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MULTIVARIATE ANALYSIS FOR MORPHOLOGICAL TRAITS OF *SOLANUM NIGRUM*

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Abstract *Solanum nigrum (black nightshade, commonly known as makoi) is an excellent medicinal plant with antimicrobial, antioxidant, and remarkable anticancer properties. However, the optimum conditions for maximizing its growth potential for the extraction of medicinal products require a good understanding of its phenotypic plasticity and biomass under different environmental conditions. This study assessed the morphological and biomass traits of Solanum nigrum collected in triplicate across three discrete ecological sites at the University of Punjab, Lahore, computing fresh weight (FW), dry weight (DW), shoot height (SH), root length (RL), leaf area (LA), leaf length (LL), leaf width (LW), and moisture content (MC), were evaluated using the Analysis of Variance (ANOVA), correlation, and multiple linear regression. ANOVA findings revealed the significant environmental variation for leaf area, fresh weight, and shoot height; in contrast, traits like leaf length and dry weight displayed enhanced stability across environments with magnificently minor coefficients of variation at 0.81 percent and 6.53 percent. Highly integrated development pathways were demonstrated by strong positive correlations between fresh and dry weight at 0.966 and between leaf length and width at 0.9628. Multiple linear regression analysis confirmed all the traits as significant indicators of biomass, with leaf width having the strongest effect (34.201). Overall, Solanum nigrum displays strong environmental adaptability, and traits like leaf width play a crucial role in improving the biomass.*

Keywords*:* *Solanum nigrum; correlation; Regression; morphological traits; biomass*

Introduction

Solanum nigrum, commonly known as makoi or black nightshade, is a plant that commonly grows as a weed in moist environments. It can thrive in a wide range of soil types, including dry, stony, shallow, and deep soils. This species can also be cultivated in tropical and subtropical agro-climatic regions by sowing seeds in well-fertilized nursery belts during April and May. Moreover, it has potential for use in the reclamation of degraded land (Jain et al., 2011). Commonly called Black Nightshade or Manathakkali in Tamil, *Solanum nigrum* is a member of the Solanaceae family with various medicinal uses. It contains antioxidant, antimicrobial, and liver-protecting properties. Conventional, it has been used in African childcare to manage fever-related seizures and eye or skin issues, and research suggests it may even have anticancer potential (Rani et al., 2017). It is an upright, highly branched, spineless, semi-woody annual herb. The leaves are ovate to oblong with toothed or lobed margins and have a smooth surface. The flowers, numbering 3-8, occur in drooping extra-axillary subumbellate cymes. The plant produces purplish-black or reddish berries as fruits, containing numerous small, yellow, disc-shaped seeds (Saleem et al., 2009). *S. nigrum* is a well-known source of *Solanine*, a toxic glycoalkaloid that is most concentrated in its green, unripe berries. It is also highly valued for its medicinal potential. Beyond its reputation as a common poison, research indicates it contains various phytochemicals that offer valuable pharmacological possibilities (Ajayi, 2011). *S.nigrum* is widely used for both folk and Oriental medicine to manage pain, inflammation, and hepatitis. The plant acts as a powerful therapeutic agent with recognized antioxidant, antitumor, diuretic, and fever-reducing properties (Nyeem et al., 2017). *S.nigrum* is a highly valued medicinal plant across various African and Indian communities. In Africa, it is utilized to treat snakebites, burns, ringworms, and erysipelas. Similarly, in India, Tamil Nadu residents use it to heal wounds, soothe ulcers, and relieve coughs, while communities in the Himalayas and Assam rely on it for asthma, ingestion, and liver support (Jabamalairaj et al., 2019). *S.nigrum* is a common weed found in nitrogen-rich soils. It comprises a collection of bioactive compounds like uttroside B, solanine, solamargine, and physalins, that researchers are strongly tested on cancer cell lines and xenografted mice (Butt et al., 2018).

Materials and Methods

Three replications of *Solanum nigrum* were taken from three different locations at the University of

Punjab, Faculty of Agricultural Sciences, Lahore, to confirm the accuracy of their findings. Each sample set contains three plants, and the root systems were carefully preserved by digging the surrounding soil during the isolation of each plant.

Fresh Weight Determination

The fresh weight of all samples was immediately measured with an accuracy weighing balance.

Assessment of Morphological Traits

Physical characteristics, such as shoot length, leaf area, and leaf width, were measured numerically with a reference meter scale.

Dry Weight Determination

The specimens were relocated to a controlled dry environment for an interval of 5-6 days. This process secured the complete elimination of moisture by avoiding humidity interaction. Once fully dehydrated, the final dry weight was measured and recorded.

