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Genetic association studies in rice landraces

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Abstract
Genetic association studies were conducted using 110 rice germplasm in the current research for biometrical traits at AC & RI, Killikulam during the Rabi season in the year 2022-2023. The significant differences were recorded among germplasm for yield contributing traits using Analysis of variances (ANOVA) which reveals that germplasm used in the current study were differed for all traits. By using association studies, the degree and direction of relationship was determined. Among the yield contributing traits, four traits *viz.,* number of tillers per plant (0.178), number of productive tillers per plant (0.587), number of filled grains per panicle (0.425), thousand grains weight (0.174) had significant positive correlation with single plant yield. The number of tillers per individual plant and the count of productive tillers per individual plant showed a positive direct impact on the yield of a single plant. Principal component analysis reveals out of fourteen PCs, six PCs were reliable which were having Eigen values of 2.58, 2.18, 1.73, 1.53, 1.23, 1.18 respectively and they had contributed 18.79%. 15.63%, 12.39%, 10.96%, 8.79%, 4.46% of variance to the total variance. Together they contributed 74.72% of the total variance. Therefore, these traits could be deemed important for future selection procedures in programs aimed at improving crops.

Keywords: Rice, genetic association, correlation, path analysis, PCA, yield

Introduction
Rice serves as the sustenance of life, and it is widely regarded as the most important source of human sustenance on the planet, directly feeding a large number of people (Nirubana *et al.*, 2019) [13]. It holds the utmost significance as a primary food source in India, constituting around sixty per cent of daily energy requirements or forty-one per cent of the overall production of food grain originating from just 35% of the national food grain region, this factor plays a crucial role in ensuring the nation's food security. (Bandumula *et al.*, 2022) [1]. Over half of the world's population regularly includes rice in their diet, a vital component in guaranteeing food security. Anticipated figures suggest that by the year 2030, worldwide rice production will surge from 58 million tonnes to 567 million tonnes. In addition to providing a substantial calorie content, rice also contains a diverse array of vital vitamins, minerals, and other essential nutritional elements. (Mohidem *et al.*, 2022) [12]. With a vast rice cultivation expanse of 44 million hectares, India holds the distinction of having the largest rice-growing area. It stands as the second-largest rice producer globally, yielding 131 million tonnes, trailing only behind China, which produces 197 million tonnes. At the current population growth rate (1.5%), by the year 2025, India's demand for rice is projected to reach approximately 125 million tonnes (Manohar, *et al*, 2017) [10]. Over the course of time, numerous rice varieties have been developed through ongoing cultivation and selection. Nonetheless, landraces are infrequently integrated into plant breeding initiatives. Therefore, leveraging the genetic diversity present in these various genotypes during breeding endeavors could prove advantageous for enhancing productivity. The present research aimed to assess genetic associations in order to establish the degree and direction of relationship among various traits in rice genotypes. This was done with the goal of pinpointing traits that contribute to enhancing rice yield.

Materials and Methods
Experimental material and design
A total of 110 germplasm available in Agricultural college and Research institute, Killikulam collected from NBPGR, New Delhi, Regional Agricultural Research Station, Pattambi, Kerala, TRRI, Aduthurai and Directorate of Rice Research, Hyderabad were used in this study.

The entire germplasm was cultivated using a Randomized Block Design, ensuring appropriate spacing and adhering to established agronomic practices. The germplasm accessions utilized in the investigation are detailed in Table 1.

Collection and Analysis of data

Yield and its contributing characteristics including plant height (cm), days to fifty percentage flowering, number of tillers per plant, number of productive tillers per plant, panicle length (cm), thousand grain weight (g), number of filled grains per panicle, grain length (mm), grain breadth (mm), grain L/B ratio, grain length after cooking(mm), grain breadth after cooking (mm), linear elongation ratio, breadth wise expansion ratio, single plant yield (g) were recorded. The recorded observations were subjected to statistical analysis using MS EXCEL and STAR software. In association studies, the correlation between yield contributing traits were worked out using the methods outlined by Johnson *et al.* (1955) [7]. Path studies allow for the identification of both direct and indirect relationships between variables and the independent variable outlined by Wright (1921) [17] and Dewey and Lu (1959) [3]. Principal Component Analysis (PCA) was executed using the STAR software. Within the context of PCA, data is employed to calculate Eigen values and the percentage of variation, which is then aggregated. Load coefficient values are determined between the initial attributes and their corresponding principal components (PC). The scatter diagram of the cultivars is plotted using the principal components that contribute the most to the variation.

