

DISSECTING PHENOTYPIC DIVERSITY AND TRAIT ARCHITECTURE IN MAIZE (*ZEA MAYS* L.) GENOTYPES THROUGH MULTIVARIATE STATISTICAL APPROACHES

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ABSTRACT

Maize (*Zea mays* L.) is a versatile cereal crop of global significance. It is often referred to as the "Queen of Cereals" because of its highest genetic yield potential among cereal crops. Efficient crop improvement relies on the identification of genotypes with superior yield potential, favourable plant architecture, and desirable agronomic attributes. The experimental study was done using 39 maize genotypes during *rabi* season 2023-2024 under irrigated condition in Randomized Block Design (RBD) with two replications for 11 quantitative traits. Principal component analysis revealed that PC 1 TO PC 5 had eigen value of more than 1 and contributed for maximum variability indicating that these components were sufficient to represent the overall diversity present in the evaluated genotypes. PC1 exhibited the highest eigenvalue (3.65) and accounted for 33.19% of the total variance which explained that it was the most important contributor to the genetic variability. PC2 explained 16.94% of the variation, and PC3, PC4, PC5 contributed 12.58%, 10.28% and 9.46% of variation respectively. In correlation study, plant height (0.5058), ear height (0.419), and ear length (0.446) exhibited significant positive correlations with plant yield, indicating their importance in contributing to higher yield. Ear length was positively and significantly associated with kernels per row (0.427) and number of kernel rows per cob (0.409), highlighting its contribution to yield component development. Hence, the findings from the study will provide useful guidance for the identification and selection of superior maize genotypes in breeding programmes aimed at improving grain yield performance.

KEYWORDS: Maize, Principal Component Analysis, Correlation, Anthesis Silking Interval,

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop grown worldwide which has significant role in food security, livestock feed, and industrial applications. The crop has wide adaptability, high productivity potential, and diverse uses, making it a major crop in global agriculture. Improvement in maize productivity largely depends on the development and utilization of superior parental lines with desirable agronomic traits and good combining ability. Identification of genotypes with high yield potential, desirable plant architecture, and superior agronomic performance is prerequisite for crop improvement. Assessment of maize genotypes involves the study of variability for important traits such as plant height, ear height, flowering duration, ear characteristics, kernel traits, and grain yield. Understanding the extent of variation among inbred lines is essential for selecting suitable parents for hybrid development and improving yield-related traits (Javaid *et al.*, 2023). Statistical approaches such as analysis of variance, correlation analysis, principal component analysis (PCA), are useful tools for assessing genetic diversity and identifying important traits contributing to yield performance. These analyses help breeders select promising parental lines to develop improved maize hybrids with enhanced productivity and adaptability. Study of maize genotypes under irrigated conditions is essential for identifying superior genetic materials and strengthening maize breeding programs aimed at increasing grain yield and sustainable production (Adhikari *et al.*, 2018). Hence present study of maize genotypes is conducted to identify the yield contributing traits in maize and select best performing maize genotypes for development of crop improvement.

MATERIALS AND METHODS

The experiment was conducted during *rabi* season 2023-2024 under irrigated condition. A total of 39 inbreds (Table. 1) were sown in Randomized Block Design (RBD) with two replications. Data were recorded for 11 quantitative traits *viz.*, plant height (cm), ear height (cm), ear length (cm), tassel length (cm), days to 50% tasselling, days to 50% silking, anthesis silking interval (ASI), kernels per row, number of kernels rows per cob, 1000 seed weight, and single plant yield. The seeds were sown in two rows each of 4m length with spacing 60 x 25 cm. The data were collected from five randomly selected plants from each inbred and the mean was used for analysis.

Statistical analysis was carried out using R software. Genotypic and phenotypic correlation coefficients were estimated according to the method described by Falconer, (1981). Correlation coefficients were interpreted as weak (<0.30), moderate (0.31–0.60), and strong (>0.60) based on the classification proposed by Searle, (1965). To determine the direct and indirect effects of component traits on grain yield, path coefficient analysis was performed following the method developed by Wright, (1921). The magnitude of path coefficients was interpreted according to the scale proposed by Lenka and Misra, (1973), where values of 0.00–0.09 were considered negligible, 0.10–0.19 low, 0.20–0.29 moderate, 0.30–0.99 high, and values greater than 1.00 considered very high.

