



A Chemical and Morpho-Anatomical Study of *Aerva javanica* from Punjab, Pakistan

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Abstract

Aerva javanica is a species of Amaranthaceae family that mostly grows in deserts. It is used as fodder and fuel, and to treat headache, toothache and many other disorders by many indigenous communities across the country. The fresh samples (roots, stem and leaves) of *A. javanica* were collected from six different ecological habitats of Taunsa Sharif, Dera Ghazi Khan to investigate their anatomical characters. Small 3 cm pieces were cut treated with formalin acetic acid solution, after 48 hours the samples were preserved in acetic alcohol solution for long time. Free hand sectioning was done followed by double staining of safranin and fast green stains. Photographs were taken to analyze various anatomical parameters and permanent slides were prepared to study latter. The rhizospheric soil and water samples were also collected to analyze their physiochemical parameters and correlated with the plant anatomy. Morpho-anatomical parameters of *A. javanica*, including root, stem, and leaf characteristics such as epidermis, cortex thickness, xylem area, vascular bundle area, and vascular stroma, were assessed. The data were presented to one-way ANOVA with the help of SPSS software, and the means were compared across the groups (plant anatomical traits to physiochemical traits to soil and water). Almost all the habitats possessed same chemical characteristics of soil and water. Similarly, all morphological parameters of roots, stems, and leaves of *A. javanica* were found within the standard range ($p \geq 0.05$). These results indicated that *A. javanica* is very specific to anatomical traits that revealed its ecological success in different ecological habitats with different physico-chemical characteristics of soil and water.

Keywords: *Aerva javanica*, Physiochemistry of soil and water, Morpho-Anatomical Adaptations, Soil Plant interaction.

Introduction

Aerva javanica, the kapok bush or desert cotton, is a species of plant in the Amaranthaceae family. This family includes the former goose-foot family Chenopodiaceae and contains about 165 genera and 2,040 species, making it the most species-rich lineage within its parent order, Caryophyllales [Movaliya, V, 2014]. Most species in the Amaranthaceae are annual or perennial herbs or sub-shrubs; others are shrubs, and very few species are vines or trees. Some species are succulent. Many species have stems with thickened nodes. The wood of the perennial stem exhibits a typical “anomalous” secondary growth; only in the subfamily Polycnemoideae is secondary growth normal [Carlquist, S, 2003]. The leaves are simple and mostly alternate, sometimes opposite. They never possess stipules. The leaves are flat or terete, and their shape is extremely variable, with entire or toothed margins. In some species, the leaves are reduced to minute scales. In most cases, neither basal nor terminal aggregations of leaves occur [Srinivas, P. S. R. R. et al., 2012].

The flowers are solitary or aggregated in cymes, spikes, or panicles and are typically perfect (bisexual) and actinomorphic. Some species have unisexual flowers. Bracts and bracteoles are either herbaceous or scarious. Flowers are regular with an herbaceous or scarious perianth of (one to) mostly five (rarely up to eight) tepals, often joined. One to five stamens are opposite to tepals or alternating, inserting from a hypogenous disc, which may have appendages (pseudostaminodes) in some species [S. Mussadiq et al., 2013]. The anthers have two or four pollen sacs (locules). The pollen grains are spherical with many pores (pantoporate), with pore numbers ranging from a few to 250 (as in *Froelichia*). One to three (rarely six) carpels are fused to a superior ovary with one (rarely two) basal ovule [Silvia, N. et al., 2014]. Idioblasts are found in the tissues. The diaspores are seeds or fruits (utricles); more often the perianth persists and is modified in fruit for means of dispersal. The green or white embryo is either spirally (and without perisperm) or annular (rarely straight) [Phondani, P. C. et al., 2015].

Aerva javanica is deep-rooted and is used as a soil binder in desert reclamation. It is used for fuel and as fodder for goats. In traditional medicine, the seeds are believed to cure headaches [Waqas, M. et al., 2021]. A gargle made from the plant is used to treat toothache. It has a wide range of distribution and can grow in various regions with suitable conditions. The plant has naturalized in northern regions of Australia as an alien introduction. It is cultivated and utilized by the indigenous peoples. The thick, white inflorescences have traditionally been harvested in Arabia for stuffing cushions and saddle pads. Today, the soft fibers are still used as kapok for pillows [Muf-ti, F. U. D. et al., 2012]. It is called Bilhanga in the languages of the Yindjibarndi and Ngarluma people; the English term is Kapok Bush. It thrives in arid and semi-arid climates, tolerating high temperatures and drought conditions. It prefers regions with dry and hot summers and mild winters. It can grow in a variety of soil types, including sandy, loamy, and rocky soils [Azhar, M. F. et al., 2022]. The Invasion of plant species poses a significant threat to the biodiversity of local plant communities. Invasive plant species have negative impacts on flora and cause great ecological and economic damage [McGeoch, M. A. et al., 2010]. In Pakistan, *Aerva javanica* thrives well on calcareous and sandy soils of arid and semiarid rangelands. [Shahin, S. M. et al., 2021].

The limited documentation on the morpho-anatomical characteristics of *Aerva javanica* and its anatomical relationship with the physicochemical properties of soil and water in Taunsa Sharif, Punjab, Pakistan, highlights a significant research gap. The present study aims to address this gap by investigating the structural, morpho-anatomical, and ecological traits of *Aerva javanica*, focusing on their contribution to ecological succession. Additionally, the study explores the correlation between anatomical traits and the physicochemical characteristics of soil and water.

Materials and Methods

Study Area

The study focused on six different ecological regions within Tehsil Taunsa Sharif, District Dera Ghazi Khan, Punjab, Pakistan, including Vahova, Tibbi, Retra, Ladha, Balchani, and Taunsa Sharif. The fresh plants samples (roots, stems and leaves) were collected from these ecologically distinct sites. Plant material was collected directly from the fields for dif-

ferent morpho-anatomical parameters. The Geographic coordinates of all these sites is represented in the table 1. Although the selected habitats possessed ecologically different features, but the study was limited to this specific tehsil. The study was conducted under the supervision of the Department of Botany, University of Education Lahore, Dera Ghazi Khan Campus, Punjab, Pakistan.