Results and Discussion

Significant genetic variation in the experimental material was evident across all investigated traits, as indicated by the highly significant differences observed between genotypes. This was determined through the use of Analysis of Variance. (ANOVA) in Table 2. The outcomes are in agreement with Gnaneswari *et al.*, (2023), Laxmi and Chaudhari (2019), Kishore *et al.*, (2015) [5, 9, 8].

Association studies

Through the utilization of association studies, the direction and strength of the relationships among the traits in the examined genotypes were inferred (Table 3).

4.2.1 Correlation studies

Among the traits that contribute to yield, four traits *viz.*, number of tillers per individual plant (0.178), number of productive tillers per plant (0.587), number of filled grains per panicle (0.425), thousand grains weight (0.174) had significant positive correlation with single plant yield. Comparable findings were documented by Zayed *et al.*, (2023) for number of filled grains per panicle; Manojkumar *et al.*, (2022) [11] for the number of filled grains per individual panicle; for number of tillers per plant, number of productive tillers per individual plant, thousand grain weight, number of filled grains per panicle (Noatia *et al.*, 2021, Saleh *et al.*, 2020, Hossain *et al.*, 2018, Singh *et al.*, 2018) [14, 15, 6, 16]. The trait days to fifty per cent flowering (-0.018) and plant height (-0.014), grain breadth after cooking (-0.015) and breath expansion ratio (-0.712) had negative but non-significant association with yield of single plant. Other traits *viz.*, panicle length (0.044), grain length (0.019), grain breadth (0.079), grain length after cooking (0.064), linear elongation ratio (0.068) recorded positive but non-significant association with yield of single plant.

Inter correlation among yield components

Days to fifty per cent flowering

The trait days to fifty per cent flowering had significant and negative correlation with number of tillers per individual plant (-0.163), number of productive tillers per individual plant (-0.224). The character days to fifty percentage flowering had significant and positive correlation with plant height (0.261), grain length (0.165), and grain length after cooking (0.228), thousand grains weight (0.118), linear elongation ratio (0.144). With all other traits positive but non-significant correlation was recorded.

Plant height (cm)

The trait plant height recorded significant and negative correlation with the number of tillers (-0.159) and nonsignificant negative correlation with number of productive tillers per plant (-0.028). The character plant height recorded significant positive correlation with the grain breadth (0.145) and linear elongation ratio (0.240). All remaining traits exhibited positive correlations; however, these correlations were not statistically significant.

Number of tillers per plant

The trait number of tillers had significant and positive correlation with number of productive tillers per plant (0.839) and a significant negative correlation with panicle length (-0.218). All other traits had positive but non-significant correlation.

Number of productive tillers per plant

The trait number of productive tillers per plant recorded significant positive correlation with number of filled grains per panicle (0.205) and grain length (0.146), grain length after cooking (0.138) and significant negative correlation with panicle length (-0.153), grain breadth (-0.215).

Panicle length (mm)

The trait panicle length had a significant positive correlation with number of filled grains per panicle (0.155), grain length (0.163), thousand grain weight (0.144), linear elongation ratio (0.204), breadth expansion ratio (0.341) and all other traits had a positive and non-significant correlation.

Number of filled grains per panicle

The trait number of filled grains per panicle had a significant and positive correlation with linear elongation ratio (0.370) and all the other traits displayed a positive correlation with each of the other traits under investigation.

Grain length (mm)

The trait grain length had a significant positive correlation with grain breadth (0.179), grain length after cooking (0.931), linear elongation ratio (0.400), breadth expansion ratio (0.136) and all other had non-significant positive correlation.

