INT. J. BIOL. BIOTECH., 22 (2): 305-312, 2025.

ASSESSMENT OF GENETIC DIVERSITY FOR YIELD ASSOCIATED TRAITS IN NEWLY SYNTHESIZED MAIZE (*ZEA MAYS* L.) HYBRIDS

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ABSTRACT

This study assessed the genetic diversity and performance of local maize hybrids for yield and associated traits. A total of 27 hybrids were assessed for twelve traits using a randomized complete block design with two replications at the Maize Research Station, AARI Faisalabad during the Kharif 2023 season. Analysis of variance revealed significant differences ($p<0.01$, $p<0.05$) among hybrids for all measured traits. The highest cob length (19.85 cm) was recorded in local hybrid FH-1400. NK-8441 exhibited highest grain length (13.3 mm) and FH-1622 showed highest 100 grain weight (34.55 g). Grain yield ranged from 114.4 q/ha (FH-1743) to 48.89 quintals/ha (FH-1528), with FH-1743 being the top-performing hybrid. The correlation analysis revealed significant positive associations between cob length and grains per row ($r = 0.51$) and between plant height and ear height ($r = 0.64$). Principal Component Analysis (PCA) explained 83.6% of the total variation across six principal components, with the first two PCs accounting for the largest share (43%). Key contributors to the total variance included cob girth, grain length, and 100-grain weight. This comprehensive assessment underscores the potential of specific hybrids, such as FH-1743 and FH-1453, for enhancing yield and related traits in maize breeding programs.

Key-words: PCA, LSD, Pearson Correlation, Kernel related traits

INTRODUCTION

Maize (*Zea mays*, 2n=20) is an important cereal crop belonging to family *Poaceae*. It is ranked 3rd most widely cultivated and consumed cereal after wheat and rice globally hence providing the food and nutritional security to the world's poorest regions including Africa, Asia and Latin America (Ogunniyan *et al*., 2014). According to an estimate, Maize contributes about 15 to 56% of the total daily protein and calories to diets of the poor people in many developing countries of Africa and Latin America where the animal protein is scarce and expensive (Prasanna *et al*., 2001). Utility of the Maize crop as staple food attributes to its high nutritive value being rich source of starch (72%), protein (10%), oil (4.8%), fiber (8.5%), sugar (3%) and ash (1.7%) (Mustafa *et al*., 2014; Singh *et al*., 2020). Apart from being the staple food to millions of people in the world, Maize crop holds an important position in the animal fodder, poultry and industrial sector in the form of its value added products such as oil, starch, ethanol and textile dyes etc. (Shehzad *et al*., 2019). Maize is also known as the 'queen of cereals' because of its vast genetic production potential (Magar *et al*., 2015).

Maize is one of the most widely adapted crop to diverse environmental conditions and the only cereal crop which is grown in different seasons (Ghani *et al*., 2020). The crop requires moderate climate loamy soils for better optimum growth and production (kumar *et al*., 2017; Rocha *et al*., 2019). In Pakistan, Maize is cultivated in both autumn and spring season and preferably chosen by the farmers due to its better grain yield per acre and established industry for further processing (Jamil *et al*., 2020). During 2023-24, maize was cultivated on an area of 1.6 Mha and produced annual yield of 9.8 million tons. The annual maize production in the country was reduced 10.4% compared to previous year due to the decreased area under the cultivation of the crop (Economic survey of Pakistan 2023-24). An increased and consistent food supply is required to meet the global food demands of the increasing world population. Likewise, demand for Maize grain production is predicted to be quadruple by 2025 with major share of production in the developing countries. Moreover, maize crop development is also affected by the intensifying global climate (Balbaa *et al*., 2022). Keeping the current scenario of increasing world population and extreme climate patterns, it is highly needful to develop maize hybrids giving better yields and resilient to extreme weather conditions (Mallhi *et al*.,2025).

Correlation analysis is a statistical method used to measure and analyze the strength and direction of the relationship between two or more variables (Yousaf *et al*., 2021). This approach is fundamental in scientific research as it provides insights into whether and how variables are related, laying the groundwork for understanding

underlying patterns and potential causal mechanisms (Yousaf *et al*., 2022). By quantifying relationships through correlation coefficients, researchers can evaluate the extent to which changes in one variable are associated with changes in another.

Principal Component Analysis (PCA) is a widely used statistical technique for dimensionality reduction and data visualization. By transforming original variables into a smaller set of uncorrelated components, PCA simplifies complex datasets while retaining most of the variance. This is achieved by identifying orthogonal directions known as principal components that maximize the variance in the data (Aman *et al*., 2020).