Table 1: The Coordinates of Ecological Zones in Taunsa Sharif, Punjab, Pakistan

Collection Sites	Altitude(m.asl)	Longitude (N)	Latitude (S)
Vahova	212.1	31°07'54.4"	70°30'34.8"
TibbiQaisrani	149.5	31°00'08.5"	70°40'49.5"
BaitLadha	146.0	31°00'12.3"	70°45'35.3"
Retra	146.8	30°56'12.3"	70°42'16.6"
BastiBalchani	187.3	30°57'40.6"	70°35'05.1"
TaunsaSharif	161.8	30°42'50.7"	70°39'41.2"

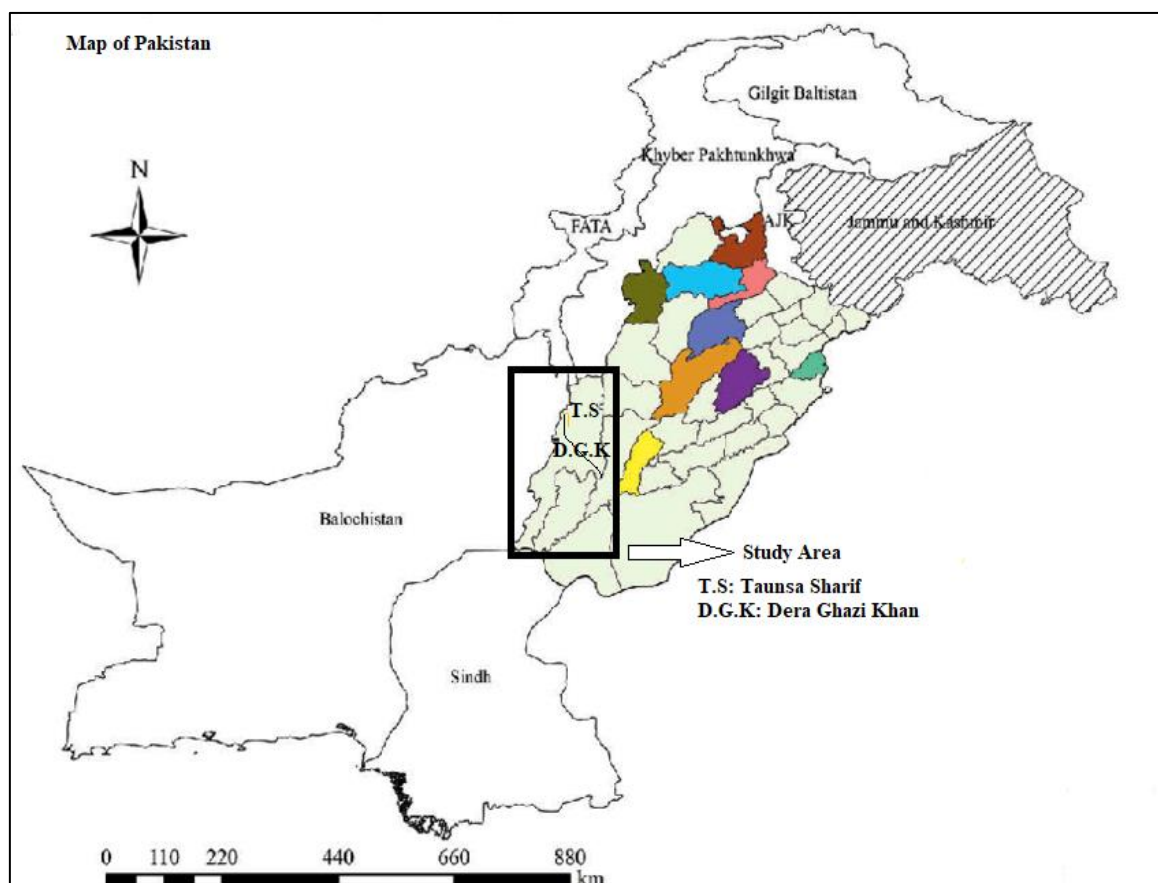


Fig. 1: Map of Pakistan Showing Study Area (Taunsa Sharif, Punjab Pakistan)

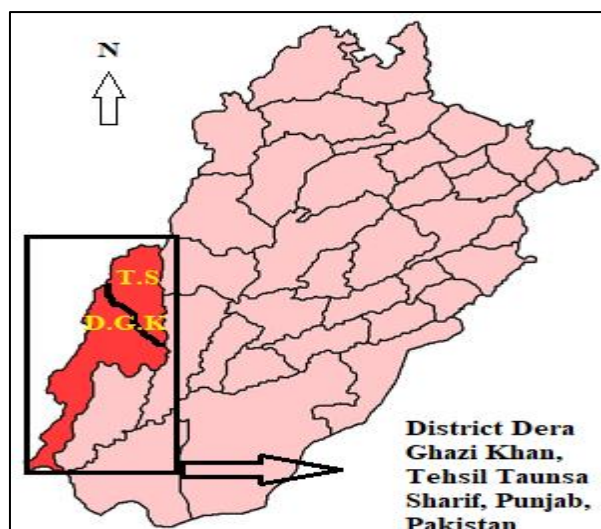


Fig. 2: Map of Study Area (Taunsa Sharif, Punjab, Pakistan)

2.2: Soil Analysis

In order to determine the chemical characteristics of the soil, samples were taken from the rhizosphere portion of each plant at a depth of 0-16 cm. Three soil samples (500 g each) were collected from each habitat. For the measurement of pH and electrical conductivity of soil samples, a pH and EC meter (WTW series InoLab pH/Cond 720, UK) was used, respectively. The ionic content, i.e., sodium (Na^+), potassium (K^+), and calcium (Ca^{2+}), was determined using a flame photometer

(PFP-7, Jenway, UK) [Samejo, M. Q. et al., 2012].

2.3 Plant Analysis and Measurements

After the situ anatomical observations, the plants were carefully placed in an ice bag and brought to the Taxonomy Laboratory of the Botany Department at the University of Education Lahore, Dera Ghazi Khan Campus (Pakistan). The plant samples were washed with distilled water for further morpho-anatomical and physiological analysis.



Fig. 3: Habitat view of *Aerva javanica* Vahova Region



Fig. 4: Ecological perspective of *Aerva javanica* Tibbi Qaisrani Region



Fig. 5: ecological niche of *Aerva javanica* Basti Ladha Region



Fig. 6: Habitat view of *Aerva javanica* Retra Region



Fig. 7: Habitat view of *Aerva javanica* Basti Balchani Region



Fig. 8: Natural habitat *Aerva javanica* Taunsa Sharif Region

Through histology, different morphological parameters were studied, such as stem, root, and leaf cross-sections, to correlate soil physicochemical characteristics with plant morphology [Mouhoub, F. et al., 2018]. For the study of plant anatomy, 3 cm piece was excised from the stem branch and adventitious roots. This plant material was preserved in acetic acid solution (10% formalin, 5% acetic acid, 50% ethyl alcohol, and 35% distilled water) for 48 hours, and later shifted into an acetic alcohol solution (25% acetic acid and 75% ethanol) for long-term preservation. Freehand sectioning was followed by a double staining technique using safranin and fast green stains. Although the freehand sectioning was performed professionally, it has some limitations, as it may introduce variability in sections, affecting the measurement precision. Permanent slides were prepared using the peel-off method. A camera-equipped microscope (Meiji Techno, Japan) was used to take photographs and measurements with the help of an ocular micrometer, a stage micrometer calibrated device.

2.4.1 Root Anatomy

Root anatomy included epidermal thickness (μm), cortex thickness (μm), and xylem area (μm^2).

2.4.2 Stem Anatomy

Stem anatomy included measurement of epidermal thickness (μm), cortex region thickness (mm) and vascular bundle area (μm).

2.4.3 Leaf Anatomy

Leaf anatomy included epidermal thickness (μm), Cortex thickness (μm), and vascular stroma (μm).

