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MULTI-VARIATE ANALYSIS FOR MORPHOLOGICAL TRAITS OF *CHENOPODIUM MURALE*

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Abstract *The Chenopodium murale is a very troublesome weed and an invasive species on a large scale, and also a serious threat to agricultural systems throughout the world, especially in cereal and vegetable crops. The purpose of this study was to assess the morphogenetic variability of C. murale and to obtain insight into the adaptive mechanisms under different environmental conditions. Samples were taken from three different sites at the Faculty of Agricultural Sciences, University of the Punjab, Lahore, Pakistan. The morphological traits, such as length of leaf, width of leaf, leaf area, shoot height, root length, fresh weight, dry weight, and moisture percentage, were recorded and analyzed by analysis of variance (ANOVA), correlation, regression, and PCA biplot analysis. The analysis revealed that the plant height, leaf area, fresh weight, and percentage of moisture were significant ($p \leq 0.05$) between locations, thereby indicating a very high phenotypic plasticity and stress tolerance in the case of these traits. Heritability (h^2) ranged from 0.847 to 0.993, indicating that the genetic control of these adaptive traits was additive. The fresh weight, leaf area, leaf length, leaf width, moisture content, and root length were highly positively correlated. PCA accounted for 96.4% of the total variance, which was indicative of a good 2D representation of morphological variation. Multiple morphological traits need to be targeted with an integrated weed management strategy to produce effective control for this noxious weed.*

Keywords: *Morphological traits; correlation; PCA; integrated weed management; invasive weed; Chenopodium murale*

Introduction

Chenopodium murale L. The most common summer annual and a broadleaf plant is (nettle leaf goosefoot). It is a member of the Amaranthaceae family (Goosefoot Family). It is indigenous to Europe, North Africa, and some parts of Asia, including southwestern Asia. Its geographic span increased significantly in Asian countries. In South Asia, it is present in Cholistan, Punjab, Jammu and Kashmir, Rajasthan, West Bengal, Balochistan, and Himachal Pradesh (Bajwa et al., 2019). Its infestation has been recorded in approximately 25 cultivated crop species and 57 countries all over the world (Holm et al., 1997). As a weed, it is highly invasive, causing significant damage to crop yield. It is an erect, fast-growing weed with a plant height range between 10-100cm tall and can reach up to 90-100cm under favorable conditions. It is densely branched and pubescent with farinose new growth **(**Sami et al., 2023**)**. The stem is erect, tenuous, stalky, and often deeply grooved. It is usually green but often becomes reddish carrot under environmental stress or as the plant matures. Older stems are glabrous, while the younger stems are covered with fine, blistered hairs that give them a scaly and grainy texture (Naqvi et al., 2020). Leaves are arranged alternately along the stem. They ranged from broadly oval and deltoid to roughly rhombic with an average length of 2-8cm and a width between 5-50mm (Rehman and Rao, 2023). The inflorescence consists of dense, small green or reddish fine clumps of flowers called glomerules. The flowers are tiny, 1-1.5mm in diameter, and usually hermaphrodite (Fuentes-Bazan et al., 2012). The plant produces small, rounded lenticular seeds, and they have a higher dispersal rate, with a single plant capable of producing 24000 seeds (Kühn et al., 1993). The traditional uses reported for the Chenopodium species include the use of the leaves and seeds by various communities as medicinal plants, but not many years have passed since then, and today

Chenopodium murale is known as one of the most troublesome weeds in agriculture, negatively affecting economic crops and reducing yields(Srivastava et al., 2013). The *Chenopodium murale* has been reported to overrun over 25 crops in different ecologies of the world, including wheat *(Triticum aestivum L.),* maize *(Zea mays* L.), potato (*Solanum tuberosum* L.), cauliflower *(Brassica oleracea L.),* garlic *(Allium sativum L.),* onion (*Allium cepa L.),* and spinach *(Spinacia oleracea L.),* and cause substantial yield damage based on the scale of infestation (Bana et al., 2022; Raza et al., 2023). It is known to be very efficient in nutrient uptake and assimilation while growing in a crop (Bhowmik and Reddy, 1988). A weed species, *Chenopodium murale*, has allelopathic characteristics due to the release of a number of phytotoxic secondary compounds, called allelochemicals, in the rhizosphere surrounding the plant. These inhibit the growth and germination of adjacent plants (Bajwa et al., 2019).

Materials and Method

Sampling and Collection

Three replications of Chenopodium murale were taken from various locations of the Faculty of Agricultural Sciences, University of the Punjab, Lahore, Pakistan. Three individual plants per location were selected, and 3 replications were maintained and investigated for their vegetative and structural characteristics. To avoid damage to the plant structure and for precise morphological observations, complete plants were carefully uprooted from the soil (Ahmed and Aliwy, 2023). The collected plants were then carefully transported to the lab to be studied further.