In this study maize hybrids have been evaluated for yield and its related traits using statistical and multivariate analysis to explore the variation present among them and select for the candidate traits for future breeding programs.

MATERIAL AND METHODS

Experimental Location and Plant Materials:

This experiment was conducted at Maize Research Station, AARI Faisalabad. Plant-plant distance was 15 cm and row-row distance was 75 cm. Recommended doses of NPK were applied and appropriate plant protection measures implemented for optimum crop health (Shehzad *et al*., 2019). The study was conducted in field condition during Kharif 2023. Twenty seven hybrids viz., FH-1205, FH-1206, FH-1337, FH-1400, FH-1428, FH-1453, FH-1528, FH-1622, FH-1675, FH-1677, FH-1678, FH-1682, FH-1685, FH-1720, FH-1721, FH-1724, FH-1725, FH-1731, FH-1740, FH-1743, FH-1744 and FH-1745 and five check hybrids viz., DK6724, FH-1046, FH-988, NK-8441 and YH-5427 were evaluated in RCBD design with two replications. These hybrids were acquired from germplasm collection of Maize Research Station, AARI Faisalabad. The fields chosen for the investigation had well-aerated, clay loamy soil.

Data Collection of Grain Yield and its Related Traits:

For data collection on the studied traits, grain yield (yield) was recorded in quintals per hectare (q/ha) and calculated using the equation described by Yousaf *et al*. (2022). Cob length (CL) was measured using a 30 cm rod while cob girth (CG), grain length (GrL), grain width (GrWd) and grain thickness (GrTh) were measured using vernier calipers. A weighing balance was used to determine the 100-grain weight (GrWt). Days to 50% silking (DS) were recorded at the time of anthesis. The number of grains per row (GpR) was counted. Plant (PHt) and ear height (ErHt) were measured using a long rod. Shelling percentage (Shell) was calculated using the following formula.

$$Shelling\ \% = \frac{Grain\ weight}{Ear\ weight} \times 100$$

Statistical Data Analysis:

The collected data of grain yield and its associated traits were statistically analyzed for analysis of variance (Steel *et al*., 1997) with Statistix 8.1 (Analytical Software, Tallahassee, FL, USA). Replicated data were taken to find Least Significant Differences (LSD) for all pairwise comparison. Principal Component Analysis (PCA) was calculated for data interpretation and presentation. Various libraries of R were used to interpret the data and collage images of LSD and PCA.

RESULTS

Analysis of variance (ANOVA) and All Pairwise Comparison (LSD):

All the hybrids were found to be significantly different from one another ($p<0.01$, $p<0.05$) for all the traits under study. Traits i.e. cob length, cob girth, grain length, grain width, grain thickness, 100 grain weight, plant height, shelling % and yield showed high significant differences ($p<0.01$), while days to 50% silking, grains per row, ear height showed significant differences ($p<0.05$).

Maximum cob length (19.85 cm) was observed in the local hybrid FH-1400 while the least (14.5 cm) was observed in FH-1740. FH-1400 was found at par with the check hybrid FH-1046 for cob length. Highest and lowest cob girth of 5.05 and 4.1 cm was observed in check hybrid FH-988 and local hybrid FH-1682 respectively. Local hybrid FH-1400 was found significantly different from the check FH-988 but was found at par with the other check DK-6724 with the CG of 4.95 cm. Check hybrid NK-8441 displayed highest grain length of 13.3 cm while local hybrid FH-1685 came last with the least grain length of 9.9 cm. Local hybrid FH-1622 was found significantly different from the check NK8441 but was found at par with the check FH-988 with GrL of 13.05 cm. Grain thickness ranged from 5.2 MM (FH-1740) to 3.5 mm (NK-8441) in all the hybrids under study. Local hybrids FH-1740, FH-1743 and FH-1675 were found at par with each other with higher GrTh. Grain width (GrWd) ranged from 9.7 mm (FH-1428) TO 7.6 MM (FH-1685) in all the hybrids under study. Local hybrids FH-1428 and FH-1725

were found at par with each other with highest GrWd. 100 grain weight (GrWt) ranged from 34.55 g (FH-1622) to 23.6 g (FH-1740) in all the hybrids. FH-1622 was found at par with the check hybrid NK-8441 with highest GrWt (Fig 1).