RESULTS AND DISCUSSION

Principal Component Analysis was carried out to assess the magnitude and pattern of variation among maize the 39 maize genotypes under irrigated conditions. The PCA extracted eleven principal components, which together accounted for 100% of the total variation observed among the genotypes (Table 2 and 3). Among these, the first five principal components possessed eigenvalues greater than unity and explained a major proportion (82.45%) of the total variability, indicating that these components were sufficient to represent the overall diversity present in the evaluated genotypes.

The first principal component (PC1) exhibited the highest eigenvalue (3.65) and accounted for 33.19% of the total variance which explained that it was the most important contributor to the genetic variability. The second principal component (PC2) recorded an eigenvalue of 1.86 and explained 16.94% of the variation, with cumulative variance of 50.13%. The third principal component (PC3) contributed 12.58% of the total variation with an eigenvalue of 1.38, raising the cumulative contribution to 62.71%. The fourth (PC4) and fifth (PC5) principal components accounted for 10.28% and 9.46% of the total variation, respectively, resulting in a cumulative contribution of 72.99% and 82.45%. The remaining principal components (PC6–PC11) contributed comparatively lower proportions of variation. Scree Plot, Variable plot and PCA are represented in figure 1, 2, and 3. The predominance of PC1, PC2, and PC3 in explaining the total variability indicated that these components can be effectively used for characterizing genotypes, identifying superior parental lines, and selecting diverse materials for future hybrid breeding programmes under optimal moisture conditions.

PCA Trait Contribution Analysis

The principal component loading analysis was performed to identify the contribution of different quantitative traits towards the variability among maize genotypes under irrigated conditions. The trait loadings indicate the relationship between individual traits and principal components, where higher absolute loading values represent greater contribution of a trait to the respective component.

In PC1, which explained the highest proportion of total variability, the major contributing traits were days to silking (–0.817), days to tasseling (–0.788), plant height (0.805), ear height (0.697), and plant yield (0.692). This component mainly represented variation associated with plant architecture, flowering duration, and yield performance. The negative contribution of flowering traits indicated that early flowering genotypes were differentiated from late flowering types along this component. The PC2 was primarily associated with yield-related ear traits *viz.*, ear length (0.765), number of kernels per row (0.637), and number of kernel rows per cob (0.686) showing high positive loadings (Ravi *et al.*, 2018; Worknesh *et al.*, 2019; Hossain *et al.*, 2016). The findings suggest that this component represented variation in cob size and kernel arrangement characteristics distinguishing the genotypes based on yield components. The PC3 was largely influenced by anthesis–silking interval (–0.796), tassel length (0.483), days to tasseling (0.463), and kernels per row (0.409). The strong negative loading of ASI indicated its importance in explaining reproductive behaviour and synchronization of flowering among the evaluated genotypes. The PC4 was mainly associated with thousand seed weight (0.751) and anthesis–silking interval (0.481), indicating that seed size and reproductive traits contributed substantially to this component. The PC5 showed higher contributions from ear height (0.501), plant height (0.381), days to silking (0.371), and days to tasseling (0.309), reflecting additional variation related to plant growth and maturity characteristics.

Overall, the PCA revealed that plant height, ear height, flowering traits, ear characteristics, kernel traits, thousand seed weight, and grain yield were the major contributors to genetic variation among the maize genotypes under evaluation. The traits with high loading values in the first five principal components can be considered important selection criteria for identifying superior and diverse parental lines in maize breeding programmes.

Correlation Analysis

Correlation analysis was studied to understand the interrelationship among quantitative traits and to identify characters that can be effectively used for indirect selection for grain yield improvement. The correlation coefficients among eleven traits revealed considerable variation in the magnitude and direction of associations among traits (Table. 4).

A highly significant and positive correlation was observed between plant height and ear height (0.858), indicating that genotypes with increased vegetative growth tended to exhibit higher ear placement. Similar positive associations between plant height and ear height have been widely reported in maize, reflecting the common genetic control of these architectural traits. Plant height exhibited a significant positive correlation with grain yield