2.5 Statistical Analysis

The data was analyzed using T-test and regression analysis with the help of SPSS software. The level of significance was kept $P \leq 0.05$. Data were presented as mean $\pm$ SD [Danie, W. W, 2022]. A relatively small sample size limit the statistical tests.

3. RESULTS

3.1 Soil Chemical Characteristics

Soil was collected from Retra, Basti Ladha, Basti Balchani, Tibbi Qaisrani, Vahova, and Taunsa Sharif. The values of variables are represented in table 2 and graphically visualized in Fig. 9. Electrical conductivity was the highest in Basti Balchani and the lowest in Taunsa Sharif. The maximum pH was recorded in Vahova and the minimum in Basti Ladha. Or-

ganic matter was highest in Tibbi Qaisrani and lowest in Retra. The maximum available phosphorus was observed in Vahova, and the minimum in Basti Ladha. The highest available potassium was recorded in Tibbi Qaisrani and the lowest in Retra. The highest soil saturation was recorded in Basti Balchani and the lowest in Retra.

Table 2: Chemical Characteristics of Soil Collected from Vahova, Tibbi Qaisrani, Basti Balchani, Bait Ladha, Retra, and Taunsa Sharif

Characteristics	EC (dS m ⁻¹)	pH	Organic Matter	P (mg L ⁻¹)	K ⁺ (mgL ⁻¹)	Saturation (%)	Mean±S.D
Vahova	2.89	8.11	0.38	9.13	162	64	41.08±63.8
Tibi Qaisrani	3.44	7.95	0.75	8.50	392	62	79.10±154.9
Balchani	3.7	8.04	0.66	7.19	311	68	66.43±122.4
Ladha	2.74	7.78	0.54	4.96	160	33	34.83±62.4
Retra	2.54	7.74	0.36	5.76	140	31	31.23±54.4
Taunsa Sharif	1.72	7.82	0.58	5.72	150	45	35.14±58.6

There was no significant difference between groups associated with all study parameters with $p=0.928$ ($p \geq 0.05$).

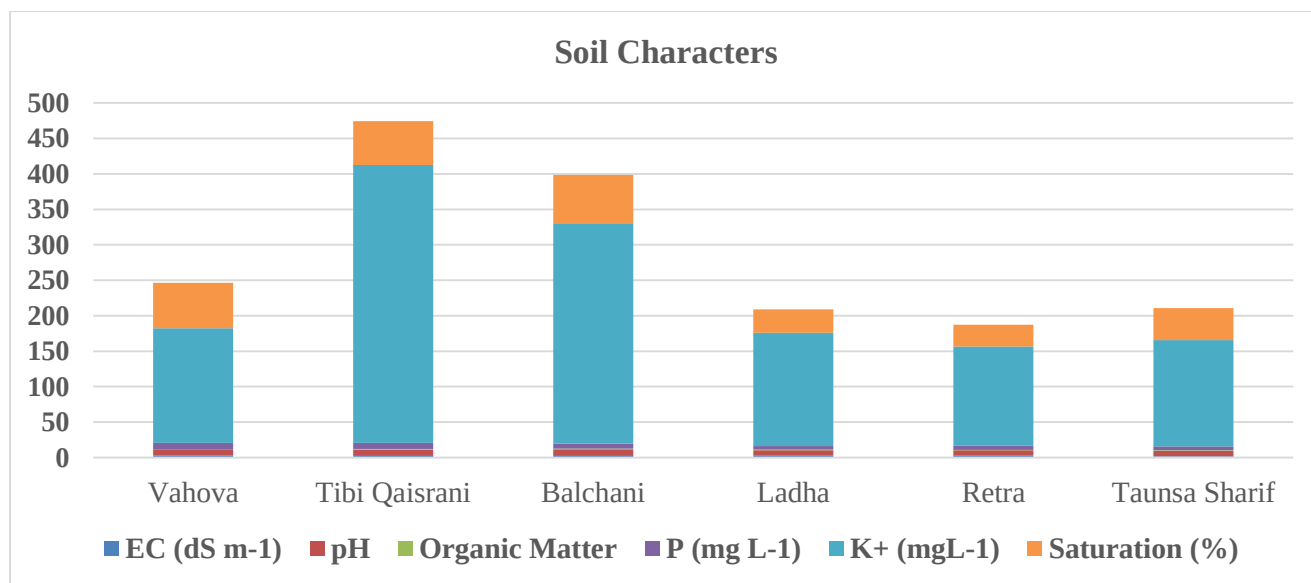


Fig. 9: Graphical representation of soil physicochemical characteristics

3.2 Water

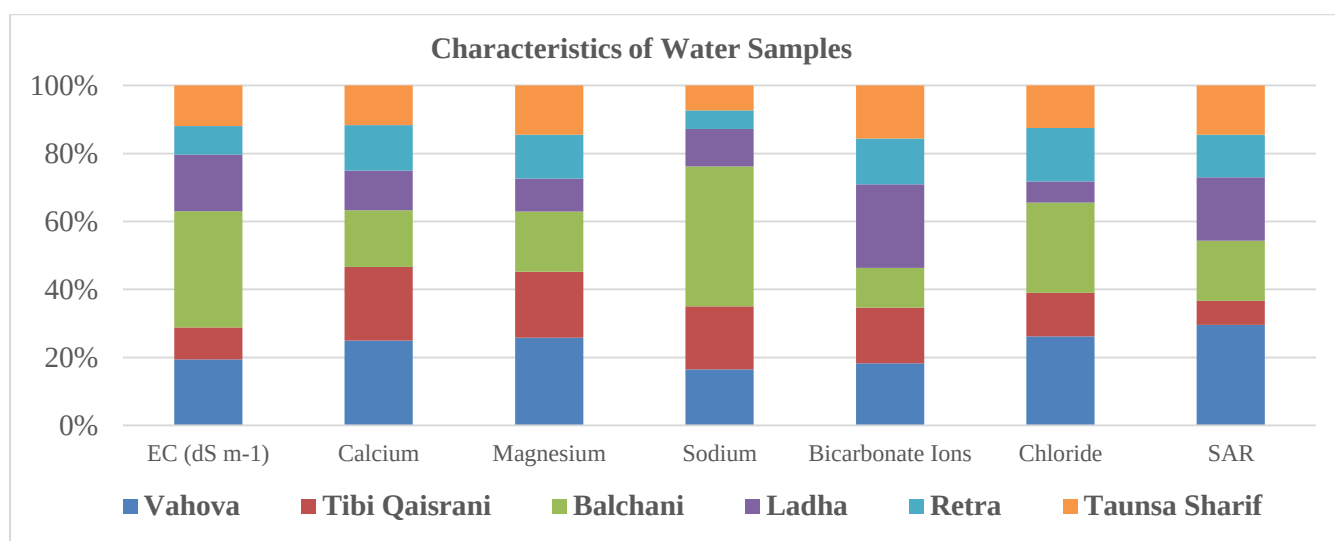
The water was collected from Vahova, Basti Balchani, Tibbi Qaisrani, Bait Ladha, Retra, and Taunsa Sharif. The electrical conductivity was highest in Tibbi Qaisrani and lowest in Retra. Calcium and magnesium levels were highest in Vahova, while the minimum levels were found in Taunsa Sharif and Ladha, respectively. Sodium was highest in Tibbi Qais-

rani and lowest in Taunsa Sharif. Bicarbonate ions were highest in Ladha and lowest in Tibbi Qaisrani. Chloride ions were highest in Tibbi Qaisrani and lowest in Ladha. The Sodium Adsorption Ratio (SAR) was highest in Vahova and lowest in Balchani. The values of all the variables are expressed in the table 3 and visualized in Fig. 10.

