**Genetic Diversity and Yield Trait Analysis using Multivariate Approach in Bread Wheat varieties**

**ABSTRACT**

The present study was carried out at Nawabganj Farm, CSAUAT, Kanpur during *Rabi* season 2023-24. In this study, 24 wheat genotypes were tested using the complete randomized block design in five random plants per genotype for 19 traits. The harvest index had the highest coefficient of variability, while ear-bearing tillers per plant had the lowest. Results showed that PCV and GCV were high for Leaf area index and Flag leaf length. Additionally, all of the traits exhibit high heritability and some traits exhibit high genetic advance per cent of mean thus confirming additive gene action. Highly positive correlation was observed between grain yield per plant and days to 50% heading (0.50\*\*), days to maturity (0.52\*\*), ear weight (0.70\*\*), spikelets per spike (0.73\*\*), grains per spike (0.67\*\*), biological yield per plant (0.73\*\*) and harvest index (0.68\*\*) indicating that the selection for these traits will increase yield. Eleven traits, including biological yield (0.7899), leaf area index (0.1094), harvest index (0.714), and grain width (0.0949) exerted positive direct effect on grain yield. The genotypes were grouped into five clusters using the Tocher's method and the distance between clusters IV and V was the highest, note genetic diversity high among these clusters, proof that hybridization should be productive to take advantage of heterosis and transgression segregation between these clusters. Principal component analysis (PCA) produced six principal components with eigenvalues > 1.0, which accounted for 83.3% of the total variation. PC1 contributed 28.7% of the variation with the highest eigenvalue (5.46). Traits associated with PC1 and PC2 are ideal candidates for selection.

Keywords: Variability, correlation, PCA, Bread wheat

**INTRODUCTION**

Bread wheat (*Triticum aestivum* L.), known as the "king of cereals" or chapati wheat, is the most widely cultivated and consumed cereal globally. It supports diverse products like chapati, bread, pasta, and noodles. Wheat contributes 11-12% of dietary protein as well as vitamins, fiber and phytochemicals that are good for human health (Shewry and Hey, 2015). By the year 2050, the demand of wheat is predicted to increase by about 60% from its present level while its production is expected to decline by ~30% in this period owing to extreme climate conditions (Patidar *et al*., 2023). In India, Uttar Pradesh is first in area and production, Punjab is leading state in productivity. Wheat crops are cultivated in six diverse agro-ecological production zones covering an area of 30.47 million hectares to produce about 113.3 million tons of wheat in india (FAO Stat., 2024). Wheat, an ancient crop, classified into the kingdom Plantae, division Magnoliophyta, class Liliopsida, and order Poales. It is a member of the Poaceae family, the largest of all monocots. Bread wheat is an allohexaploid (AABBDD genomes), with its genomic plasticity providing environmental adaptability. A, B, and D genomes originate from *T*. *monococcum*, an unknown species, and *Aegilops squarossa* (*T. tauschii*), respectively (Schulman *et al*., 2005). Multivariate approach includes correlation, Path, Principal component analysis and D2 analysis. It assess genetic variability in yield-related and quality traits. Correlation analysis was used to assess the relationship among different traits, while path coefficient analysis provided insights into the direct and indirect effects of these traits on the dependent variable. Principal Component Analysis (PCA) was employed to reduce data dimensionality and identify key traits contributing to the overall variation. Tools like analysis of variance, PCV and GCV, heritability, and genetic advance help assess variability and association reveal relationships among traits, guiding breeders in selection strategies. Non-hierarchical cluster analysis further classifies genotypes based on similarity, facilitating diverse parental selection for breeding. However, environmental factors can affect genotypic expression, making morphological analysis less reliable, especially in closely related populations. The main objective of this study is to utilize the genetic diversity in tested varieties by identifying trait-specific germplasm, which can be used for intellectual property protection and further applied in crop improvement.

**MATERIALS AND METHODS**

The morphological characterization of twenty four elite wheat varieties was conducted on the Nawabganj Experimental Farm, EBR, CSAUAT, Kanpur, Uttar Pradesh during *Rabi* season of 2023-24 under normal irrigated ecology. Geographically, the trial field is situated at the latitude of 26.449°N and 80.331°E longitude with altitude of 132 m. The experimental material was collected from the Section of Economic Botanist, *Rabi C*ereals (EBR), CSAUAT, Kanpur. Sowing was carried out on 2nd December 2023 under suitable climatic conditions for germination. The passport details of the materials used are provided in Table 1. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Each genotype was sown in a six-row plot with a gross area of 5 m × 1 m, maintaining a row spacing of 22.5 cm, using a seed drill in a well-prepared field. Each plot accommodated approximately 133 plants. All recommended agronomic practices were followed in a timely manner. Observations were recorded for nineteen quantitative traits days to 50% heading(DH), days to 50% anthesis(DA), days to maturity(DM), plant height (PH), effective bearing tillers per plant (EBT), flag leaf length (FLL)cm, flag leaf width (FLW)cm, leaf area index(LAI), ear weight (EW) g, spike length (cm), spikelets per spike(SPS), grains of per spike(GPS), thousand grain weight (TGW) (g), Grain length (GL) (mm), Grain width (GW) (mm), Grain L/W (GLW) ratio, biological yield per plant (g), harvest index (HI) (%) and grain yield per plant (GY) (g). The observations was recorded on five selected plants and then subjected for analysis of genetic variability, correlation coefficient, path analysis, PCA and D2 using the statistical tool BIOSTAT (Statistical Analyses Software).

**Standard error mean**



**Coefficient of variation**



**¯**

Where, X Mean of character

**Mean**

Mean (X) = ∑X/N

Where, ∑X = the sum of all observations

N = number of observation

**Test of significance**

If the value of variance ratio (Vt/Ve) for treatment is greater than table value at (5%) or 1% level of significance.

Standard error (differences) = 

Critical difference = S.E. (differences) x t’5% d.f.