Grain breadth (mm)

The grain breadth had significant and positive correlation with grain breadth after cooking (0.960), breadth expansion ratio (0.785), linear elongation ratio (0.188) and non-significant positive correlation with thousand grain weight (0.054), grain length after cooking (0.080).

Thousand grain weight (g)

Thousand grain weight had a significant correlation with linear elongation ratio (-0.202) and all other traits had non-significant positive correlation.

Grain length after cooking (mm)

This trait recorded significant positive correlation with breadth of grain after cooking (1.04) and breadth expansion ratio (0.142) and non-significant positive correlation with linear elongation ratio (0.043).

Grain breadth after cooking (mm)

This trait showed significant positive correlation for linear expansion ratio (0.344), breadth expansion ratio (0.547), breadth of the grain (0.960), grain length after cooking (1.04) and non-significant association was observed for all other the traits.

Linear elongation ratio

Linear elongation ratio recorded positive correlation with breadth expansion ratio (0.097).

Breadth expansion ratio

Breadth expansion ratio had a significant and positive correlation with the panicle length, length of the grain, breadth of the grain, length after grain cooking, grain breadth after cooking and a non-significant positive correlation with all other traits.

Path analysis

The genotypic correlation coefficients were subsequently partitioned into direct and indirect effects for each of fourteen traits through path analysis. The genotypic residual effect is 0.4611. These results are outlined in Table 2.

Days to fifty per cent flowering

Days to fifty per cent flowering showed negative direct effect (-0.0101) on single plant yield. The indirect effects through height of the plant (-0.0025), number of tillers per individual plant, number of productive tillers per individual plant, length of the panicle, length of the grain, breadth of the grain, thousand grain weight, length after grain cooking, breadth after grain cooking, linear elongation ratio, breadth expansion ratio were negatively low. The indirect effects through number of filled grains per panicle (0.0174) were positively low.

Plant height

Plant height exhibited negative and direct effect (-0.0101) on yield of single plant. The indirect effects via number of tillers (0.0207), length of the grain (0.2478), breadth of the grain (0.0823), length after grain cooking (0.0451) were positively low. The indirect effect via number of productive tillers per individual plant (-0.0014), length of the panicle (-0.0013), number of filled grains per individual panicle (-0.0208), weight of thousand grain (-0.0105), grain breadth after cooking (-0.0891), linear elongation ratio (-0.2409), breadth expansion ratio (-0.004) were negatively low.

Number of tillers per plant

Number of tillers per plant exhibited positive and direct effect (0.1297) on yield of single plant. The indirect effects through number of productive tillers per plant (0.032), length of the panicle (0.0047), number of filled grain per panicle (0.0037), breadth of the grain (0.0256), thousand grain weight (0.0034), grain length after cooking (0.0646), grain breadth after cooking (0.0044), linear elongation ratio (0.1355) and breadth expansion ratio (0.0004) were positively low. The indirect effects through grain length (-0.0918) was negatively low.

Number of productive tillers per plant

Number of productive tillers per plant exhibited positive and direct effect (0.5388) on single plant yield. The indirect effects through length of the panicle (0.0035), thousand grain weight (0.0057), length after grain cooking (0.3867), number of filled grains per individual panicle (0.0013), breadth after grain cooking (0.0681), linear elongation ratio (0.0807) and breadth expansion ratio (0.0004) were positively low. The indirect effects via grain length (-0.4512) and grain breadth (-0.0388) were negatively low.

Panicle length

Panicle length exhibited positive and direct effect (0.0224) on single plant yield. The indirect effects through number of filled grains per panicle (-0.0036), length of the grain (-0.324), breadth of the grain (-0.1164), grain length after cooking (-0.2369) and breadth expansion ratio (-0.003) were negatively low. The indirect effects through thousand grain weight (0.0275) and grain breadth after cooking (0.1019), linear elongation ratio (0.2279) were positively low.

