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Yield Related Traits Prioritization in Maize (*Zea mays L.*) Hybrid Breeding using Principal Component Analysis (PCA)

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Abstract:

The present study comprises of 16 indigenous hybrids with two replications and evaluated in RCBD during Kharif 2023 to assess the hybrids for kernel yield and its associated traits at Faisalabad, Punjab, Pakistan. Analysis of variance revealed that plant height (PHt), ear height (ErHt), ear length (ErL), ear girth (ErG), kernel/row (KeRo), kernel length (KeL), kernel width (KeW), kernel thickness (KeTh), 100 kernel weight (KW), shelling % (Shell) showed highly significant variation, kernel yield (Y) possessed significant variation while days to 50% silking (Silk) showed non-significant variation among 16 hybrids. Pearson correlation analysis revealed that highly significant association found between PHt and KeW (0.72**), KW and ErL (0.68**), KeRo and KeTh (-0.64**). Significant correlation found between KW and KeRo (0.53*), ErL and KeRo (0.52*), ErG and KeL (0.57*), KW and KeTh (-0.51*), KeL and KeTh (-0.53*). The first two components of PCA accounted for 53.2 % of the total variance. PCA biplots arrow for Y aligns in the direction of ErG and KeL that showed significant association for Y improvement. Arrow head of PHt and ErHt point in the same direction, suggesting both traits can be improved simultaneously but they are oriented opposite to Y. Similarly, arrows of ErG and KeL point in the same direction, connecting positive relation between them which can be improved together. Kernel yield (Y) can be enhanced by improving ErG and KeL. Finally, FH-1720 and YH-5427 exhibited superior performance in Y, KeL and ErG, making them promising candidates for achieving higher grain yield.

Key Words: Maize hybrid, Trait breeding, correlation, multivariate analysis

Introduction

Maize is an essential crop both in Pakistan and globally. It is a C4 plant, enabling it to efficiently fix CO2 and achieve higher grain yields. It is a diploid species (2n = 20) that demonstrates remarkable adaptability to diverse agro-climatic conditions, making it suitable for cultivation across various regions worldwide. Farmers prefer maize due to its high grain yield per acre compared to other cereal crops and the presence of a well-established processing industry (Mallhi *et al.*, 2025). Maize serves a dual purpose, being utilized as both fodder and grain. Additionally, it is recognized as an industrial crop, with 70–80% of its production used in industrial applications, while only 13% contributes to human consumption globally (Yousaf *et al.*, 2023). The crop has a wide range of applications beyond human food and animal feed. Its cob powder is used as filler in explosives and in the production of glues, vinegar, plastics, resins, adhesives, artificial leather, paper, pulp, and hardboard (Ghani *et al.*, 2020). Maize also acts as a carrier and diluent in pesticide and insecticide formulations. Corn grain is processed into products such as flour, flakes, syrup, starch and oil (Yousaf *et al.*, 2021).

Pakistan is an agrarian country with huge fertile plains to cultivate a variety of crops to provide food to its people. In Pakistan, maize ranks as the third most significant cereal crop after wheat and rice (Jamil *et al.*, 2024). During the 2023-24, it was cultivated on 1.6 million hectares, producing 9.8 million metric tons with an average grain yield of 6199 kg/hectare. The crop contributes 2.9% to value addition in agriculture and 0.7% to the national GDP. Pakistan population is growing at the rate of 2.0 % with total population of 251 million. To feed such a big population, there is desirable to cultivate cereal crops with higher grain yield per acre (Pakistan, 2023-24).

Maize grain yield is shaped by the complex interrelationships among various traits which are influenced either positively or negatively by climatic fluctuations. Understanding the relationships among these traits is crucial for identifying the degree and direction of their associations, ultimately aiding in the enhancement of economic crop production (Alam *et al.*, 2022). So, for determining the dependency of yield on various traits, pearson correlation and Principal Component Analysis (PCA) serve as vital statistical methods commonly utilized in maize research. These tools facilitate the exploration of relationships and patterns among traits, offering valuable insights for improving yield and other agronomic characteristics.

