



MULTIVARIATE ANALYSIS FOR MORPHOLOGICAL AND ECOLOGICAL ADAPTATIONS OF *RUMEX DENTATUS*

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Abstract *Rumex dentatus* is one of those important weeds found in wheat fields in Pakistan. In this paper, the authors focus on the study of the morphological features and adaptive strategies of *R. dentatus* depending on geographical habitats to determine the ecological versatility of the species and its advantage over competitors. Large differences were revealed in such important morphological characters as plant body length, the dimensions of the leaf, and allocation of biomass, all of which suggested its capacity to adapt to local environmental conditions. The results showed that the parameters of fresh weight and moisture percentage were the main contributors to the variation affecting water-use efficiency, which played a key role in maintaining homeostasis in stressed conditions in the plant species. From the Principal Component Analysis (PCA), we discovered that the dependence of the species on such characteristics as moisture percentage, fresh weight, and plant length was mutually influential and central to fortifying the species. Overall, the results turn attention towards the fact that *R. dentatus* is not only an agronomic competitor weed but also a useful model object for studying stress responsiveness. It provides a better understanding of the ecological importance of *R. dentatus* for effective control of weeds in the agroecosystems and the stress tolerance promotion for ecological restoration..

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Introduction

In agroecological systems, weeds are significant because they are rivals to the cultivated crops and reduce the quality and yield of crops. *Rumex dentatus* is one of those important weeds found in wheat fields in Pakistan (Waheed et al., 2017). Yield losses in wheat have been documented as high as 55% when *R. dentatus* was growing in a 1:1:1 ratio with wheat and ranged from 2.02 to 210 (Ahmad Malik and Khan, 2012). Those populations are significantly affecting their environment and consist of *Beauveria bassiana*, *Lecanicrusters spp.*, *Mucor spinosus*, *Paecilomyces marquandii*, *Penicillium spp.*, *Rhizopus stolonifer*, and *Trichoderma spp.* (Khalid et al., 2020). Currently, there is no acceptable cultural practice to combat such weeds except by the use of chemicals, which include Bromoxynil+MCPA, fluroxypyr +MCPA, and traisulfuron+terbutryn (Waheed et al., 2017). Nevertheless, there are negative effects on the environment due to these synthetic agrochemicals, including the development of weed resistance to herbicides and toxicity (Singh et al., 2013). It is therefore required that these synthetic agrochemicals

be substituted with friendly herbicides from plants and microbes (Akbar and Javaid, 2015).

These are plants that are not beneficial to the farmer and cause a decline in yield (Batool et al., 2017). Most weeds, as well as crops, share allelopathy, that is, competition for resources, and some plants cause weeds to grow along with crops (Anwar et al., 2018). Crop yield increases, reduced use of synthetic herbicides, and enhancement of the ecological environment are likely to be achieved through the use of allelopathy in weed control (Anwar et al., 2018). Several works indicated allelochemicals as a potential option to synthetic herbicides to manage weeds (Anwar et al., 2018). *Rumex dentatus* L., or teetled dock, is the key winter-season broad-leaved weed of irrigated wheat in India. Mature plants are on average 30-50 cm taller than wheat, with a plant height of 160 ± 20 cm, and they yield a lot of seeds, about 16000 fruits/seeds per plant (Dhanda et al., 2020). It is a very competitive weed due to its rapid growth and can cause yield losses of up to 70% in wheat grains where 30 plants/m² exist (Waheed et al., 2017). Its manifestation is reported more in wheat under the

rice-wheat system (Singh et al., 2013) and is additionally promoted where NT is practiced in wheat (Parihar et al., 2021). The NT-wheat and rice-wheat systems provide both favorable conditions for the growth of this weed, i.e., higher soil moisture and 0-2 cm seed burial (Sharma et al., 2021).