Morphological Data Collection

Different morphological characteristics of Chenopodium murale were recorded and documented. The morphological parameters include plant height, root length, leaf length, leaf width, and leaf area. The fresh weight of the plants was recorded using an analytical weighing balance. Plants were sun-dried to a constant and stable biomass weight to determine dry weight. After that, the moisture content of the plants was calculated.

Mathematical formulas

The following formulas are used in calculations;

Leaf area:

$$\text{Leaf area} = \text{Leaf length} \times \text{Leaf width} \times 0.74$$

Moisture content:

$$MC\% = FW\text{-}DW/FW \times 100$$

Results and Discussions

The results from Table 1 regarding the morphological characteristics of *Chenopodium murale* under different environmental conditions indicate various mechanisms that allow it to become invasive and survive. Several characters were found to be significant at the level of 5%, including Spread of Vegetation (SOV), Leaf Area (LA), Plant Height (PH), Fresh Weight (FW), Dry Weight (DW), Fresh Weight/Dry Weight Ratio (FW/DW), Moisture Percentage (MP), and Root Length (RL). These characteristics reflect the reaction to environmental conditions like water, light, soil nutrients, and temperature changes (Bana et al., 2022). The coefficient of variation (CV) was between 1.16 – 12.83, indicating moderately high variability between accessions. High heritability ($h^2 = 0.847–0.993$) and moderate to high genetic advance (GA) were observed for most traits, particularly for SOV (90.49), PH (57.95), and FW (34.14). This suggests that these characteristics are additive genetic in nature and Chenopodium murale is a persistent and competitive weed (Gupta and Narayan, 2012). There was also a significant variation in secondary characters, RL and DW, which might be due to changing environments. Overall, *C. murale* has exhibited a high ability to cope with environmental stresses and therefore requires an integrated weed management program (Abdo et al., 2025).

Table 1. ANOVA for morphological traits of *Chenopodium murale*

SOV	LA	SH	FW	DW	FW/DW	MP	RL
Rep	0.7078*	0.27111*	0.0833*	0.39*	0.21358*	8.68*	0.8611*
Location	39.2811*	6.82111*	72.3333*	3.49*	20.7258*	431.83*	17.5278*
Error	0.7511	0.38778	0.9167	0.09	10.1855	0.97	0.3611
G. mean	6.7556	21.022	14.5	5.2667	2.75314	61.133	11.944
S. Error	0.5004	0.3595	0.5528	0.1732	3.19168	0.5686	0.3469
CV	12.83	2.96	6.6	5.7	1.15789	1.61	5.03
GA	90.492	11.2504	57.9486	34.1447	1.69714	34.2884	34.0896
H^2	0.94475	0.84686	0.96292	0.92643	1.03938	0.99329	0.94064

*= Statistically significant at 5% level of probability, G. mean= grand mean, S. Error= Standard error, CV= Coefficient of variance, GA= Genetic advance, h^2= Heritability, LA= leaf area, SH= shoot height, DW= dry weight, MP= moisture percentage, FW/DW= fresh weight and dry weight ratio, FW= fresh weight, RL= root length

The correlation analysis (Table 2) showed that there are some significant positive correlations between most of the morphological traits of *Chenopodium murale*. Fresh weight (FW) showed strong positive correlations with leaf area (LA) (r = 0.9188*), leaf length (LL) (r = 0.9038*), leaf width (LW) (r = 0.9145*), moisture content (MC) (r = 0.8953*), and root length (RL) (r = 0.9125*). The strong correlations suggest that plants with larger moisture content have bigger leaves, longer roots, and are more competitive in *C. murale*, which is consistent with the results (Sami et al., 2023).

Taller plants (SH) were found to have a positive correlation with dry weight (DW) (r = 0.6853*) and fresh weight (FW) (r = 0.7489*), which shows the accumulation of biomass with the increase in plant height. Leaf area (LA) had a very high correlation with the other leaf morphological traits, LL (0.9629), LW (0.959), and MC (0.9237*). The results indicated that the morphological traits of leaf area are highly interrelated (Abdo et al., 2025). The moisture content (MC) was strongly positively correlated with most growth traits, with the exception of dry weight (r = -0.1247), suggesting that an increase in moisture may not necessarily lead to an increase in dry matter. Root length (RL) showed significant positive correlations to SH (0.7263), FW (0.9125), and LA (0.9247*), showing a high correlation between root and shoot development. The positive correlations generally point to the fact that Chenopodium murale is well adapted to deal with the unfavorable agricultural settings (Al-Johani et al., 2012).