Pearson correlation provides information pertinent to the strength and direction of the linear association between two variables, offering insights into how traits are interrelated. For instance, a strong positive correlation between two traits indicates that selecting for one trait may indirectly improve the other (Rafique *et al.*, 2020). Additionally, PCA is a multivariate technique used to reduce data dimensionality while retaining the maximum variance. It transforms correlated traits into uncorrelated components, enabling researchers to identify key traits contributing to variability in a dataset. In maize breeding, PCA helps prioritize traits for selection by pinpointing those with the highest influence on overall genetic diversity and productivity (Al-Naggar *et al.*, 2020).

The current study was conducted to assess the various maize kernel yield related traits using multivariate analysis to improve the grain yield of maize.

Material and Methods:

Experimental Location and Plant Materials

This study was conducted at the Maize Research Station, Ayub Agricultural Research Institute, Faisalabad (31.4504° N, 73.1350° E) at an elevation of 186 m above sea level. The research was carried out under field conditions during the Kharif seasons of 2023. A total of sixteen hybrids (FH-1046, FH-1205, FH-1400, FH-1428, FH-1453, FH-1675, FH-1677, FH-1682, FH-1685, FH-1720, FH-1724, FH-1731, FH-1740, FH-1744, NK-8441 and YH-5427) were assessed using a randomized complete block design (RCBD) with two replications. Each experiment unit possessed $4 \times 1.5\ m^2$ dimension. The spacing between plants was maintained at 15 cm, while the distance between rows was 75 cm. Recommended levels of NPK fertilizers were applied and crop protection practices were carried out to ensure optimal plant health (Shehzad *et al.*, 2019). At the maturity stage, ten plants of each hybrid from each plot were randomly chosen to record data of F_1 plant for all the traits. All the plants in each experimental unit were considered for plot yield which latterly converted to kg/ha. These hybrids were sourced from the germplasm collection of the Maize Research Station, AARI Faisalabad. The experimental plots were located on well-drained, clay loam soils.

Data Collection of Yield-Linked Traits

For this study, data of twelve traits i.e. plant height cm (PHt), ear height cm (ErHt), days to 50% silking (Silk), ear length cm (ErL), ear girth cm (ErG), kernels/row (KeRo), kernel length mm (KeL), kernel width mm (KeW), kernel thickness mm (KeTh), 100 kernel weight (KW), shelling percent (Shell) and kernel yield kg/ha (Y) were taken. Kernel yield (KY) was measured in kilogram/hectare (kg/ha) based on equation described by (Yousaf *et al.*, 2021).

Statistical Data Analysis

The collected data were statistically examined for analysis of variance (Steel, Torrie, & Dickey, 1997) with Statistix 8.1. Mean data of all the traits was utilized to find the Pearson Correlation and Principal Component Analysis (PCA) using various libraries of R (Mallhi *et al.*, 2025).

Results:

Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) unveiled that plant height, ear height, ear length, ear girth, kernel/row, kernel length, kernel width, kernel thickness, 100 kernel weight, shelling % found highly significant ($p \leq 0.01$) variation, kernel yield possessed significant ($p \geq 0.05$) variation while days to 50% silking showed non-significant variation among 16 hybrids. It is submitted that performances of hybrids were significantly different for all studied traits except days to 50% silking.

Pearson Correlation of Grain Yield Components

The Pearson correlation coefficient measures the linear relationship between two variables. Its values range from -1 (negative) to 1 (positive). The current correlation analysis revealed a highly significant positive relationship between plant height and kernel width (0.72), 100-kernel weight and ear length (0.68). In contrast, a negative relationship was observed between kernel rows and kernel thickness (-0.64). A positive and significant correlation was found between ear height and plant height (0.60), 100-kernel weight and kernel rows (0.53), ear length and kernel rows (0.52), as well as ear girth and kernel length (0.57). Conversely, a negative and significant correlation was observed between 100-kernel weight and kernel thickness (0-.51), as well as between kernel length and kernel thickness (-0.53). Kernel yield (Y) showed a non-significant relationship with all traits and it exhibited relatively stronger associations with kernel length (0.32) and kernel width (−0.36).

