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MULTIVARIATE ANALYSIS FOR MORPHOLOGICAL TRAITS OF *CHENOPODIUM ALBUM*

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Abstract *Chenopodium album is a highly noxious weed species found in maize, soybeans, sugar beets, potatoes, and various vegetable crops. Various crop plants faced major losses in yield due to this weed through competition for water, minerals, and nutrients. The designated study was conducted to analyze the morphological traits of this species and to evaluate its adaptability across harsh environmental conditions to understand its survival mechanisms. Nine plant samples were collected from three different locations at the Faculty of Agricultural Sciences, University of the Punjab, Lahore, Pakistan. Analysis of variance, variance components, correlation, regression, and GGE biplot analyses were conducted to evaluate the relationship among the studied traits. Results revealed that fresh weight and dry weight exhibited the highest broad-sense heritability and genetic advance values, which indicate higher genetic vigor for growth and development of Chenopodium album plants. Most of the traits showed positive and significant associations, while moisture content was negatively correlated with all other parameters. Regression analysis revealed that leaf length, leaf width, and dry weight were the major contributors to plant height. Also, location 2 was the most favorable environment for the growth and development of Chenopodium album. Timely management and control of this invasive species is clearly needed to reduce yield losses of crops.*

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Keywords: *Chenopodium album; troublesome weed, morphological traits, heritability, genetic advance, correlation, regression, GGE biplot*

Introduction

Chenopodium album is classified as one of the ten most troublesome weed species in the world. (Netland et al., 2001). It is an invasive species in China and in Pakistan. It is the most widely distributed and damaging weed. It persists particularly in modern agricultural systems that depend on intensive tillage practices, chemical herbicides, and nitrogen-based fertilizers (Ansong and Pickering, 2013). It is best adapted to sub-tropical, tropical, and temperate climates (Bajwa et al., 2019; Krak et al., 2016). It belongs to the *Amaranthaceae* family and has a long history of use in traditional medicine practices. It is a broad-leaved annual herbaceous plant and is mostly recognized by its common name "lamb's quarter (Arora and Itankar, 2018; Sahin and Isik, 2025). It has been found across various cultivated crops and is an edible weed belonging to the genus *Chenopodium* (Singh et al., 2021). It typically emerges during spring and summer, with germination peak in early to mid-spring, rapidly spreading throughout agricultural fields (Chamkhi et al., 2022; Poonia and Upadhayay, 2015). In terms of biological classification, it is a C3 plant and is salt-tolerant (Attar et al., 2023). Although it is primarily a self-pollinating species, cross-pollination can also take place through wind (Aper et al., 2012). A major contributor to its rapid increase is its high seed output. It produces over 70,000 mature seeds per plant that can remain dormant and viable in the soil for up to 30 to 40 years (Yerka et al., 2012). The abundant seed production enables it to develop dense, long-lasting seed banks. This supports its long-term survival and continuous new emergence in agricultural fields (Aper et al., 2012). Moreover, a portion of its seeds becomes permeable shortly after dispersal, which enables them to germinate readily under favorable conditions. The remaining seeds break dormancy following winter and later germinate at normal temperatures the following spring. In this way, it collectively poses a persistent and continuous challenge throughout the entire crop growing season (Rahman et al., 2014; Werle et al., 2014). The characteristics allow *Chenopodium album* to compete strongly with crops during early growth stages. This leads to large reductions in both yield and quality of crops (Damalas and Koutroubas, 2022). *Chenopodium album* is a natural weed among the cultivated crops, and it is described as a highly competitive weed. Its particular spread seen in soybean (*Glycine max* L.), rapeseed (*Brassica napus* L.), maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.) fields across various regions worldwide (Guglielmini et al., 2017; Salonen et al., 2022). Additionally, this species has also been reported to negatively impact the yield of horticultural crops (Hwang et al., 2015). Efficient weed management in an agricultural system needs a clear understanding of environmental factors to reduce crop yield losses(Tang et al., 2022).

Figure 1: Sample collecting Locations

Materials and Methods

The plant samples required for trial and research were collected from the experimental land of Faculty of Agricultural sciences, University of the Punjab, Lahore, Pakistan during the month February 2026 (Figure 1). There were three distinct locations with three plants per site, giving a total of nine replications from a 1 m² area. After taking initial measurements, the plant samples were first sun-dried on newspaper for two days and then subjected to shade drying.

