.000
ADI 43	0.000	0.000	0.000
ASU 19	0.000	0.000	0.000
GEH24	0.000	0.000	0.000
Malhaci	0.000	0.000	0.000
IR 64	0.000	0.000	0.000
Kalpeera	0.000	0.000	0.000

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