Table 3: Chemical Characteristics of Water Samples Collected from Vahova, Tibbi Qaisrani (TQ), Basti Balchani, Bait Ladha, Retra and Taunsa Sharif

Characteristics	EC (dS m ⁻¹)	Calcium	Magnesium	Sodium	Bicarbonate Ions	Chloride	SAR	Mean±S.D
Vahova	3722	15	16	22.2	3.12	10.5	8.13	5.42±1402
Tibi Qaisrani	1793	13	12	24.9	2.8	5.1	1.94	2.64±673.9
Balchani	6549	10	11	55.4	1.99	10.65	4.88	9.48±2469.4
Ladha	3189	7	6	14.8	4.21	2.5	5.11	4.61±1202.8
Retra	1603	8	8	7.3	2.3	6.3	3.46	2.34±603.6
Taunsa Sharif	2290	7	9	9.9	2.66	5	3.98	3.32±863.1

There was no significant difference between groups associated with all study parameters with $p=0.928$ ($p \geq 0.05$).

**Fig. 10:** Graphical Visualization of Physicochemical features of water samples.

3.2 Morpho-Anatomical Parameters

Variations in morphological characteristics in response to different habitats were observed. Statistical data indicated variations in morphology across different collection sites. These variations can be helpful for investigating anatomical parameters.

3.2.1 Root Anatomy

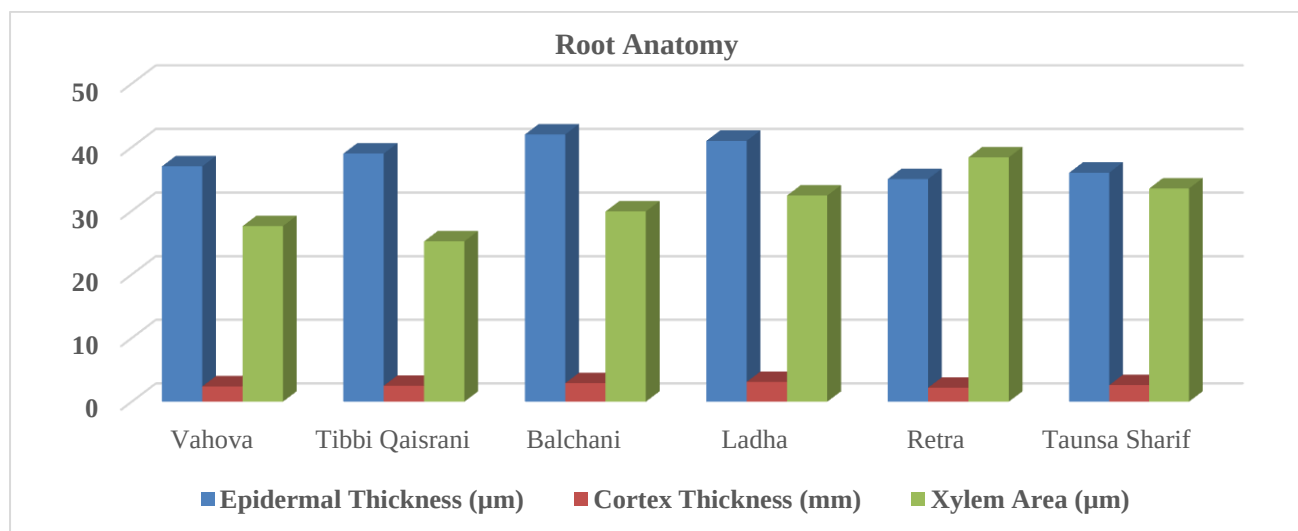
The root area of different populations collected from various areas of Taunsa Sharif shows varying patterns. Statistical data shown in the table 4 and illustrated graphically in Fig. 11,

indicates that there was no significant difference among different populations of *Aerva javanica*. Epidermal thickness of various species collected from different areas exhibits diverse patterns. The maximum epidermal thickness was observed in the Balchani population, and the minimum in the Retra population. Cortex region thickness was observed to be maximum in the Ladha population, while it was minimum in Retra. The Retra population showed the maximum xylem area, whereas Tibbi Qaisrani showed the minimum.

Table 4: Morphological Characteristics of Root Samples Collected from Vahova, Tibbi Qaisrani (TQ), Basti Balchani, Bait Ladha, Retra and Taunsa Sharif

Characteristics	Epidermal Thickness (μm)	Cortex Thickness (mm)	Xylem Area (μm)	Mean ± S.D
Vahova	37	2.4	27.6	22.33±17.89
Tibbi Qaisrani	39	2.5	25.2	22.23±18.42
Balchani	42	2.9	29.9	24.93±20.01
Ladha	41	3.1	32.4	25.50±19.86
Retra	35	2.2	38.4	25.20±19.99
Taunsa Sharif	36	2.6	33.5	24.03±18.60

There was no significant difference between groups associated with all study parameters with $p=1.00$ ($p \geq 0.05$).

**Fig. 11:** Graphical representation of root anatomical traits of *A. javanica* from different sites

Figures showing EP=Epidermis, XY=Xylem and CR=Cortex.

**Fig. 12:** Transverse Section of Root of *Aerva javanica* From the Vahova Region**Fig. 13:** Transverse Section of Root of *Aerva javanica* From the Tibbi Qaisrani Region

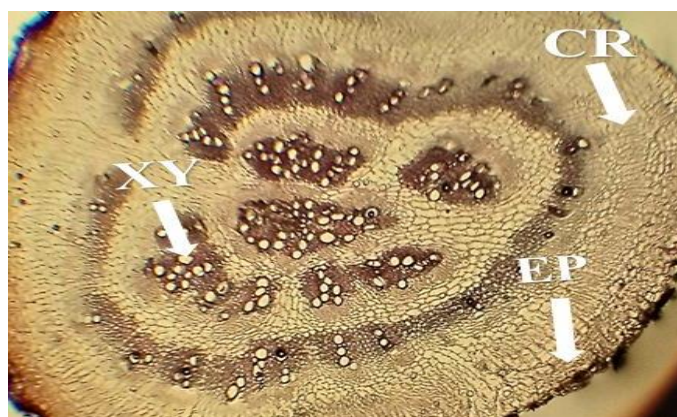


Fig. 14: Transverse Section of Root of *Aerva javanica* From the Retra Region

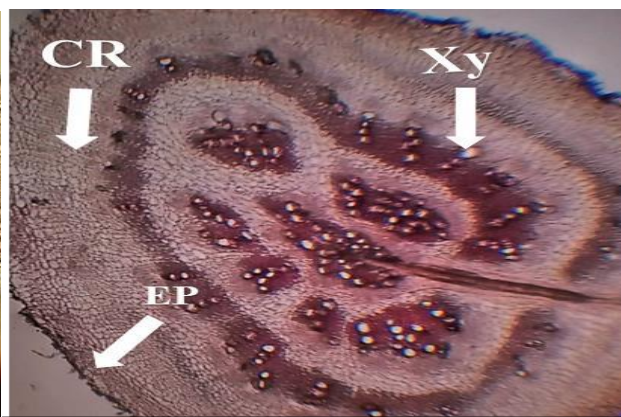


Fig. 15: Transverse Section of Root of *Aerva javanica* From the Bait Ladha Region