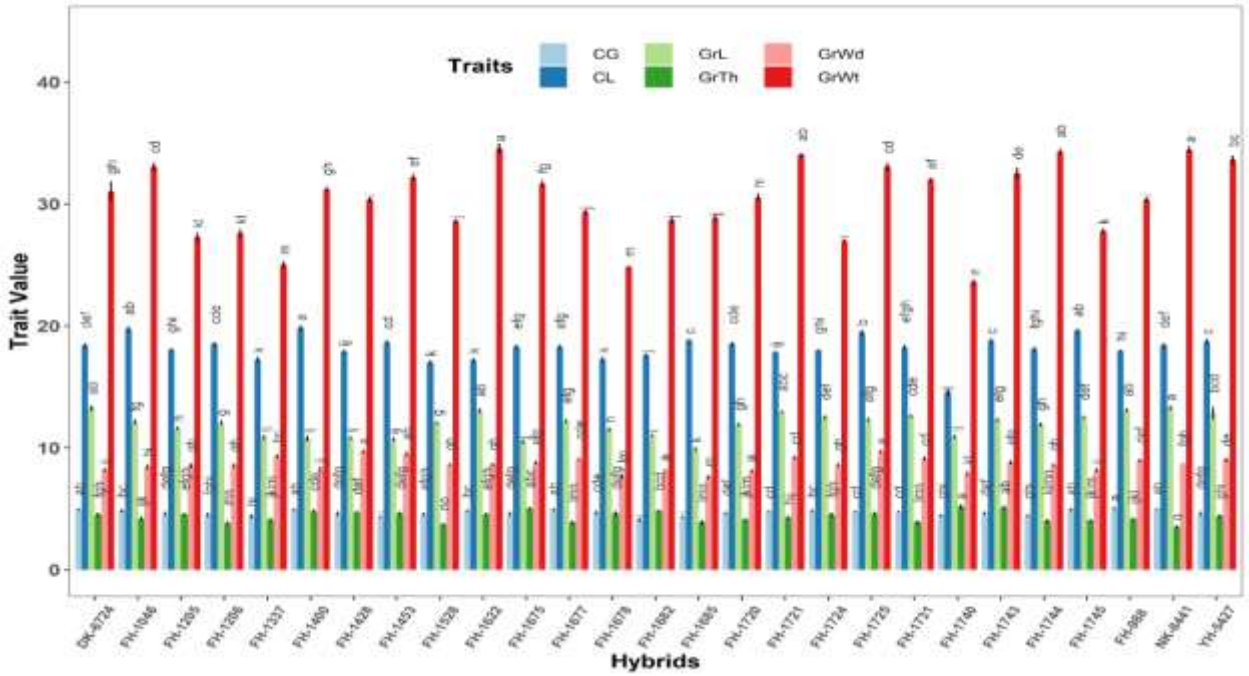

Fig. 1. All Pairwise Comparison of Means Of Maize Hybrids For Cob Girth, Cob Length, Grain Length, Grain Thickness, Grain Width and 100-Grain Weight.

Table 1. ANOVA for Grain Yield and its Related Traits of Maize Hybrids.

Trait	Genotypes	Error
Cob length (cm)	2.18**	0.002
Cob girth (cm)	0.11**	0.002
Grain length (mm)	1.79**	0.02
Grain width (mm)	0.61**	0.01
Grain thickness (mm)	0.38**	0.006
100-grain weight (g)	19.28**	0.12
Days to 50% silking	6.59*	5
Grain per row	21.1*	0.79
Plant height (cm)	284.75**	77.28
Ear height(cm)	108.13*	48.39
Shelling (%)	6.65**	0.46
Yield (quantiles/ha)	5436139**	1128418
DF	26	26

Days to 50% silking (DS) ranged from 64 days (DK-6724) to 57 days (FH-1743) in all the hybrids. Local hybrid FH-1743 was found to be the earliest maturing candidate and at par with local hybrids FH-1678, FH-1720, FH-1206, FH-1205, FH-1682, FH-1721, FH-1528 and FH-1428 and check hybrids FH-988anf FH-1046. Ear height (ErHt) ranged from 73.5 cm (FH-1622) to 42.5 cm (FH-1724). Both FH-1622 and FH-1724 were found to be significantly different from all the other hybrids for ErHt. Grains per row (GpR) ranged between 47 grains (FH-1745) to 35 grains (FH-1682) in a row. FH-1745 was found to be significantly superior from all other hybrids with highest GpR. Plant height (PHt) ranged from 162.5 cm (FH-1453) to 112.5 cm (FH-1685). FH-1453 was found to be the significantly tallest one among all the hybrids. Shelling percentage (Shell) ranged from 90.3 % (FH-1740) to 81.3 % (FH-1744) among all the hybrids. Both FH-1740 and FH-1744 found to be significantly different from all other hybrids for shelling percentage. Yield ranged from 114.4 quantile/ha (FH-1743) to 48.89 quantiles/ha (FH-1528). FH-1743 was the significantly superior from all other hybrids for total grain yield (Fig 2).