Morphological parameters

Eight morphological parameters were measured and recorded which were plant height (PH), leaf length (LL), leaf width (LW), leaf area (LA) that is calculated as LL × LW × 0.74, root length (RL), fresh weight (FW), dry weight (DW) and moisture content percentage (MC%) that is calculated as [(fresh plant weight) - (dry plant weight) / (fresh plant weight) x100]. Plant length and leaf dimensions were measured using a ruler and measuring tape. Fresh and dry weights were recorded using a weighing balance.

Statistics

The systematic evaluation of data to show meaningful patterns and to draw reliable conclusions is possible by using ANOVA, correlation, and regression analyses. These support decision making based on evidence for the determination of the significance of the results (Cole and Grizzle, 1966; Fuentes et al., 2010). ANOVA is a statistical method for comparing multiple groups or conditions. It allows to detect significant differences and effects of the independent variables (Nielsen, 2001). Correlation analysis determines the degree and direction of relationships between two or more variables(Prion and Haerling, 2014). Regression analysis uses the relationship between variables to make predictions about results. It provides a deep insight into the mechanisms driving those relationships(McEvoy and Cascio, 1987).

Results and discussions

Table 1 shows significant differences between the three studied locations for all the morphological traits of *Chenopodium album*. This suggests a number of mechanisms related to its invasiveness and its ability to survive in a variety of environmental conditions. The mean values obtained were plant height (23.442±0.1839 cm), root length (8.167±0.1546 cm), fresh weight (19.736±0.1724 g), dry weight (3.330±0.0359 g), leaf length (2.626±0.076 cm), leaf width (1.832±0.0291 cm), leaf area (3.633±0.1657 cm²), and moisture content (83.311±0.3745 %). The coefficient of variation (CV) remained low across all traits, which indicates high experimental precision and reliability of the recorded data. A specific trait of this highly competitive weed species, *Chenopodium album*, that is widely recognized is to build up considerable biomass under a range of environmental conditions. The comparatively high fresh weight observed across different locations supports this trait (Nxele et al., 2017). The higher percentage of moisture content further reveals the ability of *Chenopodium album* to retain water efficiently, which allows it to survive and persist under fluctuating climatic conditions. These characteristics combine to give it an aggressive competitive nature on cultivated crops (Sami et al., 2023).

Table 1. Analysis of Variance for morphological traits of *Chenopodium album*

SOV	PH	RL	LL	LW	LA	FW	DW	MC%
Locations	26.8294*	3.24333*	1.13108*	0.24421*	4.73575*	87.7569*	3.76643*	3.51599*
Error	0.1015	0.07167	0.01733	0.00254	0.08233	0.0891	0.00387	0.4207
Grand mean	23.442	8.1667	2.6256	1.8322	3.6328	19.736	3.33	83.311
Standard error	0.1839	0.1546	0.076	0.0291	0.1657	0.1724	0.0359	0.3745
CV	1.36	3.28	5.01	2.75	7.9	1.51	1.87	0.78

*= Significant at 5% probability level. LL= Leaf Length, LW= Leaf Width, LA=leaf area PH=Plant height, FW=fresh weight, DW=dry weight, MC%=moisture content percentage, RL =root length

Table 2 presents the values for genotypic variance (GV), phenotypic variance (PV), broad sense heritability (h^2bs), and genetic advance (GA) for all examined traits. Fresh weight showed the highest GV (29.223) and PV (29.312), and then the plant height (GV = 8.909; PV = 9.011). It suggests a high level of genetic variability for these traits across the populations studied. The strong similarity between GV and PV values for most traits indicates that their phenotypic expression was largely controlled by genetic factors rather than environmental influences. It is a conclusion that is further reinforced by the low environmental variance (EV) observed for the majority of traits. The genotypic and phenotypic coefficients of variation were higher for fresh weight, dry weight, and plant height. It reflects substantial variability in these traits. Conversely, moisture content showed the lowest coefficients, which suggests relatively limited genetic variation. The small differences between GCV and PCV for most traits further indicate that environmental effects had only a minor influence on their expression. Broad-sense heritability values were very high for most of the traits examined. Fresh weight and dry weight showed the greatest heritability, followed by plant height, leaf width, leaf length, leaf area, and root length. In contrast, moisture content exhibited the lowest heritability, which indicates a comparatively stronger influence of environmental factors on this trait. The high heritability suggests that these characteristics are mainly governed by genetic factors and can be consistently passed from one generation to the next. It makes them useful for interpreting the genetic structure of *Chenopodium album* populations. Genetic advance percentage was highest for dry weight than for leaf area, leaf length, fresh weight, and leaf width. It shows strong potential for improvement in these traits through selection. However, moisture content showed the lowest genetic advance. It suggests a very limited scope for enhancement. The combination of high heritability and high genetic advance is generally considered the most reliable indicator of additive gene action. It implies that selection-based strategies would be particularly effective for improving traits such as fresh weight, dry weight, and leaf area in *Chenopodium album*.