Number of filled grains per panicle

Number of filled grains per panicle showed positive and direct effect (0.4846) on yield of single plant. The indirect effects through breadth of grain (0.0299), weight of thousand grain (0.0012), and grain length after cooking (0.1316) were positively low. The indirect effects through length of the grain (0.2006), breadth after grain cooking (-0.04327), linear elongation ratio (-0.2803) and breadth expansion ratio (-0.0002) were negatively low.

Grain breadth

Grain breadth showed negative and direct effect (0.0293) on yield of single plant. The indirect effects through thousand grain weight (-0.0072), grain breadth after cooking (-0.5098), linear elongation ratio (-0.1606) were negatively low. The indirect effects through grain length after cooking (0.7007), breadth expansion ratios (0.0012) were positively low.

Thousand grain weight

Thousand grain weight showed positive direct effect (0.3894) on yield of single plant. The indirect effects through grain length after cooking (0.1059), linear elongation ratio (0.1074), and breadth expansion ratio (0.0002) were positively low. The indirect effects through grain breadth after cooking (-0.0173) was negatively low.

Grain length after cooking

Grain length after cooking showed positive direct effect (2.8774) on single plant yield. The indirect effects through grain breadth after cooking (-0.1599), linear elongation ratio (-0.2362) were negatively low. The indirect effect through breadth expansion ratio (0.0002) was positively low.

Grain breadth after cooking

Grain breadth after cooking showed positive and direct effect (-0.5444) on single plant yield. The indirect effects via linear elongation ratio (-0.3299) was negatively low and indirect effects through breadth expansion ratio (0.0004) was positively low.

Linear elongation ratio

Linear elongation ratio showed positive and direct effect (-1.3387) on yield of single plant. The indirect effects through breadth expansion ratio (-0.0007), days to fifty per cent flowering (-0.0013), number of filled grains per panicle (0.0135) and grain breadth after cooking (-0.1341) were negatively low. The indirect effects through height of the plant (0.0018), number of tillers per plant (0.0131), length of the panicle (0.0038) and length of the grain (0.9412) were positively low.

Breadth expansion ratio

Breadth expansion ratio showed negative and direct effect (0.0120) on yield of single plant. The indirect effects via height of the plant (-0.0001), number of productive tillers per individual plant (-0.0058), number of filled grains per panicle (-0.0044), breadth of the grain (-0.2586), linear elongation ratio (-0.3715) were negatively low. The indirect effects through days to fifty per cent flowering (0.0014), number of tillers (0.0203), length of the grain (0.1626), thousand grain weight (0.0110), breadth expansion ratio (0.076) were positively low.

Furthermore, these traits exerted a positive and direct influence on the yield of individual plants. Similar outcomes were in agreement.

Principal component analysis based on morphological observations

Principal Component Analysis (PCA) was utilized to elucidate the divergence among different rice genotypes. To ascertain the proportionate impact of the traits on the overall variability and to offer guidance for trait selection, PCA was employed. The significance and influence of each component on the overall variance for each trait can be evaluated by considering their respective phenotypic values. Meanwhile, the extent of contribution of each initial variable is mirrored in the coefficients of relevant vectors associated with each principal component. By using STAR 2.0.1 software, PCA was done and the components having Eigen values with above 1 were further used.

The biometrical traits such as plant height (PH), days to fifty % flowering (DFF), number of tillers (NT), number of productive tillers (NPT), length of the panicle (PL), thousand grain weight (TGW), length of the grain (GL), breadth of the grain (GB), number of filled grains per panicle (NFP), Grain length after cooking (GLC), grain breadth after cooking (GBC), linear elongation ratio (LER), breadth expansion ratio (BER), single plant yield (SPY) were subjected to principal component analysis (Table 4 and Figure 1) and Eigen vectors and scree plot for various traits from PCA (Figure 2).