Table: 2 *Chenopodium murale* morphological traits correlation

Traits	DW	FW	LA	LL	LW	MC	RL
FW	0.3225						
LA	0.0812	0.9188*					
LL	0.1366	0.9038*	0.9629				
LW	0.1583	0.9145*	0.959	0.8649*			
MC	-0.1247	0.8953*	0.9237*	0.8987*	0.8693*		
RL	0.1097	0.9125*	0.9247*	0.9273*	0.859*	0.9242*	
SH	0.6853*	0.7489*	0.5772	0.6833*	0.5297	0.4964	0.7263*

*= Statistically significant at 5% level of probability, DW= dry weight, FW= fresh weight, LA= leaf area, LL= leaf length, LW= leaf width, MC= moisture content, RL= root length, SH= shoot length

None of the predictor variables (DW, FW, LA, LL, LW, MC, RL) was significant ($p > 0.05$) in the stepwise multiple regression analysis of fresh weight of *Chenopodium murale* (Table 3). Of the various traits, only the traits RL (t = 7.6) and LL (t = 4.66) had high t-values, but all p-values were above 0.05, meaning that none of the morphological traits were found to have a significant effect on the fresh weight of *C. murale* alone (Sami et al., 2023). The non-significant coefficients of all the predictors indicate that the growth of fresh weight of *C. murale* is influenced by several factors and traits interacting with each other and not by one of them alone(Hayyat et al., 2025). This finding is in agreement with earlier studies that suggest growth and biomass production of *C. murale* are affected by the polygenic systems as well as high phenotypic plasticity (Bajwa et al., 2019; Gupta and Narayan, 2012). The negative value of DW (-1.272), LA (-1.491), and MC (-0.412), and positive values of LL (3.209), LW (2.331), and RL (0.961) suggest complex relationships which may be due to the multicollinearity of some of the variables as indicated in the correlation analysis (Table 2). The result suggests that multiple growth parameters should be targeted when developing management strategies for *C. murale*, instead of just focusing on a single trait, as this will yield a greater benefit (Alsherif, 2020; Raza et al., 2023).

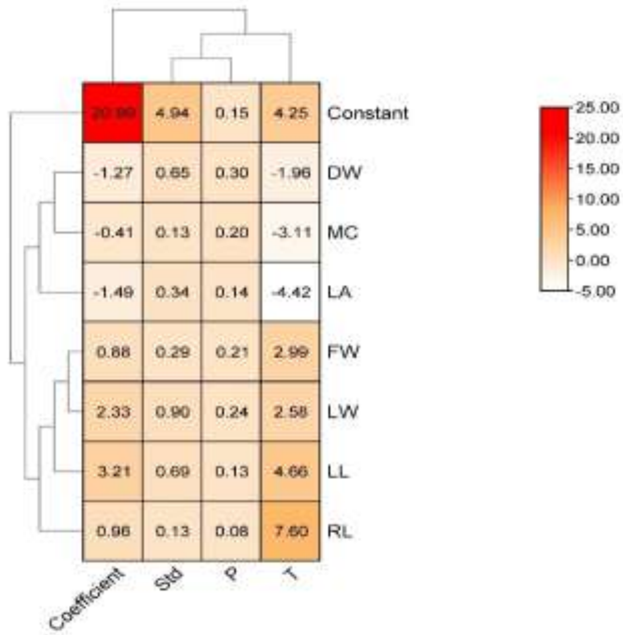

Figure 1 Step-wise multiplelinear regression for different traits of *Chenopodium murale*