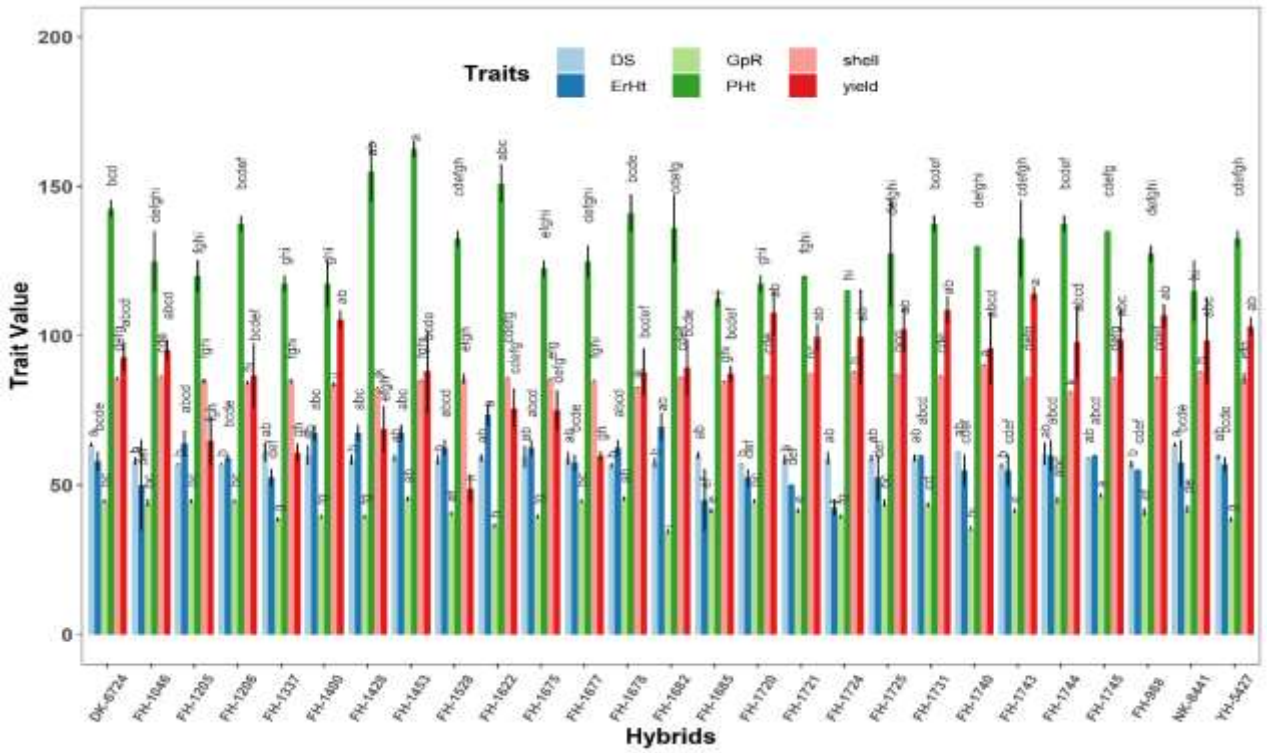

Fig. 2. All Pairwise Comparison of Means Of Maize Hybrids for Days to Silking, Ear Height, Grains per Row, Plant Height, Shelling Percentage and Yield.

Table 2. Minimum, Maximum, Mean, SD, CV% and LSD Values for Yield and its Related Traits.

Trait	Min	Max	Mean	SD	CV%	LSD
Cob length (cm)	14.55	19.85	18.18	1.04	0.29	0.1
Cob girth (cm)	4.1	5.05	4.67	0.23	1.03	0.09
Grain length (mm)	9.9	13.3	11.9	0.94	1.28	0.31
Grain width (mm)	7.6	9.7	8.66	0.55	1.16	0.2
Grain thickness (mm)	3.5	5.2	4.36	0.44	1.9	0.17
100-grain weight (g)	23.6	35.05	30.42	3.23	1.18	0.73
Days to silking	56	64	59.01	1.81	3.79	4.59
Grain per row	34	47	41.7	3.25	2.14	1.83
Plant height (cm)	112.5	162.5	130.57	12.68	6.56	17.59
Ear height(cm)	42.5	73.5	58.37	7.35	11.92	14.3
Shelling (%)	81.2	90.2	85.63	1.84	0.8	1.4
Yield (Q/ha)	48.8	114.1	89.61	17.01	11.98	22.06

Correlation analysis

Correlation analysis was performed in order to determine the association between the traits under study. Significant positive correlation ($p \leq 0.05$) was observed between cob length and grains per row (0.51), cob length and 100-grain weight (0.48), cob girth and grain length (0.66), grain length and 100-grain weight (0.47) and plant height and ear height (0.64). However, significant negative correlation ($p \leq 0.05$) was observed between grains per row and grain thickness (-0.43) and Shelling percentage and ear height (-0.39). All other correlation remained non-significant such as yield displayed non-significant positive correlation with the cob length, cob girth, grains per row, grain length, grain thickness, 100-grain weight and Shelling percentage (Fig 3).