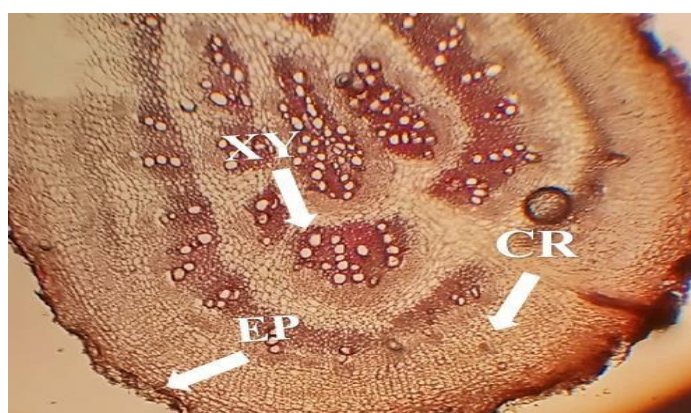


Fig. 16: Transverse Section of Root of *Aerva javanica* From the Balchani Region



Fig. 17: Transverse Section of Root of *Aerva javanica* From the Taunsa Region

3.2.2 Stem Anatomy

The stem radius of different populations collected from various areas of Taunsa showed diverse patterns. Epidermal thickness was recorded highest in the Tibbi Qaisrani population, while it was lowest in the Vahova population. Cortex region thickness was highest in

the Tibbi Qaisrani population and lowest in the Vahova population. The vascular bundle area was highest in the Balchani population and lowest in the Retra population. All the values of these variables are demonstrated graphically in Fig. 18.

Table 5: Morphological Characteristics of Stem Samples Collected from Vahova, Tibbi Qaisrani (TQ), Basti Balchani, Bait Ladha, Retra and Taunsa Sharif

Characteristics	Epidermal Thickness (μm)	Cortex Thickness (mm)	Vascular Bundle Area (μm)	Mean±S.D
Vahova	17	1.8	39	19.26±18.7
Tibbi Qaisrani	28	2.9	44.1	25±20.76
Balchani	26	2	45.3	24.43±21.69
Ladha	19	2.3	29.5	16.93±13.71
Retra	23	2.4	23.4	16.26±12.01
Taunsa Sharif	21	2.2	28.2	17.13±13.42

There was no significant difference between groups associated with all study parameters with $p=0.974$ ($p \geq 0.05$).

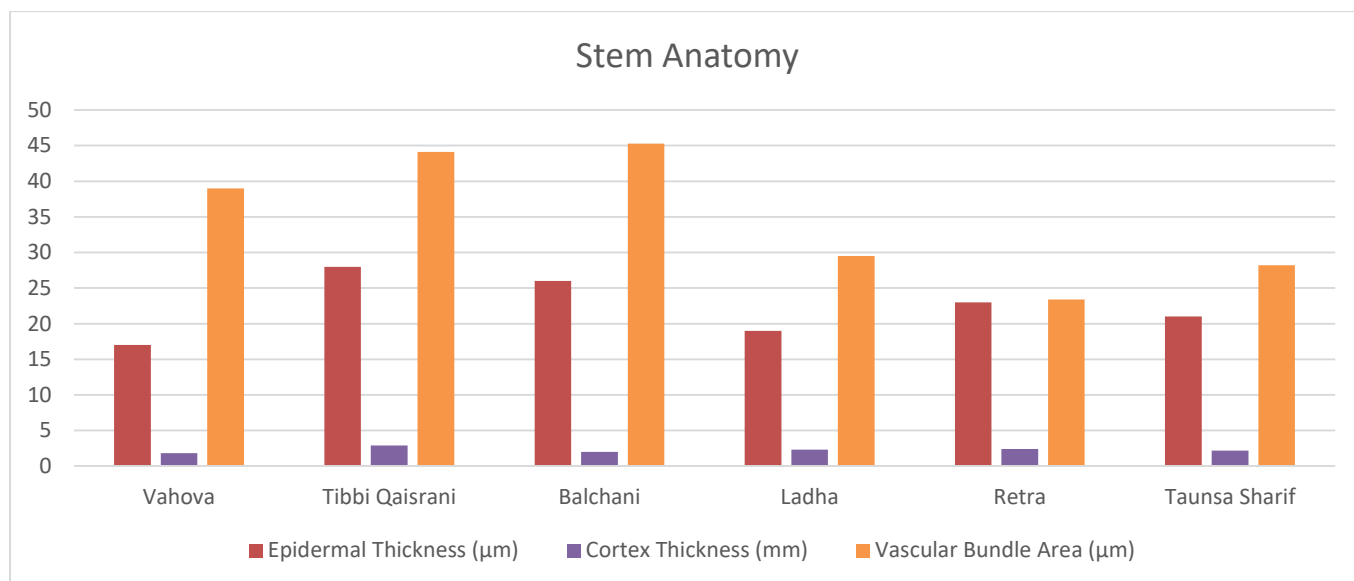


Fig. 18: Graphical illustration of stem anatomical features from different sites

Figures are showing EP=Epidermis, CR=Cortex, VB= Vascular Bundle Area

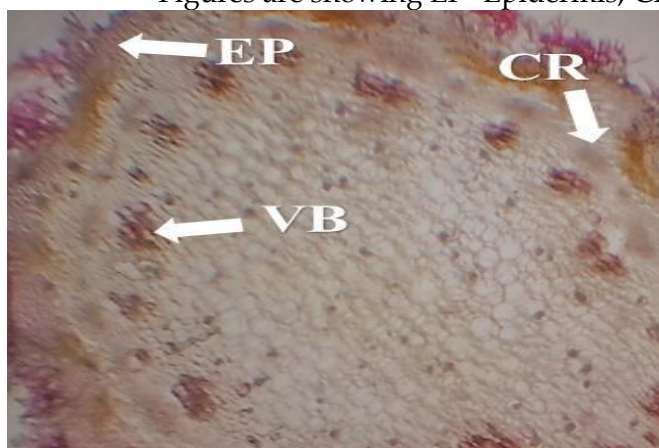


Fig. 19: Transverse Section of Stem of *Aerva javanica* From Vahova Region

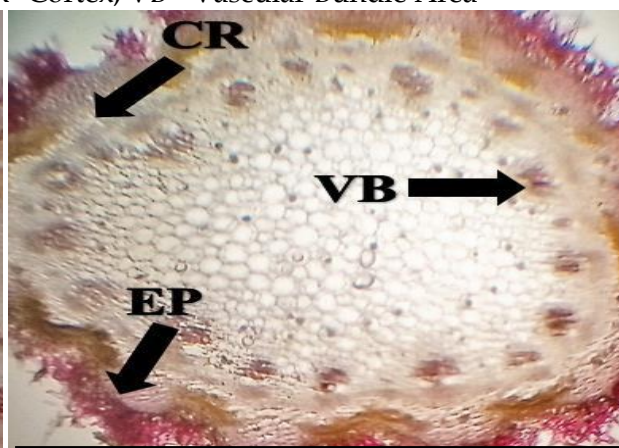


Fig. 20: Transverse Section of Stem of *Aerva javanica* From Tibi Qaisrani Region