**Estimation PCV and GCV coefficients of variation**

(a). GCV = / X x100

(b). PCV = / X x 100

Where,

Vg = Genotypic variance

Vp = Phenotypic variance

**Heritability (h2b)**

σ2g

σ2g

h2b (%) = ×100

σ2p

σ2g

Where,

σ2g = genotypic variance

σ2p =phenotypic variance

**Genetic advance**

GA = K×σp×h2b

K = Selection differential (K is 2.06 at selection intensity of 5%)

σp = square root of phenotypic variance

**RESULTS AND DISCUSSION**

**ANOVA and Mean performance:** The variance for 19 quantitative traits revealed significant differences for all the traits, this is in conformation of the results reported by (Patel et al., 2016 and Nasir *et al*., 2024). The phenological traits showed variability: days to 50% heading (71.96-82.97days), maturity (108.58-135.34 days). Plant height varied from 62 to 108.5 cm (mean: 84.85 cm), EBT/plant ranged from 6.2 to 8.81 (mean: 6.92), FLL (17.6-30.63 cm) showed greater variation than width (1.47-2.1 cm). The grain characteristics viz., GL, GW and L/W ratio displayed high level of genetic variation under freely environment. The grain length (6.03-7.15 mm), grain width varied from (3.08 to 3.57mm), L/W ratio (1.77 to 2.28). It was found that, K9351 show highest grain yield, BY, EW and GPS. K1711 recorded highest TGW. Days to 50% heading and PH was recorded highest in K9465 and K9006 respectively.

**Phenotypic and Genotypic Coefficient of Variation:** According to **Burton and De Vane (1953),** Genotypic coefficient of variation (GCV) and Phenotypic coefficient of variation (PCV) values are considered low (<10%), moderate (10–20%), and high (>20%), indicating the extent of genetic and phenotypic variability in traits. The results pertaining to highest GCV was recorded for LAI with 18.77% GCV followed by FLL (15.47%), GY (14.54%), PH (14.23%) and EW (13.49%) etc.The highest value of PCV was recorded for LAI (19.49%) followed by FLL (16.04%), GY (15.26%) and PH (14.32%) etc. Our results showing wide range of variation and maximum scope for giving positive response in selection scheme.

**Heritability and Genetic advance per cent of mean:** The percent of the mean was calculated for 19 traits and elucidated in Table 2. High value of heritability in broad sense were observed for the characters viz.,1000 grain weight (98.3%) followed by EBT per plant (98.1%), biological yield per plant (95.8%), number of grains per spike (93.3%), FLL (93%) and LAI (92.8%). High heritability values for these traits indicated that the variation observed was mainly under genetic control and was less influenced by environment and can be used for mass selection or heterosis breeding.Genetic advance in per cent of mean 5% for the studied characters were observed from high to low magnitude. The high genetic advance per cent of mean were recorded for LAI (37.24%) fallowed by FLL (30.72%), PH (29.15%), GY (28.54%) and ear weight (25.81%). After that the low genetic advance per cent of mean value for the characters viz., GLW ratio (9.57%) followed by grain length (9.12%) and days to maturity (7.51%).Singh and Rai (1987), Barnwal *et al.,* (2012) and Yadav *et al.,* (2014) reported similar results for high heritability with low genetic advance for days to heading.

Table 1:The details of bread wheat varieties used in the study along with name of accession, Pedigree, common name, released date and remarks

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sl. No** | **Name of accession** | **Common name** | **Released date** | **Pedigree** | **Remarks** |
| 1. | K65 | - | 1964 | NP733/PB561 | Limited irrigation condition, good *chapati* making quality |
| 2. | K68 | - | 1963 | NP773/C13 | Recommended for limited irrigation, and good tillering, excellent *chapati* making quality |
| 3. | K0307 | Shatabdi | 2007 | K 8321/UP 2003 | Tall plant height, non-synchronous tillering, and bold grain |
| 4. | K0402 | Mahi | 2013 | HP1731/UP2425 | Semi-dwarf plant height, good tillering, and white ears |
| 5. | K0424 | Golden Halna | 2010 | K8962/K8020 | Medium plant height, brown ear , and heat tolerant |
| 6. | K0607 | Mamta | 2014 | HUW468/HD2402//2/K9162 | Diseases resistant and terminal-heat tolerant |
| 7. | K1006 | - | 2014 | PBW343/HP1731 | Amber grain colour |
| 8. | K1317 | - | 2018 | K 0307/K 9162 | Rust resistant and high yield |
| 9. | K1616 | - | 2022 | HD 2711/K 711 | Aphid resistant and high protein (11.8 % ) |
| 10. | K1711 | - | Pipeline | K 68/K 616 | Suitable for salt stress and rust resistant |
| 11. | K2208 | - | Pipeline | K 922/2K-21 | Suitable for timely sown and rust resistant |
| 12. | K2210 | - | Pipe line | K9533/DBW107 | Suitable for late sown and rust resistant |
| 13. | K7903 | Halna | 2002 | HD 1982/ K 816 | Dwarf plant height and tolerant to terminal heat stress |
| 14. | K8027 | Magahar | 1989 | HD 1969/\*2K 852 | Recommended for rainfed and timely sown variety |
| 15. | K8434 | Prasad | 2002 | HD 2160/ K 68 | Medium plant height, dark brown awns, and dark green leaf |
| 16. | K8962 | Indra | 1996 | K 7401/ HD 2160 | Non synchronous tillering |
| 17. | K9006 | Ujiyar | 1998 | CPAN 1687/HD 2204 | Medium, stem robust, profuse tillering |
| 18. | K9107 | Deva | 1996 | K 8103/ K 68 | Tall plant height, robust stem, amber and bold grains |
| 19. | K9162 | Gangotri | 2002 | K 7827/ HD 2204 | Tall plant height and light green leaves |
| 20. | K9351 | Mandakini | 2006 | K 72/ K 8027/ K72 | Medium plant height, and tolerant to drought |
| 21. | K9423 | Unnat Halna | 2005 | HP 1633/  K. SONA /UP 262 | Medium plant height, good tillering, early maturity |
| 22. | K9465 | Gomati | 1998 | B 1153/ CB 85 | Tall plant height, early maturity and bold grains |
| 23. | K9533 | Naina | 2006 | HI 1077/ HUW 234 | Medium plant height, white ear and bold grains |
| 24. | K9644 | Atal | 2000 | HD 2402/ K 8305 | Tall plant height, Late sown varieties |