(0.508), suggesting that greater plant vigour under optimal moisture conditions contributed to enhance assimilate production and yield potential. Likewise, ear height showed a significant positive relationship with yield (0.419), indicating that plant architecture traits may serve as useful indicators during selection. Yield component traits showed significant associations with grain productivity. Ear length exhibited significant positive correlations with kernels per row (0.427), number of kernel rows per cob (0.409), and plant yield (0.446). Similar results were obtained by Leite *et al.*, 2022. These results indicate that increased ear size contributes to greater kernel number and improved yield performance. The positive relationship between kernels per row and number of kernel rows per cob (0.427) further emphasizes the importance of cob characteristics in determining yield potential. The flowering traits, days to tasseling and days to silking, exhibited a very strong positive correlation (0.958), confirming their close genetic association and coordinated expression during reproductive development. However, both days to tasseling (0.425) and days to silking (−0.455) showed significant negative correlations with plant yield, indicating that early flowering and reduced maturity duration may be advantageous for improving productivity. Similar negative relationships between delayed flowering and grain yield have been documented in maize, particularly where early-maturing genotypes efficiently utilize available resources. Tassel length demonstrated significant positive correlations with plant height (0.450), ear height (0.428), and thousand seed weight (0.516), suggesting its association with overall plant growth and reproductive capacity. Thousand seed weight showed a positive relationship with grain yield (0.256), although the association was non-significant, indicating that seed weight alone may not determine yield performance and should be considered along with other yield components. The anthesis–silking interval (ASI) showed weak and non-significant associations with most traits, including plant yield (−0.066). This indicates that water availability minimized reproductive stress and reduced the influence of ASI on yield variation. Overall, the correlation analysis demonstrated that plant height, ear height, ear length, kernel number traits, and flowering duration were the major contributors to yield variation among the maize genotypes. Traits exhibiting significant positive associations with grain yield, particularly plant height, ear height, and ear length, can be considered important selection criteria in maize improvement programmes. The negative association of flowering duration with yield suggests that the selection of early flowering and high-yielding lines may enhance breeding efficiency. Selection based on multiple correlated traits will improve the efficiency of maize hybrid development programmes. These findings highlight the importance of integrating morphological and reproductive traits for the development of superior maize hybrids adapted to favourable irrigated environments (Mohanapriya *et al* 2023).

Path Coefficient Analysis of Yield Contributing Traits

Path coefficient analysis was carried out to determine the direct and indirect contributions of yield-related traits towards grain yield in maize inbred lines under irrigated conditions (Guo *et al.*, 2023). The analysis revealed that the studied traits collectively influenced grain yield, with a residual effect of 0.6263, indicating that the selected characters explained a considerable proportion of the variation in yield.

The correlation coefficient between each trait and grain yield was partitioned into direct and indirect effects. Plant height, ear height, and ear length showed significant positive correlations with grain yield (0.5083, 0.4185, and 0.4459, respectively), indicating their importance in yield determination. Among these traits, ear height exhibited the highest positive direct effect (0.6734) on grain yield, followed by plant height (0.5778) and ear length (0.1261). The positive direct effects along with positive correlations suggest that these traits have a true association with yield and can be effectively used as selection criteria in maize improvement programmes. The positive correlation of plant height with grain yield was mainly attributed to its direct effect (0.5778) and indirect contribution through ear height (0.5778×0.8581 relationship), indicating that taller plants with suitable ear placement had better yield potential under irrigated conditions. Similarly, ear height contributed positively to yield both directly and indirectly through plant growth-related traits, highlighting its role in maintaining favourable plant architecture.

Among reproductive traits, days to tasseling and days to silking showed significant negative associations with grain yield ($r = -0.4247$ and -0.4551 , respectively). The anthesis–silking interval (ASI) showed a weak and non-significant correlation with grain yield ($r = -0.0663$). Although ASI exhibited a positive direct effect, its indirect effects through other traits reduced its overall contribution, suggesting that ASI had limited importance under optimum moisture conditions where reproductive stress was minimized. Yield component traits showed favourable contributions towards grain yield. Number of kernel rows per cob recorded a positive direct effect (0.2436), followed by thousand seed weight (0.2237) and kernels per row (0.1462). Their positive direct effects indicate that these traits contribute directly to grain productivity and should be considered during selection. The direct effect of tassel length was negative (−0.1929), while its correlation with grain yield was positive but non-significant (0.2204), suggesting that its association with yield was mainly due to indirect effects through other plant growth traits. Similarly, thousand seed weight showed a positive direct contribution but a moderate relationship with yield, indicating that seed size alone is insufficient for yield improvement without considering other yield components. Path analysis revealed that ear height, plant height, ear length, kernel row number, and thousand seed weight were the most important traits contributing positively to grain yield. The significant positive correlations combined with high direct effects indicate that these traits can serve as reliable selection criteria for improving maize productivity (Fadhli *et al*, 2025).