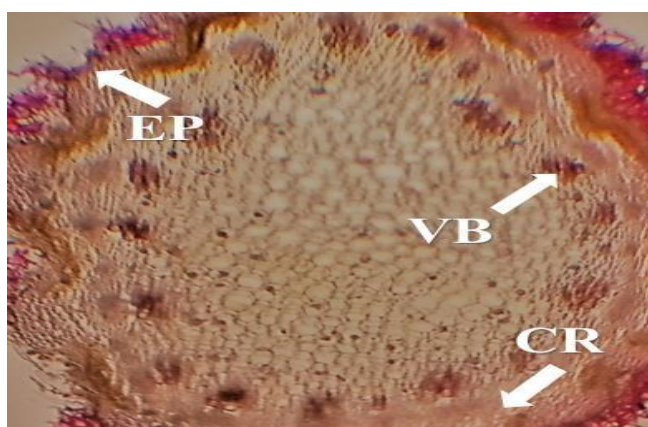


Fig. 21: Transverse Section of Stem of *Aerva javanica* From Retra Region

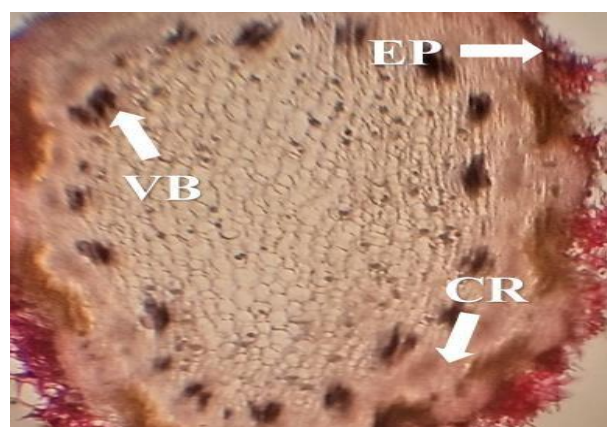


Fig. 22: Transverse Section of Stem of *Aerva javanica* From Ladha Region

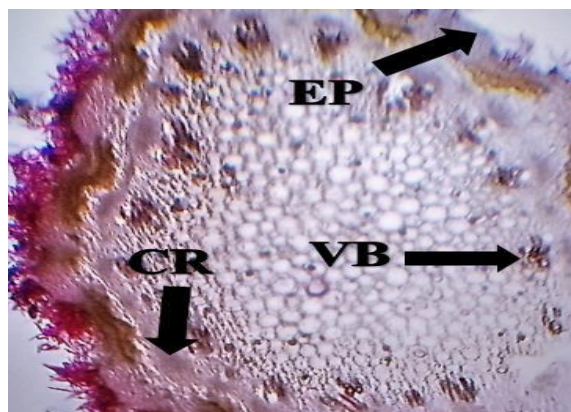


Fig. 23: Transverse Section of Stem of *Aerva javanica* From Balchani Region

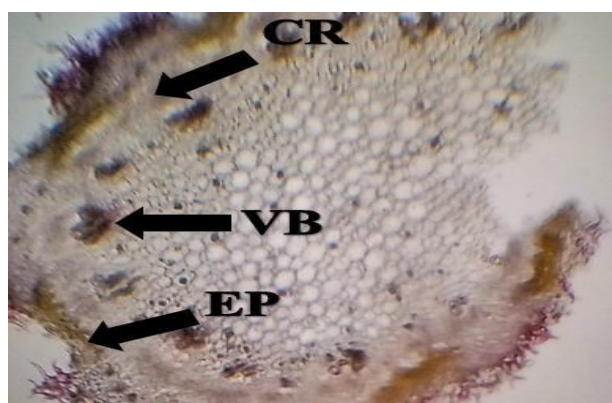


Fig. 24: Transverse Section of Stem of *Aerva javanica* From Taunsa Region

3.2.3 Leaf Anatomy

Epidermal thickness was highest in the Vahova population, while it was lowest in the Balchani population. Vascular stroma was highest in the Retra population, while it was lowest in the Balchani population. Cortex

thickness was highest in the Taunsa Sharif populations, while it was lowest in Balchani. Table 6 and Fig. 25 are showing different values of different anatomical traits of *A. javanica* from all the six sampling sites.

Table 6: Morphological Characteristics of Leaf Samples Collected from Vahova, Tibbi Qaisrani (TQ), Basti Balchani, Bait Ladha, Retra and Taunsa Sharif

Characteristics	Epidermal Thickness (μm)	Vascular Stroma (μm)	Cortex (μm)	Mean±S.D
Vahova	41	2.1	2.3	15.13±22.4
Tibbi Qaisrani	25	2.5	2.4	9.96±13.01
Balchani	17	2.4	1.9	7.1±8.57
Ladha	21	2.3	2.2	8.5±10.82
Retra	29	3.1	2.1	11.4±15.25
Taunsa Sharif	35	2.5	3.2	13.56±18.56

There was no significant difference between groups associated with all study parameters with $p=0.986$ ($p \geq 0.05$).