Table 2: Estimation of genetic parameters and mean performance of 19 traits in bread wheat

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Characters | General mean | Range | | GCV (%) | PCV (%) | Broad sense heritability (h² in %) | Genetic Adv as % of Mean |
| Min | Max |
| Days to 50% heading | 76.76 | 71.96 | 82.97 | 3.08 | 4.39 | 75.4 | 4.54 |
| Days to 50% Anthesis | 82.98 | 76.98 | 90.97 | 4.13 | 4.79 | 74.3 | 7.34 |
| Days to maturity | 122.69 | 108.58 | 135.34 | 4.45 | 5.42 | 67.3 | 7.51 |
| Plant height (cm) | 84.85 | 62 | 108.5 | 14.23 | 14.32 | 78.3 | 29.15 |
| EBT per plant | 6.92 | 6.2 | 8.81 | 9.73 | 9.82 | 98.1 | 19.85 |
| Flag leaf length (cm) | 22.43 | 17.6 | 30.63 | 15.47 | 16.04 | 93 | 30.72 |
| Flag leaf width (cm) | 1.73 | 1.47 | 2.1 | 7.3 | 8.29 | 77.6 | 13.26 |
| Leaf area index (cm2) | 29.12 | 20.75 | 42.92 | 18.77 | 19.49 | 92.8 | 37.24 |
| Ear weight (g) | 2.17 | 1.51 | 2.81 | 13.49 | 14.53 | 86.3 | 25.81 |
| Spike length (cm) | 10.27 | 7.29 | 12.98 | 12.9 | 13.57 | 90.4 | 25.27 |
| No. of spikelets/spike | 18.55 | 15.33 | 22.53 | 9.18 | 9.71 | 89.4 | 17.89 |
| No. of grains/spike | 58.99 | 49.29 | 82.72 | 12.95 | 13.41 | 93.3 | 25.76 |
| 1000 Grain weight(g) | 37.51 | 28.42 | 46.31 | 10.89 | 10.99 | 98.3 | 22.24 |
| Grain length(mm) | 6.65 | 6.03 | 7.15 | 4.65 | 4.88 | 90.7 | 9.12 |
| Grain width(mm) | 3.32 | 3.08 | 3.57 | 3.83 | 4.13 | 86.1 | 7.32 |
| Grain L/W Ratio | 2.01 | 1.77 | 2.28 | 5.04 | 5.47 | 85 | 9.57 |
| Biological yield/ plant(g) | 35.26 | 28.67 | 42.66 | 10.56 | 10.79 | 95.8 | 21.29 |
| Harvest index (%) | 42.72 | 30.49 | 49.46 | 8.8 | 10.35 | 72.3 | 15.42 |
| Grain yield/ plant (g) | 15.05 | 10.27 | 20.28 | 14.54 | 15.26 | 90.8 | 28.54 |

**Correlation Coefficient Analysis:** correlation coefficients were analyzed for 19 traits and represented in Table 3. In the phenotypic correlation coefficient, GY showed a highly significant and positive correlation with DH (0.50\*\*), DM (0.52\*\*), EW (0.70\*\*), GPS (0.67\*\*), BY (0.73\*\*) and HI (0.68\*\*). Its significant and positive correlated traits can be used in improvement of yield using phenotypic selection. Grain yield per plant also showed a non-significant and negative correlation with PH (-0.17) and LAI (-0.01). In the genotypic correlation coefficient, Grain yield per plant showed a highly significant and positive correlation with DH (0.76\*\*), DA (0.55\*\*), DM (0.60\*\*), EW (0.79\*\*), SPS (0.50\*\*), GPS (0.73\*\*), BY (0.80\*\*) and HI (0.66\*\*). The present analysis revealed that GY had highly significant and positive correlation with DH, DA, DM, EW, SPS, BY and HI at phenotypic and genotypic level. Thus improvement of grain yield in bread wheat varieties can be achieved by selection of these characters. These results are in confirmed through Baranwal *et al.,* (2012), Desheva (2015), Ozukum *et al.*, (2019), Anu *et al.,* (2021), Singh *et al.,* (2021). Days of 50% heading, days to maturity were recorded the highly significant positive correlation with GY. Similar results have come from Kumar *et al*., (2019).

**Path Coefficient Analysis:** The path coefficient analysis suggested by Dewey and Lu (1959) helps to resolve these correlations further and throws more light on the way in which component traits contribute towards specifically identifying important component traits. Results revealed that, eleven out of eighteen characters had a positive direct effect on grain yield per plant. The characters which had a positive direct effect on biological yield per plant (0.7899), grain L/W ratio(0.1343), days to 50% anthesis (0.1233), leaf area index (0.1094), grain width (0.0949), days to 50% heading (0.0875), grains per spike (0.0727), harvest index (0.714), 1000 grain weight (0.0524), number of spikelets per spike (0.0274), plant height (0.0081). Similar results were also recorded for these traits by Rajshree and Singh (2018).While flag leaf width (-0.0392), spike length (-0.0469), ear bearing tillers per plant (-0.0538), flag leaf length (-0.0856), grain length (-0.0964), ear weight (-0.1501), days to maturity (-0.255) had a negative direct effect on grain yield per plant. This indicated that biological yield per plant and harvest index are most important characters in influencing grain yield per plant. Grain yield per plant could be improved by selection based on these characters. The results are in agreement with Singh *et al.,* (2010), Kumari *et al.,* (2020). While ear bearing tillers per plant (-0.157), days to 50% anthesis (-0.2122), days to 50% heading (-0.3455), ear weight (-1.7684), flag leaf length (-3.9742), plant height (-5.9814), number of grains per spike (-7.7497), grain width (-39.535) and grain L/W ratio (-50.9773) had a direct negative effect on grain yield per plant. Residual effects for grain yield per plant are 0.012 and 0.048 at phenotypic and genotypic level.