The PCA extracted six components which were having Eigen value of 2.58, 2.18, 1.73, 1.53, 1.23 and 1.18 respectively, had contributed 18.49%, 15.63%, 12.39%, 10.96%, 8.79%, 4.46% of variance to the total variance. Together they contributed 74.72% of the total variance. The scree plot serves as a diagnostic tool to assess the effectiveness of PCA on the collected data. Based on amount of variation, PCs are created. Scree plot PC 1 carries the most variation, PC 2 captures the second most and so on Figure 2.

It was observed that, the characteristics *viz.*, total number of tillers per plant, total number of productive tillers per plant, total number of filled grains per individual panicle, length of the grain, breadth of the grain, weight of thousand grain, grain length after cooking, grain breadth after cooking, linear elongation ratio and yield of single plant were positively associated with component 1 (PC 1). In component 2 (PC 2) the traits *viz.*, number of tillers per plant, number of productive tillers per plant, grain length, and grain length after cooking were positively associated. In component 3 (PC 3) the traits *viz.*, breadth of the grain, grain breadth after cooking and yield of single plant were positively associated. The traits *viz.*, plant height, days to fifty per cent flowering, number of tillers per plant, number of productive tillers per plant, number of filled grains per panicle, linear elongation ratio and breadth expansion ratio were positively associated with component 4 (PC4). The traits *viz.*, number of tillers per plant, grain after cooking, grain breadth after cooking, linear elongation ratio, breadth expansion ratio and yield of single plant were positively associated to component 5 (PC5). The traits *viz.*, height of the plant, days to fifty per cent flowering, number of tillers per individual plant, number of productive tillers per plant, length of the panicle, number of filled grains per panicle, length of the grain, breadth of the grain and yield of the single plant were positively associated with component 6 (PC 6). Dhakal *et al.*, (2020) [4] reported that out of the 13 PCs, only five were reliable, and it was found that the landraces overall variability was influenced by the thousand-grain weight, yield of single plant, percentage of filled grain, grain width, total grain per panicle, flag leaf breadth, kernel width, and grain length. The traits *viz.*, length of the grain, weight of 1000 grain, yield of the single plant, weight of the panicle, and fertility percentage of spikelet have recently been identified as primary attributes among landraces, positively influencing PC1 and PC2. This underscores the significance of classifying the landraces. (Burman *et al.*, 2021) [2].

Table 1: The genotypes utilized in the study

S. No	Name of the genotypes	No of genotypes	Sources
1	Abiyan, Adukan, Anna 4, Karuppu kavuni, Pisni, Kaviya, Mulampunchan, Chinapunchan, Kalyani, Jaya, J13, Molikarumbu, White sanam, Swarnamalli, Vattan 5052, Chembavu 5599, Thuyamalli, Mahi suganth,Amman, Jaisreeram, Mallikar, Seeraga samba, Harathi, Karutha Navara, Kothamalli samba, Kodivilaiyan, Kotara samba, Kullakar, Varaputha, Sivappumalli, Thamarai, Purple puttu, Srilanka, Mapillai samba,Chittiraikar,Karsamba, Chinaponni, Pusa basmati,Poongar, Kuliyadichan, Kallondaikar, Meikuruvai, Dhalaheera, Virendra, Palkudavazhai, Shadabahar, Shabahidhan, Thavalai Kannan, Rajalakshmi, Noothipattu, Athoor kitchali samba, Veethiruppu, Swarna masuri, Sivamullai, Kalinga,Illupaipoo samba, Anjali, Rathali, Vallan.	60	AC and RI, Killikulam
2	ARYAN 1205, ARYAN1108, ARYAN 1204, ARIYAN, ARYAN 6333, ARYAN 1203, ARYAN 1102,	20	NBPGR, New Delhi