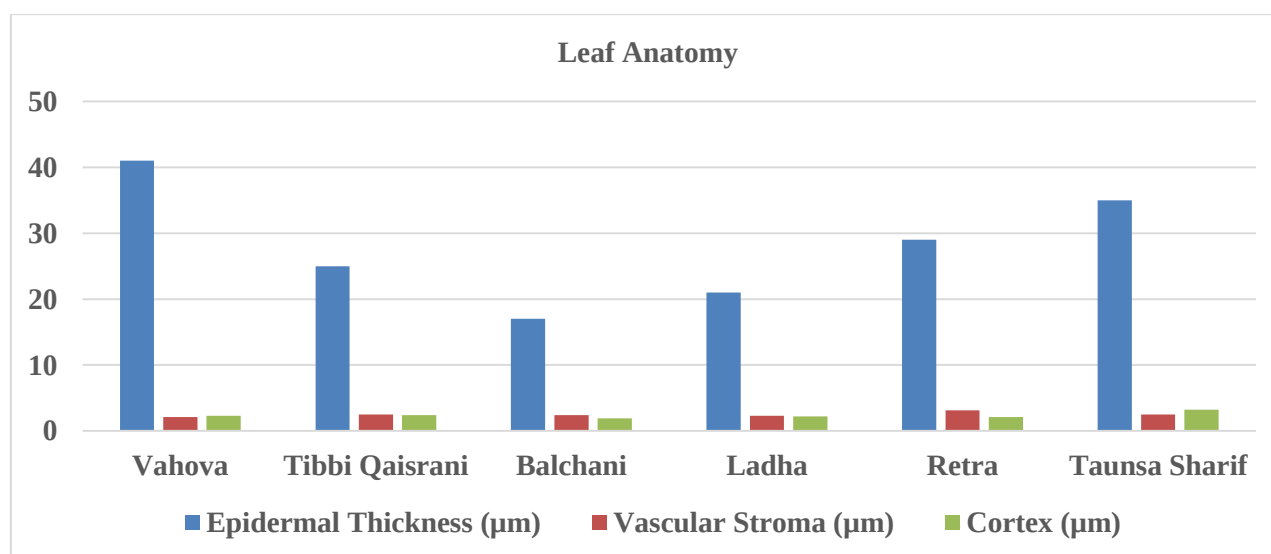


Fig. 25: Visualization of leaf anatomical characteristics from different habitates.

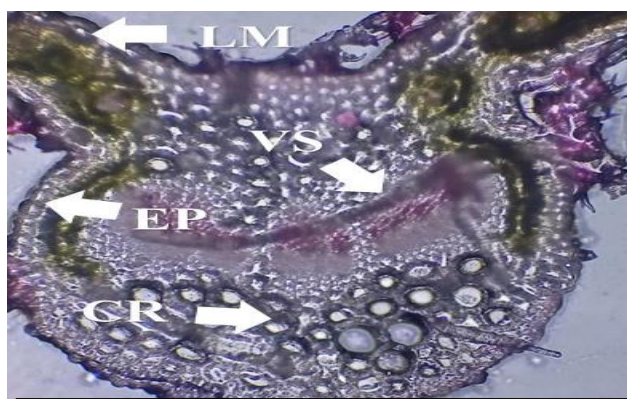


Fig. 26: Transverse Section of leaf of *Aerva javanica* From Vahova Region

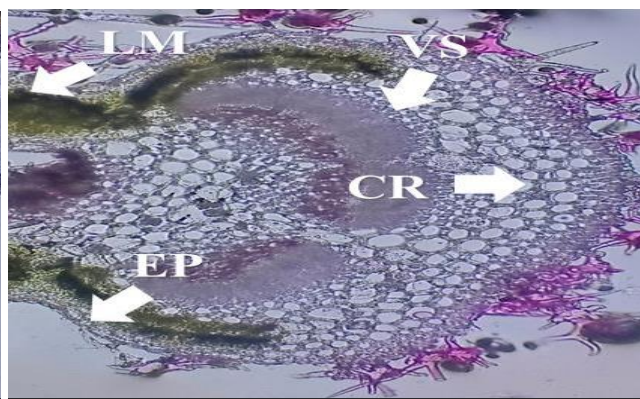


Fig. 27: Transverse Section of leaf of *Aerva javanica* From Tibi Qaisrani Region

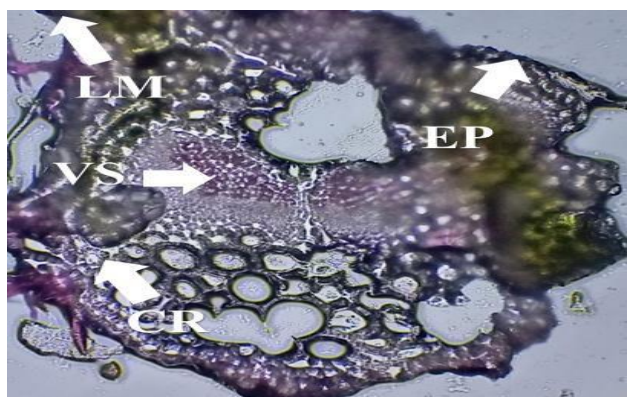


Fig. 28: Transverse Section of leaf of *Aerva javanica* From Retra Region



Fig. 29: Transverse Section of leaf of *Aerva javanica* From Ladha Region

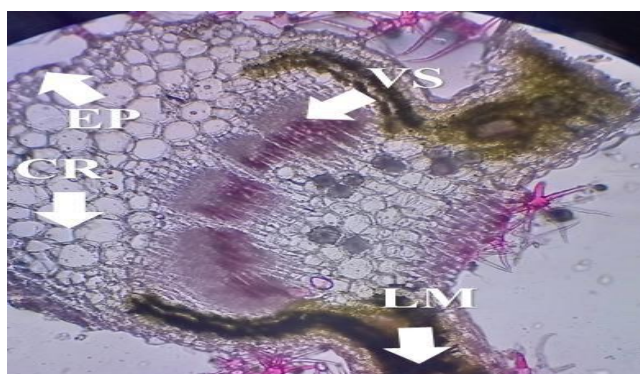


Fig. 30: Transverse Section of leaf of *Aerva javanica* From Balchani Region

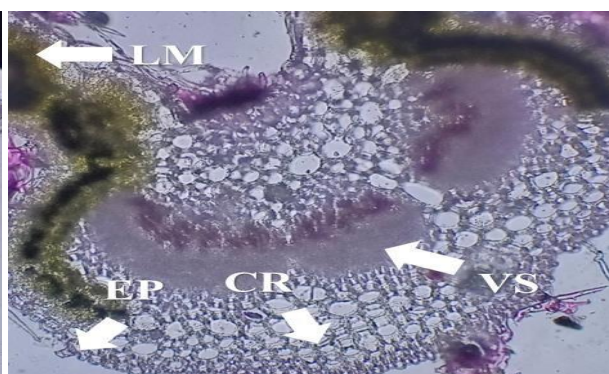


Fig. 31: Transverse Section of leaf of *Aerva javanica* From Taunsa Region

Discussion

Environmental heterogeneity is an essential aspect of the Pakistani landscape that directly affects species richness by providing various climates, habitats, water resources, productivity, and biotic interactions. In the present study, *Aerva javanica* was collected from different ecological habitats to examine adaptive components and plasticity in their morpho-

anatomical attributes, which will help in understanding the ecological success of this species.

Variations in genetic material among various plant species enable survival in diverse environmental conditions [Stein, A. et al., 2014]. All populations of *Aerva javanica* showed different modifications in their morpho-anatomical traits in response to soil physiog-

onomic traits. However, these modifications could be permanent in response to changing environments.