**Principal Component Analysis:** The results of principal component analysis (PCA) for nineteen traits of 24 bread wheat genotypes are presented in Table 6 and 3D plot depicted in Figure 1. For first two component using PCA biplot analysis, inter-trait correlations (positively associated characteristics (<90°), independent attributes (=90°) and negatively associated traits (>90°)) and genotype dispersion. PCA indicated the first six vectors with Eigen values greater than one combined explained about 83.3% of the gross variation. The first PC accounted for 28.70% of the total variation, whereas the corresponding values for the second to the sixth PCs were 17.5%, 14.4%, 10%, 7.1% and 5.5%, respectively. The maximum Eigen root value (5.46) was recorded for PC1 followed by PC2 (3.32), PC3 (2.74), PC4 (1.91), PC5 (1.35) and PC6 (1.05). Among the six principal components, the maximum variation was found in PC1 and PC2; therefore selection of lines for characters under PC1 and PC2 may be desirable. It revealed that the first principal component (PC1) which accounted for the highest variation (28.70%) was mostly related with yield traits such number of days to 50% heading, days to maturity, number of grains per spike, biological yield per plant and biological yield per plant. The second principal component (PC2) was dominated by yield related traits viz., ear weight and thousand grain weight, while PC3 consisted with traits viz., plant height, leaf area index, spike length and number of spikelets per spike. Fourth principal component (PC4) was related with grain L/W ratio, fifth principal component (PC5) with flag leaf length, sixth principal component (PC6) with EBT per plant, flag leaf length, flag leaf width, grain length, grain width and harvest index. Similar results were also reported by Ali *et al.,* (2015), Khan *et al.,* (2015) and Bhanupriya *et al.,* (2014).The results on PCA indicated that these traits are important for trait manipulation and diversity in this population was present due to these traits.

**D2 Cluster Analysis:** D2 statistical approach evaluates differentiation forces at both intra-cluster and inter-cluster levels, facilitating the identification of genetically diverse parent plants for hybridization purposes. The 24 varieties were grouped into five clusters using the Tocher's method with the criterion that the intra-cluster average D2 values should be less than inter cluster D2 values and presented in Fig. 2. When, the cluster mean for 19 characters among the five clusters are also presented in Table 7. Group constellations of maximum number of varieties was present in cluster I (20), followed by remains each variety in each cluster (cluster II, cluster III, cluster IV and cluster V). The magnitude of genetic divergence between two clusters is indicated by their spatial distance; a greater distance signifies higher-divergence. Consequently, genotypes within the same cluster exhibit less diversity relative to genotypes from different clusters.

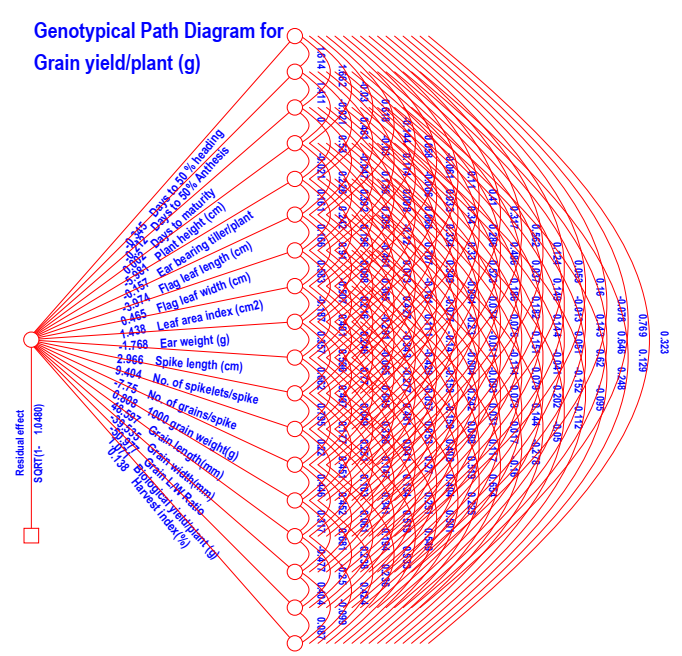
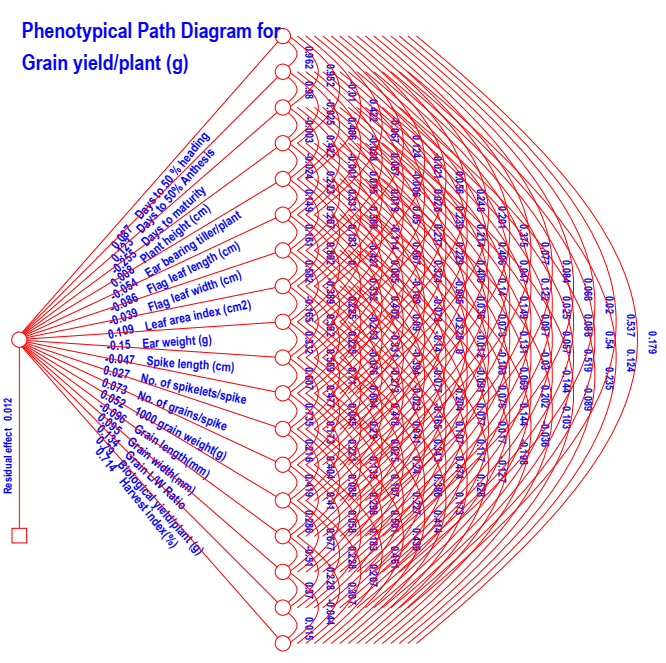
Table 3: Genotypic (above diagonal) and Phenotypic (below diagonal) correlation coefficients among various traits of Bread wheat varieties