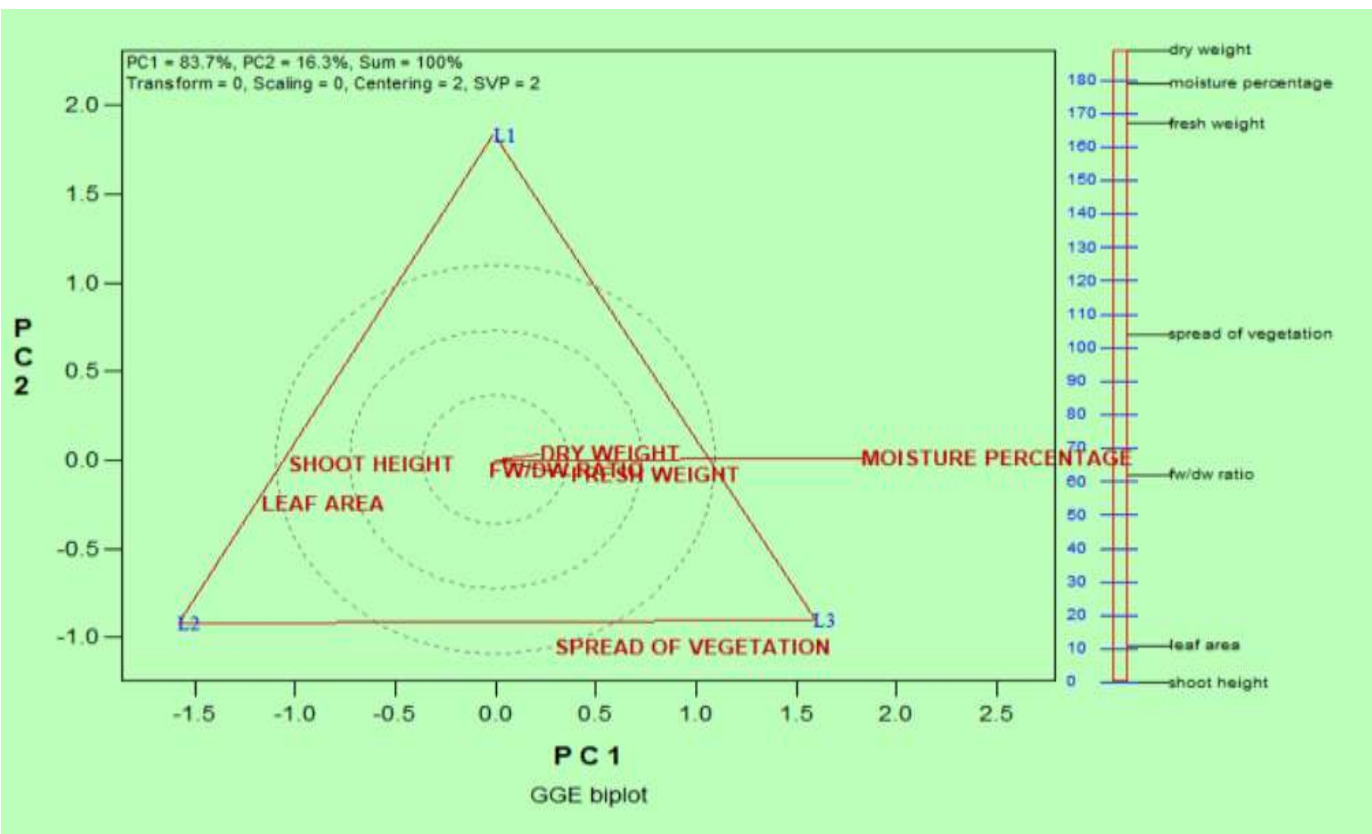

Figure 2 *Chenopodium murale* morphological traits in a GGE plot at three different locations

DW = dry weight, FW= fresh weight, LA= leaf area, LL= leaf area, LW= leaf width, MC=moisture content, RL= root length, Std= standard error, T=t-statistics, P= probability level

GGE biplot indicates that the first principal component (PC1) accounts for 83.7% of the total variation, the second principal component (PC2) accounts for 16.3%, and it is a 2-dimensional graph, representing 100% of the total variation. Shoot height, leaf area, and fresh weight, moisture percentage, and spread of vegetation are strongly correlated with PC1 and are the main contributors of morphological variation (Sami et al., 2023). Dry weight, the fresh to dry ratio, and root length, on the other hand, contribute more along PC2, thus demonstrating secondary variation(Bajwa et al., 2019). The three sites along the three categories are compared, with L1 being on the minus side on PC1, meaning that the plants are smaller with lower biomass and weaker competitiveness. L2 is around the middle growth rate and balanced characteristics. L3 has a strong positive score on PC1, indicating it has the largest leaf area, moisture percentage and biomass accumulation and is the most competitive population(Abdo et al., 2025). Based on the overall results, it can be concluded that the overall performance of the growth rate of L1, L2, and L3 is quite different, and it is clear that L3 is the best growth location. This indicates that adaptability and competitiveness *Chenopodium murale L.* depend on multiple traits, not a single trait (Hayat et al., 2025).

Conclusion

From the results, it can be concluded that the species *Chenopodium murale* showed high morphological variability and phenotypic plasticity, which can be demonstrated by the differences in various traits such as leaf area, plant height, biomass, and moisture content between the sites. They are under additive genetic control and highly heritable, making them persistent and competitive weeds. High positive relationships between growth traits improve their biomass accumulation and crop competition. The PCA (96.4% variance) supports the reliable morphological characterization. Thus, integrated weed management (IWM) that seeks to control multiple traits of *C. murale* simultaneously is recommended.

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Declaration

Data Availability statement

All authenticated data have been included in the manuscript.

Consent for publication

Not applicable

Declaration of Competing Interests

The authors declare that they have no conflict of interest.

Author Contribution Statement

BS collected data and conducted research and wrote article. MMB and QH make final editing was carried out and approved for final publication.

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Informed Consent

Not applicable.

Ethical Statement

Not applicable