The current study was conducted to analyze the morpho-chemical properties of *Aerva javanica* plants from Tehsil Taunsa Sharif, Punjab, Pakistan. In the study, soil electrical conductivity was recorded highest in Balchani and lowest in Taunsa Sharif. Soil pH was highest in Vahova and lowest in Retra. Organic matter content was highest in Tibbi Qaisrani and lowest in Retra. Potassium levels were highest in Tibbi Qaisrani and lowest in Retra. Available phosphorus was highest in Vahova and lowest in Ladha. Soil saturation was highest in Balchani and lowest in Retra. Water analysis showed that electrical conductivity was highest in Vahova and lowest in Retra. Calcium and magnesium levels were highest in Vahova and lowest in Ladha. Sodium was highest in Tibbi Qaisrani and lowest in Retra. Bicarbonate ions were highest in Ladha and lowest in Tibbi Qaisrani. Chloride ions were highest in Tibbi Qaisrani and lowest in Ladha. The Sodium Adsorption Ratio (SAR) was highest in Vahova and lowest in Balchani.

All populations of *Aerva javanica* exhibited variation in morpho-anatomical features due to its widespread adaptability to diverse environments, such as plains, deserts, and other habitats. According to [Porter, T. M. et al., 2012], biomass production is a standard measure to assess the tolerance of a species or population under harsh environmental stress. Phenotypic plasticity enables plants to develop features appropriate for specific environments. This strategy allows plants to acclimate to different environments and distinguish variations in unique environments [Auld, J. R. et al., 2010-Radersma, R. et al., 2020].

Anatomical features are more responsive to abiotic stresses [Caemmerer, S. V. et al., 2015], enabling plants to survive under severe environmental conditions [De Micco, V. et al., 2012]. In the context of climate change, such anatomical adaptations may provide a survival advantage for *Aerva javanica*, allowing it to persist in increasingly arid and saline habi-

tats. This adaptability not only supports its ecological success but also positions it as a valuable species for habitat restoration efforts in regions facing soil degradation and water scarcity. An increase in root cross-sectional area enhances the water-storing capacity of plants, increases the mechanical strength of sensitive tissues, and improves the transport of water and minerals. The root areas of different populations collected from various areas of Taunsa Sharif show various patterns. Statistical data indicate that there is no significant difference among the different populations of *Aerva javanica*. Epidermal thickness of various species collected from different areas shows numerous patterns. The maximum epidermal thickness was observed in the Balchani population, while the minimum was in the Retra population. Cortex region thickness was observed to be the maximum in the Ladha population and the minimum in Retra. The Retra population showed the maximum xylem area compared to all other populations. Increased xylem is an important modification, especially under limited water resources, and is certainly responsible for the improved transport of water and minerals [Naseer, S. et al., 2017].

Anatomical modifications are more receptive to various environmental stresses. These modifications are used in plant identification and determine the impact of several types of stresses, such as salinity, waterlogging, and drought [Naskar, S. K. et al., 2015]. Plants develop numerous structural modifications for water conservation, including sclerenchyma formation, broad xylem vessels, and parenchyma formation. These anatomical traits are vital for plants to withstand harsh climatic conditions [Boughalleb, F. et al., 2014].

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The maximum thickness was recorded in the Tibbi Qaisrani population, while the minimum was in the Vahova population. Cortex region thickness was highest in the Tibbi Qaisrani population and lowest in the Vahova population. The vascular bundle area was highest in the Balchani population and lowest in the Retra population. All of these features improve water storage capacity, solute uptake, solute movement, and protection of the plant surface, which are crucial for plant existence in harsh environments as reported by [Batool, A. et al., 2013] and [Vicentini, A. et al., 2015]. A thick sclerenchymatous layer inside the periphery is important for preventing water loss from the stem [Ahmad, M. et al., 2016].

Plant success in different habitats mainly depends on leaf anatomical features, which enable them to cope with various abiotic environmental stresses. Leaf traits protect the plant by reducing the effects of several stresses such as salinity and drought. Midrib thickness, epidermis thickness, vascular stroma, and cortex thickness were maximum in the Balchani, Vahova, Retra, and Taunsa populations, respectively, while they were minimum in the Tibbi Qaisrani, Balchani, Balchani, and Balchani populations, respectively. An increase in leaf epidermal thickness is generally observed under abiotic stresses, but these changes completely depend on the intensity of water scarcity [Akram, N. A. et al., 2016].

Aerva javanica showed various anatomical changes with different water and soil physicochemical properties, including decreased vessel diameter, mesophyll, and cortical parenchyma formation, while increased stomatal density and wall thickness were observed. These characteristics are suggested to be involved in adapting to water and soil properties, enabling the plants to survive in different types of environments. Roadside populations showed a decrease in xylem area, which is an adaptation to drought conditions [Salama, F. et al., 2018].

All populations of *Aerva javanica* showed a significant response to soil and water physicochemical factors. This response could be related to adaptation for survival under harsh environmental conditions. The populations from different habitats showed morpho-anatomical responses, which could be due to several chemical factors that vary with increasing elevation. The population from Vahova showed particular changes, such as increased vascular bundle area. Such features could be adaptations to altitudinal stress and water deficit to enhance water uptake. The population from Balchani showed maximum root area and epiblema thickness, associated with adaptations for preventing water loss and maintaining succulence. The population from Ladha showed increased epidermal thickness, which gives them mechanical strength to survive. The population from Balchani showed the maximum xylem area for better translocation of water and minerals.

The altitude gradient decreased the abundance of these species, while their abundance increased in deserts. Moderate soil did not affect their abundance. These species had adaptive mechanisms, making them more successful than other invasive species. Morpho-anatomical characteristics were different for each population, and these differences were linked to specific habitat conditions with specific chemical characteristics.

While this study provides valuable insights into the morpho-anatomical adaptations of *Aerva javanica* across six ecological regions, certain limitations should be considered. The restricted geographic scope and seasonal sampling limitations may affect the broader applicability of these findings. Nonetheless, the observed adaptations, such as enhanced root water storage, increased vascular bundle area, and thicker epidermal tissues, highlight potential of *Aerva javanica* to thrive under harsh environmental conditions. These characters are particularly relevant in the context of climate change. Furthermore, the species' adaptability and plasticity make it a promising candidate for habitat restoration in degraded landscapes, especially in arid and

semi-arid regions. Future research could explore its application in such efforts, while incorporating multi-depth soil sampling, advanced data analysis techniques, and comparisons across broader geographic and climatic gradients to enhance the understanding of its ecological potential.

Conclusion

Aerva javanica demonstrated significance morpho-anatomical adaptations that enables its survival in different types of environments with varying soil and water chemical characteristics. *Aerva javanica* showed various responses through changes in morphological and anatomical factors in different habitats with different soil and water chemical properties. *Aerva javanica* exhibited anatomical and morphological changes in response to soil and water factors, increasing its plasticity for invading new habitats. At the root level, an increase in epidermal thickness and a decrease in xylem area and cortical region prevent cavitation. At the stem level, an increase in vascular bundle area, cortex, and epidermal thickness enables efficient transpiration and survival. Midrib thickness and maximum vascular stroma are highly associated with good plant health and support. All these modifications in *Aerva javanica* enable the plant to invade a variety of environmental conditions. The genetic studies, long term monitoring and the study on nearby areas could be more beneficial to understand its adaptability and modification to cope with the sever environmental conditions.

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