Most *R. dentatus* germinates from seeds buried in the top soil layer of 0-2 cm and does not germinate with a seeding depth of >4 cm (Singh and Punia, 2008). Even though the perianth overlies and hinders germination in some ways, it remains beneficial in packing the seeds nearer to the surface during the puddle flooding situations of rice with regard to lower seed density (Chhokar et al., 2022). Also, its seed can cope with flood regimes, and a flooding period of 80 days has reduced the emergence of *R. dentatus* by 46% only (Singh and Punia, 2008). Therefore, the high seed production, seed germination lasts longer in the soil (Farooq and MIS, 2018), and the capacity to place seeds at the upper layer of soil, along with the facility of flood, gave it a proper place in the rice-wheat system. Besides, seeds are also not easily eaten by predators (Kumar et al., 2013), and therefore, if regulations on their spread are not well put in place, their number will keep rising in successive years (Chhokar et al., 2022).

Based on morphological characteristics, *Rumex dentatus* has broader, lanceolate leaves with crenate margins and contains an erect and ramified stem and small triangular achenes covered by persistent sepals (Rayia et al., 2020). These characteristics are not only essential for the understanding of the taxonomic status of the species but are also typical of various ecological interactions important for the survival and further reproduction of representatives of this species (Chhokar et al., 2022). The ability to live in disturbed environmental conditions and to tolerate different abiotic stresses like salinity, drought, and nutrient deficiency stresses affects the productivity of this species (Koner et al., 2022). To this effect, such resilience is a result of its kinetic morphology flexibility, adequate water management, and reproductive method, which involves high seed production mystery (Singh and Punia, 2008). That is why, studying the features of the life of *R. dentatus*, it is necessary to take into account the physiological and morphological answers as well as ecological behaviors (Rayia et al., 2020). It has several adaptations for dealing with stress factors within the habitats it occupies, including having a deep tap root for water source extraction, phenotypic plasticity in adaptation to resource-limited growth, and having chemical influences to control competition from other plant species (Waheed et al., 2017). Also, the creation of a viable seed bank that can germinate under proper conditions guarantees the species' survival and distribution. Such features align *R. dentatus* with the ideal classic ecological species and a competitively sensitive species of more concern within agricultural ecosystems (Koner et al., 2022). Ecological functions

of *R. dentatus* not only depend on morphology and physiological response (Balzanzi et al., 2020). However, it can be limited by the description of the morphological and physiological characteristics of the plant. With halophytic properties and growing in saline soils, the variant can perform ion-excluding and osmotic stress protection (Chhokar et al., 2015). In addition, concerning the relationships of a given plant with other plants and animals, its function in nutrient cycling, and its behavior under grazing conditions, the results elucidate the ecological processes in disturbed and semi-natural communities. These characteristics place *R. dentatus* at the center of studies on plant-endured environment transformation and adjustment (Khalil et al., 2022).

The purpose of this study is to systematically evaluate and document the aspects of the morphology and adaptations in *Rumex dentatus* to discover how effectively it survives in a given environment/location. Precisely, it aims at describing its AT under different environmental factors and physiologically and ecophysiological responses to abiotic and biotic stress factors, and determining its roles in spatial structure dynamics in disturbed habitats, and evaluating the potential uses of some of its traits in agriculture and restoration.

Material and method

The present study was performed in the flowering and fruiting field of the Department of Plant Breeding and Genetics, Faculty of Agricultural Sciences, University of the Punjab, Lahore, to evaluate the morphological diversities and adaptability features of *Rumex dentatus*. In the present experiment, only one genotype of *Rumex dentatus* was taken, and the data were recorded from three places. There was a replication of three for assessment of the data and for testing the performance of plants at different places in different environments (WALEED et al., 2025).

Experimental Design

The experiment used a complete randomized block design (RCBD) and replicated three times in each location. Randomization of the plot reduced experimental bias while replication increases the dependability of results under varying environmental conditions.

Plant Height

Measurements were taken from the base of the stem to the distant tip of the stem using a measuring scale to determine the height of each plant. Currently, this parameter is being observed in order to determine the generalized rate of growth and development within different environmental perturbations in different regions.

Leaf Length and Leaf Width

Length of a leaf was taken from the junction where the petiole started to the extreme point of the apex of the lamina of the third leaf, counting from the highest point, while the width of a leaf was measured at the widest part of the lamina of the said leaf. To avoid any approximations, the measurements were done with a

ruler. All these parameters give some information about the photosynthetic ability and water utilization of this plant.