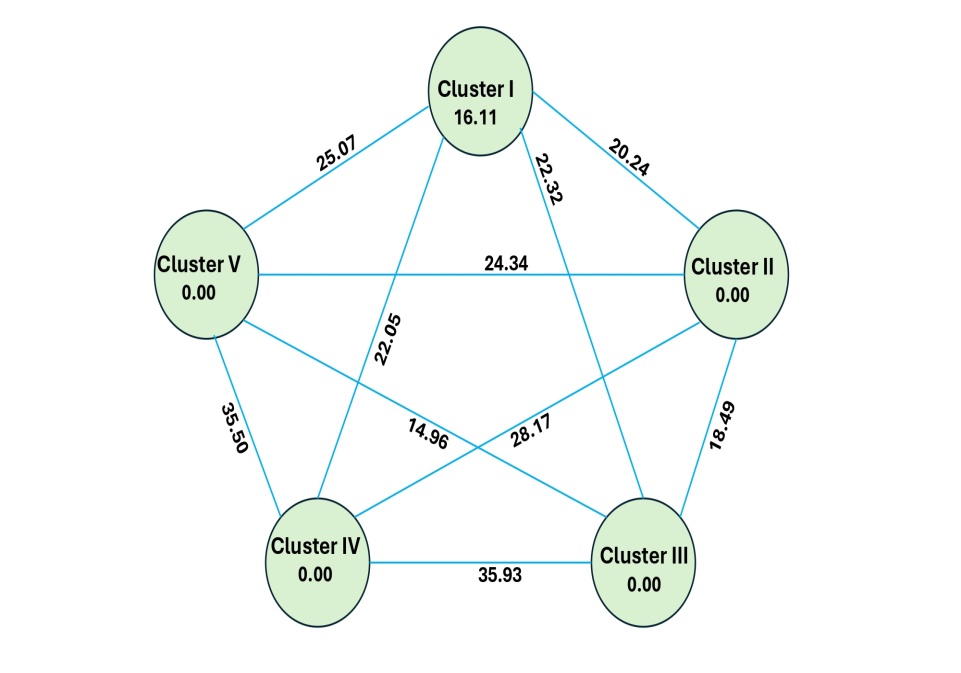
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Traits | Days to 50 % heading | Days to 50% Anthesis | Days to maturity | Plant height (cm) | Ear bearing tiller/plant | Flag leaf length (cm) | Flag leaf width (cm) | Leaf area index (cm2) | Ear weight (g) | Spike length (cm) | No. of spikelets/ spike | No. of grains/ spike | 1000 grain weight(g) | Grain length (mm) | Grain width (mm) | Grain L/W Ratio | Biological yield/plant (g) | Harvest index (%) | Grain yield/ plant (g) |
| Days to 50 % heading | 1.00 | 0.99\*\* | 0.99\*\* | -0.03 | 0.61\*\* | -0.14 | 0.06 | -0.06 | 0.11 | 0.41\* | 0.32 | 0.56\*\* | 0.12 | 0.05 | 0.16 | -0.08 | 0.76\*\* | 0.32 | 0.76\*\* |
| Days to 50% Anthesis | 0.96\*\* | 1.00 | 0.98\*\* | -0.02 | 0.46\* | -0.03 | 0.11 | -0.01 | 0.03 | 0.34 | 0.29 | 0.48\*\* | 0.04 | 0.15 | -0.01 | 0.14 | 0.64\*\* | 0.13 | 0.55\*\* |
| Days to maturity | 0.95\*\* | 0.98\*\* | 1.00 | 0.00 | 0.52\*\* | -0.05 | 0.14 | 0.01 | 0.07 | 0.33 | 0.33 | 0.52\*\* | 0.19 | 0.18 | 0.14 | 0.05 | 0.61\*\* | 0.25 | 0.60\*\* |
| Plant height (cm) | -0.01 | -0.02 | 0.00 | 1.00 | -0.02 | 0.23 | 0.39\* | 0.38\* | -0.12 | 0.70\*\* | 0.35 | -0.09 | 0.03 | 0.08 | 0.15 | -0.04 | -0.15 | -0.10 | -0.18 |
| Ear bearing tiller/plant | 0.42 | 0.41 | 0.42 | -0.02 | 1.00 | 0.16 | 0.24 | 0.20 | -0.46\* | 0.07 | -0.10 | -0.08 | -0.23 | -0.01 | -0.11 | 0.08 | 0.20 | -0.11 | 0.06 |
| Flag leaf length (cm) | -0.07 | -0.03 | 0.00 | 0.22 | 0.15 | 1.00 | 0.17 | 0.90\*\* | 0.01 | 0.37 | 0.42\* | 0.11 | -0.14 | 0.00 | -0.09 | 0.07 | 0.14 | -0.05 | 0.07 |
| Flag leaf width (cm) | 0.12 | 0.09 | 0.09 | 0.33 | 0.21 | 0.16 | 1.00 | 0.58\*\* | -0.51 | 0.22 | -0.29 | -0.34 | -0.42\* | -0.15 | -0.24 | 0.03 | 0.02 | -0.28 | -0.17 |
| Leaf area index (cm2) | -0.02 | -0.01 | 0.02 | 0.37 | 0.18 | 0.89\*\* | 0.58\*\* | 1.00 | -0.19 | 0.40\* | 0.25 | -0.06 | -0.28 | -0.04 | -0.16 | 0.09 | 0.12 | -0.16 | -0.01 |
| Ear weight (g) | 0.06 | 0.03 | 0.05 | -0.11 | -0.42\*\* | 0.00 | -0.38\* | -0.17 | 1.00 | 0.36 | 0.59\*\* | 0.77\*\* | 0.64\*\* | 0.48\* | 0.05 | 0.40\*\* | 0.51\*\* | 0.65\*\* | 0.79\*\* |
| Spike length (cm) | 0.25 | 0.24 | 0.24 | 0.66\*\* | 0.07 | 0.33 | 0.22 | 0.39\* | 0.33 | 1.00 | 0.66\*\* | 0.49\* | 0.05 | 0.33 | 0.04 | 0.27 | 0.40\* | 0.22 | 0.43\* |
| No. of spikelets/spike | 0.20 | 0.21 | 0.23 | 0.32 | -0.11 | 0.40 | -0.25 | 0.22 | 0.55\*\* | 0.60\*\* | 1.00 | 0.79\*\* | 0.18 | 0.25 | 0.15 | 0.13 | 0.25 | 0.50\*\* | 0.50\*\* |
| No. of grains/spike | 0.37 | 0.41 | 0.41 | -0.08 | -0.07 | 0.09 | -0.33 | -0.08 | 0.70\*\* | 0.47\*\* | 0.73\*\* | 1.00 | 0.22 | 0.45 | 0.10 | 0.34 | 0.51\*\* | 0.54\*\* | 0.73\*\* |
| 1000 grain weight(g) | 0.08 | 0.05 | 0.14 | 0.04 | -0.23 | -0.14 | -0.39\* | -0.27 | 0.60\*\* | 0.04 | 0.17 | 0.22 | 1.00 | 0.45 | 0.45\* | 0.06 | 0.19 | 0.53\*\* | 0.46\* |
| Grain length(mm) | 0.08 | 0.12 | 0.15 | 0.07 | -0.01 | 0.00 | -0.08 | -0.02 | 0.41\* | 0.29 | 0.22 | 0.40\* | 0.41\* | 1.00 | 0.32 | 0.68\*\* | 0.24 | 0.24 | 0.34 |
| Grain width(mm) | 0.07 | 0.02 | 0.10 | 0.13 | -0.10 | -0.09 | -0.20 | -0.17 | 0.04 | 0.02 | 0.13 | 0.09 | 0.40\* | 0.29 | 1.00 | -0.47\* | -0.25 | 0.42\* | 0.08 |
| Grain L/W Ratio | 0.02 | 0.09 | 0.06 | -0.03 | 0.07 | 0.08 | 0.08 | 0.11 | 0.34 | 0.24 | 0.11 | 0.30 | 0.06 | 0.67\*\* | -0.51\*\* | 1.00 | 0.40\* | -0.10 | 0.25 |
| Biological yield/plant (g) | 0.53\*\* | 0.54 | 0.51\*\* | -0.14 | 0.20 | 0.14 | 0.02 | 0.12 | 0.47\* | 0.38\* | 0.23 | 0.50\*\* | 0.18 | 0.23 | -0.23 | 0.37 | 1.00 | 0.09 | 0.80\*\* |
| Harvest index (%) | 0.18 | 0.12 | 0.23 | -0.09 | -0.10 | -0.04 | -0.20 | -0.13 | 0.52\*\* | 0.17 | 0.41\* | 0.43\* | 0.46\* | 0.21 | 0.31 | -0.04 | 0.02 | 1.00 | 0.66\*\* |
| Grain yield/plant (g) | 0.50\*\* | 0.47\* | 0.52\*\* | -0.17 | 0.05 | 0.07 | -0.13 | -0.01 | 0.70\*\* | 0.39\* | 0.45\* | 0.67\*\* | 0.44\* | 0.32 | 0.05 | 0.24 | 0.73\*\* | 0.68\*\* | 1.00 |