PCA Analysis of All Traits

Scree plot of principal component analysis (PCA) of all traits revealed that the first two principal components explained 53.2 % of the total variance, capturing the major patterns in the dataset. PC1 contributed 28.9 %, while PC2 accounted for 24.3% of the total variance.

Variables-PCA biplot (Figure 3C) is summarizing the relationship among twelve traits along the first two PCs that explaining 53.2% of the total variation. The length and direction of each trait arrow indicate the contribution and alignment among traits. Traits such as ErG, KeL and Shell have long arrows pointing in a positive direction along PC1, indicating that these traits strongly influence PC1 and positively correlated. KeW, PHt and Eht have a long arrow pointing negatively along PC1, showing that it is negatively associated with these traits. Silk and Y have relatively short arrows, indicating that their contributions to both PC1 and PC2 are smaller compared to other traits. Color gradient also confirmed that Silk and Y have lower contributions compared to other traits. Angle between arrow revealed the strength of relationship between variables. Small angles revealed high relationship, orthognola anlges means no relaltionship, while opposite angle means negative relationship among variables. KE, EL, KeRo are in the same direction with close anlge tells strong relationship among them. In the similar way, KeW, PHt, EHt has the same relationship. Shell is in opposite direction to EHt, PHt and KeW.

PCA-biplot (Figure D) is visualizing the distribution of 16 hybrids (shown in red) and their relationship with 12 traits (shown in blue) along the first two PCs that showing 53.2% variation. Hybrids located in the direction of a trait arrow are strongly associated with that trait. For instance, hybrids like FH-1720 and YH-5427 are positioned toward the Silk and Y arrows, indicating these hybrids are characterized by higher values for these traits. Conversely, hybrids such as FH-1428 and FH-1453, located near the EHt, PHt, KeW arrows, are associated with higher ear height, plant height and kernel width values.

In conclusion, FH-1720 and YH-5427 are superior for traits such as grain yield (Y), silk, shelling percentage (Shell), kernel length (KeL) and ear girth (ErG) while FH-1731, FH-1677 and FH-1400 excel in kernel width (KW), ear length (ErL) and kernel rows (KeRo).

Discussion:

ANOVA

The analysis of variance (ANOVA) revealed significant/highly significant differences among maize hybrids for eleven traits, as shown in Table 1. This indicates substantial genetic variability within the breeding material. Similar findings were reported by (Rafique *et al.*, 2020), who observed highly significant variations for traits such as days to tasseling (DT), days to silking (DS), plant height (PH), ear height (EH), 100 kernel weight (KW), kernel/cob (KC), cob length (CL), cob width (CW) and grain yield (GY). The presence of considerable genetic variability among the hybrid genotypes suggests that selective improvement of these traits could effectively boost grain yield (Rafique *et al.*, 2020; Rahman *et al*., 2017). The study also found that the coefficient of variation (CV) was less than 20% for all traits, demonstrating the accuracy and reliability of the research conducted under field conditions. Highly significant mean square (MS) results were observed for DS, PH, EH, ear length (EL), ear width (EWid), rows per ear, kernels per ear and 1000-grain weight (GW), validating the findings of (Rafique *et al.*, 2020). Furthermore, (Tan *et al.*, 2022) calculated CV values for several traits: PH (8.7%), EH (15%), EL (7%), ear diameter (EDia) (6.6%), rows per ear (11%), kernels per row (10%) and ear yield (10.3%). The findings of the current study align with those of (A. Al-Naggar *et al*., 2020) who reported similar CV% ranges for DT (2.9%), PH (6.7%), EH (9.6%), kernels per plant (3.2%), 1000-grain weight (8%) and grain yield (5%).