Principal Component Analysis (PCA):

Principal component analysis was used to categorize the yield and its related traits into six main principal components (PCs) covering 83.6 % of the total variation. The first two principal components or Dim explains the 43% of the total variance. From the scree plot, PC1 turned out to be the most important component explaining

highest of the variance amongst all components. The scatter plot of the individuals was drawn for the grain yield considering first two PCs on the x and y- axis respectively. Individuals far from the axis such as FH-1453 and FH-1428 contributed more towards the variation as compared to the individuals lying near or on the axis such as FH-1046 and FH-1675 etc.

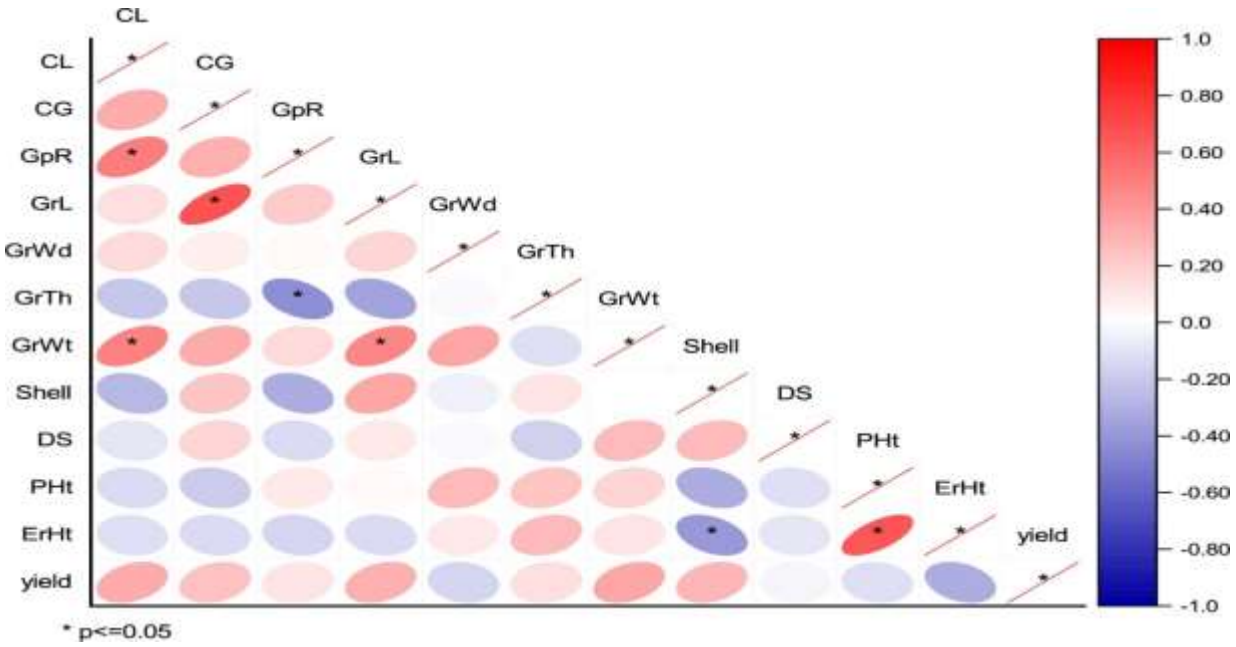

Fig. 3. Correlation Analysis of Yield and its Related Traits for all Maize Hybrids.