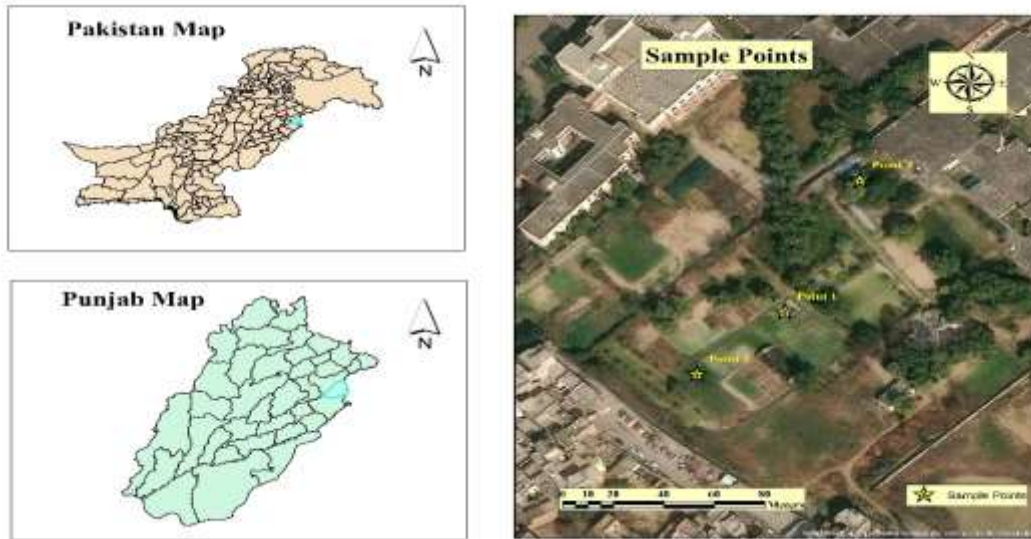


Figure 1: Sample collecting locations

Fresh Weight

The fresh weight was recorded soon after harvesting so as to determine the water content as well as the biomass of plants. Newly collected samples were weighed using a precision electronic balance. This holo trait can be interpreted as a measure of the likelihood of the plant to capture such resources under defined environmental circumstances.

Dry Weight

Dry weight was assessed by placing plant samples in an oven at 70°C until a constant weight had been reached. The samples were thereafter weighed with an accuracy of 0.1 using an electronic balance. From this parameter, the total biomass after the extraction of water is indicated, and the large areas of the plant’s arrangement of resources can be seen.

Moisture Percentage

Moisture content was calculated using the formula:

$$\text{Moisture Percentage} = \frac{\text{WeightFresh Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

This parameter helps in understanding water retention capacity and hydration levels, crucial for the species’ adaptability to varying soil moisture conditions.

Statistical Analysis

Analysis of Variance (ANOVA) was performed on the data to test for significance in the disparity of the consequence between the locations and replications. For the Determination of the association between candidate plant traits, correlation analysis and regression analysis were employed, while to compare relationships between plant traits and environmental adaptability, biplot analysis was used. In fact, expectancy tables, cross tabs, descriptive statistics, and proportional stratified analysis are all computed using Microsoft Excel, Statistix 8.1, and RStudio.

Results

The morphological differentiation of *Rumex dentatus* revealed that it has distinct geographic variation, which resulted from its ability to adjust to distinct regional climate features. A statistically significant difference in plant length, leaf width, shoot fresh weight, and moisture content was noted with respect to both light and location: ($p \leq 0.05$) using ANOVA. This implies that *R. dentatus* has a rather high level of plasticity with regard to habitat changes, which are a primary determinant of the species’ success. Plant length significantly differed among the sites as indicated by the ANOVA outcome (14.2*). This strongly suggests that the specific local conditions at each site –the quality of the soil, water, and light at each site –would have had a large influence on how and in what manner plant growth occurred. Nevertheless, the CV of 15.46% indicates that plant length was a little sensitive to fluctuations in its environmental conditions, but did not have much variation in its adaptive mechanism. Analysis of variance also revealed significant differences in both leaf length ($F=3.84^{**}$; $P<0.05$) and leaf width ($F=6.22^{**}$; $P <0.05$) among locations, indicating that *R. dentatus* has undergone morphological changes. Fluctuations regarding its size and shape can be explained by broad factors like allocation of resources and stress factors. Bigger leaves in good environments increase photosynthesis, while the small ones may decrease transpiration in a region with little rainfall. The CV for these traits is 17.63 % and 17.71 %; moderate and, therefore, speaks for “white noise” of morphological constancy and phenotypic plasticity. The difference in fresh weights of plants was highly significant ($p<0.001$) across locations (13.5*), which reveals how water and nutrient conditions prevailing at the sites influenced the mass of the biomass.