Pearson Correlation Analysis:

A positive and significant correlation was observed between plant height (PHt) and ear height (EHt) (0.60), indicating that an increase in plant height leads to a corresponding increase in ear height in the studied hybrids. However, excessive increases in PHt are undesirable, as they can hinder yield improvement (-0.20) due to lodging. The negative association between kernel thickness (KeTh) and kernel length (KeL) (-0.53) suggests that an increase in kernel length reduces kernel thickness. This reduction, in turn, increases the number of kernels per row, which shows a positive correlation with ear length (ErL) (0.52) and ultimately a positive relationship with kernel weight (KW). (Sinana *et al.*, 2023) supported the current study by relating that ear yield has a positive and significant correlation with ear girth (0.55) and kernels per row (0.28) but a non-significant correlation with EH (0.15). In contrast, the positive relationship between grain yield and PH does not align with the findings of this study.

Additionally, the study revealed that kernel length (KeL) positively influences kernel yield (0.32) and ear girth (ErG) (0.57) but is negatively associated with kernel thickness (KeTh). Thus, KeTh is not suitable for improving grain yield, kernel rows (KeRo) and ear girth. (Rafique *et al.*, 2020) reported highly significant and strong positive genotypic correlations between cob length (CL) and kernel weight (KW) (0.798), CL and kernel count (KC) (0.986), cob width (CW) and CL (0.901) as well as grain yield and KC (0.973), CL (0.846) and CW (0.911). These findings partially support the current study. (Rafique *et al.*, 2020) concluded that the strong genotypic correlations are a result of genetic relationships among the studied traits, which could prove effective for trait improvement.

(Yousaf *et al.*, 2021) emphasized the need to improve positively and strongly associated traits to enhance grain yield. Their findings revealed that grain yield has a negative and significant relationship with PH but positive relationships with ear width, rows per ear and kernels per ear. Non-significant correlations were found for EH, EL, DS, DT and 1000-grain weight (KW), which align with the current study (Yousaf *et al.*, 2022). Finally, current study concluded that kernel yield in maize can be enhanced by improving KeL, KW, ErG, ErL and KeRo.

Principal Component Analysis

Principal component analysis (PCA) has been widely used by researchers (AL-Asadi *et al.*, 2023; A. Al-Naggar *et al.*, 2020; Rafique *et al.*, 2020) to explore the relationships among various traits and to identify the key traits contributing the most to overall variation. Grain yield is a complex trait that requires a thorough understanding of the variability present within the maize breeding population. For effective grain yield improvement, the selection of parental lines should be based on substantial genetic diversity. This approach ensures a broader range of combinations for specific traits, facilitating the identification of superior hybrids for breeding programs (Patel *et al.*, 2023).

Variance of first two principal components is 53.2% that align with (4) who calculated 58% and described substantial capturing of variation by first two principal components (Figure 2A).

Grain yield is represented by a long arrow (Figure 2C), indicating the presence of sufficient genetic variability among the hybrids. The arrowheads of traits such as ErG, KeL and Silk are moving in the same direction as Y, indicating a positive relationship among these traits. This suggests that kernel yield could be improved by enhancing these traits. The arrowheads of KW, ErL and KeRo are also moving in the same direction, describing their dependence on one another. This implies that KW can be improved by enhancing KeRo and ErL. (Rahman *et al.*, 2017) revealed that the maximum positive direct contribution for yield was influenced by seed number/ear, 1000 seed weight and kernel length that is align with the current study.

On the other hand, the arrowheads of KeW, PHt and EHt are moving in the opposite direction to Y, indicating a negative relationship. The arrow of KeTh is moving opposite to KeL and ErG, signifying a negative relationship between these traits. (Long *et al.*, 2024) reported that ear length, 100-kernel weight, plant height, and ear height positively influenced grain yield. In contrast, the current study revealed that plant height (PH) and ear height (EH) negatively impacted grain yield.