	ARYAN1024, ARYAN 917, ARYAN 957 Kaivarai samba, Chiruchitteni 882, Chiruchitteni Chennelu 6805, Chitteni 5208, Chembavu 6305, Navara, Navara 957, Chuvanna chitteni, Pattani.		
3	Chomala, Chenkayamma, Chenkayamma 5523, Oheru chitteni, Orkaima, Chenna, Chembavu 4331, Kerala gandasala, Kunju kunju, Navara black.	10	Regional Agricultural Research Station, Pattambi, Kerala
4	Geethanjali Basmati, Parthiban, Burma Gowni, Arupatham Kuruvai, Kalanamak	5	Tamil Nadu Rice Research Institute, Aduthurai, Tamil Nadu
5	NL 24, PS 68, RNR 1986, NLR 3385, NLR 3247, NL 22, NL 37, NL 9, NL 142, NL 16, NL148, NL 3, NL 248, NLR 3217, Lemont.	15	Directorate of Rice Research, Andhra Pradesh

Table 2: Genotypic correlation coefficient matrix for fourteen biometrical traits

Traits	DFF	PH	NT	NPT	PL	NFP	GL	GB	TGW	GLC	GBC	LER	BER	SPY
DFF	1	0.261*	-0.163*	-0.224**	0.053	0.061	0.165*	0.065	0.118*	0.228**	0.077	0.144*	0.058	-0.018
PH		1	-0.159*	-0.028	0.060	0.021	0.075	0.145*	0.05	0.024	0.080	0.240**	0.037	-0.014
NT			1	0.839**	-0.218**	0.067	0.027	0.058	0.0043	0.069	0.001	0.002	0.059	0.178*
NPT				1	-0.153*	0.205**	0.146*	-0.215**	0.051	0.138*	1.030	0.041	0.001	0.587**
PL					1	0.155*	0.163*	0.016	0.144*	0.055	0.020	0.204**	0.341*	0.044
NFP						1	0.069	0.001	0.012	0.054	0.091	0.370**	0.053	0.425**
GL							1	0.179**	0.081	0.931**	0.067	0.400**	0.136*	0.019
GB								1	0.054	0.080	0.960**	0.188*	0.785*	0.079
TGW									1	0.011	0.048	-0.202*	0.051	0.174*
GLC										1	1.04**	0.043	0.142*	0.064
GBC											1	0.344*	0.547**	-0.015
LER												1	0.097	0.068
BER													1	-0.712
SPY														1

'* and ** indicates level of significance at 0.05 and 0.01 respectively.

DFF - Days to fifty per cent flowering, PH - Plant height, NT- Number of tillers, NPT- Number of productive tillers per plant, PL - Panicle length, NFP – Number of filled grains per panicle, TGW - Thousand grain weight, GL - Grain length, GB - Grain breadth, GLAC- Grain length after cooking, GBAC- Grain Breadth after cooking, LER- Linear expansion ratio, BER- Breadth Expansion Ratio, SPY - Single plant yield.

Table 3: Path analysis for fourteen biometrical traits in rice genotypes

Traits	DFF	PH	NT	NPT	PL	NFP	GL	GB	TGW	GLC	GBC	LER	BER	SPY
DFF	-0.0101	-0.0025	-0.0072	-0.0009	-0.0010	0.0174	-0.3640	-0.0034	-0.0207	-0.6061	-0.0416	-0.1788	-0.000	-0.0184
PH	-0.0025	-0.0101	0.0207	-0.0014	-0.0013	-0.0208	0.2478	0.0823	-0.0105	0.0451	-0.0891	-0.2409	-0.004	-0.0140
NT	0.0006	0.0016	0.1297	0.0320	0.0047	0.0037	-0.0918	0.0256	0.0034	0.0646	0.0044	0.1355	0.0004	0.1780*
NPT	0.0042	0.0034	-0.1070	0.5388	0.0035	0.0013	-0.4512	-0.0388	0.0057	0.3867	0.0681	0.0807	0.0004	0.5872**
PL	-0.0005	-0.0006	0.0273	-0.0061	0.0224	-0.0036	-0.324	-0.1164	0.0275	-0.2369	0.1019	0.2279	-0.0003	0.0441
NFP	-0.0027	0.0033	0.074	0.0008	-0.0012	0.4846	-0.2006	0.0299	0.0012	0.1316	-0.04327	-0.2803	-0.0002	0.4251**
GL	-0.0013	0.0009	-0.0264	0.0060	-0.0002	-0.0045	0.0120	0.0978	-0.0129	0.5083	-0.0887	0.4327	0.0001	0.0191
GB	0.0001	-0.0015	-0.0059	-0.0027	0.0047	-0.0034	-0.5094	-0.0293	-0.0072	0.7007	-0.5098	-0.1606	0.0012	0.0788
TGW	0.0011	-0.0026	0.0023	-0.0012	0.0033	0.0004	-0.1985	0.0213	0.3894	0.1059	-0.0173	0.1074	0.0002	0.1740*
GLC	-0.0021	0.0002	-0.0209	0.0052	-0.0018	-0.0030	-2.5385	0.1362	-0.0072	2.8774	-0.1599	-0.2362	0.0002	0.0641
GBC	0.0008	-0.0017	0.0011	-0.0049	00042	-0.0052	-0.4743	0.5238	-0.0060	0.8454	-0.5444	-0.3299	0.0004	-0.015
LER	-0.0013	0.0018	0.0131	-0.0023	0.0038	-0.0135	0.9412	0.0671	0.0152	0.5076	-0.1341	-1.3387	-0.0007	0.068
BER	0.0014	-0.0001	0.0203	-0.0058	-0.0023	-0.0044	0.1626	-0.2586	0.0110	0.2239	0.0760	-0.3715	-0.0026	-0.712