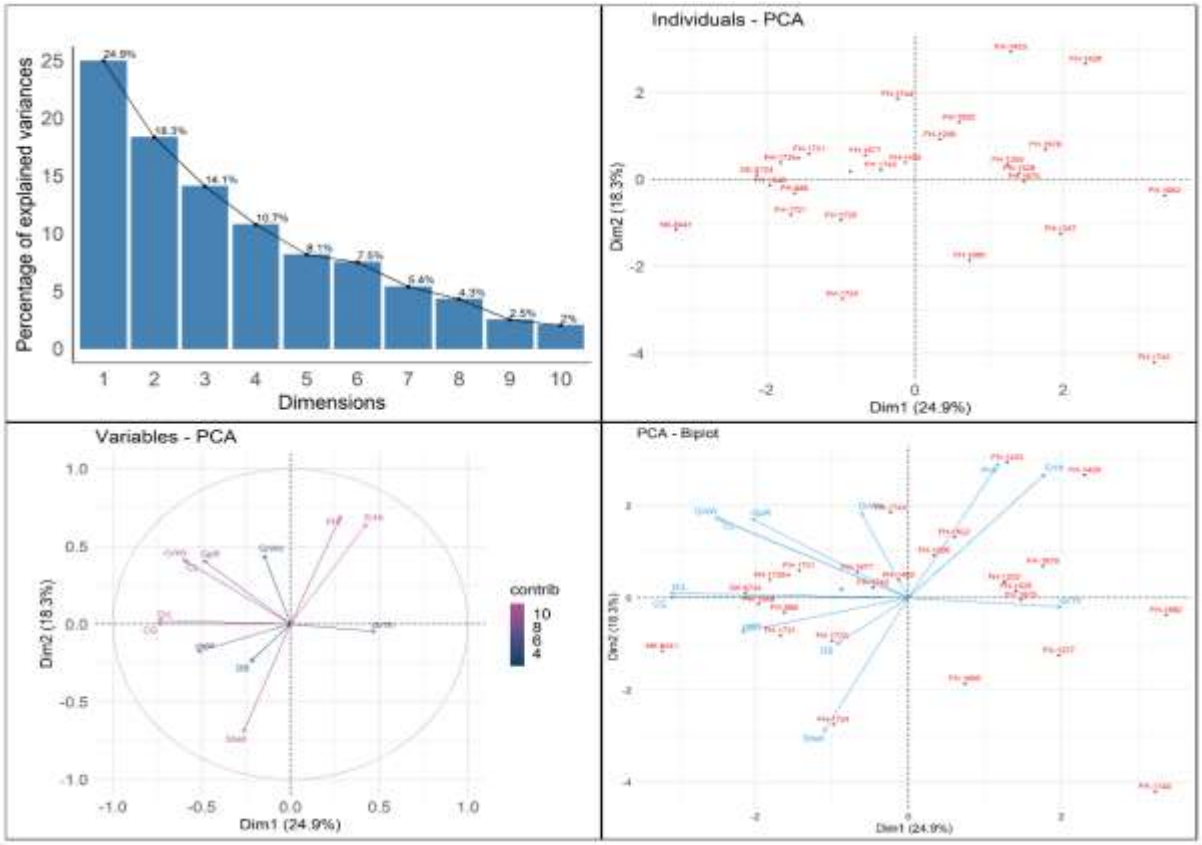

Fig. 4. Principal Component Analysis of Twelve Traits for 27 Maize Hybrids.

The variables PCA plot illustrates the correlation among the variables and their contribution to Dim1 and Dim2. The arrowheads of GrL, CG, and Y point in the same direction, indicating a positive correlation, while they are oriented opposite to GrTh. Similarly, PH and EH have arrowheads pointing in the same direction. DS, GrTh, and GrWd exhibit shorter arrow lengths, suggesting low variability in these traits. Lastly, the PCA biplot integrated both the individuals and variables in order to explain how the variables influenced the placement of individuals on the PCA plot and the relationship between them. For instance, plant height turned out to be the most influencing variable for the placement of FH-1453 on the PCA plot. Likewise yield exhibited the highest variation for the individual FH-1721 (Fig 4).

DISCUSSION

Characterization and evaluation of maize hybrids based on the variation in their yield and its related traits is the fundamental objective in maize breeding program (Yousaf *et al*., 2023). The analysis of variance (ANOVA) revealed significant differences among the hybrids for grain yield and all associated traits, including cob length, cob girth, grain length, grain width, grain thickness, 100-grain weight, days to 50% silking, grains per row, plant height, ear height, and shelling percentage. These significant variations suggest that these traits contribute to yield differences and can be effectively utilized in breeding programs to enhance maize grain yield (Singh *et al*., 2020).

Correlation analysis helps to determine the direction and strength of associations between traits. In maize breeding, traits positively correlated with yield are crucial for developing high-yielding hybrids (Shehzad *et al*., 2019). This study identified both positive and negative associations among traits. A significant positive correlation was found between cob length and grains per row, suggesting that an increase in cob length leads to a higher number of grains. Cob girth was positively correlated with grain length, indicating that an increase in cob girth can enhance grain length due to the additional space provided by the increased girth or diameter. These finding are supported by Yousaf *et al*., 2022 who found positive relationship and stated that improvement is beneficial for target trait enhancement. Similarly, grain length was correlated with 100-grain weight, meaning that an increase in grain length contributes to greater grain weight. Additionally, this research suggests that plant height may enhance ear height. Conversely, a significant negative correlation was observed between grains per row and grain thickness, indicating that an increase in grain thickness may reduce the number of grains per row. Finally, total grain yield showed a positive but non-significant correlation with 100-grain weight, grain length, and cob length. Therefore, improving these traits may contribute to increased grain yield.