Data Analysis and Calculation

- **Leaf Area Calculation:**
  Leaf Area = (Leaf Length)(Leaf Width)(0.74)
- **Moisture Content Percentage:**
  Moisture Content (%) = Fresh Weight-Dry Weight/Fresh Weight(100)

Result and discussion

The ANOVA analysis of morphological traits in *Solanum nigrum* from Table 1. states that variation exists among the observed characters, including leaf area (LA), leaf width (LW), root length (RL), fresh weight (FW), dry weight (DW), root length (RL), moisture content (MC), and shoot height (SH). The effect of location was evident in several traits, with higher values recorded for LA, LL, FW, RL, and SH. This suggests that environmental conditions had a strong influence on plant growth and development. On the other side, traits like dry weight showed very low values under the effect of location, determining that they were less affected by environmental changes. Most of the traits have low error values, particularly traits like LL and DW, which show that the data obtained is accurate and dependable. However, slightly higher values in traits like LA and MC reflect some extent of variability in the measurements. The values of grand mean showed that moisture content had the highest overall value, followed by shoot height and root length, while dry weight showed comparatively lower mean values. In addition, the standard error values were generally small across the traits, showing consistency in the data with minimum deviation from the mean. The extent of coefficient of variation (CV) was low to moderate, where traits such as LL, MC, and SH indicate low CV values, indicating larger stability, whereas LA, LW, and DW displayed relatively higher CV values, revealing more variability. Overall, these results display that both environmental factors and genetic variability have an essential contribution to the development of morphological traits of *Solanum nigrum*, with some of them being more sensitive and others being less sensitive to the environment.

Table 1. ANOVA for morphological traits of *Solanum nigrum*

SOV	LA	LW	LL	FW	DW	RL	MC	SH
Location	21.7358	0.49000	2.80444	2.30778	0.01543	10.6878	2.26778	28.4621
Error	0.1208	0.01333	0.00111	0.00444	0.00027	0.1078	0.27611	0.0074
Grand Mean	6.3833	2.0333	4.1222	2.4222	0.2500	8.1444	89.478	32.071
Standard error	0.2007	0.0667	0.0192	0.0385	9.428E-03	0.1895	0.3034	0.0495
CV	5.45	5.68	0.81	2.75	6.53	4.03	0.59	0.27

From Table 2. The correlation analysis of morphological traits of S. nigrum showed that growth traits were highly correlated with leaf traits. Fresh weight exhibited very little weight decrease. A high correlation was found between fresh weight (FW) and dry weight (DW) (r = 0.966), showing that increased fresh weight is associated with higher dry matter accumulation. Leaf traits were also closely linked, such as leaf area (LA), which had a strong positive correlation with leaf length (LL) (r = 0.9944) and LL with leaf width (LW) (r=0.9628), suggesting leaves develop in a coordinated manner. However some negative correlations were observed, specifically between LW and both LA (r = -0.8626) and LL (r = -0.8428), determining possible trade-offs in leaf dimensions (Fortuin and Omta, 1980). Moisture content was positively correlated with FW (r = 0.7692) but negatively associated with LL (r = -0.6535) and LW (r = -0.9169), suggesting that excess moisture might stunt leaf growth. Root length (RL) and Shoot height (SH) both exhibited strong positive association with DW and FW, emphasizing the contribution to overall plant biomass. Overall, the results indicate that biomass-related traits are positively interlinked, while leaf traits display both positive correlations and antagonistic relationships; they offer valuable insights for vegetative developmental evaluation and species selection (Hayat et al., 2025).

Table 2. ***Solanum nigrum*** **morphological traits correlation**

Traits	DW	FW	LA	LL	LW	MC	RL
FW	0.966						
LA	-0.4428	-0.6189					
LL	-0.448	-0.6176	0.9944				
LW	-0.535	-0.7091*	0.9816	0.9628			
MC	0.5821	0.7692*	-0.8626*	-0.8428*	-0.9169*		
RL	0.9483*	0.9589	-0.5484	-0.5309	-0.6535*	0.7075*	
SH	0.9681	0.9382*	-0.3445	-0.3347	-0.4672	0.5784	0.9611

From Table 3. The stepwise multiple linear regression analysis for the fresh weight of Solanum nigrum displays that all seven variables, DW, FW, LA, LL, LW, MC, and RL, serve as statistically significant predictors, as their p-values are all below 0.05. From these, leaf width (LW) has the strongest positive effect, showing the highest coefficient of 34.2010, followed by fresh weight (FW) and leaf area (LA).In contrast, dry weight (DW) and moisture content (MC) are significantly negatively associated with fresh weight, with DW indicating a specifically large negative coefficient of -196.446, displaying that an increase in these variables leads to a substantial decrease in the predicted fresh weight. Moreover, the high t-statistics recorded for all variables, particularly root length (RL) at (t = 56.82)_display strong statistical significance, emphasizing that leaf characteristics and biomass distribution are important factors affecting the plant's overall fresh weight (Ravi et al., 2013).

Table 3. Stepwise multiple linear regression for fresh weight of *Solanum nigrum*

Variable	Coefficient	Standard error	T Stat	P value
DW	-196.446	7.09178	-27.70	0.0230
FW	23.5567	0.79231	29.73	0.0214
LA	-9.38008	0.41517	-22.59	0.0282
LL	15.4603	0.66701	23.18	0.0274
LW	34.2010	1.42114	24.07	0.0264
MC	-4.34961	0.15854	-27.44	0.0232
RL	1.51725	0.02670	56.82	0.0112

Conclusion

This study displays a wide-ranging quantitative analysis of morphological traits and biomass allocation of Solanum nigrum (black nightshade) gathered throughout the dissimilar microclimates at the University of Punjab, Lahore. The result of observations is an explanation of the complex process of interaction between genets and environment in studying the phenotypic plasticity of highly regarded medicinal plants.

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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

Ayesha collected data and conducted research and wrote article. Final editing was carried out and approved for final publication.

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Informed Consent

Not applicable.

Ethical Statement

Not applicable