CONCLUSION

Genotypes VIM 626, VIM 620, VIM 600, VIM 637, VIM 593, VIM 448, VIM 309 were genetically divergent genotypes. The genotypes VIM 600 and VIM 593 possess good yield and yield contributing traits. PCA revealed that selection based on plant architecture traits, plant height, ear height, flowering traits, ear characteristics, kernel traits, thousand seed weight, and grain yield were the major contributors to genetic variation among the maize genotypes and can be considered for identifying superior and diverse parental lines in maize breeding programmes. Significant positive associations with grain yield, particularly plant height, ear height, and ear length, highlighted the importance of the traits in selection criteria for improving the yield

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Table. 1. Genotypes used in the study

Genotypes used in the study							
S.No.	Genotype	S.No.	Genotype	S.No.	Genotype	S.No.	Genotype
1.	VIM 300	11.	VIM 492	21.	VIM 591	31.	VIM 609
2.	VIM 302	12.	VIM 528	22.	VIM 593	32.	VIM 615
3.	VIM 309	13.	VIM 564	23.	VIM 594	33.	VIM 616
4.	VIM 349	14.	VIM 579	24.	VIM 595	34.	VIM 619
5.	VIM 377	15.	VIM 580	25.	VIM 598	35.	VIM 620
6.	VIM 419	16.	VIM 582	26.	VIM 600	36.	VIM 626
7.	VIM 421	17.	VIM 584	27.	VIM 601	37.	VIM 627
8.	VIM 425	18.	VIM 585	28.	VIM 605	38.	VIM 631
9.	VIM 448	19.	VIM 587	29.	VIM 606	39.	VIM 637

10.	VIM 449	20.	VIM 590	30.	VIM 607		
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Table2. Eigen value, percentage of variance and cumulative percentage of variance

Components	Eigenvalue	Percentage of variance	Cumulative percentage of variance
PC1	3.65	33.19	33.19
PC 2	1.86	16.94	50.13
PC 3	1.38	12.58	62.71
PC 4	1.13	10.28	72.99
PC 5	1.04	9.46	82.45
PC 6	0.63	5.76	88.22
PC 7	0.53	4.82	93.04
PC 8	0.41	3.68	96.72
PC 9	0.26	2.41	99.13
PC 10	0.10	0.87	100.00
PC 11	0.00	0.00	100.00

Table. 3. Principal component analysis for yield and yield attributing traits

Traits	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Plant Height	0.805	-0.271	0.130	-0.008	0.381
Ear Height	0.697	-0.407	0.057	-0.028	0.501
Ear Length	0.258	0.765	-0.223	0.084	0.144
Tassel Length	0.594	-0.254	0.483	0.270	-0.329
Days to 50% tasselling	-0.788	0.068	0.463	0.173	0.309
Days to 50% Silking	-0.817	0.075	0.230	0.321	0.371
Anthesis to Silking Interval	-0.028	0.014	-0.796	0.481	0.192
Kernels per row	0.227	0.637	0.409	0.167	0.188
No of Kernels rows per cob	0.280	0.686	0.064	-0.303	-0.164
1000 seed weight	0.447	0.084	0.095	0.751	-0.318
Plant yield	0.692	0.284	0.006	-0.048	0.287

Table. 4. Correlation analysis of yield and yield attributing traits

Traits	Plant Height	Ear Height	Ear Length	Tassel Length	DA T	DA S	A SI	KP R	N K R	T S W	Plant yield
Plant Height	1 **										
Ear Height	0.8581 **	1 **									
Ear Length	-0.0331	0.0584	1 **								
Tassel Length	0.4496 **	0.4282 **	-0.1376	1 **							