Another important factor concerning the status with respect to moisture was the moisture percentage, which was also highly significant (17.7*), making the plant more efficient to manage in terms of water retention in different environmental conditions. The observed CV of 22.6% for moisture percentage indicates variations in the degree of moisture conservation, perhaps resulting from variations in the sampling site soil moisture content and climate. However, there were no significant differences with

respect to the dry weight of the vegetation (mean = 1.09). However, the exceptionally high CV (114.23%) for this parameter provides evidence of a high degree of variation in samples, which might be attributed to local stress effects such as salinity or nutrient concentrations within samples. These fluctuations in dry biomass could be due to variations in the plant’s resource mobilization patterns at stress conditions.

Table 1. ANOVA table among the different traits of *Rumex dentatus*

SOV	Plant Length	Leaf Length	Leaf Width	Fresh Weight	Dry Weight	Moisture percentage
Locations	14.2*	8.49*	7.86 *	13.5 *	1.09	17.7*
Error	22.16	4.3	0.6	0.65	0.2	5217.5
Grand Mean	30.46	11.7	4.4	3.4	0.39	319.3
Standard Error	2.7	1.2	0.45	0.5	0.26	41.7
CV	15.46	17.63	17.71	24.1	114.23	22.6
*= Level of significance (0.05)				CV= Coefficient of Variance		

Regression

The coefficients of determination shown in the regression analysis range in the extent of impact of morphological traits on the dependent variable. The intercept of -0.0846 represents the expected value of the dependent variable at the grand mean level of independent variables, but is non-significant (p = 0.483). Among the morphological traits, fresh weight was statistically significant with a coefficient = 3.1372 on the dependent variable level of significance of 0.018. In addition, a confidence interval of (1.278 to 4.996) also confirms the significance of this relationship, hence the importance of fresh weight in determining the dependent variable. On the other hand, moisture percentage was significantly negatively correlated to the dependent variable (coefficient = -0.0302 and p = 0.017). The confidence interval (-0.0476 to -0.0129) does not contain zero, as

is the case in all other tests performed in this project, thus making this result quite reliable. This means that a higher moisture percentage is inversely related to the dependent variable and that *Rumex dentatus* may use a moisture trade-off mechanism. The other regressor variables that include plant length with the coefficient of (-) 0.0059 and the p-value of 0.567, the length of the leaf with the coefficient of 0.144 and the p-value of 0.897, and finally the width of the leaf with the coefficient of (-)0.793 and the p-value of 0.833 were shown to have no significant influence on the dependent variable. Such findings indicate that their findings are either inconsequential or fluctuating within the analysed data set. The p-values for these traits are rather high, and that means that somehow factors unique to environments or other factors unmeasured may have masked these effects.