Correlation significance value @5% = \* = 0.388 & @1% = \*\* = 0.496

Table 4: Phenotypic path matrix direct and indirect effects of 19 characters on grain yield per plant of wheat varieties as independent variable at phenotypic level

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Traits | Days to 50% heading | Days to 50% Anthesis | Days to maturity | Plant height | Ear bearing tiller/ plant | Flag leaf length (cm) | Flag leaf width (cm) | Leaf area index (cm2) | Ear weight (g) | Spike length (cm) | No. of spikelets/ spike | No. of grains/ spike | 1000 -grain weight (g) | Grain length (mm) | Grain width (mm) | Grain L/W Ratio | Biological yield per Plant(g) | Harvest index(%) | Grain yield/plant (g) |
| Days to 50% heading | 0.0875 | 0.0842 | 0.0833 | -0.0008 | 0.0369 | -0.0058 | 0.0108 | -0.0019 | 0.0049 | 0.0217 | 0.0176 | 0.0328 | 0.0067 | 0.0074 | 0.0059 | 0.0018 | 0.047 | 0.0157 | 0.50\*\* |
| Days to 50% Anthesis | 0.1186 | 0.1233 | 0.1209 | -0.0031 | 0.0501 | -0.0035 | 0.0107 | -0.0008 | 0.0032 | 0.0294 | 0.0264 | 0.0501 | 0.0059 | 0.015 | 0.003 | 0.0108 | 0.0666 | 0.0152 | 0.47\* |
| Days to maturity | -0.2428 | -0.25 | -0.255 | 0.0008 | -0.1077 | 0.0003 | -0.0242 | -0.0049 | -0.0127 | -0.0605 | -0.0584 | -0.1043 | -0.0357 | -0.038 | -0.0246 | -0.0146 | -0.1322 | -0.0598 | 0.52\*\* |
| Plant height (cm) | -0.0001 | -0.0002 | 0.000 | 0.0081 | -0.0002 | 0.0018 | 0.0027 | 0.003 | -0.0009 | 0.0054 | 0.0026 | -0.0007 | 0.0003 | 0.0006 | 0.0011 | -0.0002 | -0.0012 | -0.0007 | -0.17 |
| Ear bearing tiller /plant | -0.0227 | -0.0218 | -0.0227 | 0.0013 | -0.0538 | -0.008 | -0.0111 | -0.0098 | 0.0229 | -0.0035 | 0.0058 | 0.0039 | 0.0121 | 0.0007 | 0.0056 | -0.0037 | -0.0109 | 0.0055 | 0.05 |
| Flag leaf length (cm) | 0.0057 | 0.0024 | 0.0001 | -0.0191 | -0.0127 | -0.0856 | -0.0138 | -0.0763 | 0.000 | -0.0284 | -0.0344 | -0.0077 | 0.012 | 0.000 | 0.0078 | -0.0065 | -0.0123 | 0.0031 | 0.07 |
| Flag leaf width (cm) | -0.0049 | -0.0034 | -0.0037 | -0.013 | -0.0081 | -0.0063 | -0.0392 | -0.0228 | 0.0152 | -0.0088 | 0.0099 | 0.013 | 0.0154 | 0.003 | 0.008 | -0.003 | -0.0007 | 0.0078 | -0.13 |
| Leaf area index (cm2) | -0.0023 | -0.0007 | 0.0021 | 0.0403 | 0.020 | 0.0976 | 0.0637 | 0.1094 | -0.0181 | 0.0429 | 0.0246 | -0.0083 | -0.0299 | -0.0025 | -0.0181 | 0.0117 | 0.0128 | -0.0139 | -0.01 |
| Ear weight (g) | -0.0084 | -0.0039 | -0.0075 | 0.017 | 0.0641 | 0.000 | 0.0584 | 0.0248 | -0.1501 | -0.0498 | -0.0839 | -0.1065 | -0.0907 | -0.0627 | -0.0062 | -0.0514 | -0.0711 | -0.0792 | 0.70\*\* |
| Spike length (cm) | -0.0116 | -0.0112 | -0.0111 | -0.0312 | -0.0031 | -0.0156 | -0.0105 | -0.0184 | -0.0155 | -0.0469 | -0.0285 | -0.0224 | -0.0021 | -0.0136 | -0.0012 | -0.0113 | -0.0181 | -0.0081 | 0.39\* |
| Spikelets/ spike | 0.0055 | 0.0059 | 0.0063 | 0.0089 | -0.003 | 0.011 | -0.0069 | 0.0062 | 0.0153 | 0.0166 | 0.0274 | 0.0201 | 0.0047 | 0.0061 | 0.0036 | 0.0029 | 0.0062 | 0.0113 | 0.45\* |
| No. of grains / spike | 0.0272 | 0.0295 | 0.0297 | -0.0062 | -0.0053 | 0.0065 | -0.0241 | -0.0055 | 0.0516 | 0.0346 | 0.0534 | 0.0727 | 0.0157 | 0.0293 | 0.0062 | 0.0216 | 0.0364 | 0.0319 | 0.67\*\* |
| 1000 Grain weight(g) | 0.004 | 0.0025 | 0.0073 | 0.0019 | -0.0118 | -0.0073 | -0.0206 | -0.0143 | 0.0317 | 0.0023 | 0.009 | 0.0113 | 0.0524 | 0.0219 | 0.0215 | 0.0031 | 0.0096 | 0.0241 | 0.44\* |
| Grain length(mm) | -0.0081 | -0.0117 | -0.0144 | -0.007 | 0.0012 | 0.000 | 0.0074 | 0.0022 | -0.0403 | -0.0279 | -0.0213 | -0.0389 | -0.0404 | -0.0964 | -0.0276 | -0.0653 | -0.0219 | -0.02 | 0.32 |
| Grain width(mm) | 0.0064 | 0.0023 | 0.0092 | 0.0125 | -0.0098 | -0.0087 | -0.0193 | -0.0157 | 0.0039 | 0.0024 | 0.0126 | 0.0081 | 0.0389 | 0.0272 | 0.0949 | -0.0485 | -0.0216 | 0.0291 | 0.05 |
| Grain L/W ratio | 0.0027 | 0.0118 | 0.0077 | -0.004 | 0.0093 | 0.0101 | 0.0104 | 0.0144 | 0.046 | 0.0323 | 0.0144 | 0.04 | 0.0078 | 0.0909 | -0.0686 | 0.1343 | 0.0497 | -0.0059 | 0.24 |
| Biological yield/Plant | 0.4239 | 0.4269 | 0.4097 | -0.1138 | 0.1599 | 0.1138 | 0.0135 | 0.0924 | 0.3744 | 0.3048 | 0.1792 | 0.396 | 0.1443 | 0.1797 | -0.180 | 0.2925 | 0.7899 | 0.0122 | 0.73\*\* |
| Harvest index (%) | 0.1277 | 0.0883 | 0.1675 | -0.0635 | -0.0737 | -0.0257 | -0.1416 | -0.0906 | 0.3768 | 0.1235 | 0.2955 | 0.3131 | 0.329 | 0.1478 | 0.219 | -0.0312 | 0.011 | 0.714 | 0.68\*\* |