Diagonal values indicates direct effects
'* and **' indicates level of significance at 0.05 and 0.01 respectively.
Residual effect= 0.4611

Table 4: Eigen value, Eigen vectors, variance (%), cumulative (%) from PCA for morphological traits

Traits	PC1	PC2	PC3	PC4	PC5	PC6
PH	-0.086	-0.330	-0.163	0.231	-0.2610	0.307
DFF	-0.118	-0.181	-0.432	0.102	-0.210	0.116
NT	0.219	0.486	-0.027	0.389	0.013	0.017
NPT	0.167	0.463	-0.110	0.457	-0.019	0.122
PL	-0.205	-0.056	-0.173	-0.284	-0.0966	0.4606
NFP	0.0615	-0.258	-0.275	0.312	-0.184	0.275
GL	0.3817	0.240	-0.3122	-0.4381	-0.0028	0.0557
GB	0.4926	-0.2269	0.3476	-0.0194	-0.045	0.0341

TGW	0.0709	-0.0118	-0.0391	-0.0357	-0.598	-0.409
GLC	0.436	0.0723	-0.3959	-0.2604	0.2108	-0.0662
GBC	0.469	-0.3003	0.2155	-0.0072	0.0473	-0.0967
LER	0.0718	-0.3415	-0.1326	0.3665	0.4269	-0.2609
BER	-0.2104	-0.122	-0.4600	0.0030	0.2888	-0.3528
SPY	0.050	-0.027	0.1248	-0.0248	0.4149	0.4589
Eigen value	2.588	2.188	1.734	1.535	1.230	1.184
Variance (%)	18.49%	15.63%	12.39%	10.96%	8.79%	4.46%
Cumulative (%)	18.49%	34.12%	46.51%	57.47%	66.26%	74.72%