DAT	- 0.4 748 **	- 0.40 32 *	- 0.1 53 5	- 0.33 02 *	1 **						
DAS	- 0.5 149 **	- 0.40 82 **	- 0.1 08 5	- 0.43 45 **	0.95 75 **	1 **					
ASI	- 0.0 597	0.03 49	0.1 85 7	- 0.31 47	- 0.24 26	0.04 7	1 **				
KPR	0.1 503	0.00 64	0.4 27 1 **	0.14 76	0.02 74	- 0.01 04	- 0. 13 47	1 **			
NKR	0.0 553	- 0.10 75	0.4 09 2 **	- 0.07 69	- 0.23 72	- 0.29 48	- 0. 19 07	0.42 68 **	1 **		
1000 seed weight	0.2 676	0.10 25	0.1 41 9	0.51 63 **	- 0.25 18	- 0.21 27	0. 16 8	0.17 67	0.0 79 7	1 * *	
Plant yield	0.5 083 **	0.41 85 **	0.4 45 9 **	0.22 04	- 0.42 47 **	- 0.45 51 **	- 0. 06 63	0.24 99	0.3 01 5	0. 2 5 4	1 * *

Days to 50% tasselling – DAT, Days to 50% Silking –DAS, Anthesis to Silking Interval –ASI, Kernels per row – KPR, No of Kernels rows per cob NKR

Figure. 1

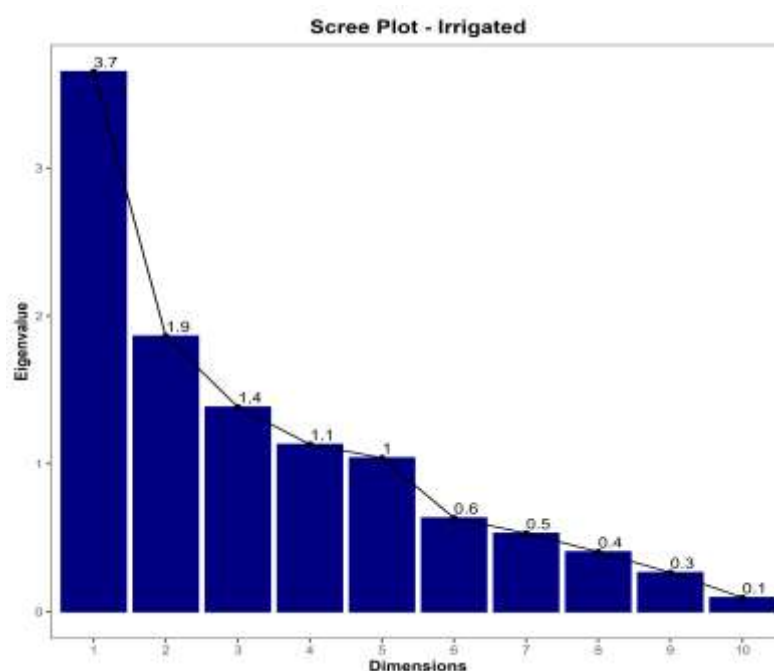


Figure. 2

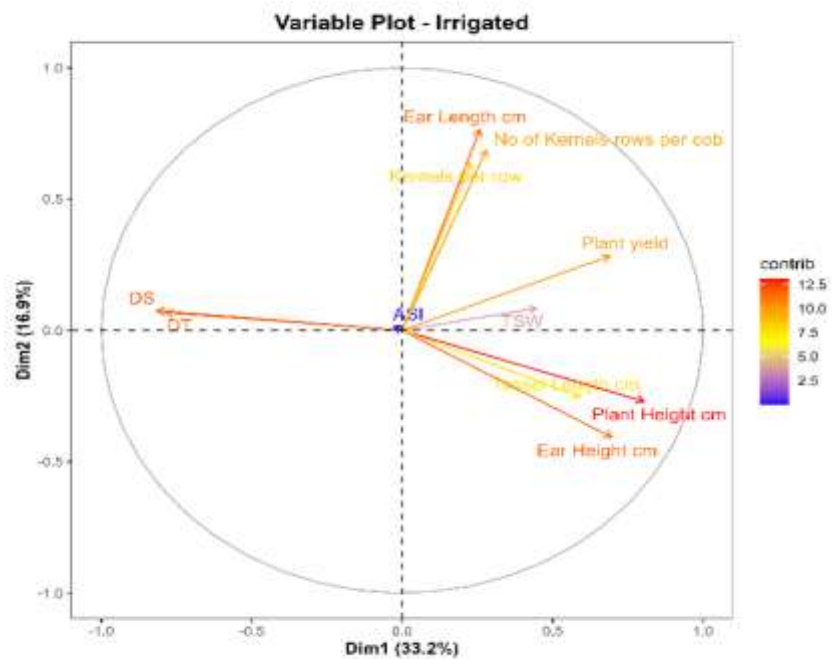


Figure. 3