**130**

**24**

**17**

**120**

**18**

**23**

**19**

**10**

**6**

**3**

**7**

**1**

**21**

**15**

**8**

**14 22**

**16**

**110**

**11**

**13**

**2**

**100**

**9**

**5 12**

**4**

**20**

**25**

**30**

**35**

**40**

**45**

**20 50**

**90**

Figure 1: 3D PCA Plot of 24 bread wheat varieties Figure 2: D2 cluster diagram of bread wheat varieties

The maximum inter-cluster distance was recorded between cluster-IV and cluster-V (38.50) followed by cluster-III and cluster-IV (35.93), cluster-II and cluster-IV (28.17), cluster-I and cluster-V (25.07), cluster-II and cluster-V (24.34), cluster-I and cluster-III (22.32) and cluster-I and cluster-IV (22.05). It was revealed that the varieties of cluster-IV and cluster-V were genetically more diverse as compared to other clusters. So, Maximum diversity between these two clusters and crossing between them will be very useful for getting maximum heterosis. The minimum inter-cluster distance was recorded between cluster-III and cluster-V (14.96) followed by cluster-II and cluster-III (18.49) and cluster-I and cluster-II (20.24). It revealed that the varieties of cluster-III and cluster-V are genetically related to each other as compared to other clusters. The grouping of genotypes into different cluster by using Tocher’s method was also reported by Tsegaye *et al*., (2012) and Singh *et al*., (2015).

Table 5: cluster mean values of five clusters for nineteen characters in bread wheat varieties

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Traits /Cluster | DH | DA | DM | PH (cm) | EBT/ plant | FLL (cm) | FLW (cm) | LAI (cm2) | EW (g) | SL (cm) |
| Cluster I | 76.36 | 82.53 | 121.93 | 82.8 | 6.92 | 22.64 | 1.73 | 29.33 | 2.18 | 10.1 |
| Cluster II | 73.96 | 78.98 | 116.77 | 105.33 | 6.4 | 18.87 | 1.47 | 20.86 | 2.43 | 10.5 |
| Cluster III | 75.96 | 82.98 | 122.96 | 108.5 | 6.8 | 27.23 | 2.1 | 42.92 | 1.51 | 11.17 |
| Cluster IV | 81.97 | 89.98 | 133.8 | 69.8 | 6.4 | 18.8 | 1.49 | 20.75 | 2.81 | 11.3 |
| Cluster V | 82.96 | 88.98 | 132.25 | 96.73 | 8.2 | 20.57 | 1.81 | 27.89 | 1.74 | 11.47 |
|  |  |  |  |  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SPS | GPS | TGW (g) | GL (mm) | GW (mm) | GLWR | BY/ Plant(g) | HI (%) | GY/ plant (g) |
| 18.37 | 57.98 | 37.35 | 6.61 | 3.3 | 2.01 | 35.36 | 42.7 | 15.06 |
| 20.4 | 63.14 | 46.32 | 6.9 | 3.57 | 1.93 | 28.68 | 43.5 | 12.49 |
| 17.7 | 50.47 | 32.8 | 6.75 | 3.33 | 2.03 | 33.31 | 34.19 | 11.4 |
| 20.4 | 82.72 | 42.98 | 7.15 | 3.42 | 2.09 | 42.66 | 47.54 | 20.29 |
| 19.37 | 60 | 31.24 | 6.49 | 3.38 | 1.92 | 34.54 | 45.89 | 15.83 |