Principal Component Analysis (PCA) is a widely used technique for examining trait relationships and identifying key contributors to overall variation in plant breeding (Mustafa *et al*., 2014). In maize breeding, grain yield is a complex trait influenced by multiple factors, requiring a detailed assessment of variability within breeding populations. To enhance grain yield effectively, selecting parental lines with substantial genetic diversity is crucial for breeding high yielding hybrids (Rafique *et al*., 2020).

The PCA variable plot illustrates the relationships among traits and their contributions to Dim1 and Dim2. Traits such as GrL, CG and yield point in the same direction, indicating a strong positive correlation, while GrTh is oriented oppositely, suggesting a negative association. Similarly, PHt and ErHt) are closely aligned, reflecting their shared influence. Traits like DS, GrTh, and GrWd have shorter arrow lengths, indicating lower variability among these traits (Yousaf *et al*., 2021). The arrowheads of GrWt, CL and GpR are also moving in the same direction, describing their dependence on one another. This implies that GrWt can be improved by enhancing the traits that move parallel to the target trait (Rafique *et al*., 2020).

The PCA biplot integrates both genotypes and traits, offering insights into their interrelationships and how variables influence genotype placement. For instance, plant height was the most influential factor in positioning FH-1453, whereas FH-1721 exhibited the highest yield variation, distinguishing it from other genotypes. Further analysis revealed that grain length, cob girth, and grain thickness were the primary contributors to PC1, while grain width and shelling percentage dominated PC2. This differentiation highlights the complexity of yield determination, where various traits contribute through distinct pathways. Overall, the PCA biplot serves as a valuable tool for understanding trait interactions and genotype variability, aiding in the identification of key traits for targeted breeding strategies.

Summary/Conclusion

It was concluded that ample amount of variability existed among all twelve traits of 27 hybrids, thus, selection for enhancement of maize grain yield would be proved efficient. Correlation analysis identified positively associated traits, such as cob length with grains per row, while found negative correlation between grains per row and grain thickness. Finally, this suggests that selection for grain length, 100 grain weight and cob girth traits can lead to

genetic gains in grain yield. Additionally, PCA biplots revealed that some genotypes FH-1743 and FH-1453 did better for grain yield and its components, emphasizing their potential for breeding programs.

Ethics Declarations:
Funding: No funding was collected to perform this study
Conflicts of interests: The authors declare that they have no known competing financial interests or conflicts in performing this research that could influence the work reported in this manuscript.

Author Contribution to Perform this Research

Order	Name	Contribution
1	Ahsan Raza Mallhi	Design the experiment and support crop Production
2	Aamar Shehzad	Make Figures and Tables
3	Samia Fatima	Wrote manuscript, performed experiment
4	Najma Parveen	Statistical Analysis and interpretation
5	Adila Shahzadi	Data Analysis using R, Grammar correction
6	Muhammd Qasim Ali	Data collection and Arrangement
7	Muhammad Kashif Aziz	Make correction and review the article

REFERENCES

Aman, J., K. Bantte,S. Alamerew and D.B. Sbhatu (2020). Correlation and path coefficient analysis of yield and yield components of quality protein maize (*Zea mays* L.) hybrids at Jimma, western Ethiopia. *International Journal of Agronomy*, ID: 9651537. doi.org/10.1155/2020/9651537

Balbaa, M.G., H.T. Osman, E.E. Kandil, T. Javed, S.F. Lamlom, H.M. Ali, H.M. Kalaji, J. Wróbel, A. Telesiñski, A. Brysiewicz, R.Y. Ghareeb, N.R. Abdelsalam and A.M. Abdelghany (2022). Determination of morpho-physiological and yield traits of maize inbred lines (*Zea mays* L.) under optimal and drought stress conditions. *Frontiers in Plant Science*, 13:959203. doi: 10.3389/fpls.2022.959203

Ghani, A., M.I. Yousaf, M. Arshad, K. Hussain, S. Hussain, D. Hussain, A. Hussain and A. Shehzad (2020). YH-5427: A highly productive, heat tolerant, stalk rot and lodging resistance, yellow maize hybrid of punjab, pakistan. *International Joural of Biology and Biotechnology*, 17(3): 561-570.