Hence, hybrid development should cater to particular requirements to enhance the efficiency of the breeding program. This strategy guarantees that hybrids are tailored to align with market demands, making the breeding process more targeted (Yousaf *et al.*, 2021). By focusing on the most critical traits, plant breeders can improve the overall effectiveness of their hybrids (Yousaf *et al.*, 2020).

PCA biplot (Figure 2D) shows a negative relationship between variables/traits and hybrids. FH-1720 and YH-5427, which exhibited higher grain yields (9770 and 9132 kg/ha, respectively), are placed near the Y arrow. Kernel yield and KeW arrows are in opposite directions, indicating the difficulty in improving both traits simultaneously. FH-1428 and FH-1453 perform better in KeW, PHt and EHt, indicating their close resemblance. KeTh is in the 1st quadrant with hybrid FH-1682, which is opposite to the 3rd quadrant traits ErG and KeL, along with hybrid NK-8441.

Finally, this suggests that selecting for ErG and KeL traits can lead to significant genetic gains in kernel yield. Additionally, PCA biplots revealed that some genotypes did better across multiple traits, emphasizing their potential for breeding programs.

Summary:

It is concluded that a sufficient amount of variability exists among all traits of the 16 hybrids, indicating that selection for enhancing maize grain yield would be effective. Pearson correlation analysis revealed a positive correlation between KeL and ErG, while KeRO and KeTh showed a negative association. Furthermore, it is suggested that traits such as ErG and KeL have the potential to achieve significant genetic gains in kernel yield (Y). PCA biplots demonstrated that hybrids FH-1720 and YH-5427 are strongly associated with kernel yield. Additionally, the biplots identified hybrids excelling across multiple traits, highlighting their potential as candidates for future breeding programs.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be taken as a potential conflict of interest.

Authors' 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 , write manuscript

3	Adila Shahzadi	Data Analysis using R, Grammar correction
4	Muhammad Altaf	Statistical Analysis and interpretation
5	Wasim Akbar	Data collection and Analyze data using statistics
6	Aamir Ghani	Data collection and Arrangement
7	Muhammad Saeed	Make correction and review the article

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Table 1: Analysis of Variance (ANOVA) of Twelve Traits in Maize Hybrids

SOV	PHt	ErHt	Silk	ErL	ErG	KeRo	KeL	KeW	KeTh	KW	Shell	Y
Replication	42.78	9.03	12.51	0.32	0.05	0.13	0.14	0.13	0.15	0.26	0.28	4E+06
Hybrid	373.94**	133.7**	5.26 NS	2.61**	0.13**	22.26**	1.90**	0.61**	0.47**	16.22**	9.59**	4747655*
Error	49.11	44.96	5.9	0.003	0.01	0.92	0.01	0.01	0.007	0.07	0.21	1E+06
CV%	4.97	11.31	4.17	0.33	2.01	2.43	0.96	1.39	1.94	3.87	3.55	15.1
Mean	140.91	59.28	58.25	17.71	4.43	39.5	11.36	8.47	4.4	31.04	84.22	7938
Range	123.5-173.5	42.5-69.5	56-62.5	14.05-19.35	3.9-4.8	32.5-43.5	9.67-13.07	7.47-9.57	3.5-5.2	24.26-35.11	79.8-88.79	4890-9770

SOV: source of variation, d.f: degree of freedom, CV: coefficient of variation, * : significant at p≤ 0.05, ** : significant at p≤ 0.01, NS : non-significant, PHt:plant height, ErHt:ear height, Silk:days to 50% silking, ErL:ear length, ErG:ear girth, KeRo:kernels/row, KeL:kernel length, KeW:kernel width, KeTh:kernel thickness, KW:100 kernel weight, Shell:shelling %, Y:kernel yield