Table 2. Variance Components, Heritability and Genetic Advance

Traits	M.S	G.M	GV	GCV %	PV	PCV %	EV	ECV%	h^2bs	h^2bs%	GA%
PH	26.829	23.442	8.909	61.649	9.011	61.999	0.102	6.58	0.989	98.874	22.22
RL	3.243	8.167	1.057	35.98	1.129	37.179	0.072	9.368	0.937	93.651	21.383
FW	87.757	19.736	29.22	121.68	29.312	121.87	0.089	6.719	0.997	99.696	47.997
DW	3.766	3.33	1.254	61.37	1.258	61.465	0.004	3.409	0.997	99.692	58.931
LL	1.131	2.626	0.371	37.603	0.389	38.47	0.017	8.124	0.955	95.54	39.808
LW	0.244	1.832	0.081	20.968	0.083	21.296	0.003	3.723	0.969	96.943	26.768
LA	4.736	3.633	1.551	65.344	1.633	67.056	0.082	15.054	0.95	94.96	58.632
MC%	3.516	83.311	1.032	11.129	1.452	13.204	0.421	7.106	0.71	71.035	1.803

LL= Leaf Length, LW= Leaf Width, LA=leaf area PH=Plant height, FW=fresh weight, DW=dry weight, MC%=moisture content percentage, RL =root length, M.S= Mean sum of square, G.M= Grand mean, GV= Genotypic Variance, GCV %= Genotypic coefficient of variance, PV= Phenotypic Variance, PCV %= Phenotypic Coefficient of variance, EV= Environmental Variance, ECV %= Environmental coefficient of variance, h^2bs= Broad sense heritability, GA%= Genetic Advance percentage

In Table 3, correlation analysis was conducted to assess the relationships among the morphological traits of *Chenopodium album*. The results showed mainly positive and significant relationships among most of the traits analyzed, whereas moisture content was negatively correlated with the majority of the other parameters. Fresh weight had a very strong positive correlation with dry weight, plant height, leaf length, leaf area, and root length, whereas a moderate positive relationship with leaf width. These strong connections show that plants with more biomass tend to have better growth across several physical traits (Reddy et al., 2003). Plant height had highly significant positive relationships with leaf length, leaf area, dry weight, root length, and leaf width. These results suggest that taller *Chenopodium album* plants often have larger leaf sizes and more total biomass. It improves its ability to photosynthesize and compete against other crops. Root length was strongly and positively correlated with dry weight, fresh weight, leaf length, plant height, leaf area, and leaf width. The close association between the length of roots and the traits of biomass is the primary function of root development that improves growth and nutrient uptake. This allows *Chenopodium album* to effectively compete with crops for moisture and necessary nutrients. On the contrary, moisture content was found to have inverse correlations with the height of the plant, length of the root, dry weight, fresh weight, leaf area, leaf length, and leaf width. The inverse correlations suggest that plants having high moisture content generally allocate less energy towards the development of vegetative parts of the body. A pattern that may reflect a trade-off between water retention and growth under fluctuating environmental conditions (dos Santos et al., 2015).

Table 3. Correlation among morphological traits of *Chenopodium album*

Traits	DW	FW	LA	LL	LW	MC%	PH
FW	0.9894*						
LA	0.873*	0.908*					
LL	0.9493*	0.973*	0.970*				
LW	0.6475	0.6994*	0.9211*	0.8008*			
MC%	-0.828*	-0.7427*	-0.6098	-0.6789*	-0.4168		
PH	0.9503*	0.9794*	0.9644*	0.9891*	0.8153*	-0.6672*	
RL	0.9777*	0.9649*	0.8511*	0.9305*	0.6206	-0.8169*	0.925*

*=Significant at 5% probability level. LL= Leaf Length, LW= Leaf Width, LA=leaf area PH=Plant height, FW=fresh weight, DW=dry weight, MC%=moisture content percentage, RL =root length

Table 4 shows a regression analysis used to evaluate the extent to which different morphological traits contribute to plant height in *Chenopodium album* (Lee, 2022). The regression analysis showed a very high coefficient of determination (R^2 = 99.85%), which indicates that the predictor variables collectively accounted for nearly all of the observed variation in plant height. The adjusted coefficient of determination R^2 value (98.8%) supported the strength and reliability of the analysis. Leaf width showed the highest positive contribution, and then leaf length, dry weight, and moisture content among the indicator variables. This suggests that these traits have the strongest positive effects on plant height. Conversely, fresh weight and leaf area showed negative coefficients. It indicates that their independent contributions to plant height were inversely associated when other variables were held constant. Root length showed the smallest coefficient, which shows a negligible independent effect in the analysis. Although none of the individual variables were statistically significant. I may be due to strong multicollinearity among predictors, as suggested by high VIF values. The overall regression analysis was highly significant (Leon et al., 2003).