Jamil, S., R. Shahzad, E. Yasmeen, S.U. Rahman, M. Younas and M.Z. Iqbal (2020). DNA fingerprinting of pakistani maize hybrids and parental lines using simple sequence repeat markers. *Pakistan Journal of Botany*, 52 (6): 2133-2145. doi.org/10.30848/PJB2020-6(17)

Kumar, R., G.K. Chikkappa, S.B. Singh, G. Mukri, J. Kaul, A.K. Das, D. Sravani, D.S. Olakh, D. Bhatia (2017). Multivariate analysis for yield and its component traits in experimental maize hybrids. *Journal of Agricultural Science*, 9(3): 219-225. doi:10.5539/jas.v9n3p219

Magar, P.B., G.B. Khatri-Chhetri, S.M. Shrestha, T.R. Rijal (2015). Screening of maize genotypes against southern leaf blight (Bipolaris maydis) during summer in Rampur, Chitwan, Nepal. *Journal of the Institute of Agriculture and Animal Science*, 33:115-122.

Mallhi, A.R., A. Shehzad, M. Altaf, A. hussain, S. Saleem and R. Shahzad (2025). Pioneering new frontiers of maize breeding: Genesis of a novel high temperature stress tolerant hybrid FH-988. *Pakistan Journal of Botany*, 57(2): 433-440.

Mustafa H.S.B., M. Aslam, E-U Hasan, F. Hussain, J. Farooq (2014). Genetic variability and path coefficient in maize (Zea mays L.) genotypes. *Journal of Agricultural Sciences–Sri Lanka*, 2014, 9(1). 37-43. doi.org/10.4038/jas.v9i1.6352

Ogunniyan, D.J. and S.A. Olakojo (2014). Genetic variation, heritability, genetic advance and agronomic character association of yellow elite inbred lines of maize (*Zea mays* L.). *Nigerian Journal of Genetics*, 28(2): 24-28.

Pak. Economic Survey (2023-24). *Pakistan Bureau of Statistics*, Ministry of Planning, Development & Reform, Govt. of Pakistan, Islamabad, Pakistan.

Prasanna, B.M., S.K. Vasal, B. Kassahun and N.N. Singh (2001). Quality protein maize. *Current science*, (10):1308-1319.

Rafique, M., A. Shahzad, A.R. Mallhi, M. Abbas, K.M. Mughal and M.I. Yousaf (2020). Assessment of heritability, correlation, and path coefficient analysis for yield-associated traits in newly synthesized corn (*Zea mays L.*) hybrids. *J. Agric. Res*., 58(4): 233-237.

Rocha, R.S., M.R. Nascimento, J.T.B. Chagas, R.N. Almeida, P.R.D. Santos, D.P. Cruz, K.D.S Costa, G.A. Gravina, R.F. Daher (2019). Association among Agro-morphological Traits by Correlations and Path in Selection of Maize Genotypes. *Journal of Experimental Agriculture International*, 34(2):1-12.

Shehzad, A., M.I. Yousaf, A. Ghani, K. Hussain, S. Hussain and M. Arshad (2019). Genetic analysis and combining ability studies for morpho-phenological and grain yield traits in spring maize (*Zea mays L.*). *International Journal of Biology and Biotechnology*, 16(4): 925-931.

Singh, D., A. Kumar, R. Kumar, N. Kushwaha, T.A. Mohanty and P. Kumari (2020). Genetic variability analysis of QPM (Zea mays L.) inbreds using morphological characters. *International Journal Current Microbiology and Applied Science*, 9(2):328-338.

Steel, R.G., J.H. Torrie and D.A. Dickey (1997). Principles and procedures of statistics: a biometrical approach.

Yousaf, M.I., M.W. Riaz, Y. Jiang, M. Yasir, M.Z. Aslam, S. Hussain, *et al.*, (2022). Concurrent effects of drought and heat stresses on physio-chemical attributes, antioxidant status and kernel quality traits in maize (*Zea mays L.*) hybrids. *Frontier in Plant Science*, 13: 898823. doi: 10.3389/fpls.2022.898823

Yousaf, M.I., N. Akhtar, A. Mumtaz, A. Shehzad, M. Arshad, M. Shoaib and A. Mehboob (2021). Yield stability studies in indigenous and exotic maize hybrids under genotype by environment interaction. *Pakistan Journal of Botany*, 53(3): 941-948. doi: 10.30848/PJB2021-3(41)

Yousaf, M.I., M.W. Riaz, A. Shehzad, S. Jamil, R. Shahzad, S. Kanwal, A. Ghani, F. Ali, M. Abdullah, M. Ashfaq and Q. Hussain (2023). Responses of maize hybrids to water stress conditions at different developmental stages: accumulation of reactive oxygen species, activity of enzymatic antioxidants and degradation in kernel quality traits. *Peer Journal*, 11:e14983. doi 10.7717/peerj.14983

(*Accepted for publication March 2025*)