Figure 1: Pearson Correlation Analysis of Twelve Traits in Maize Hybrids

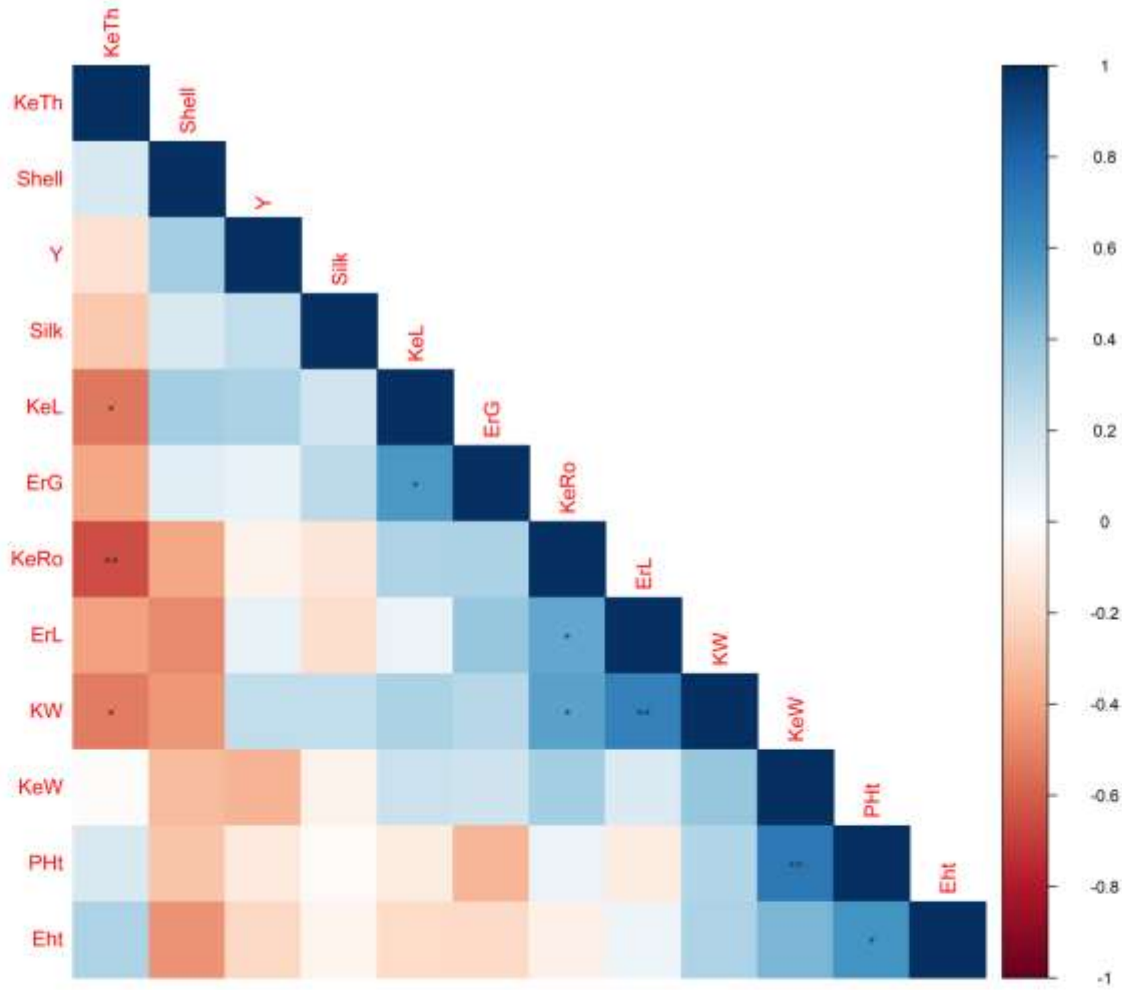

Figure 2: Principal Components Analysis of Twelve Traits in Maize Hybrids