Table 4. Stepwise multiple linear regression for Plant Height of Chenopodium album

Variables	Coefficient	Std Error	T	P	VIF
FW	-3.09628	4.27855	-0.72	0.6012	39736.4
LA	-17.7756	17.9506	-0.99	0.5031	39714
LL	28.6617	27.9213	1.03	0.4917	22611.2
LW	35.0055	34.1159	1.03	0.4918	7502.8
RL	0.06119	0.54051	0.11	0.9282	24.5
MC%	2.52765	3.10789	0.81	0.5653	1318
DW	16.4283	20.8673	0.79	0.5754	40982.2

LL= Leaf Length, LW= Leaf Width, LA=leaf area PH=Plant height, FW=fresh weight, DW=dry weight, MC%=moisture content percentage, RL =root length

The GGE biplot analysis (Figure 2) revealed that PC1 accounted for 76.6% of the total variation, while PC2 explained 23.2%, with both components collectively representing 100% of the observed variation among the studied morphological traits of *Chenopodium album* across the three locations. High values of variance accounted for by PC1 suggest that there is mainly one dominant effect that caused differences in the traits among all locations. It suggests distinct patterns of morphological diversity across the habitats. From the biplot diagram, plant height and fresh weight were located closely together on the positive side of the PC1 axis. It can be noted that location 2 was the best habitat to express these traits. This suggests that location 2 provided the best environment to achieve vegetative growth and biomass production for *Chenopodium album*. The results are also supported by ANOVA analysis, where location 2 showed high grand means for growth characteristics (Clegg et al., 2009). However, root length was located on the top left side of the biplot, while moisture content was on the bottom center position. It can be inferred that these traits were linked to different habitats than growth traits. The traits leaf area, leaf length, and leaf width were plotted closer to the center of the biplot. This shows moderate stability in terms of their expression within the three locations. The vertex points of the biplot show locations with optimal performance levels with respect to specific trait combinations. Location 2 proved to be the optimal growing location for plant height and fresh weight. This clearly reveals that it offered better growing conditions for encouraging robust growth and competitiveness in the establishment of

Chenopodium album. Based on these results, weed management strategies must be prioritized at location 2. It provides the most favorable conditions for the growth and spread of *Chenopodium album*. Early control in such highly productive areas is important to reduce competition and crop yield losses caused by this invasive weed species (Afzal et al., 2016; Mahmood et al., 2016).

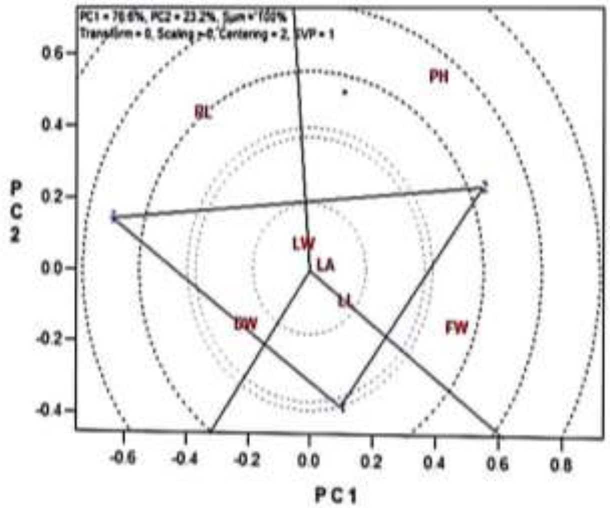

Figure 1. Total score plot for morphological traits of *Chenopodium album* under 3 different locations

Conclusion

Results showed significant morphological variation in *Chenopodium album* among different environments, with high heritability and genetic advance for most of the traits. It indicates strong additive genetic control. Location 2 was identified as the most favorable site for *Chenopodium album* growth, so essential management and control measures at that location are necessary to reduce crop yield losses caused by this invasive weed.

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Statements and Declarations

Data Availability statement

All relevant data are within the manuscript file.

Author's Contribution Statement
EY, KT, Amna, and MW collected data and wrote manuscript equally. All authors have read the final manuscript and approve its submission.
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