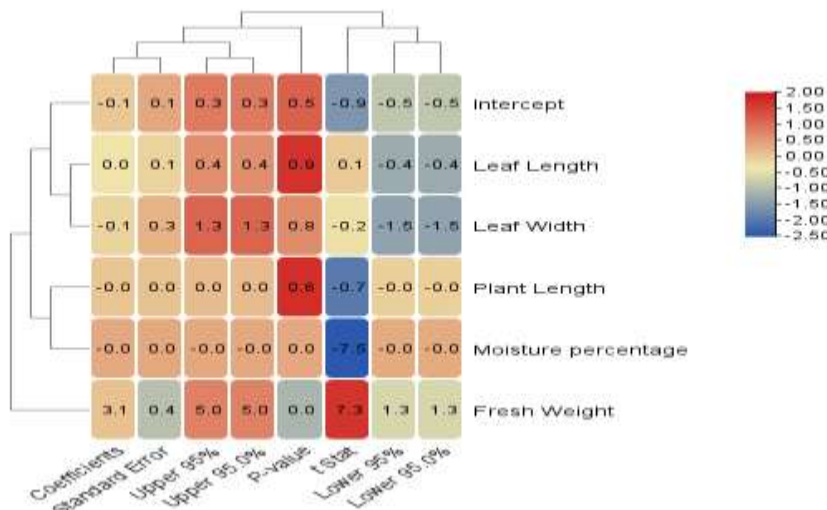


Figure 2: Regression table among the different traits of *Rumex dentatus*

Correlation

The correlation study of different traits in *Rumex dentatus* shows the presence of a significant association between the morphological and physiological traits. Plant length, when compared with FW, has a better positive correlation equation (Corr = 0.850) and MW (Corr = 0.814), meaning taller plants come with more biomass and water content than shorter ones, hence less DW (Corr = 0.462) in such fresh biomass, moisture seems to have a bigger influence than structure. The lengths and widths of the leaves are synchronized in their perfect positive correlation (Corr = 1.000**), which also identifies them as jointly fundamental factors of the leaf area. These traits also have a moderate positive association with fresh weight (Correlation Coefficient = 0.844 – 0.848) and moisture percentage (Correlation Coefficient = 0.808 – 0.812) for water content and

biomass yield. As expected, new growth has a high positive correlation with moisture percentage (Corr = 0.998*), which establishes that water content is a major driving force behind the fresh biomass production and a negative correlation with DW (Corr = -0.074), which implies a mutually opposite relationship between fresh weight and structural dry matter. On the other hand, dry weight has low and negative correlations with most of the traits, and moisture percentage has the lowest correlation with dry weight (Corr = -0.139) for the variation in dry weight, which is less affected by the water factor than other physiological factors. Combined, these results provide further evidence for the value of moisture conservation and morphological flexibility as supreme strategies for survival in ever- changing environments in *R. dentatus*.



Figure 3: Correlation among morphological traits of *Rumex dentatus*

Principal component analysis

The PCA biplot for *Rumex dentatus* reveals how the traits are related to one another and which, when combined, explain the variation in the data set. The first component derived, that is Dim1, accounts for 77.9% of the total variance and is characterized by plant length, length of the leaves, width of the leaves, weight of the fresh plant, and percentage moisture content. These traits are closely located on Dim1, showing their positive relation and their importance in plant growth and plasticity.

The second Axis (Dim2) captured 22.1% of the variance, in which the major component is dry weight in a direction perpendicular to the other traits. This would indicate that dry weight characterized a unique plane of differentiation, which is unrelated to the moisture-associated characteristics captured under Dim1. The detachment of DW from these other traits reveals how they specifically affect plant structure and biomass production under environmental stresses (Hayat et al., 2025). From cos2 values

(revealed through the vector lengths), it can be measured to what extent each of the traits represents the PCA dimensions. That is why Fresh weight and moisture percentage that characterizes the sample in terms of fresh weight witness high cos2 values, which allow defining that they are the key parameters represented in Dim1, more of Dry weight, which impacts more on Dim2. The aggregation of leaf dimensions (length and width) with plant length enhances the consideration of their joint impact on the morphological plasticity and plant adaptation.

Overall, the PCA results emphasize two key adaptive strategies of *R. dentatus*: Fresh biomass, as registered by Dim1, includes moisture retention and volume added by new production, while structural biomass, Dry wt as tested in Dim2, is an additional factor, though it adds the second dimension. These observations demonstrate the versatility of *R. dentatus* from an ecological and morphological perspective in an environment of fluctuating conditions (Hayat et al., 2025).