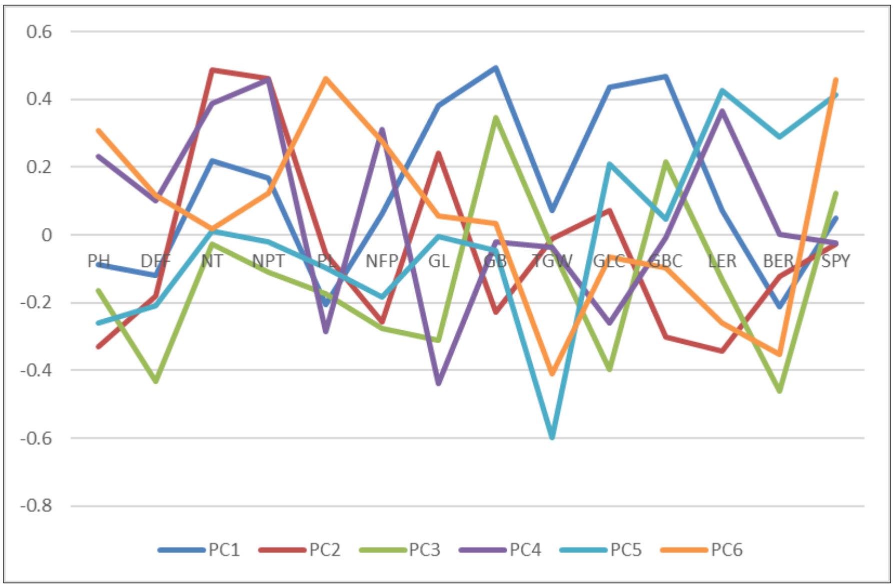

Fig 1: Eigen vectors for various traits from PCA

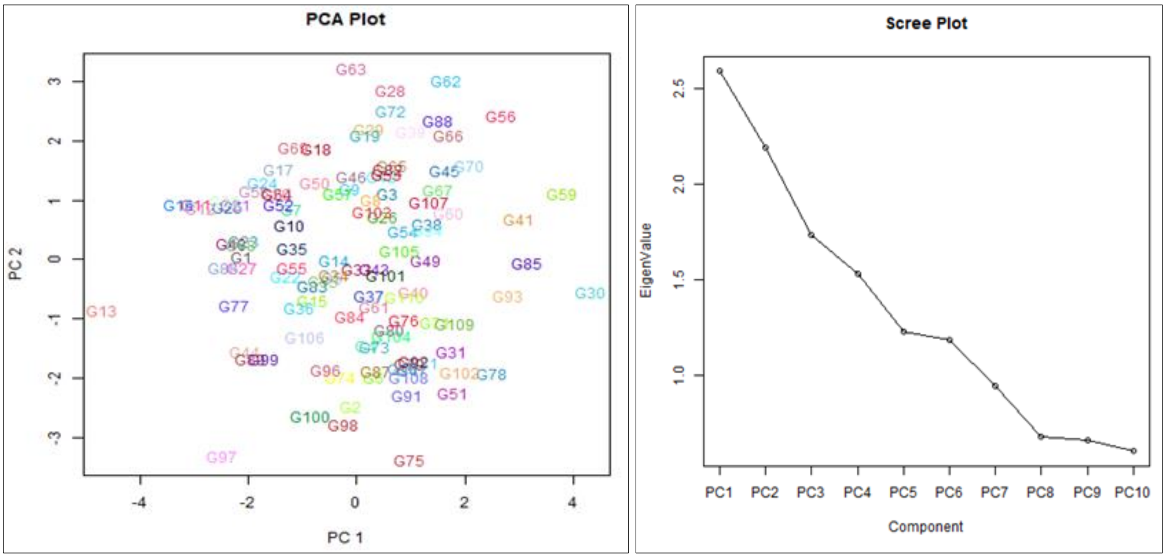

Fig 2: PCA plot and scree plot of germplasm accessions

Conclusion

Over half of the world's population regularly consumes rice, which is essential for ensuring food security. Based on the results obtained from character association and path analysis, the single plant yield can be improved by increasing the number of productive tillers per plant, number of tillers per plant, number of filled grains per panicle, thousand grain weight because it has a positive direct effect and significant positive correlation with single plant yield. Therefore, through indirect selection of related traits, any one of the traits could be improved. These traits would be a major concern for yield improvement programs because they also had a positive direct effect on single-plant yield. Hence selection for these traits could bring improvement in single plant yield.

Abbreviations

DFF - Days to fifty per cent flowering, PH - Plant height, NPT- Number of productive tillers per plant, PL - Panicle length, NGP – Number of grains per panicle, TGW - Thousand grain weight, GL - Grain length, GB - Grain breadth, GLAC- Grain length after cooking, GBAC- Grain Breadth after cooking, LER- Linear expansion ratio, =BER- Breadth Expansion Ratio, SPY - Single plant yield.

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