Table 6: Principal component analysis for 19 traits recorded in 24 bread wheat varieties

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Traits | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
| Days to 50 % heading | 0.283 | -0.237 | -0.326 | -0.117 | -0.032 | -0.078 |
| Days to 50% Anthesis | 0.283 | -0.247 | -0.318 | -0.076 | -0.036 | -0.095 |
| Days to maturity | 0.297 | -0.229 | -0.306 | -0.128 | -0.048 | 0.005 |
| Plant height (cm) | 0.015 | -0.18 | 0.323 | -0.327 | -0.356 | -0.347 |
| Ear bearing tiller/plant | 0.046 | -0.33 | -0.205 | 0.01 | -0.064 | 0.258 |
| Flag leaf length (cm) | 0.056 | -0.249 | 0.371 | -0.052 | 0.312 | 0.389 |
| Flag leaf width (cm) | -0.069 | -0.38 | 0.089 | 0.006 | -0.217 | 0.102 |
| Leaf area index (cm2) | 0.013 | -0.368 | 0.365 | -0.042 | 0.139 | 0.347 |
| Ear weight (g) | 0.295 | 0.303 | 0.174 | 0.144 | 0.102 | -0.042 |
| Spike length (cm) | 0.241 | -0.174 | 0.326 | -0.125 | -0.148 | -0.319 |
| No. of spikelets/spike | 0.277 | 0.029 | 0.288 | -0.184 | 0.22 | -0.239 |
| No. of grains/spike | 0.353 | 0.102 | 0.075 | 0.049 | 0.161 | -0.214 |
| 1000 grain weight(g) | 0.189 | 0.312 | 0.003 | -0.126 | -0.239 | 0.288 |
| Grain length(mm) | 0.21 | 0.114 | 0.134 | 0.163 | -0.569 | 0.247 |
| Grain width(mm) | 0.051 | 0.184 | -0.039 | -0.543 | -0.237 | 0.253 |
| Grain L/W Ratio | 0.15 | -0.038 | 0.154 | 0.56 | -0.325 | 0.026 |
| Biological yield/plant (g) | 0.304 | -0.127 | -0.064 | 0.279 | 0.103 | 0.007 |
| Harvest index(%) | 0.231 | 0.22 | 0.019 | -0.22 | 0.126 | 0.264 |
| Grain yield/plant (g) | 0.378 | 0.065 | -0.032 | 0.057 | 0.159 | 0.176 |
| Eigen value | 5.4597 | 3.3158 | 2.7405 | 1.9065 | 1.3526 | 1.0439 |
| Proportion (%) | 28.70 | 17.50 | 14.40 | 10.00 | 7.10 | 5.50 |
| Cumulative (%) | 28.70 | 46.20 | 60.60 | 70.60 | 77.80 | 83.30 |

**Table 7: Analysis of variance (ANOVA) for 19 characters in 24 bread wheat varieties**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **(a) Plant phenological and morphological traits** | | | | | | | | | | | | | | | | |
| **Source of Variation** | | **D.F.** | | **DH** | | **DA** | | **DM** | | **PH (cm)** | | **EBT per plant** | | **FL (cm)** | **FW (cm)** | **LAI (cm2)** |
| **Replication** | | 2 | | 0.63 | | 2.08 | | 1.75 | | 2.45 | | 0.007 | | 2.35 | 0.05\* | 20.99 |
| **Treatment** | | 23 | | 34.18\* | | 47.48\*\* | | 132.67\*\* | | 442.89\*\* | | 1.39\*\* | | 38.83\*\* | 0.061\*\* | 96.64\*\* |
| **Error** | | 46 | | 17.38 | | 12.21 | | 43.41 | | 5.27 | | 0.03 | | 2.72 | 0.013 | 6.99 |
| **(b) Spike, grain and yield-related traits** | | | | | | | | | | | | | | | | |
| **SL (cm)** | **SPS** | | **EW (g)** | | **GPS** | | **TGW (g)** | | **GL (mm)** | | **GW (mm)** | | **GLWR** | **BY (g)** | **HI (%)** | **GY/plant (g)** |
| 2.21\* | 5.92\*\* | | 1.80\*\* | | 6.88 | | 3.82\* | | 0.05 | | 0.002 | | 0.007 | 3.21 | 1.47 | 0.41 |
| 5.82\*\* | 9.73\*\* | | 0.29\*\* | | 187.72\*\* | | 50.95\*\* | | 0.32\*\* | | 0.056\*\* | | 0.036\*\* | 43.42\*\* | 58.69\*\* | 15.82\*\* |
| 0.56 | 1.03 | | 0.04 | | 12.65 | | 0.88 | | 0.03 | | 0.007 | | 0.005 | 1.82 | 16.27 | 1.46 |

\*Significant at 5% (P value- less than 0.05) \*\*Significant at 1% (P value- less than 0.01)

**CONCLUSION**

The study revealed significant differences among 19 traits in bread wheat varieties. K9351 recorded the highest grain yield, biological yield, ear weight, and grains per spike, while K1711 had the highest thousand-grain weight. K9533 excelled in EBT per plant, days to anthesis, and maturity. Traits like leaf area index, with high PCV and GCV, offer good selection potential for breeding. Grain yield per plant showed significant positive correlations with key traits at both phenotypic and genotypic levels, facilitating yield improvement through associated character selection. Cluster analysis grouped the 24 varieties into five clusters, with cluster I being the largest (20 varieties). The highest cluster distance between clusters IV and V indicates high heterosis potential. Out of nineteen, only six principal components (PCs) exhibited more than 1.0 Eigen value, and showed 83.3% variability, aiding in the selection of efficient lines for breeding and hybridization programs.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE) :** Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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