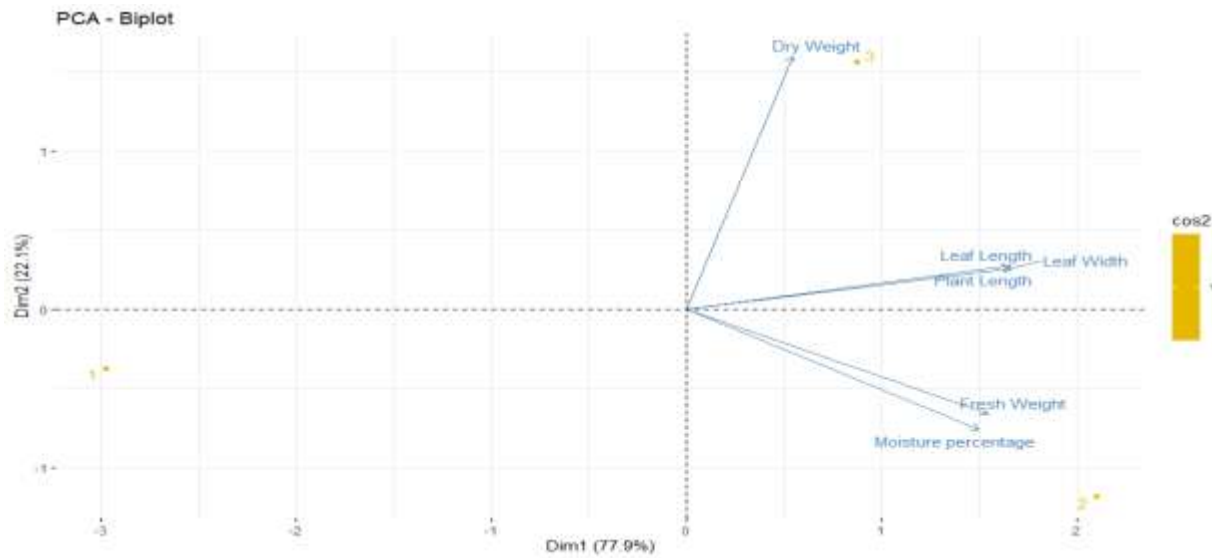


Figure 4: GGE biplot for morphological traits of *Rumex dentatus* under 3 different locations

Discussion

These attributes are fundamental to *Rumex dentatus* endurance in various environmental situations due to high phenotypic plasticity and resource control mechanisms. Therefore, plant length, leaf length, and leaf width display distinct differences in various locations, which indicates the species' potential to adapt the development parameters appropriate to different environments (Sajad et al., 2019). In fact, this kind of phenotypic integration provides the opportunity to adjust resource acquisition patterns and maintain a stable homeostasis in conditions that are frequently and generally unfavorable (Chaudhary et al., 2021). When comparing these traits across various willow locations, it was obvious that the environment has a major effect on the manifestation of phenotypes, which indicates that local adaptations are of utmost importance for *R. dentatus* (Chaudhary et al., 2021). The moisture percentage on the fresh weight was revealed as a major parameter determining the efficiency of the plant in regulating water amounts (Chaudhary et al., 2021). The strong linkage between such a character and environmental factors in the plant reveals its adaptive feature towards water use efficiency, an important factor in plant survival under stress conditions in habitats (Umm-e-Kulsoom et al., 2018). It also guarantees that *R. dentatus* can carry out various metabolic processes, whether in conditions of low water regime or salinity stress (Khaliq et al., 2023). Such traits are indicative of stress tolerance seen in the study species and other halophytes and other successional plants (Usman et al., 2016). The changes in moisture percentage would show how the plant structural model possesses effective water retention capacity to stabilize its physiological function during changes in environmental conditions (Khan et al., 2024).

That is why the length of the leaves as well as their width are other important factors determining the flexibility of *R. dentatus* (Shakeel et al., 2023). These

latter characteristics affect photosynthetic potential, yield, and the plant's resistance to stress factors, including high temperature and water deficit (Soheili et al., 2023). Intraspecific differences in the shape and size of the leaves from different locations suggest that each location harbors flexible strategies in capturing light and in the exchange of gases. This flexibility, following the ecological model of other stress-tolerant plant species, points to the ability of *R. dentatus* to titer resource capture and conservation in these conditions effectively (Kaur et al., 2024). In addition, the structure of leaves affects the plant-competition interaction for resources, thereby increasing its ecological niche (Kaur et al., 2024). The dry weight of *R. dentatus* enables the comparison of biomass production and allocation patterns necessary for survival in disturbed habitats (O'Donovan, 2022). That strategic ability to decide on precise resource placement, necessary for biomass production, allows *R. dentatus* to colonize rapidly and dominate and later succeed in areas of low nutrients or where agriculture has taken its toll (Haq et al., 2024). This trait is evidence of a competent plant and explains why it stays a dominant weed in some ecosystems. This research paper establishes that continued management of *R. dentatus* in agricultural systems entails specific approaches to minimize interference from the competitor species (O'Donovan, 2022).

In the next step, the multivariate analysis provided a better understanding of the interaction of specific morphological descriptors on environmental stress. Principal Component Analysis (PCA) identified that fresh weight, moisture percentage, and plant length are influential for the adaptability of *R. dentatus* (Mehta and Chawla, 2024). It is also noteworthy that all of the identified traits have been clustered in the PCA and together explain the plant's survival. On the other hand, the fact that dry weight is separated from the moisture-related characteristics in the second PC axis indicates that there is an entirely different strategy of allocation for biomass accumulation

regardless of water content (Soheili et al., 2023). Thus, these results stress that the adaptivity of *R. dentatus* is not a single phenomenon, and this species employs various tactics for existence and for further development (Idris et al., 2019). From an ecological point of view, the versatility of *R. dentatus* means that this species is well-suited for disturbed environments. Because it can establish itself in degraded habitats and exhibit competitive behavior, it is a useful species for analyzing plant reactions to abiotic stress (Mehta and Chawla, 2024). The discovery of this research also has implications for ecological restoration. From the study above, it's evident that the findings will be useful in coming up with ways of improving the coping ability of different species in stress-susceptible environments, as informed by the various adaptive mechanisms shown by *R. dentatus* (Soheili et al., 2023). Moreover, the given competitive traits provide information on this species for its usage as an agricultural weed, therefore implying the necessity of implementing an integrated approach to control the species and its negative impact on the yields (Mehta and Chawla, 2024). Through the consideration of *Rumex dentatus* adequacy and viability of its adaptive strategies has been highlighted. *R. dentatus* has proved to be a tenacious species with the use of recognized traits like phenotypic plasticity to manage water efficiently and biomass production for enhanced growth in tough environments (O'Donovan, 2022). The outcomes extend a wide-ranging reference to ecological applications of *R. dentatus* as the species that can be a competitor weed and a source of a stress-tolerant model for selecting plants for restoration applications. Further studies should therefore be made to establish the genetic and molecular basis of these traits to explore the underlying biomolecular dynamics of *R. dentatus* that inform its robustness (Haq et al., 2024).

Conclusion

This study, therefore, reveals the high ability of *Rumex dentatus* to withstand water stress, which could be due to water use efficiency, phenotypic plasticity, and biomass production. Such physiological and phenotypic plasticity, as these processes are known, allows the species to survive in disrupted and transformed habitats and under various types of environmental pressure, thus proving the perspective ecologist's versatility. The consequences of these findings are even wider and broader. In agricultural systems where this species is considered a competitive weed, this information about the studied species' adaptive traits can be useful in the development of an efficient pattern to reduce its negative impact on crop productivity. However, other relative advantages, such as inherent stress tolerance to provide knowledge for the restoration of the stress tolerance in other species of plants, are very important. Besides, the present work has not only contributed to the existing knowledge of plant ecology and evolution but also paved the way for

further research on the ecological functions, restoration, and application of *R. dentatus* in sustaining agriculture and ecosystem recovery.

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Statements and Declarations

Data Availability statement

All relevant data are within the manuscript file.

Author's Contribution Statement

JZ, AS, SMA, and QH collected data and wrote manuscript equally. All authors have read the final manuscript and approve its submission.

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Conflict of interest

The investigation was undertaken without any financial conflicts of interest or any other commercial relationships that could be seen as such by any of the authors.



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